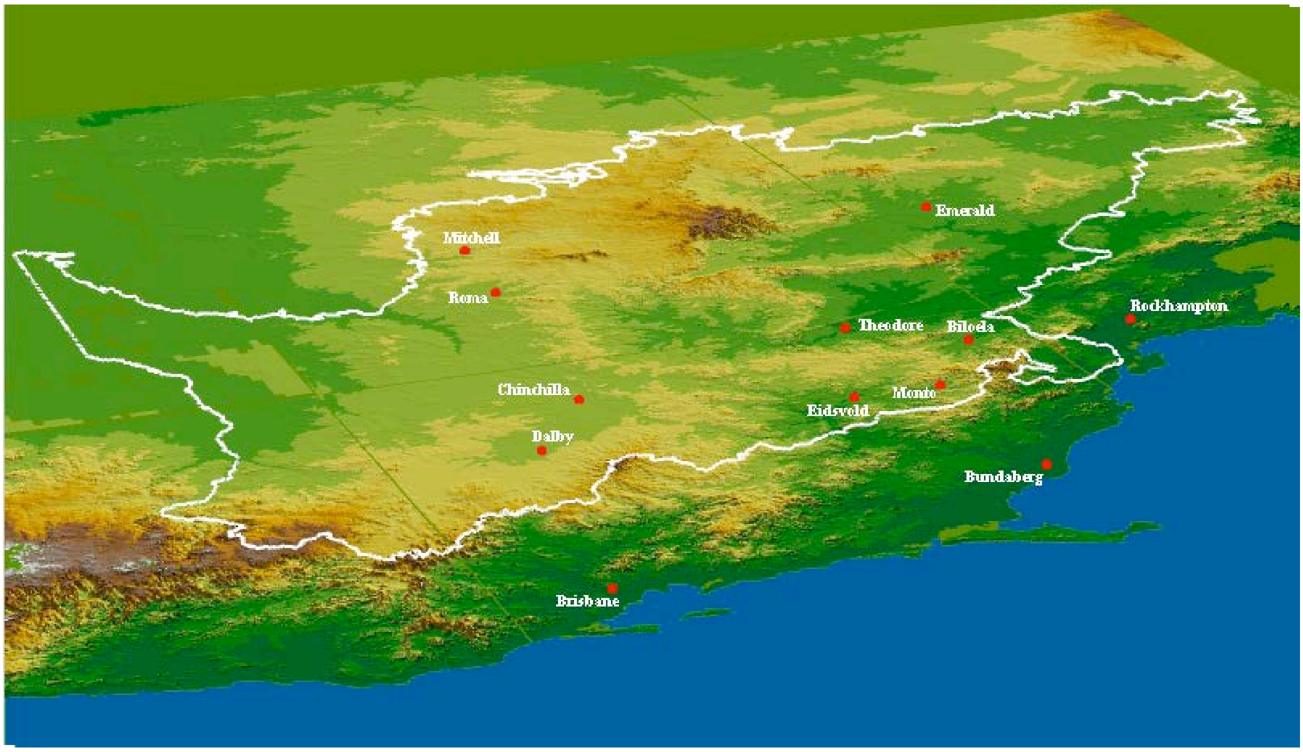
Conservation Values and Integrity of the Western Hardwoods Area

Brigalow Belt and New England Tableland Bioregions
Southern Queensland



Australian Rainforest Conservation Society

May 2004

Conservation Values and Integrity of the Western Hardwoods Area

Prepared by the Australian Rainforest Conservation Society for the purposes
of the Statewide Forests Process

May 2004

Looking over Hurdle Gully rainforest, Coominglah State Forest Photo: Simon Kennedy
This regional ecosystem is endangered, having formerly been the most extensive rainforest type across the Brigalow Belt South. The former major occurrence of around 80 000 hectares in the Arcadia Valley is all but completely cleared.

Aila Keto
Simon Kennedy
Andrew Kwan
Keith Scott

The analysis of spatial data and the production of maps for this report were carried out using ArcGIS software provided to the Australian Rainforest Conservation Society under the ESRI Conservation Program. The grant is gratefully acknowledged. Information on the ESRI Conservation Program can be found on the Program's web site at www.conservationgis.org.

Printed on 100 per cent recycled paper

Contents

List of Tables

List of Figures

List of Plates

List of Maps

Abbreviations Used

E	Endangered	R	Rare
EVR	Endangered, Vulnerable, Rare	RE	Regional Ecosystem
MYA	Millions of years ago	SF	State Forest
NP	National Park	TR	Timber Reserve
OC	Of Concern	V	Vulnerable

.

Preface

> The Brigalow Belt in Queensland is a fine example of how to diminish diversity — encourage clearing of native forests, through taxation and other incentives; fail to secure in conservation reserves representatives of all vegetation types in the region; recognise late, after several species have become extinct or are in decline, that a major problem in maintaining diversity exists; and proceed with plans for further development …
>
> Covacevich, Couper and McDonald (1998)

This report documents the biodiversity of the Study Area — the Queensland Brigalow Belt and New England Tableland bioregions — and attempts to understand the origins of this biodiversity and factors relevant to its persistence and ongoing evolution.

There is little doubt that the Study Area is one of the more critically ill environments in Australia. This situation has arisen principally through vegetation clearing for agricultural development. Only 40 per cent of the original vegetation remains and much of that has been degraded by a range of management practices.

Predictably, the losses have been greatest on the lower alluvial plains and valleys including the most fertile soils in Queensland — the areas most suitable for crops. Of the 12 million hectares of vegetation remaining in the Western Hardwoods Area — the area that, from an industry point of view, is the focus of this report — nearly 8 million hectares occur above 300 metres elevation. In these elevated areas, soils are generally thin and nutritionally poor and unsuitable for cultivation.

However, as demonstrated in this report, these elevated areas are of outstanding significance for conservation of biodiversity and especially for conserving genetic diversity among eucalypts and for ongoing evolution within this plant group that forms such a major part of Australia’s landscape. These areas also play a critical role in conserving a wide range of fauna including species that are in serious decline in other parts of the continent.

It is fortunate that a significant proportion of the elevated areas of forest and woodland, some 2.3 million hectares, have been largely protected from clearing by reservation as State Forest or Timber Reserve. In addition, more than 5 million hectares of forest and woodland on leasehold land have been protected from clearing because the Queensland Government holds the rights to the timber. The principal issue in these areas is the impact on biodiversity of current management practices.

There are two priorities for biodiversity conservation in the Western Hardwoods Area; the first is to secure remnants of threatened ecosystems on lower-elevation fertile areas, and the second is to protect the higher-elevation forests and woodlands that currently support more than 60 per cent of the vegetation, are the least fragmented, and provide the core for biodiversity conservation and ongoing evolution in the region.


Western Hardwoods Area
Locality Map
0 25 50 100 150 200 250 Kilometers
Legend
Western Hardwoods Area
Townsville
Ayr
Charters Towers
Proserpine
Mackay
Clermont
Rockhampton
Emerald
Alpha
Springsure
Blackall
Biloela
Carnarvon
Tambo
Monto
Theodore
Mulgildie
Bundaberg
Eidsvold
Mundubbera
Gayndah
Taroom
Maryborough
Injune
Allies Creek
Wandoan
North Dulacca
Mitchell
Roma
Yuleba
Miles
Chinchilla
Jandowae
Surat
Dalby
Toowoomba
Brisbane
Millmerran
St George
Inglewood
Goondiwindi
Dirranbandi
Yelarbon

Executive Summary

The nature conservation values of the Western Hardwoods Area (WHWD Area) are essentially those of the Brigalow Belt Bioregion, of which it encompasses 85 per cent, and the New England Tableland bioregion, which is entirely included in the Area. In this report, the Brigalow Belt and New England Tableland bioregions together define the Study Area.

1 The Study Area

1.1 The Study Area covers 37 million hectares of which the WHWD Area is 31 million ha or about 18 per cent of Queensland.

1.2 The principal land tenures in the WHWD Area are

- Leasehold, 13.6 million ha (44 per cent)
- Freehold, 13.6 million ha (44 per cent)
- State Forest and Timber Reserve, 2.3 million ha (7 per cent)
- Protected Area, 0.6 million ha (1.9 per cent)

2 Natural History

The physical environment

2.1 The Brigalow Belt is bioclimatically unique on a global scale, and one of only three regions that are unique to a single continent.

2.2 The unique and dominant landscape features of the Study Area that drove the direction of biological evolution in Australia derive from a number of key features:

- the geological history of the region that resulted in the most westerly orientation of the Great Divide in Australia;
- the westerly bulge in the Great Divide that gave rise to the most extensive coastal drainage systems in eastern Australia (the Burnett, Fitzroy and Burdekin River basins);
- the massive sandstone deposits, laid down between 250 and 130 million years ago, that formed the backbone of the most extensive uplands along the east coast of Australia; giving rise to one of Australia's great watershed areas, and providing the bulk of the soil-forming parent rocks for the sandy and clay soils that dominate the Study Area;
- the massive mantle of basalt, deposited between 60 and 20 million years ago, from one of Australia's largest lava fields, that helped preserve much of the old Palaeozoic and Mesozoic landscape features and enriched the leaching soils; and
- one of the most significant outcroppings of Palaeozoic granite-like rocks in Australia and especially the eastern highlands with a key role in the evolution of scleromorphous flora adapting to nutrient-deficient environments.

2.3 The Brigalow Belt is unique on a global scale with the largest extent of cracking clay soils which occur in the sub-humid zone east of the Great Divide.

The evolutionary significance of the Study Area

2.4 The Study Area provides an unparalleled representation of one of the most significant periods in Australia's evolutionary history — the transformation of the Australian landscape during the Neogene (25–2.5 million years ago) from a rainforest-dominated flora to the modern flora dominated by eucalypts and acacias. This transformation resulted from a change from uniformly warm, humid continental climates to sub-humid and semi-arid environments in inland areas. Eucalypts and acacias evolved from rainforest ancestors in more moist environments and radiated into nutrient-poor soils in the increasingly arid interior.

2.5 A range of key factors applying between around 5 and 2.5 million years ago, including rainfall associated with the extensive sandstone uplands, unparalleled water retention capacity of the vast clay deposits, preservation of relictual landscapes and soils of earlier periods and volcanic rejuvenation of soil fertility, have made the Study Area one of the most significant refugial areas for antecedents of dry-adapted flora in Australia.

2.6 Whilst the Wet Tropics World Heritage Area preserves the greatest concentrations of old lineages relating to the origins of flowering plants, and the Central Eastern Rainforest Reserves of Australia the greatest diversity of plants relating to the intermediate secondary radiations within the *Rosidae* subclass of flowering plants, the Brigalow Belt contains an unparalleled representation of ancestral groups from which the modern flora was derived.

2.7 The Study Area contains the highest diversity of ancestral eucalypt lineages anywhere in the world.

2.8 Further elements of evolutionary significance are described below under *The flora*.

2.9 Taxa of evolutionary significance are also found among the fauna of the Study Area. Antecedents of major radiations within three of the five families of Australian lizards are endemic to the Brigalow Belt. The radiations can be linked to the Neogene transition.

3 Conservation values

The vegetation

3.1 The vegetation of the Study Area includes eucalypt forests and woodlands, acacia forests and woodlands including Brigalow (*Acacia harpophylla*) communities, rainforests, cypress forests, casuarina forests and woodlands and tussock grasslands.

3.2 The diversity of regional ecosystems in the Study Area exceeds that of any other region in Queensland. In addition, statistical analyses by ARCS have revealed significant geographic variation in the flora within a number of regional ecosystems as currently mapped, and there is a strong case for division of at least several ecosystems. Such division not only would appropriately increase recognition of the biodiversity that exists in the bioregion, but also is likely to show that some areas currently incorporated in broader ecosystem types warrant threatened status as a result of past clearing and their presently restricted remnant occurrence.

3.3 The Environmental Protection Agency's Biodiversity Planning Assessment rated 95 per cent of the remaining vegetation in the Study Area as being of 'State

Significance' for biodiversity, including 91 per cent of the State Forest and Timber Reserve lands within the WHWD Area.

The flora

3.4 The Study Area has a rich flora with around 5100 vascular plant species and infra-specific taxa, representing 1355 genera and 292 families. This compares favourably with the diversity found in the Wet Tropics (3700, 1360, 325) and the Central Eastern Rainforest Reserves of Australia (1625, 695, 170). In the WHWD Area, there are 4220 species and infra-specific taxa, 1110 genera and 265 families.

3.5 Around 378 plant taxa are endemic[1] to the Study Area compared with 273 in South-East Queensland and 150 in the Central Eastern Rainforest Reserves of Australia. Of the endemic plant taxa in the Study Area, 158 or 42 per cent are rare or threatened.

3.6 A total of 337 plant species found in the Study Area are rare or threatened, including 50 'Endangered', 102 'Vulnerable', 172 'Rare' and 10 'Provisional' taxa. Three species, *Amphibromus whitei*, *Corchorus thozetii* and *Paspalum batianoffii* are considered to be extinct. The numbers of 'Endangered', 'Vulnerable', 'Rare', 'Provisional' and 'Extinct' taxa in the WHWD Area are 41, 84, 152, 9 and 1, respectively.

3.7 In a national assessment of Australia's 85 bioregions with respect to endemicity among acacias and eucalypts (comparing total number of species, number of endemic species, endemicity index and irreplacability index), Brigalow Belt South was one of only three bioregions to score highly for all four biodiversity measures.

3.8 The Study Area is of outstanding significance for eucalypts, a plant group that exhibits a level of differentiation probably unparalleled among woody plants worldwide. *Eucalyptus* is the largest genus in the family Myrtaceae, the second most species-rich genus in Australia (exceeded only by *Acacia*), occurring in virtually every vegetation type and exhibiting an array of growth forms from stunted mallees to the tallest hardwood trees on earth.

3.9 The Study Area has the highest diversity of eucalypt subgenera of any bioregion in Queensland or any other State in Australia, representing the most complete range of evolutionary lineages known.

3.10 The Study Area, bordered by the Great Escarpment and Great Divide, contains the highest diversity of any bioregion of the genus *Angophora*, considered the most primitive group of all the eucalypts.

3.11 The Study Area and its boundaries exemplify a complete evolutionary catena of *Angophora*, from the more moist-adapted taxa centred in the humid, coastal mesotherm refugia (*A. woodsiana*, *A. subvelutina*) through core sub-humid (*A. leiocarpa*, *A. floribunda*) to the more dry-adapted forms characteristic of Mulga country (*A. melanoxylon*).

3.12 The Study Area is the major centre for Bailey's Stringybark, *Eucalyptus baileyana*, a near Queensland endemic and the most southerly disjunct occurrence on the Australian east coast of the oldest lineage of non-bloodwood eucalypts

---

[1] A plant or animal species or subspecies is considered to be endemic to a particular region if more than 75 per cent of its occurrence is within that region.

(Subgenus *Eudesmia*) which now survive mainly in the tropics. Key refugial areas for the survival of *E. baileyana* in the Brigalow Belt include Allies Creek State Forest, Beeron Holding, Little Morrow Creek, Bigge Range, Shotover State Forest, Arcadia Valley and Dawson Range State Forest.

3.13 The Study Area has the highest diversity of monotypic non-bloodwood eucalypt subgenera of any bioregion in Australia (*Acerosae*, *Cuboidea, Idiogenes, Primitiva*). These represent the most primitive or phylogenetically basal of this vast group of eucalypts.

3.14 The Study Area represents the largest known population range for Plunkett's Mallee, *Eucalyptus curtisii*, the only member of the Subgenus *Acerosae* which is basal to all non-bloodwood members of the eucalypts, and may represent an early precursor to the mallee habit. Individual populations are extremely relictual and highly differentiated genetically indicating extremely long (pre-Pleistocene) periods of isolation. Monoclonal populations at Waaje in Barakula State Forest may represent the oldest known living organisms of up to 15 000 years old. Key refugial areas are found in Belington Hut SF, Barakula (Waaje and Turkey Mountain), the Inglewood Sandstones Subregion and Beeron Holding.

3.15 *Eucalyptus tenuipes* (Subgenus *Cuboidea*), which is essentially endemic to the Brigalow Belt, holds a unique phylogenetic position and is not closely related to any other eucalypts. Key refugial areas for its survival include State Forests in the Carnarvon – Bigge Range arc, Barakula, Gurulmundi and Allies Creek State Forests, and the Little Morrow Creek refugium near Eidsvold.

3.16 The Study Area represents the core distribution of Gympie Messmate (*Eucalyptus cloeziana*), an important plantation species, which is not closely related to any other eucalypt and is placed in its own subgenus (*Idiogenes*). It is endemic to Queensland, occurring in highly disjunct, mostly relictual or scattered localised populations on residual ranges and in refugial gorges. Key areas include the Expedition and Bigge Ranges, Coominglah SF and Callide TR. A rare inter-subgeneric hybrid with *E. acmenoides* has been recorded, and the most significant co-occurrence of these species in the Study Area is at Blackdown Tableland.

3.17 Isla Gorge Mahogany, *Eucalyptus rubiginosa* (Subgenus *Primitiva*), is another significant species endemic to the Study Area. It is the only member of a subgenus that is considered the most primitive and ancient lineage of the 'Monocalypts', the third largest group of Australian non-bloodwood eucalypts which now dominate the southern part of the continent. Its relictual nature and sympatric distribution with so many other ancient, basal monotypic subgenera is consistent with the early evolutionary diversification of the eucalypts within this area followed by radiation to other parts of the continent with the collapse of moderately wet (mesic) conditions around 2.5 million years ago. The key refugial areas occur in the upper Dawson gorges of the Bigge and Auburn Ranges (Belington Hut State Forest, Isla Gorge, Cracow Creek) and the wetter, highest elevation watersheds of the Great Divide in Barakula (Waaje, Coondarra and Turkey Mountain).

3.18 Of all regions in Australia, the Study Area has the highest diversity of white mahoganies (Subgenus *Eucalyptus*, Section *Amentum*), an isolated group of eucalypts with core populations of *Eucalyptus contracta, E. apothalassica*, *E. mediocris* and relictual occurrences of *E. acmenoides*, *E. umbra*, *E. helidonica*, *E portuensis*, and *E. latisinensis* in the Study Area.

3.19 Brigalow Belt endemics *E.* sp. (Mt Moffatt Homestead) and *E. mensalis* (R), and relict disjunct distributions of *E. laevopinea* and *E. eugenioides* to those further south, indicate that stringybark species (Subgenus *Eucalyptus*, Section *Capillulus*) radiated from Queensland during the last 2 million years when glacial climates of the Pleistocene period dominated. Almost half of the group have a distribution north of the Hunter Valley and can be considered to have a common biogeographical history associated with elevated sandstone ranges and plateaux. The remaining key area to protect for this group is the New England Tableland.

3.20 A member of the Blue Ash group (Subgenus *Eucalyptus*, Section *Cineraceae*), *E. sphaerocarpa* (Rare), is restricted to the Blackdown Tableland. Its geographic and phytogenetic isolation is indicative of the long evolutionary history of the Blue Ash group in the north-east of Australia, and consistent with a very early diversification of eucalypts from rainforest ancestors during the Neogene. Shotover SF and Planet Creek are important areas for protection of this species.

3.21 Queensland has the highest diversity and endemism of ironbarks and boxes (Subgenus *Symphyomyrtus*, Section *Adnataria*) anywhere in Australia. Ten are endemic to the Study Area, and a further 38 that occur in the area are endemic to Queensland.

- Over half of the ironbarks (Series *Siderophloiae*) are endemic or near endemic to the Brigalow Belt bioregion. Core areas are the Inglewood Sandstones, Carnarvon, Expedition and Bigge Ranges and Barakula and Coominglah State Forests.
- *E. thozetiana* is one of two members in the isolated Series *Coalitae* (inland boxes). A small disjunct population 780 km away north of Alice Springs attests to its relictual nature, possibly dating back to the early Pleistocene. Key populations occur between Clermont and Emerald, north of Banana and Biloela, Belington Hut and Yuleba State Forests, and near Talwood in the far south of the bioregion.
- Series *Heterophloiae* (boxes) has regionally restricted distributions consistent with significant age and northern origins. *E. conica* occurs relictually in the Carnarvon Ranges, Barakula SF, Inglewood region forests and New England Tableland. *E. magnificata* (V; E in NSW) is also relictual and in the Study Area is restricted to the New England Tableland.
- Subseries *Concolores* (Series *Rhodoxylon*, ironbarks) has its core concentration in the Brigalow bioregion – *E. sicilifolia* and *E. corynodes* are narrowly restricted in the area to small refugia within the Dawson and Burnett River catchments, whilst *E. panda* and *E. virens* are near endemics with important centres on the Inglewood Sandstones, Barakula, Gurulmundi and Allies Creek State Forests, and the Carnarvon Range. The presence of *E. dura* in Barakula SF represents the only population south or west of the Great Divide.
- In the Series *Melliodorae*, *E. sideroxylon* subsp. (Waaje) is a highly restricted taxon endemic to Barakula SF.

3.22 Chinchilla White Gum, *Eucalyptus argophloia* (V), a potentially important plantation species found only in the Study Area, is a highly restricted member of an isolated ditypic series (*Submelliodorae*) within the *Symphyomyrtus*, and separated by 820 km from its closest relative (*E. bosistoana*). The geographic and phylogenetic isolation, the close association with rainforest or wetter forest on more fertile soils is indicative of an old lineage dating back some 20 million years. Key refugia vital for its survival are remnant vegetation areas in Burraburri Creek/Charleys Creek catchment and adjoining Barakula and Nudley State Forests.

3.23 The Study Area has important relictual occurrences of species from Section *Liberivalvae* (red gums)(Subgenus *Symphyomyrtus*), a group generally of more coastal and southerly distribution. These occurrences are associated with sandstone ranges: *E. broviniensis* is critically endangered and highly restricted within Allies Creek SF, while the most significant area for *E. interstans* and *E. prava* is the New England Tableland. *E. interstans* also has a northern disjunct population at Blackdown Tableland.

3.24 Section *Bisectae* (southern mallees) occurs primarily in Western Australia but its putative origins have been attributed to north-eastern Australia. However, the greatest diversity of extant relict mallee taxa occurs in the Brigalow Belt bioregion. *E. pachycalyx* subsp. *waajensis* is endemic to the bioregion, restricted to occurrences in and near Barakula SF and a disjunct in the far west of the Carnarvon Range. *E. bakeri* is near endemic to the bioregion, with a scattered disjunct distribution; key areas include the Inglewood Sandstones, Durikai SF on the New England Tableland, and Barakula and Coominglah State Forests.

3.25 The Brigalow Belt has relictual occurrences of species from the small subgenus *Minutifructus*. *E. howittiana* (R) and *E. raveretiana* (V) are endemic to Queensland and have disjunct occurrences in the northern Brigalow Belt around Rockhampton, Eungella NP and Charters Towers. Of the only other members in the group, one is restricted to north-western Australia and the other occurs in New Guinea and South-East Asia.

3.26 With respect to overall eucalypt species richness, Barakula State Forest has a higher level than any national park in the WHWD Area or in South-East Queensland. When Barakula is considered together with the national parks and state forests that form a continuous area of forest from Carnarvon NP to Isla Gorge NP and north to Blackdown Tableland, an area of 1 195 670 ha, the number of eucalypt taxa totals 85. This compares favourably with the Greater Blue Mountains World Heritage Area (1 032 649 ha) which has 90 eucalypt taxa and for which World Heritage listing was based significantly on eucalypt diversity.

3.27 The Brigalow Belt exhibits a range of outstanding features regarding casuarinas, including

- a major refugium for elements of the Casuarinaceae, one of the oldest known Gondwanan families of flowering plants;
- the highest diversity of arborescent casuarinas in Australia;
- a living ‘museum’ representing the transformation of *Gymnostoma*-dominated palaeo-rainforests into *Allocasuarina*/*Casuarina*-dominated open forests of modern times;
- a combination of species demonstrating the greatest range of evolutionary strategies within the Casuarinaceae in response to the increasing nutrient depletion, and aridity and seasonality of Neogene and Quaternary climates;
- the best representation of the family’s key role in rejuvenation of a Tertiary legacy of deeply weathered, nutrient-deficient soils;

- the best exemplified catalytic role of the Casuarinaceae in transforming the deteriorating environmental conditions of the Quaternary into ones suitable for the superdominance by eucalypts.

3.28 Acacias played a central role in the major evolutionary event of the Neogene transition, which saw Australia's predominant vegetation transform from palaeo-rainforest floras to more open vegetation communities typifying modern floras.

3.29 *Acacia* is in the top six most speciose genera in the world, and is the largest genus of vascular plants in Australia with over 70 per cent of its species being present. The Brigalow Belt represents the largest core of acacia-dominated vegetation in eastern Australia, has the highest diversity of species of any bioregion in Queensland, and the highest sectional diversity of any bioregion in Australia.

3.30 The Brigalow Belt and immediately adjoining bioregions represent one of the most significant centres of diversity and endemism for acacias in Australia. Approximately 41 (20 per cent) of the 207 species of *Acacia* in the Brigalow Belt are endemic to it.

3.31 A very large number of *Acacia* species comprising relictual and recently evolved taxa in all the major genetic lineages of the acacias occur in geographically restricted and disjunct distributions in the Brigalow Belt. These reveal the important role of the old dissected uplands in extensive radiations during climatic fluctuations of the Quaternary. Refugial areas now include trachyte or granite outcrops, sandstone ridges on skeletal soils, lateritic surfaces and Cenozoic sand plains.

3.32 Disjuncts and range extensions of several *Acacia* species indicate the important role played by the Brigalow Belt and adjoining coastal Queensland in the original radiations from rainforest origins.

3.33 *Acacia porcata* is unlike any other species in Section *Lycopodiifoliae*, a morphologically very distinct taxonomic group. Its highly restricted presence at Beeron Holding in the Brigalow Belt is the most southerly distribution for the section, and is of outstanding evolutionary significance. *A. eremophiloides* is also restricted to this locality.

3.34 The bioregion represents the northernmost range of Section *Botrycephalae*, and contains five endemics and one near endemic species from the group. The New England Tableland also supports five species narrowly or regionally endemic to Queensland and/or NSW.

3.35 Two outstanding examples of relictual endemism are *A. storyi* on the Blackdown Tableland, which is 1500 km from its nearest relative on the southern tablelands of NSW, and *A. loroloba* in Coominglah SF, which is 600 km from its nearest relatives in northern NSW.

3.36 Approximately 30 per cent of the Brigalow Belt's representatives in Section *Phyllodinae* are endemic. More than 75 per cent of these endemics are rare or threatened, and are confined to refugial areas across the Study Area.

The fauna

3.37 The Western Hardwoods Area has a rich fauna with around 718 vertebrate taxa, including 111 mammals, 384 birds, 178 reptiles and 45 frogs. This compares favourably with the diversity found in the Wet Tropics (105 mammals, 370 birds, 150 reptiles and 54 frogs) and the Central Eastern Rainforest Reserves of Australia (75 mammals, 270 birds, 110 reptiles and 45 frogs).

3.38 The woodlands of the Brigalow Belt, with a total area of about 10 million hectares, represent 42 per cent of the "sub-humid" woodlands remaining in Australia. The unfragmented landscapes in the Brigalow Belt provide habitat for the most intact assemblage of a woodland fauna that once occurred across tens of millions of hectares of sub-humid southern and eastern Australia.

3.39 Faunal elements that are extinct or declining in much of Australia's sub-humid woodland (top-order predators, small macropods and woodland birds) persist at sufficient abundances to drive ecosystem processes, meaning that the Study Area provides a major opportunity to conserve these species.

3.40 The landscape position, climate, topography and soils of the Study Area enable it to support elements from all of Australia's faunal regions. Hence, species richness is high.

3.41 The Brigalow Belt South has the highest resident bird species richness of any bioregion in Australia and Brigalow Belt North has the second highest.

3.42 There are 52 threatened species of fauna in the Study Area. Some are localised while others require large areas of high-quality habitat for long-term viability.

3.43 The Study Area has a great diversity of burrowing frogs, representing a significant example of the adaptive radiation of Australian fauna into drought-prone environments.

3.44 The Brigalow Belt is part of one of three areas of high reptile diversity in Australia. It has a higher richness at a genus level than the other areas of diversity.

3.45 The Brigalow Belt has a highly endemic reptile fauna which is particularly significant in that it includes several species from genera with just one or two species. Most are threatened.

3.46 The Study Area is home to 35 species of arboreal reptiles, a richness equaling or exceeding that of all other States and Territories.

3.47 The Study Area has the highest number of genera (15) of elapid snakes of any bioregion. (South-East Queensland and New South Wales North Coast also have 15 genera.) As a result these areas, have the highest richness of elapid genera in the world, as no other continent has 15 elapid genera.

3.48 The Brigalow Belt has the highest richness of specialist eucalypt woodland birds of any bioregion in Australia, and is significant for populations of woodland birds that are declining in southern Australia where remaining habitat patches are too small. The large unfragmented tracts in the Study Area may provide the only chance of long-term viability for these birds.

3.49 Queensland is outstanding with respect to insectivorous bats. Of the 56 species in Queensland, 36 (64 per cent) occur in the Study Area, a number that exceeds the tally in all other States.

3.50 The Study Area has the richest macropod fauna of any bioregion in Australia (14 species), a level of richness shared with the Wet Tropics.

3.51 The topography and climatic history of the Study Area has resulted in disjunct populations of a large number of fauna species. Areas of significance for disjunct populations include Blackdown Tableland, Carnarvon Ranges and State Forests on the Bigge, Murphy and Lynd Ranges.

3.52 The Brigalow Belt provides the largest area of winter habitat in the Eastern Bird Migration System, considered to be the most important of Australia's seasonal bird movement patterns. A major factor is the combination of winter rainfall and soil moisture retention that provides a positive winter plant growth response.

3.53 Species richness of threatened fauna in large tracts including Barakula, Inglewood Sandstones and the Belington Hut-Presho-Theodore State Forest group is similar to that of the equivalent-sized Carnarvon National Park. Between any pair of these areas, 25 to 50 per cent of the threatened species are not shared.

3.54 The Brigalow Belt contains the largest area of (modelled) high-quality habitat in Queensland for the Yellow-bellied Glider and the Greater Glider, both priority species. National parks protect only 6.6 and 10 per cent, respectively, of this habitat in the Western Hardwoods Area. Around 21 and 20 per cent of high-quality habitat for the Yellow-bellied Glider and the Greater Glider, respectively, in the Western Hardwoods Area occurs on State Forest and Timber Reserve. More than 65 per cent of high-quality Yellow-bellied Glider habitat occurs on Crown land used for timber production.

3.55 Avian lineages that arose in the Neogene period are more prominent among the birds of the Study Area than they are in South-East Queensland. Neogene avian lineages favour eucalypt habitat rather than rainforest.

3.56 Neogene avian lineages have a higher proportion of cooperatively breeding species than do older or younger lineages. Cooperatively breeding species are richest in eastern inland parts of the continent including the Brigalow Belt.

3.57 Initial studies lead to the tentative conclusion that bark- and litter-foraging bird species are more at risk of extinction than leaf gleaners and flower feeders. Bark and litter foraging resources in eucalypt forests and woodlands in the Study Area are diminished by a number of threatening processes such as attrition of large trees and increased fire frequency associated with management for wood production and grazing.

3.58 Antecedents of major Neogene radiations within three of the five lizard families are endemic to the Brigalow Belt. These are *Strophurus taenicauda* (Golden-tailed Gecko), the legless lizard *Paradelma orientalis* (Brigalow Scaly-foot) and the skink *Menetia timlowi*. The radiations subsequent to these basal taxa are major elements of the contemporary Australian reptile fauna of eucalypt-dominated and arid habitats.

3.59 The endemic gecko *Strophurus taenicauda* (Golden-tailed Gecko) is basal to the largest radiation of Australian dry-adapted geckos, the subgroup Diplodactylini, which account for nearly 50% of Australian geckos. The species represents the oldest extant example of arboreality in the *Diplodactylus/Strophurus* group, an adaptation that may have been a response to aridity. From these origins, the *Diplodactylus/Strophurus* group (37 species) radiated largely during the Neogene and now occupies virtually the entire Australian mainland.

3.60 The endemic legless lizard *Paradelma orientalis* (Brigalow Scaly-foot) is basal to *Pygopus*, a small but very widespread and successful genus that occurs in a range of habitats across the entire Australian mainland. *P. orientalis* arose about 23 MYA, corresponding with the commencement of the Neogene.

3.61 The near endemic *Menetia timlowi* is basal to the *Carlia-Lygisaurus* radiation, which includes 31 species found across tropical and sub-tropical Australia, with some species extending to Papua, southern Australia and arid regions of northern Australia. *Menetia timlowi* is the oldest species in this lineage not restricted to mesic microhabitats, an adaptation enabling the lineage to occupy large areas beyond the rainforests and mesic refuges within eucalypt forests inhabited by the ancestors of *M. timlowi*.

3.62 The uplands provide mesic refugia for reptile lineages with a long history of ecological shifts into mesic microhabitats in response to the contraction of rainforests since the Mid-Miocene. The relative climatic and geological stability of the uplands has enabled these elements to persist as relicts to the present day. Examples include the skink *Eulamprus sokosoma* and *Saltuarius salebrosus* (Giant Leaf-tailed Gecko).

3.63 The Pale-headed Snake, which has a large part of its range in the study area, is the basal species of *Hoplocephalus*, Australia's only genus of truly arboreal-adapted snakes. The most closely related species is a relict in semi-arid woodlands of Western Australia, demonstrating that this lineage once occupied much of the Australian mainland.

Centres of endemism

3.64 Initial analyses have identified 11 centres of floral endemism in the Study Area; many of these centres are comprehensively significant across a range of other conservation values.

3.65 Particularly outstanding among the centres of endemism are the Marlborough serpentinite area, with a highly specialised group of species, the Bigge-Murphy Range area which records four of the six monotypic eucalypt subgenera, and Beeron Holding which retains elements of the earliest lineages of *Acacia* and *Corymbia* in Australia.

3.66 The sandstone uplands, plateaux, gorges and weathered Tertiary surfaces within the Brigalow Belt preserve an exceptional diversity of endemic and edaphically adapted relictual or recently radiated lineages that shaped Australia's modern flora.

4 A priority area for protection

National recognition of the Brigalow Belt as a conservation priority

4.1 The Brigalow Belt bioregion has been identified as one of Australia's National Biodiversity Hotspots by the Australian Government's Threatened Species Scientific Committee, with input from recognised experts in the field of biodiversity conservation. Biodiversity hotspots are areas under immediate threat from impacts such as salinity, land clearing, weeds and feral animals, and are strongholds for large numbers of Australia's unique plants and animals. The hotspots are home to endemic species.

4.2 Because of the limited area reserved, the bias in the ecosystems sampled and the degree of threatening processes operating, the Brigalow Belt South bioregion has been classified as 'Priority 1' at the national level for consolidation of the protected area system (Australian Terrestrial Biodiversity Assessment 2002, National Land and Water Resources Audit, Canberra).

4.3 The Commonwealth of Australia has identified almost all of the two bioregions in the Study Area as “Very High” priority (highest rating given) regions for purposes of the National Reserve System.

A highly threatened area

4.4 More than 60 per cent of the WHWD Area has been cleared.

4.5 More than half of the regional ecosystems in the WHWD Area are endangered or ‘of concern’.

4.6 The Brigalow Belt has the highest number of endangered regional ecosystems of any bioregion in Queensland.

4.7 The Commonwealth of Australia has listed three ecological communities in the Brigalow Belt as endangered under the *Environment Protection and Biodiversity Act 1999*. The three communities are blue grass (*Dichanthium* species) grasslands, brigalow and semi-evergreen vine thickets.

4.8 Less than 2 per cent of the WHWD Area is protected in national parks; this compares with a Statewide figure of 4.1 per cent and a national figure of 7 per cent (IUCN Categories I to IV).

4.9 Around 39 per cent of the Brigalow Belt and New England Tableland regional ecosystems in the WHWD Area have no representation in national parks.

4.10 Only 12 per cent of the regional ecosystems in the WHWD Area meet the JANIS target for representation in conservation reserves (15 per cent of the pre-clearing area); only 13 per cent meet the IUCN target for representation in conservation reserves (10 per cent).

4.11 A range of threatening processes has been identified in the forests and woodlands of the Area, including loss of tree hollows, nectar resources, understorey integrity and ground layer structure and integrity.

4.12 Despite the presence of relatively large areas of forest and woodland remaining in the Study Area, fauna sensitive to threatening processes such as loss of old-growth elements, grazing and frequent burning are not secure.

5 Recommendations

5.1 The conservation values of the WHWD Area justify a major increase in the conservation reserve system. In addition, the following actions are recommended:

- A specific program to protect leasehold and freehold land, through conservation agreements or acquisition, targeting high-quality fauna habitat and threatened ecosystems
- Comprehensive flora site data collection for RE diversity — many REs are urgently in need of comprehensive survey
- Given the significance of the Einasleigh Uplands bioregion for biodiversity, it would be appropriate to expand the scope of the North

Queensland component of the Statewide Forests Process to incorporate the whole of the bioregion.

1 Introduction

1.1 Purpose of the Report

This report is produced by the Australian Rainforest Conservation Society to further the aims of the Statewide Forests Process (See below.) The report describes the conservation values of the Study Area, both broadly and specifically, and makes some recommendations for protection of the identified values. It is expected that the report will be used as one source of information for defining new conservation reserves in the Western Hardwoods Area.

1.2 The Statewide Forests Process

The Queensland Government, in partnership with the Australian Rainforest Conservation Society (ARCS) and Timber Queensland (TQ), has been undertaking a Statewide Forests Process (SFP), modelled on the outcomes of the South-East Queensland Forests Agreement (SEQFA), to resolve forestry issues in Queensland's State-owned native forests outside South-East Queensland.

The SEQFA model, the most successful Forest Agreement in Australia, involved the Queensland Government, the timber industry and conservationists working together as partners to find long-term solutions and a shared vision for South-East Queensland's native forests and the future of the hardwood timber industry.

The SFP involves a similar assessment and planning approach for the three other hardwood producing regions in Queensland — the Western Hardwoods Area, the Mackay-Proserpine region and the North Queensland Ecotone Forests.

The broad aims of the SFP are to:

- protect environmental values,
- provide certainty to the timber industry, essentially through a transition to plantations, and
- ensure ecologically sustainable management of all forests.

The specific aims are to:

- plan for the phasing out of logging of hardwood from native forests on State-owned lands over an agreed timeframe,
- transition the timber industry to principally a plantation-based resource,
- increase the area of the conservation estate,
- provide for other forest uses consistent with the broad aims of the SFP,
- maintain or increase regional employment opportunities in ecologically sustainable forest-based industries, including recreation and tourism opportunities,
- provide support for the growth and development of a vibrant timber industry recognising the changing nature and sourcing of the resource, and
- recognise and respect the interests and aspirations of indigenous people in protection and management of forests identified for addition to the conservation estate.

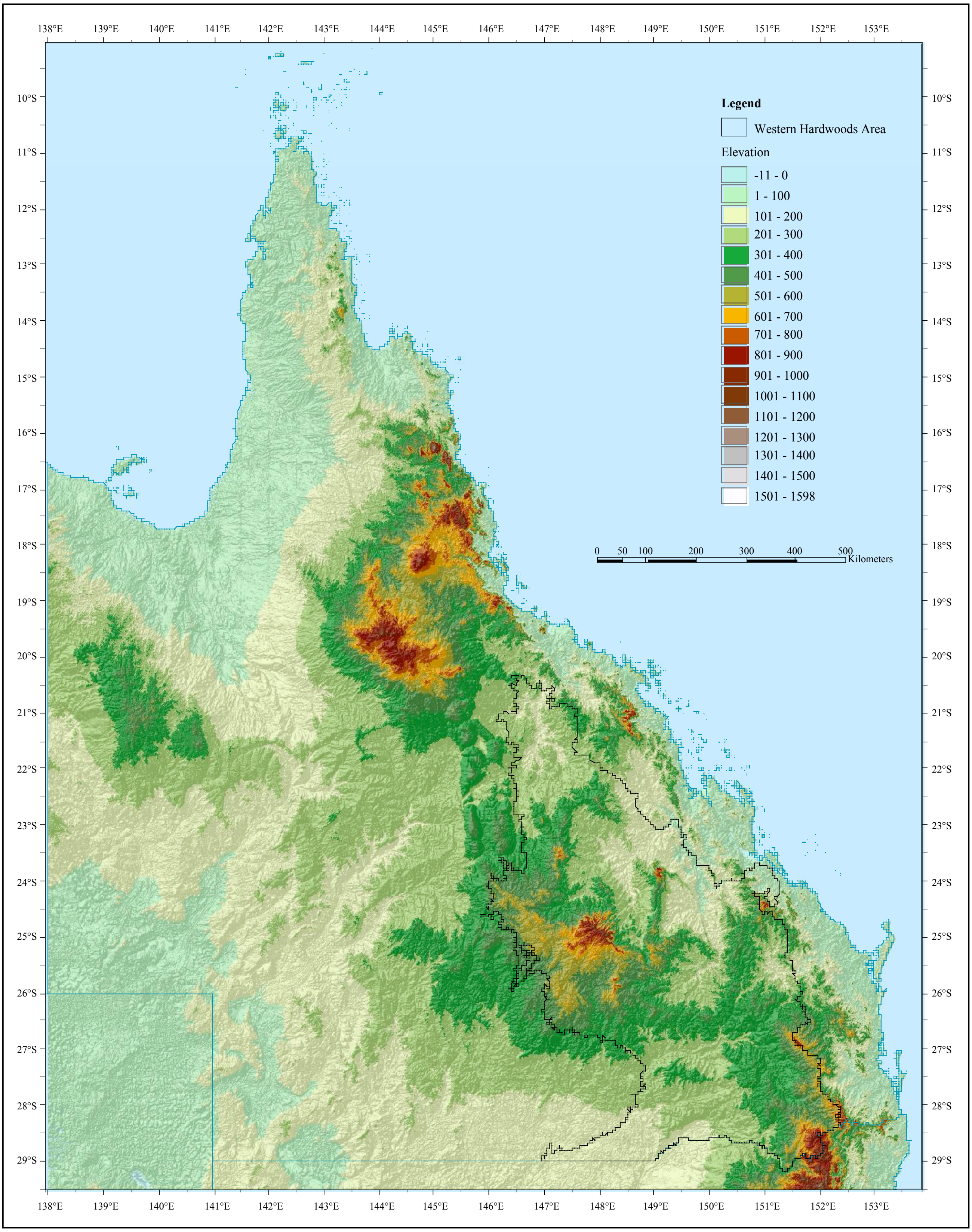


Figure 1.1 The Western Hardwoods Area
The area covers 18 per cent of Queensland and includes a major part of the land above 500 metres altitude.
The map is derived from the 9 Second DEM Version 2.1 provided under licence by GeoScience Australia. © Commonwealth of Australia (Geoscience Australia) 2002

1.3 The Study Area

1.3.1 Overview

The Study Area for this report comprises the Brigalow Belt and New England Tableland Bioregions. The Western Hardwoods Area (WHWD) covers 31 million hectares or 84 per cent of the Study Area and about 18 per cent of Queensland.

The WHWD Area is defined on the basis of the hardwood supply area for sawmills receiving a Crown allocation from State Forests, Timber Reserves and Other Crown Land (leasehold) over which the State has timber rights.

The WHWD Area encompasses about 85 per cent of the Brigalow Belt, the largest bioregion in Queensland. It includes the whole of the New England Tableland bioregion adjoining the New South Wales border (Figure 1.2).

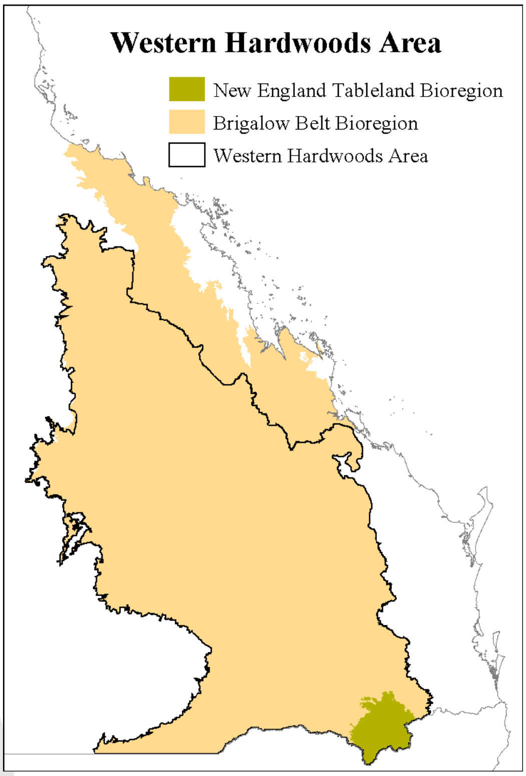


Figure 1.2 The Western Hardwoods Area and Bioregions

The area supplies wood from Crown lands to 14 sawmills, all situated within the WHWD Area. Currently, the total annual hardwood allocation from the area is 53 400 m^3. However, the Department of Primary Industries – Forestry estimates that the sustainable yield is 11 500 m^3 per annum. This problematic wood supply situation has been a major focus of the Statewide Forests Process.

1.3.2 Land tenure

Table 1.1 provides a breakdown of the WHWD Area and of the vegetated land within the Area by tenure. State Forests and Timber Reserves and Protected Areas are shown in Map 1 and Map 2, respectively.

Table 1.1 Land tenure in the WHWD Area

Tenure	**All Land**		**Vegetated Land**	
	Area (ha)	**Percentage**	**Area (ha)**	**Percentage**
National Parks	608 985	1.97	586 628	4.77
Forest Reserve	6723	0.02	6722	0.06
State Forest	2 191 045	7.09	2 091 418	17.00
Timber Reserve	76 059	0.25	71 184	0.58
Leasehold with Crown timber rights	9 549 645	30.91	5 366 612	43.62
Leasehold with no Crown timber rights	4 123 790	13.35	969 463	7.88
Freehold	13 610 278	44.06	2 892 893	23.51
Other	725 827	2.35	317 914	2.58
Total	**30 892 352**	**100**	**12 302 834**	**100**

As shown in Table 1.1, the largest single tenure is Leasehold over which the Queensland Government holds the rights to the timber. Combining that land with State Forest and Timber Reserve gives a total of around 7.5 million hectares of vegetated land.

1.4 Data sources

The following datasets were used in preparing this report:

- Wildnet flora and fauna database, current at February 2003; this database is maintained by the Environmental Protection Agency (EPA) and contains data from a range of sources including —
    - HERBRECS and CORVEG records, Queensland Herbarium
    - EPA Fauna Database
    - IBIS database
    - EPA Sustainable Forest Sciences WHWD survey records
    - ARCS fauna survey records
- Additional CORVEG records, September 2003
- ARCS flora survey records
- Brigalow Belt interim 2001 Regional Ecosystem Mapping
- New England Tableland Regional Ecosystem mapping (version 3.1)
- Brigalow Belt North Biodiversity Planning Assessment v. 1.2
- Brigalow Belt South Biodiversity Planning Assessment v. 1.2
- New England Tableland Biodiversity Planning Assessment v. 1.2
- Modelled high-quality habitat for the Yellow-bellied Glider and Greater Glider (provided by Teresa Eyre, Environmental Protection Agency)(Eyre 2002)
- Forest type mapping, National Forest Inventory 2003, Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry
- Vegetation mapping, National Vegetation Information System 2003, Natural Heritage Trust
- Climate zones of Australia, Bureau of Meteorology (Stern *et al*. 2000)

Statistics relating to tenure were provided by Randall Storey, Department of State Development and Innovation.

As can be expected, there are significant gaps in the flora and fauna data. The distributions of records for flora and fauna are shown in Figures 1.3 and 1.4, respectively.

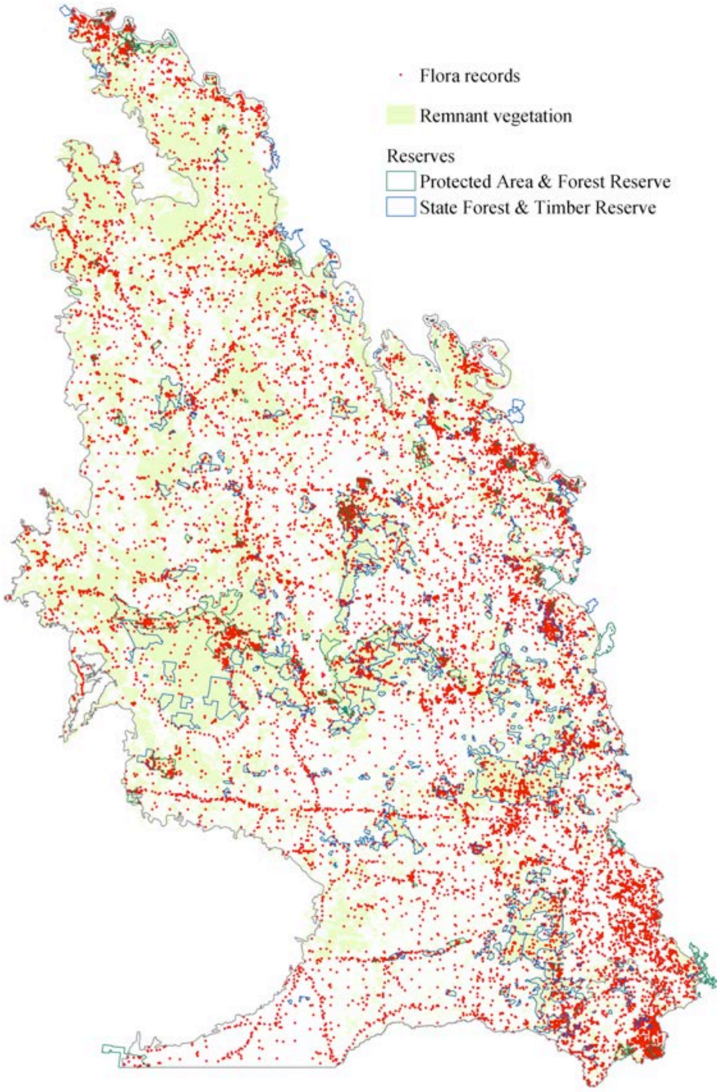


Figure 1.3 Distribution of flora records used in preparing this report

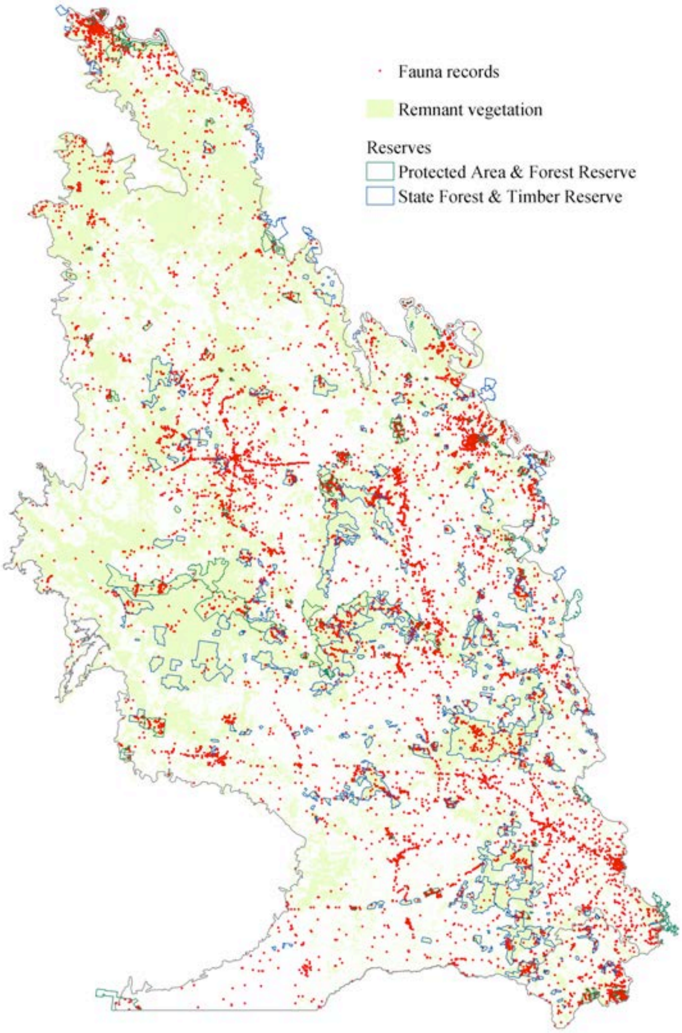


Figure 1.4 Distribution of fauna records used in preparing this report

2 Description and Inventory of the Natural Features

2.1 The physical environment

2.1.1 Climate

The WHWD Area lies mainly in the subtropics with an extension into the tropics. Annual mean temperature ranges from 13ºC on the New England Tableland to 23ºC at the northern end of the Area (Figure 2.1).

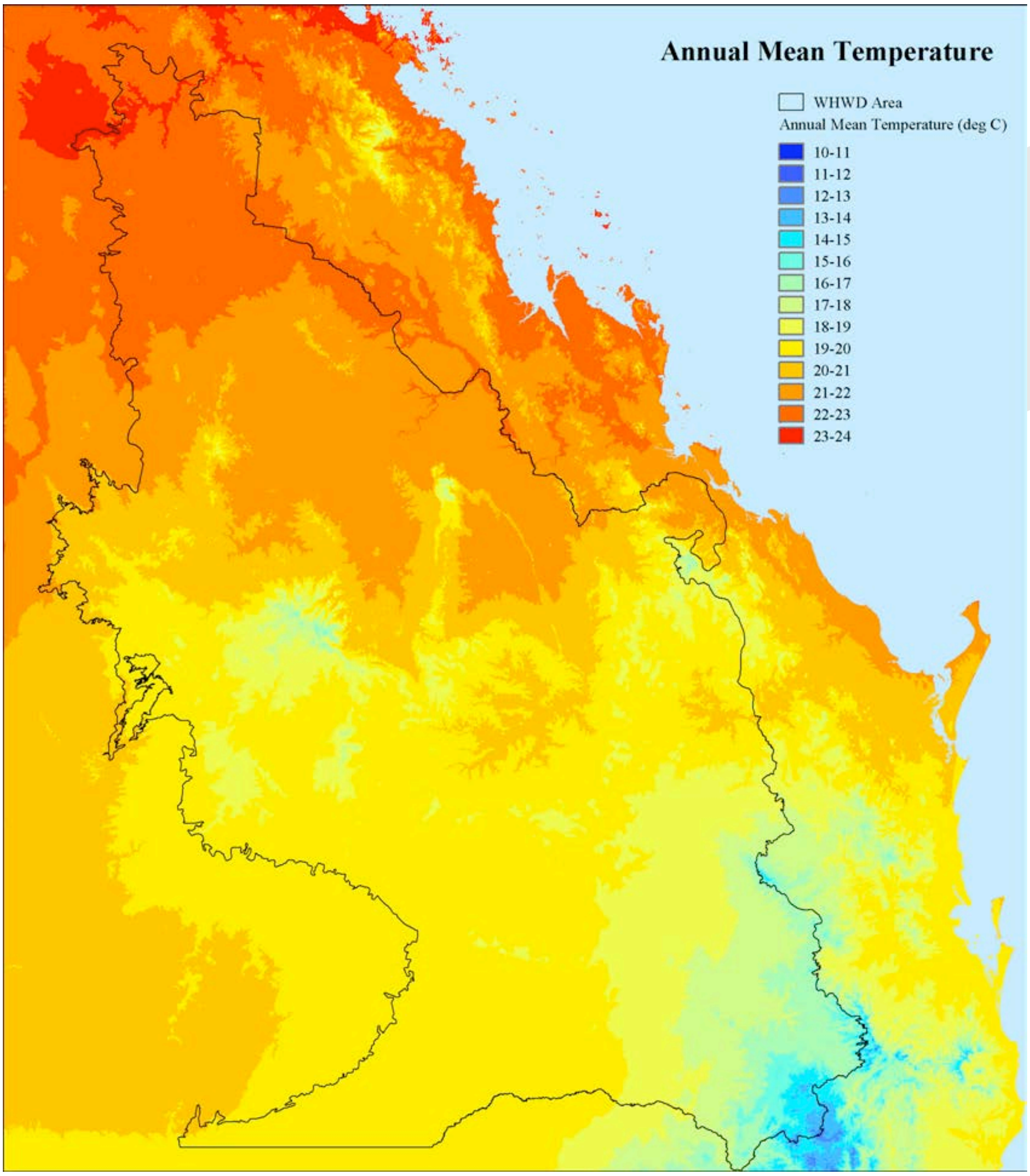


Figure 2.1 Annual mean temperature in the WHWD Area.
The data layer was produced using the BIOCLIM component of ANUCLIM 5.1 (CRES, Australian National University 1999) and climate surfaces from the same source.

Mean annual rainfall ranges from 800 mm to 400 mm across the WHWD Area, generally declining from north-east to south-west, but with more elevated areas including Consuelo Tableland, Carnarvon Range, Bigge Range, Blackdown Tableland and Dawson Range breaking an otherwise even gradient (Figure 2.2). Mean annual rainfall on Consuelo and Blackdown Tablelands exceeds 850 mm.

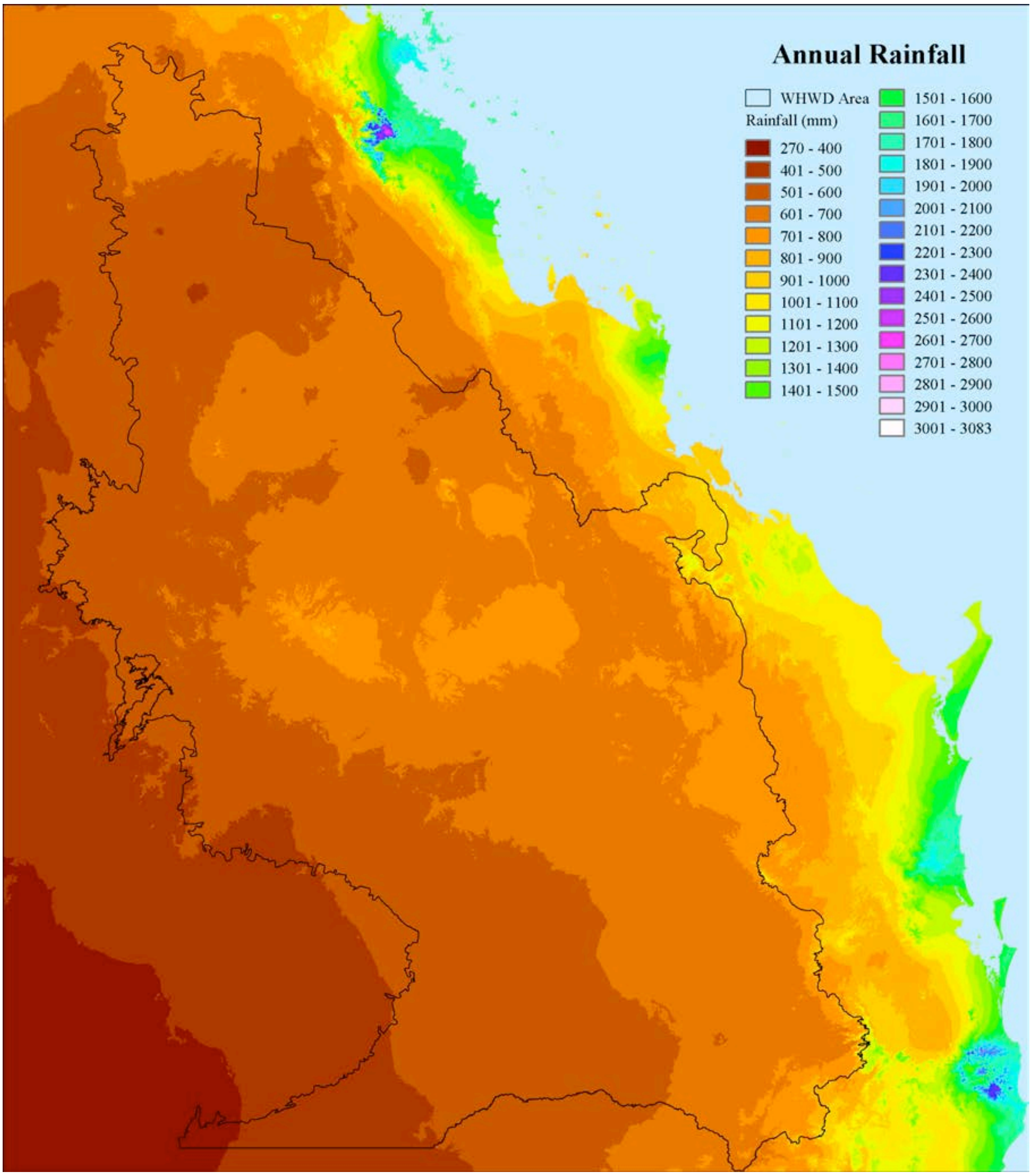


Figure 2.2 Annual rainfall in the WHWD Area.
The data layer was produced using the BIOCLIM component of ANUCLIM 5.1 (CRES, Australian National University 1999) and climate surfaces from the same source.

A notable feature is the fact that the winter rainfall is higher in the southern part of the Area than in the northern part, a reversal of the summer pattern (Lloyd 1984). Whereas summer rainfall dominates, both rainfall and soil moisture indicate peaks in summer and winter separated by autumn and spring troughs (Nix 1994). Nix notes that the winter rainfall plays a vital role in recharging soil moisture, thus reducing the impact of the driest season in Spring.

The Brigalow Belt is generally considered to lie in the sub-humid climatic zone. The global distribution of sub-humid climatic zones is shown in Figure 2.3.

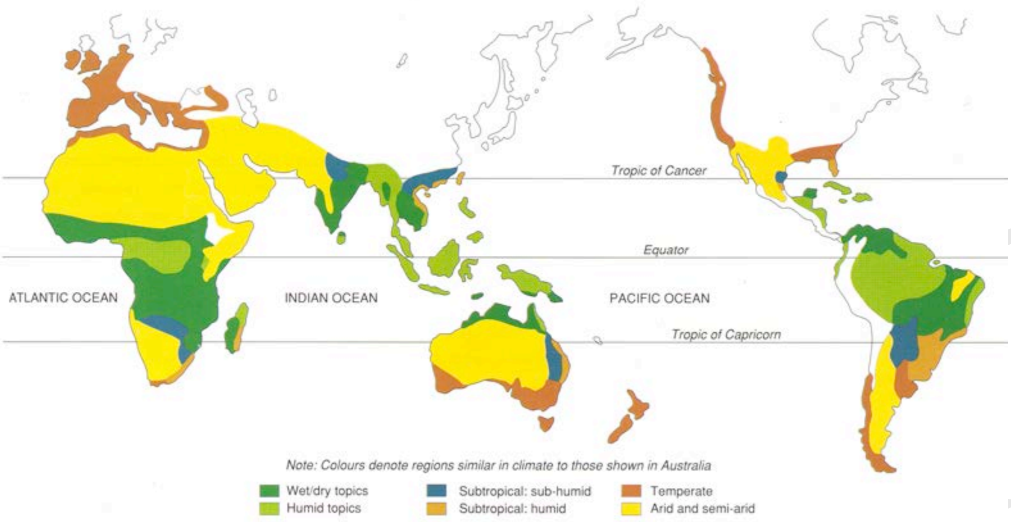


Figure 2.3 Global climatic zones (From Doran and Turbull 1997)

However, Hutchinson *et al.* (1992) have shown the Brigalow Belt to be a globally unique area with respect to bioclimate and one of only three bioclimatic zones that are unique to a single continent.

Nix (1994) notes that the climatic zone in which Brigalow (*Acacia harpophylla*) occurs has a high interannual rainfall variability but a moderate seasonality with respect to water regime. Figure 2.4 shows the annual mean moisture index[2] across the Brigalow Belt. The moisture index has a value of zero when water is completely limiting and a value of unity when water is not limiting. A major part of the WHWD Area has an annual mean moisture index above 0.30, with the eastern section, including part of Allies Creek and Coominglah State Forests, and more elevated areas including Barakula, Consuelo Tableland and the Carnarvon Range–Bigge Range arc, and Blackdown Tableland being above 0.35. Small areas have an annual moisture index exceeding 0.50, including Consuelo and Blackdown Tablelands and, notably, Grevillea State Forest.

Figure 2.5 provides a measure of equability in the moisture index between summer and winter. It shows a line of greatest equability dissecting the Brigalow Belt, essentially paralleling, or as in Barakula coinciding with, the Great Divide. Outside this band, equable areas (±10 per cent) occur in Allies Creek, Auburn Range, Coominglah, Grevillea and Blackdown Tableland.

---

[2] The moisture index is the ratio of actual to potential evapotranspiration calculated from a measure of water balance using a plant-available water capcity of 150 mm and assuming a clay-loam soil (Nix 1994).

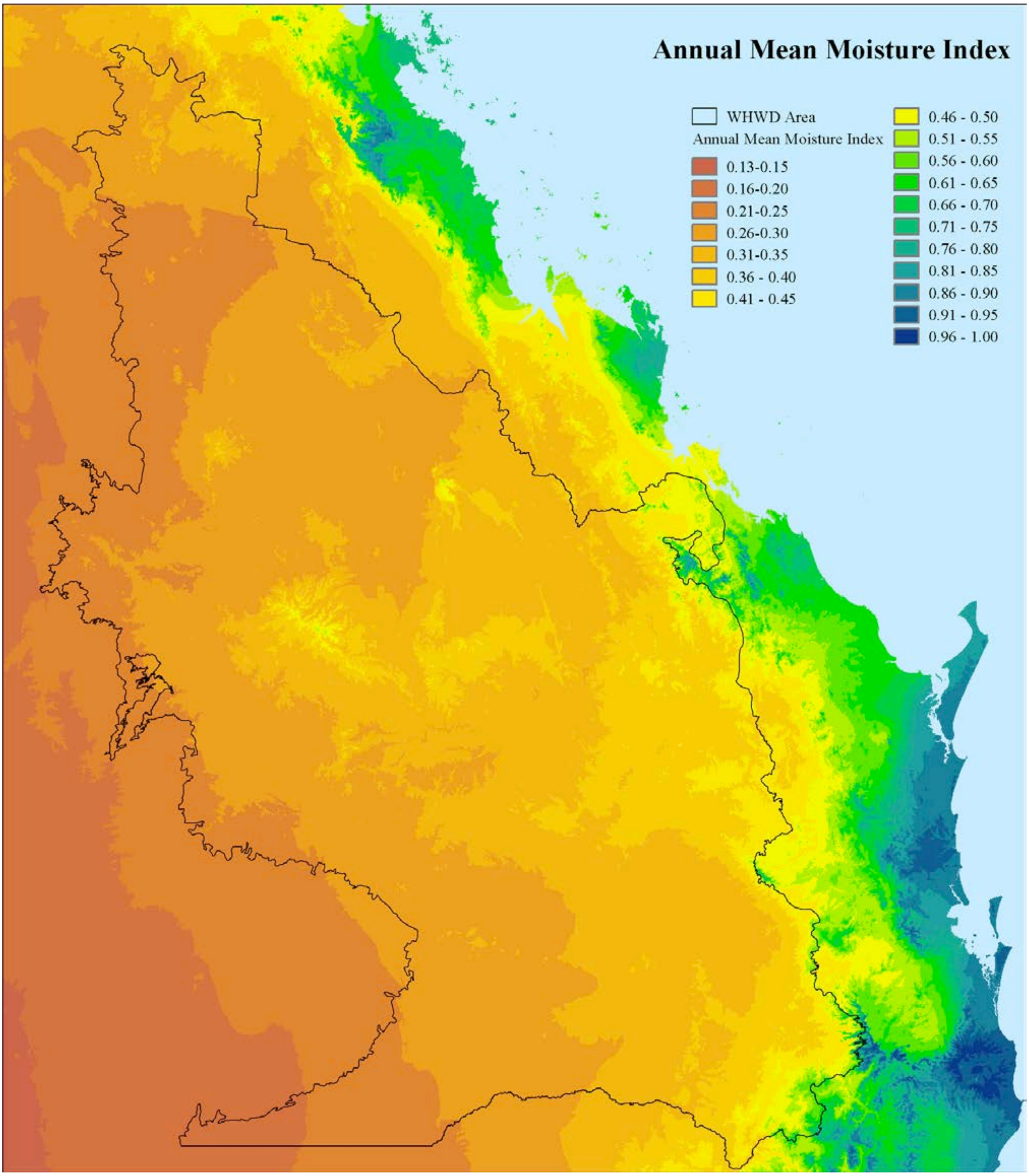


Figure 2.4 Annual Mean Moisture Index across the WHWD Area.
The data layer was produced using the BIOCLIM component of ANUCLIM 5.1 (CRES, Australian National University 1999) and climate surfaces from the same source.

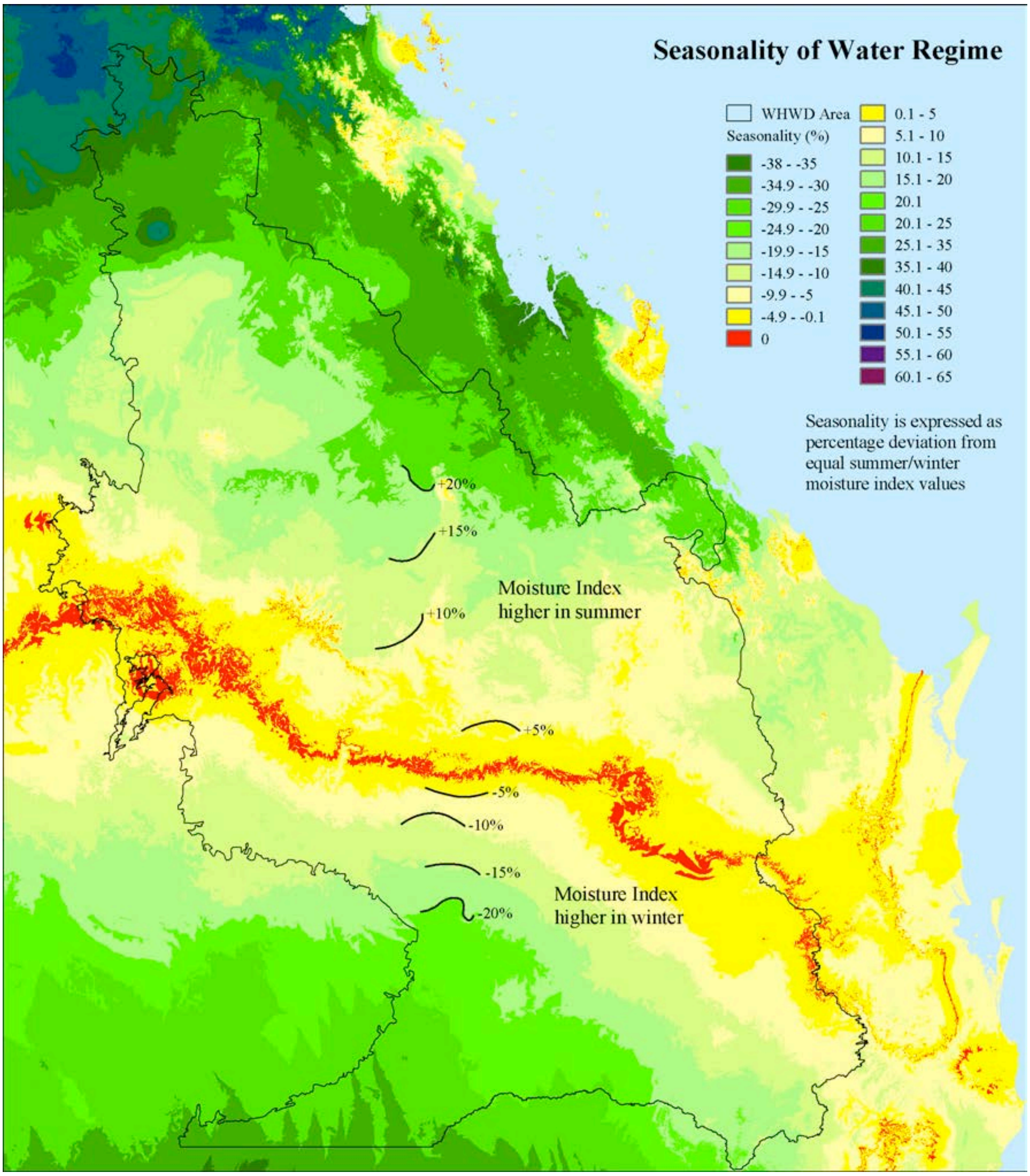


Figure 2.5 Seasonality of water regime in the WHWD Area.
Mean Moisture Index data for summer and winter were produced using the BIOCLIM component of ANUCLIM 5.1 (CRES, Australian National University 1999) and climate surfaces from the same source. From these data, seasonality of water regime was calculated as the percentage deviation from equal summer and winter mean moisture index values. The value is zero when summer and winter mean moisture indices are equal, +100 per cent when the summer index value is unity and the winter value zero, and –100 per cent when the summer value is zero and the winter value unity (Nix 1994).

2.1.2 Topography

There is considerable topographic diversity within the WHWD Area ranging from lower sections of the Fitzroy catchment at about 50 metres altitude to the Consuelo Tableland in Carnarvon National Park at more than 1200 metres (Figures 1.1, 2.6 and 2.7). However, the majority of the Area consists of undulating hills and plains above 200 metres. The region is essentially dissected by the Great Divide, running from the Bunya Mountains (~1100 m) westward through Barakula State Forest (~400 m), northward through Mt Hutton (~900 m) to Carnarvon Range, then north-westward through Consuelo and Buckland Tablelands to the boundary of the bioregion. To the north of the Great Divide, the area is drained by three easterly flowing river systems — Burnett, Fitzroy and Burdekin. Drainage to the south of the Divide is part of the Murray-Darling system.

As discussed later, the location of the Great Divide has a major influence on the biota of the Brigalow Belt. Uniquely in its stretch through eastern Australia, the Great Divide in this region swings inland and is well separated from the Great Escarpment (Figure 2.8). The Great Escarpment is breached by the Burnett, Fitzroy and Burdekin Rivers. The Fitzroy and Burdekin basins lying between the Escarpment and the Divide are the largest easterly flowing drainage systems on the continent.

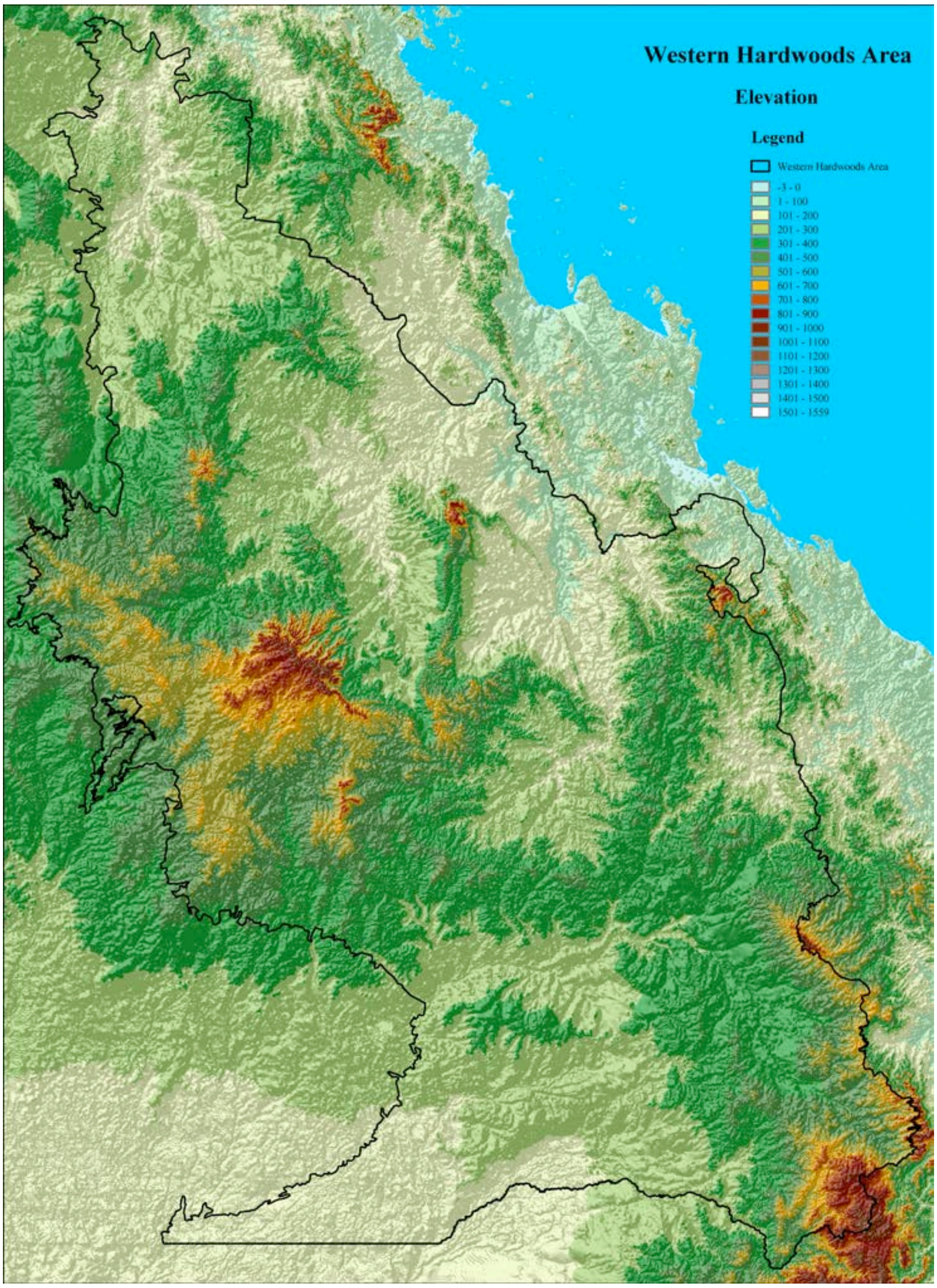


Figure 2.6 Elevation in the Western Hardwoods Area.

Derived from 9 Second DEM Version 2.1 provided under licence by GeoScience Australia.

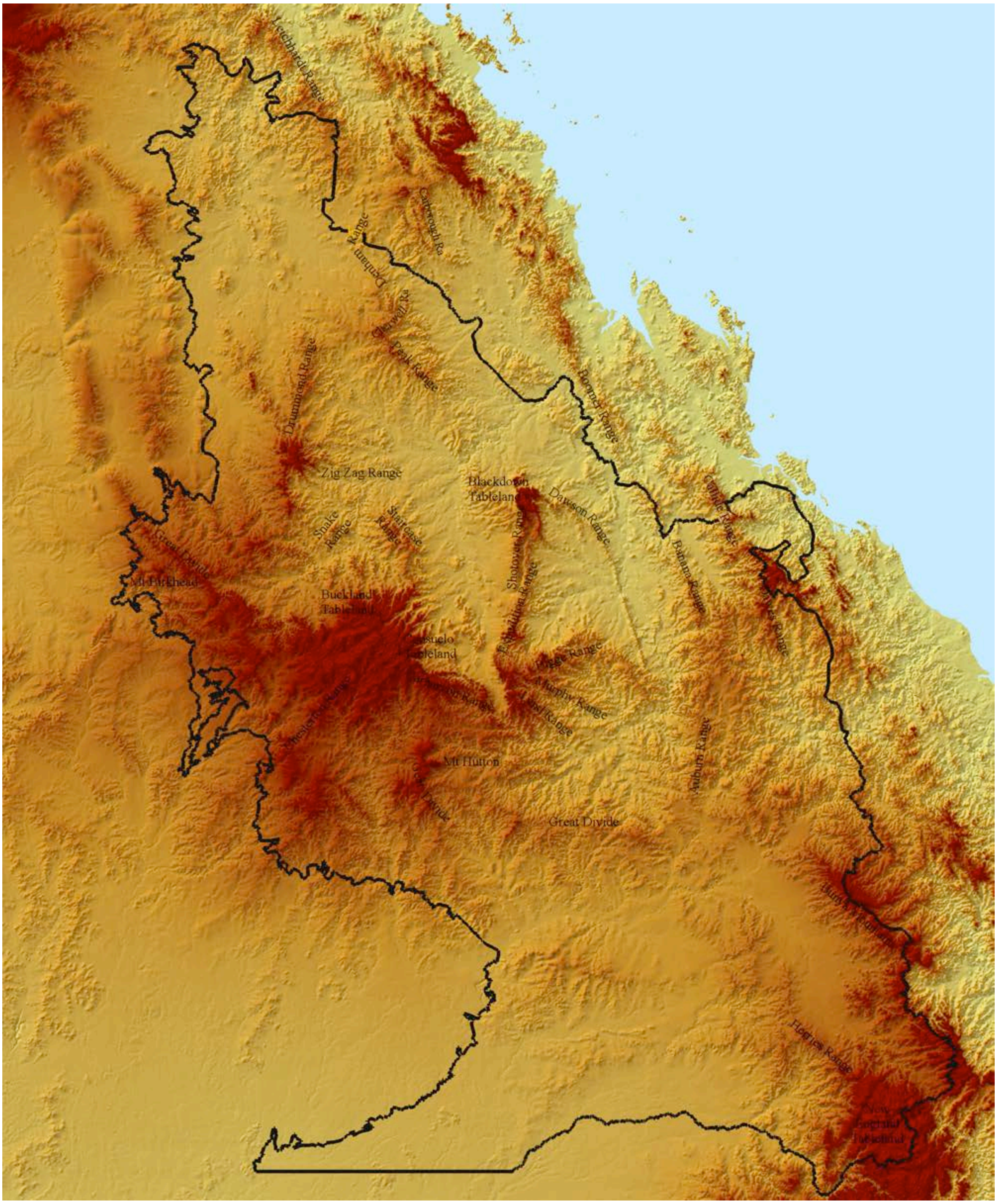


Figure 2.7 Major ranges and tablelands in the Study Area. Elevation is greatly exaggerated. The map is derived from the 9 Second DEM Version 2.1 provided under licence by GeoScience Australia. Commonwealth of Australia (Geoscience Australia) 2002

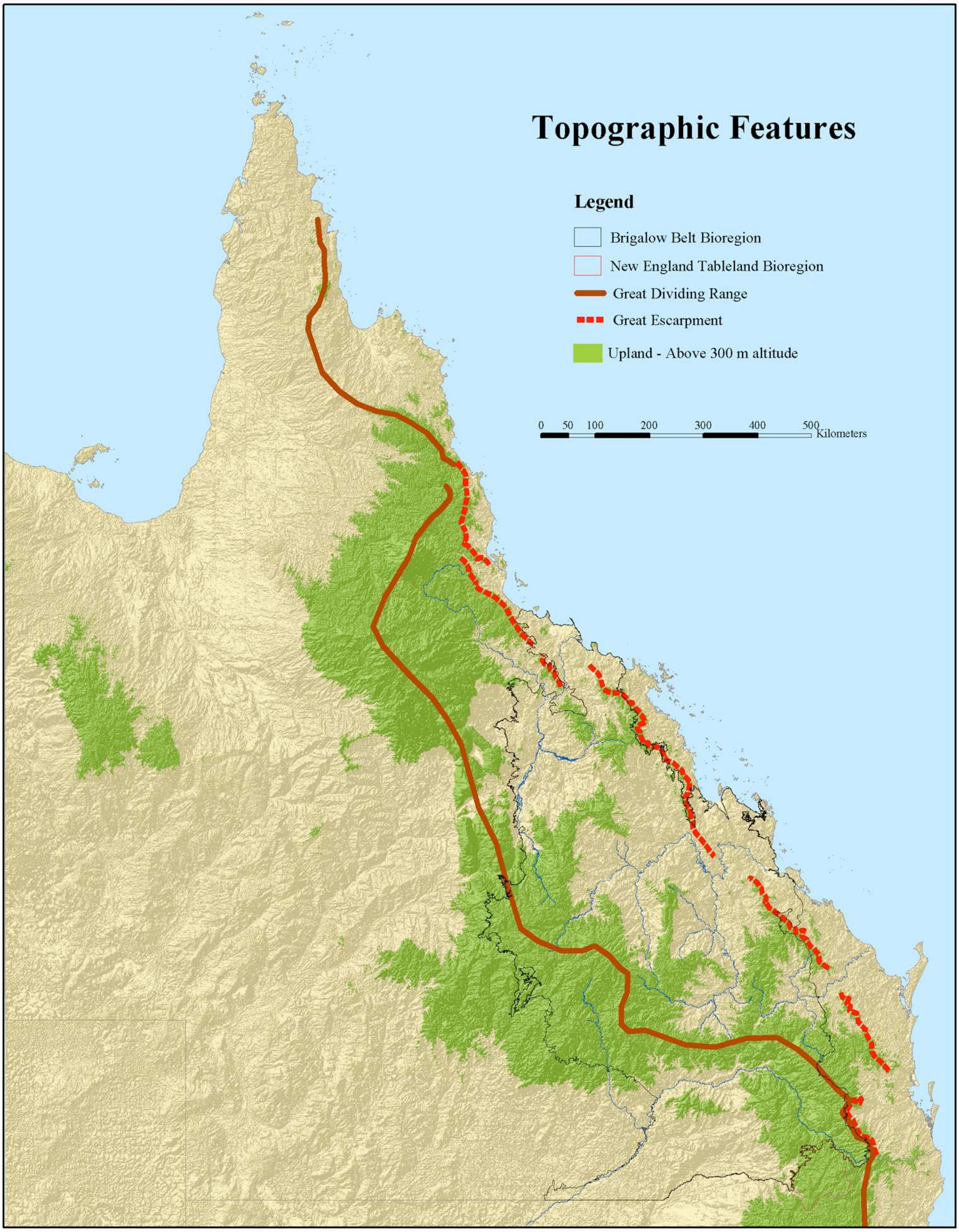
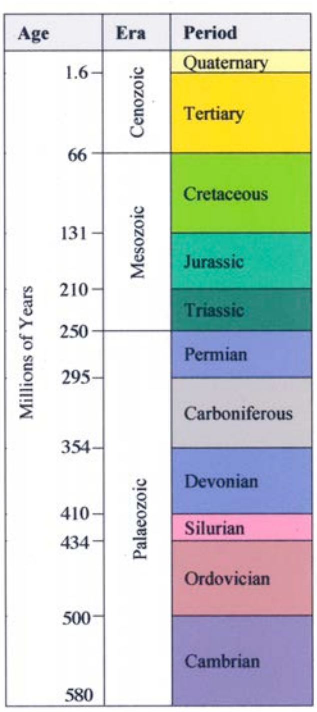


Figure 2.8 General topographic features of the Brigalow Belt bioregion, including the Great Divide and the Great Escarpment. Elevation is derived from the 9-second DEM supplied under licence by Geoscience Australia. Great Escarpment after Ollier (1982).

2.1.3 Landscape evolution

An understanding of the flora and fauna of the Brigalow Belt Bioregion within a global and Australian evolutionary context requires a description and understanding of the geology, soils, landforms and climate and their evolutionary history.



The Australian continent achieved its present outline only between 150 and 50 million years ago but many landscapes are much older. In simple terms they comprise the oldest Pre-Cambrian (Proterozoic or even Archaean) uplands in the western two-thirds of the continent, the younger (Palaeozoic) eastern highlands and the intervening even younger (Mesozoic) lowlands of the Great Artesian Basin. The evolution of these landscapes provides a key to understanding the unique natural values and biogeography of the Brigalow Belt.

The old Pre-Cambrian shield preserved in the western uplands of the Australian continent represents one of the earliest stable formations of the earth's continental crust (cratons). It contains the oldest surface rocks on earth, 600 to 1800 million years old, but mostly covered with younger sedimentary basins variously uplifted and planated (Lindsay 2002). Highest points reach 1500 m, sharply dissected in places to produce permanent water and mesic refugia. Deep gorges cut through massive sandstones, ironstones and quartzites in the Hamersley, Pilbara and Kimberley plateaux. Highest points occur in Central Australia, where extremely narrow, steep sided ranges rise to 1500 m in the Macdonnell and Musgrave Ranges and are dissected by incredibly narrow gorges such as the Serpentine Gorge. The Barkly Tableland, however, is a flat treeless limestone area to 240 m altitude with little surface water. The south-east boundary of this old craton is bounded by the Flinders Ranges in South Australia that rise to 1100 m. Outcrops of Proterozoic rocks in Queensland are restricted to the Mount Isa, Georgetown, Coen and Yambo Inliers. These high points feature significantly in the palimpsest of related and relictual flora across the continent.

The origins of the eastern third of the continent date to the Palaeozoic, when the old ancestral craton enlarged in an easterly direction by accretion of new crustal fragments as far as the margin of the present continental shelf. Deposition of new continental rocks was initiated along the Tasman orogenic zone (formerly known as the Tasman Geosyncline) comprising fold belts such as the Lachlan-Thomson (Cambrian to Carboniferous) and New England (Silurian to Triassic) fold belts. Several cycles of deposition and subsidence followed by folding and granitic intrusion, then uplift and erosion occurred over the next 400

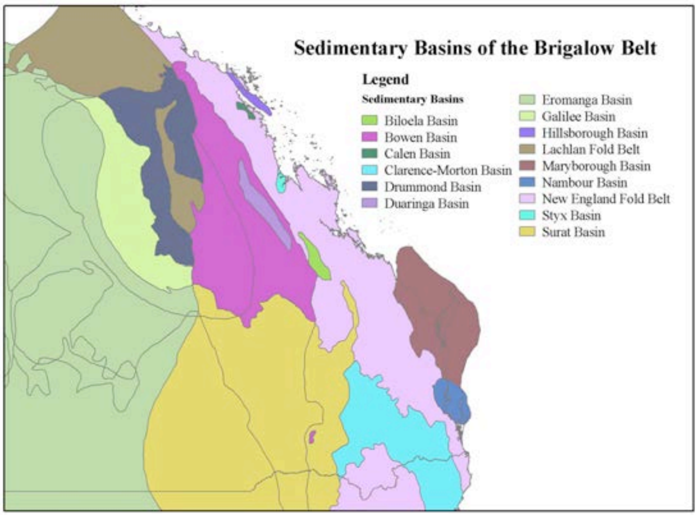


Figure 2.9 Sedimentary basins relevant to the Brigalow Belt

million years. Sedimentary basins (Figure 2.9) such as the Drummond and Bowen Basins were formed by sagging between fold mountains, then filling with sediments from the eroding and weathering flanking highlands.

Figures 2.10 (Geological Eras), 2.11 (Geological Periods) and 2.12 (Lithology) relate to the following discussion.

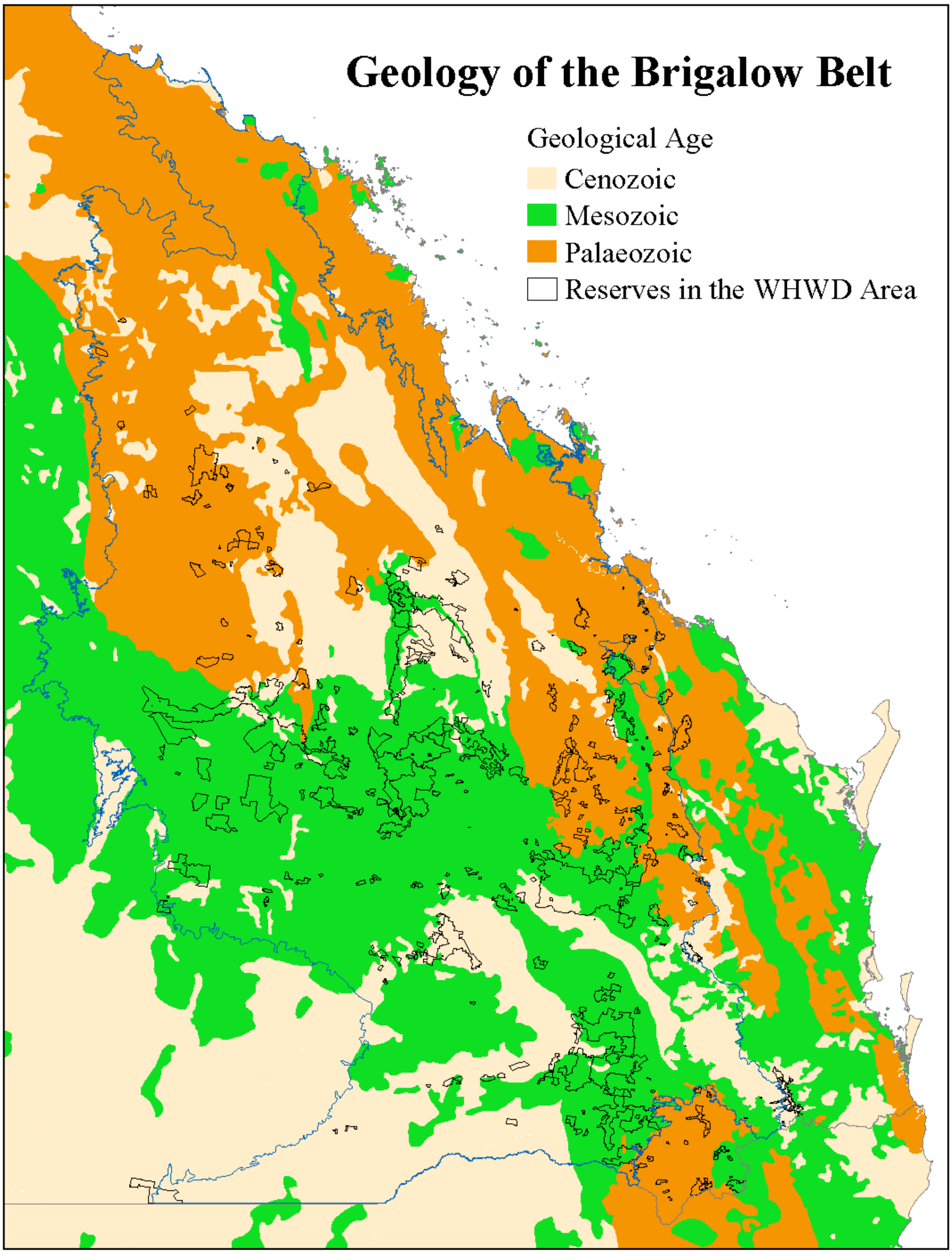


Figure 2.10 Geological Eras relating to the Brigalow Belt

© Commonwealth of Australia (Geoscience Australia)

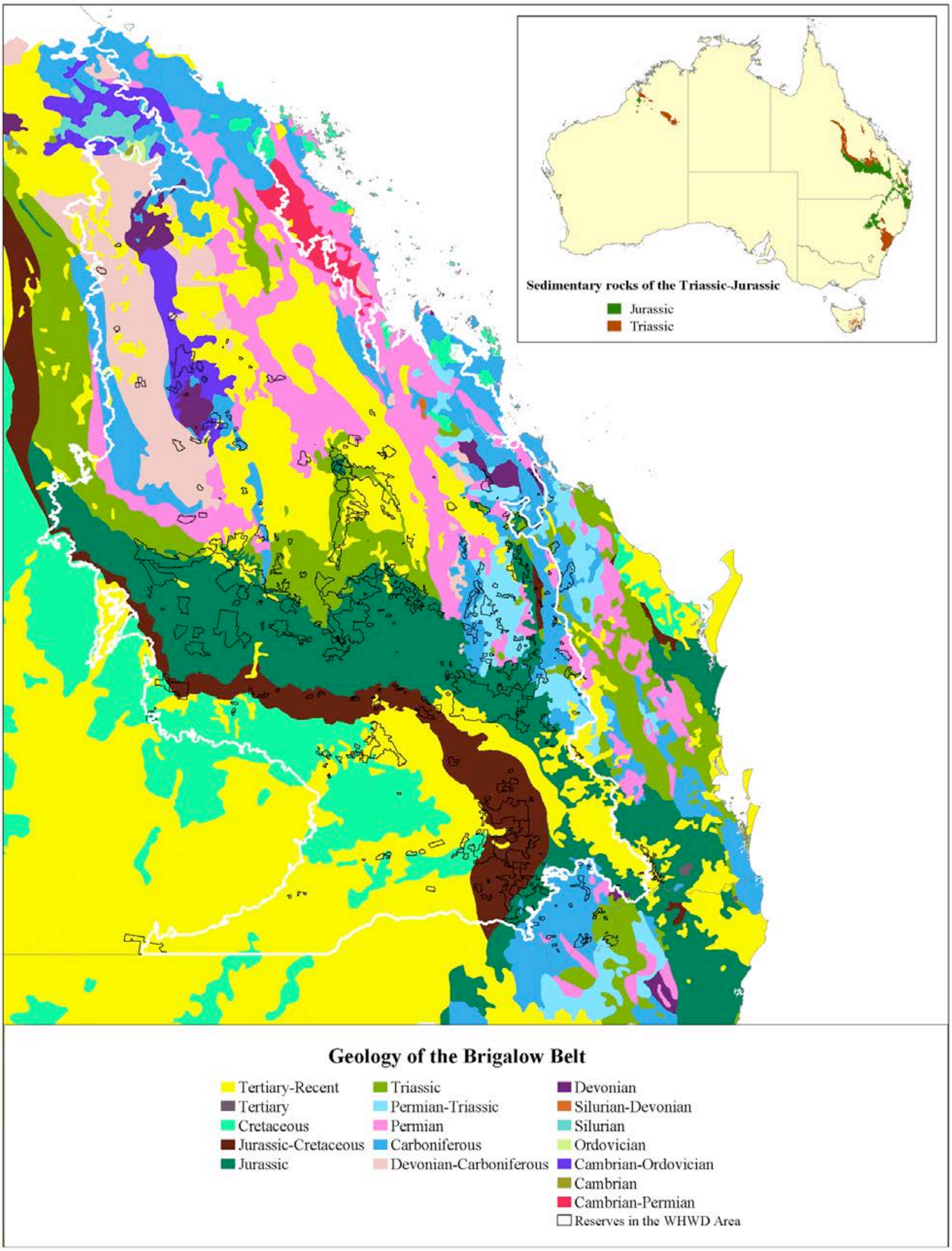


Figure 2.11 Geological Periods in the Brigalow Belt © Commonwealth of Australia (Geoscience Australia)

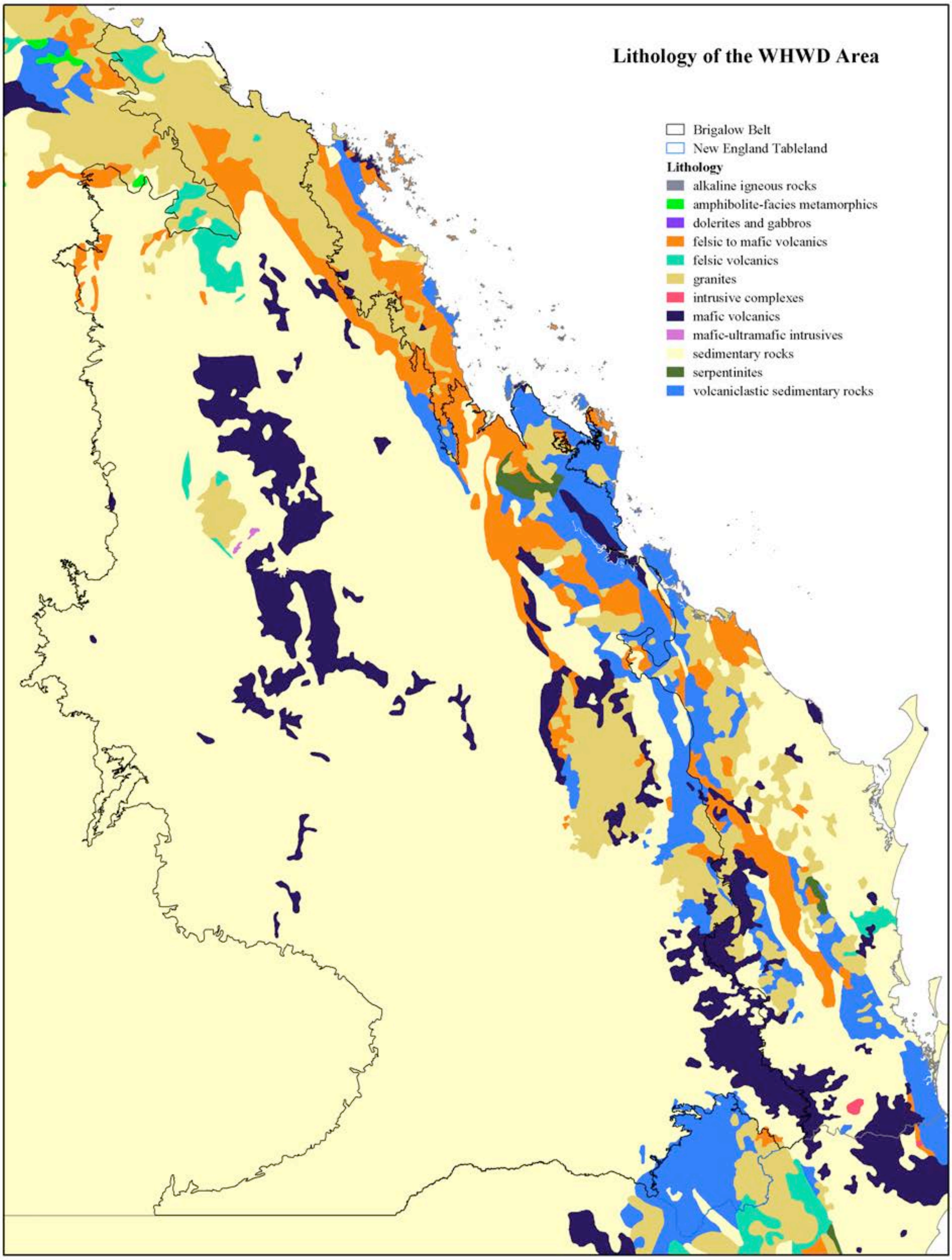


Figure 2.12 Lithology of the Western Hardwoods Area
© Commonwealth of Australia (Geoscience Australia) 2002

The Drummond Basin which surrounds the Anakie Inlier and has arcuate western boundaries was the earliest intermontane basin formed during the Permian and Triassic (Henderson and Stevenson 1980) or Late Devonian-Early Carboniferous Periods (Davis and Henderson 1996). Lava and ash from volcanic activity were inter-layered with sediments. Magma was either extruded from the earth's crust as felsic, silica-rich rhyolites and ignimbrite that accompanied granitic intrusions or was intruded from deep within the basement mantle by ultramafic rocks rich in olivine especially as in the Marlborough Block of the New England Fold Belt. Low-grade metamorphism of these ultramafic rocks, fragments of oceanic crust and mantle, in the Early Permian produced rare serpentinite along thrust faults in the subduction zone of this fold belt (Figure 2.13)(Lacy 1980, Geological Survey of Queensland 1983). Serpentinites in the Marlborough district represent the single largest deposit in Australia (Batianoff *et al*. 2000) and the southern hemisphere, and a significant occurrence among a relatively restricted distribution throughout the rest of the world (Kruckeberg 1992). These rocks produce some of the lowest-nutrient soils known, requiring specialized plant adaptations. Key areas overlying serpentinite in the Brigalow Bioregion include Marlborough, Lake Learmouth, Alligator Creekand Eugene State Forests, and part of Aricia State Forest.

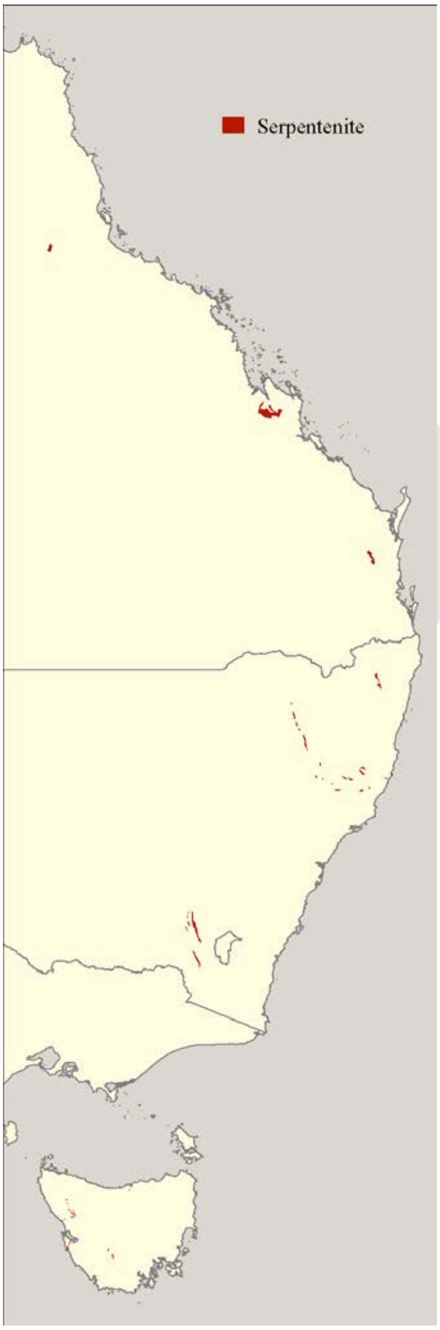


Figure 2.13 Serpentinite in Australia

The Anakie Inlier, one of the few exposed parts of the Lachlan-Thompson Fold Belt, contains one of only three outcroppings of Lower-Mid Palaeozoic granitoids found along the entire east coast of Australia (Richards 1980, Davis and Henderson 1996). The age of these rocks (the Retreat Granites and metamorphics) is thought to be Ordovician (up to 500 million years old), or Mid Devonian, associating them with the earliest cycles of the Palaeozoic accretion of continental crust. The outcrop straddles Tomahawk Creek between Kettle and Carbine State Forests.

The Auburn Arch within the younger New England Fold Belt represents the largest outcropping of Upper Palaeozoic (Permian/Triassic) granitoids in Queensland (Lacy 1980). These Permian-Triassic granitoids underlie State Forests Calrossie, Montour, Hefferon, Yule, Yerilla, Redbank to Rosehall, Delembra, Beeron Holding and the most easterly parts of Allies Creek. Both outcroppings, part of the Coastal Ranges Igneous Subregion, represent significant elements in the original crustal development of Queensland — a very important episode in terms of geological history — and in the evolution of scleromorphous flora adapting to nutrient deficient environments.

This Palaeozoic Era of mountain building was essentially stabilised by the Late Triassic about 200 million years ago, setting the stage for the next major era, the Mesozoic, characterised by repeated filling and forming of younger sedimentary basins, with the elevated areas providing ongoing sources of sediments into their flanking basins. Those like the Galilee, Surat and Eromanga Basins were entirely intra-cratonic where tectonism was milder.

By the Jurassic (early Mesozoic Era), huge sags (epeirogenic downwarping) developed in the older intra-cratonic sedimentary basins. These then began to massively fill with sandy fluvial sediments from major river systems formed during the long warm wet Jurassic Period. New basins such as the Surat Basin formed over the southern parts of the Bowen Basin and the huge Eromanga Basin to the west all but covered the older Galilee Basin. By the end of the Jurassic, the Eromanga and northern Basins were conjoined to form a vast expanse of lowland alluvial plains (The Great Artesian Basin) flanked to the east and west by slopes and uplands of older sedimentary and basement rocks and receiving quartzose sand via the rivers that drained these uplands. The highest sea levels of the entire Phanerozoic Eon occurred during the early Cretaceous inundating these plains contributing both a sequence of marine sediments and extensive marine incursion totally isolating the flanking eastern and western highlands. This fragmentation of the newly formed continental extension of Gondwana coincided with the origins of flowering plants on earth and may have contributed to early regionalisation of nascent angiospermous floras.

Overall, the accreted Late Palaeozoic-Early Mesozoic sediments of the north eastern uplands, represent the largest aggregation of an almost continuous sequence of Gondwanan rocks (Permian, Triassic and Jurassic sandstones) in Australia (Figure 2.11, inset), and certainly one of the largest Mesozoic sandstone deposits in the Southern Hemisphere. They span 250 million years of still intact Gondwana just before rifting and drifting of the individual tectonic plates.

Early Permian sediments are preserved in the Staircase Range stretching from Mt Hope SF to Cardbeign SF, and further north in Fairbairn SF, Crystal Creek and Llandillo SF.

Late Permian sediments persist in part of the Mackenzie River catchment north of Blackdown Tableland, extending north into the Northern Bowen Basin subregion (Amaroo SF, Bundoora SF).

Carborough and Clematis quartz sandstones of the Triassic form the rugged mountainous terrain of the Carnarvon, northern Expedition NP, the triangularly oriented Expedition, Shotover and Dawson Ranges and enclosed Kidell Plains, the Carborough Ranges as well as underlying rocks of Planet Creek between the Expedition and Shotover Ranges, Mount Pleasant SF and Serocold SF.

The Precipice and Hutton Sandstones comprising quartzose to sub-labile sandstone are of Jurassic origin. They form much of the backbone of the Great Divide in this region and give rise to most of the spectacular scenery of the Carnarvon Gorge. The deposits extend through Expedition NP, Presho SF, Palm Grove NP, Theodore SF and Isla Gorge NP to Precipice NP. The Precipice Sandstone outcrops also in Coominglah SF, Cania Gorge, Grevillea SF, Kroombit Tops, Callide TR and, possibly, Blackdown Tableland.

A band of middle Jurassic-Early Cretaceous sediments include the deeply weathered and laterised Inglewood Sandstones.

Associated with these Mesozoic sandstone deposits are some of the most outstanding fossil records of plants and animals of those periods. The Arcadia formation at Bluff (north of Arthurs Bluff SF) represented one of only three known Triassic sites on this continent with the earliest known bony reptile remains, and one of the most diverse early Triassic tetrapod fauna deposits of any Gondwanan continent in the world (Thulborn 1986)(Figure 2.14). This record has been pushed back recently with confirmation of remains in Lower Carboniferous strata in the Drummond Basin (Warren and Turner 2004). The Chinchilla district is recognized as one of the largest areas in the world of petrified gymnospermous wood originating in the Jurassic (Smith 1988).

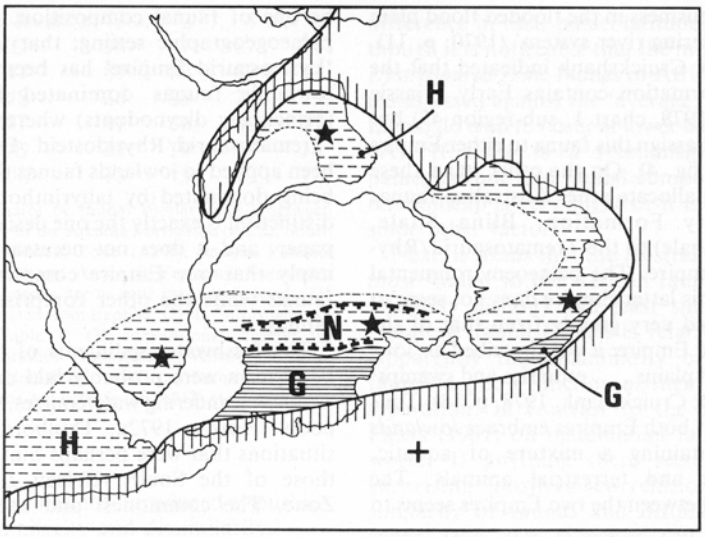


Figure 2.14 Southeastern Gondwana at the start of the Triassic. Locations of tetrapod faunas indicated by stars. Palaeographic features: vertical hatching, shoreline; G (horizontal hatching), Gondwanan orogen; H (broken hatching), middle to high latitude humid belt; N, Nilsen-Mackay Basin. From Thulborn (1986)

The modern landscapes and floras of the Brigalow Belt appear to have been largely developed during the Cenozoic with the formation of the Great Divide, the Great Escarpment, modern climates, the modern asymmetric drainage systems, and deep weathering and erosion to produce new landforms and suites of soils unparalleled in any previous era. All these developments have their origins in plate tectonics — the separation of the Australian and Antarctic plates coincident with the opening of the Tasman Sea, the subsequent northward drifting of the Australian plate on its collision course with the Asian plate (Veevers 1999, Ollier and Pain 1996, 2000).

The formation of new sedimentary basins during the Tertiary was not extensive. The Duaringa Basin which formed during the early Tertiary is thought to be a half graben resulting from rifting of the continental plates, when the Coral Sea floor opened 60-50 million years ago and the Australian Plate finally separated from the Antarctic Plate freeing the Australian Plate to drift northwards during the Palaeocene and Eocene (Grimes 1980). It is the only deep onshore basin of this Period with at least 1000 m of fluvial and lacustrinal depositional sequences including sandstone, conglomerate, siltstone and oil shale with some basalt. The surface has been deeply weathered and preserved, in part, by laterites. The basin extends from Dipperu NP through Junee Tableland, Moultrie and Duaringa State Forests, and is bounded on the east by the Isaac and Mackenzie Rivers to the junction with the Fitzroy. A smaller, younger basin (Mid Tertiary, Miocene), the Biloela Basin, lies parallel to the Duaringa Basin towards its southern end. The unit is dominated by fluvial mudstone and siltstone, and is partly laterised, silcreted and overlain by basalts. Overdeen State Forest lies wholly within this Basin.

The uplift that formed the Great Divide and the Great Escarpment began around 80 million years ago in the southern highlands of Australia (Seidl *et al.* 1996, van der Beek and Braun 1998, Ollier and Pain 1996, 2000) but probably not until just before the Eocene in Queensland (Ollier 1982) and most likely post-dating formation of the Ebor Volcano 18.5

million years ago (Mid Miocene) in the New England Tableland region of northern NSW (Gleadow and Ollier 1987). The Clarence River bears the hallmarks of barbed reversed drainage resulting from the beheading of the Condamine River as lifting and tilting formed the Great Divide. The timing of these changes greatly assists an understanding of patterns of endemism in the eucalypts and acacias as they evolved and radiated in response to climate changes initiated by the final break-up of Gondwana in the Tertiary.

The Great Divide reaches 400 km from the coastline within the Brigalow Belt — the most inland section along its entire length (Figure 2.15)(See also Figure 2.8.). The resulting westerly bulge in the uplands that occurs in the Brigalow Belt is very significant given that 87 per cent of the Australian landscape occurs at altitudes below 500 m and less than 0.5 per cent is above 1000 m. One of the most extensive core areas above 1000 m in Queensland occurs in the Brigalow Belt providing orographic rainfall in an otherwise semi-arid to sub-humid rainfall belt.

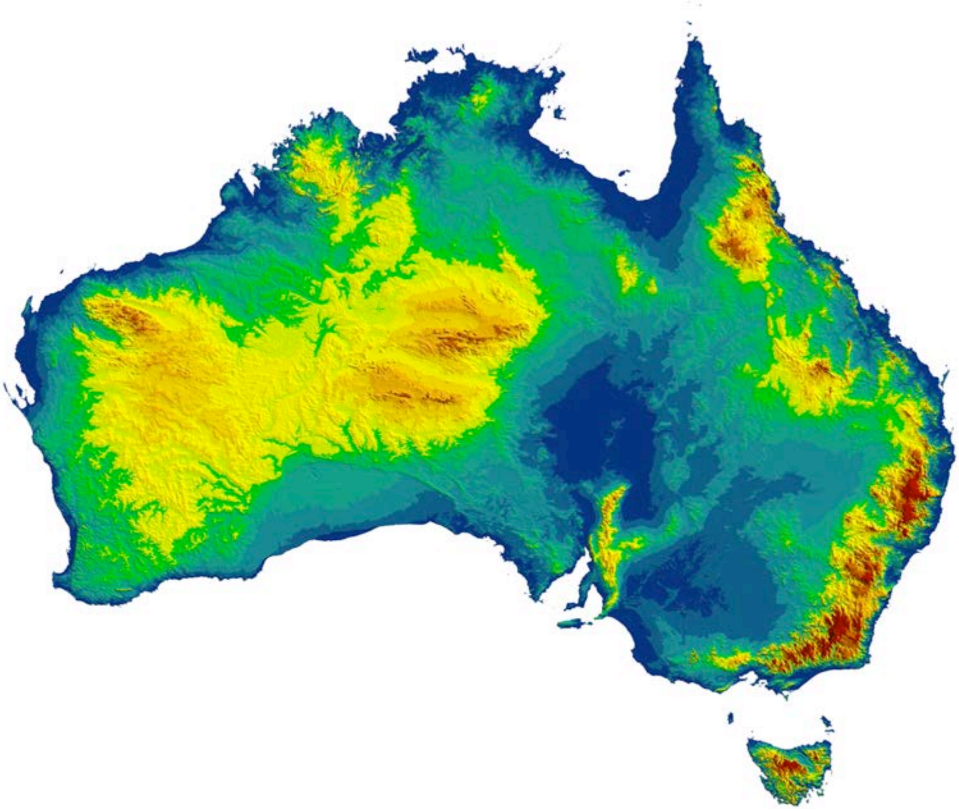


Figure 2.15 Elevation in Australia

Derived from 9 Second DEM Version 2.1 provided under licence by GeoScience Australia.

© Commonwealth of Australia (GeoScience Australia) 2002

The uplift of the Great Divide also resulted in the development of the largest coastal drainage system in eastern Australia — the Burnett, Fitzroy and Burdekin systems and their tributaries. Almost all have their upper valleys aligned north-northwest along old fault lines (feeding the ancestral Darling River system southwards), before sharp changes to modern transverse lower courses. Those that preceded or developed with uplift have produced sharply incised profiles exacerbated by cycles of changing sea levels. For example, the Fitzroy River crosses high coastal ranges such as the Boomer Range on its way to the Pacific suggesting that uplift of the coastal ranges as well as that of the Great Divide accompanied the development of an antecedent (ancestral) drainage system. Differential erosion of the old weathered sandstone uplands has resulted in a rich variety of landforms from plateaus, escarpments, gorges and ranges, to a vast expanse of rolling hills and alluvial plains.

During the Tertiary, progressive volcanic activity occurred over a long period as the Australian plate drifted northwards over 'hot spots' in the magma (Wellman and McDougall 1981, Zhang *et al*. 2001). Hence, the Tertiary 'central volcano' type basalts become increasingly younger to the south. Gunn (1984) notes that Tertiary volcanic and sedimentary rocks probably covered most of the Brigalow Belt at one time, but they have been generally stripped away to expose the older rocks. Tertiary volcanics are predominantly basalt which was very extensive and may have covered most of the central and eastern parts of the Fitzroy River basin. Much has been eroded but caps and plugs remain. Sheets over 500 m thick underlie trachyte on Lords Table Mountain on the Peak Range in the north-west of the bioregion and 300 m of basalt overlies Jurassic sandstone in Carnarvon NP (Beeston and Gray 1993). Lava field basalts erupted near Anakie 31 to 19 million years ago (Zhang et al. 2001). Tertiary basalts extend through the Bunya Mountains and the Main Range in the south-east of the bioregion.

These Central Queensland Tertiary basalts are the largest of the three major occurrences of central volcano or flood basalts in Queensland, and one of the few large areas of Tertiary basalts in Australia. Through nutrient enrichment they undoubtedly played a critical role in the survival and ongoing evolution of rainforest and related floras in the region as climatic conditions and soil nutrient status generally deteriorated from Late Tertiary to the present.

In summary, the unique and dominating landscape features of the Brigalow Belt Bioregion that drove the direction of biological evolution derive from a number of key features:

- the arcuate western margins of the oldest Palaeozoic depositional basins such as the Drummond and Galilee Basins, that closely coincide with the line of Cenozoic uplift and resulted in the most westerly orientation of the Great Divide in Australia;
- one of the most significant outcroppings of Palaeozoic granitoids in Australia and especially the eastern highlands with a key role in the evolution of scleromorphous flora adapting to nutrient deficient environments;
- the westerly bulge in the Great Divide gave rise to the most extensive coastal drainage systems in eastern Australia (the Burnett, Fitzroy and Burdekin River basins);
- the massive Mesozoic sandstone deposits that formed the backbone of the most extensive uplands along the east coast of Australia (Figure 2.15) giving rise to one of Australia's great watershed areas, and providing the bulk of the soil-forming parent rocks for the sandy and clay soils that dominate the Brigalow Belt; and
- the massive Cenozoic basaltic mantle from one of Australia's largest lava fields that helped preserve much of the old Palaeozoic and Mesozoic landscape features and enriched the leaching soils.

2.1.4 Landscapes and soils of the Cenozoic

Modern soils of the Brigalow Belt have their origins almost entirely in the Cenozoic. Essentially none of the pre-Tertiary regolith remained but Early to Mid Tertiary climates provided the ideal warm and humid conditions necessary for deep weathering and new regolith development — this was the so-called warm well watered golden age when rainforests covered most of the continent.

Regions with rocks containing labile minerals (igneous and volcanogenic or felspathic sedimentary rocks) developed deep regoliths, to depths of thousands of metres over high water tables and over very long periods of time, whereas those with quartzose sedimentary rocks, because of their resistance to chemical weathering, produced thin regoliths and soils.

Thus the Mesozoic depositional inheritance of the largest quartzose sandstone deposits in Australia underpinned a relatively stable system of rugged uplands dominated by skeletal infertile soils (lithosols). These ranges that form part of the Great Divide and other residual uplands such as the Blackdown Tableland, the Carnarvon, Expedition, Shotover, Dawson, Carborough Ranges and other smaller ranges, are some of the oldest environments dating to the evolutionary origins of the modern flora. Most of the relictual palaeo-endemic taxa adapted to infertile environments, especially amongst the eucalypts, are restricted to these landscapes and their associated gorges. Variation in the original sedimentary depositional environments resulting in textural and compositional differences in the sandstones provide regional differences in depth, fertility and water retentivity of the soils, in turn influencing the composition of regional vegetation.

The Palaeozoic granites composed primarily of quartz and feldspars (sodium and potassium) were relatively more resistant to weathering than non-quartzose sandstones. Physical breakdown, hydrolysis and oxidation initially formed clay minerals — kaolinite (the most infertile from potassium feldspar), illite (of moderate base status and fertility largely from sodium feldspars and mica) — and sesquioxides of iron (“limonite”) from the minor mafic or iron-bearing components (biotite, amphibole, or pyroxene), the latter being responsible for the reddish, yellowish to chocolate-brown colours of soils derived from these parent rocks. Ongoing leaching resulted in loss of colloidal clay fractions, humus and iron oxides to lower levels of the landscape leaving behind various grades of pale sandy soils *in situ* or producing transported sediments of low fertility (mainly Rudosols and Tenosols on steeper slopes and Chromosols on lower slopes where more of the iron oxides were retained or accumulated).

The vast mantles of unstable volcanic ash and mafic rocks (biotite mica, amphibole, pyroxine and olivine) from flood basalts that covered much of the landscapes at varying times during the Tertiary were the most prone to rapid and deep weathering and erosion.

The deep weathering would have been greatly assisted by acid rain associated with the volcanic activity. Chemical weathering produces a range of clay minerals and sesquioxides and hydroxides of iron and aluminium such as “limonite”, illite (of moderate fertility from mica) and montmorillonite, one of the smectite group of minerals derived primarily from volcanic ash and of high fertility.

Major drying and cooling episodes at the end of the Miocene and again during the Quaternary Period resulted in laterisation of deeply weathered regoliths. The classic deeply weathered profiles graded upwards from parent rock through kaolinite-rich saprolite (in situ weathered parent rock), upward through an increasingly pallid or bleached zone overlain by a mottled zone (consisting of a white or pale-coloured matrix containing ferruginous red mottling) capped by a ferruginous crust (ferricrete). The process over tens of thousands of years involved percolating groundwater progressively leaching silicates and iron compounds from upper layers to accumulate in a reduced form at lower anaerobic levels. Flat topography favoured deep weathering that must exceed the rate of erosion. Relatively sudden episodes of aridity at the end of the Miocene resulted in the zones with higher concentrations of iron oxide cementing conglomerates of sand and gravel into hard brick-like lateritic duricrust.

Where the iron oxides had been transported downslope by groundwater and accumulated in valleys, they similarly hardened and capped profiles formed. Erosion during subsequent wetter cycles produced inverted landscapes where former valleys, indurated with ferricrete, were more resistant to erosion and became the highest landscape features as mesas and scarps. The soils formed on the old deeply weathered surfaces and sediments produced from them, such as the massive red and yellow earths and their associates (Kandosols), are highly leached, acid, with a low base status and rich in kaolinite, quartz and sesquioxides (Fe_2O_3). The majority were either destroyed by erosion in the Late Tertiary and Quaternary or buried under massive sedimentary clay deposits during the Quaternary. Today they remain only as relicts of ancient soils and fossil landscapes that were widespread during the Tertiary when the key transformation of Australia's flora from mesic rainforests to its xeric replacements took place.

The red earths have good water permeability and storage but a very low base status. Only the very surface layers have limited stores of temporary nutrient bases. The core area is centred on Barakula and Allies Creek State Forests. The yellow earths, primarily derived from basalts are now very rare with relicts still found on the Binjour Plateau and Coominglah. Grazing and burning resulting in widespread sheet erosion have the potential to shift the nutrient balance below levels necessary for survival of the ancient and relictual plant communities associated with these fossilised landscapes.

2.1.5 Regoliths and soils of the Quaternary

A fundamental transformation of climates globally was initiated at the boundary between the Tertiary and Quaternary coinciding with bipolar glaciation and the development of the ice ages in the Pleistocene. Great ice-sheets in the northern hemisphere stripped the greater proportion of soils to bare rock initiating regolith and soil development afresh.

In great contrast and uniquely, much of Australia was spared these extremes. Many of the ancient land surfaces with strongly leached and deeply weathered soils remained relatively protected by resistant lateritic skins of varying thicknesses. Where they were broken, the deep lateritic profiles with sesquioxidic concentrates over kaolinized zones were dissected and redistributed across the lower landscapes to be re-weathered and leached to form the modern soils of the Quaternary.

The initial most active periods of hillslope erosion were accompanied by formation of alluvial fans and alluviation of valleys with coarse sands and gravels. Red to yellow podsolic and earth soils developed on these substrates. During periods of greater hillslope stability a fine alluvium accumulated on valley floors on which prairie soils formed (Dermosols).

Associated with the drying was a switch from predominantly acid weathering during the Tertiary to 'alkaline' weathering characteristic of unstable arid to semi-arid climates.

Mafic igneous rocks or those derived from such, provided an immense source of clay minerals rich in montmorillonite, a trimorphic (three-layered) clay comprising one sheet of octahedral, hydrated aluminium sesquioxide (Al_2O_3) interleaved between two sheets of tetrahedral silica (SiO_2) and held together by weak forces allowing entry of water and exchangeable ions into the intercrystalline spaces. These soils retain high amounts of water because of their fine texture, but shrink and swell greatly with seasonal changes in soil-water content. These 'cracking' clays are high in base status (fertility) especially Ca and Mg and are near neutral. Where the organic content is enhanced, fertility is amongst the highest in the State although much of the water and nutrients is held by the montmorillonite clay particles and not available to plants.

In older sediments the montmorillonite clays have become converted to the more common non-cracking clays (illite) through aluminium replacing 10 to 15 percent of the silicon, tightening the intercrystalline spaces and bonding thereby destroying montmorillonite's high base status and unique property of expanding with addition of water.

Sedentary medium to heavy clay soils (chernozems) developed on the newly exposed, old argillaceous sedimentary rocks and basic volcanics of Permian, Jurassic and Cretaceous origin after the complete stripping of their Tertiary surfaces.

A further group of clays, the grey, brown and red clays, developed along the watercourses and flood plains and support woodlands of *Casuarina*, *Acacia* and *Eucalyptus* in all but the most arid areas.

Australia has the greatest area and diversity of clay soils (Vertosols) of any country in the world. The Brigalow Belt Bioregion is unique at a global scale with the largest extent of cracking clays which occur in the sub-humid zone east of the Great Divide.

The soils of the Brigalow Belt are summarised in Table 2.1.

Table 2.1 Major soil groups of the Brigalow Belt (after Gunn 1984 and Isbell *et al*. 1993)

Order	Major soil group	Component soils	Description
Rudosols/Tenosols	Skeletal soils	Lithosols	shallow sandy or loamy soils with little or no profile development; mainly in hilly terrain
Kandosols	Sesquioxide soils	Red and yellow earths	Sandy to loamy soils with weak profile development; low fertility;
Sodosols	Texture-contrast soils	Soloths, solodized solonetz and solodic soils	Sandy-loam to clay loam surface horizons sharply differentiated from clay subsoils; widespread in the bioregion; generally low fertility; extensive throughout the Brigalow Belt
Chromosols	Texture-contrast soils	Red-brown earths	Loam to clay loam surface horizons with brown clay subsoils; minor areas in the Brigalow Belt
	Texture-contrast soils	Non-calcic brown soils	Sand loam to loam surface with clay subsoils; small areas on the eastern margin, otherwise confined to the far north of the bioregion
Kurosols	Texture-contrast soils	Red podzolic soils	Sandy to loamy surface soils and subsoil of high clay content; minor component of the bioregion
Dermosols	Brown and grey-brown soils	Prairie soils	Clay loam surface soil grading to clay subsoil; relatively fertile; confined in the bioregion to the far south-east corner west of the Main Range
Ferrosols	Brown and grey-brown soils	Euchrozems	Well-drained clay loams to clay soils, usually developed on basalt; occurs in the Marlborough subregion
Vertosols	Cracking clay soils	Grey, brown and red clay soils	Moderately deep to deep cracking, with a self-mulching surface; these soils crack deeply on drying and have well developed gilgai
	Cracking clay soils	Black earths	Very dark and very deep clay soils, commonly occurring on basaltic rocks; among the most fertile soils with high moisture storage
	Alluvial soils	Sands to clays	

2.2 Vegetation

2.2.1 Overview

The vegetation of the Study Area includes eucalypt forests and woodlands, acacia forests and woodlands including brigalow (*Acacia harpophylla*) communities, rainforests, cypress forests, casuarina forests and woodlands, heathlands and tussock grasslands. Table 2.2 lists the areas of broad vegetation types in the Brigalow Belt bioregion.

Table 2.2 Broad vegetation types in the Brigalow Belt bioregion

Broad Vegetation Type	**Area (ha)**
Eucalypt forest	1 440 000
Eucalypt woodland	10 434 000
Rainforest (vine forest and vine thicket)	287 000
Brigalow	1 001 000
Non-eucalypt forest	518 000
Non-eucalypt woodland	1 347 000
Non-forest	683 000

Source: National Forest Inventory Australia, Bureau Resource Sciences, 2003

The distribution of broad forest types in the Brigalow Belt is shown in Figure 2.16.

By far the most extensive vegetation type is eucalypt woodland. It is, however, poorly represented in the reserve system (Figure 2.17). The major occurrence is in Expedition NP.

Of the nine regional ecosystems in which the vegetation community is open eucalypt or tall open eucalypt forest, seven are naturally restricted or of limited extent. They occur in only half of the landzones defined in the bioregion, and eight of them occur in only one or two subregions. Five of the nine are classified as ‘Of Concern’ because of the extent of clearing.

The brigalow communities that give their name to the region are now very restricted in occurrence as a result of clearing for agricultural development.

Rainforests at the drier end of the spectrum (semi-evergreen vine thickets, softwood scrubs or bottle-tree scrubs) occurred across the central and northern parts of the bioregion but have also suffered greatly from clearing.

The Commonwealth of Australia has listed three ecological communities in the Brigalow Belt as endangered under the *Environment Protection and Biodiversity Conservation Act 1999*. The three endangered ecological communities are —

- Blue grass (*Dichanthium* spp.) dominant grasslands of the Brigalow Belt (North and South) Bioregions,
- Brigalow (*Acacia harpophylla* dominant and codominant),
- Semi-evergreen vine thickets of Brigalow Belt (North and South) and Nandewar Bioregions.

These ecological communities are further discussed in Section 5.6.

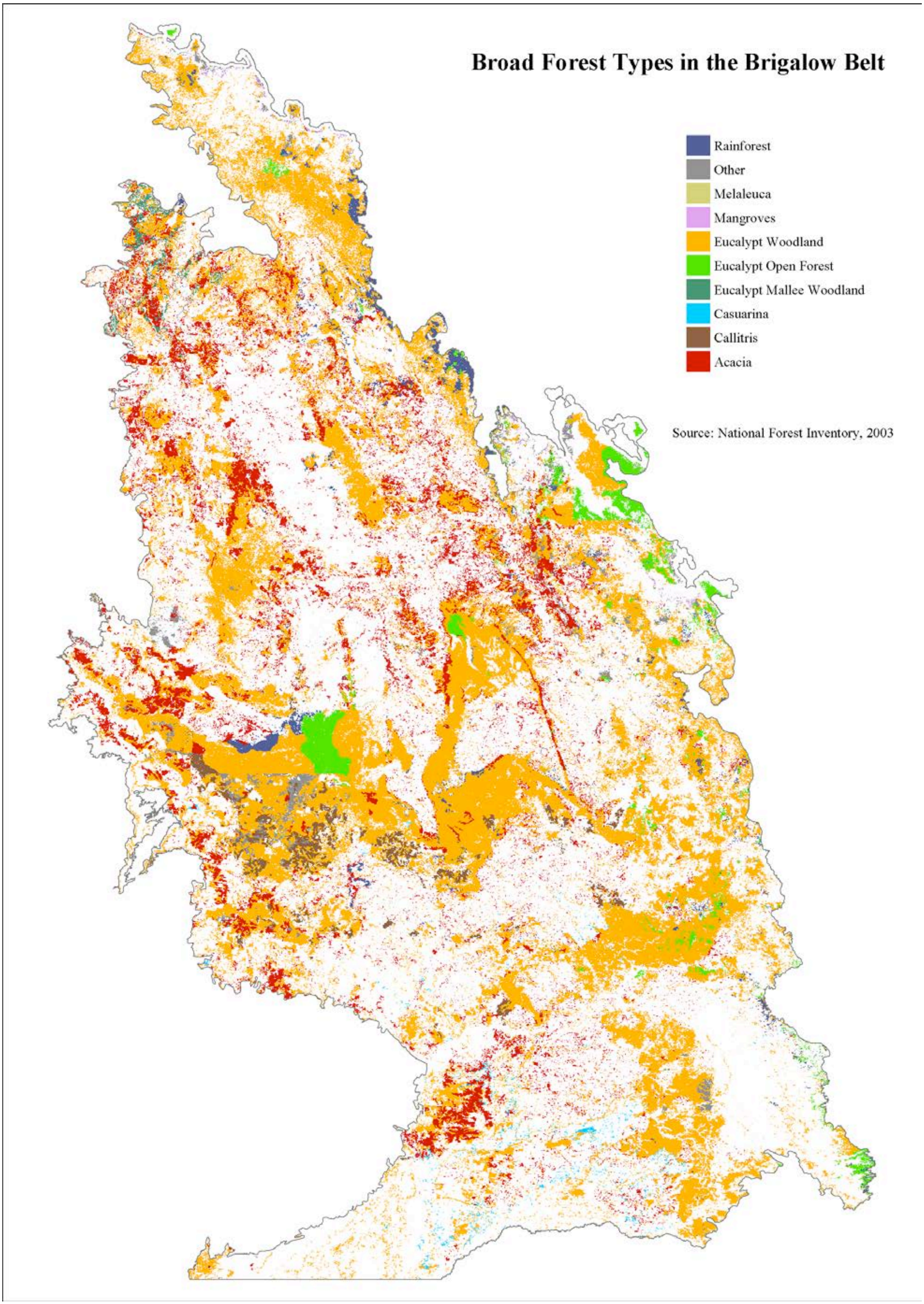


Figure 2.16 Broad vegetation types in the Brigalow Belt (National Forest Inventory Australia 2003)

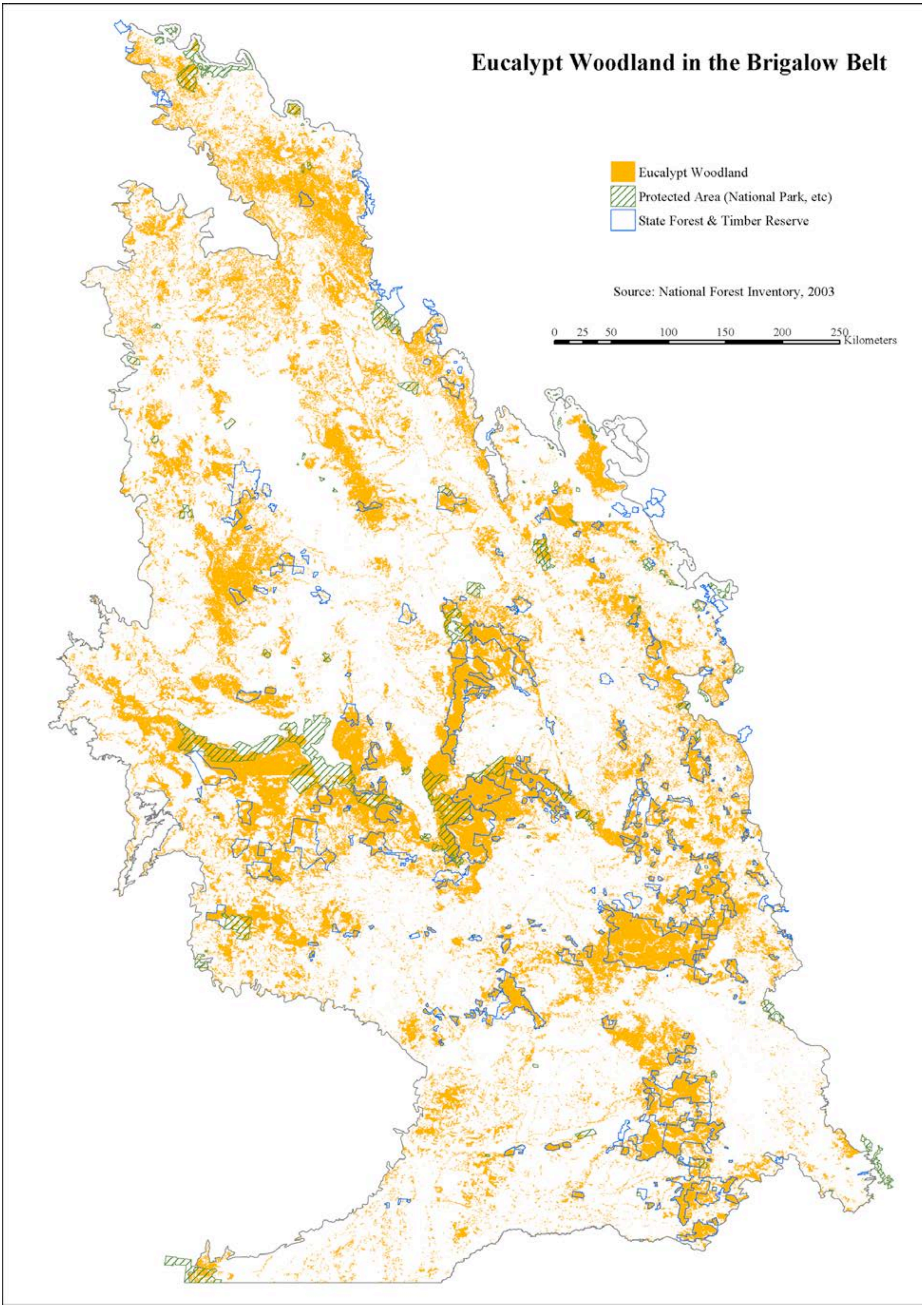


Figure 2.17 Eucalypt woodland in the Brigalow Belt (National Forest Inventory Australia 2003)

2.2.2 Regional Ecosystems and assessment of their geographical variation within the Western Hardwoods Area

2.2.2.1 Regional Ecosystems in Queensland

In Queensland, the Regional Ecosystem classification system is used to categorise different vegetation types. Regional Ecosystems are defined by Sattler and Williams (1999) as vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil.

The use of the term 'ecosystem' for the purpose of classifying vegetation communities, while consistent with nationally adopted guidelines, is unfortunate and has the potential to compromise the effectiveness of biodiversity conservation strategies and reserve outcomes.

There is no widely agreed definition of 'ecosystem' and deliberations in Australia over the past decade or so have led to acceptance by governments of a pragmatic definition based on vegetation mapping and the desire for a system for classifying biodiversity that can be applied within the context of generally inadequate spatial data.

The Macquarie Dictionary defines ecosystem as "a community of organisms, interacting with one another, plus the environment in which they live and with which they also interact". Classically, definitions have generally referred to a community of organisms interacting with one another and with the abiotic components of their environment.

The *Environment Protection and Biodiversity Conservation Act 1999* (section 528) defines an ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit".

For the purposes of the National Reserve System, an ecosystem is defined as "a unique unit comprising a recognisable floristic composition in combination with substrate (lithology/geology layers) and position within the landscape, and including their component biota (where known)" (Natural Resource Management Ministerial Council 2004).

Inevitably, ecosystems have become subject to classification such that similar communities are grouped in order to simplify planning processes. In these classification systems, it is apparently acceptable for the 'unique unit' to occur at various disjunct locations across the landscape. In the case of the Brigalow Belt bioregion, the disjunct occurrences in some cases extend over a range of 900 km, greater than the distance between Brisbane and Sydney. Inevitably, the 'unique unit' has become a definitional group of (generally) similar, spatially distinct units. This is, of course, a common result of classifying natural systems and the practical basis is understood. However, there should be no pretence that in applying such classification systems to conservation planning the full range of biodiversity is being addressed.

It can be argued that the formerly accepted definition of ecosystem meant a community of organisms that is not replicated across the landscape. Classification of ecosystems to provide groupings of *similar* communities is a planning convenience. It does not preserve the concept of an ecosystem as a community.

It should not be inferred that designers of such classification systems are unaware of the weaknesses. Sattler and Williams (1999) note "the more comprehensively environmental variables are described, the more robust will be the classification of regional ecosystems and the greater their usefulness for biodiversity planning". The principal problem lies in the application of these systems where their inadequacies are commonly ignored.

In Queensland, there is a link between the Regional Ecosystem classification system and the *Nature Conservation Act 1992*. The Act requires protection of biodiversity including regional, ecosystem, species and genetic diversity. At this point in time, Regional Ecosystems are used as surrogates for biodiversity and as the unit of measure for its protection.

From the *Master Plan for Queensland's Parks System* (Environmental Protection Agency 2001), it can be inferred that a purpose of the system is to help conserve biodiversity at all levels. The principal measure for achieving conservation of biodiversity is the level of representation of Regional Ecosystems in the Protected Area estate. The goal is to raise representation from 70 per cent to a minimum of 80 per cent. Whereas one could question the adequacy of the 80 per cent figure, the more serious issue is that the value of setting any goal is compromised by the nature of the Regional Ecosystem. The purpose of the studies described below was to assess the geographic variation in the flora of a range of Regional Ecosystems.

Regional Ecosystems (REs) have been mapped by the Environmental Protection Agency (EPA) for a significant part of Queensland. REs are given a Vegetation Management status under the *Vegetation Management Act 1999* based on an assessment of their pre-clearing and remnant extent. REs are also assigned a Biodiversity Status by the EPA based on an assessment of the condition of remnant vegetation in addition to the pre-clearing and remnant extent.

2.2.2.2 Regional Ecosystems in the Brigalow Belt

The Brigalow Belt (34 million ha) is the largest bioregion in the State, the third largest in Australia (National Land and Water Resources Audit 2001) and one and a half times the size of Victoria. It stretches for over 1000 km from north to south (covering 10 degrees in latitude) and over a maximum of 550 km (or 6 longitudinal degrees) from east to west.

As a result of this sheer size, the area encompasses a range of climatic conditions (See Section 2.1.1.). Furthermore, significant variation in the physical features of the landscape (See Section 2.1.) is reflected by the occurrence of ten of the twelve landzones defined for Queensland (Sattler and Williams 1999). This combination of climatic and physical factors has resulted in the designation of 38 subregions (Figure 2.18), a greater number than in any other bioregion in Australia. Accordingly, there is a wide range of responses to these conditions within vegetation communities, such that the diversity of REs in the Study Area exceeds that of any other region in Queensland.

There are 365 REs in the WHWD Area, of which 183 are Brigalow Belt REs (11.n.n) and 29 are New England Tableland REs (13.n.n). In addition there are outliers of the South East Queensland, Desert Uplands, Mulga Lands, Einasleigh Uplands and Mitchell Grass Downs REs (Table 2.3).

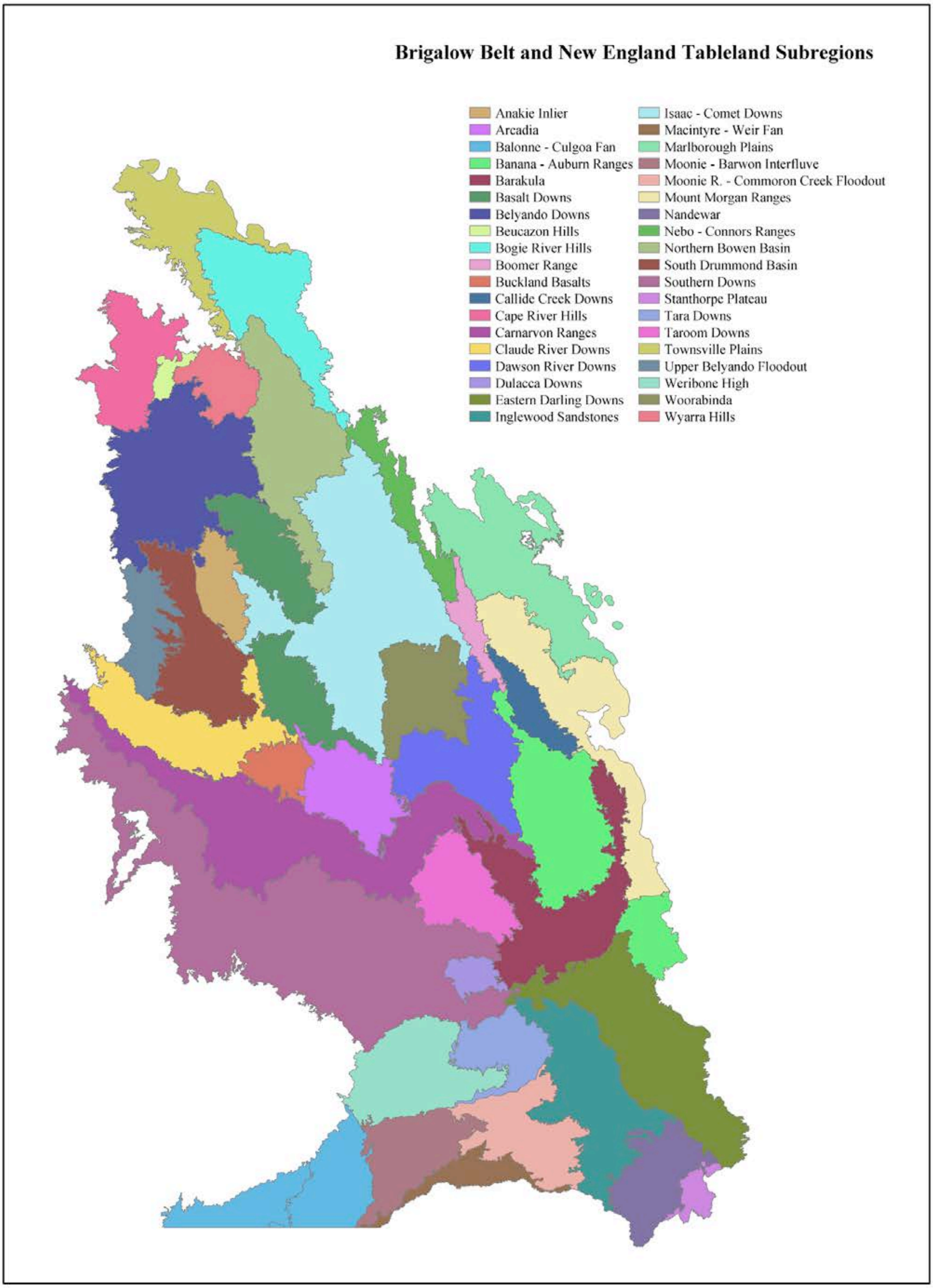


Figure 2.18 Subregions of the Brigalow Belt bioregion

Table 2.3 Regional Ecosystems in the Western Hardwoods Area

Bioregion	**Number of Regional Ecosystems**
Brigalow	183
New England Tableland	29
South East Queensland	61
Desert Uplands	31
Mulga Lands	27
Einasleigh Uplands	19
Mitchell Grass Downs	15
Total	365

A short description of all REs in the WHWD Area is given in Appendix 1.

2.2.2.3 Limitations in Regional Ecosystem classification for conservation

Despite the existing richness of REs in the Study Area, many REs are currently mapped as covering large areas of the bioregion, crossing multiple subregions and in geographically disjunct patches separated by up to 200 km (Figure 2.19).

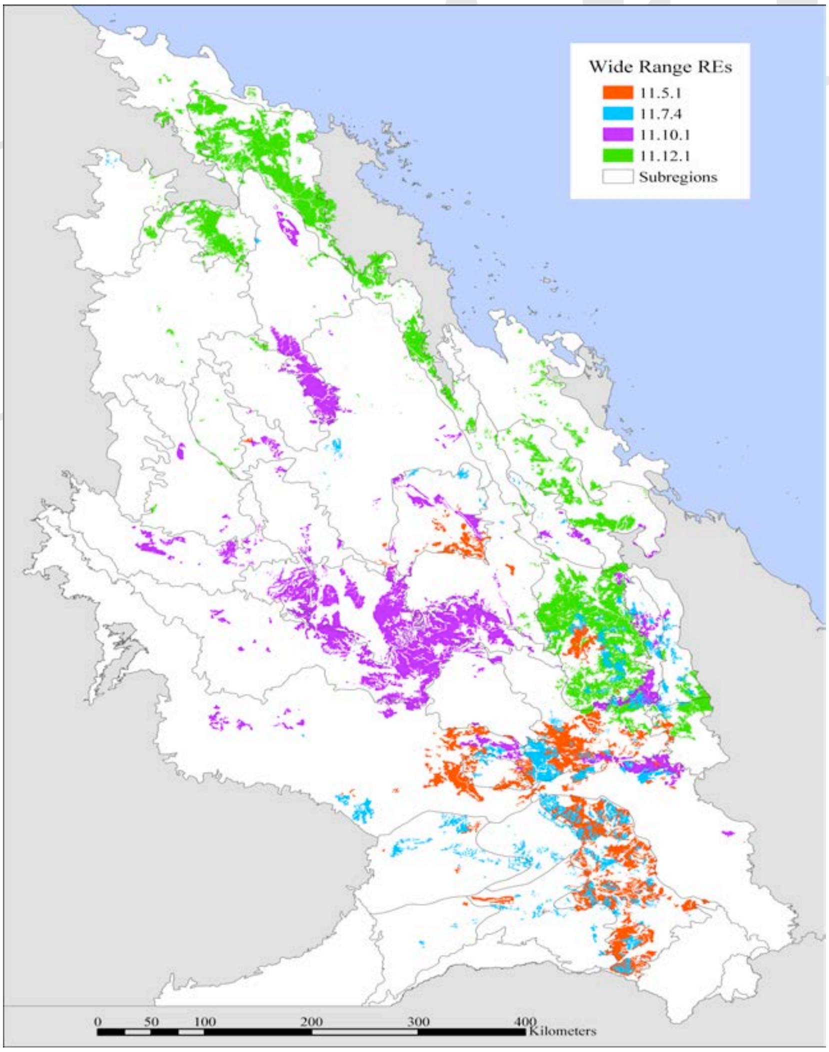


Figure 2.19 Examples of Brigalow Belt Regional Ecosystems mapped with wide geographic distributions; pre-clearing extent is shown

These broadly spread REs encompass areas of varying environmental conditions, so that within a particular RE the vegetation community can be subject to large differences across its range. For example, wide variation in bioclimatic attributes can be seen in Corveg sites for 11.10.1 (Appendix 2, Figure A2.6). Gradients in these variables exist with respect to elevation and key factors in plant community composition such as minimum temperature of the coldest period and precipitation of the driest quarter (Figure 2.20). Outlying sites are usually due to their relative geographical position being either more coastal, further inland or more southern or northern than other sites. These may represent sites with misclassified RE information, or are in those communities that require reclassification in respect of further divisions and groupings.

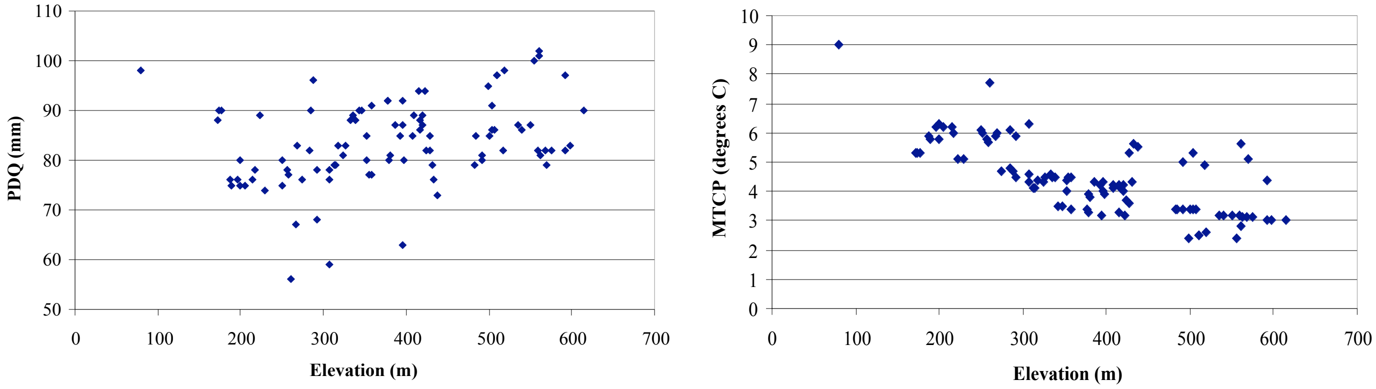


Figure 2.20 Precipitation of the driest quarter and minimum temperature of the coldest period compared to elevation for all 11.10.1 Corveg sites.

Whilst some species with large ecological amplitudes could be expected to occur across all sites, it is reasonable to expect an associated change in overall species composition with these gradients. However, looking in more detail at species listed at the sites is not always helpful due to poor surveying, with often only prominent species having been recorded. An additional consideration is the genetic diversity of those wide-ranging species which occur under varying environmental conditions – an extremely important element in recognising and planning for the total biodiversity present.

Further analysis could investigate the bioclimatic ranges of particular species or groups of species at the generic or family level (See, for example, Moss and Kershaw 2000.) within an RE to aid in community reclassification.

As REs are used as surrogates for floral diversity (and biodiversity in general), it is important that this diversity is represented in their classification. However, initial vegetation mapping using aerial photograph interpretation cannot readily detect differences in forest and woodland understorey species. Hence, REs with broad geographic ranges with varying understorey species due to changes in environmental conditions may be 'lumped' vegetation communities. While RE definition remains based primarily on dominant canopy species, the classification system cannot reflect the total species composition.

The following text describes the results of analyses carried out by ARCS to investigate the geographic variation in floristics within a number of example REs in the WHWD Area. The results suggest that current classifications of some REs are inadequate in reflecting floral diversity. Regardless of whether or not reclassification is undertaken, nationally agreed reserve criteria require that reserves should reflect the biotic diversity of the communities (JANIS 1997), hence the need to identify that diversity.

Multivariate statistical analyses were undertaken with four REs.[3] Cluster analysis of species data from systematic survey sites was carried out to investigate spatial patterns in groups of sites with similar composition[4]. Significant group-associated indicator species were also identified for those groups to aid in determining compositional differences[5]. Of the REs investigated, geographically distinct groups of sites formed within 11.5.1 and 11.12.1, albeit at different scales (Figure 2.20). Other REs showed high levels of species heterogeneity between groups of sites, often within a relatively small area. For example, 11.7.4 sites split into three groups in the Banana-Auburn Ranges area[6] whilst analysis only of woody species for the complex of 11.10.1 and 11.10.13 had four groups forming in Callide Timber Reserve[7]. This is indicative of the need for finer scale classification and mapping.

To further examine the relationships between groups, ordination was conducted to investigate differences when considering all sites in multidimensional ecological space. Overlaying group classification and correlating selected bioclimatic variables and elevation gave an indication of the relevant factors influencing group distributions[8]. REs that generally differentiate over a north-south gradient (RE 11.5.1 and 11.12.1)[9] are influenced more by equability of moisture index and minimum temperature of the coldest period. Differences in elevation of between 50 and 100m appear to have an influence on the internal variability of some REs (e.g. 11.7.4 in the Auburn Ranges). Other factors such as soils and geology (which were not included in the analysis) may also play a role.

These preliminary findings provide a strong case for further subdividing a number of existing REs together with a reassessment of their conservation status. A reclassification that reflects overall composition would result in the recognition of even greater RE richness in both the Brigalow Belt as a whole and in specific parts of the bioregion. Furthermore, public land could assume an even greater importance in cases where it harbours the only significant remnants of reclassified REs. For example, analysis of 11.12.1 indicated the need for reclassifying areas of occurrence in the Auburn Ranges that have been heavily cleared, and highly likely to be threatened. In addition, it is apparent from investigating several REs that large areas still require further comprehensive field survey[10]. This is especially evident in areas subject to clearing such as the south-west distribution of 11.7.4[11] and the Woorabinda Subregion occurrences of 11.5.1 (Figure 2.21).

---

[3] For the full analysis method with worked examples, see Appendix 2.

[4] See Figure A2.1, Appendix 2.

[5] See Table A2.2, Appendix 2.

[6] See Figure A2.5, Appendix 2.

[7] See Figures A2.6.and A2.7, Appendix 2.

[8] See Figure A2.2, Appendix 2.

[9] See Tables A2.3 and A2.7, Figures A2.3 and A2.5, Appendix 2.

[10] See Table A2.12, Appendix 2.

[11] See Figure A2.5, Appendix 2.

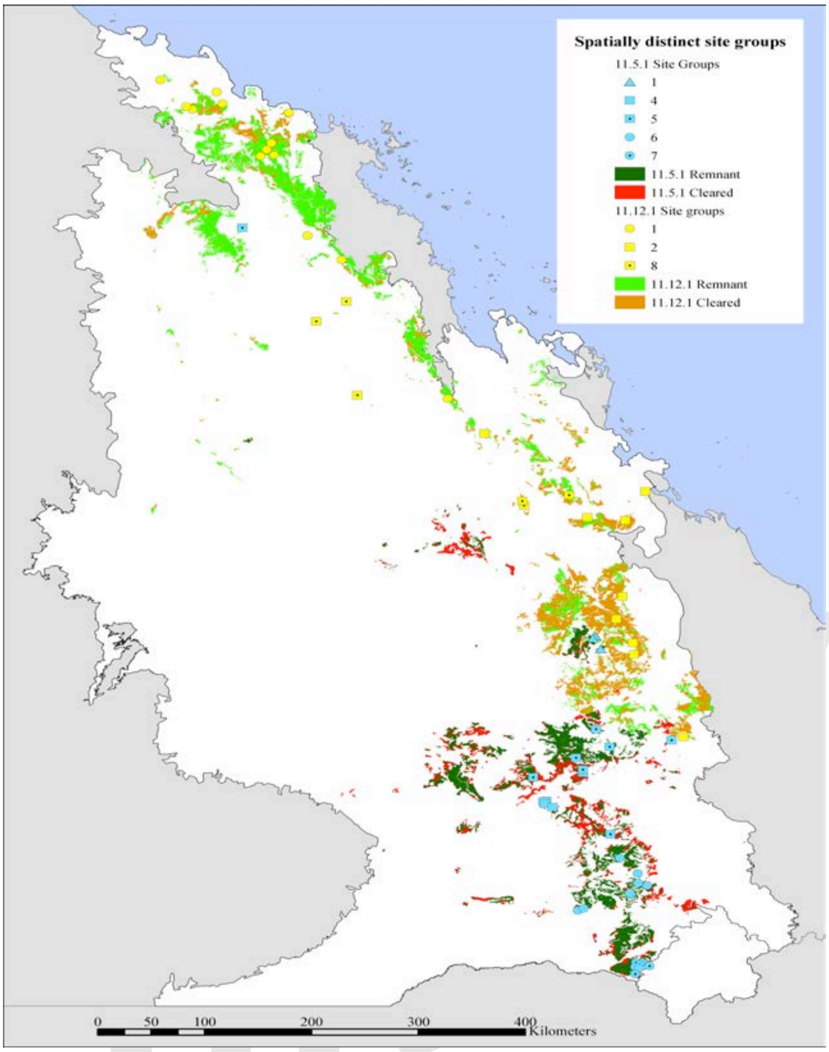


Figure 2.21 Examples of Regional Ecosystems with geographically distinct cluster site groups; remnant and cleared vegetation shown

In summary, regional ecosystem mapping has significant limitations with respect to its use for conservation planning and the development of biodiversity strategies. Firstly, a reserve system based on representation of REs as currently mapped is unlikely to capture floristic diversity unless geographic variation is taken into account. Comprehensive information on such variation is not currently available. Secondly, classification that does not take account of floristics other than dominant canopy species may disguise the actual conservation status of particular communities which would therefore not be provided with the appropriate protection.

2.3 Flora

The Study Area has a rich flora with around 5100 vascular plant species and infra-specific taxa, representing 1355 genera and 292 families. Approximately 4220 higher plant species and infra-specific taxa have been recorded from the WHWD Area. They represent 1110 genera and 265 families.

The most speciose families (species recorded in the Study Area) are Poaceae, Myrtaceae, Fabaceae and Mimosaceae. The most speciose genera are *Acacia*, *Eucalyptus* and *Cyperus*.

Around 378 plant taxa are endemic to the Study Area compared with 273 in South-East Queensland and 150 in the Central Eastern Rainforest Reserves of Australia.

Whereas the flora of the Brigalow Belt is highly diverse, acacias and eucalypts are most conspicuous and determine much of the character of the (natural) landscape.

More than 200 *Acacia* taxa are recorded from the region. They include many well known species that are commonly associated with the Brigalow Belt and adjoining regions to the west and north: Brigalow (*Acacia harpophylla*), Gidgee (*A. cambagei*), Lancewood (*A. shirleyi*), Blackwood (*A. argyrodendron*), Bendee (*A. catenulata*), Rosewood (*A. rhodoxylon*), Myall (*A. pendula*) and Mulga (*A. aneura*).

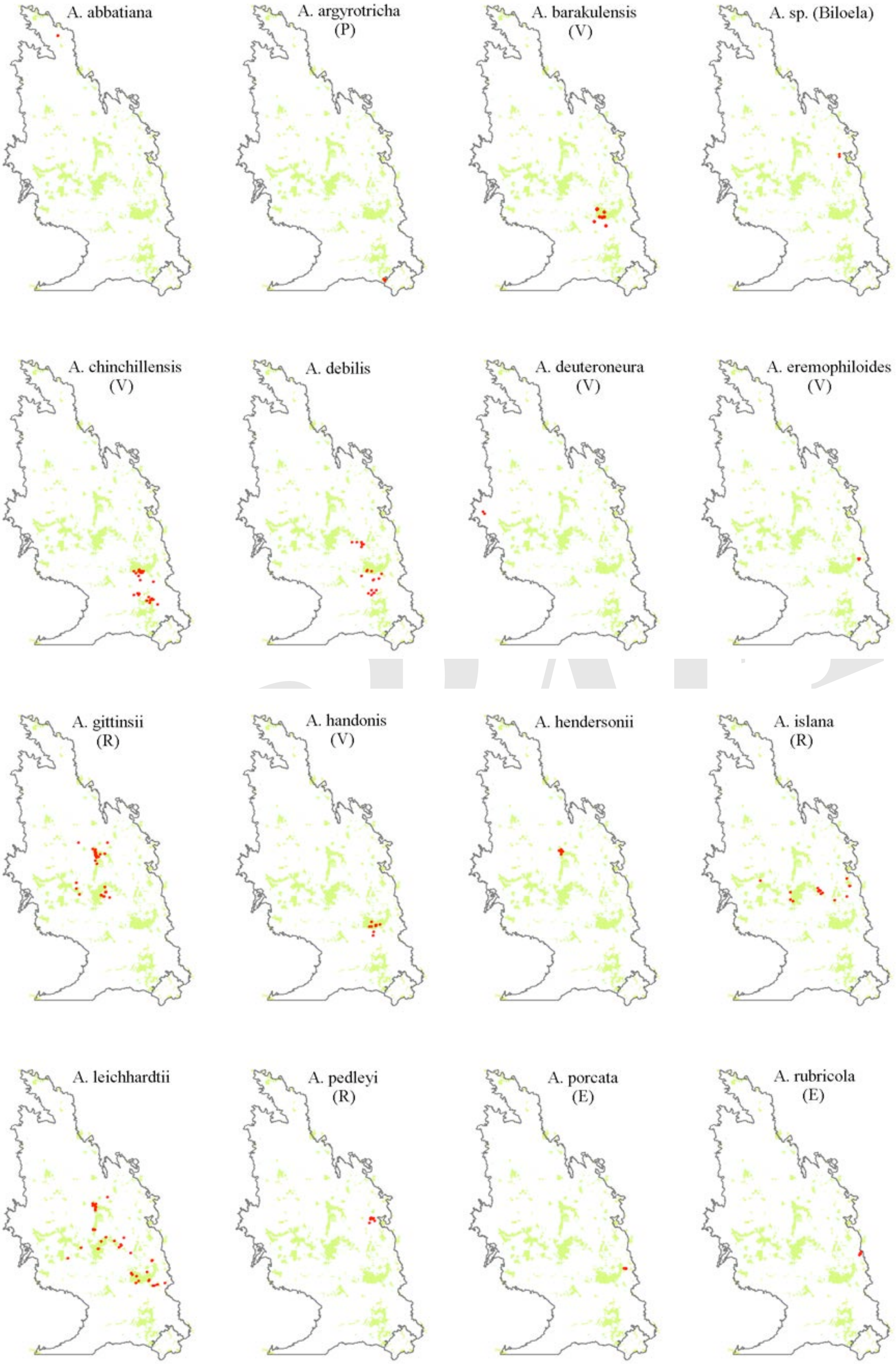
A. harpophylla is one of the few tree species that grows on the deep cracking clays that are a feature of the bioregion. It also occurs on lighter clays and on texture-contrast soils where it often grows in association with *Eucalyptus* species including *E. populnea*, *E. cambageana* and *E. thozetiana*. On heavy clays in the lower rainfall areas in western parts of the bioregion, *A. harpophylla* is replaced by *A. cambagei*.

Brigalow open forests and woodlands, now reduced to a fraction of their former extent, occurred mainly on the more fertile soils of the region. A range of other species occurs in the canopy including Belah (*Casuarina cristata*), Ooline (*Cadellia pentastylis*) and the ‘bottle trees’, *Brachychiton rupestris* and *B. australis*. The moderately dense to dense understorey commonly includes *Geijera parviflora*, *Eremophila mitchellii* and *Alectryon diversifolius*. In some areas, the understorey is dominated by rainforest species.

Among the acacias are 49 species that are essentially endemic to the Study Area. Many of these endemics are highly localised occurring at one to a few sites, e.g. *A. porcata*, *A. eremophiloides*, *A. abbatiana*, *A. pubifolia, A. argyrotricha*, *A. storyi*, *A. deuteroneura*, *A. hockingsii*, *A. handonis*, *A. arbiana*, *A. hendersonii*, *A. rubricola*, *A. barakulensis*, *A. chinchillensis*, *A. islana* and the undescribed species, *A.* sp. (Gayndah), *A.* sp. (Ruined Castle Creek) and *A.* sp. (Nantglyn). Distribution maps for a number of the endemic species are shown in Figure 2.22.

There are 171 eucalypts recorded from the WHWD Area including 6 *Angophora* taxa, 33 *Corymbia* taxa and 132 *Eucalyptus* taxa. This compares with 83 eucalypt taxa in South-East Queensland and 90 taxa in the Greater Blue Mountains World Heritage Area (1 032 649 ha) for which World Heritage listing was based significantly on eucalypt diversity.

Whereas the more well known and widespread eucalypt species are most abundant, such as Spotted Gum (*E. citriodora*), ironbarks (*E. crebra*, *E. melanophloia*, *E. drepanophylla*),



A. abbatiana

A. argyrotricha (P)

A. barakulensis (V)

A. sp. (Biloela)

A. chinchillensis (V)

A. debilis

A. deuteroneura (V)

A. eremophiloides (V)

A. gittinsii (R)

A. handonis (V)

A. hendersonii

A. islana (R)

A. leichhardtii

A. pedleyi (R)

A. porcata (E)

A. rubricola (E)

Figure 2.22 Records for a selection of *Acacia* species endemic to the Study Area

Forest Red Gum (*E. tereticornis*), Poplar Box (*E. populnea*) and Coolabah (*E. coolabah*), there are 48 eucalypt taxa that are essentially endemic to, and often highly localised within, the Study Area. The endemics include *E. rubiginosa*, *E. mensalis*, *E. sphaerocarpa* (Blackdown Stringybark), *E. beaniana*, *E. broviniensis*, *E. virens*, *E. sideroxylon* subsp. (Waaje), *E.* sp. (Mt Moffat), *Corymbia clandestina*, *C. xanthope* and *C. bloxsomei*, *C. petalophylla*, *C. watsoniana* subsp. *capillata* and *C. watsoniana* subsp. *watsoniana*. Distribution maps for a number of the eucalypt endemics are shown in Figure 2.23.

E. populnea and *E. cambageana* (Dawson Gum) commonly occur in association with *Acacia harpophylla*, mainly on texture-contrast soils, but also on clays. *E. thozetiana* (Napunyah, sometimes Yapunyah) occurs with *A. harpophylla* on shallow clay soils.

Also prominent among the vegetation of the Brigalow Belt are casuarinas. Nine species are recorded from the region. *Casuarina cristata* (Belah) is one of few tree species to exploit the heavy cracking clay soils of the region. It grows in association with *A. harpophylla* and these communities can vary from almost pure *C. cristata* to almost pure *A. harpophylla*.

As is the case for Brigalow forests and woodlands, the dry rainforests or bottle tree scrubs (semi-evergreen vine thickets) of the Brigalow Belt have been largely cleared. In the surviving remnants, common canopy species include *Croton insularis*, *Geijera parviflora*, *Planchonella cotinifolia*, *Flindersia australis* and *Canthium* spp., with *Brachychiton rupestris*, *B. australis* and *B. populneus* occurring as emergents.

Macropteranthes is a small genus of just six species that is endemic to northern Australia. *M. leichhardtii* (Bonewood) is largely restricted to the Brigalow Belt where it occurs mainly in the Nogoa and Comet River catchments and in the catchment of Acacia Creek, a tributary of the Dawson River. *M. leichhardtii* can form dense, low scrubs, often with emergents of *Acacia harpophylla* or *Brachychiton* species. Another much more restricted species, *M. leiocaulis*, is endemic to the Brigalow Belt.

Cadellia pentastylis (Ooline), a vulnerable species, is the only member of the genus and is essentially endemic to the Brigalow Belt bioregion. *C. pentastylis* can form closed microphyll vine forests up to 18 m tall with a diverse understorey of rainforest species. It also occurs in association with *Acacia harpophylla* and *Brachychiton* species. *Cadellia* is one of just four genera in the ancient family, Surianaceae, which is now essentially confined to Australia. There are just five species surviving in the family. A small, almost pure stand of *C. pentastylis* is a feature of Tregole NP on the western edge of the Brigalow Belt.

In the south and west of Brigalow Belt South, cypress (*Callitris* spp.) and mixed cypress/eucalypt forests are relatively extensive.

Grass genera in the Brigalow Belt are mainly tropical (Johnson 1984). They include *Bothriochloa*, *Aristida* and *Eragrostis* mainly in eucalypt woodlands, *Dichanthium* in grasslands and *Paspalidium* in acacia open forests. In the western drier margins, *Astrebla* spp. (Mitchell grass) replace *Dichanthium sericium* (blue grass)..

Sattler and Creighton (2002) assessed Australian bioregions and subregions with respect to endemicity among acacias and eucalypts. The authors compared total number of species, number of endemic species, endemicity index and irreplacability index across all bioregions.

Only three bioregions scored highly for all of these four biodiversity measures — Coolgardie and Esperance Plains in Western Australia, and Brigalow Belt South.

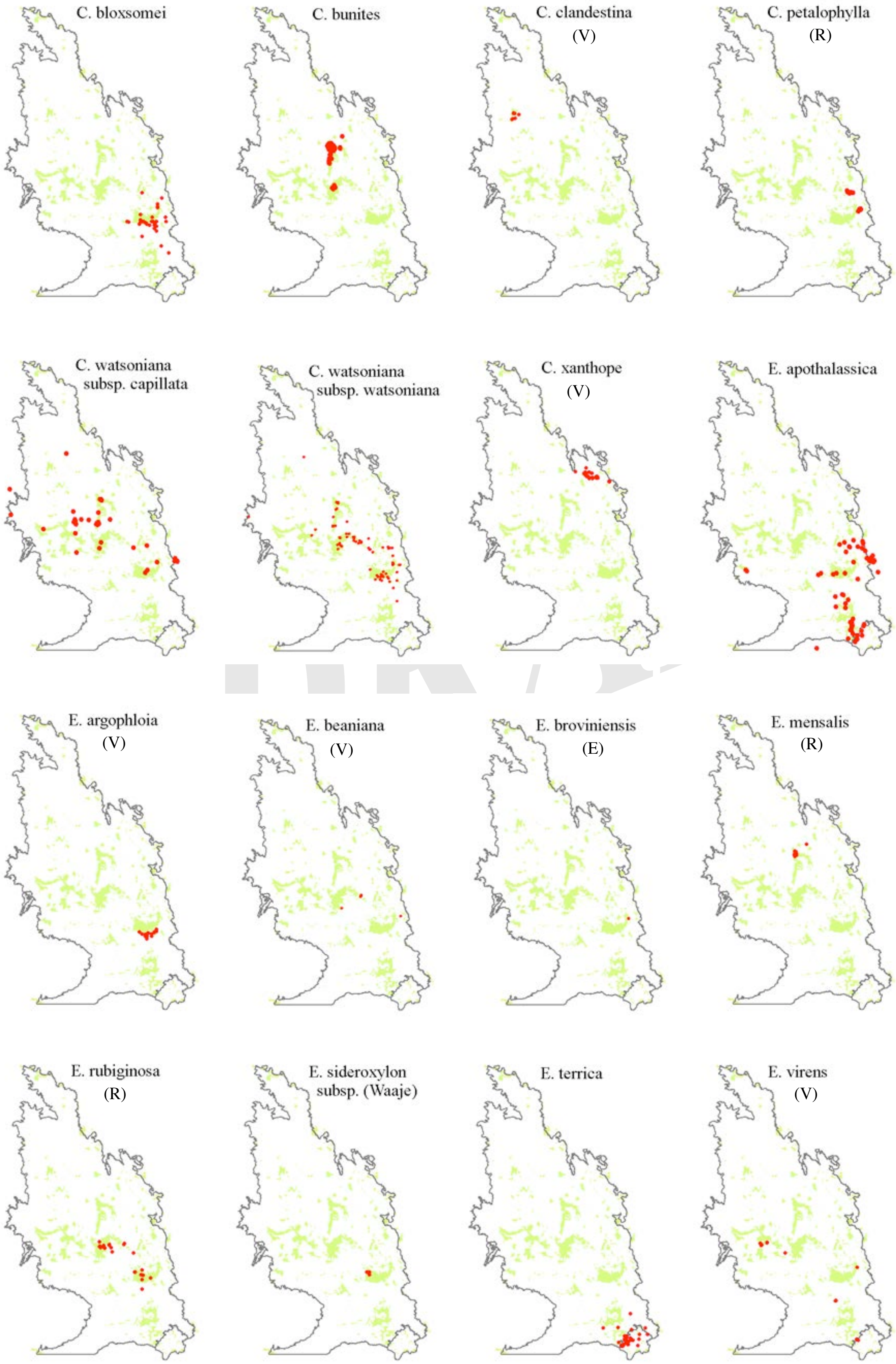


Figure 2.23 Records for a selection of *Corymbia* and *Eucalyptus* taxa endemic to the Study Area

◀ **Plate 1** *Acacia handonis* (Endangered), found only in Barakula State Forest

Plate 2 *Phebalium whitei* (Vulnerable), found only in the Queensland section of New England Tableland ▶

Plate 3 *Acacia chinchillensis* (Vulnerable), found only in a section of Brigalow Belt South from Barakula to the northern part of the Inglewood Sandstones subregion ▶

◀ **Plate 4** *Acacia lauta* (Vulnerable), found only in the Brigalow Belt

Plate 5 *Acacia curranii* (Vulnerable) ▶

All images on this page are derived from photographs by Murray Fagg, Australian National Botanic Gardens

Plate 6 *Acacia tenuinervis* (Rare)

Plate 7 Melaleuca groveana (Rare)

Plate 8 Boronia repanda (Endangered)

2.4 Fauna

2.4.1 Overview

The Western Hardwoods Area has a rich fauna with around 718 vertebrate species, including 111 mammals, 384 birds, 178 reptiles and 45 frogs. This compares favourably with the diversity found in the Wet Tropics (679 vertebrate species, 105 mammals, 370 birds, 150 reptiles and 54 frogs) and the Central Eastern Rainforest Reserves of Australia (500 vertebrate species, 75 mammals, 270 birds, 110 reptiles and 45 frogs).

There are 52 Endangered, Vulnerable or Rare species in the Study Area (Table 3.11 in Section 3.4.2), and nine species have become extinct in the Brigalow Belt. These nine species include six mammals (Darling Downs Hopping-mouse, Western Quoll (Plate 9), White-footed Rabbit-rat, Kultarr, Northern Bettong and Greater Bilby) and three birds (Paradise Parrot (Plate 10), Star Finch and Flock Bronzewing). Of these, three species the Darling Downs Hopping-mouse, White-footed Rabbit-rat and Paradise Parrot are globally extinct. The vertebrate extinction rate averages one species every 18 years since the Leichhardt expedition of 1844–45, and is one of the worst extinction rates of any bioregion in Queensland.

Several more species are Endangered. The Bridled Nailtail Wallaby (Plate 11) and Northern Hairy-nosed Wombat (Plate 12) were once widespread in eastern Australia but now the only wild populations are in single locations in the Brigalow Belt. Recovery Actions to ensure their persistence cost more than $700,000 a year in total (Horsup 1999; Lundie-Jenkins 2001). When one considers the former range of these species, a large proportion of the Study Area (including Brigalow Belt South as a whole) has actually lost eight mammal species. The current status of the Spotted-tailed Quoll and Brush-tailed Phascogale in the Brigalow Belt is also uncertain, with the last records of these species in 1990 and 1987 respectively, although populations of both species may persist on the New England Tableland.

Plate 9 The Western Quoll (*Dasyurus geoffroii*) was an early casualty of European invasion of the Brigalow Belt. It was reported by early visitors such as the biologist Richard Semon and surveyor Hedley Finlayson. The last verified record was in 1905. *Photo: Museum of Victoria*

Plate 10 The Paradise Parrot (*Psephotus pulcherrimus*) is the only bird to have become extinct on mainland Australia. It was largely found in the Brigalow Belt, and was last sighted in 1927. *Image: Blake Twigden*

Plate 11 The Bridled Nailtail Wallaby (*Onchyogalea fraenata*) once occurred throughout the temperate and subtropical woodlands of eastern Australia, as far south as northern Victoria, where it was common. It is now Endangered and there is only one wild population, in Taunton NP. *Photo: Museum of Victoria*

Plate 12 The Northern Hairy-nosed Wombat (*Lasiorhinus kreffti*)(Endangered) is one of the most restricted mammals in Australia, occurring only in Epping Forest NP, an area of 3160 hectares. *Photo: Environmental Protection Agency*

Plate 13 The Glossy Black-Cockatoo (*Calyptorhynchus lathami*) (Vulnerable) is found largely in the upland areas. However, it is one of the most specialized parrots in the world, relying on a small number of *Allocasuarina* species for food. A significant proportion of the population is in the Brigalow Belt, where *Allocasuarina torulosa and A. inophloia* appear to be the primary food species. *Photo: Australian National Parks and Wildlife Service*

The 52 threatened species can be divided into two broad categories. One group had core habitats on the fertile lowlands which have now been fragmented, and diminished populations are isolated by large areas of agricultural land. They include the aforementioned Bridled Nailtail Wallaby (Endangered) and Northern Hairy-nosed Wombat (Endangered) and vine-thicket specialists such as the Black-breasted Button-quail (Vulnerable) and the skink *Anomalopus brevicollis* (Rare). The other group has core distributions on the elevated areas with relatively large areas of habitat, but populations are threatened by a range of processes within the remaining vegetation. Species include *Paradelma orientalis* (Brigalow Scaly-foot), Powerful Owl and Glossy Black-Cockatoo (Plate 13), all Vulnerable.

It is no longer possible to protect the viability and integrity of populations of lowland core species throughout their former range without significant restoration initiatives. These species will often require intensive recovery efforts (e.g. translocation, captive breeding) to ensure their survival. Adequate fauna conservation also requires a focus on the elevated area species, whose future status is contingent on the health of the remaining vegetation. Species of particular importance are those with a regulatory role in the ecosystem. These include top-order trophic predators (e.g. Dingo, Northern Quoll, Powerful Owl, Barking Owl and *Varanus varius* (Lace Monitor)), and major pollinators such as the Little Red Flying-fox.

A reserve system that concentrated on the large core areas of remnant habitat would primarily benefit the species of elevated areas. However, some species of lowland and fertile habitats would also benefit. For example, some of the largest vine-thicket remnants in the Chinchilla-Mundubbera area are in Allies Creek SF. Even though the forest was not a core area of vine-thicket prior to clearing, the remnants are now of great importance as habitat for the Black-breasted Button-quail (Vulnerable).

Endemism is high among reptiles and birds, and only a small number of Australian bioregions support a higher number of endemic taxa in either of these groups. Covacevich *et al.* (1998) identified 13 reptile species as "*confined to, or virtually confined to the Brigalow Belt*". There were six endemic bird taxa although one is now extinct, another is possibly extinct and a further two are threatened. Among mammals, an undescribed native rat of the genus *Pseudomys*, the 'Central Highlands Plague Rat', is known only from Brigalow Belt North. Brigalow Belt endemics have been identified from a wide range of insect groups, although further taxonomic inventory is certain to discover many more.

The sandstone uplands harbour a large number of disjunct populations across a range of species groups. These naturally isolated populations of frogs, reptiles, birds and mammals are potentially genetically distinct from the larger coastal populations, and if so may be important for future capacity of these species to adapt to change. Population isolation as a result of climatic fluctuation is also one of the drivers of evolution of new species.

The Brigalow Belt is exceptionally rich in a number of species groups including the burrowing frogs, arboreal reptiles, elapid snakes, specialist woodland birds, microchiropteran bats and macropods. This seemingly disparate group of animals is bound by a trend of greater diversity in woodland than in denser open eucalypt forest, rainforest or sparser semi-arid habitats. The characteristics of these groups, their richness in context with other parts of Australia and possible reasons for their diversity are discussed in Section 3.6.

2.4.2 Environmental influences on the distribution of the fauna

2.4.2.1 Introduction

The composition of the Brigalow Belt's fauna reflects its position between the forested humid coastal regions and the woodlands and shrublands of the semi-arid zone. The sub-humid regions of Australia all have an overlap between "wet and dry" fauna, but the Brigalow also supports a prominent tropical element and a large proportion of the Tumbunan rainforest birds.

Regions where biogeographic assemblages intersect were termed 'biogeographic crossroads' by Spector (2002), who considered such areas to be key sites for processes such as speciation and coevolution and therefore global conservation priorities. The biogeographical position and climate of the Brigalow Belt enables faunal elements of all five Australian faunal regions (Eyrean, Torresian, Tumbunan, Irian and Bassian) to intersect. As such, it is one of the "busiest" crossroads on the continent, with arguably the most even representation of each region.

2.4.2.2 Distribution patterns within the bioregion

Whilst the bioregion as a whole is a significant area of overlap, "crossroads" *within* the bioregion can also be identified. A major 'biogeographic crossroad' between "coastal" and "inland" species pairs appears to occur within Brigalow Belt South. This "crossroad" runs north-south along the Inglewood Sandstones Subregion, then continues north and west along the boundary of the Barakula and Eastern Darling Downs Subregions, west along the Great Divide along the Southern Downs Subregion, north across the western section of the Carnarvon Ranges Subregion and then swings east of the Great Divide north of the Carnarvon Ranges. North of the Great Divide the "crossroad" is at the interface of the river basins and the Drummond, Carnarvon and Expedition Ranges, before becoming ill-defined in the tropics. Investigation of fauna distributions located 15 pairs (eight reptile and seven bird pairs) of species with similar foraging substrates that largely meet along this "crossroad" (Table 2.4). The "crossroad" also closely matches the inland limits of many other species such as the White-naped Honeyeater, Yellow-tufted Honeyeater, Australian King-Parrot and *Oedura tryoni* (Southern Spotted Velvet Gecko) and the coastal limits of species such as the Mallee Ringneck, Crested Bellbird and *O. marmorata* (Marbled Velvet Gecko).

Table 2.4 Species "pairs" that contact along a narrow "crossroad" in the Brigalow Belt.

Genus	Coastal species	Inland species	Type
Gehyra	*dubia*	*variegata*	Arboreal geckos
Oedura	*robusta*	*monilis*	Arboreal geckos
Strophurus	*taenicauda*	*williamsi*	Arboreal geckos
Diplodactylus	*vittatus*	*steindachneri*	Terrestrial geckos
Nephrurus	*milii*	*asper*	Terrestrial geckos
Cryptoblepharus	*virgatus*	*carnabyi*	Arboreal skinks
Lerista	*fragilis*	*punctatovittata/muelleri*	Terrestrial skinks
Morethia	*taeniopleura*	*boulengeri*	Terrestrial skinks
Acanthiza	*pusilla*	*apicalis*	Understorey thornbills
Acanthiza	*reguloides*	*uropygalis*	Understorey thornbills
Malurus	*cyaneus*	*splendens*	Understorey fairy-wrens
Gerygone	*olivacea*	*fusca*	Canopy gerygones
Lichenostomus	*fuscus*	*penicillatus*	Canopy honeyeaters
Eurostopodus	*mystacalis*	*argus*	nightjars
Petroica	*rosea*	*goodenovii*	Understorey robins

2.4.3 Invertebrates

2.4.3.1 Overview

No bioregion in Australia has a comprehensive inventory of invertebrate fauna, as the sheer number of species would make such a task almost impossible. However, invertebrates probably account for 99 percent of the faunal diversity, display high levels of local endemism and may have a high degree of ecological specialization. Invertebrates may be dependent on a single plant species and even particular growth phases of these species. Such fine-scale dependencies illustrate the risk of biodiversity loss with habitat degradation. The high level of short-range endemism among invertebrates makes this group the most vulnerable when a reserve system is based on representation of Regional Ecosystems.

A number of aspects of the Brigalow Belt's invertebrate fauna are significant. The dung beetle and soil burrowing cockroach faunas are the richest in Australia, there are relict populations of charopid land snails on dry rainforest peaks in the eastern Brigalow Belt, and a newly discovered subfamily of bugs from the family Pentatomidae displays a fine scale ecological relationship with old acacias. Some of Australia's rarest butterflies occur in the Brigalow Belt (See Section 3.4.2.8.).

2.4.3.2 Inventory

Dung beetles

The dung beetle fauna of the Brigalow Belt is very rich, with a number of endemic species. Surveys at the Brigalow Research Station near Theodore recorded the richest inland dung beetle fauna detected in Australia (26 native species) (G. Monteith pers. comm.), and it is likely that richness is also high in brigalow and vine-thicket in nearby Isla Gorge NP, Theodore SF and Palmgrove NP.

Several apterous (wingless) dung beetles are present, including an entire genus (*Canthosoma*, three species) that is endemic to the bioregion. The presence of four apterous species restricted to the Brigalow Belt is an "*indication of a long evolutionary process*" (G. Monteith pers. comm.). The development of aptery in these beetles appears to be an evolutionary response to the daily movements of the Black-striped Wallaby, which shelters in vine-thicket and brigalow habitat by day and grazes in surrounding open habitats at night. The Black-striped Wallaby is gregarious and returns to the same refuge each day, resulting in a reliable and abundant supply of dung for the beetles to exploit. This unusually abundant and reliable food source negated the need for these beetles to fly, a unique phenomenon as most Australian dung beetles require strong flight to locate sufficient food. *Canthosoma* is an entirely wingless genus and the fourth wingless species (*Onthophagus apterus*) (Plate 14) that is restricted to the Brigalow Belt is a member of a large genus of otherwise strong fliers (Monteith 1999).

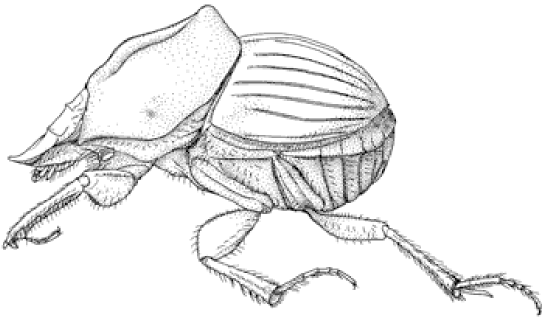


Plate 14 The Wingless Dung Beetle (*Onthophagus apterus*) has evolved aptery by co-habiting the permanent daytime shelters of the Black-striped Wallaby and Herbert's Rock-wallaby. The ecology of this species has made is susceptible to the fragmentation of vine-thicket vegetation and persecution of Black-striped Wallabies. *Image: Geoff Thompson/Queensland Museum*

The apterous dung beetle's combination of low mobility and a close association with brigalow and vine-thickets makes the species vulnerable to the widespread destruction of these habitats. If Black-striped Wallabies disappear from a site (and given their current existence as a series of isolated and often small populations this is a real risk in many areas) a unique element of the invertebrate fauna with evolutionary significance will disappear with them. It is likely that even if Black-striped Wallabies recolonise a remnant, the beetles will not, and unless other invertebrates take over their functional role, the soil nutrient balance in the remnant (and therefore floristic composition) could be altered.

Soil-burrowing cockroaches

The giant burrowing cockroaches (Geoscaphinae) belong to a subfamily found only in Australia. Most of this subfamily (approximately 25 species) is found entirely in Queensland, and their main concentration is in the Brigalow Belt (G. Monteith pers. comm.). A well-known member of the Geoscaphinae is the enormous *Macropanesthia rhinocerous* (Plate 15), which at 30–35 grams is the heaviest cockroach on Earth (Maekawa *et al.* 2003), and is heavier than many birds (Australian bush birds such as thornbills and whistlers weigh 10–15 grams). The Geoscaphinae collect leaf litter from the surface and take it underground to deep, long-term burrows.

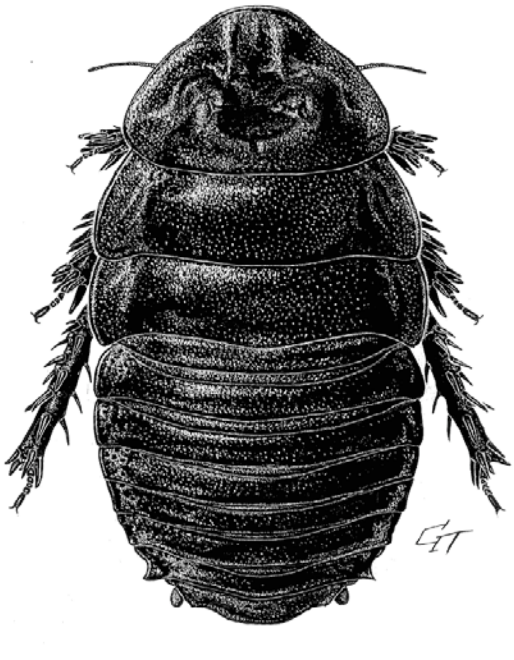


Plate 15 The Giant Burrowing Cockroach (*Macropanesthia rhinocerous*) is the heaviest cockroach in the world. The main concentration of species in the burrowing cockroach subfamily is in the Brigalow Belt. Other cockroaches in the world are known to burrow to avoid predators, but this group is unique in creating long-term shelters. *Image: Geoff Thompson/Queensland Museum*

Maekawa *et al.* (2003) proposed that soil-burrowing cockroaches evolved from wood-burrowing ancestors that entered Australia from the north after the Asian and Australian tectonic plates collided about 20 million years ago. It was suggested by Maekawa *et al.* (2003) that the evolution of soil burrowing was an adaptation to the periods of aridity that have occurred in Australia since the Miocene. When rainforests underwent extensive contraction and xeric vegetation expanded during either the Miocene or the beginning of the Pliocene, selection pressures may have forced Geoscaphinae ancestors to switch from rotting logs to leaf litter, and to seek humid conditions by burrowing underground.

Charopid land snails

The land snails of the Gondwanan family Charopidae are closely aligned with rainforest, with few species spreading into the drier habitats that began to expand in the Tertiary. Charopid snails live in a variety of microhabitats, such as under logs, under bark of fallen trees and under rocks, and there is a small number of arboreal species.

The Brigalow Belt bioregion reaches the coast between Gladstone and St Lawrence, and it is this "dry corridor" that enabled species in the rainforests to the north and to the south to develop in isolation. This corridor has been in place since the late Miocene (Stanisic 1990). Charopid snails are very small and have low vagility, which has resulted in fine-scale speciation as a result of persistence of refugia *within* the "dry corridor" on high peaks through dry periods. The evolution of land snails in these refugia has been less complex than in the subtropical rainforests to the south, but dry rainforests within this region nonetheless support at least one endemic species and are also refugia for several other relict populations.

Species such as *Gyrocochlea curtisiana* and *Rotacharopa kessneri* are unique to the dry rainforests from northern SEQ (e.g. Dawes Range and Bobby Range) and the "dry corridor" of the Brigalow Belt (e.g. Dee Range, Mt Archer, and Mt Etna). One species (*Rotacharopa annabelli*) has only been found in the eastern Brigalow Belt, with a congener (*R. kessneri*, which may be sympatric) occupying similar habitats in northern SEQ. *R. annabelli* was described by Stanisic (1990) and there are relict populations at Mt Archer, Gavial Creek near Bouldercombe Gorge, and Mt Moore south of Gladstone. *R. annabelli* is the most northerly representative of the genus of three species, which replace each other in a north-south series from the Main Range in southern Queensland north to Mt Archer. All the refugia listed in Table 2.5 are high points in their local landscapes, and all are surrounded by habitat unsuitable for charopid snails. Each refugium is isolated from the others by 20–70 kilometres.

Table 2.5 Refugia for land snails in the Brigalow Belt

Refugium location	Charopid species present
Mt Etna Caves	*Discocharopa aperta*
Mt Archer	*D. aperta, Rotacharopa annabelli*
Bouldercombe Gorge/Mt Morgan	*D. aperta, R. annabelli, Omphaloropa varicosa*
Rundle Range	*Sinploya intensa*
Mt Larcom	*Gyrocochlea curtisiana*
Mt Moore	*R. annabelli*
Cania Gorge	*R. kessneri*

Source: Stanisic (1990)

Undescribed sub-family of acacia-dependent Hemiptera

A recently discovered and hitherto undescribed subfamily of the Pentatomidae (Order Hemiptera) has been found in the fissured bark of acacias in the Brigalow Belt. One species has been found only on Brigalow (*Acacia harpophylla*) and another only on Gidgee (*A. cambagei*). These bugs have undergone a rather unique evolutionary morphological adaptation to exploit the deep and narrow bark fissures of old trees to reach the living vascular plant tissue, and their discoverers have dubbed them "arrow-headed bugs" as a result. The unusual shape of the insect is probably an "*ancient evolutionary adaptation*" as the subfamily has an isolated taxonomic position (G. Monteith pers. comm.). They appear to be absent in regrowth trees, suggesting that only large, old trees have the bark characteristics to support these endemic bugs.

2.4.4 Frogs

2.4.4.1 Overview

There are 203 species of frogs in Australia (SoE 1996), of which 45 are found in the Study Area. The Study Area supports 24 of the 111 species from the family Myobatrachidae ("southern frogs") and 21 of the 71 species from Hylidae ("tree frogs"). The Hylidae and Myobatrachidae dominate the contemporary Australian frog fauna as many species in both families have successful adaptations to the drying of the continent. Of the other two native frog families in Australia, the third largest family (Microhylidae) has not adapted to dry conditions and remains in a series of rainforest refuges and tropical wetlands in northern Australia, the southernmost of which is the rainforested summit of Mt Elliot near Townsville in BBN. The Ranidae is a large cosmopolitan family represented by a single species on Cape York Peninsula and the Wet Tropics that is almost certainly a recent arrival from Asia.

2.4.4.2 Inventory

Burrowing frogs

A prominent feature of the frog fauna is the great diversity of burrowing frogs, representing a significant example of the radiation of Australian fauna into drought-prone environments. Frogs depend on water, so environmental stresses on this group during the Neogene transition (25–2.5 MYA) would have been particularly severe. The evolutionary response of some frogs was to develop a burrowing habit, and with it a unique life cycle and morphological characteristics. A large percentage of today's Australian frogs can burrow and then aestivate for long periods, enabling them to occupy the often dry but occasionally flooded environments that characterise northern and central Australia (Tyler 1989).

Burrowing frogs have a globose body form to reduce the surface area to volume ratio and hence reduce water loss, and short stout limbs (Plate 16). Other adaptations to the burrowing habit include a large urinary bladder, the ability to lower metabolic rate by as much as 80 percent (increasing the potential period of aestivation) and rapid metamorphosis (to exploit the often brief window of opportunity to reach reproductive maturity) (van Beurden 1982). The ability to form a "cocoon" to reduce water loss is also employed by some species. One of the more remarkable adaptations defies a seemingly inflexible biological rule that some loss of muscle performance is inevitable over a long period of immobilisation. *Cyclorana alboguttata* has been found to fully preserve muscle size and locomotor performance (i.e. swimming ability) throughout a three-month underground aestivation (Hudson and Franklin 2002), an adaptation that enables the species to capitalize on a major but unpredictable rainfall event in peak condition (Plate 17).

Plate 16 The burrowing Eastern Snapping-frog (*Cyclorana novaehollandiae*) is typical of the genus. The large size and rounded form are adaptations to reduce water loss during periods of aestivation. Diverse burrowing frog assemblages are known to exist in alluvial areas in Barakula and Yuleba State Forest. *Photo: M. Hero*

Plate 17 The burrowing Greenstripe Frog (*Litoria or Cyclorana alboguttata*) was the subject of a remarkable recent study that demonstrated that it was capable of preserving muscle performance and condition over a three month period of immobilization. This adaptation enables the species to exploit unpredictable rainfall events at peak capacity. *Photo: Brisbane Frog group*

A recent study of burrowing frog morphology concluded that there have been at least three separate evolutions of the burrowing habit among the Myobatrachidae alone (Burton 2001). Frogs of the *Cyclorana* genus in the Hylidae developed the habit separately, and apparently later than the Myobatrachidae. The convergence between the hylid and myobatrachid dry-adapted frogs has been so complete that the affiliation of *Cyclorana* with the Hylidae was only recognised in the early 1970s (Van Beurden 1982). Species derived from all four separate evolutionary lineages involving the burrowing habit occur in the Study Area.

Frogs of mesic refugia

Several species are not adapted to the frequently dry conditions outside permanently moist refugia. These species are relatively widespread in wetter coastal bioregions, but their Brigalow Belt populations are localized, found only in the wettest habitats. The topography, geology and hydrology (Artesian springs) of the Carnarvon, Bigge and Expedition Ranges and Blackdown Tableland provide mesic refugia for disjunct populations of these species, which were widespread in wetter times but have been "stranded" by subsequent climatic oscillations. There are inland populations of species such as *Adelotus brevis* (Tusked Frog), *Litoria lesueuri* (Stony-creek Frog), *Uperoleia fusca* (Sandy Gungan), *Limnodynastes peronii* (Striped Marshfrog) and *Crinia signifera* (Clicking Froglet). *L. lesueuri* was listed as an obligate stream-breeder and *A. brevis* as a facultative stream-breeder by Gillespie and Hines (1999). These disjuncts are a significant and potentially vulnerable component of the frog diversity in the Brigalow Belt. Two of these species, *A. brevis* and *U. fusca* are considered "Of Concern" in this bioregion (Environmental Protection Agency 2002b).

Frogs that use terrestrial shelters and tree hollows

The most widespread frogs in the Study Area are those that utilise dry habitats such as eucalypt forests by finding refuge in shelters either in trees, in creekside vegetation or under woody debris or rocks. These species are neither edaphically restricted as are the burrowing frogs, nor dependent on mesic refuges. This flexibility enables species in this group such as *Litoria latopalmata*, *L. caerulea, L. rubella* and *Limnodynastes tasmaniensis* to be among the most widespread frogs, with records on nearly all subregions in the Brigalow Belt (Table 2.6). Kelly *et al.* (2003) located these species at a wide range of sites during their extensive forest fauna surveys.

Table 2.6 Grouping of frog species according to major adaptations in the Brigalow Belt.

Group	**Burrowing frogs**	**Terrestrial and arboreal shelter frogs**	**Permanent water frogs**
Adaptation	Survive dry periods by burrowing well underground.	Seek refuge under logs and stones or in trees and emerge after rain.	Not adapted to absence of water.
Restrictions	Soil type, need friable soil to burrow into, e.g. cracking clays, sandy loams.	Generalists.	Presence of permanent surface water.
Distribution	Lowland areas, especially Eastern Darling Downs, Moonie River-Commoron Creek Floodout, Tara Downs and Southern Downs.	Widespread across both downs and upland subregions.	Disjunct and localised in upland subregions especially Carnarvon, Woorabinda and Barakula, some also along Dawson River.
Threats	Large areas of habitat destroyed. Remaining populations threatened by grazing.	Fire regimes and grazing of some concern but species apparently secure.	Habitats still ostensibly intact, but pressure on habitat quality from grazing in drought. Total area of habitat small.

Patterns of distribution

All frog records from the Queensland Fauna Database were divided into “upland” and “downs” subregions to investigate landscape preferences among frogs. Table 2.7 demonstrates the specialization among burrowing frogs to areas with fertile “downs” habitat. Burrowing frogs such as the Murray-Darling Basin-centred *Neobatrachus sudelli* and *Notaden bennetti* and the arid-adapted *Cyclorana platycephala* have a particularly high percentage of records on the “downs” subregions. The specialization among frogs of mesic refugia is also evident, with a disproportionately high percentage of records of *Pseudophryne major*, *Adelotus brevis* and *Limnodynastes peronii* in the “upland” subregions. Frogs without specialization for burrowing or for mesic refugia were common on both subregion types.

Conservation issues

Table 2.7 could be considered to describe two aspects of vulnerability among the frog fauna in the Brigalow Belt. At one extreme, the burrowing frogs of the “downs” are vulnerable to intensive agriculture, clearing and water extraction. Most of their habitat has been destroyed and there needs to be an endeavour to protect what is left. At the other extreme, the frogs of mesic refugia may be the first casualties of severe droughts related to climate change, associated drought-relief grazing and changed fire regimes that could dry out naturally permanent waterholes and watercourses. The frogs of mesic refugia were already relict prior to European invasion, but are more vulnerable now with climate change, grazing and fire. By contrast, populations of burrowing frogs were widespread and probably continuous, but are now highly fragmented.

Table 2.7 Distribution of frog records in relation to "downs" and other subregions in the Brigalow Belt (species with >20 records in the bioregion).

Species	Status	Adaptation	% records on "downs" subregions	No. subregions with records
Notaden bennetti		Burrowing	94	11
Cyclorana platycephala		Burrowing	90	8
Neobatrachus sudelli		Burrowing	86	9
Limnodynastes salmini		Burrowing	83	19
Litoria rothii			80	10
Litoria (Cyclorana) alboguttata		Burrowing	79	26
Cyclorana verrucosa	Rare	Burrowing	77	9
Litoria inermis			76	14
Litoria caerulea		Generalist	73	32
Cyclorana novaehollandiae		Burrowing	70	27
Uperoleia rugosa		Burrowing	69	22
Litoria fallax		Permanent water	67	19
Limnodynastes tasmaniensis		Generalist	64	28
Cyclorana brevipes		Burrowing	64	21
Limnodynastes fletcheri			63	18
Litoria peronii			59	23
Litoria rubella		Generalist	57	33
Litoria latopalmata		Generalist	55	31
Limnodynastes ornatus		Generalist	55	33
Limnodynastes terraereginae		Burrowing	40	23
Crinia parinsignifera			39	13
Litoria lesueuri		Permanent water	36	16
Limnodynastes peronii		Permanent water	24	14
Pseudophryne bibronii			20	11
Adelotus brevis	Of Concern	Permanent water	18	7
Uperoleia laevigata			18	10
Pseudophryne major		Permanent water	17	12

NB-The "downs" subregions of the Brigalow Belt for Table 2.7 are Arcadia, Balonne-Culgoa Fan, Basalt Downs, Belyando Downs, Callide Creek Downs, Claude River Downs, Dawson River Downs, Dulacca Downs, Eastern Darling Downs, Isaac-Comet Downs, Macintyre-Weir Fan, Marlborough Plains, Moonie-Barwon Interfluve, Moonie R. Commoron Creek Floodout, Southern Downs, Tara Downs, Taroom Downs, Townsville Plains and the Upper Belyando Floodout.

2.4.5 Reptiles

2.4.5.1 Overview

The diversity of Australia's reptile fauna is still being documented. Taxonomic endeavour and targeted fieldwork by herpetologists in the last 30 years has resulted in reptiles overtaking birds as the most speciose vertebrates in Australia. The number of recognised species increased from 664 in 1975 to 1050 in 2000 (Cogger 2000) and is still increasing through detailed investigation of existing "species" and new discoveries. Taxonomic investigation of the "widespread" skink "*Eulamprus tenuis*" (Cogger 2000) led to the recognition of several species, including one (*E. sokosoma*) with a disjunct distribution in the Brigalow Belt and on the southern edge of the Einasleigh Uplands. Targeted studies in poorly surveyed areas resulted in the discovery of a leaf-tailed gecko, *Phyllurus championae*, in the late 1990s at Blue Mountain on the Brigalow Belt North/Central Queensland Coast boundary, and at a nearby site in the Central Queensland Coast bioregion.

The Brigalow Belt, with 198 species (including 178 in the WHWD Area) is part of one of three major areas of reptile diversity in Australia. The three areas are eastern Queensland (including most of South-East Queensland and Wet Tropics and the eastern half of the Einasleigh Uplands and Brigalow Belt), northern Australia (Kimberleys and Top End) and central-west Australia (a band linking southern NT to the Pilbara region) (Figure 2.24)(SoE 1996).

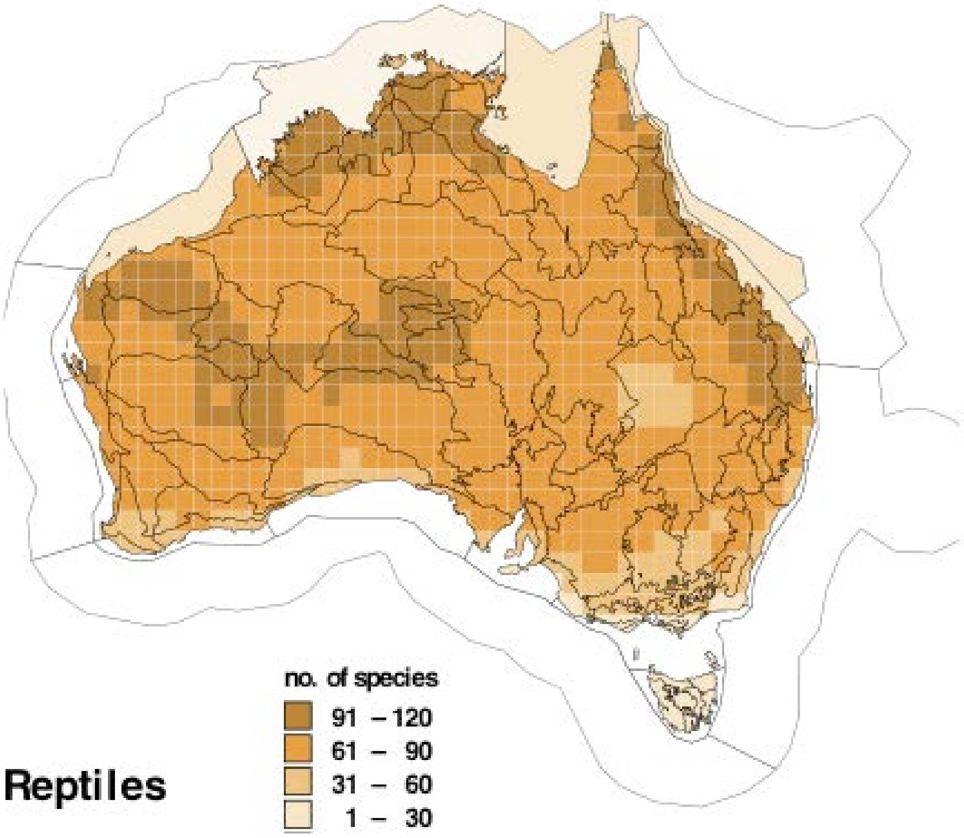


Figure 2.24 Distribution of species richness for reptiles. *Australia: State of the Environmen*t (SoE 1996)

Reptile richness tends to increase with decreasing latitude and increasing levels of sunshine (Heatwole and Taylor 1987). However this underlying trend is influenced by site factors such as structural diversity and the presence of features such as rock outcrops, both of which positively influence richness (Heatwole and Taylor 1987). The Brigalow Belt provides favourable conditions across climate, vegetation and geology, with a warm, sunny subtropical to tropical climate, structurally diverse and varied vegetation and extensive areas of outcropping rocks.

2.4.5.2 Inventory

The Brigalow Belt has greater richness at a genus level than the northern Australia or central-west Australia centres of reptile diversity. It also has more genera than the other bioregions *within* the eastern Queensland centre of diversity. The families Elapidae, Scincidae and Agamidae are particularly diverse in the Brigalow Belt (Table 2.8). The elapid snakes are of particular interest, as the Australian radiation of this family is the most diverse in the world (Keogh 1998). The Brigalow Belt has the greatest generic richness of elapid snakes of any bioregion in Australia (along with South-East Queensland).

The families Varanidae and Colubridae are more diverse in the northern Australian centre of diversity but are still prominent features of the Brigalow Belt's reptile fauna. The higher diversity of colubrid snakes in northern Australia reveals the affinity of this group with Papua New Guinea, which shares all eight genera. Varanidae in Australia are represented by a single genus, *Varanus*. Northern Australia has a range of aquatic and saxicolous species as well as woodland-dwelling representatives in this genus. The Brigalow Belt varanid fauna is relatively poor but includes two major terrestrial and arboreal predators, *Varanus varius* and *V. gouldi*.

Table 2.8 Richness of genera in the Brigalow Belt and in other Australian centres of reptile diversity.

Centre of diversity		**Central west Australia**	**Northern Australia**	**Eastern Queensland**			
Family	**Total genera**			Cape York	Wet Tropics	**Brigalow Belt**	South-east Queensland
Acrochordidae	**1**		**1**	1	1	**1**	
Agamidae	**13**	**6**	**7**	4	5	**8**	6
Boidae	**4**	**3**	**3**	4	3	**3**	2
Carettochelydidae	**1**						
Chelidae	**5**	**1**	**3**	3	3	**4**	3
Colubridae	**8**		**8**	7	5	**3**	3
Crocodylidae	**1**		**1**	1	1	**1**	1
Elapidae	**20**	**8**	**10**	10	14	**15**	15
Gekkonidae	**17**	**10**	**9**	9	9	**8**	7
Pygopodidae	**8**	**5**	**3**	3	3	**4**	3
Scincidae	**31**	**13**	**13**	14	15	**20**	21
Typhlopidae	**1**	**1**	**1**	1	1	**1**	1
Varanidae	**1**	**1**	**1**	1	1	**1**	1
Total	**111**	**48**	**60**	**58**	**61**	**69**	**63**

Reptiles and vegetation structure

Reptiles are the most numerous vertebrates in the eucalypt habitats of the Brigalow Belt. The structural features of these habitats are as fully exploited by reptiles as any in Australia. Structural elements such as tree hollows, decorticating bark, fallen timber and accumulations of leaf litter are all used for foraging and/or sheltering by several species. In contrast, southern Australian eucalypt habitats have fewer reptile species (especially arboreals), for while they are as structurally diverse as those in the Brigalow Belt the climate is cooler. The tropical eucalypt woodlands of northern Australia are also poorer, for while the climate is warm these habitats are less structurally diverse. Tropical woodlands have few large trees and may also have a lower volume of coarse woody debris because of low standing timber volumes, frequent fires and possibly the greater prominence of termites.

The Brigalow Belt has more species of arboreal reptile than any other bioregion in Australia (See Section 3.6.2.). Most of the arboreal species occur in eucalypt forests and woodlands. Two genera (*Oedura, Gekkonidae* and *Hoplocephalus, Elapidae*) appear to be particularly closely allied to eucalypts.

The velvet geckoes (*Oedura*) reach their maximum diversity in the Brigalow Belt. Unlike other arboreal gecko genera, *Oedura* are largely absent from both *Acacia* shrublands of semi-arid areas and rainforests and several species have close affinities with eucalypts.

Several of the other arboreal genera are rainforest specialists, the distantly related *Gehyra* also occurs throughout much of Asia and Madagascar, and arboreal geckoes from *Diplodactylus*/*Strophurus* include several species that utilise *Acacia* dominated shrublands. Only *O. marmorata* extends into the Eyrean zone and the inland populations are said to be generally saxicolous (Cogger 2000). The digits of arboreal geckoes that occur in eucalypt forests and woodlands are flattened and extended to form a broad “pad”. This adaptation enables the geckoes to negotiate surfaces as smooth as the “gum-barked” eucalypts such as Spotted Gums and Forest Red Gums. These “pads” do not appear to have arisen in rainforest. The Australian rainforest arboreal geckoes (e.g. *Phyllurus, Saltuarius*) which evolved much earlier than *Oedura* have slender, bird-like feet with digits that are moderately flattened or not flattened (See section 3.12.2.3).

Hoplocephalus is the only elapid genus in Australia that has significantly adapted to arboreality. As such they have one of the most distinctive morphologies of any Australian snake, with highly keeled ventral scales to aid in climbing and wide, angular heads (Keogh *et al.* 2003). The three species occur in eastern Australia, two in coastal NSW in open forest and tall open forest respectively, and one, *H. bitorquatus* (Pale-headed Snake) in the sub-humid inland, including much of the Brigalow Belt. *H. bitorquatus* is the oldest and most genetically distinct member of the genus, suggesting that the first Australian arboreal elapid snake may have scaled eucalypts in the dry woodlands, perhaps in the Brigalow Belt where a large proporttion of the current population exists (Table 2.31).

“*Especially given its genetic distinctiveness, we suggest that* H. bitorquatus *should be an urgent focus of conservation-related research to identify the status of existing populations and to clarify habitat features important for the species’ persistence*”

(Keogh *et al.* 2003)

Keogh *et al.* (2003) place emphasis on the use of riparian habitats by *H. bitorquatus*, and these are likely to be important in the Study Area, but Kelly *et al.* (2003) and ARCS (S. Kennedy pers. obs.) also located the species on *Corymbia citriodora* and *Eucalyptus crebra* well away from watercourses in the Carnarvon Ranges subregion. This population has access to extensive rocky areas, but the individuals were observed on eucalypts. It is possible species undertake seasonal movements between rock shelters and tree hollows in the manner of *H. bungaroides* in NSW, as described by Webb and Shine (1997). If so, the retention of large old trees with hollows will be important for *H. bitorquatus* as it is for *H. bungaroides*. The status of *H. bitorquatus* as the only truly arboreal snake in the Study Area could be significant. Keogh *et al.* (2003) suggest that arboreal snakes may be significant key predators and significant ecological effects may result if they are extirpated.

Frogs have been cited as a major food source of *H. bitorquatus* (Wilson and Knowles 1988), but the presence of *H. bitorquatus* on tree trunks in areas with scarce or no surface water and a high abundance of arboreal geckoes (especially *Gehyra dubia*) suggests that the primary prey in at least some parts of the Brigalow Belt is arboreal geckoes rather than frogs.

Reptiles and outcropping rocks

The outcropping sandstones of the Carnarvon, Expedition, Bigge, Murphy and Lynd Ranges greatly enhance reptile diversity by providing a suitable thermal microhabitat in otherwise hostile environments. Several saxicolous reptiles (*Saltuarius salebrosus*, *Egernia frerei*, *E. cunninghami*, *Eulamprus sokosoma*) display highly disjunct distributions, suggesting the sandstone areas provide refuges for species forced by climatic changes to contract from once widespread ranges. One of the most striking of the saxicolous reptiles is *S. salebrosus* (Giant Leaf-tailed Gecko) (Plate 18). This species is a relict with rainforest origins.

Plate 18. The Giant Leaf-tailed Gecko (*Saltuarius salebrosus*) is superbly camouflaged against both rock and the surfaces of some eucalypts. This species lives in rocky refuges provided by the extensive sandstone uplands of the Carnarvon Ranges and Woorabinda Subregions. Individuals have also been found on old individuals of *Eucalyptus decorticans* (which have coarse, lichen encrusted bark) in Grevillea SF. *Photo: B. Akeret*

2.4.6 Birds

2.4.6.1 Overview

There is an estimated 777 species of birds in Australia (SoE 1996). The Brigalow Belt South and Brigalow Belt North bioregions have the highest resident bird species richness of any bioregion in Australia, with 342 and 332 species, respectively (Sattler and Creighton 2002). Some coastal bioregions have higher total bird richness but these avifaunas are augmented by a larger number of non-resident elements such as non-breeding migratory waders and pelagic species.

This high species richness is a result of a combination of tropical, temperate, arid and rainforest-derived bird elements. Torresian (e.g. Red-winged Parrot, White-throated Honeyeater), Bassian (e.g. Striated Thornbill, Spotted Pardalote), Eyrean (e.g. Singing Honeyeater, Mallee Ringneck), Tumbunan (e.g. Black-faced Monarch, Regent Bowerbird) and Irian avifaunas (e.g. Scarlet Honeyeater, White-eared Monarch) are all well represented. The aforementioned species can all occur in the same landscape in the Study Area (albeit in different habitats), a breadth of overlap that is unique in Australia. Richness of Bassian fauna is boosted by mesotherm temperature regimes in the uplands suitable for Bassian birds which would otherwise not occur north of South-East Queensland. These uplands, termed the ‘mesotherm archipelago’ by Nix (1993) occur in a chain through central Queensland and into north Queensland, and include Blackdown Tableland and the Carnarvon, Bigge, Expedition, Peak and Drummond Ranges.

Australia has a highly endemic and unique bird fauna. It was long thought that the Australian avifauna was derived from a series of invasions from Asia, as taxonomy was based on morphological characteristics in the era before DNA analysis. Many Australo-Papuan songbirds such as robins, flycatchers, wrens, warblers and babblers morphologically resemble the robins, warblers and flycatchers of Eurasia, and these morphological similarities were considered evidence of a close relationship.

However, DNA-DNA hybridization studies by Sibley and Ahlquist (1985; 1990) to investigate relationships among the world's birds led to the discovery of a major Australo-Papuan endemic radiation of songbirds. The old endemic passerine groups of Australia and New Guinea are the results of adaptive radiation from Gondwanic stock, rather than the products of a series of invasions from Asia. Australian songbird families are actually more closely related to one another than to superficially similar songbirds in Eurasia. The similarities in form are the result of convergence in adaptations to life history strategies (Sibley and Ahlquist 1990).

The Australo-Papuan songbird radiation was given momentum by the drying of the once-rainforested continent. The drying of Australia resulted in the radiation of Australia's modern day flora from Gondwanan rainforest stocks, and concurrently elements of the Gondwanan songbird fauna also radiated and adapted to form the distinctive and diverse sclerophyll-adapted avifauna that occupies most of Australia today (Schodde 1989).

The rainforests of the Wet Tropics and subtropical eastern Australia harbour the best living record of the Gondwanan rainforest stocks that were the source of the contemporary eucalypt avifauna. The eucalypt avifauna itself is most diverse in eastern Australia, and within this the largest assemblage of eucalypt woodland birds is in the Brigalow Belt. These woodlands are dominated by Australo-Papuan endemic families, which accounted for 84 percent of all records in ARCS bird surveys in the Brigalow Belt (ARCS unpub. data). The families Meliphagidae (honeyeaters), Pardalotidae (thornbills, pardalotes and allies) and Corvidae are particularly prominent. These three families are now more species rich in eucalypt habitats than they are in rainforests and display a range of adaptations to life in these drier environments.

2.4.6.2 Inventory

Woodland birds

Woodlands support a distinct bird assemblage, which has been the subject of significant conservation attention (e.g. Robinson and Traill 1996; Garnett and Crowley 2000; Ford *et al.* 2001). The woodland bird assemblage differs from that of other eucalypt habitats (i.e. open forest and tall open forest) in supporting a higher richness of granivores, ground-foraging insectivores and nectarivores (See Section 2.4.6.2.), a number of which are found almost exclusively in woodland (See Section 3.6.4.).

The insectivorous ground-foraging guild in woodlands includes the Apostlebird, Grey-crowned Babbler, White-browed Babbler, a ground-foraging treecreeper (Brown Treecreeper), Hooded Robin, Speckled Warbler, Southern Whiteface and Chestnut-rumped Thornbill, all of which are absent or rare in open eucalypt forest. Only five ground-feeding insectivores found in open forest (White-winged Chough, Buff-rumped Thornbill, Yellow-rumped Thornbill and Eastern Yellow Robin and Scarlet Robin) also regularly occur in woodlands (Traill and Duncan 2000).

Granivorous birds, especially finches (e.g. Diamond Firetail, Plum-headed, Double-barred and Black-throated Finch), and parrots (e.g. Blue Bonnet, Galah, Turquoise Parrot, Red-rumped Parrot, Budgerigar) are diverse and abundant. This probably reflects the greater availability of seeding grasses in woodlands compared with denser forests.

Eucalypt nectar is a key resource, and eucalypt flowering events are a major driver of bird movements throughout the woodlands. Honeyeaters and lorikeets often dominate woodland communities, with honeyeaters in particular dictating community composition through interspecific aggression (Traill 1995). Spectacular aggregations of nectarivores may occur at eucalypt flowering events, and this phenomenon is far more frequent in woodlands than in open forest. Many nectarivores are woodland specialists, such as the Regent Honeyeater (Endangered), Yellow-tufted Honeyeater, Brown-headed Honeyeater and Fuscous Honeyeater.

Dry rainforest birds

The basalt flows during the Tertiary have enabled the persistence of dry rainforests that harbour a distinctive element of the Brigalow Belt's bird diversity. Resident populations of rainforest birds such as the Australian Brush-turkey, Wonga Pigeon, Emerald Dove, Regent Bowerbird and Varied Triller are joined each spring by breeding migrants that winter in New Guinea, such as the Black-faced Monarch, Little Bronze-Cuckoo and Rufous Fantail. The avifauna in the dry rainforests has a much higher Tumbunan component than the surrounding eucalypt habitats (ARCS unpub. data). At least 15 of the 28 rainforest-dwelling Tumbunan birds that occur in South-East Queensland (Nix 1993) also have resident or breeding migrant populations in the Brigalow Belt.

Remnants of the once extensive dry rainforests (or 'vine scrub') and brigalow represent a significant percentage of the remaining habitat for the dry rainforest specialist Black-breasted Button-quail (Vulnerable). These habitats also support rainforest species such as the Black-faced Monarch, Little Bronze-cuckoo, Emerald Dove and Regent Bowerbird.

2.4.7 Mammals

2.4.7.1 Overview

The mammal fauna of the Brigalow Belt (111 of Australia's 268 species) includes exceptionally rich insectivorous bat and macropod assemblages. Arboreal marsupials are also a prominent feature; the Study Area has the largest areas of Yellow-bellied Glider and Greater Glider habitat in Queensland (See Section 2.4.8.). The Brigalow Belt's eucalypt habitats still support a number of "critical weight range" (CWR) mammals such as bandicoots, bettongs and hare-wallabies. This is a notable feature on a continent where this element of the fauna has been widely decimated (See Section 3.4.2.2.). Species with key functional roles include the Dingo and Northern Quoll, predators which have a major role in regulating mammal populations. The Little Red Flying-fox is a major eucalypt pollinator which forms aggregations of thousands of animals.

Six mammal species have become extinct in the Brigalow Belt and two of the rarest mammals on the continent (Bridled Nailtail Wallaby and Northern Hairy-nosed Wombat) remain as single wild populations in the Study Area.

2.4.7.2 Inventory

Macropods

The Brigalow Belt has the richest macropod fauna in Australia (14 species), equaled only by the Wet Tropics. There are no recorded bioregion-level macropod extinctions in the Study Area, an unusual distinction on a continent where bioregional and state-level macropod extinctions have been numerous. However, species such as the Spectacled Hare-wallaby and Bridled Nailtail Wallaby have declined dramatically. The Bridled Nailtail Wallaby survives in a National Park (Taunton NP) of only 11 000 hectares, and the Brigalow Belt population of the Spectacled Hare-wallaby is largely dependent on the continuation of a relatively conservative grazing system in an area of *Eucalyptus melanophloia* (Silver-leaved Ironbark) woodland near Emerald (McCosker 1997). The presence of these smaller macropods is significant, as many parts of Australia have lost most or all of their species of nailtail wallaby and hare-wallaby (e.g. box-ironbark region of Victoria (ECC 1997)).

A diverse wallaby fauna including the Swamp, Whiptail and Red-necked Wallaby and the brigalow/vine thicket specialist Black-striped Wallaby can still be found in most forests. There are three species of rock-wallaby (*Petrogale sp.*) with a north-south pattern of replacement. The Brush-tailed Rock-wallaby in the far south of the Study Area is replaced by the Herbert's Rock-wallaby across most of Brigalow Belt South, which in turn is replaced by the Unadorned Rock-wallaby in Brigalow Belt North.

Dingo

The Dingo is still present across much of the Study Area. The Dingo is Australia's largest terrestrial predator, weighing around 15 kilograms (Menkhorst 1995) and appears to have a major regulatory influence on fauna composition. It is reported that areas with Dingoes have fewer Red Foxes and grey kangaroos. Species susceptible to fox predation such as the Bush Stone-curlew (Of Concern), Rufous Bettong (Of Concern) and Squatter Pigeon (Vulnerable) are more common north of the 'Dingo Fence' (Environmental Protection Agency 2002b). If this observed link is causal and not coincidental, then the continued presence of the Dingo appears to be desirable for nature conservation.

Little Red Flying-fox

The Little Red Flying-fox has a significant functional role as a eucalypt pollinator in the Brigalow Belt. It is the only large mammal that congregates in the thousands in the Study Area. It forms large roosts, generally in dense vegetation, which may be dry rainforest or riparian understorey vegetation. The Little Red Flying-fox is largely nectarivorous, and is not equipped to exploit fruit to the same extent as other flying-foxes (Vardon and Tidemann 1999). The bats disperse from roosts into the surrounding eucalypt forests and woodlands in the evening in search of nectar, sometimes traveling tens of kilometres each night. When large numbers of Little Red Flying-foxes congregate in a forest, it is likely they will be the major eucalypt pollinator.

Hollow-dependent marsupials

Arboreal marsupials are a prominent feature of the mammal fauna. The Study Area has the largest area of habitat in Queensland for the Yellow-bellied Glider and Greater Glider (See Section 2.4.8.). It is possible to locate all five glider species of the area (Yellow-bellied, Greater, Squirrel, Sugar and Feathertail Glider) at a single site. Common Brushtail Possums are also present.

Bandicoots

Two species (Northern Brown Bandicoot and Long-nosed Bandicoot) occur in the Study Area. Bandicoots have disappeared from large areas of Australia, although they remain locally common in some coastal regions. Bandicoots are medium-sized ground-dwelling mammals, and require dense vegetation for shelter. Both species are said to be in decline in Brigalow Belt South (Environmental Protection Agency 2002b). A primary reason for this is likely to be the loss of brigalow and vine-thicket habitat, but also the loss of dense understorey vegetation in other habitats as a result of grazing and too frequent fire (particularly on riparian zones). Fire intervals of less than 15 years were considered too frequent for the Long-nosed Bandicoot and Southern Brown Bandicoot by an expert fauna panel in south-eastern NSW (Environment Australia 2000). Vegetation in south-eastern NSW is likely to recover more quickly than in the Brigalow Belt, suggesting that fire intervals would have to be even longer in the Brigalow Belt. Currently, large areas are burnt every 3–6 years for grazing purposes, and these landscapes are probably devoid of bandicoots.

Bats

The insectivorous bat fauna of the Brigalow Belt is one of the richest in Australia (See Section 3.6.5.). Five of the 36 species are threatened. The Brigalow Belt is the national stronghold of the Little Pied Bat (Rare), which occurs in all of the large tracts of vegetation. The Large-eared Pied Bat (Rare) is a more localized cave-dwelling species, with an isolated disjunct population in the Presho SF-Belington Hut SF-Expedition NP area in the eastern Carnarvon Ranges Subregion. The Greater Long-eared Bat (Rare) is a tree-hollow dependent species of the woodlands, with a stronghold in the Inglewood Sandstones Subregion. It is thought to occur only in the larger tracts of vegetation (Southwood NP (7 000 ha) or larger, Environmental Protection Agency 2002b). The Common and Little Bent-wing Bats (Of Concern) are largely found in uplands such as Coominglah SF and the Carnarvon Ranges Subregion, where they probably roost in large numbers in caves (Kelly *et al.* 2003).

Quolls

Quolls have vanished from large tracts of Australia, and are threatened in many areas in which they remain. Three species have been recorded in the Study Area, of which one (Western Quoll) is extinct in Queensland, and another (Spotted-tailed Quoll) has not been recorded in the Brigalow Belt since 1990. The Northern Quoll is present in the Carnarvon NP, and may be present in other remote areas of the Carnarvon Ranges Subregion, such as in Expedition NP, Belington Hut SF and Presho SF.

Quolls are a group of major terrestrial mammal predators that is severely impacted by fragmentation. Their presence generally indicates an extensively vegetated and little disturbed habitat with few introduced predators. The Northern Quoll would be one of the major beneficiaries of conservation planning for areas with little human disturbance in the Study Area. The Northern Quoll has contracted significantly in Australia (Braithwaite and Griffiths 1994), so the extant Carnarvon Ranges Subregion population is of major importance. The species is susceptible to the Cane Toad, so extensive areas without artificial watering points may be beneficial.

Rodents

There were 18 species of native rodents in the Study Area, of which two have become extinct. Native rodents have undergone serious declines in Australia generally. Dickman *et* *al.* (2000) reviewed the status of rodents in Queensland and found that neither foraging substrate nor habitat influenced the likelihood of a species becoming threatened. Weight was not a factor either, with species under 35 grams (under “critical weight range”) no less likely to be threatened than those above 35 grams. However species with specialized diets were more likely to have declined, with dietary generalists such as those in the *Rattus* genus faring relatively well in Queensland. Feral cats pose a more serious threat than do foxes for native rodents and stock grazing and inappropriate fire regimes threaten several species (Dickman *et al.* 2000).

Dickman *et al.* (2000) evaluated the status of Queensland’s rodents by investigating attributes such as population size, population trend, current distribution size and distribution trend. They concluded that two species found in the Brigalow Belt, the Queensland Pebble-mound Mouse (*Pseudomys patrius*) and the Desert Mouse (*P. desertor*) should both be listed as Rare in Queensland (both are currently listed as Common). The Queensland Pebble-mound Mouse was rediscovered in the early 1990s after being “missing” for more than 80 years (Van Dyck 1997). The species has since been found to be widespread but highly localized across Queensland, with a number of records in the Brigalow Belt. The Desert Mouse is found in the far west of the bioregion (Wildnet records).

2.4.8 Habitat models for Gliding Possums in Southern Queensland

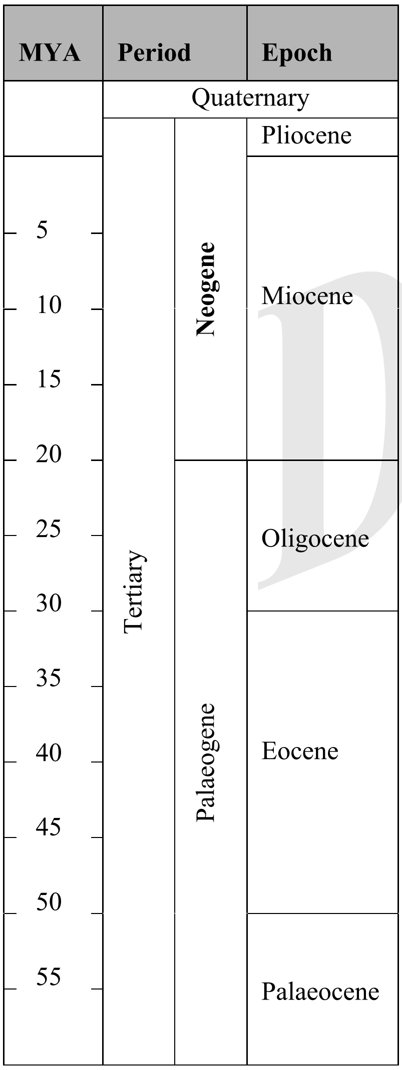
Based on habitat modelling by the EPA, the Study Area contains the largest area of high-quality habitat in Queensland for the Yellow-bellied Glider. Of this, only 6.6 per cent occurs in Protected Areas. Around 21 per cent occurs on State Forest and Timber Reserve in the WHWD Area. More than 65 per cent occurs on State Forest, Timber Reserve and leasehold land used for timber production. The models are discussed in Section 7.2.3.

Similarly, the Study Area contains the largest area of modelled high-quality habitat in Queensland for the Greater Glider. Around 10 per cent occurs in Protected Areas and 20 per cent in State Forests and Timber Reserves.

3 Significance of the Study Area for Biodiversity Conservation and Ongoing Evolution

3.1 Palaeoclimate and the evolution of the modern Australian flora

The Brigalow Belt Bioregion provides one of the best representations of the Neogene period in Australia's vegetation history. This timespan of around 20 million years comprising the Miocene and Pliocene Epochs at the close of the Tertiary Period saw the most radical transformation of the Australian landscape from the old to the modern floras — from one dominated by rainforest to one composed predominantly of the open drier vegetation communities that characterise most of the continent today (Kershaw *et al.* 1994). This was a critical turning point in the history of Australian vegetation and a major stage in the earth's biological and evolutionary history.



The immediate ancestral stock for this transition derives from the Early Tertiary when temperatures such as at the Palaeocene/Eocene boundary were higher than at any other time during the Tertiary. Continent-wide rainforests dominated under these almost uniformly and equably warm/wet conditions — the golden age for rainforests. It is this Gondwanan rainforest stock from which the Australian sclerophyllous flora evolved. Earliest pre-Neogene *Acacia* and *Eucalypt* species were strongly associated with mesothermal rainforest types (Macphail *et al.* 1994). [The early Cretaceous marine incursions are also likely to have left a legacy of differentiated gene stock in northeast Australia, separated as it was from the remaining three exposed discrete sections of the continent at the time of earliest emergence of angiosperms.] Whilst temperatures and rainfall declined markedly during the Middle to Late Eocene Periods the composition of rainforests changed rather than there being any significant emergence of open-canopied sclerophyllous vegetation. *Brachychiton* and araucarian dry rainforest taxa became more prominent in the fossil record.

The next stage — the Oligocene-Middle Miocene interval —was the key interval marking the transition from an essentially continuous Cretaceous-Eocene regime to one leading directly to the modern climate of Australia. Distinct latitudinal temperature gradients emerged for the first time in the Oligocene, a cool dry interval coinciding with initiation of sea ice development in the Antarctic and glaciation of Antarctica. This was the maximum laterite-forming period. A sharp peak of warming by at least 3˚C at the beginning of the Miocene caused rising sea levels from Antarctic ice melt, higher rainfall and increased weathering. Moderate uplift of the Great Divide keeping pace with erosion and extensive volcanic activity in the Springsure to Clermont region helped preserve much of the landforms of the Tertiary. By Middle Miocene seasonality was clearly evident with marked dry periods especially in central Australia. Evolutionary pressures associated with cooling were favouring the evolution and diversification of nectarivores over insectivores for the first time (Ford 1989). The northward drift of the Australian plate, however, would have ameliorated the more severely deteriorating conditions experienced elsewhere in the world. Capella, halfway between Clermont and Emerald reveals a fossil flora 30 million years ago that was still dominated by rainforest and included proteaceous taxa such as *Athertonia* now restricted to disjunct, relict populations in moist, fertile refugia in the Wet Tropics (White 1994). It is likely that the origins of the subhumid subtropical “C” rainforest floristic region of Webb and Tracey (1994)(Figure 3.1), the largest of all regions and corresponding to the Brigalow Belt and western half of the South-East Queensland bioregion today, date from this time.

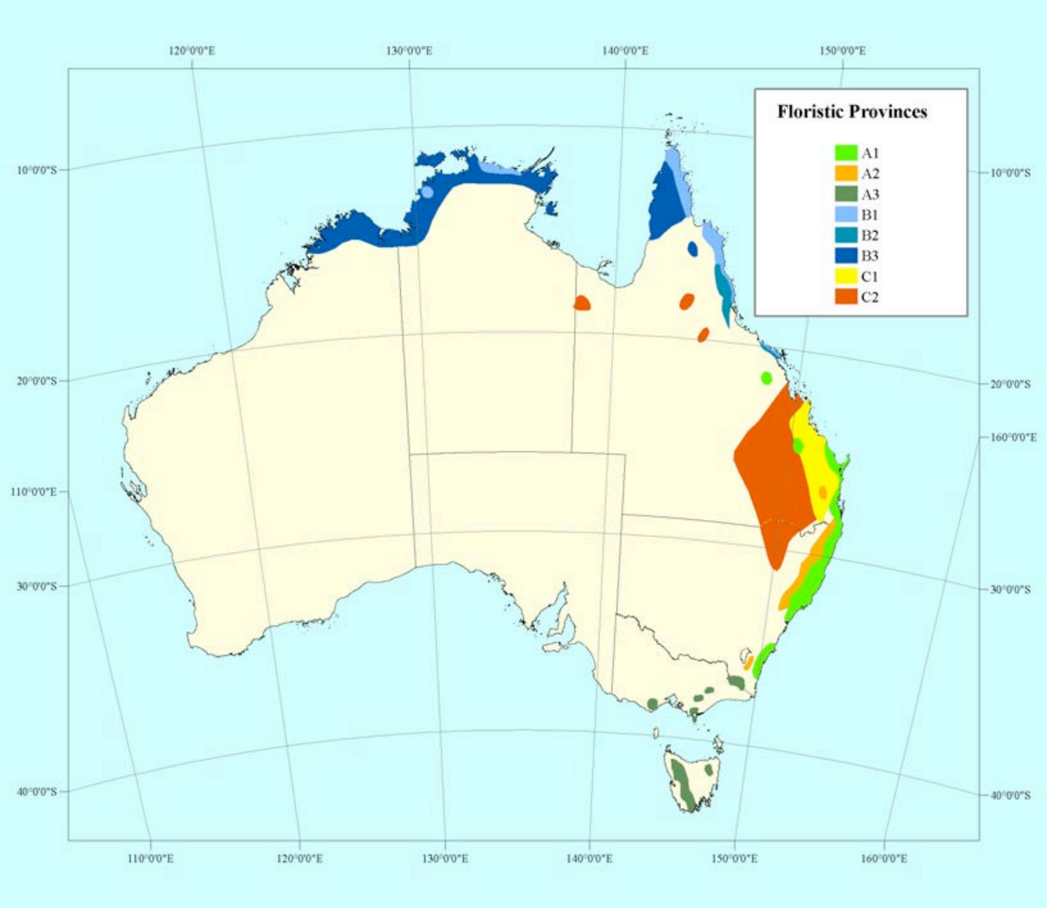


Figure 3.1 Rainforest Regions (A, B, C) and Provinces (A1 to C2)(after Webb and Tracey (1994))

At the end of the Miocene (about 6 million years ago), temperatures dropped precipitously, the ‘terminal Miocene event’, with a switch to winter rainfall in the southern half of the continent completed by the end of the Neogene. A short warm and wet interval accompanied by high sea levels followed the ‘terminal Miocene event’ initiating another cycle of renewed deep weathering followed by ferricrete formation in the ensuing dry snap. The end of the Neogene at the close of the Pliocene epoch about 2.5 million years ago marked the most

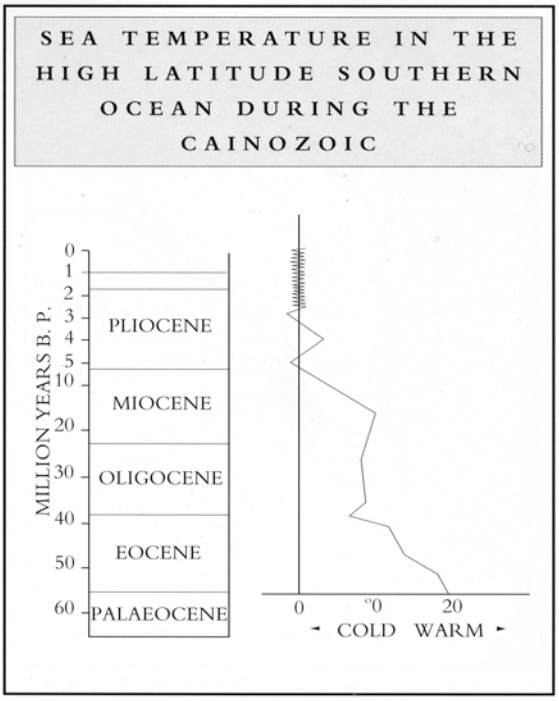


Figure 3.2 High-latitude sea temperature during the Cenozoic (From White 1994)

stark changeover from aseasonally warm wet climates to seasonal aridity (Figure 3.2). The major contributing factor was the formation of the North Pole ice cap. The effect of bipolar glaciation was to accentuate both latitudinal temperature gradients and overall cooling. This marks the starting point of the modern Australian flora.

The fluctuating climatic conditions of the Pliocene towards the end of the Neogene drove major range shifts in flora. Sifting of floras was more pronounced than in the Miocene with repeated expansion and contraction of ranges. Plants either adapted to new conditions or retreated to suitable refugia. Orographic rainfall associated with the extensive sandstone uplands of the Brigalow Belt, unparalleled water retentive capacities of its vast clay sheets formed later in the Quaternary, the preservation of relictual landscapes and soils of the Early Tertiary, and volcanic rejuvenation of soil fertility are some of the critical factors that have made the Brigalow Belt one of the most significant refugial areas for antecedents of dry-adapted flora in Australia.

In the extremely short time interval following the Neogene Period (less than two per cent of the Cenozoic era) eucalypts and acacias came to dominate and characterise the woody vegetation of this continent. The Neogene stands as the transition zone and evolutionary cauldron, transforming a pool of rainforest genes to ones capable of sustaining modern-day conditions of seasonal rainfall, aridity and poor soils.

The final transformation of the Australian flora in the late Quaternary, as the country emerged from the cyclical grip of severe 'icehouse' conditions and receding seas, was seeded from a gene pool that has its greatest number of relictual representatives in the Brigalow Belt.

Whilst the Wet Tropics World Heritage Area preserves the greatest concentrations of old lineages relating to the origins of flowering plants, and the Central Eastern Rainforests Reserves of Australia the greatest diversity of plants relating to the intermediate secondary radiations within the Rosidae Subclass of flowering plants, the Brigalow Belt contains an unparalleled representation of ancestral groups from which the modern flora was derived.

3.2 Flora

3.2.1 The Eucalypts (*Angophora*, *Corymbia*, *Eucalyptus*)

3.2.1.1 Introduction

Eucalypts are unambiguously the most quintessentially Australian of any plant group. Of more than 800 species known, only four are found exclusively outside Australia. They exemplify a level of differentiation probably unparalleled among woody plants (Wardell-Johnson *et al*. 2003). Eucalypts dominate 124 million hectares of open forest, woodland and mallee or 80 per cent of the nation's native forests (NFI 1998). They are present in virtually all vegetation types and exhibit growth forms from the smallest stunted mallees to the tallest trees on earth, occur from the lowest to highest elevations, from the most to least fertile of terrains and from the wettest to driest climes. Their evolution and rise to dominance represents a major stage in the earth's evolutionary history —the Neogene transition of the Australian flora. This major evolutionary stage within the Cenozoic represents the transformation from the rainforest-dominated continent of the early Tertiary to the dry-adapted floras of the modern era.

Nowhere is this critical and radical transformation better represented than in the Brigalow Belt bioregion, circumscribed east-west in Queensland essentially by two dominating features — the ranges and uplands of the Great Escarpment and the Great Divide and their flanking sedimentary basins.

The Brigalow Belt preserves, to a greater degree than any other bioregion in Australia, the most complete living record of that dramatic transformation. The patterns of relictual and recent distributions of eucalypt taxa represent an unparalleled evolutionary catena of radiations and ecological sifting in response to temporally and spatially changing environments associated with cycles of climate change beginning in the Miocene.

The Brigalow Belt exhibits a range of outstanding features regarding eucalypts, including —

- the highest genetic diversity and the broadest evolutionary catena of *Angophora* in Australia,
- the most significant bioregion in Australia for the bloodwoods (*Corymbia*), with 30 per cent of all Australian species,
- the highest diversity of relictual and recently evolved taxa within the majority of the bloodwoods, especially the brown, red and yellow bloodwoods and spotted gums, and
- outstanding evolutionary significance with respect to *Eucalyptus*, with the highest diversity in Australia of the oldest, most primitive species and representation of almost all subgenera.

3.2.2.2 Eucalypt origins and radiations

The oldest reliably dated eucalypt macrofossils are associated with mesotherm rainforests of the early Miocene (21 Ma). Capsular-fruited myrtaceous rainforest taxa are likely to be most closely related to the rainforest ancestors from which eucalypts evolved. Old lineages of the capsular-fruited Myrtaceae surviving as relicts in today's rainforests include *Barongia*, *Ristantia*, *Sphaerantia*, *Lophostemon*, *Xanthostemon* and *Eucalyptopsis*.

Whilst the earliest eucalypts are likely to have been present in pre-Miocene rainforests, most modern day taxa are unlikely to have evolved and/or radiated from these mesic environments to dominate open forests or woodlands until the last few million years when cycles of increasing seasonality, aridity and fluctuating temperatures profoundly affected the Australian continent — more moderately during the Neogene, then intensely during the Pleistocene and Holocene Periods. Pollen and charcoal records from terrestrial and marine sediments in north-east Australia indicate a rise of 4˚C in sea-surface temperatures around 245 000 years ago (Kershaw *et al*. 2002). These greatly increased temperatures may have added fire as the additional environmental factor that tipped the evolutionary balance in favour of eucalypts.

Eucalypts in broad terms include *Angophora*, *Corymbia* and *Eucalyptus*. The most visible distinguishing feature within the eucalypts is their bark which can be either persistent (non-decorticating), spongy, fibrous and furrowed (stringybarks), hard and deeply furrowed (ironbarks), flakey or tessellated (boxes, bloodwoods), or decorticating and shed annually either completely or in part (gums and peppermints). These intuitive groups can have strong evolutionary underpinnings plausibly linked to fire.

Taxonomic classification among the eucalypts remains contentious. Brooker (2000) considers eucalypts to be monogeneric, placing angophoras in subgenus *Angophora*, the yellow and red bloodwoods and spotted gums in subgenus *Corymbia*, and the paper-fruited bloodwoods or ghost gums in subgenus *Blakella*. Hill and Johnson (1995) recognise the genera *Angophora*, *Corymbia* and *Eucalyptus*, placing the paper-fruited bloodwoods in *Corymbia*. The eucalypt groupings considered in this discussion are equivalent to Brooker's subgenera. However, consistent with the classification adopted by the Queensland Herbarium (and all other State herbaria), *Angophora* and *Corymbia* are treated as genera.

Two major evolutionary lineages of eucalypts are clear (Figure 3.3). The first lineage (clade 1) includes *Angophora*, *Corymbia* and (in the sense of Brooker 2000) *Blakella*. They have strong affinities with the mesic forests of the early Tertiary and their members are largely associated with warm climates. The second major group (clade 2) comprises all other subgenera of *Eucalyptus*. Steane et al. (2002) propose further major changes in taxonomic rankings. Whilst the study is significant, this report will not adopt their recommended changes until further work addresses recent concerns regarding the use of a single markers and especially the lower resolving power of nuclear ribosomal DNA for developing plant phylogenies (Despres et al. 2003, Nickerson and Drouin 2004).

3.2.2.3 Angophora

Angophora is considered the most primitive (plesiomorphic) of the entire eucalypt group. *Angophora* pollen type has been detected in rainforest palaeofloras as far back as either the Late Eocene or Middle Miocene with silicified moulds of fruit also from central Australia in the Middle Miocene (Martin 1999). Today it is a small monophyletic group of 12 species endemic to eastern Australia. Most *Angophora* species are confined to woodlands in wetter areas on infertile sandstone soils. Very rarely do they dominate communities in the same way as eucalypts, acacias, melaleucas or casuarinas. An exception is found with *Angophora leiocarpa*, which dominates woodlands on deep texture-contrast soils with thick sandy surfaces overlying quartz sandstones in the Brigalow Belt (Johnson 1984). There appear to be two major centres of *Angophora* diversity corresponding to the two great Jurassic/Triassic sandstone regions of Australia — the sub-humid Brigalow Belt, and the high rainfall Sydney Basin — with a minor centre in coastal south-eastern Queensland/north-eastern NSW. The highest genetic diversity and the most westerly and sub-humid distributions of *Angophora* occur in the Brigalow Belt (Table 3.1).

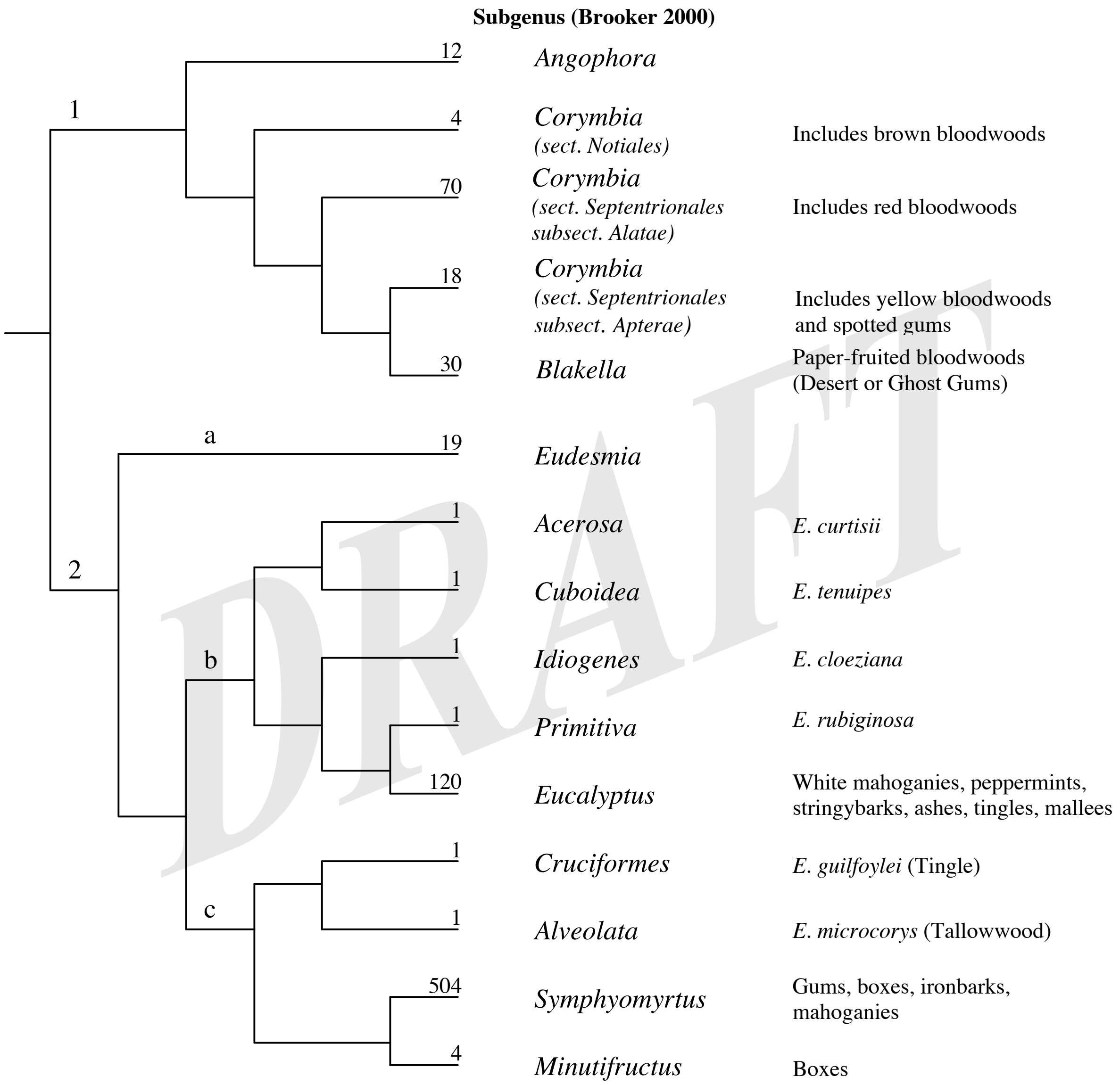


Figure 3.3 Phylogeny of the major groups of eucalypts based on morphological and molecular data (after Ladiges 1997; Ladiges and Udovicic 2000; Brooker 2000). Numbers refer to species tally per group (includes subspecies). Taxonomic classification is that of Brooker (2000)

Table 3.1 Distribution of *Angophora* in Australia

Species	**Group affinity**	**Brigalow Belt**	**SEQ/NE NSW**	**Sydney Basin**
A. costata*	costata	Disjunct relicts		Disjunct relict
A. melanoxylon		Western		
A. leiocarpa	costata	Centre–East	SEQ only	
A. woodsiana	costata	Relictual	SEQ mainly	
A. subvelutina		Eastern	SEQ mainly	Disjunct relict
A. paludosa	bakeri		NE NSW only	
A. rubur			NE NSW only	
A. floribunda*		Inland Core		Coastal relicts
A. hispida**				Endemic
A. bakeri**	bakeri			Endemic
A. crassifolia	bakeri			Endemic
A. euryphylla**	costata			Endemic
TOTAL species		6		7 (5 in WHA)

* Recorded in Greater Blue Mountains World Heritage Area; ** Endemic to Sydney Basin and in the WH Area.

The Brigalow Belt best exemplifies the broadest evolutionary catena of *Angophora* in Australia. Six species follow a continuous 650 km east-west gradient with respect to moisture, soil nutrients and climatic variability that reflects the radiation of early eucalypts in response to the climatic collapse heralded by the Neogene (Figure 3.2). The gradient of sympatric/parapatric distributions ranges from the more stable, fertile and mesic coastal habitats of *A. woodsiana* and *A. subvelutina* through core areas for *A. leiocarpa* in the eastern Brigalow Belt to a central core distribution for *A. floribunda* to *A. melanoxylon* at the western boundary of the Brigalow Belt with less than 500 mm annual rainfall.

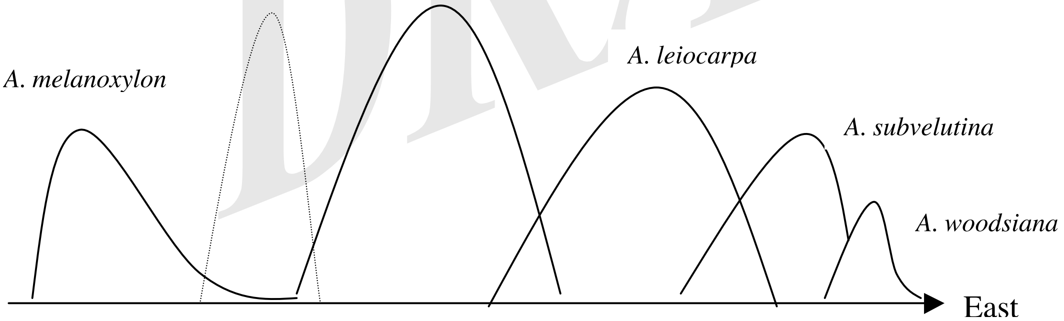


Figure 3.4 East-West sympatric distributions of *Angophora* in the Brigalow Belt.

These vegetation patterns within the Brigalow Belt reflect a clear soil nutrient gradient, especially soil phosphorus and/or nitrogen paralleling the phosphate status of parent rock types. Low woodlands occur on the sandstones that are lowest in soil phosphorus. Low open forest occurs on ancient lateritic soils with somewhat higher soil phosphorus levels, while the tall open forests of *A. woodsiana* occur on basalt-enriched sites on the eastern boundary where the Great Divide and Great Escarpment first diverge.

A. costata, the tallest of the angophoras and one of only three closely related smooth-barked members, appears to have a relictual (allopatric) distribution in Queensland restricted to areas above 400 m, separated by as much as 370 km along the Great Divide — at White Mountains NP (at the margin of the Einasleigh Uplands), at the western margin of the Brigalow Belt bioregion near Alpha, and at Blackdown Tableland.

The Brigalow Belt represents the larger part of the Australian distribution of *A. leiocarpa* and *A. floribunda*.

A. leiocarpa, primarily a Queensland species and medium-sized tree, is associated with sandstone outcrops especially along the boundary between the northern and southern Brigalow Belts, mainly on deep texture-contrast soils with a thick sandy surface developed on quartz sandstones (RE 11.5.1) and on associated deep uniform sands accumulated in wide valley floors (RE 11.5.4). It is a major component of RE 11.5.7 in an unusual association with relict populations of *Eucalyptus acmenoides* (Subgenus *Eucalyptus*), one of the white mahoganies.

A. floribunda is most dominant in the Brigalow Belt, commonly occurring as gnarled, tall, hollow-forming trees that track areas with highest Mean Moisture Index (Figure 2.4). *A. floribunda* occurs on both elevated areas and deep alluvial soils. In the latter case they are commonly associated with *E. tereticornis* woodlands and in the former with woodlands or open forests with *E. crebra*, *E. chloroclada* and *Callitris glaucophylla*. Small disjunct populations occur on Einasleigh Plateau especially adjoining the western boundary of the Wet Tropics near Herberton. In NSW populations follow the Brigalow Belt South bioregion along the Great Divide only to north of the Hunter River. More southerly populations then are coastal from the Sydney basin at Port Macquarie with attenuated isolated populations in Victoria.

The humid mesotherm coastal region north and south of the McPherson Range is a key centre for three largely coastal species: *A. subvelutina*, *A. woodsiana* and *A. paludosa* together with *A. leiocarpa*. *A. paludosa* is a medium-sized tree to 18 m occurring on sandy, often inundated alluvial soils. *A. woodsiana*, also a medium-sized tree to 20 m, is mostly found in three disjunct population centres growing in dry sclerophyll forest on coastal sandy soils on sandstone hillsides centred at Beerwah on the Sunshine Coast and Daisy Hill Forest Reserve/Plunkett Conservation Park south of Brisbane. The third disjunct population is subcoastal on sandstones of the Helidon Hills but extends to the tall open forests on olivine basalts of the Great Divide. There it is sympatric with *E. pilularis*, *E. microcorys*, *E. eugenioides*, *E. carnea* and *E. helidonica*. The distribution of *A. subvelutina* is more subcoastal, where for most of its range it occurs with *E. tereticornis* as a co-dominant. In the wettest sites a dense layer of mesomorphic rainforest species occurs including *Lophostemon suaveolens*, *Archontophoenix cunninghamii*, *Castanospermum australe* and *Calochlaena dubia,* an ancient fern within the Dicksoniaceae. Such communities still are found in Coominglah SF.

The much wetter Sydney basin is a key centre for four endemic species closely related to *A. costata*: *A. crassifolia* (restricted to Kuringai Plateau), *A. bakeri* (Port Stevens to Nowra, west to Katoomba*)*, *A. hispida* (confined to Sydney region on Hawkesbury sandstones), and *A. euryphylla* (restricted to Judge Dowling Range between Putty and Wollombi west of Newcastle). The area also contains disjunct populations of *A. costata*, *A. floribunda* (on deep alluvial soil south from Port Macquarie), and *A. subvelutina*. Interestingly, locally endemic species and subspecies of this species group are all small trees — *A. crassifolia* (10 m)*, A. bakeri* (10 m), *A. hispida* (8 m), *A. euryphylla* (2.5 m). Five of the angophoras occur in the Greater Blue Mountains World Heritage Area, three of which are endemic. Unlike the Brigalow Belt, the Sydney basin is characteristically in a high rainfall zone but shares with the Brigalow Belt bioregion a predominance of highly infertile and skeletal soils derived from sandstone.

3.2.2.4 Corymbia

The bloodwoods and angophoras are closer to each other than to any other eucalypt group. The bloodwoods, named because of their propensity to exude red sap (kino), dominate the flora of Northern Australia. Their bark characteristically fractures or peels into small polygonal scales to appear tessellated (Hill and Johnson 1995).

This broad group of about 100 species (122 taxa including subspecies) divides clearly into three major subgroups: the red bloodwoods (70 species and subspecies in Section *Rufaria*, yellow bloodwoods (13 taxa including subspecies in Section *Ochraria*) and the paper-fruited bloodwoods (30 taxa including subspecies in Subgenus *Blakella*) (Ladiges 1997, Hill and Johnson 1995). There are four additional monotypic or tritypic sections or series, including spotted gums.

Brooker (2000) uses alternative rankings and names. However, despite disputes regarding the generic or subgeneric rank of species groups and the placement of some individual species within those groups (Hill and Johnson 1995, Brooker 2000, Ladiges 1997, Ladiges 2000), there is broad correspondence of species groupings (See Figures 3.5 and 3.6.). For consistency with the nomenclatural system adopted by the Queensland Herbarium, a classification based on Brooker (2000) is largely followed, except where Hill and Johnson (1995) detail coherent subgroups unaddressed by Brooker (2000). The generic rank for *Corymbia* is retained.

From an examination of species distributions within the bloodwoods one can draw clear conclusions. The Brigalow Belt with 35 (37) species of *Corymbia,* or about 30 per cent of all Australian bloodwoods and spotted gums, ranks as one of the most significant bioregions for the genus in Australia. It has the highest diversity of relictual and recently evolved taxa within the majority of bloodwood groupings especially the brown, red and yellow bloodwoods, and spotted gums. The only broad phylogenetic groups that occur or are more diverse elsewhere are the paper-fruited bloodwoods (desert gums), the desert sandhill bloodwoods and the monotypic Sections *Torellinae* (*C. torelliana*) and *Jacobsinae* (*C. jacobsiana*).

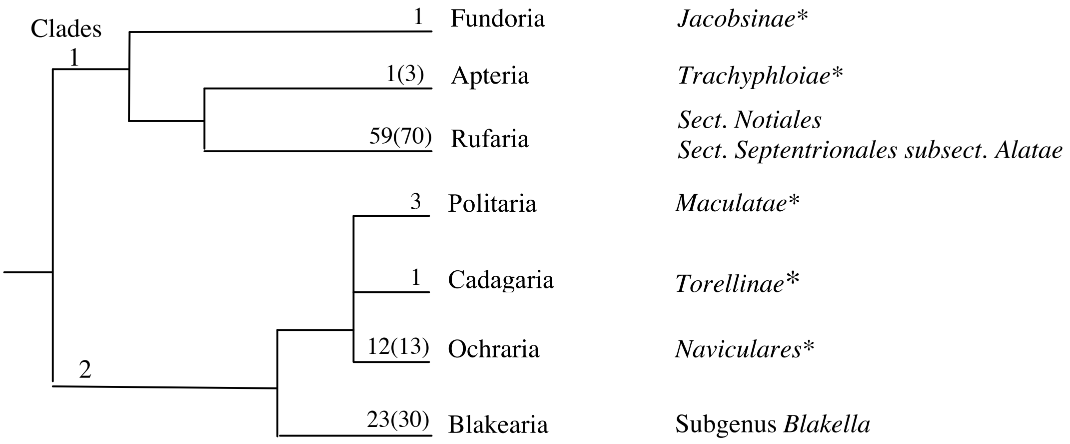


Figure 3.5 Phylogeny of the major bloodwood groups based on morphological and molecular data, showing corresponding classifications at Section level on the left (Hill and Johnson 1995) and subgenus or series level on the right. All with * occur in Sect. *Septentrionales*, Subsect. *Apterae.* Numbers refer to number of species with the number of taxa including subspecies shown in brackets.

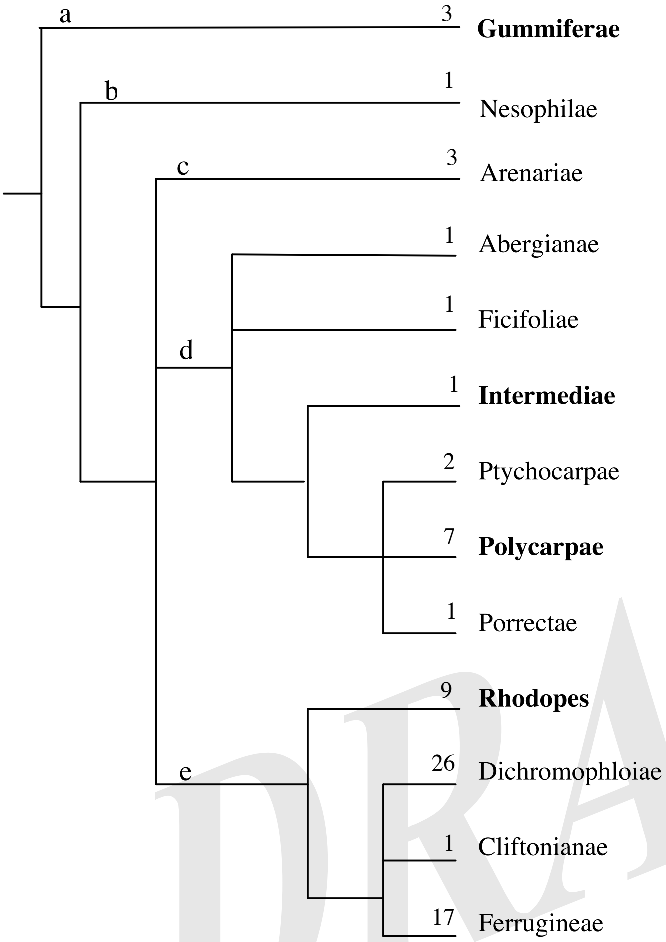


Figure 3.6 Series level phylogeny of Section *Rufaria* (Hill and Johnson 1995) corresponding to Section *Notiales* and Subsection *Alatae* of Section *Septentrionales* (Brooker 2000).

Present-day bloodwood distributions most likely represent a mixture of old pre-Miocene relicts of mesic Australia overlaid by post-Miocene radiations and vicariant speciations, especially as a response to the rapid Quaternary oscillations in sea levels, temperatures, soil fertility and depth, and rainfall. As a general rule, primitive groups occur on the more nutrient deficient soils of uplands, scarps and gorges of humid/semi-humid environments — relictual homologues of their "palaeo" counterparts. The Brigalow Belt, together with the Kimberley and Arnhem Land plateaus and the Einasleigh Uplands, represent widely separated elevated refugia for relictual taxa in an otherwise vast but flat and arid continent. The more recently evolved groups occupy areas significantly affected in the Quaternary by alkaline weathering, stripping of land surfaces, major alluviation of river valleys, and fluctuating sea-levels which inundated coastal flood-plains during pluvial maxima. Some authors believe the less oligotrophic substrates became available to bloodwoods (and other eucalypts) only after loss of closed forests through climatic change and associated increased incidence of fire (Hill and Johnson 1995, Kershaw *et al.* 2002).

Table 3.2 Australian distribution of species within Sections of *Corymbia*

Section (Hill & Johnson 1995)	**Section** Brooker 2000	**Total species (taxa)**	**QLD** Total (End)	**BB** Total (End)	**EIN**	**DU**	**WT**	**NSW**	**WA**	**NT**
Fundoria	*Jacobsinae*[3]	1	-	-	-	-	-	-	-	1 (1)
Apteria (brown bloodwoods)	*Trachyphloiae*[3]	3	3 (1)	3 (1)	1 (0)			2 (0)		
Rufaria (red bloodwoods)	2 sections[1]	70	35 (21)	16 (3)	19 (7)	6 (0)	8 (0)	3 (1)	27 (17)	28 (13)
Politaria (spotted gums)	*Maculatae*[3]	4	3 (2)	2 (0)	1 (0)	1 (0)	1 (0)			
Cadagaria (cadargi)	*Torellinae*[3]	1	1 (1)	-	-	-	1 (1)	-	-	-
Ochraria (yellow bloodwoods)	*Naviculares*[3]	13	11 (11)	10 (8)	4 (0)	1 (0)	2 (1) nr	1 (1)		
Blakearia (paper-fruited bloodwoods)	*Blakella*[2]	30	15 (6)	6 (1)***	7 ()			1 (0)	17 (8)	14 (4)
TOTAL		122	69 (41)	37 (12)	32 (4)			8 (2)	47 (26)	44 (19)

[1] Sect. *Notiales* and Sect. *Septentrionales* Subsect. *Alatae*; [2] includes *C*. sp. Springsure. [3] All in Sect. Septentrionales, Subsect. Apterae.

The first lineages to have diverged after the angophoras and Series *Jacobsiniae* were the brown bloodwoods and red bloodwoods (Figure 3.5, clade 1).

The greatest diversity of the brown bloodwoods occurs in the Brigalow Belt. This monotypic lineage with three subspecies is consistent with a replacement series restricted largely to the humid to sub-humid east coast of Queensland. *Corymbia trachyphloia* subsp. *trachyphloia* has the more northerly distribution, on low-nutrient, generally siliceous skeletal soils, with the Brigalow Belt constituting the major part of its area of occurrence. *C. trachyphloia* subsp. *amphistomatica* ranges south from about Barakula into NSW along the western slopes of the New England Range to about Coonabarabran, similarly on skeletal, siliceous soils. *C. trachyphloia* subsp. *carnarvonica* occupies an intermediate position, narrowly restricted to within the Brigalow Belt at higher altitudes on skeletal siliceous soils of Carnarvon and Chesterton Ranges (Boxvale SF and Orkadilla SF, respectively), the Great Divide and Blackdown Tableland.

The red bloodwoods comprising about 70 species are delineated within Section *Rufaria* (Hill and Johnson 1995) or its equivalent defined by Brooker (2000)(Section *Notiales* and Subsection *Alatae* of Section *Septentrionales*). This grouping represents the largest proportion (almost 60 per cent) of species within *Corymbia* and was further divided into a phylogenetic tree of 14 series by Hill and Johnson (1995)(See Figure 3.6.).

The distribution of members of Section *Notiales* is clearly relictual with major continental disjunctions. *C. gummifera* (Red Bloodwood) occurs on the east coast with one relict population within Beeron Holding east of Allies Creek. The other two representatives of the section, *C. calophylla* (Marri) and *C. haematoxylon* (Mountain Marri), occur in south-west Western Australia. Such continental disjunctions in present-day flora are rare and imply a substantial evolutionary separation within the bloodwoods, most likely before the middle-Miocene isolation of the east and south-west of Australia.

The only other member of Section *Notiales* is the monotypic series *Disjunctae* (*C. ficifolia*) in south-west Western Australia which may have some affinity with *C. intermedia* (Pink Bloodwood) in Subsection *Alatae* of Section *Septentrionales* (alternatively placed in a corresponding monotypic series, *Intermediae*, by Hill and Johnson 1995). Both are wet climate specialists, and exemplify rare and extreme continental disjunctions. *C. intermedia,* usually associated with soils of moderate fertility, has disjunct populations within the Brigalow Belt at Blackdown Tableland and within Mimosa/Zamia/Wattle and Roundstone Creek catchments completely enclosed by the residual Expedition, Dawson and Bigge Ranges. These disjunctions at the western margins reflect a range expansion from the core coastal populations during more mesic climatic cycles, or retreat to such refugia with increasing aridity.

Series *Polycarpae* (Hill and Johnson 1995) is an essentially tropical, mesic group of seven closely related species, largely restricted to deep alluvial soils of the main eastern catchments draining the Great Divide, and displaying a putative geographic replacement series across its range characteristic of recent speciations and intergradations. All show considerable intra-populational variation indicative of active ongoing evolution. Whereas the Queensland Herbarium does not accept some of the species rankings of Hill and Johnson (1995), i.e. *C. dolichocarpa* and *C. maritima* are subsumed within the super-species *C. clarksoniana*, recognition of this variation is important from a conservation point of view. National and State biodiversity conservation strategies and statutes require genetic diversity to be addressed. Populations within the highly variable *C. clarksoniana* were considered by Hill and Johnson (1995) to be plesiomorphic (or ancestral) for the series. The form predominating in and largely restricted to alluvia in the Brigalow Belt corresponds to the *C. dolichocarpa* of Hill and Johnson (1995). *C. ligans* displays a significant departure from the norm occupying residual lateritic capping or shallow stony or sandy soils at higher elevations. The main refugial core for all three parapatric subspecies appears to be the Einasleigh Uplands but *C. ligans* subsp. *burdekinensis* extends marginally into the northern Brigalow Belt on deep lateritic red earths, calcareous sandstones or deep sands. *C. plena* next in the replacement series is centred largely on the Great Divide in the Desert Uplands, and similarly occurs largely on deep red sandy or lateritic soils. Disjunct populations occur in Belington Hut SF, Theodore SF and Condamine SF 400 km to the south. The latter represents the most easterly and southerly range limit in Australia, the only occurrence south of the Great Divide, and within the southward flowing catchment of the Condamine River. Hybrids between *C. plena* and *C. brachycarpa* (Series *Rhodopes*) have been recorded.

Series *Rhodopes* (the ‘true’ red bloodwoods) represents a group of nine species within three subseries, endemic to Queensland, and showing allopatric type replacement patterns of distribution reflecting both relictual and recently speciating populations plausibly associated with leaching, laterising and eroding soil profiles on the sandstone hill slopes where they generally occur. *C. lamprophylla* is the most southerly element of a geographic replacement pattern within the tritypic subseries *Stockerianosae*. Key areas within the Brigalow Belt are residual low ranges between the Suttor and Belyando Rivers in the northern Brigalow Belt, the Narrien Range, Blair Athol SF, and 500 km to the south, in a remarkable disjunction, Condamine SF. Subseries *Brachycarposae* represents a group of two pairs of putatively allopatric sister species — *C. xanthope*/*C. hendersonii* (endemic to the Brigalow Belt), and *C. clandestina*/*C. brachycarpa*. *C. clandestina* is a Brigalow Belt endemic. *C. xanthope* is narrowly restricted to heavy red clay loams over rare coastal serpentinite in contrast to *C. hendersonii* on subcoastal skeletal sandy soil derived from Precipice Sandstones of Blackdown Tableland and Carnarvon Ranges. Likewise, *C. clandestina* survives on gravelly loams on one residual rise of the Drummond Range west of Clermont whilst *C. brachycarpa* is restricted to deep residual, often reddish, sands derived from sandstone or laterite outcrops of the Great Divide that forms the backbone of the Desert Uplands. The two pairs of species appear to reflect an evolutionary catena along a moisture gradient with niches of sharply contrasting fertility within each part of the gradient. *C. clandestina* is known from just two stands, each of less than 100 trees in Blair Athol SF (Bean 1994) and is extremely vulnerable to extinction. Unless connectivity can be re-established along cleared areas of the Drummond Range the species will be cornered and prevented from range shifts in response to future climate change. *C. rhodops* of the monotypic subseries *Rhodopsoae* is likewise threatened (Vulnerable). It bears a close resemblance to *C. xanthope* and *C. hendersonii* from the Brigalow Belt but is now restricted to a few small stands on shallow soils of steeply sloping acid volcanics on Windsor Tableland and Mt Mulligan in North Queensland. Relictual extant populations do not necessarily indicate centres of origin given the capacity for enormous range shifts, especially during the Pleistocene. Whatever the mode and direction of speciation, it is clear that the Great Divide and its flanking sedimentary basins, from the Brigalow Belt to the Einasleigh Uplands, were a primary ‘centre of origin’ and centre of speciation within the red bloodwoods.

It is also likely, on the basis of known hybridisations, that they are closely related to ancestors of the remainder of the bloodwoods within Clade c (Figure 3.6) which radiated prolifically into the coastal flood plains of northern Australia vacated by receding seas of the Late Pleistocene, the vast sand plains and desert loams of the interior, or deep red lateritic earths. Series *Dichromophloiae* constitutes a geographic replacement series across tropical northern Australia from east to west. The most easterly, *C. erythrophloia*, is primarily centred in the Brigalow Belt and Einasleigh Uplands, and very unusually for bloodwoods, occurs on heavy clay soils over basic igneous rocks or on alluvial clay. Neighbours in the replacement series, analogous to *C. brachycarpa* in Series *Rhodopes*, occur on sandy lateritic rises with deep, undisturbed relict soil mantles. Loss or erosion of the latter causes local extinctions, with *C. capricornia,* for example, giving way to lancewood (*Acacia shirleyi*).

Sections *Blakearia*, *Politaria* and *Cadagaria* (Hill and Johnson 1995) [or Subgenus *Blakella*, and Series *Maculatae* and *Torellinae* (Brooker 2000)] together with the yellow bloodwoods represent the second group of early radiations within the broad bloodwoods group (clade 2, Figure 3.5).

Section *Blakearia*, the paper-fruited bloodwoods or ‘ghost gums’, is a diverse group of still actively evolving species that radiated into the post-Neogene environments of monsoonal and arid northern Australia. Most of the 29–31 taxa show geographic replacement patterns and intergradations over large and continuous ranges. Five of the species in this group occur in the Brigalow Belt, one being endemic to it (*C*. sp. (Springsure)). A large group, possibly the oldest members of the section, occur on skeletal soils of ancient lateritic duricrust surfaces. Queensland members form hybrids with two closely related but parapatric species that occur in the Brigalow Belt (*C. aparrerinja* and *C. dallachiana*). *C. aparrerinja* is classically associated with deserts (the ‘ghost gum’ of central Australia and Namatjira’s paintings) and occurs within the Brigalow Belt only at Mt Birkhead, its most easterly occurrence in Australia. *C. aparrerinja* and *C. dallachiana* hybridise where their distributions overlap on the Great Divide in the western Brigalow Belt (Mt Birkhead) and

Desert Uplands. The Mt Birkhead region of the Great Divide is clearly a refugium for a number of restricted, rare or otherwise disjunct taxa including *Corymbia trachyphloia* subsp. *carnarvonica*, *Eucalyptus tholiformis*, *Acacia spania* (Rare) and *A. pubicosta* (Rare), *A. deuteroneura* (vulnerable and restricted to this area), as well as *Neurachne queenslandica* (locally endemic member of a very small (tritypic) Australian endemic genus of grasses, with another member similarly restricted to only the Bigge Range and sandstone gorges of the Macdonnell Ranges in the NT). The geographic ranges of *C. dallachiana* and *C. tessellaris* also overlap but they occupy different ecological niches. *C. dallachiana* occurs largely in the northern Brigalow Belt as scattered trees on a variety of substrates but mainly on clays of moderate fertility, similar to *C. erythrophloia*. *C. tessellaris* mostly tracks the flat floodplains and creek-lines flanking the Great Divide and coastal ranges of humid to sub-humid Queensland. In addition to forming rare intersectional hybrids with Section *Cadagaria*, *C. tessellaris* also forms hybrids with several other series within Section *Blakearia* typifying geographic replacement patterns either on coastal alluvial flats and stream-lines across northern Australia or on skeletal soils of silicic or granitic substrates in the drier interior. *C. tessellaris* thus seems to have had a nodal role in the evolution of a major group of Australian bloodwoods.

Section *Cadagaria (C. torelliana)*, closely associated with wet tropical rainforests and putatively linked ancestrally to the yellow bloodwoods, also forms intersectional hybrids with both members of *Politaria* and *Blakearia* supporting the evolutionary origins of this group in Queensland. Section *Politaria* is unique among bloodwoods in all members having smooth decorticating bark throughout, and its core diversity is in the Brigalow Belt bioregion and adjoining south-east Queensland. *Corymbia citriodora* subsp. *citriodora*, unique among the eucalypts for distinctively high concentrations of citronellal in its leaves, has disjunct populations centred largely in the Einasleigh Uplands and Brigalow Belt bioregions. In the north it tracks skeletal soils on high siliceous ridges as far as White Mountains NP, is largely missing in the intervening drier and lower 400-km corridor of the Great Divide in the Desert Uplands, and is restricted in the Brigalow Belt largely to sporadic populations in the ranges bordering the Nogoa and Comet River catchments (Drummond, Staircase, Shotover, Expedition Ranges), northern Auburn Range at Montour SF and Dawes Range in Coominglah SF. Its southerly limit in this bioregion is 25˚S where it intergrades with *C. citriodora* subsp. *variegata*. The latter, scentless and intermediate morphologically between the more northerly *C. citriodora* subsp. *citriodora* and *C. maculata* in NSW, has its most extensive distribution in the Brigalow Belt. Strongholds occur on medium fertility soils of hilly country of the Staircase Range, Carnarvon Range, an outlier at Blackdown Tableland, the arc of Lynd, Murphy and Bigge Ranges, the Dawes Range through Coominglah SF, the Great Divide through Gurulmundi and Barakula State Forests, Allies Creek SF, Auburn Range especially at Calrossie SF, and Herries Range in the south. Both subspecies occur with disjunctions in coastal southeast Queensland. The only other species of the section, *C. henryi,* is narrowly restricted, with three disjunct populations — in the Brisbane River catchment, the Richmond Range in NSW, and the eastern slopes of the Great Divide near Helidon, White Mountains and Ravensbourne. Some populations occur within one kilometre of the bioregional boundary with the Brigalow Belt.

The Brigalow Belt contains the greatest diversity of yellow bloodwoods in Australia with all but two of the 12–13 species found there and seven entirely restricted to it. Hill and Johnson's sectional name of *Ochraria* derives from Latin *ochra* (yellow) referring to the distinguishing and strikingly yellow colour of the flakey rough bark associated with this small congeneric group of bloodwoods. Major disjunctions and relictual distributions characterise this isolated group of eucalypts indicating relatively early divergence from ancestral stock. Whether the Brigalow Belt represents a centre of origin or not is difficult to determine because major range shifts can obscure patterns of geographical speciation. However, the almost universal association with Mesozoic or Cenozoic sandstones of the Great Divide and associated ranges, and the widely separated nature of relictual congener populations, with *C. eximia* 700 km to the south and *C. leptoloma* 1000 km to the north of the major centre of extant yellow bloodwoods distributions, indicates the key role of the Great Divide for gene flows.

These relict species at the range extremes occur in high rainfall areas most closely resembling pre-Miocene conditions. *C. eximia* occurs in the high rainfall belt associated with Hawkesbury sandstones of the Blue Mountains area. *C. leptoloma*, a rare tall eucalypt, occurs only in riverine sites close to *Eucalyptus grandis* in Hidden Valley near Paluma in the Wet Tropics. Both *C. leptoloma* and *E. grandis* have discolorous adult leaves characteristically associated with eucalypts in high rainfall areas (Brooker and Bean 1991).

It is tempting to speculate that the Brigalow Belt represents the most diverse example of radiations from mesic precursors in response to aridity escalating significantly in the Neogene. The wettest environments with highest annual rainfall and mean soil moisture index occur on the highest elevations and gorges — the least labile residuals and boundaries of the old sedimentary basins. *C. bunites* is restricted to stony soils of the steeper slopes of Blackdown Tableland and proximate sections of the Shotover and Dawson Range State Forests, with possibly disjunct occurrences on Expedition Range SF, and at Presho SF and Robinson Gorge. *C. aureola* (rare) occurs in three small disjunct populations on skeletal soils of the low residuals and ranges that used to connect Blackdown Tableland, through the Peak and Cherwell Ranges (Permian sandstones) to the Carborough Range (Triassic sandstones). The southernmost population in Amaroo SF and adjoining ridges occurs sympatrically with *C. hendersonii* and *C. bunites*. In the central disjunct population on Cherwell Range, *C. aureola* occurs as emergents in semi-evergreen vine thicket containing the rare *Cerbera dumicola*. The northernmost population on the Carborough Range also occurs in vine forest containing the rare *Persoonia amaliae* (Proteaceae). It is likely these rainforest communities with capsular-fruited myrtaceous emergents analogous to the nearby Capella fossil flora have survived and evolved continuously since about 30 million years ago in the Tertiary. This old ‘geneway’ used to extend virtually in a straight line north along the eastern boundary of the Bowen Basin through the Leichhardt Range to the Paluma Range where *C. leptoloma* is found. The connections have clearly been eroded.

Corymbia scabrida occurs on drier skeletal sandy soils of sandstone ridges of the Great Divide at Mt Ogg where it occurs sympatrically with *C. watsoniana* subsp. *capillata* together with a relictual acacia, *A. everistii*. *C. scabrida* also occurs on the sandy fluvial deposits from the Buckland Tableland around Mantuan Downs where it co-occurs with another rare acacia, *A. tindaleae*, separated from its nearest neighbour in the Pilliga by 700 km. The refugial nature of the Mantuan Downs area (including Squire SF6 and Nandowrie SF3) is highlighted further by the presence of another disjunct relict *Zieria aspalathoides* subsp. (Springsure). *C. scabrida* appears to have been strongly selected to survive in these stressed environments during prolonged aridity by being reproductively mature whilst only possessing a juvenile crown (Brooker and Bean 1991).

Corymbia watsoniana, the largest budded member of the yellow bloodwoods, is further divided into two subspecies by Brooker and Bean (1991) and three taxa by Hill and Johnson

(1995). Whilst the Queensland Herbarium does not accept *C. catenaria* (Hill and Johnson 1995) as a valid taxon, from a conservation point of view it is important to take into account significant geographic variation within species populations. Speciation most likely occurs at the population or species interface and only those newly diverged species or taxa that can rapidly expand in range size are likely to survive (Chesser and Zink 1994, Losos and Glor 2003). Lumping of variants within a single species, whilst justified taxonomically, can inadvertently result in clearing or loss of populations deemed to be identical to those protected elsewhere. Hill and Johnson (1995) considered 'pure' *C. watsoniana* subsp. *capillata* to be restricted to the Expedition Range whilst *C. catenaria* was used to define populations in the Staircase Range and flanking valleys with intervening intergradations. Both are subsumed under *C. watsoniana* subsp. *capillata* (Brooker and Bean 1991) which also forms intersectional hybrids in the Staircase Range with *C. citriodora* subsp. *variegata* (Sect. *Maculatae*). Whatever the actual taxonomic rank finally adopted, it is clear that this area is inadequately surveyed, highly dissected topographically, providing 'fertile' ground for active ongoing evolution.

Corymbia watsoniana subsp. *watsoniana* appears to be most abundant where annual mean soil moisture index is highest or, in areas of lower mean annual rainfall where seasonality of soil water regimes is lowest. Unusually, it occurs sympatrically over parts of its range with four other yellow bloodwoods (*C. bunites*, *C. watsoniana* subsp. *capillata*, at its western range limits, and *C. petalophylla* and *C. bloxomei* to the east), with no evidence of intergradation or hybridisation between congeners. The implication is that this group of species have diverged and stabilised relatively early in their history and survive largely as relictual populations within old refugia or centres of endemism.

There appear to be three major types of refugial systems involved. The first relates to the Auburn Arch characterised by outcroppings of Palaeozoic granitoids as part of the geological Coastal Ranges Igneous Subregion. Many of the regional ecosystems on soils derived from these granites have been pushed towards extinction from clearing, completely limiting future range shifts in response to climate change. Edaphically specialised taxa associated with these refugia have effectively been hemmed in by land allocated to serve human interests exclusively, and have nowhere to go. Key surviving refugia centre on Beeron Holding, parts of Allies Creek and Barakula State Forests, and Little Morrow Creek near Eidsvold. *C. petalophylla* is known only from Allies Creek SF and the adjoining Beeron Holding and Little Morrow Creek 60 km to the north-west, where it co-occurs on skeletal soils with *C. watsoniana* subsp. *watsoniana* and *Macrozamia crassifolia* (a highly restricted and vulnerable cycad). The refugial character of these sites is highlighted by the presence of *Acacia porcata* (endangered and restricted to Beeron Holding) and *Leptospermum venustum* (vulnerable and restricted to Little Morrow Creek). What makes these eucalypt refugia even more remarkable is the relictual occurrence of *E. baileyana*, the only non-tropical member and sectional monotypic representative of the Eudesmids, the oldest lineage of non-bloodwood eucalypts.

The second group of refugia are associated with fossil soils and landscapes formed during the long warm wet interval in the Tertiary when rainforests covered most of the continent. These are highly leached and deeply weathered profiles formed only on rocks (in situ or transported) comprising labile minerals (igneous rocks and volcanogenic or feldspathic sedimentary rocks). Most have been either completely dismembered, buried under massive Quaternary sediments or eroded leaving behind relictual plateaus and mesas some of which were protected by ferricrete capping. The soils are highly leached and acidic, comprised largely of kaolinite (with a very low base status), quartz and sesquioxides (from mafic rocks). Erosion has deposited kaolinite and quartz down into some of the valleys incised into these eroded profiles. These old relictual surfaces played a large part in the early evolution of Australia's modern flora and retain many of these ancestral elements. Both old exposed lateritic duricrust surfaces (landzone 7) and uncrusted plateau remnants, but sometimes overlying duricrust (landzone 5), survive to a very significant extent in Barakula and Allies Creek State Forests. The Brigalow Belt endemic *C. bloxsomei* (with bright glossy green leaves, a character shared only with *C. aureola* and *C. leptoloma*) is narrowly restricted almost exclusively to Barakula and Allies Creek State Forests and is associated with RE 11.5.1, whilst *C. watsoniana* subsp. *watsoniana* can dominate in RE 11.7.4 as a canopy emergent.

The third group of refugia for *C. watsoniana* subsp. *watsoniana* in the western extreme of its range encompass the rugged, partially connected and dissected uplands with skeletal soils over quartzose sandstone discussed earlier (Blackdown Tableland, Expedition, Lynd, Murphy and Bigge Ranges and associated gorges, including that of Cracow Creek).

The four north Queensland yellow bloodwoods (*C. dimorpha*, *C. peltata*, *C. leptoloma* and *C. leichhardtii*), generally display an allopatric replacement-type distribution rather than sympatry, with *C. dimorpha* restricted to granites and *C. peltata* to skeletal sandy soils on sandstone ridges. *C. leichhardtii*, with its apparently greater ecological amplitude, best exemplifies the concept of 'rivers' or highways of genes flowing along the old stable ridgelines of the Great Divide and sedimentary basin margins. The fragmentation of these geneways by Quaternary climatic change and accelerated scarp retreat, today is being compounded by land clearing and erosion of soil mantles and life-history survival strategies that gave a competitive edge to these 'old eucalypts' in newly emerging stressful environments. The loss of critical mass for effective pollination through removal of the largest, oldest and most resilient or prolifically flowering individuals can become a limiting factor in the long-term survival of these groups and their dependent communities (Hopkins xxxx.

This combination of factors appears to signal the end to an evolutionary era that has shaped and characterised the modern face of Australia's flora.

3.2.2.5 Eucalyptus

Phylogenies based on chloroplast DNA data (Ladiges 1996) identify three major lineages within the non-bloodwood eucalypts, i.e. Clade 2 (Figure 3.3):

- the Eudesmids (Clade 2a)(warm climates);
- the Eucalyptus group (Clade 2b)(old 'Monocalyptus') (cool climates); and
- the Symphyomyrtus group (Clade 2c)(also largely restricted to cool climates)

Of the 10 *Eucalyptus* subgenera within Clade 2, the most primitive or phylogenetically basal are represented by monotypic subgenera (*Acerosae*, *Cuboidea*, *Idiogenes*, *Primitiva*).

Overall, the Study Area has the highest diversity of both non-bloodwood eucalypt subgenera and monotypic eucalypt subgenera of any bioregion in Queensland or any other State in Australia (Table 3.3).

Table 3.3 Australian distribution of species within subgenera of *Eucalyptus* (Clade 2)

Subgenus	**Total species**	QLD	Study Area	NSW	VIC	TAS	SA	WA	NT
		Total/Endemic	Total/Endemic						
Eudesmia	19	7/1	2/0	1			1	16	7
Acerosae	1	1/1	1/0						
Cuboidea	1	1/1	1/0						
Idiogenes	1	1/1	1/0						
Primitiva	1	1/1	1/1						
Eucalyptus	120	30/10	24/3	68	28	11	7	26	
Cruciformes	1							1	
Alveolata	1	1/0		1					
Symphyomyrtus	504	135/52	99/14	139	72	15	61	249	35
Minutifructus	4	2/2	2/0					1	1
Total species	653	179/69	131/18	209	100	26	69	293	43
Total Subgenera	10	9	9	4	2	2	3	5	3

The Eudesmids (Clade 2a)

Subgenus *Eudesmia* (19 species) represents the oldest lineage of the non-bloodwood eucalypts. The Eudesmids are primarily tropical species restricted to northern WA, NT and QLD. Of the 19 species within this subgenus, two have a relictual distribution in the Brigalow Belt bioregion. *Eucalyptus baileyana*, sole member of Section *Reticulatae* Series *Scutelliformes*, has the most southerly disjunct distribution on the Australian east coast. A small disjunct population occurs 200 km to the south in the Richmond valley, north-east NSW. *E. similis* occupies drier habitats on the extreme western boundary of the Study Area and extends northward along the Great Divide on low-nutrient soils of sandstone hills and plains.

The Eucalyptus ('Monocalyptus') Group (Clade 2b)

This is the second largest combined subgroup of the eucalypts with 124 species and typically known as the white mahoganies, peppermints, stringybarks, green ashes, blue ashes, black sallies and mallees. Despite the highest species diversity occurring in the southwest and southeast of the continent, the northeast region contains the largest number of primitive and relictual taxa suggesting either very early biogeographic isolation (Ladiges 1997) or a dramatic collapse of palaeoclimates in centres of original radiations. The outstanding significance of the Brigalow Belt in the evolution of eucalypts is highlighted by not only the remarkable concentration of the oldest, most primitive species but also the representation of all subgenera.

The following section analyses the phylogenetic and biogeographic relationships in more detail.

The former Monocalyptus group (Ladiges 1997) has been further split by Brooker (2000) to better reflect the phylogenetically isolated nature of many group members. Brooker split the old 'Gaubaea' into two monotypic subgenera — *Acerosae* (*E. curtisii*) and *Cuboidea* (*E. tenuipes*), and the old 'Monocalyptus' into a primitive monotypic Subgenus *Primitiva* (*E.* rubiginosa) and Subgenus *Eucalyptus* (the rest of this group).

Subgenus *Acerosae*

The monotypic subgenus *Acerosae* (*E. curtisii*) is basal to all other members of the Monocalyptus group and is thought to be the sole remnant of an ancient lineage that diverged prior to the evolution of the main monocalypt lineage (Ladiges 1997). *E. curtisii* exists as a rare mallee eucalypt occurring in small, naturally isolated populations over a total range of 500 km and restricted to primarily sandstone outcrops and ridges. The populations at Isla and Robinson Gorges represent the most northerly and westerly limits of the population, with the Inglewood population (Bringalily SF) the most southerly limit on record. Evidence suggests significant morphological differentiation at range extremes, with the highest level of heterozygosity found in the Inglewood population (Smith *et al*. 2003). Levels of heterozygosity may be related to the phylogenetic 'age' with highest levels associated with the oldest (Soulé 1972). The high degree of genetic differentiation between populations of *E. curtisii* suggests long evolutionary periods of reproductive isolation (Smith *et al*. 2003). A high degree of clonality resulting from lignotuberous reproduction exists through the species range indicating extreme age of individual clones. Lignotubers swell and expand radially with the growth of each new stem. On ageing, the old wood of lignotubers decays from the centre creating isolated ramets of the same individual around the lignotuber’s former rim. The largest clones representing single individuals were found at Beerwah on the Sunshine Coast (471.4 m^2), and at Waaje (413.7 m^2) in Barakula SF. A possible maximum age of 9000 years for the Beerwah individual was based on an estimated radial expansion of the genet by 1.5 mm/a. Given the likely slower growth rates at Waaje of possibly 0.75 mm/a (in a 600–700 mm/a rainfall zone) compared with that at Beerwah (~1700 mm/a mean annual rainfall), the individual at Waaje may be 10000–15000 years old making it the oldest living organism known. Shapcott (1997) conjectured 11000 years for monoclonal Huon Pine (*Lagarostrobos franklinii*) as the oldest recorded age for plants. Key refugial areas needing high levels of protection are found near Chinchilla in Barakula SF (the Waaje and Ballon sites), in the Inglewood sandstone area (Bringalily SF, Devine SF, Vickery SF, Braemar SF and Daandine SF) and at Beeron Holding east of Allies Creek SF.

Subgenus *Cuboidea*

Subgenus *Cuboidea* (*E. tenuipes*) is near-endemic to the Brigalow Belt bioregion and not closely related to any other eucalypt group. It is essentially restricted to the Springsure area, Junee Tableland, the Carnarvon-Bigge Range arc, the Chinchilla region (disjunct populations at Barakula, Gurulmundi, Allies Creek), and the Little Morrow Creek refugium near Eidsvold.

Subgenus *Idiogenes*

Subgenus *Idiogenes* comprises a single species, *E. cloeziana* (Gympie Messmate) not closely related to any other eucalypts (Brooker and Kleinig 1994, Brooker 2000). Its closest affinity with the monocalypts (subgenera *Primitiva* and *Eucalyptus*) is indicated by a rare hybrid with *E. acmenoides* found in Neerdie SF on the western boundary of Toolara SF in South-East Queensland — the only known natural hybrid between *Eucalyptus* subgenera (Brooker and Kleinig 1994, Ladiges 1997). *E. cloeziana* is endemic to Queensland occurring in highly disjunct, mostly relictual or scattered localised populations. Optimal development occurs in wetter tall open forests on more fertile soils, often in ecotonal rainforest communities. The most significant extent of its range occurs in the Brigalow Belt bioregion mainly on the residual ranges and refugial gorges within the old uplifted and eroded Bowen and Drummond Basins. Noteworthy populations occur at Blackdown Tableland, Coominglah SF, Allies Creek SF and along the Expedition, Dawson, Carnarvon and Bigge Ranges. Disjunctions of over 500 km occur between southern populations and those on the Stannary Hills and Herberton Range bordering the Einasleigh Uplands and Wet Tropics bioregions.

Subgenus *Primitiva*

The monotypic Subgenus *Primitiva* (*E. rubiginosa*) has no close relatives and is narrowly restricted to the Study Area. It was formerly included in the old Monocalyptus group which was split into the monotypic Subgenus *Primitiva* and Subgenus *Eucalyptus*. *E. rubiginosa*, like all the monocalypts has a single operculum but primitive reproductive structure and so is generally accepted as an early lineage at the base of this large group of eucalypts (Ladiges 1997). It is now extremely rare and confined to shallow sandy soil on sandstone in Bigge Range (Upper Dawson gorges) and the higher, wetter watersheds of the Great Divide in Barakula SF (refugia centred at Waaje, Coongarra and Turkey Mt). *E. rubiginosa* is more narrowly restricted than *E. curtisii* but occurs sympatrically in its limited areas of occurrence. It is likely that *E. rubiginosa* has also been isolated since before the Pleistocene.

Subgenus *Eucalyptus*

Subgenus *Eucalyptus* is dominant in cooler climates of southern Australia. It comprises 120 species in 11 sections circumscribing the white mahoganies (Sect. *Amentum*), pseudostringybarks (Sect. *Pseudophloius*), stringybarks (Sect. *Capillulus*, Sect. *Nebulosa*), peppermints (Sect. *Aromatica*), green ashes (Sect. *Eucalyptus*), black sallies (Sect. *Longitudinales*), blue ashes (Sect. *Cineraceae*, Sect. *Insolitae*), tingles (Sect. *Pedaria*) and mallees (Sect. *Longistylus*) (Table 3.4).

The white mahoganies (Section **Amentum***)*

Section *Amentum* comprising 9–12 species (*E. acmenoides*, *E. apothalassica*, *E. carnea*, *E. contracta*, *E. mediocris*, *E. helidonica*, *E. irritans*, *E. portuensis*, *E. psammitica*, *E. latisinensis*, *E. uvida* and *E. umbra*) with primarily coastal and subcoastal distributions, has its highest diversity in the Study Area (Hill 1999)(Table 3.5).

Table 3.4 Australian distribution of species within sections of Subgenus *Eucalyptus*

Section	**Total species**	**QLD**	**Study Area**	**NSW**	**VIC**	**TAS**	**SA**	**WA**	**NT**
		Total/Endem	Total/Endem						
*Amentum*** (white mahoganies)	9–12	9/4	7/0	5					
Pseudophloius (pseudostringybarks)	2	1/0	1/0	2					
Capillulus (stringybarks)	32	11/4	9/2	22	9		3		
Nebulosa (stringybarks)	1			1					
Aromatica (peppermints)	11	1/0	1/0	4	5	7	1		
Eucalyptus (green ashes)	14	2/0	2/0	13	5	2	1		
Cineraceae (blue ashes)	21	6/2	5/1	18	5	2	1		
Insolitae (blue ash)	1	1/0		1					
Longitudinales (black sallies)	3			2	3				
Pedaria (tingles)	1							1	
Longistylus (tingles & mallees)	25				1		1	25	
Total species	**120**	**30/10**	**24/3**	**68**	**28**	**11**	**7**	**26**	
Total Sections	**11**	**7**	**6**	**9**	**6**	**3**	**5**	**2**	

Table 3.5 Australian distribution of species within Section *Amentum* (White Mahoganies)

Species		WT	EU	DU	BB	CQ	SEQ	NSW
E. acmenoides	North from Sydney (coastal) to CQ				Y	Y	Y	Y
E. apothalassica	Largely Study Area (subcoastal)				Y			Y*
E. psammitica	Endemic to NSW, coastal							Y
E. contracta	Endemic to Blackdown Tableland				Y			
E. carnea	North of Hunter R to SEQ, coastal				Y?		Y	Y
E. mediocris	Endemic to Q, subcoastal			Y	Y			
E. irritans	Endemic to Q, subcoastal		Y					
E. uvida	Endemic to Q, coastal wetter forests	Y						
E. helidonica	Endemic to Q, subcoastal				Y		Y	
E. portuensis	Endemic to Q coastal (Shute Harbour)				Y	Y	Y	
E. latisinensis	Endemic to Q, coastal (disjunct in BB)				Y?		Y	
E. umbra	Q and Hawkesbury Sandstone in NSW		Y		Y		Y	Y
TOTAL		1	1	1	10	2	5	5

* marginal

Eucalyptus acmenoides has the widest distribution of the group on fertile loamy or clayey soils in wet sclerophyll forest extending from near Proserpine to north of the Hunter River in NSW (Hill 1999). It extends into the Brigalow Belt in Grevillea and Coominglah State Forests and a disjunct population occurs at Blackdown Tableland. Similarly *E. carnea* extends north from the Hunter River in fertile loamy or clayey soils to the Glasshouse Mountains in South-East Queensland and west to the Great Divide near Toowoomba in the C rainforest floristic region defined by Webb and Tracey (1994). A single record has been reported from Blackdown Tableland (IBIS database). *E. apothalassica* is primarily a species of the southern Brigalow Belt with one record in NSW. Disjunct populations are closely associated with deep texture-contrast soils with a thick sandy surface developed on quartz sandstones (RE 11.5.1), and deep uniform sands accumulated in wide valley floors (RE 11.5.4) of the upper Burnett catchment near Eidsvold (Binjour Plateau, Little Morrow Creek), and the Condamine River near Tara and Inglewood. *E. helidonica* (Rare), endemic to Queensland, with an isolated position within the white mahoganies, has a very restricted distribution on sandstones near the southeastern boundary of the Study Area. *E. latisinensis* is largely coastal, endemic to Queensland and restricted to isolated populations between Byfield and Cooroy with a disjunct subcoastal population near Mt Wooroolin (within Webb and Tracey's C rainforest floristic region) that is the most southerly and inland range extreme. Northern occurrences are within the Brigalow Belt. *E. contracta* is endemic to Queensland and restricted to Blackdown Tableland. *E. irritans* is restricted to the Einasleigh Uplands. *E. umbra* is restricted in NSW to Hawkesbury River sandstones with disjunct relictual populations 1000 km to the north at Blackdown Tableland in the Brigalow Belt bioregion, and another 800 km again further to the north in the Einasleigh Uplands. The major area of occurrence is on the coastal lowlands in the Mary River catchment and to a lesser extent, that of the Brisbane River. These are major disjunctions indicative of great age.

Blackbutts or Pseudostringybarks (Section Pseudophloius*)*

Section *Pseudophloius* is a small and somewhat isolated group within the monocalypts comprising two species – *E. pilularis* (Blackbutt) and *E. pyrocarpa* (Large-fruited Blackbutt). The latter is restricted to wet sclerophyll forests of north-east NSW from Washpool to Wauchope; the former has a broader distribution in coastal and subcoastal (Brigalow Belt) southern Queensland and NSW between Fraser Island and Bega. The major population densities are in Queensland.

The Stringybarks (Sections **Capillulus** *and* **Nebulosa***)*

Section *Capillulus*, with 32 species, is the largest section within Subgenus *Eucalyptus*. Section *Nebulosa* (1 species) is restricted to north-eastern NSW. Overall species diversity is highest in cooler climates or at higher altitudes. However, endemism and relict disjunct distributions indicate radiations from Queensland during the last 2 million years when glacial climates during the Pleistocene period dominated. Of the 32 stringybarks, a high proportion (14) have a northern distribution, north of the Hunter River, and can be considered to have a common biogeographical history associated with elevated sandstone ranges and plateaux. The remainder occur primarily on the central or southern tablelands of NSW, or Victoria (2 species) with one of these extending into South Australia.

Of the northern group, the majority (11) occur in Queensland, with nine in the Study Area. *Eucalyptus* sp. (Mt Moffatt Homestead) and *E. mensalis* are restricted entirely to the sandstone uplands of the Carnarvon Range (Mt Moffatt) and Expedition Range (Blackdown Tableland). *E. conglomerata* is endemic to South-East Queensland. *E. laevopinea* has a relictual distribution in the Carnarvon Range, with the main extent 300 km south on the New England and Liverpool Ranges in Queensland/NSW. The distribution of *E. eugenioides* is similarly disjunct, with isolated populations at Blackdown Tableland, Allies Creek and Kroombit Tops. The species appears to have major centres of distribution in South-East Queensland and New England Tableland but extends along the escarpment to near the Victorian border. Three other NSW species (*E. cameronii*, *E. ligustrina*, *E. mckieana*) are restricted to the northern tablelands and coastal alluvia.

The Peppermints (Section **Aromatica***)*

Section *Aromatica* comprises largely southern eucalypts. *E. radiata* subsp. *radiata* is the only true peppermint in Queensland and represents the northern limit of this group in Australia. The core of its distribution centres on the New England Tablelands of which the Queensland section is highly significant. These eucalypts are related to *E. pilularis*.

The Ashes (Sections **Eucalyptus, Cineraceae, Insolitae***)*

The broad group of 34 species comprises the green ashes (including mallee ashes), blue ashes and scribbly gums that are traditionally associated with the forests of the high ranges and tablelands of southern Australia.

E. codonocarpa and *E. obliqua* are the only representatives in Queensland of the green ash group of eucalypts (Section *Eucalyptus*) that dominate the cool tablelands of the south. Both have been placed in a small series of Mallee Ashes (*Regulares*). *E. codonocarpa* is a rare species with a relictual distribution. Isolates occur on the New England Tableland (Glen Innes, Wallangarra district in the Study Area) and along the McPherson Range from Mt Maroon to Springbrook. *E. obliqua* has a wider, but nevertheless disjunct pattern of distribution. It occurs in disjunct populations along the eastern Great Divide reaching as far as the Mt Lofty Ranges of South Australia and tablelands of Tasmania. The population in Queensland is very rare and is restricted to wet sclerophyll forests with *Lophostemon confertus* on fertile soils at Mt Castle and Gambubal in the Main Range section of the Great Divide.

The blue ash group (Section *Cineraceae*) comprises 21 species in six series reflecting considerable differentiation. They occur primarily in coastal and near coastal areas of eastern Australia from Mackay to Tasmania (Bean 1997). The section is represented in the Study Area by five species in three series (*E. sphaerocarpa*, *E. planchoniana*, *E. montivaga*, *E.*

racemosa, *E. rossii*). *E. sphaerocarpa* is not closely related to any other group and has been placed in its own series, *Sphaerocarpae*. This is a rare species entirely restricted to the Blackdown Tableland. Its geographic and phylogenetic isolation are indicative of the long evolutionary history of the blue ash group in the north-east of Australia, consistent with a very early diversification of eucalypts from rainforest ancestors during the Neogene. This ancestry is supported by the relictual distributions of *E. planchoniana* (also an isolated taxon in its own series), and *E. montivaga* in Series *Psathyroxyla*. Series *Psathyroxyla* includes the scribbly gums (Subseries *Haemastomae*) and the related New England blackbutts and silvertop ashes (*E. andrewsii*, *E. campanulata*, *E. olida*, *E. montivaga*).

Scribbly gums (Subseries *Haemastomae*) belong to an isolated group of three species (*E. racemosa*, *E. haemastoma* and *E. rossii*). [The former *E. sclerophylla* and *E. signata* are indistinguishable from *E. racemosa* and have been subsumed under that name (Bean 1997).] *E. racemosa* is primarily a coastal species ranging from near Bundaberg and Fraser Island to Mt Warning with additional localised centres near Coffs harbour and Port Kembla. Subcoastal populations occur in southern Queensland where the Great Divide and the Great Escarpment first diverge near Crows Nest, part of the C rainforest floristic region (Webb and Tracey 1994). *E. rossii* occurs on the western slopes of the Great Divide from the New England Tableland near but not within the Queensland border as far as Canberra, and *E. haemastoma* is confined to the central coast of NSW near Sydney.

The Symphyomyrtus Group (red mahoganies, mallees and gums, northern and eastern red gums, boxes and ironbarks) — Clade 2c

The Symphyomyrtus Group includes four subgenera (*Cruciformes*, *Alveolata*, *Symphyomyrtus* and *Minutifructus*). The most basal groups, each monotypic, are Subgenus *Cruciformes* and Subgenus *Alveolata*. *E. guilfoylei* (Tingle), sole member of Subgenus *Cruciformes*, is restricted to southwest Western Australia — the tall Tingle forests of Walpole. *E. microcorys* (Tallowwood) in Subgenus *Alveolata* is restricted to rainforests of south-east Queensland dominated by sclerophyllous myrtaceous emergents. A subcoastal disjunct population occurs on the higher rainfall ranges where the Great Divide and the Great Escarpment diverge just north of Toowoomba near Crows Nest.

Subgenus *Symphyomyrtus*

The *Symphyomyrtus* subgenus is the most speciose of all the *Eucalyptus* subgenera, representing a wide range of morphological adaptations to increasing aridity, climatic variability and nutrient deficiency — the results were a vast array of gums, boxes, ironbarks, red mahoganies, and mallees.

These are largely cool climate groups (Gill 1985) comprising 504 species or 70 per cent of the eucalypts. Whilst they are most diverse in Western Australia (49 per cent of all species in the subgenus), the evolutionary origins are in northeastern Australia. Six major sections have been recognised in *Symphomyrtus* (Figure 3.7). Brooker (2000) has further classified *Transversaria* into 10 sections (Table 3.6), illustrating the high level of differentiation of species into groups that have been genetically isolated for very long periods.

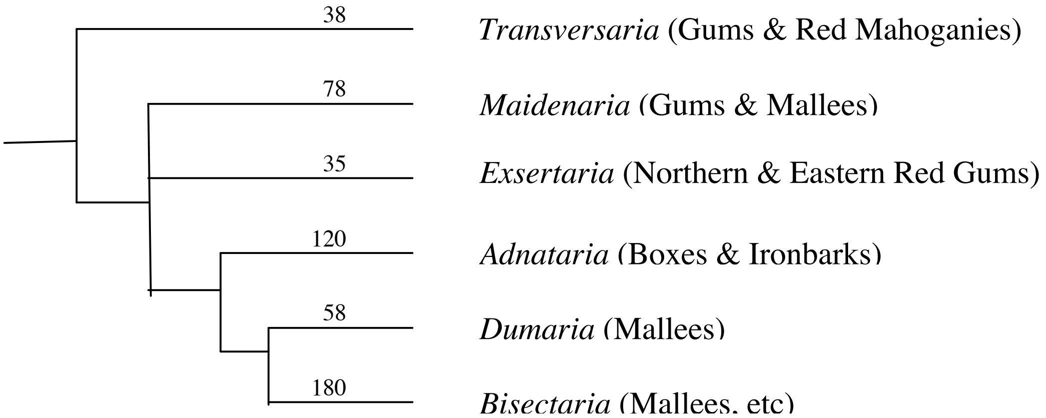


Figure 3.7 Relationships of the major sections within *Symphyomyrtus* (as reported in Ladiges 1995). Numbers represent species in each section.

Seven of the 15 sections within Subgenus *Symphyomyrtus* are represented within Queensland — *Adnataria* (boxes and ironbarks), *Exsertaria* (northern and eastern red gums), *Bisectae* (mallees and gums), *Latoangulatae* (blue gums, grey gums and red mahoganies), *Maidenaria* (southern mallees and gums), *Liberivalvae* (eastern red gums) and *Racemus* (an isolated gum type). All but Section *Racemus* occur in the Study Area. The latter comprises one species, *E. michaeliana*, a rare eucalypt with relictual, disjunct populations at Mt Barney/Mt Ballow in the McPherson Range (near the southeastern boundary of the Study Area), and in north-east NSW. The six sections represented in the Study Area comprise 432 species (86 per cent of the subgenus), of which 99 occur in the Study Area and 14 are endemic thereto.

Table 3.6 Australian distribution of species within Subgenus *Symphyomyrtus*

Section	Total species	**QLD**	Study Area	**NSW**	**VIC**	**TAS**	**SA**	**WA**	**NT**
		Total/Endemic	Total/Endemic						
Adnataria	120	80/37	60/10	44/12	18/1		14/4	14/5	15/3
Exsertaria	35	19/9	13/2	12/4	5/0		2/1	10/3	9/2
Bisectae	180	7/1	5/0	10/1	5/0		20/3	165/149	8/0
Latoangulatae	18	13/3	9/1	14/3	1/0				
Maidenaria	73	10/1	8/0	48/17	38/11	15/10	5/0		
Liberivalvae	6	5/1	4/1	5/1					
Sejunctae	1						1/1		
Racemus	1	1/0		1/0					
Bolites	1							1/1	
Inclusae	1							1/1	
Similares	1			1/1					
Incognitae	2						2/2		
Platysperma	6							5/3	3/1
Pumilo	1			1/1					
Dumaria	58			3/0	5/0		17/3	53/41	
Total species	504	135/53	99/14	139/40	72/12	15/10	61/14	249/203	35/6
Total Sections	15	7	6	10	6	1	7	7	4

Ironbarks, boxes (Sect. Adnataria*)*

Section *Adnataria* is most diverse in Queensland with 80 of the 121 listed species, 48 of which are endemic to Queensland. Fifty seven species occur in the Study Area, of which 20 are endemic to the Area and 35 are Queensland endemics. Only 12 of the 41 species not occurring in Queensland are endemic to NSW. Only 19 of the 44 species occurring in NSW do not occur in Queensland.

Ironbarks are primarily divided into Series *Siderophloiae* (38 species), *Rhodoxylon* (16 species), and *Melliodorae*, subseries *Solidae* (3 species) comprising 57 species in all.

Within Section *Adnataria*, the ironbarks (Series *Siderophloiae*) represent a large series of about 38 species the majority of which are endemic (or near endemic) to Queensland. 'Iron' bark is the most easily recognisable form of rough bark in all eucalypts. Of thirty-eight species in the series, 35 occur in Queensland and 26 occur in the Study Area, of which 11 are restricted to the Brigalow Belt bioregion — *E. decorticans, E. beaniana, E. tholiformis, E. rhombica, E. fibrosa* subsp. (Glen Geddes), *E.* sp. (Rewan), *E* sp. (Inglewood), *E.* sp. (Clermont), *E.* sp. (Chinchilla), *E.* sp. (Rossmoya) and *E. paedoglauca.* Most of the relictual narrow endemics occur on low-nutrient, coarse-grained sedimentary substrates, granites or laterites. *E. taurina* occurs at Allies Creek as a widely disjunct population from the main occurrence in Helidon Hills

Table 3.7 Australian distribution of species within Section *Adnataria*

Series	Total species	**QLD**	Study Area	**NSW**	**VIC**	**TAS**	**SA**	**WA**	**NT**
		Total/Endemic	Total/Endemic						
Aquilonares	16	9/4	2/0	1/0				8/2	9/3
Dawsonianae	1			1/1					
Buxeales	30	16/7	15/	13/2	10/1		11/3	5/3	3/0
Coalitae	2	2	1	1*					1*
Submelliodorae	2	1/1	1/1	1/0	1/0				
Siderophloiae	38	35/28	28/22	8/1				1/0	1/0
Heterophloiae	8	2/0	2/0	6/2	3/0		1/0		1/1
Rhodoxylon	16	10/8	8/2	9/					
Melliodorae	6	3/1	3/1	4/0	4//0		2/1		
Total species	119	79/37	61/10	44/12	18/1		14/4	14/5	15/4
Total Sections	9								

* marginal occurrence

Series *Aquilonares* (northern boxes) is almost exclusively tropical or subtropical. Many of the 16 species are narrowly endemic to one of the three northern states, WA, NT and Queensland. The only exception is *E. coolabah*, a widespread species. *E. chlorophylla* has a scattered but widespread distribution across the far northern tropics of mainly Northern Territory, then again in Cape York, and an apparently extraordinary disjunction 1000 km to the south in the Carnarvon Ranges near Boxvale SF in the upper headwaters of the Dawson River (record from a Quaternary CORVEG Site, Bruce Wilson 2001).

Series *Buxeales* (eastern boxes), the second largest series within Section *Adnataria* is separated into subseries *Continentes* (16 species) and *Amissae* (14 species).

Subseries *Amissae*: This group is associated with flats, plains and the lower slopes of ranges. *E. brownii* is endemic to Queensland and is distributed from the Wet Tropics through the Einasleigh and Desert Uplands into the northern Brigalow Belt. *E. cambageana* is also a Queensland endemic, is widespread in the central and northern Brigalow Belt and extends into the adjoining western bioregions and Einasleigh Uplands. Concentrations occur around Taroom on the southern slopes of the Bigge Range, and between Blair Athol and Emerald in Apsley and Fairbairn SFs and Kettle TR. *E. populnea* has a widespread distribution throughout the Brigalow Belt and Mulga Lands bioregions, and also the western plains of NSW. *E. populnea* with a more northerly warm sub-humid distribution, is one of the few trees to grow on black, heavy-textured cracking clays. Significantly, *E. populnea* and *E. cambageana* commonly occur in association with *Acacia harpophylla* (Brigalow) on texture-contrast soils or, in the case of *E. populnea*, clays. *E. orgadophila* also occurs on heavy clay soils, is endemic to Queensland and has its core in the Brigalow Belt (particularly the Darling Downs) with a disjunct group in the Einasleigh Uplands. *E. orgadophila* also occurs as an emergent in *A. harpophylla* woodlands. *E. rummeryi* is restricted to tablelands and ranges of north-east NSW west of Coffs Harbour, and borders rainforest. *E. largeana* occurs as tall forest trees of the northern tablelands bounded by the Hunter to upper Macleay and Manning Rivers. *E. lucasii* (Barlee Box) is restricted to mallee shrubland on the ancient uplands from the Kalgoorlie goldfields to the Hammersley Range in northwest WA. *E. sparsa*, a mallee box, is restricted to the Musgrave and Blackstone Ranges of Central Australia. *E. largiflorens* occurs in the south-west of the Brigalow Belt and follows the deep-soiled river flats of the Murray Darling bounded by the Grey Range, part of a series of low rises that are remnants of an old plateau connecting the Flinders Ranges with the Eastern Uplands in Queensland. *E. intertexta* has a widespread, scattered and disjunct distribution in central Australia occurring in all States but Victoria and Tasmania. The disjunct populations in Queensland spread from the south-west Brigalow Belt into the Mulga Lands bioregion. *E. normantonensis* is a mallee with a core distribution in central Northern Territory and widespread disjunct occurrences in western Queensland.

Subseries *Continentes*: *E.viridis* is relictual in the Study Area as the only box in Queensland with a mallee habit, the other mallee forms being mainly in south-eastern Australia. *E. viridis* var. *latiuscula* is endemic to the Study Area and has disjunct occurrences south of the Carnarvon Range and in the Inglewood area. *E. viridis* var. *viridis* has a similar distribution, but is also present in the Bigge Range and central NSW. Important areas for these species are Presho, Belington Hut, Gurulmundi and Bracker State Forests and the northern part of the NET. *E. viridis* subsp. *wimmerensis* (recognised as *E. wimmerensis* by other herbaria) is in Victoria and SA.

Of the tree form boxes, *E. albens* and *E. microcarpa* have similar distributions along the western slopes of the Great Dividing Range from north-eastern Victoria into Queensland, with a disjunct population in the southern Flinders Ranges of SA. Both species have high concentrations on the New England Tableland, but whereas *E. albens* only extends as far as the Bunya Mountains, *E. microcarpa* extends north to the Rockhampton area with a disjunct occurrence in the Einasleigh Uplands. It also essentially follows the slopes of the Great Dividing Range inland to the Carnarvon Range. *E. pilligaensis* is distributed on the northern part of the western slopes and plains of NSW and the southern part of the Study Area. Key areas are the western slopes of NET, and the forests of the Inglewood Sandstones. *E. moluccana* occurs on coastal plains and ranges from southern NSW all the way north to the Atherton Tablelands, with occurrences on the New England and Consuelo Tablelands. Other key localities in the Study Area include Barakula, Allies Ck and Shotover SFs, and the Auburn-Banana Ranges. *E. persistens* is endemic to Queensland and is distributed from north of Clermont in Brigalow Belt North through the Desert and Einasleigh Uplands to Cape York Peninsula. *E. tardecidens* is also endemic to Queensland: it has its core population in the north of the Einasleigh Uplands fringing the Wet Tropics, and a disjunct occurrence 500km to the south in the west of the Desert Uplands.

Series *Coalitae* (inland boxes) is an isolated ditypic series restricted essentially to Queensland, the only State with both members present. The two species are not closely related to any other. *E. thozetiana* occurs on sandy plains and low rises in the western half of the Study Area (Overdeen SF, the most eastern limit) and low rises of the Thompson, Barcoo and Diamantina River catchments in south-western Queensland. An isolated, small disjunct population 780 km to the west in the Northern Territory, north of Alice Springs attests to the relict nature of the species possibly dating to the early Pleistocene. The other species in the series, *E. ochrophloia* is more restricted to the silty soils or cracking clays of the drainage channels of the above rivers. The species extends marginally into NSW.

Series *Submelliodorae* (coastal boxes) is also an isolated, ditypic series. The two species are highly restricted and disjunct, without close relatives, and are the largest of the boxes. *E. argophloia* is restricted to the Study Area (Burraburri Creek/Charlies Creek section of the Condamine near Chinchilla) occurring in heavy clay soils of moderate fertility often with strong gilgai development. It is vulnerable to extinction. Most of the records occurred in Brigalow woodlands that have been cleared. The only other species in this series is *E. bosistoana* (Gippsland Grey Box) occurring 820 km to the south in a narrow strip of coastal plains centred on the NSW/Victorian border, in wet forests on deeper and more fertile soils. The edaphic preferences and disjunct, phylogenetically isolated and relictual nature of the two members of this series suggest a closer affinity to mesic forests of the early Neogene.

Whilst the highest diversity of Series *Heterophloiae* (Subsection *Terminales*) (boxes) is in southern NSW (six species, two endemic), most species have regionally restricted distributions consistent with significant age and northern origins. Two species have relictual distributions in Queensland. The box-barked *E. conica* occurs mainly west of the Great Divide in NSW and southern Queensland to Barakula with a disjunct population around Carnarvon Range. *E. magnificata* was separated as a new species comprising the very rare relictual population in the Granite Belt of Queensland in the New England Tableland bioregion. *E. lucens*, a completely smooth-barked mallee to 3 m has an unexpected and restricted distribution in the Northern Territory on shallow soils in gorges and sandstone or quartzite ranges. *E. fasciculosa* is essentially restricted to SA. *E. baueriana* occurs in coastal NSW and Victoria. *E. polyanthemos* is restricted to southern NSW and Victoria.

Series *Rhodoxylon* (Subsection *Terminales*) contains 16 species that are further segregated into two subseries — *Concolores* and *Discolores*. These are all ironbarks, smaller in size than the *Siderophloiae*, but similarly concentrated in the Study Area. Subseries *Concolores* contains 11 species (*E. fusiformis*, *E. tetrapleura*, *E. dura*, *E. suffulgens*, *E. melanoleuca*, *E. corynodes*, *E. panda*, *E. virens*, *E. sicilifolia*, *E. beyeri* and *E. caleyi*).

Three members of the group that are not concentrated in the Study Area (*E. fusiformis*, *E. tetrapleura* and *E. dura*) form a coastal species group that can be considered part of an evolutionary catena reflecting declining nutrient and moisture regimes from the Neogene to the present. *E. fusiformis* has disjunct populations separated by 60 km at Mt Barney and

Numinbah Forest Reserve in Queensland, then 100 km south of Mt Barney at Mt Neville on the southern end of the Richmond Range that connects both regions. Other scattered populations in NSW occur along segments of the Great Divide, the Hastings and New England Ranges. The species never crosses the major break in the Divide at the Hunter River. *E. tetrapleura* is restricted entirely to the most southerly escarpment of the Richmond Range near Grafton in NSW. *E. dura* is restricted to the Brisbane and upper Burnett River Basins largely within the SEQ bioregion, but extends into the Brigalow Belt where the Burnett River breaches the Great Escarpment to drain the arc of the Auburn Range and Great Divide. The occurrence in Barakula SF represents the only population south or west of the Great Divide. These areas were formerly part of the same upland regions prior to formation of coastal drainage systems during the Neogene.

The remaining species are all subcoastal and concentrated in the Brigalow Belt bioregion. *E. caleyi* (Caley's Ironbark) occurs on the drier western slopes of the New England Range feeding the Gwydir and Macintyre Rivers with major core centres near Inglewood in Queensland (Yelarbon, Bringalily, Texas and Greenup SFs) and disjunct Bundarra in NSW. The longest axis of its occurrence is no more than 240 km (regionally restricted). The remaining species are endemic to Queensland, with two narrowly restricted to the Study Area — *E. sicilifolia* (at Little St Peter Mountain and Mt Zamia near Springsure) and *E. corynodes* (in small refugia within the Dawson and Burnett River catchments, i.e. Ruined Castle Creek, Cracow Creek, Little Morrow Creek, Coominglah SF, Grevillea SF, western section of Kroombit Tops and near Bauhinia Downs, and Expedition Range). The centre of distribution for *E. suffulgens* is in the Brigalow Belt with a disjunct population 500 km to the north on the Einasleigh Uplands (Lolworth Range). This is the northernmost range limit within the entire *Rhodoxylon* series. *E. melanoleuca* (Nanango Ironbark) displays a remarkable distribution along the 300 m contour on either side of the Great Divide. Most core occurrences have disjunctions separated by 250 to 400 km. Western occurrences are concentrated at the Thomby Range outlier near Surat, and the Great Divide western margin near Tambo-Augathella — the western limit of Brigalow (*Acacia harpophylla*). The most northerly occurrences also parallel the 300 m contour and the limit of Brigalow. *E. panda* is endemic to Queensland and the Brigalow Belt bioregion, marginally extending 10 km over the NSW border to Beebo SF just north of Yetman. Major centres in Queensland include Bracker, Bringalily, Boondandilla, Gurulmundi, Barakula, and Allies Creek State Forests. Major relictual population centres for *E. virens*, a Brigalow Belt endemic and vulnerable species, are Tara and near Bracker SF on the Inglewood Sandstones, Allies Creek SF, Binjour Plateau and Mt Moffatt.

E. beyeri, restricted entirely to NSW, is the only member of Subseries *Concolores* that crosses the biogeographical barrier of the Hunter River.

E. decolor is the sole member of Subseries *Discolores* in Queensland. About 650 km separate this Queensland species from the other four series members which are endemic to NSW and centred in wet forests on the deep fertile soils of the Hunter and Macleay River catchments. *E. decolor*, in contrast, is narrowly restricted to a small number of isolated populations mainly on granite-intruded disjunct coastal ranges spanning about 180 km — all short north-northwest striking residuals — in the coastal New England fold belt just east of the Brigalow Belt. The species always occurs on shallow infertile soils formed on granites or sandstones.

Series *Melliodorae* comprises six species in two groups or subseries (*E. sideroxylon* subsp. *sideroxylon*, *E. sideroxylon* subsp. (Waaje), *E. tricarpa* in Subseries *Solidae*; *E. melliodora*, *E. leucoxylon*, *E. petiolaris* in Subseries *Leucoxylon*). These form the backbone of the eucalypt woodlands. Mostly they are slow-growing species of the warm sub-humid woodland zones on the western slopes of the Great Divide, able to tolerate extensive periods without rain (Florence 1996).

E. sideroxylon subsp. *sideroxylon* is the major ironbark of the sub-humid woodland zone of NSW. Its northern range limit in Queensland is a disjunct population in the Carnarvon Ranges around Mt Moffat. Unless an imprecise single record at Roma is for a valid natural occurrence, the closest population is over 330 km away near Tara in the northern Inglewood Sandstones. Eastern disjuncts also occur from Murgon to Yarraman in SEQ, and it exists in high concentrations around Bracker SF and on the New England Tableland. *E. sideroxylon* subsp. (Waaje) is endemic to the Study Area, being restricted to the sandy areas of north-west Barakula SF. *E. melliodora* is widely distributed on plains and tablelands from western Victoria, through NSW and into Queensland along the Great Divide to the Bunya Mountains and Barakula SF, along the Great Escarpment to Kroombit Tops, and east to the Lamington Plateau. It is the only other species in the group to occur in the Study Area, and has disjunct occurrences on the Consuelo Tableland (nearly 300 km) and Chesterton Range. There is also a single record by G. Batianoff in 1992 from Gloucester Island near Bowen which would represent a remarkable northern disjunct of 500 km.

The remaining members are southern species: *E. tricarpa* (south-east NSW and central Victoria), *E. leucoxylon* (South Australia, Victoria) and *E. petiolaris* (Eyre Peninsula in South Australia)

Southern mallees (Sections **Bisectae** *and* **Dumaria***)*

Eighty eight per cent of all species within Subgenus *Symphyomyrtus* occur in sections *Bisectae* and *Dumaria*. These southern mallees occur primarily in Western Australia.

Section *Bisectae* (the largest group of all the eucalypts with 180 species) is overwhelmingly Western Australian but the putative origins of the group have been attributed to north-eastern Australia where the highest numbers of relictual, capsular-fruited Myrtaceae are found in rainforests of the Wet Tropics and adjoining Einasleigh Uplands (Ladiges 1997). However, the greatest diversity of extant relict mallee taxa from Section *Bisectae* occurs in the Brigalow Belt bioregion (*E. salubris*, *E. bakeri*, *E. eucentrica*, *E. socialis*, and *E. pachycalyx* subsp. *waajensis*). The occurrence of *E. salubris* near Tara in the Inglewood district is remarkable with the nearest population 1800 km away in WA where it also grows on sandy loams to clays. There has been some doubt as to the authenticity of the identification given its unusual disjunction, but there have been three separate reputable collections by K.A. Williams in 1971, L. Pedley in 1968, and J. Brogan in 1970. *E. socialis* occurs near Tara sympatrically with another remarkable and relict mallee, *E. curtisii*. Other Brigalow Belt refugia for relict mallees occur at Cracow Creek, Waaje in Barakula SF, and Little Morrow Creek near Eidsvold. These refugia typically also support many other rare and relictual taxa in other families. *Acacia deuteroneura*, a rare and vulnerable wattle, is found growing only in association with *E. bakeri*.

A similar origin can be inferred for the mallees of Section *Dumaria* (58 species) although no longer represented in Queensland. The section is similarly speciose and richly endemic to Western Australia. *E. spathulata*, a Western Australian mallee (Section *Bisectae*, Series

Erectae), has pollen most closely resembling that of the earliest unambiguously recognisable *Eucalyptus* taxon in the fossil pollen record from the late Oligocene in eastern Australia (23 Ma). It was then clearly associated with rainforests (Macphail 1994).

Section Liberivalvae*: the red gums*

The species in this group are of coastal areas and nearby ranges and tablelands, from Sydney north to the Blackdown Tableland. *E. parramattensis* has the most southern distribution around Sydney, *E. seeana* and *E. bancroftii* have a coastal distribution in SEQ and NSW, and *E. hallii* is endemic to Queensland being restricted to between Bundaberg and Childers and Fraser Island. The species which occur in the Study Area are relictual and mostly associated with sandstone ranges. *E. broviniensis* is critically endangered and a bioregion endemic, being highly restricted to Allies Creek SF. *E. interstans* occurs on the New England Tableland, adjacent parts of the Main Range and around Crows Nest NP, and has a disjunct population at Blackdown Tableland. *E. prava* is on the tablelands of northern NSW and the Queensland section of the New England Tableland.

Section Latoangulatae

These species have largely coastal and subcoastal distributions along the eastern seaboard with disjunct inland occurrences of *E. saligna*, *E. propinqua* and *E. major* in east-central Queensland.

Series *Transversae* (eastern blue gums): *E. deanei* has two disjunct populations: the Queensland and NSW sections of the New England Tableland through to the Main Range east of Warwick, and the coastal ranges of central NSW. *E. grandis* occurs along the northern NSW coast and lower ranges through to Gympie in Queensland, then has disjunct populations at Eungella NP, the Wet Tropics and west of Staaten River NP on Cape York. *E. saligna* occurs along the coast and ranges of NSW through to near Kilkivan in SEQ, with wide disjuncts at Blackdown and Consuelo Tablelands, and Kroombit Tops.

Series *Lepidotae-fimbriatae* (grey gums): *E. punctata* and *E. canaliculata* are endemic to the coast and ranges of central NSW. *E. biturbinata* is distributed in the coastal ranges of northern NSW and SEQ to west of Gympie, while *E. propinqua* occurs from Sydney north to near Gympie, with a disjunct occurrence at Blackdown Tableland. *E. grisea* is endemic to the Brigalow Belt being restricted to the western Carnarvon Range near Mt Moffat. *E. longirostrata* and *E. major* are endemic to Queensland, have a similar widespread distribution in SEQ from Toowoomba north to Gladstone, and in the Brigalow Belt are on the Carnarvon, Expedition and Bigge Ranges and in Coominglah SF. Barakula SF and Blackdown Tableland also have important populations of *E. longirostrata*.

Series *Annulares* (red mahoganies): This group has two northern species - *E. pellita* is in the Wet Tropics, Cape York and New Guinea, and *E. urophylla* is endemic to Timor and Indonesian islands. *E. resinifera* is distributed from just south of Sydney to Fraser Island, at Lamington Plateau, Mt Barney and Crows Nest, then with disjunct populations in the Central Mackay Coast bioregion and Wet Tropics. *E. notabilis* is on the NSW tablelands north east of Glen Innes, and the Scenic Rim at Springbrook and Mt Barney. *E. scias* is scattered along the NSW coastal ranges. *E. robusta* has a coastal distribution in SEQ and NSW and *E. botryoides* is in coastal NSW extending into Victoria.

Section **Exsertaria***: northern and eastern red gums*

Series *Subexsertae*: *E. platyphylla* is endemic to Queensland, stretching from about Rockhampton north to Cape York and inland on the Einasleigh Uplands. It is the only species in the series to occur on the east coast and in the Study Area; the other members are restricted to the Kimberley and northern parts of the Northern Territory, except for *E. herbertiana* which just stretches into the far west of Queensland. *E. platyphylla* hybridises inter-series with *E. tereticornis* from Rockhampton north to the Wet Tropics.

Series *Rostratae*: This series consists of forms all based on the River Red Gum, *E. camaldulensis*. *E. camaldulensis* var. *camaldulensis* is the typical form along rivers and valleys of south-eastern Australia, particularly the Murray-Darling system and tributaries from southern Queensland. *E. camaldulensis* var. *obtusa* is on the watercourses throughout the continent outside the Murray-Darling system. *E. camaldulensis* subsp. *simulata* is restricted to a few river systems in central Cape York. Hybrids are recorded with *E. tereticornis* (interseries – central northern Queensland), *E. largiflorens* (intersectional - Victoria), *E. platyphylla* (interseries – northeastern Queensland) and *E. viminalis* (intersectional – Victoria/South Australia). Intergrades with *E. chloroclada* (interseries – northwestern plains NSW) and *E. tereticornis* (interseries – Petford area of northern Queensland) are also recorded.

Series *Phaeoxylon* is a small series of five species mostly of northern Australia. *E. ammophila* is endemic to central inland Queensland on deep yellow or red sandplains in four disjunct patches each separated by up to 350 km. It occurs on the flats south of Charleville, on the slopes west of Alpha, the southern slopes of White Mountains NP, and the slopes southwest of Einasleigh. There is also a single record from near Westmar in the far south of the Study Area. *E. lockyeri* subsp. *lockyeri* and *E. lockyeri* subsp. *exuta* are also endemic to Queensland and restricted to the Atherton Tableland. *E. exserta* is near endemic to Queensland, except for some occurrences on the New England Tableland in NSW. It prefers the stony rises of low hills and plains and is widespread throughout central and eastern Queensland, extending north to the Wet Tropics and inland as far the Mulga Lands and Einasleigh Uplands, but is absent from far south-eastern Queensland. Concentrations in the Study Area include the southern Inglewood Sandstones, Gurulmundi and Barakula SFs, and around Eidsvold. An inter-series hybrid with *E. platyphylla* has been recorded on Magnetic Island. *E. brassiana* occurs on Cape York and in New Guinea, while *E. morrissii* is endemic to the stony slopes of the Cobar Plain in NSW.

Series *Erythroxylon*: Most species in this group are distributed along the eastern coast, tablelands and plains. *E. tereticornis* is a widespread species along the coast and adjacent hills and plains from eastern Victoria through to Cooktown, and also New Guinea. It occurs as far inland as the south-west Einasleigh Uplands and Carnarvon Range. *E. tereticornis* subsp. (Consuelo Tableland) is endemic to the Study Area being restricted to the Consuelo Tableland on black soils/basalt. *E. tereticornis* subsp. (Bunya Mountains) is endemic to Queensland in the Bunya Mountains and on the range north of Main Range NP. *E. tereticornis* subsp. *mediana* is in southern NSW and eastern Victoria.

E. terrica is also endemic to the Study Area, occurring in stony or shallow, sandy loam soils on rises in the New England Tableland and Wondul Range. *E. infera* (Vulnerable) is endemic to the Study Area, known only from Durikai SF on the New England Tableland where it occurs in areas of deposition from sandstone runoff. *E. amplifolia* subsp. *sessiliflora* occurs on the northern tablelands of NSW and the south-east corner of the Study Area on the

New England Tableland and the Main Range western slopes, east of Warwick. *E. blakelyi* occurs in the Study Area at Inglewood and Stanthorpe, but its core distribution is on the tablelands of NSW and eastern Victoria. *E. chloroclada* is distributed on sandy plains from Emerald south to the border, then with a 200 km disjunct population in the Pilliga. *E. dealbata* favours stony rises and is concentrated in the Study Area on the southern Inglewood Sandstones and New England Tableland, but also spreads down the tablelands and western slopes of NSW.

Some members of the series are confined to inland stony hills which suggests that they evolved in hilly refuges in times of aridity: *E. flindersii* (Flinders Ranges SA), *E. gillenii* (Macdonnell Ranges NT, just into WA and SA), *E. vicina* (central/northwestern NSW), *E. dwyeri* (ridges and stony rises of western slopes of NSW, extending into Victoria) and *E. nudicaulis* (on quartzite in rocky gullies and on steep hillsides in the Mt Isa-Cloncurry area).

Series *Singulares*: *E. rudis* is the only member of the group, and is endemic to the Perth region on sandy soils along waterways.

Section* Maidenaria *(Subgenus* Symphyomyrtus*): southern mallees and gums

This is a large group of over 70 species with predominantly a south-eastern distribution. The only species endemic to Queensland is the highly restricted *E. scoparia* (V) which occurs in clefts in massive granite outcrops of the Wallangarra district. A disjunct occurrence of *E. camphora* subsp. *camphora* in the same area was called subsp. *relicta* and was endemic, but the Queensland Herbarium does not currently accept this name. There is a single record south-east of Glen Innes (120 km away), but the next closest population, also disjunct from the core in north-east Victoria/southern NSW, is over 350 km away in the Blue Mountains.

The six other species which occur in the Study Area are all close to the NSW border on the New England Tableland or Main Range and are at their northernmost distribution. In this sense they are similar to *E. obliqua*, *E. pauciflora* and *E. radiata* subsp. *radiata* from Subgenus *Eucalyptus*.

Subgenus *Minutifructus*

Subgenus *Minutifructus* consists of only four species, one of which (*E. deglupta*) does not occur in Australia. *E. brachyandra* is distributed through the Kimberley and north-west Northern Territory. The remaining two are endemic to Queensland: *E. howittiana* (Rare) has a core from Lumholtz NP through to Greenvale in the Einasleigh Uplands, with a disjunct population south-east of Charters Towers in the far north-west of the Brigalow Belt. *E. raveretiana* (Vulnerable) is concentrated from Eungella NP to Charters Towers, with a disjunct occurrence around Rockhampton and Goodedulla NP.

Topographical preferences within **Eucalyptus**

An analysis of the topographic distribution of the 132 species within *Eucalyptus* indicates that at least 60 per cent of species represented within the Study Area are primarily restricted to elevated areas, rocky outcrops or mesic refugia (Table 3.8). They include all the monotypic subgenera, all representatives of the basal subgenus *Eudesmia* and the recently diverged subgenus *Minutifructus*, and almost 50 per cent of species within the subgenus *Symphyomyrtus*.

Table 3.8 Summary of topographic preferences of taxonomic groups within *Eucalyptus*

Subgenus	**Section**	**Series**	**Subseries**	**Topographic Position in the Study Area**
Eudesmia				Hills and ranges
Acerosae				Sandstone outcrops and ridges
Cuboidea				Hills and ranges
Idiogenes				Ranges and gorges
Primitiva				Upper gorges, ridges and hills
Minutifructus				Both alluvial areas and rocky outcrops
Eucalyptus	*Amentum*			Ranges and higher plains
	Capillulus			Ranges and tablelands/plateaus
	Aromatica and *Eucalyptus*			Tablelands
	Cineraceae			Ranges and tablelands
Symphyomyrtus	*Adnataria*	*Siderophloiae*		Flats/plains to hills and ranges/tablelands
		Aquilonares		Flats/plains
		Buxeales	*Amissae*	Mainly flats/plains, also hills and ranges
			Continentes	Plains and ranges
		Coalitae		Plains and low rises/slopes
		Submelliodorae		Plains
		Heterophloiae		Hills and ranges
		Rhodoxylon		Hills and ranges
		Melliodorae		Ranges and tablelands
	Bisectae			Plains to ranges
	Liberivalvae			Ranges and tablelands
	Latoangulatae			Ranges and tablelands
	Maidenaria			Tablelands
	Exsertaria	*Erythroxylon*		Plains to ranges/tablelands
		Subexsertae		Plains
		Rostratae		Plains/flats/valleys
		Phaeoxylon		Hills/plains

3.2.2 Casuarinas

Casuarinas are a characteristic feature of the modern Australian landscape, dominating about one million hectares and influencing a further 8 million as sub-dominant canopy species. The forests in the Brigalow Belt represent one of only two core areas of extant casuarina forests in Australia (NFI 1998). Of the 19 taxa within the Casuarinaceae occurring in Queensland, six are endangered, vulnerable or rare, and most occur in threatened regional ecosystems. Nine species occur in the Brigalow Belt, 12 in south-east Queensland, and six in the Wet Tropics.

The Brigalow Belt exhibits a range of outstanding features regarding casuarinas, including

- a significant refugium for key elements of the Casuarinaceae, one of the oldest known Gondwanan families of angiosperms;
- the highest diversity of arborescent casuarinas in Australia;
- a living 'museum' representing the transformation of *Gymnostoma*-dominated palaeo-rainforests into *Allocasuarina/Casuarina* dominated open forests of modern times;
- a combination of species demonstrating a range of evolutionary strategies within the Casuarinaceae in response to the increasing nutrient depletion, and aridity and seasonality of Neogene and Quaternary climates;
- illustration of the family's key role in rejuvenation of a Tertiary legacy of deeply weathered, nutrient-deficient soils;
- the catalytic role of the Casuarinaceae in transforming the deteriorating environmental conditions of the Quaternary into ones suitable for the superdominance by eucalypts.

3.2.2.1 Origins and radiations

The conifer-like Casuarinaceae, with no close relatives, is an isolated southern hemisphere Gondwanan family in its own order, the Casuarinales, within the subclass Hamamelidae. This ancient subclass is replete with taxonomically isolated, relictual families and genera, including *Nothofagus*. Primitive flavonoids occur in the Casuarinaceae that are generally more common in taxa that preceded the flowering plants (Johnson and Wilson 1989). There are only 79 species and subspecies in three extant Casuarinaceae genera in Australia — *Gymnostoma*, *Allocasuarina* and *Casuarina*. *Gymnostoma* is reduced to a single species narrowly restricted to the rainforests of the Wet Tropics whilst *Allocasuarina* and *Casuarina*, like eucalypts and acacias, adapted to xeric and oligotrophic environments during and since the Neogene, and rose to dominate the composition and character of much of the modern vegetation of Australia. This transition is well reflected in extant flora of geomorphologically related regions of Queensland and the Brigalow Belt.

The earliest Australian fossil pollen records of the Casuarinaceae are Early- to Mid-Tertiary and all are of *Gymnostoma*, a scleromorphic (but not xeromorphic) rainforest taxon adapted to marginal oligotrophic soils. However, records from Africa and South America imply even earlier origins in the Late- perhaps Early-Cretaceous, possibly in conifer-beech floras of those periods. Rainforests of north-eastern Australia in the Eocene were uniquely dominated by *Gymnostoma* rather than *Nothofagus*. The first *Casuarina* macrofossils date from the Miocene (Campbell and Holden 1984, Christophel 1989). Unequivocally identified *Allocasuarina* fossils do not appear until the early Pleistocene (Jordan 1997). By the Late Miocene (the 'terminal Miocene event'), rapidly declining temperatures, increasing seasonality and dryness in 'Queensland', precipitated a short transition from more mesic rainforests dominated by *Gymnostoma* to araucarian rainforests and floras dominated by xeromorphic *Allocasuarina*/*Casuarina* taxa. Both casuarinas were morphologically adapted to avoid excess water loss by shifting photosynthetic activity from leaves to needle-like woody branchlets that enclosed stomata in deeply buried grooves (encryption) instead of on exposed surfaces as in *Gymnostoma* (Hill 1994). The recent discovery of Casuarinaceae branchlets with encrypted stomata from Late Oligocene sediments at Riversleigh (Guerin 2001), in addition to the known fossil and contemporary history of *Gymnostoma* in Queensland, adds weight to the significance of north-east Australia in the adaptive radiations of casuarinas in response to early drying. These more advanced casuarinas, like the Fabaceae, Mimosaceae and Zamiaceae, also possessed nitrogen fixing, nodulated rootlets equipping them to exploit the growing legacy of deeply weathering and dismembering, nutrient-deficient environments of the Neogene. In fact, casuarinas are the only non-leguminous angiosperms in Australia known to form symbiotic nitrogen-fixing associations with the filamentous bacterial genus *Frankia*. This unusual capacity together with mycorrhizal symbioses facilitating uptake of other essential nutrients endowed casuarinas a keystone role in transforming inhospitable environments to ones suitable for subsequent colonisation by other species. Moreover, species of *Allocasuarina* developed long-lived seeds in cones that remain unopened for years (serotiny), so providing some competitive advantage in post-fire environments of the Quaternary.

The sifting from multiple episodes of speciations, radiations, range contractions and extinctions within the Casuarinaceae reflect the escalating climatic oscillations and latitudinal gradients of Pliocene and Pleistocene ice ages. The Brigalow Belt may have played a key evolutionary source/sink role in the final modernisation of Australia’s floras. The sheer size of upland massifs, the largest in eastern Australia, sustained populations adapted to those environments above critical bottleneck levels. The preservation of old Tertiary surfaces most closely associated with the evolution of Australia’s mesic rainforest flora ensured a rich gene pool for ongoing speciation. The nutrient rejuvenation of soils from Tertiary volcanism in one of the most significant lava fields in eastern Australia, sustained a broader range of source populations for speciations. The deep basaltic mantles also gave rise, especially during the Quaternary, to some of the largest expanses of water-retentive, nutrient-rich clay soils in Australia, a prime habitat for *Casuarina cristata*. Rejuvenated coastal drainage systems were the largest in Australia, providing essential habitats for the rheophytic *Casuarina cunninghamiana*. Thus the preservation, dissection and transformation of landscapes in the Brigalow Belt during this period provided a wealth of ancient refugial and newly emerging niches on a scale critical for viability and ongoing evolution during the next phase of climatic instability.

The full development of the Antarctic ice sheet in the Early Pliocene five million years ago resulted in lower temperatures and a drop in sea levels that were the lowest of the entire Cenozoic. The Brigalow Belt, with its more inland location exacerbated by the fully exposed Queensland Plateau, felt the brunt of the first intense phase of aridity. Tectonically associated warming and easing of aridity from ongoing drifting and collision of plates was counteracted by subsequent bi-polar cooling in the Mid Pliocene. Then, final docking of the Australian Plate into the south-east Asian plate blocked warm equatorial ocean currents, setting off the formation of the West Pacific warm pool (Isern *et al.* 1996) precipitating a regional greenhouse effect and an ensuing pattern of ENSO drying events reverberating throughout the rest of Australia and the eastern Pacific (Kershaw *et al.* 2002, Moss and Kershaw 2000, van der Kaars *et al.* 2000). With sea levels, temperatures, rainfall and soil nutrients changing cyclically, the Brigalow Belt became a conduit for range expansions southwards along ranges, rivers and plains during cooling episodes and northwards and/or westwards during warmings.

Results of phylogenetic studies (Sogo *et al*. 2001, Steane *et al*. 2003) are still equivocal on evolutionary relationships within the Casuarinaceae. However, both studies support the earlier divergence of *Casuarina* after *Gymnostoma*, the basal mesic taxon. *Casuarina cristata* (Belah) centred in the Brigalow Belt, at this stage appears at the base of the *Casuarina* clade (Steane *et al*. 2003).

3.2.2.3 *Casuarina*

The genus *Casuarina* (17 species worldwide, six in Australia) is the most widespread genus in the family, largely because of the littoral distribution of the type species *C. equisetifolia*, but it occupies soils that are not as nutrient-deficient as those associated with *Allocasuarina*. Dependence on and specificity for the filamentous nitrogen-fixing soil bacteria, *Frankia*, is greater within *Casuarina* but there are less specific mycorrhizal associations. Six species (nine taxa including subspecies) occur in Australia. All are arborescent, with *C. cunninghamiana* reaching very large sizes (Plate 19). *C. equisetifolia* subsp. *incana* (found on the east coast of Queensland, New Caledonia and southern Vanuatu) is restricted to the sea coast parts of the Brigalow Belt bioregion near Rockhampton. *C. glauca* exploited inhospitable water-logged and brackish soils of coastal estuaries, streams and saline swamps. *C. obesa* is the western and inland vicariant of *C. glauca* associated with brackish inland rivers and salt lakes (Wilson and Johnson 1989). Subcoastal or inland species most effectively colonised the vast Pleistocene water-retentive, relatively fertile, alkaline cracking clay plains of the Brigalow Belt (*C. cristata*) or less fertile texture-contrast soils associated with inland non-brackish river systems (*C. cunninghamiana*). Hybridisation between *C. glauca* and *C. cristata* indicate clear links between these two species.

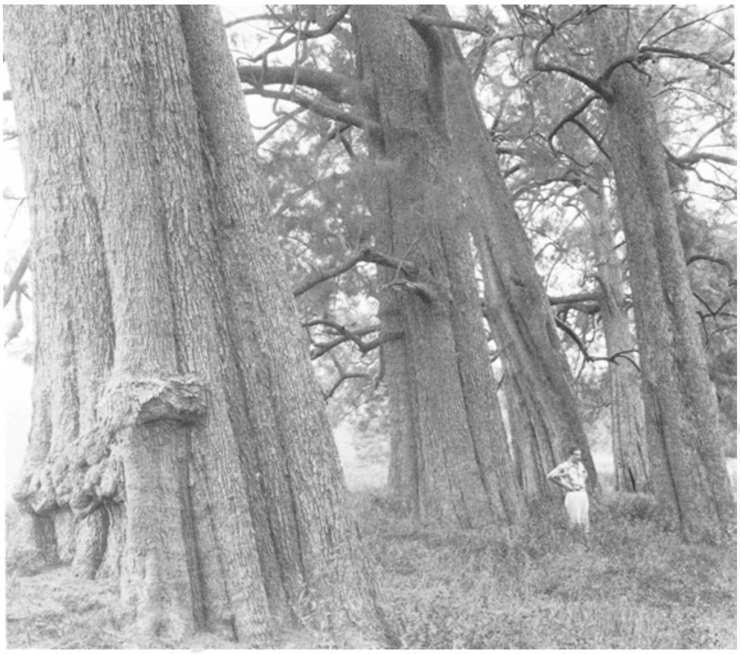


Plate 19 Casuarina cunninghamiana

C. cristata (Belah) forms one of the most distinguishing open-forest communities of the Brigalow Belt. Its associations range from microphyll vine woodlands and semi-evergreen vine thickets that are relicts of the major ‘C’ floristic province (Webb and Tracey 1994) of the Neogene, to co-dominance in water-logged sites with *Acacia harpophylla* (Brigalow) or with *Eucalyptus populnea* and *E. coolabah*, two of a small group of eucalypts able to colonise cracking clay soils. All the *C. cristata* communities are endangered from past clearing. Key areas for conservation of almost pure stands of *C. cristata* include State Forests 266, 270 (near St George) and 472, 369, 381 (south-east of Roma). The largest rainforest associations (RE11.9.4) survive only in Coominglah SF. It is likely that the fast early growth rates, nitrogen-fixing actinorhizal and mycorrhizal characteristics, and root-suckering capacity, rendered *C. cristata* a critical role as early pioneer in the new environments produced by alkaline weathering in the Pleistocene. The closely related *C. pauper*, most likely derived from *C. cristata*, exploited drier habitats (200-350 mm annual rainfall) on the red-brown soils into far-western NSW through to Western Australia across the Nullarbor.

C. cunninghamiana is also closely related to *C. glauca*, and the largest, most long-lived arboreal member of the family capable of growing to 35 m and 1.5 m diameter. It is one of the few truly riparian trees (rheophytes) in Australia (Woolfrey and Ladd 2001). It is characteristic of river bank vegetation flanking the east Australian uplands, on acid to neutral sands or sandy loams (rarely clays) in areas with annual rainfall above 500 mm. Almost all of its occurrences are endangered or vulnerable as a result of clearing and extreme grazing pressure and most old-growth individuals have long-since been removed. Like *C. cristata*, it is associated with gallery rainforest assemblages particularly in the northern range extremes (RE 11.3.25b). Key areas to conserve include Epsom SF 100 which retains many other threatened ecosystems including co-occurrences of *C. cunninghamiana* with the vulnerable *Eucalyptus raveretiana,* both always along creek beds and river banks (RE11.3.25a). Significant remnant occurrences of *C. cunninghamiana* and *Eucalyptus camaldulensis* (RE11.3.25) occur in the headwaters of the Burnett River between the Dawes Range and the Auburn Range (Coominglah SF and Montour SF), Mimosa Creek (Expedition SF), Planet Creek (Shotover SF and Planet Downs Leasehold), Comet River tributaries draining Consuelo Tableland (Mt Hope and Serecold State Forests), and Dawson River headwaters (Boxvale SF). Overall, *C. cunninghamiana* is restricted to areas below the elevational limit of floods with a return time of 500 years, in river valleys upstream of flood plain stretches of rivers, particularly steep, fire-protected, rocky valleys. The occurrences at elevations of 400-600 m in Carnarvon and Robinson Gorge in the Brigalow Belt, and Porcupine Gorge near Hughenden, may be relictual given the large seed size and mainly water-mediated dispersal of the species.

3.2.2.2 *Allocasuarina*

Allocasuarina, a sister taxon to *Casuarina*, appears to have radiated more recently, but with intergradations and hybridisations confusing phylogenetic relationships (Steane *et al.* 2003). The genus is endemic to Australia with 70 species in 11 Sections. It was the most successful in exploiting newly emerging environments from the most mesic to most arid and nutrient-poor, displaying the greatest diversity of morphological variation and form within the family — from dwarf shrubs to, more rarely, tall trees. However, until the end of the Neogene, tree cover dominated the continental landscape. The Brigalow Belt has the highest diversity of tall arborescent forms of the Casuarinaceae in Australia. Only two other tree species of Casuarinaceae retain the distinctive quadrangular morphology of branchlet articles seen in *Gymnostoma*. *Allocasuarina torulosa* and *A. decussata*, the only members of Section *Allocasuarina*, display the same extraordinary continental disjunctions as some ‘primitive’ *Corymbia* and plesiomorphic *Eucalyptus* taxa. Both are more closely associated with tall open forests at the mesic end of their range. The Western Australian *A. decussata* is associated with *Eucalyptus diversicolor* (Karri), also the only species of Section *Transversaria* (Pryor and Johnson 1971) found in Western Australia. *A. torulosa* is restricted to eastern Australia and occurs as an understorey on drier rainforest sites and in rainforest-allied forests containing *Lophostemon confertus*, *E. saligna* and primitive eucalypts such as the relictual, sectional monotypics, *E. microcorys* and *E. pilularis*. Its core centre of survival is in south-east Queensland with major disjunctions in the Brigalow Belt (the most inland occurrences known). Minor disjunct populations occur in the Wet Tropics, McIlwraith and Iron Ranges, and southwards mainly in the Blue Mountains west of Sydney. Key moister refugial areas in the Brigalow Belt occur largely north of 25˚S at Blackdown Tableland, Carnarvon Range (Boxvale SF), Bigge Range (Belington Hut SF, Presho SF), Mt Hutton, Middle Mountain in the Wonga Hills north of Barakula SF, Auburn Range (Calrossie SF), Coominglah SF and Callide Timber Reserve. Some occurrences in Coominglah are associated with relictual communities of *Livistona decipiens*, *Xanthorrhoea johnsonii* and *Eucalyptus acmenoides* on soils derived from granites (RE11.12.15) or whipstick *Lophostemon confertus*/*Eucalyptus acmenoides* associations on metamorphics (RE11.11.3).

Allocasuarina inophloia, with ribbony-fibrous bark that is unique within the family (Wilson and Johnson 1989), has no close relatives and is placed in its own section, *Inopitys*. It is essentially endemic to the Brigalow Belt South with its most optimal development on old tertiary surfaces and their derivatives centred at Barakula and the Inglewood sandstones. The northern bioregional range limit of 25˚S follows the east-west trending uplands with isolates at Blackdown Tableland and Coominglah. Three small and isolated disjunct populations occur 630 km to the north in the Einasleigh Uplands. Important regional ecosystems as surrogates for *A. inophloia* distributions include RE11.5.1, RE11.7.4, RE11.10.1 and RE11.12.20. Both *A. inophloia* and *A. torulosa* are putatively related to a group of five continentally disjunct Western Australian shrubs or small trees within Section *Ceropitys* (*A. helmsii*, *A. acutivalvis*, *A. tessellata*, *A. campestris*, and *A. eriochlamys* (Steane *et al*. 2003).

A. luehmannii, similarly with no close relatives and placed in its own section (*Platypitys*), occurs over a wider latitudinal gradient than *A. inophloia,* from the Wet Tropics to Victoria but has its core area of occurrence in the Brigalow Belt bioregion. It is largely restricted to solodized solonetz and solodic texture-contrast soils (Sodosols) and some Grey Clays (deep gilgaied cracking clays). The widespread duplex soils formed during the Quaternary, mainly on valley floors to lower and mid slope positions in the 400–1000 mm annual rainfall belt, and are severely deficient in many essential nutrients, especially nitrogen, phosphorus and calcium. *A. luehmannii* can be considered a keystone species facilitating the early colonisation of these inhospitable Holocene environments because of its symbiotic actinorhizal associations. In the Brigalow Belt *A. luehmannii,* alone or with *Callitris glaucophylla*, dominates some of the open forest associations on texture-contrast soils. Key areas occur in upper Mimosa Creek flanked by the Dawson and Expedition Ranges, in Barakula SF and Bracker SF. The results of Steane et al. 2003) surprisingly imply ancestral relationships between *A. luehmannii*, a tree species to 15 m, and shrub taxa within Section *Ceropitys*, the second most speciose group of *Allocasuarina*, and essentially restricted to Western Australia.

Allocasuarina littoralis, a widespread coastal species, was critically important in colonising nutrient-deficient sand dunes, saline environments as well as flood plains subject to repeated inundation by oscillating sea levels during the Pleistocene. It reaches only to within 150 km inland from the coast and is largely restricted within the Brigalow Belt to lower altitude eastern forests of the Burnett River catchment (includes Coominglah SF, Dangore SF). *A. littoralis* is closely related, directly or through common ancestors, to most other species of its section (*Cylindropitys*), the most speciose within the Casuarinaceae. Its allies are all shrubby or dwarf heath or low woodland species on oligotrophic soils of restricted environments including sandstone ridges, granite, trachyte or rhyolite mountain tops, cliffs, or Tertiary alluvial gravels.

In summary, the Brigalow Belt exemplifies the critical role played by the Casuarinaceae in the evolution of a distinctive, modern Australian, dry-adapted flora capable of surviving on large expanses of oligotrophic soils. The unique adaptive mechanisms of the casuarinas assisted the rejuvenation of environments within an old, tectonically stable Gondwanan fragment, whose rifting and drifting changed world climates and floras.

3.2.3 Acacias

Acacia is considered generally as one of the most important genera of woody plants on Earth (Stone 2003). It is an iconic Australian genus, the official national floral emblem, and second only to eucalypts in the extent to which it dominates the forests, woodlands and savannahs of this country. Brigalow, gidgee, mulga, lancewood, myall are all names of the Australian bush that forms a quintessential part of our cultural history.

Acacias provide critical ecosystem services — nutrient enrichment of soils, the maintenance of critical biomass of ecosystem pollinators, breeding and nesting sites for a range of fauna, and many other services (Keast *et al.* 1985). Acacias have also been a major source of food, fibre and ecosystem services for human societies in about 70 different countries around the world — for timber, fodder, re-mediation of saline or degraded soils (Stone 2002, Midgley and Turnbull 2003). Society is thus highly reliant on protection of the diversity of wild strains constituting this multi-functional gene pool.

The first significant presence of *Acacia* in the Australian fossil record is acknowledged as corresponding to the base of the Miocene (Kershaw 1994). Open-canopied vegetation comprising herbs and sclerophyllous shrubs and trees did not exist to any great extent prior to the Miocene. The flora of the Brigalow Belt provides one of the best representations of the Neogene transition in Australia's vegetation history. This transition is epitomised by the transformation of the Australian landscape from one dominated by palaeo-rainforest floras to a modern one composed predominantly of open vegetation communities (Kershaw *et al.* 1994) – this was a turning point in the history of Australian vegetation and a major stage in the earth's evolutionary history. The acacias played a central role. The Brigalow Belt today represents the largest core of *Acacia*-dominated vegetation in eastern Australia (NFI 1998).

With 1350 species, *Acacia* ranks among the top six most speciose genera in the world, and the largest genus of vascular plants in Australia (Maslin 2001) with more than 70 per cent of its species in Australia (964 species), mostly within a near endemic subgenus *Phyllodineae* (948 Australian species). As currently defined, the two other recognised subgenera have their major centres of richness in Central America (185 species) and Africa (145 species). Most Australian members characteristically have vertically flattened photosynthesising leaf rachises (phyllodes), of diverse sizes and shapes, and long-lived flowers. A smaller group have bipinnately compound leaves (Section *Pulchellae*).

Delineating the phylogenetic and evolutionary relationships within Subgenus *Phyllodineae* have been hampered for a long time by its enormous size (with yet another 100 species still to be described), significant morphological variation but limited infrageneric genetic divergences. Confusion and robust botanical debate on infrageneric divisions and rankings has proliferated since Bentham's original delineation of the genus in 1842. Not until recently has sufficient information from chloroplast and nuclear DNA sequencing been available to develop a sustainable and well-supported classification and phylogeny based on cladistic analyses (Murphy *et al.* 2000, 2003). These molecular studies are likely to cause as great an upheaval in the taxonomy of acacias as they did in that of the world's bird kingdom (Sibley and Ahlquist 1990, Christidis and Schodde 1991).

With such analyses still in progress, a detailed understanding of the role of the Brigalow Belt in the evolution and radiations of *Acacia* is not possible. The molecular studies have shown that some of the older classifications based on seven sections (and about 100 informal species groupings), are largely artificial and can be misleading. However, some of the smaller sections such as *Lycopodiifoliae* (17 species) and *Pulchellae* (27 species with bipinnate compound leaves) remain robust and appear to be basal clades within the newly emerging phylogenies. Within these basal clades, however, are some representatives of sections *Juliflorae* and *Phyllodineae* (Table 3.9).

Table 3.9 Australian distribution of species within sections of Subgenus *Phyllodinae* (after Murphy *et al.* 2003)

Section	Distribution in Australia	No. of species		
		Aus	Q	BB
Alatae	Temperate SW Western Australia	21	-	-
Pulchellae	Temperate SW Western Australia	27	-	-
Lycopodiifoliae	Tropical and subtropical Australia	17	6	2
Botrycephalae	Subtropical to temperate E Australia	42	20	17
Phyllodineae	Eastern and western Australia	408	102	83
Plurinerves	South-west and eastern Australia	212	49	33
Juliflorae	Tropical, subtropical and SW Australia	235	123	72

The *Lycopodiifoliae* clade, one of the securely established basal lineages in the Australian acacias, and distinguished by members having uniquely whorled phyllodes, is morphologically very distinct from all other taxonomic groups in Subgenus *Phyllodineae*. Earlier recommendations even suggested elevating the *Lycopodiifoliae* to subgenus rank (Pedley 1987). The presence within the Brigalow Belt of *Acacia porcata* at Beeron Holding (a key centre of endemism also for eucalypts, cycads and Lamiaceae) appears to be of outstanding scientific significance regarding the early evolution of acacias. *A. porcata* in many respects is unlike any other species in its section (Forster 1990). Its distribution, the most southerly for the section in Australia, is restricted to an area of granite outcrops with a radius no larger than three kilometres. Also restricted to this localised area is *A. eremophiloides*, a uninerved, non-racemose taxon within Section *Phyllodineae*, a large section with a small number of representatives grouping within the basal clade.

What is also clear from the molecular studies is that the Australian acacias underwent an extremely large and rapid Quaternary radiation, most likely in response to the Pleistocene sea level changes, climatic fluctuations and accompanying diversification of soils caused by accelerated erosion and alkaline weathering, characteristic of drier climates. At the same time the old dissected upland landscapes of northern Australia especially the Brigalow Belt area, with their moister micro-niches, provided refugia for relictual species. Like the Casuarinaceae, acacias were ideally pre-adapted for their role in colonising nutrient-depleted soil or otherwise inhospitable environments of the increasingly unpredictable and arid modern Australian environment.

The Brigalow Belt has the highest diversity of *Acacia* species in Queensland and a level of sectional diversity unparalleled in any other bioregion of Australia (Table 3.10).

Table 3.10 Study Area distribution of species within sections of Subgenus *Phyllodinae*

Section	Distribution in Brigalow Belt and New England Tableland Bioregions	No. of species		
		BB	end	evr
Lycopodiifoliae	Granite outcrops and skeletal sandstones	2	2	1
Botrycephalae	Lateritic Tertiary surfaces	17	5	4
Phyllodineae	Low nutrient soils of uplands & Gt Divide	83	25	19
Plurinerves	Fine-textured alkaline soils of flood plains	33	2	1
Juliflorae	Residual tablelands and scarps	72	7	8

end: endemic to Brigalow Belt (BB); evr: endangered, vulnerable, rare

The Brigalow Belt represents the northern range limit for the *Botrycephalae*, a small section of 42 species restricted to the more rugged uplands of eastern Australia south of the Tropic of Capricorn in a pattern of quite extraordinary disjunctions and narrow endemism. The Study Area, together with neighbouring south-east Queensland (*A. glaucocarpa*) harbour six Queensland endemics. *Acacia debilis*, *A. chinchillensis*, *A. pedleyi*, *A. storyi*, and *A. loroloba* are endemic to the Brigalow Belt bioregion, whilst *A. glaucocarpa* extends into western regions of south-east Queensland that were previous strongholds for Brigalow communities. *A. loroloba*, with a northernmost disjunct population in Coominglah SF, is closely allied to both *A. mearnsii* and *A. parvipinnula* in NSW (a 600 km separation). *A. storyi*, largely restricted to the Blackdown Tableland, is closely related to *A. olsenii* nearly 1500 km to south on peaks and gullies of the southern tablelands near the NSW/Victorian border.

Altogether, 17 of the section's 42 species are restricted to the subtropics north of the Hunter River including *A. latisepala*, *A. pruinosa*, *A. polybotrya*, *A. cangaiensis* and *A. leptoclada*, which are narrowly or regionally endemic to the New England Tableland region in Queensland and/or NSW.

A. muelleriana displays major disjunctions with populations in the Great Divide within the Carnarvon complex, then at Barakula 250 km to the south-east and in the Inglewood Sandstones, with a gap of another 480–500 km to the next populations flanking the Great Divide in NSW near the biogeographical gap of the Hunter River. *A. spectabilis* also occurs largely as two major populations — one in the southern Brigalow Belt in Queensland generally growing on laterised or sandy soils; the second in the Pilliga (Pilliga Wattle), with additional relict populations near Gungal and Cowra.

Additional disjunctions and range extensions south from Queensland such as displayed by *A. oshanesii*, *A. irrorata* (a rainforest species) and *A. deanei* add weight to the important role played by the Brigalow Belt and adjoining coastal Queensland in the original radiations from rainforest origins during cooler, dry intervals of the increasingly climatically unstable Quaternary.

The Brigalow Belt bioregion displays a very high level of endemic and relictual distributions within Section *Phyllodineae*. Recent molecular studies indicated surprising affinities of uninerved, non-racemose species of Section *Phyllodineae* with plurinerved species of Section *Plurinerves* and Section *Juliflorae* that occur in the most basal clades (Maslin *et al.* 2003). Thirty per cent of the Section *Phyllodineae* species occurring in the Brigalow Belt are endemic to the bioregion and more than 75 per cent of these are rare or threatened. Some of the most narrowly restricted endemic species confined to refugial areas include *A. islana* (R), *A. gittinsii* (R), *A. deuteroneura* (V), *A. hockingsii* R), *A. lauta* (V), *A. handonis* (V), *A. wardellii* (V), *A. holotricha*, *A. eremophiloides* (V), *A. arbiana* (R), *A. hendersonii*, *A.*

rubricola (E), *A. barakulensis* (V), *A*. sp. (Gwambagwine) (V), *A*. sp. (Ruined Castle Creek) (E), and *A*. sp. (Gayndah). Trachyte or granite outcrops, rugged sandstone ridges with skeletal soils, lateritic surfaces, or Cenozoic sand plains with texture-contrast soils are typical habitats.

Section *Juliflorae* members dominate the shallow, coarse-textured, infertile acid soils of scarp retreats and tablelands — the dissected lateritic land surfaces of the Tertiary. This section is significantly represented in Queensland (over 50 per cent of all species in the section) and in the Brigalow Belt (almost 60 percent of all Queensland species). Endemism is not as high (10 per cent) as within the *Phyllodineae* (30 per cent) but is similarly concentrated along the Great Divide and associated ranges. Some of the most restricted endemics are *A. abbatiana*, *A. cretata*, *A. grandifolia* and *A. striatifolia*. *A. abbatiana* should at least be classified as rare, being restricted entirely to Mt Abbott in the northern Brigalow Belt. *A. pubifolia* (V) is restricted to the Wallangarra district in New England Tableland bioregion.

Despite relatively low levels of endemism, the *Juliflorae* within the Brigalow Belt is characterised by some remarkable disjunctions, paralleling those observed in the *Phyllodineae. A. tingoorensis* (V) is restricted to populations on sandy soils in low hills 22 km east of Diamondy SF and 12 km north-east of Dangore SF (Dangore Mountain), then 350 km north-east within lower reaches of Mimosa Creek and on the western slopes of the Expedition Range near Planet Downs (SF 29). The third centre occurs at Mt Fox in the Wet Tropics — an extraordinary disjunction from the southern localities.

The more widespread members of Section *Juliflorae* include *A. shirleyi* (Lancewood), and *A. catenulata* (Bendee) forming some of the most extensive and distinctive open-forests of semi-arid northern Australia. *A shirleyi* characteristically forms almost monospecific stands of closely packed trees on residual tablelands and scarps, on skeletal soils extending from Barakula to the Barkly Tableland. *A. catenulata* extends to deeper, more loamy soils than *A. shirleyi* allowing the development of prominent woody and heathy understoreys including myrtaceous (*Micromyrtus*, *Lysicarpus*) and rutaceous (*Phebalium*) shrubs.

Section *Plurinerves*, one of the three largest sections of *Acacia*, comprising 22 per cent of the Australian subgenus *Phyllodineae*, contains many species that are adapted to heavier soils in low-lying areas such as the large areas of cracking and non-cracking clays of the Brigalow. The section also displays disjunctions and relictual endemism similar to that of other sections of *Acacia* but is generally considered to represent more recent radiations. The narrow endemics include *A. argyrotricha* restricted to Bracker SF, and *A. maranoensis,* restricted in the eastern sector of the Brigalow Belt to the Tingoora centre of endemism near Diamondy SF (co-occurring with *A. tingoorensis*), and in the western sector, separated by a disjunction of 300 km, to the southern scarps of the Great Divide near Mitchell.

A. harpophylla (Brigalow) was the most widespread species of Section *Plurinerves* and of any acacia open-forest or woodland type in Australia. It is specifically adapted to regimes of low and variable rainfall and high evaporation, its phyllodes showing extreme resistance to desiccation. Together with other members of the '*Microneurae*' group of Section *Plurinerves*, *A. harpophylla* occurs on fertile, deep, usually alkaline clay soils on undulating hills to lowland plains. Half of the soils supporting *A. harpophylla* possess gilgai microrelief, the depressions serving to prevent general run-off and accumulate surface moisture locally. *A. harpophylla* grows on the elevated areas surrounding the 'melon holes'. The clay-rich soils have the highest water storage capacity of all soil types which may have been a vital factor in ameliorating the harsher impacts of climate change during the Quaternary. In the drier areas *A. harpophylla* is replaced by *A. cambagei* (Gidgee)

Acacia species from this section mostly form almost monospecific upper canopy layers of forests and woodlands in the floodplains of inland river systems. Eucalypts co-occur only in marginal situations. Only *Casuarina cristata* (Belah) forms mixed stands with *A. harpophylla* over wide areas of southern Queensland. In the more mesic areas, woody understorey rainforest species proliferate in lowland clays.

The Brigalow Belt and immediately adjoining bioregions represent one of the most significant centres of diversity and endemism for acacias in Australia. A very large number of species comprising relictual and recently evolved taxa in all the major genetic lineages of the acacias occur in geographically restricted and disjunct distributions in the Brigalow Belt. A very high proportion of these species and the ecosystems they support are now very rare or threatened with extinction because of past clearing, burning and other land management practices. Further habitat loss and fragmentation urgently needs to be halted and reversed in order to promote the long-term persistence of this immensely significant part of our biological inheritance in fully functional ecosystems.

3.2.4 Cypress (*Callitris*)

The Brigalow Belt and New England Tableland bioregions together, with six species, have the highest diversity of extant *Callitris* taxa in the world. The distribution of these six species exemplifies the transition during the Neogene from predominantly continental wide mesic to xeric taxa in response to the rapid deterioration of climate during this period.

Compared with that of other continents Australian vegetation has relatively few conifers. Of those that occur here, *Callitris* (Cupressaceae), particularly in semi-arid areas, is the only conifer genus with species that can dominate whole vegetation types (Fox 1999). However, only during the Late Neogene (Pliocene Epoch) has speciation of *Callitris* occurred into more xeric habitats (Page and Clifford 1981).

Today the genus still has a typically East Gondwanan distribution with 19 species restricted to Australia and New Caledonia. In this respect the Cupressaceae share broad ecological and biogeographical distribution patterns with other Southern Hemisphere (Gondwanan) conifers. *Callitris* is recognised as an ancient archetypal Gondwanan conifer that was typically a major component of mesic to dry rainforest that covered much of the continent from the Mid Cretaceous to Mid Tertiary (Bowman and Harris 1995).

However, macrofossils are rare and have been found only from central Queensland (Peters 1985). The fossil pollen record in Pleistocene deposits of Regatta Point in Tasmania revealed a ‘curious’ rainforest flora distinct from any modern vegetation. It contained many Tertiary relicts including *Callitris*, *Acacia* and *Allocasuarina* along with other more typical rainforest taxa of both mesotherm and microtherm affinities including *Quintinia*, *Rubrus* v.f. *moorei* (close relative extant in Queensland), *Acacia melanoxylon* and members of the Lauraceae (Carpenter *et al*. 1994).

In New Caledonia *Callitris* species still occur as canopy trees (along with Araucariaceae) in the high altitude ‘cloud forests’ (Jaffre 1995). Only *C. macleayana* occurs as a natural component of Australian rainforests as disjunct populations in the Wet Tropics, southern

Queensland and north-east NSW, this pattern parallelling that of both *Agathis robusta* and *Araucaria bidwillii* (Enright 1995). Its ecology is related to pure rainforest stands and their wet sclerophyll forest margins. Co-occurring species include *Lophostemon confertus*, *Casuarina torulosa*, and *Acacia melanoxylon*, seemingly a modern homologue of the Regatta Point Pleistocene palaeoflora of Tasmania.

Since most taxa within the Cupressaceae share broad ecological distribution patterns with other southern conifers they may be expected to have experienced similar distributional changes. During the last 200 000 years of the Quaternary, there was an alternating pattern of complex rainforest with araucarian/*Callitris* forests through alternating wet interglacial and drier glacial periods. The pattern was broken in the middle of the last glacial with almost total replacement of the araucarian/*Callitris* rainforests by eucalypt-dominated sclerophyll vegetation. This replacement was accompanied by a substantial and sustained increase in charcoal deposits indicative of intensified fire regimes (Kershaw and McGlone 1995). *Araucaria* became virtually extinct in north-eastern Australia in the Late Pleistocene. Most southern conifers have not generally been able to exploit the semi-arid and arid, fire-prone areas of Australia, possibly because of the late arrival of aridity when *Eucalyptus* species had already got a hold. *Callitris* appears to be the one exception that thrived and expanded into more xeric environments, albeit not readily in competition with eucalypts as demonstrated by the disappearance from north-east Queensland during the late Quaternary and the generally fragmentary distribution of the genus.

Like most other southern conifers, *Callitris* is rarely prominent in mesic, shaded habitats where it is outcompeted by angiosperms. It can, however, successfully compete where environmental stresses reduce the competitive edge of the angiosperms (Enright and Ogden 1995). Like eucalypts, southern conifers are generally sclerophyllous, show extreme nutrient-use efficiency for nitrogen and phosphorus relative to other taxonomic groups, are slow-growing, long-lived with high investment in plant defence strategies. These life-cycle strategies appear to be adaptations to low-frequency/high-intensity disturbance regimes on nutrient-poor sites. Organic-rich, more weathered but nutrient and water-retentive, clay-rich soils generally favoured angiosperms over conifers. On the other hand, conifers were able to compete more effectively on poorly drained, poorly aerated, thin soils that rapidly lost most nutrients. However, like all other conifers, *Callitris* is relatively intolerant of fire. Topographic and edaphic factors that limit fire appear to be critical factors in determining *Callitris* distributions with intact stands on sandy soils developing only limited fine fuel loads thus reducing the probability of fire (Bowman and Harris 1995).

The ongoing survival of *Callitris* communities, given the ecological characteristics of the genus, appears to be dependent on achieving stable old-growth communities in fire-protected niches and nutrient-poor soils where they have a competitive advantage over angiosperms.

3.2.5 The daisy flora

to be completed

3.2.6 Other families (grasses, Euphorbiaceae, Restionaceae, etc)

to be completed

3.2.7 Rainforest

to be completed

3.3 Fauna

The Brigalow Belt represents all or a significant part of the remaining population of many of the 52 endangered, vulnerable or rare fauna species present. Fauna characteristics relating to habitat, soil type, foraging type and weight appear to have influenced the likelihood of species becoming threatened. Mammals in the Critical Weight Range, granivorous birds, species with large home ranges, woodland birds, lowland or "downs" specialists, Brigalow/vine-thicket specialists and invertebrates with fine-scale ecological relationships are all vulnerable (Section 3.4). The Brigalow Belt represents a significant proportion of the remaining habitat for particular species within all of the above categories.

Bird and reptile endemism is among the highest in Australia at a bioregional level. Endemics occur across a wide range of families in both of these fauna groups. All endemic birds are concentrated on the lowland areas, while the distribution centres of the reptiles vary, with species such as *Strophurus taenicauda* (Golden-tailed Gecko) and *Paradelma orientalis* (Brigalow Scaly-foot) mainly found in the large core areas of vegetation on public land. The bird and reptile endemics as a group are highly threatened, with 85 per cent listed as threatened or extinct (13 of the 14 reptiles and four of the six birds) (Section 3.5). This group includes the Paradise Parrot, Australia's only mainland bird extinction, and the skink *Lerista allanae*, which may be Australia's first mainland reptile extinction (Section 3.4.2.7).

The relatively mesic habitats on parts of the Great Divide and the Expedition and Dawes Ranges support naturally disjunct populations of fauna that are relatively widespread in coastal regions. These populations, left behind from past climatic fluctuations, have not speciated (to our knowledge) but may have diverged genetically from populations to the east. Hence they may represent a significant component of the genetic diversity and capacity to adapt to change for each of these species. The disjunct populations include birds, bats, frogs and reptiles. These naturally small disjunct populations are vulnerable to degradation of their remaining habitats (Section 3.5.4).

The Brigalow Belt reptile and bird faunas as a whole are among the richest in Australia, with a range of temperate, tropical and arid elements. At a finer scale, the Brigalow Belt is exceptionally rich in a number of species groups, which are compared with other parts of Australia in Section 3.6. The more fertile areas within the Brigalow Belt are home to a great diversity of burrowing frogs. The Brigalow Belt assemblage of elapid snakes, a major and characteristic element of the Australian snake fauna, is richer at a genus level than any other bioregion apart from South-East Queensland and NSW North Coast (All support 15 genera). The arboreal reptile assemblage is a conspicuous element of the forests and woodlands at night, and is richer than in any other Australian state (Section 3.6). Birds that are largely restricted to eucalypt woodland are a special and vulnerable element of the Australian avifauna (Section 3.4.2.5). The Brigalow Belt has the largest representation of woodland specialist birds (Section 3.6.4), and also supports relatively secure populations of species that are endangered or vulnerable elsewhere in their range (Section 3.7.4). The assemblage of insectivorous bats in the forests and woodlands is richer than other Australian states, with both hollow-dwelling and cave-dwelling species prominent (Section 3.6). Three of the five threatened bat species have major stronghold populations in the Brigalow Belt (Section 2.4.7.2). Macropods are more diverse in the Brigalow Belt than any other bioregion apart from the Wet Tropics, which also supports 14 species (Section 3.6).

The extent of the Brigalow Belt's woodland habitat (more than 10 million hectares) is highly relevant for fauna conservation, enabling the persistence of a relatively intact woodland fauna assemblage. The intactness of this fauna assemblage is significant, as extensive clearing and degradation has left depauperate woodland assemblages across most of southern and eastern Australia, and further losses are predicted from these areas. The fauna components that are still extant in the Brigalow Belt include top-order trophic predators, small macropods and woodland birds. The features of intact woodland fauna communities and the history of woodlands in Australia are discussed in detail in Section 3.7.

The Brigalow Belt is a vital component of the Eastern Australian Bird Migration System., providing winter habitat for and therefore maintaining large populations of forest birds from southern and eastern Australia. While the once-important brigalow lowland habitats have been largely cleared, there are still large areas of important habitat with winter-flowering eucalypts in the Brigalow Belt. The Eastern Bird Migration System, flowering behaviour of eucalypts, adaptations by fauna to exploit eucalypt flowering behaviour and reserve implications are discussed in Section 3.8 and 3.9.

The Glossy Black-Cockatoo is a highly specialized species which occurs in a series of disjunct populations in the Study Area. The distributions of the two subspecies of Glossy Black-Cockatoo appear to correspond to those of the major food sources, *Allocasuarina torulosa* and *A. inophloia*. It is possible the difference in bill morphology between the two black-cockatoo subspecies is a result of this. The specialized foraging ecology of the Glossy Black-Cockatoo highlights the care needed in designing reserves for viability and ongoing evolution. This is discussed in Section 3.10.

3.4 Rare and Threatened Species

3.4.1 Threatened Flora

A total of 337 plant species found in the Study Area are rare or threatened, including 50 Endangered, 102 Vulnerable, 172 Rare and 10 Provisional taxa. Three species, *Amphibromus whitei*, *Corchorus thozetii* and *Paspalum batianoffii* are considered to be extinct. The numbers of Endangered, Vulnerable, Rare, Provisional and Extinct taxa in the WHWD Area are 41, 84, 152, 9 and 1, respectively.

Threatened plants of the Study Area are listed in Appendix 3. Among the threatened flora are species of major significance to science. *Acacia porcata* (E) is unlike any other species in its section (Forster 1990) and is entirely restricted to Beeron Holding just to the east of Allies Creek SF. *Eucalyptus rubiginosa* (R) has no close relatives and is the only member of the subgenus, *Primitiva*. *Cadellia pentasylis* (Ooline)(V) is the only member of the genus and is essentially endemic to the Brigalow Belt bioregion. *Cadellia* is one of just four genera in the ancient family, Surianaceae, which is now essentially confined to Australia.

3.4.2 Threatened fauna

3.4.2.1 Overview

The Brigalow Belt is important for many Endangered, Vulnerable or Rare fauna. It represents the entire range for a number of species, the bulk of the remaining habitat for several more, and two species once found well beyond Queensland are now entirely restricted to the Study Area. There are 52 Endangered, Vulnerable or Rare species in the

Study Area (Table 3.11), and the Brigalow Belt is notable for its high proportion of threatened and declining species (McFarland *et al.* 1999). The high figure has largely been brought about by the introduction of livestock and extensive clearing of the lowlands.

Table 3.11 Endangered, Vulnerable, Rare and priority fauna in the Study Area.

	Endangered	*Vulnerable*	*Rare*	*Priority*	*Extinct*	*Total*
Reptiles	**1**	**7**	**10**	**18**	**0**	**36**
Frogs	**0**	**0**	**1**	**4**	**0**	**5**
Arboreal marsupials	0	0	0	6	0	6
Small mammals	1	3	0	10	6	20
Large mammals	1	0	0	1	0	2
Megabats	0	0	0	1	0	1
Microbats	0	1	4	6	0	11
Total Mammals	**2**	**4**	**4**	**24**	**6**	**40**
Nocturnal birds	0	1	0	3	0	4
Diurnal birds	3	10	9	9	3	34
Total Birds	**3**	**11**	**9**	**12**	**3**	**38**
Total	**6**	**22**	**24**	**58**	**9**	**119**

At least nine species are known to have become extinct in the Study Area (Table 3.12), but the figure is probably higher and local extinctions continue to be recorded (See Environmental Protection Agency 2002b.).

Table 3.12 Species now extinct in the Brigalow Belt

Species	**Scientific name**	**Last record in Study Area**
Darling Downs Hopping-mouse	*Notomys mordax*	1846
White-footed Rabbit-rat	*Conilurus albipes*	1875
Northern Bettong	*Bettongia tropica*	1884
Western Quoll	*Dasyurus geoffroii*	1905
Flock Bronzewing	*Phaps histrionica*	1905
Paradise Parrot	*Psephotus pulcherrimus*	1927
Greater Bilby	*Macrotis lagotis*	1929
Kultarr	*Antechinomys laniger*	1936
Star Finch (southern)	*Neochmia ruficauda ruficauda*	1985

Source: Queensland Fauna Database

There are identifiable patterns that predispose fauna to decline in the bioregion. These characteristics include a range of factors such as habitat, soil type, foraging type and weight, and these factors may overlap for some species. Susceptible fauna groups include mammals in the Critical Weight Range, granivorous birds, species with large home ranges, woodland birds, lowland or "downs" specialists, Brigalow/vine-thicket specialists and invertebrates with fine-scale ecological relationships.

3.4.2.2 Critical weight-range mammals

The "critical weight range" (CWR) for Australian mammals is considered to be 35–5500 grams, within which nearly all major mammal extinctions and declines in Australia were found to have occurred in a landmark study by Burbidge and McKenzie (1989). Non-flying mammals in this size group are thought to be particularly vulnerable to predation, but also suffered the greatest attrition because of their relatively limited mobility combined with high daily metabolic requirements.

Cardillo and Bromham (2001) refuted the influence of the CWR on mammal extinctions after putting the theory to statistical scrutiny, concluding that only small species are less extinction-prone. In the Brigalow Belt, marsupials in the critical weight range have declined to a greater extent than larger or smaller species, with three of the four marsupial extinctions and a large number of critical weight range species “Of Concern” (McFarland *et al*. 1999) (Table 3.13). Of the eight “Of Concern” species within the CWR, one is extinct in Brigalow Belt South (Spectacled Hare-wallaby), one has not been sighted in the Brigalow Belt since 1987 (Brush-tailed Phascogale), another appears to have contracted to the Carnarvon Ranges Subregion (Northern Quoll) and a further two (Northern Brown Bandicoot and Long-nosed Bandicoot) appear to have declined severely in the landscape. In many parts of the Brigalow Belt it is likely that the loss of critical weight range marsupial species is seven or eight, or nearly half the original fauna. The difference between the various weight groups is not statistically significant but with a total of 35 marsupial species a statistically significant result would be difficult to obtain.

Table 3.13 Non-volant marsupial size and conservation status in the Brigalow Belt

Weight range	Extinct	Threatened	Priority*	Secure	Total species
Large (>5500g)	0	3 (25%)	1 (9%)	7 (64%)	11
CWR (35–5500g)	3 (18%)	1 (6%)	8 (47%)	5 (29%)	17
Small (<35g)	1 (14%)	0	1 (14%)	5 (71%)	7

*Sizes from Menkhorst (2001). *-“Of Concern” species in the Brigalow Belt (Sources McFarland* et al. *1999 and Environmental Protection Agency 2002b)*

Cardillo and Bromham (2001) suggested that large mammals may have already experienced recent extinctions, hence clouding contemporary relationships between extinction proneness and body size. There is evidence that many large species have disappeared in the last 10 000 to 60 000 years. If so, the loss of CWR species may be part of a larger extinction event of Australian mammals >35 grams in general.

3.4.2.3 Granivorous birds

The Study Area has suffered great losses among granivorous avifauna. The Paradise Parrot (extinct) was largely found in the Brigalow Belt. The Star Finch and Black-throated Finch have become extinct in Brigalow Belt South, retreating north from the bioregion and the Diamond Firetail is now declining rapidly in the opposite direction (Wildnet records; Garnett and Crowley 2000). The Flock Bronzewing has retreated inland (Garnett and Crowley 2000), and the southern race of the Squatter Pigeon (Vulnerable) has disappeared or declined from many areas (Environmental Protection Agency 2002b). These species began to decline or even disappeared *before* broad-scale land clearing commenced (Franklin 2000). These disappearances and those now occurring in northern Australia appear to be linked with the disruption of seed production caused by cattle grazing and altered fire regimes (Franklin 2000). The process of broad-scale changes in grass composition is described in Section 4.2.5.2.

3.4.2.4 Forest and woodland dependent species with large home ranges

Populations of fauna with large home ranges are more vulnerable in the Brigalow Belt than equivalent populations in the coastal forests. There are two major reasons for this. One factor is that the landscape is generally more fragmented. The coastal forest landscapes are relatively continuous albeit with varying habitat quality. The second factor is the lower productivity and greater climatic variability in these habitats, which will theoretically result in larger home ranges in species for which abundance is regulated by productivity. If so, a larger area will be needed for viable Brigalow Belt population of a given species than for a coastal population.

Major differences in the assumed home range sizes and actual home range data based on radio-tracking studies for inland populations have been found for three species. An increased home range size in areas of lower productivity has been shown for the Powerful Owl, Barking Owl and Greater Glider (Table 3.14). Greater Gliders do not have large home ranges, but they have been included here because as a major prey species their densities would almost certainly influence the viability of Powerful Owl populations.

Table 3.14 Assumed home ranges of fauna and radio-tracked home ranges in inland environments

Species	Home range	Inland home ranges
Yellow-bellied Glider	30–65 (1) 20–85 (2)	
Greater Glider	1.3–2.5* (3), 0.7–3.0 (2)	Up to 17* (4)
Squirrel Glider	0.9–7.1 (2)	
Barking Owl	100–1000 (5)	6000* (6), 1500* (7), 225* (6)
Powerful Owl	300–1000 (8), 400–1500 (9), approx. 1000 (10)	1380–4770* (11)
Masked Owl	500–1000 (10), 1017–1178* (12)	
Red Goshawk	5000–22000, 12000–20000* (13)	

*-These figures have been ascertained by radio-tracking, the most accurate way to measure home ranges.

1) Goldingay and Kavanagh (1991)
2) NPWS (2003)
3) Comport *et al.* (1996)
4) M. Mathieson pers. comm., Barakula SF, BBS.
5) Clemann and Loyn (2003)
6) NSW National Parks and Wildlife Service (2003b), Goonoo SF, NSW BBS.
7) N. Schedvin pers. comm., Box-ironbark, NE Vic.
8) Davies and Higgins (1999)
9) Davey (1993)
10) Garnett and Crowley (2000)
11) Soderquist *et al.* (2002), Box-ironbark, central Vic.
12) Kavanagh and Murray (1996)
13) NSW National parks and Wildlife Service (2002)

Soderquist *et al.* (2002) radio-tracked Powerful Owls in box-ironbark habitat in central Victoria and reported a four-fold increase on the previously assumed home range size. Soderquist *et al.* (2002) reported that "*Prior to this study, the assumed home range size of Powerful Owls was 300–1000 ha (Higgins and Davies 1999). In this study, some Powerful Owls used over four times this area (1380–4770 ha, N = 4 radio-tracked owls). These large home ranges apparently resulted from low prey densities in this forest.*" Radio-tracked Greater Gliders in Barakula SF have used areas as large as 17 hectares (M. Mathieson pers. comm.), which after an extensive literature search appears to be the largest home range ever recorded for the species. Most Greater Glider home ranges in Barakula SF were smaller than 17 hectares, but were still approximately 2–3 times larger than the assumed and frequently quoted home range size of about 1–3 hectares (Table 3.14). Barking Owl home ranges have been found to vary greatly, but reported values include radio-tracked ranges that are generally much larger than the area cited in Clemann and Loyn (2003).

One species which has not been studied to ascertain home range size of inland populations is the Yellow-bellied Glider. The abundance of the Yellow-bellied Glider is also likely to respond to habitat productivity. If this species responds to low productivity environments in a similar way to the Barking Owl, Powerful Owl and Greater Glider (i.e. home ranges are 2–4 times the generally assumed size) there are major implications for reserve design.

Goldingay and Possingham (1995) predicted that about 18 000–35 000 hectares would be needed for a viable population of Yellow-bellied Gliders if only a proportion of the forest is occupied. If it is assumed that Yellow-bellied Glider groups in the Brigalow Belt require home ranges that are twice the size of those on the coast, the area required for a viable population could be close to 70 000 hectares. It is acknowledged that productivity in the Brigalow Belt's forests and woodlands varies — the high-productivity open forests in the vicinity of Carnarvon Gorge probably have higher abundances of large owls and gliders than elsewhere in the bioregion — but for low-productivity areas such as Barakula SF and medium-productivity areas such as the eastern Carnarvon Ranges Subregion and Coominglah SF, this figure may well be accurate. The greater incidence of droughts in the Brigalow Belt may expand home ranges even further. It is important to assess response of populations to drought as populations need to survive these inevitable stochastic events.

3.4.2.5 Woodland birds

"There is now consensus amongst ecologists working in the field that woodland birds are undergoing a major and rapid wave of declines, including many local and regional extinctions, and even some statewide extinctions."

(Traill and Duncan 2000)

Extensive clearing has threatened a whole community of woodland birds, and this decline is one of the major issues in Australian bird conservation (Ford *et al*. 2001). Local extinctions and declines have been recorded in several temperate woodland regions, including the Mt Lofty Ranges in South Australia (Paton *et al*. 1994), western Victoria (Kennedy 2003), north-eastern Victoria (Traill *et al*. 1996), and the NSW western slopes (Reid 1999).

A total of 43 specialist woodland birds were identified and are listed in Section 3.7.4. It was found that woodland specialists were more than five times as likely to be threatened somewhere in Australia than species that used woodlands but also used other habitats extensively (Table 3.15). The discrepancy was even more pronounced for species threatened at a national level (Table 3.16). That is, the element of the woodland bird communities that makes them distinctive from those of other vegetation types is the element at greatest risk of being lost.

Table 3.15 Likelihood of bird species being threatened somewhere in Australia if they are woodland specialists or birds that use woodlands but are not specialists.

Habitat category	Number threatened somewhere in Australia	Total	% threatened somewhere in Australia
Birds that use woodlands	38	229	16.6
Woodland specialists	**21**	**43**	**48.8**
Non-woodland specialists	17	186	9.1

Table 3.16 Likelihood of bird species being threatened nationally (Garnett and Crowley 2000) if they are woodland specialists or birds that use woodlands but are not specialists.

Habitat category	Number threatened nationally	Total	% threatened nationally
Birds that use woodlands	8	229	3.5
Woodland specialists	**7**	**43**	**16.3**
Non-woodland specialists	1	186	0.5

The extinction of such birds from extensively cleared landscapes elsewhere in Australia is likely to continue, including from the highly fragmented "downs" areas of the Brigalow Belt itself (Garnett and Crowley 2000) in coming decades. Therefore the intact forest and woodland landscapes of the Barakula, Inglewood Sandstones and Carnarvon Ranges Subregions offer an important opportunity for conservation of declining woodland birds at a national level. These core areas support relatively large populations of woodland birds such as the Speckled Warbler, Grey-crowned Babbler, Bush Stone-curlew and Barking Owl. The national importance of the area is recognized in the Action Plan of Australian Birds, which identified that the "Subtropical woodlands", including a large proportion of the Study Area required a "Co-ordinated Conservation Plan" (Garnett and Crowley 2000). This is discussed in detail in Section 3.7.4.

3.4.2.6 Brigalow and vine-thicket specialists

The clearing of millions of hectares of brigalow and vine-thicket in the last 50 years has resulted in at least a proportionate impact on the fauna that are reliant on these habitats. However even greater losses are likely for species with relatively large home ranges and/or poor dispersal abilities as many of the remaining fragments will be too small to support these species in the long term. Two threatened species of note are the Black-breasted Button-quail (Vulnerable) and the skink *Anomalopus brevicollis*.

The conservation issues surrounding the Black-breasted Button-quail (extensive habitat loss and fragmentation, low dispersal ability, habitat degradation) are indicative of the problems facing a range of dry rainforest birds in the Brigalow Belt. Species such as the Wonga Pigeon, Black-faced Monarch, Varied Triller and Emerald Dove are not considered of conservation concern as they also occur widely in the relatively intact subtropical rainforest of South-East Queensland (unlike the Black-breasted Button-quail). However, the level of fragmentation in the Study Area places the Brigalow Belt populations of these and several other rainforest birds with poor dispersal ability at risk.

The loss of the dry rainforest specialist birds would represent a major loss of faunal diversity from the Brigalow Belt landscape. Rainforest flora may also be affected, as birds are likely to be major fruit dispersal agents for some species. The loss from the Study Area of a small frugivore such as the Lewin's Honeyeater, a common and familiar sight in coastal Queensland, could have a major impact.

Brigalow and vine-thicket patches within and adjoining State Forests and reserves will assume great importance in coming decades. Some fauna that cannot move between remnants in cleared landscapes may be able to disperse between fragments within the vegetated matrix of State Forests and and maintain relatively large metapopulations.

3.4.2.7 Downs specialists

Species found largely on the downs have lost extensive areas of habitat in much the same manner as the brigalow and vine-thicket specialists. These species prefer grassland, open grassy woodland or habitat with soft soil for burrowing. *Cyclorana verrucosa* (Rough Frog, Rare) is the only amphibian in the Brigalow Belt to be listed as threatened. It is one of several burrowing frogs with a distribution centred on the Murray-Darling Basin, but is more restricted than similar species. However, *C. verrucosa* represents the plight all of the Murray-Darling Basin's burrowing frogs in that it has lost vast areas of habitat to intensive agriculture in recent decades. Other frogs largely found in "downs" areas are listed in Section 2.4.4.2.

There are also downs specialists among the reptiles. *Hemiaspis damelii* (Grey Snake) (Endangered) and *Denisonia maculata* (Ornamental Snake) (Vulnerable) are largely found in the Murray-Darling Basin and Fitzroy Basin respectively. These are small woodland dependent snakes that prey on frogs (Wilson and Knowles 1988). The ground-dwelling gecko *Diplodactylus steindachneri* also appears to occur largely on the downs in the Brigalow Belt. Most downs species have been recorded on alluvial woodlands within State Forests on the upper parts of the catchments, but species such as *D. maculata* are so strongly dependent on the downs areas that they have never been recorded in a State Forest. *Lerista allanae* is, or was, a burrowing skink of black soil downs in the Capella and Clermont region. It could be the first Australian reptile to have become extinct in Australia (Covacevich *et al*. 1996). There are thirteen museum specimens dating from 1929 to 1960, all from the downs to the west of the Peak Range, an area now heavily modified by clearing and grazing.

3.4.2.8 Invertebrates

Identification of threatened invertebrates is in its infancy in Australia. At this point in time, three invertebrate taxa in the Brigalow Belt have been listed as threatened (Table 3.17). However, there are probably many more threatened species than have been recognised. For example, the flightless dung beetles of the genus *Canthosoma* and *Onthophagus apterus* (See Section 2.4.3.2.) have lost a large percentage of their vine-thicket habitat, are not adapted to move between these now fragmented habitats and are dependent on the persistence of Black-striped Wallaby colonies. However they are not formally recognized as threatened.

Invertebrates are at risk if they have fine-scale relationships with depleted plant species or are dependent on architectural features of old trees of species where old trees have become rare. The level of risk will depend on the mobility of the invertebrate and the level of resource abundance required for persistence. Fine-scale relationships have been identified for two threatened butterflies and a new family of Hemiptera has been described (See Section 2.4.3.2.), but it is almost certain that many other highly specialised insects are also at risk.

Table 3.17 Threatened invertebrates of the Brigalow Belt

Species	Scientific name	Status
Boggomoss Snail	*Adclarkia dawsonensis*	CE*
Buloke Jewel Butterfly	*Hypochrysops piceatus*	E
Imperial Hairstreak	*Jalmenus evagoras eubulus*	V

**-Federal listing under EPBC Act*

The Brigalow Belt is home to what Dunn (1993) considered to be "Australia's most endangered butterfly". *Hypochrysops piceatus* (Buloke Jewel Butterfly) (Endangered) is restricted to a few small areas in the southern Brigalow Belt. These sites include an area of roadsides near Leyburn, Mount Emlyn near Millmerran, and sites near Goondiwindi including Bendidee National Park and adjacent Bendidee SF, with a sighting to be confirmed in Dunmore SF (Sands and New 2002). The larvae of the species feed exclusively on Buloke (*Allocasuarina luehmannii*). Sands and New (2002) described the habitat preferences of the butterfly *H. piceatus* in detail; "*Only old, mature growth of* A. luehmannii*, with unburnt, undisturbed grasses and an abundance of dead and fallen logs supporting the particular ants, are selected by butterflies as breeding sites. Young trees and regrowth of* A. luehmannii *are not utilised and the butterflies do not inhabit them*."

Another threatened endemic butterfly, *Jalmenus evagoras eubulus* (Imperial Hairstreak) (Vulnerable) is primarily found on mature brigalow (*Acacia harpophylla*) stands. Common and Waterhouse (1981) commented that larvae are "*never found*" on brigalow regrowth, unlike some other members of the genus *Jalmenus*. The larvae are always attended by ants from the genus *Iridomyrmex*, with which *J. e. eubulus* has a mutualistic relationship.

The land snails of the unique and localized "boggomosses" of the Dawson Valley have received particular conservation attention, as these habitats are under threat. *Elsothera hewittorum* sp. nov. and the monotypic endemic *Adclarkia dawsonensis* are restricted to these perennially wet environments. The boggomosses are small elevated peatbogs scattered among woodland communities which are kept moist by springs arising from the Great Artesian Basin. They represent a mesic refuge for these two species, which are relicts from wetter times (Stanisic 1996). *A. dawsonensis* is considered threatened by the proposed Nathan Dam construction, grazing and fire and is listed as Critically Endangered nationally.

3.5 Endemic and disjunct species

3.5.1 Endemism in the Australian flora

to be completed

3.5.2 Endemic flora of the Study Area

Around 378 plant taxa are endemic to the Study Area compared with 273 in South-East Queensland and 150 in the Central Eastern Rainforest Reserves of Australia. The endemic taxa are listed in Appendix 4 together with their conservation status.

Among the endemic taxa, 34 are Endangered, 52 are Vulnerable, 62 are Rare and 7 have a Provisional status. Three species are Extinct. Overall, 42 per cent of the endemic taxa are rare or threatened.

Of the 171 eucalypt taxa recorded from the Study Area, 48 are essentially endemic to the area, including many that are of outstanding evolutionary significance. The distributions of a selection of the endemic eucalypts were shown in Figure 2.19.

Among the 200 acacia taxa occurring in the Study Area, 49 are endemic thereto. Many of these are highly restricted and threatened. The distributions of a selection of the endemic acacias were shown in Figure 2.18.

Endemism among the flora of the Study Area is further discussed in Section 7.2.4.

3.5.3 Endemic fauna of the Study Area

The Brigalow Belt is a region with a large number of endemic reptiles, several endemic bird taxa, and relatively low endemism among frogs and mammals. Many of the bioregional endemics are lowland taxa, concentrated on either the Fitzroy or upper Murray-Darling Basins. Local endemism is higher in the uplands of the Great Divide. These populations are natural isolates from larger coastal populations and may be genetically distinct. If so, they may represent a significant component of the genetic diversity of their species and therefore contribute to the future ability of the species to adapt to change.

3.5.3.1 Reptiles

A total of 14 reptile species are endemic to the Brigalow Belt; only three other bioregions in Australia have more endemics (Wet Tropics, Cape York and Northern Kimberley) (Table 3.18). Significantly, the Study Area is home to several monotypic and ditypic endemics, unlike Cape York or the Northern Kimberley (Table 3.18). The presence of more than one reptile from monotypic or ditypic genera is a feature shared only by the Wet Tropics and South-East Queensland.

Covacevich *et al.* (1998) identified 13 species as "*confined to, or virtually confined to the Brigalow Belt*" and another 14 for which the bioregion is a significant part of the species range in Queensland (Table 3.19). Another species, *Delma labialis*, has only been recorded in the Townsville area and adjacent Magnetic Island, and therefore is also a Brigalow Belt endemic. These 28 species make up nearly 15 percent of the reptile fauna of the bioregion. The most distinct elements of the Brigalow Belt reptile fauna are at risk as twelve of the thirteen endemics listed by Covacevich *et al.* (1998) are threatened. Notably, nine of the species listed in Table 3.19 have only been described since 1980 (Covacevich *et al.* 1996), highlighting the importance of recent taxonomic endeavour in elucidating the conservation significance of the Study Area.

Table 3.18 Number of reptile endemics by bioregion in Australia and size of genera that are represented by endemics

Bioregion	Species	Genera	Monotypic genus	Ditypic genus	3-5 spp. in genus	6-10 spp. in genus	11-20 spp. in genus	21-50 spp. in genus	>50 spp. in genus
Wet Tropics	24	16	2	2	3	3	4	1	1
Northern Kimberley	23	13			1	4	4	2	2
Cape York	20	13		1	3	4		3	2
Brigalow Belt	**14**	**12**	**2**	**2**	**1**	**2**	**2**	**1**	**2**
South-East Queensland	11	9	4		2		1	1	1
Carnarvon	10	4						2	2
Pilbara	10	7		1			1	3	2
NSW North Coast	9	7	1		2	2	2		
Darwin Coastal	7	4				1		2	1
Arnhem Plateau	6	5			1		2	1	1

Table 3.19 Endemic reptiles in the Brigalow Belt bioregion (from Covacevich *et al*. 1998).

Species in BB class A	**Status**	**Species in BB class B**	**Status**
Rheodytes leukops	V	*Chelodina expansa*	P
Strophurus taenicauda	R	*Gehyra catenata*	S
Paradelma orientalis	V	*Oedura monilis*	S
Anomalopus brevicollis	R	*Saltuarius salebrosus*	S
Anomalopus mackayi	V	*Anomalopus leuckartii*	P
Ctenotus ingrami	P	*Egernia modesta*	S
Lampropholis mirabilis	R	*Egernia rugosa*	V
Lerista allanae	E	*Eulamprus sokosoma*	S
Lerista vittata	V	*Glaphyromorphus punctulatus*	S
Menetia sadlieri	R	*Lerista fragilis*	S
Denisonia maculata	V	*Menetia timlowi*	S
Furina dunmalli	V	*Hoplocephalus bitorquatus*	P
Hemiaspis damelii	E	*Pseudechis guttatus*	P
		Suta spectabilis dwyeri	S

BB Class: A- "Confined to, or virtually confined to the Brigalow Belt", B- "the Brigalow Belt is a significant part of their ranges in Queensland" (Covacevich et al. *1998). Status: X-Extinct, E-Endangered, V-Vulnerable, P- Priority or "Of Concern" species in the Brigalow Belt (Sources McFarland* et al. *1999 and Environmental Protection Agency 2002b), S-Secure.*

The monotypic endemics in Table 3.19 are *Paradelma orientalis* and *Rheodytes leukops* (Fitzroy Tortoise), and the species from ditypic genera are *Denisonia maculata* (Ornamental Snake) and *Hemiaspis damelii* (Grey Snake). *P. orientalis* is considered to be one of the most primitive legless lizards (along with members of the *Pygopus* genus), with Greer (1989) commenting that "*when we look at one of these species we may be looking at an animal not too dissimilar from the ancestral pygopodid*". It occurs in dry rainforests and eucalypt forests, and has the unusual habit of feeding on plant exudates such as acacia sap (Forest Ecosystem Research and Assessment 2001). Most remaining habitat is in State Forest in the large tracts of vegetation such as the Inglewood Sandstones, Barakula and Carnarvon Ranges Subregions. *D. maculata* is a small snake of rocky and blacksoil areas near water (Environmental Protection Agency 2002b) and records are centred on the Fitzroy River Basin. *H. damelii* is a species of eucalypt forests and woodlands (Cogger 2000) and "*grassy, swamp country*" (Environmental Protection Agency 2002b), but unlike *D. maculata* the species is centred on the Darling Downs. *R. leukops* is a tortoise of the larger rivers in the Fitzroy Basin, such as the Nogoa, Mackenzie, Comet and Dawson Rivers. The distribution of endemics from larger genera varies greatly. Some species (e.g. *Lampropholis mirabilis*, *Anomalopus mackayi*) are highly localized, but others (*Strophurus taenicauda* (Golden-tailed Gecko) and *A. leuckartii*) span most of the Study Area, including large populations in the eucalypt habitats of the State Forests.

3.5.3.2 Birds

There are six bird taxa with more than 75 per cent of their range or former range in the Brigalow Belt (Table 3.20), although one (Paradise Parrot) is globally extinct and another (Star Finch, southern subspecies) is probably extinct in the Brigalow Belt and may also be globally extinct. Five of the six endemics are/were lowland taxa, and the distribution of the other taxon (Pallid Shrike-thrush) is also arguably centred on the lowlands.

Table 3.20 Endemic birds in the Brigalow belt bioregion.

Species	Taxon	Status	Described
Squatter Pigeon (southern)	*Geophaps scripta scripta*	V	1821
Black-faced Woodswallow (Dawson)	*Artamus cinereus dealbatus*	S	1999
Pallid Shrike-thrush	*Colluricincla megarhyncha gouldi*	S	1858*
Paradise Parrot	*Psephotus pulcherrimus*	X	1845
Star Finch (southern)	*Neochmia ruficauda ruficauda*	CE/X	1837
Yellow Chat (Dawson)	*Epthianura crocea macgregori*	CE	1958

*Status: X-Extinct, CE-Critically Endangered, E-Endangered, V-Vulnerable, S-Secure. *-original taxon recognised as two subspecies by Schodde and Mason (1999) which altered range of C.m.gouldi*

The Squatter Pigeon is a granivore of lowland grassy woodlands. Land clearing and changes in floristic and habitat structure as a result of grazing have resulted in a contraction of the Squatter Pigeon (southern) *Geophaps scripta scripta* from the southern and eastern parts of its range (e.g. Brigalow Belt in New South Wales (Garnett and Crowley 2000), the Inglewood area and the Lockyer Valley (Environment Protection Agency 2002b)). Grassy woodlands (e.g. Poplar Box and Silver-leaved Ironbark woodland) in the Carnarvon Ranges Subregion including those within Theodore, Belington Hut and Presho State Forests are now a key refuge for the Squatter Pigeon.

The Black-faced Woodswallow (Dawson) *Artamus cinereus dealbatus* was described by Schodde and Mason (1999) and is largely found at low altitudes, notably in the Dawson and Comet River valleys. This species is an insectivore of very open woodlands and grasslands and generally occupies more open habitats than the other woodswallows. It virtually avoids the open forests and woodlands of the ranges and even the relatively open woodlands of the Inglewood Sandstones and Barakula Subregions.

The Pallid Shrike-thrush *Colluricincla macrorhyncha gouldi* was formerly thought to occur north to the Clarke Range and the Einasleigh Uplands, but Schodde and Mason (1999) circumscribed the northern populations as *C. m. synaptica*, which is smaller and richer brown in colour than *C. m. gouldi*. This discovery means that *C. m. gouldi* is restricted to the dry rainforests of the Dawson and Mackenzie River basins, and is one of only two Brigalow Belt endemic vertebrates that are rainforest specialists (the other is the skink *Anomalopus brevicollis*). Isolated populations of the species well upstream on the Dawson River are well beyond the published range of the taxon in Schodde and Mason (1999) and are therefore of great interest. Records of the “Little Shrike-thrush” from Isla Gorge NP and Brigalow Research Station near Theodore in recent years are likely to be *C. m. gouldi* and there may be other populations in this area. A record from near the northern edge of Expedition National Park in the 1970s indicates the taxon may be present even further west. Crossman and Reimer (1986) collected this record and dismissed it as a likely vagrant but this conclusion is probably incorrect given the sedentary nature of the species (and of all species in the genus *Colluricincla*) and the suitability of dry rainforest habitat in the region as evidenced by recent “Little Shrike-thrush” records well upstream into the Dawson catchment.

The Star Finch *Neochmia ruficauda ruficauda* is probably extinct in the Brigalow Belt (the former core of its distribution); it was last recorded in the Brigalow Belt in 1985. It may be globally extinct. Garnett and Crowley (2000) reported that only four confirmed sightings had been made of the species anywhere since 1990, and suggested that less than 50 individuals remain. The uncertainty of where these small populations may remain makes it impossible to establish what bioregion if any the taxon may still be present in.

The Yellow Chat (Dawson) *Epthianura crocea macgregori* is Critically Endangered, with only one remaining population in swampy grassland and sedgeland on Curtis Island. Garnett and Crowley (2000) reported that just 14 birds were located on a three-day search of this area in June 2000. The taxon once also occurred on the mainland along the lowlands of the Fitzroy River (Garnett and Crowley 2000).

The Paradise Parrot *Psephotus pulcherrimus* was one of three *Psephotus* species in Australia that inhabited grassy woodland and nested in termitaria. It was last sighted in 1927. It represented a tropical woodland element of the Brigalow Belt; its two relatives are the Golden-shouldered Parrot of Cape York Peninsula and the Hooded Parrot of the Top End. Fairly accurate site records suggest the species may have occurred in grassy woodlands (possibly *Eucalyptus melanophloia* woodland) in Belington Hut SF, Presho SF and nearby areas.

3.5.3.3 Mammals

The only Brigalow Belt endemic among the mammals is the undescribed 'Central Highlands Plague Rat' (*Pseudomys* sp.), which is currently known only from Brigalow Belt North, where it has been recorded at several locations in recent years. However, the Brigalow Belt is now the last refuge of two Endangered species, the Bridled Nailtail Wallaby and Northern Hairy-nosed Wombat. These were dubbed '*new endemics*' to the Brigalow Belt by McKenzie and Burbidge (2002) because massive changes associated with European settlement have caused their extinction elsewhere. Both species are now restricted to single locations in Brigalow Belt North and are subject to major recovery planning efforts.

3.5.3.4 Invertebrates

Insect taxa from a wide range of groups have been recorded in the Brigalow Belt only, including spiders (*Lampona taroom*, *Lamponella taroom*, *Notsopidus broadwater*) (Platnick 2003), predatory mites (*Phytoseius brigalow*) (Walter and Beard 1997), water striders (*Microvelia carnarvon and M. woodwardi*) (Andersen and Weir 2003), land snails (*Rotacharopa annabelli*) (Stanisic 1990), and (*Elsothera hewittorum* and *Adclarkia dawsonensis*) (Stanisic 1996), dragonflies (*Austroaeschna unicornis pinheyi*) (Theischinger 2001), moths (*Paralaea maranoa*) (McQuillan *et al.* 2001), stiletto flies (*Agapophytus adonis*, *A. atrilaticlavius* and *A. fenestratum*) (Winterton and Irwin 2001), butterflies (*Hypochrysops piceatus, Trapezites taori, Acrodipsas arcana and Jalmenus evagoras eubulus*) (Sands and New 2002), *Hesperilla furva, H. delicia duaringae,* and *J. daemeli,* (Common and Waterhouse 1981) and beetles (*Sphallomorpha carnarvona*) (Baehr 1993), (*Canthosoma castelnaui*, *C. macleayi* and *C. mastersi*) (G. Monteith pers. comm.). There are probably hundreds, and possibly thousands more invertebrate species that are endemic to the Brigalow Belt.

3.5.4 Relictual and disjunct fauna

3.5.4.1 Introduction

A notable aspect of faunal endemism in the Brigalow Belt is the presence of disjunct populations in mesic refugia throughout the bioregion. The Brigalow Belt South Expert Fauna Panel (Environmental Protection Agency 2002b) recognized 14 species with disjunct populations in the Study Area, and further investigation of species records and habitat preferences suggests at least another 10 species have disjunct populations and possibly many more. There are disjuncts in all the major fauna groups.

The disjunct populations may provide important clues for unravelling the influence of geomorphology and climate change on the evolution of Australia's fauna. *Saltuarius salebrosus* has a highly relict distribution in the uplands of the Blackdown Tableland, Dawes Range (including Grevillea and possibly Coominglah State Forests) and the Carnarvon Ranges Subregion. Most populations are found in sandstone caves and overhangs although the individuals in Grevillea SF were found on eucalypts (S. Kennedy pers. obs.). The continued presence of such an ancient element of the reptile fauna implies that these refugia have a long history of relative climatic and geological stability.

Moritz and Playford (1998) stated that "*for species predominantly in mesic or higher elevation dry forests, wet sclerophyll and rainforest, genetic diversity can only be represented by protecting multiple populations across the range*". Many disjunct populations in mesic refugia in the Brigalow Belt require investigation. They have been isolated from the coastal populations, and have evolved under different environmental pressures, potentially leading to allopatric speciation. Advances in phylogenetic research have uncovered many "cryptic species" among frogs and reptiles in eastern Australia in particular, but none of this work has been targeted at the mesic refugia of the Brigalow Belt, apart from those at Blackdown Tableland (Moritz and Playford 1998).

Distinct genetic differences are potentially important for the ability of the species to adapt to future change, and should be managed as a separate biological entity (Moritz 1994, Moritz and Faith 1998). Genetic differences that exist between disjunct Brigalow Belt and coastal populations may provide valuable insights into the time of their divergence (Keogh *et al.* 2003).

Small, isolated and disjunct populations are potentially more vulnerable to extinction, particularly those dependent on permanent water or dense vegetation. Poor management or single stochastic events (e.g. fires, droughts) may eliminate populations that would otherwise have survived in higher quality habitats and larger refugial populations. Extinction of disjunct populations with essential adaptive traits would represent the endpoint of thousands or millions of years of evolutionary adjustment in fauna enabling their persistence in the Study Area.

The Carnarvon population of the Common Ringtail Possum may have already been lost (Environmental Protection Agency 2002b). If this has occurred, it would be a significant loss for the fauna of this area, and the ubiquity of the species in coastal Queensland does not diminish the seriousness of this local extinction. A disjunct southerly population of the White-browed Robin in the dry rainforests between the Dawson and Expedition Ranges was lost with the extensive clearing of these habitats in the 1960s (H. Nix pers. comm.). The nearest recent record of this species is some 120 km to the north-east in the Mt Morgan district.

3.5.4.2 Potentially distinct taxa

Genetic divergence in South-east Queensland taxa was predicted to be greater among species with limited dispersal capacity, habitat specialists, and in more separated elements of the mesotherm archipelago by Moritz and Playford (1998). The following species with these traits are worthy of further investigation in the Brigalow Belt. *Oedura tryoni* in "western populations" has already been noted as a possible separate species by Moritz and Playford (1998). Disjunct reptile populations are also found in *Saltuarius salebrosus*, *Lampropholis delicata* and *L. amicula*, *Delma torquata*, *Cyclodomorphus gerrardi, Notechis scutatus* and *Anomalopus verreauxi*.

Oedura tryoni

Oedura tryoni, the Southern Spotted Velvet Gecko is a species found predominantly in northern NSW, South-east Queensland and the Brigalow Belt. Moritz and Playford (1998) studied mtDNA variation between populations of *O. tryoni* in South-East Queensland, Girraween NP and Blackdown Tableland. They found that the Blackdown Tableland – Girraween clade had a high level of sequence divergence from other populations that suggested "western populations" may represent a separate species. Moritz and Playford (1998) concluded that "*further sampling of western populations is needed to test this hypothesis*". This result demonstrates the potential of phylogenetic studies to dramatically alter our perception of the conservation significance of fauna.

If Moritz and Playford (1998) are correct, the "western" *O. tryoni* is likely to be Brigalow Belt endemic (a probable >75% of range in Brigalow Belt, with the rest on New England Tableland). It would also represent a Brigalow Belt endemic with the closest affinity to the uplands, as the bulk of records are from the Carnarvon Ranges, Woorabinda, Barakula and Banana-Auburn Ranges Subregions.

Moritz and Playford (1998) suggested that *O. tryoni* was predominantly saxicolous. However, there are arboreal populations of *O. tryoni* in areas with no major rock outcrops (e.g. the Auburn Ranges, Barakula-Allies Creek State Forests, Coominglah State Forest). Like their congener, *O. robusta*, many *O. tryoni* were found under bark on larger trees or standing dead trees at these sites (S. Kennedy pers. obs.). There is also a population in the eastern Carnarvon Ranges Subregion, including Theodore, Presho and Belington Hut State Forests. There are records in Boxvale SF further west, but none from Carnarvon NP.

One cannot conclude on the basis of published data that sufficient sampling of western populations has occurred to test Moritz and Playford's hypothesis.

Egernia

Many skinks of the genus *Egernia* are restricted to rocky refugia and have a complex social structure. Many are also poor dispersers, with short, stout limbs.

Egernia cunninghami

A population of *E. cunninghami* is known from the Carnarvon NP, more than 400 km from the nearest records.

Egernia modesta

E. modesta is closely related to *E. whitii*. Recent taxonomic study found that the south-eastern populations of *E. whitii* actually represented three separate species (Donnellan *et al.* 2002). One species is found in isolated disjuncts on granite geology, and another only at the highest altitudes.

E. modesta occurs largely in the Brigalow Belt and the drier parts of SEQ. Records of *E. modesta* in the Carnarvon Ranges Subregion (Theodore SF) appear to represent a disjunct population, as they are more than 100 km west of the nearest records in the upper Burnett catchment. The ecological similarity of *E. modesta* and *E. whitii* and the potentially long isolation of this population make a genetic study a priority.

Eulamprus quoyii

O'Connor and Moritz (2003) noted that ongoing study of *E. quoyii* has also uncovered significant genetic variation including cryptic species, information that is not yet published. *E. quoyii* is relatively continuous in the Brigalow Belt, with lowland populations along the Dawson River in particular. However the geographic spread of the species may still include significant variation, as cryptic species may occur sympatrically among what appear to be continuous populations of a single species.

Eulamprus sokosoma

The review of *Eulamprus* by O'Connor and Moritz (2003) did not include populations of *E. sokosoma* on Blackdown Tableland and Carnarvon Ranges. These populations appear to be highly disjunct from each other and from northern populations.

Carlia mundivensis

A number of *Carlia mundivensis* were found in Nathan Gorge, 130 km south of the nearest known population (EPA records).

Disjunct frogs

Cryptic species have been found in a number of Australian frogs, and species with broad geographic ranges and a wide altitudinal range are considered prime candidates for the discovery of more cryptic species. Cryptic species were recently found in *Litoria lesueuri* (Stony-creek Frog) (Donnellan and Mahony 2004). This "species" has a broad geographic and altitudinal range with apparent disjuncts in the Brigalow Belt (Carnarvon Ranges Subregion). (Donnellan and Mahony 2004) did not study any Brigalow Belt specimens of *L. lesueuri*. Carnarvon Ranges and Woorabinda Subregion populations of *Adelotus brevis* (Tusked Frog) are also highly disjunct.

3.6 Faunal richness

The Brigalow Belt has exceptional richness in a number of fauna groups. At a bioregional level, the Brigalow Belt is the richest in Australia or shares the highest number of species with other bioregions for the groups discussed here. The main factor linking these groups is that eucalypt woodlands (as opposed to open forests, brigalow or dry rainforest) support by far the highest diversity in each group.

3.6.1 Burrowing frogs

The favourable climate, fertility and soil structure in the Brigalow Belt has enabled the development of one of the richest and most diverse assemblages of burrowing frogs in Australia (15 species). The assemblage is richer than in Queensland's coastal regions, where there is more permanent water and frogs generally do not need to burrow, and richer also than the semi-arid inland where conditions are possibly too severe for many species. The Brigalow Belt experiences long dry periods and permanent water is scarce but when heavy summer and autumn rains fall, the alluvial and "downs" areas are flooded and the burrowing frogs emerge. The cracking clays provide a major refuge for several species, which shelter in the moist layer at the foot of the cracks (Tyler 1989). The woodlands and grasslands of the fertile "blacksoil" areas may produce a high biomass of arthropods, a major component of the diet of burrowing frogs.

The Brigalow Belt's burrowing frogs include six *Cyclorana* species (the richest assemblage of the genus in Australia) and species from the genera *Limnodynastes, Neobatrachus*, *Notaden* and *Uperoleia*. Probably the best known of these is the Water-holding Frog (*Cyclorana platycephala*), which can aestivate for more than five years (van Beurden 1982). The species extends across the southern deserts of Australia but also occurs as far east as Lake Broadwater, Yuleba SF and the Moonie district in the Brigalow Belt. Key adaptations of the burrowing frogs are listed in Section 2.4.4.2.

3.6.2 Arboreal reptiles

The Brigalow Belt has the richest arboreal reptile fauna in Australia, with a total (35) that compares favourably to other Australian states (Table 3.21). The arboreal geckoes are a prominent feature of any eucalypt habitat in the Study Area, and one may observe five species at a single site (S. Kennedy pers. obs.). Arboreal skinks are also well represented but several species are localized or replace each other rather than occurring together. Key arboreal reptile genera and adaptations are discussed in Section 2.4.5.2.

Table 3.21 Species richness of arboreal reptiles in Australia

	Geckoes	Dragons	Skinks	Goannas	Pythons	Colubrid Snakes	Elapid Snakes	TOTAL
QLD	21	11	12	4	5	3	2	58
Brigalow Belt, Qld	**12**	**7**	**9**	**2**	**2**	**2**	**1**	**35**
WA	13	8	5	4	3	2	0	35
NSW	12	6	6	2	3	2	3	34
NT	7	5	4	3	4	2	0	24
SA	7	7	5	3	2	0	0	23
VIC	4	4	5	1	1	0	0	15
Aust Total	30	15	14	5	6	3	3	76

Source: Cogger (2000), ***Environmental Protection Agency fauna records***

3.6.3 Elapid snakes

Elapid snakes are a major feature of Australia's reptile fauna, and 93 per cent of terrestrial elapids are endemic. The Australian terrestrial elapids are thought to have an African or Asian origin, having entered Australia with the collision of the Australian and Asian tectonic plates in the mid-Miocene but subsequently radiating to become the most diverse elapid clade in the world (Keogh 1998). No continent outside Australia has more than 10 terrestrial elapid genera (Table 3.22). The Brigalow Belt has 15, the highest number of any bioregion alongside South-East Queensland and Northern NSW Coast (Table 3.23).

The eucalypt woodlands are the stronghold of elapid diversity, with woodland species greatly outnumbering open eucalypt forest and rainforest species. There are 25 species described as using woodlands but not open eucalypt forest or rainforest. Two of these (*Hemiaspis damelii* and *Denisonia maculata*) are endemic to the Brigalow Belt. By contrast, no Australian elapid snake species occurs exclusively in rainforest (Wilson and Knowles 1988).

Table 3.22 Richness and distribution of major elapid snake radiations

Elapid Group	Genera	Species	Distribution
Elapines			
Cobras	10	37	Africa, Middle East, Asia
American coral snakes	2	61	North, Central, and South America
Asian coral snakes	2	16	Asia
Terrestrial kraits	1	12	Asia
Hydrophiines			
Melanesian elapids	7	17	New Guinea, Solomon Islands, Fiji
Australian elapids	**20**	**88**	**Australia, New Guinea (some)**
Sea kraits	1	5	Asia
True sea snakes	16	57	Equatorial waters around the world but most in SE Asia and the Australo-Papuan region

Source: Keogh (1998)

Table 3.23 Generic richness of elapid snakes in Australian States and the Study Area

Area	**Total number of genera**
NSW	19
Qld	16
Study Area	**15**
WA	13
SA	13
VIC	12
NT	10
TAS	2

3.6.4 Woodland birds

Traill and Duncan (2000) nominated 24 bird species that identify a temperate woodland fauna in NSW. A further 19 species were identified as specialist woodland fauna by consulting National Land and Water Resources Audit (2001) for extent of woodland and investigating distribution and habitat preferences in Blakers *et al*. (1984). Based on these 43 species, the Brigalow Belt has the richest assemblage of woodland specialist birds of any region in Australia (Table 3.24). It supports nine species shared with temperate woodlands (NSS, VM and south-west Western Australia) and five shared with tropical woodlands (Northern Territory and EIU). The 43 species identified as woodland specialists are listed in Table 3.25.

Table 3.24 Species richness of specialist woodland birds in Australian States and the Study Area

Area	**Total number of species**
Queensland	31
Cape York Peninsula	17
Einasleigh Uplands	18
South-East Queensland	22
Study Area	**23**
NSW	23
WA	22
NT	20
VIC	20
SA	18

Nine SEQ species are largely restricted to woodlands in rainshadow areas such as the Lockyer Valley and some western State Forests, with much larger populations in the Brigalow Belt

Table 3.25 Status and distribution of specialist woodland birds in Australia

Species	Equivalent species**	NT*	EIU	BB	NSS	VM	SW WA*
Bush Stone-curlew		NT	NT	**P**	E	E	NT
Squatter Pigeon	Partridge Pigeon		S	**V**			
Partridge Pigeon	Squatter Pigeon	S					
Long-billed Corella						S	
Western Corella							E
Carnaby's Black-Cockatoo							E
Red-winged Parrot		S	S	**S**	S		
Red-rumped Parrot				**S**	S	S	
Paradise Parrot				**X**			
Golden-shouldered Parrot	Paradise Parrot						
Hooded Parrot	Paradise Parrot	S					
Superb Parrot	Regent Parrot				V		
Regent Parrot	Superb Parrot						S
Yellow Rosella					S		
Pale-headed Rosella	Northern Rosella		S	**S**			
Northern Rosella	Pale-headed Rosella	S					
Swift Parrot				**E**	E	E	
Turquoise Parrot				**R**	V		
Varied Lorikeet		S	S				
Brown Treecreeper	Black-tailed Treecreeper		**P**	**P**	V	NT	
Black-tailed Treecreeper	Brown Treecreeper	S	P				
Rufous Treecreeper	Brown Treecreeper						S
Speckled Warbler				**P**	V	V	
Western Thornbill							S
Western Gerygone		S	S	**S**	S	S	S
Restless Flycatcher		S	S	**S**	S	S	S
Silver-crowned Friarbird		S					
Regent Honeyeater				**E**	E	E	
Yellow-tufted Honeyeater				**S**	S	S	
Fuscous Honeyeater		S	S	**S**	S	S	
Black-chinned Honeyeater		S	R	**R**	V	NT	
Brown-headed Honeyeater				**S**	S	S	S
Rufous-throated Honeyeater		S	S	**S**			
Painted Honeyeater		NT	R	**R**	V	V	
Grey-crowned Babbler		S	NT	**P**	V	E	
Little Woodswallow		S	S	**P**			S
Black-throated Finch	Long-tailed Finch		S	**V**			
Long-tailed Finch	Black-throated Finch	S					
Plum-headed Finch			S	**S**	S		
Diamond Firetail				**P**	V	V	
Star Finch		S	E	**X**			
Masked Finch		S					
Gouldian Finch		E	E				
Threatened species		*1*	*4*	*7*	*11*	*7*	*2*
Total species		20	17	**23**	20	16	10

Status: X-Extinct, E-Endangered, V-Vulnerable, R-Rare, S-Secure. P- Priority or "Of Concern" species for the Brigalow Belt only (Sources McFarland et al. *1999 and Environmental Protection Agency 2002b),*
** NT and WA have no threatened species legislation, so classifications for these are national status from Garnett and Crowley (2000). Codes as already described except NT-Near Threatened. ** "Equivalent species" are geographically isolated pairs of congeneric species that appear to occupy the same niche in different parts of Australia.*

3.6.5 Microbats

The bat fauna of the Brigalow Belt is exceptionally rich, with 36 of Australia's 63 microchiropteran bat species, including 17 of the 26 Australian species of the family *Vespertilionidae*. There are more microchiropteran bat species in the Study Area than in other Australian States (Table 3.26). At least 23 of these species use tree hollows (Menkhorst 2001) and several more are cave-dwelling species that roost in sandstone overhangs in the Brigalow Belt.

Table 3.26 Species richness of insectivorous bats in Australian States and the Study Area

Area	**Total number of species**
Queensland	56
Study Area	**36**
WA	34
NT	33
NSW	31
SA	21
VIC	21

3.6.6 Macropods

The Brigalow Belt has the richest macropod fauna of any bioregion in Australia (14 species)(Table 3.27), equalled only by the Wet Tropics. Two of these species have declined dramatically (Spectacled Hare-wallaby and Bridled Nailtail Wallaby), but the other species are still relatively widespread, although there is some concern for the Black-striped Wallaby and the Herbert's Rock-wallaby (Environment Protection Agency 2002b). The only state with a richer macropod fauna than the Brigalow Belt is Western Australia, but no bioregion in Western Australia supports 14 species of macropods, with several species found exclusively in the tropics or the temperate south in that state.

Table 3.27 Species richness of macropods in Australian States and the Study Area

Area	**Total number of species**
Queensland	30
WA	17
Study Area	**14**
NSW	13
NT	10
SA	9
VIC	7

3.7 Significance of the Brigalow Belt for conservation of woodland fauna

3.7.1 Introduction

The eucalypt woodlands are a distinctive element of Australia's vegetation, occurring widely in tropical, subtropical and temperate Australia. Woodland is generally defined as having 20 to 50 per cent crown cover or 10 to 30 per cent foliage cover (National Forest Inventory 2003; National Land and Water Resources Audit 2001). In eastern Australia, the woodlands lie between the eucalypt open forests and rainforests of wetter coastal areas and the shrublands and grasslands of the interior.

There are large areas of woodland in the temperate, subtropical, tropical and semi-arid zones of Australia. About 50 million hectares of woodland has been cleared for agriculture. The biggest losses have been in the temperate woodlands (Yates and Hobbs 2000), but investigation of National Land and Water Resources Audit (2001) and Stern *et al.* (2000) revealed that the zone of extensive clearing for agriculture also extends well into the subtropical woodlands. The temperate and subtropical woodlands together form the "sub-humid" woodlands of Australia and share a large number of fauna.

The woodlands of the Brigalow Belt, with a total area of about 10 million hectares, represent 42 per cent of the "sub-humid" woodlands remaining. The remaining unfragmented landscapes in the Brigalow Belt provide habitat for the most intact assemblage of a "sub-humid" woodland fauna that once occurred across tens of millions of hectares of southern and eastern Australia. This distinguishes the Brigalow Belt from the other extensive areas of woodland that remain in Australia, which occur in semi-arid and tropical zones and have distinctly different fauna communities.

3.7.2 Clearing of the temperate and subtropical woodlands

The significance of the Brigalow Belt is best appreciated in the context of the environmental history of Australia's sub-humid woodlands. Historical accounts and vegetation mapping suggest that unbroken woodlands with populations of top-order predators (e.g. Barking Owl, Dingo and quolls), and woodland birds (e.g. Bush Stone-curlew, Grey-crowned Babbler, Speckled Warbler) were extensive over much of the sub-humid zone when Europeans arrived in the 18th century. However, this woodland "belt" has been decimated by clearing (See Figure 3.9.), particularly in south-west Western Australia, south-east South Australia, northern Victoria and the western slopes of New South Wales (Saunders 1989; Sivertsen 1993; Robinson and Traill 1996). This has been followed by a collapse in populations of once characteristic and widespread woodland species (Reid 1999; Ford *et al.* 2001; Possingham and Field 2001).

The demise of woodland fauna in southern Australia has been swift (in an evolutionary sense) and catastrophic. Woodland fauna assemblages are now dysfunctional across virtually all of both the sub-humid and semi-arid zones of Australia. Bettongs and hare-wallabies are extinct, top-order predators are threatened or extinct and woodland birds are in alarming decline. Local extinctions are still occurring in the highly fragmented landscapes in southern Australia several decades after broad-scale clearing ended, as the 'lag time' is completed between isolation of fauna populations and their ultimate demise in a district (e.g. Traill *et al.* 1996; Possingham and Field 2001). Given that broad-scale clearing has occurred in the Brigalow Belt relatively recently, numerous local extinctions after a "lag time" will probably also occur in the fragmented 'downs' areas in coming decades.

3.7.3 Extent of Brigalow Belt woodlands

Objective classifications of climate and vegetation were consulted to establish the relative extent of woodlands in the Study Area within the temperate and subtropical zones of Australia. Climate zones were defined in the "Objective Classification of Australian Climates" by Stern *et al.* (2000) for the Commonwealth Bureau of Meteorology (Figure 3.8). The "temperate" and "subtropical" zones were included in the analysis.

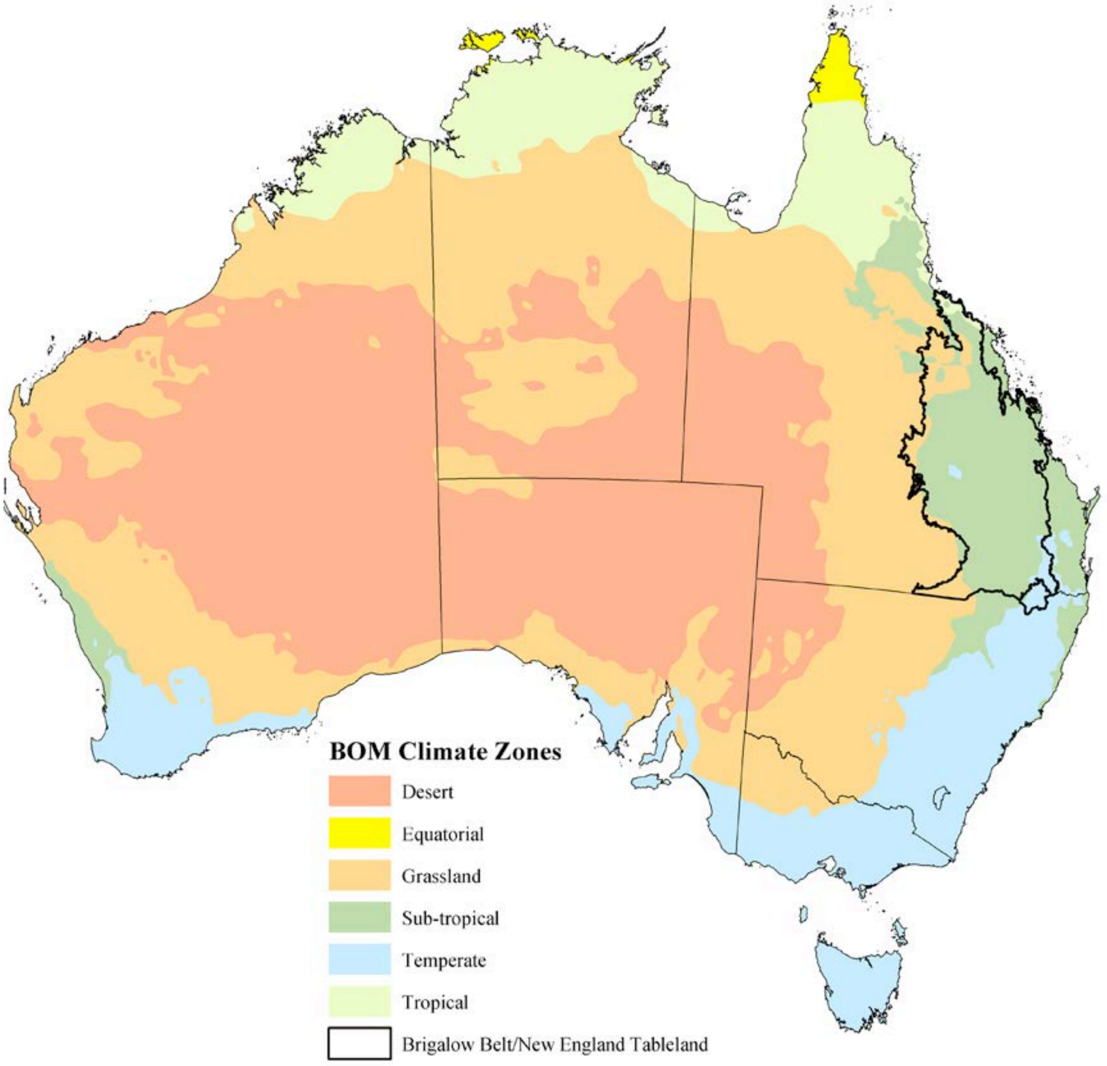


Figure 3.8 Climate zones of Australia. Source: *Objective Classification of Australian Climates*, Stern *et al.* (2000) for the Commonwealth Bureau of Meteorology

Vegetation was assessed using the National Vegetation Information System (NVIS), which was established by the National Land and Water Resources Audit for its national assessment of native vegetation (National Land and Water Resources Audit 2001). The 'eucalypt woodland' and 'open eucalypt woodland' vegetation types were included in the analysis, but not 'open eucalypt forest' of wetter, more coastal areas. It is noted that mapping of areas woodland by National Land and Water Resources Audit (2001) and by National Forest Inventory (2003) does not coincide. Maps of eucalypt woodland and eucalypt open forest contained in *Australia's State of the Forests Report* (National Forest Inventory 2003) are difficult to reconcile.

This analysis found that 58 per cent of woodland in temperate and subtropical zones (i.e. sub-humid woodland) has been cleared, and that the Brigalow Belt has most of the largest areas of sub-humid woodland remaining in Australia. The Study Area accounts for 42 per cent of what remains (Figure 3.9).

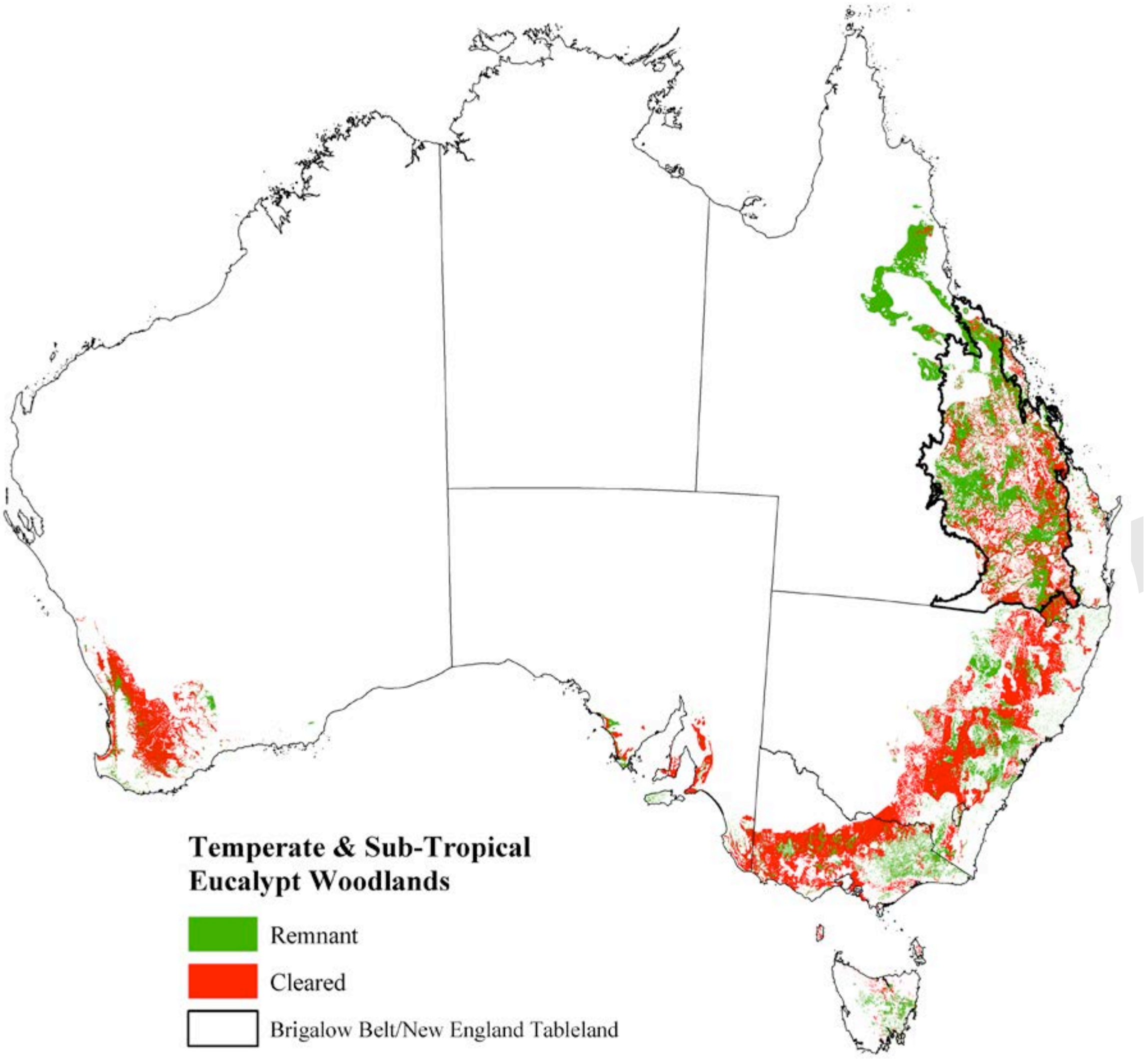


Figure 3.9 Pre-european and current distribution of temperate and subtropical woodlands of Australia

The core remnant areas (e.g. Carnarvon Ranges, Barakula-Allies Creek, Inglewood Sandstones, Auburn Ranges, Expedition Range and Pilliga (NSW)) range from around 60 000 hectares up to several hundred thousand hectares in size. This is much larger than anything left in the temperate woodlands. For example, there are no remnants of more than 30 000 hectares in the box-ironbark woodlands of the Victorian Midlands bioregion, an area of about 3 million hectares (ECC 2001).

3.7.4 Brigalow Belt as a refuge for declining woodland species

The extent of the Brigalow Belt woodland is significant as many fauna now extinct or threatened after the extensive clearing of temperate woodlands are still present in the subtropical woodlands of the Brigalow Belt. The Brigalow Belt presents an unparalleled opportunity to conserve healthy, resilient populations of many declining woodland species (B. Traill pers. comm.). Species for which the Brigalow Belt represents a major conservation opportunity are listed in Table 3.28. The Brigalow Belt woodlands are not in optimal condition, but the sheer size of the core areas may enable them to support species that will continue to disappear from the fragmented landscapes as "lag times" between isolation and extinction are completed.

Table 3.28 Species that have decline d in temperate woodlands for which the Brigalow Belt is a major conservation opportunity

Species	BB	NSW	VIC
Bush Stone-curlew	P	E	E
Square-tailed Kite	R	V	E
Glossy Black-Cockatoo	V	V	-
Turquoise Parrot	R	V	NT (only in far NE)
Barking Owl	P	V	E
Masked Owl	P	V	E
Powerful Owl	V	V	V
Speckled Warbler	P	V	V
Grey-crowned Babbler	P	V	E
Brown Treecreeper	P	V	NT
Black-chinned Honeyeater	R	V	NT
Diamond Firetail	P	V	V
Quolls (*Dasyurus spp.*)	P (Northern)	X (Eastern)	X (Eastern)
Brush-tailed Phascogale	P	V	V
Northern Hairy-nosed Wombat	E	X	X
Squirrel Glider	P	V	E
Rufous Bettong	P	V	X
Bridled Nailtail Wallaby	E	X	X
Yellow-bellied Sheathtail-bat	S	V	V
Greater Long-eared Bat	R	V	V
Dingo	S	*	X in woodland areas (ECC 1997)

Status: X-Extinct, E-Endangered, V-Vulnerable, R-Rare, S-Secure. P- Priority or "Of Concern" species for the Brigalow Belt only (Sources McFarland et al. *1999 and Environmental Protection Agency 2002b),*
**-The Dingo is present in the Pilliga and Goonoo forests in the NSW section of BBS, but their status elsewhere in the NSW woodlands is unknown*

Temperate box-ironbark woodlands of Victoria and New South Wales share many fauna with the Study Area because they are a temperate analogue of the Brigalow Belt, with similarities in vegetation structure and floristics (B. Traill pers. comm.). The Brigalow Belt, New England Tableland, New South Wales South-western Slopes and Victorian Midlands bioregions together account for most of the "sub-humid" region of eastern Australia as outlined in Hobbs and Saunders (1994). These four bioregions form the core distribution of many characteristic woodland species (e.g. Turquoise Parrot, Speckled Warbler, Yellow-tufted Honeyeater, Regent Honeyeater, Fuscous Honeyeater, Diamond Firetail and Yellow-footed Antechinus).

The differences between the Brigalow Belt and temperate woodlands largely relate to additional faunal elements present in the Brigalow Belt, rather than major contrasts in species composition. One additional element is the diverse assemblage of granivorous birds in the Brigalow Belt, a feature shared with tropical Australia. These include the *Geophaps* pigeons, *Poephila* finches, Star Finch, and formerly the termitaria-nesting group among the *Psephotus* parrots (the Paradise Parrot is now extinct). The reptile, bat and macropod faunas are all much richer in the Brigalow Belt, with many additional species to their temperate woodland equivalents. Arboreal reptiles, cave-dwelling bats and macropods of rocky areas in particular are prominent in the Brigalow Belt only.

3.7.5 Brigalow Belt as a refuge for an intact woodland fauna community

A major value of the unfragmented landscapes in the Brigalow Belt is the relative completeness of the fauna community. Elements that are extinct or declining in much of Australia's sub-humid woodland (top-order predators, small macropods and woodland birds) persist at sufficient abundances to drive ecosystem processes.

Top-order woodland predators include the Barking Owl, Powerful Owl, Dingo, Northern Quoll and Lace Monitor. These species or their equivalents are either extinct or threatened in the sub-humid woodlands across the rest of Australia (Table 3.29). The continued presence of the Dingo (See Section 2.4.7.2.) appears to suppress foxes to the benefit of Bush Stone-curlews, Rufous Bettongs and Squatter Pigeons. If this pattern is causal, then the presence of the Dingo can be considered a major factor in maintaining a functional woodland fauna community.

Table 3.29 Status of top-order predators in southern box-ironbark woodlands* and the Brigalow Belt

Species	Box-ironbark woodlands	Brigalow Belt
Quolls**	X (Eastern Quoll)	P (Northern Quoll), X (Western Quoll)
Powerful Owl	V	V
Barking Owl	E (<50 pairs in Vic, ECC 1997)	P
Dingo	X	S
Lace Monitor	V	S

*Status: X-Extinct, E-Endangered, V-Vulnerable, P-Priority species (Environment Protection Agency 2002b), S-secure *-the "southern box-ironbark woodlands" encompass the New South Wales South-west Slopes and Victorian Midlands bioregions. **The Spotted-tailed Quoll is also present but marginal and rare in both areas.*

Macropods of a range of sizes are still present in the Brigalow Belt, whereas only the larger macropods survived European invasion in the southern box-ironbark regions (Table 3.30).

Table 3.30 Status of macropods in southern box-ironbark woodlands* and the Brigalow Belt. *(Species listed in order of weight from Strahan (1983))*

Species	Box-ironbark woodlands	Brigalow Belt
LARGEST		
Grey Kangaroos	S	S
Wallaroo	_	S
Whiptail Wallaby	_	S
Red-necked Wallaby	_	S
Swamp Wallaby	S	S
Black-striped Wallaby	_	P
Herbert's Rock-wallaby	_	P
Bridled Nailtail Wallaby	X	E (now in BBN only)
Hare-wallabies	X (Eastern)	P (Spectacled) (now in BBN only)
Rufous Bettong	X	P
SMALLEST		

*Status: X-Extinct, E-Endangered, P- Priority or "Of Concern" species in the Brigalow Belt (Sources McFarland et al. 1999 and Environmental Protection Agency 2002b), S-Secure. _-Was never present. Brigalow Belt macropod communities are naturally more species rich, as they are augmented by several wallabies found in rocky areas or with Torresian distributions. *-the "southern box-ironbark woodlands" encompass the New South Wales South-west Slopes and Victorian Midlands bioregions.*

It can be seen from Table 3.25 that populations of woodland bird specialists in the Brigalow Belt are faring better than their temperate counterparts. Of 15 woodland specialists shared by the Brigalow Belt, New South Wales South-west Slopes and the Victorian Midlands, nine are threatened in NSW, seven in Victoria and only four in the Brigalow Belt. This difference in status is explained by the difference in the seven ground-feeding and/or ground-nesting birds (Table 3.31). Five of the seven species are threatened in NSW and four in Victoria, but none in the Brigalow Belt (although five are Of Concern). This is significant as this element of the woodland bird community has been a major conservation concern, and is highly vulnerable to fragmentation and understorey degradation.

Table 3.31 Status of ground foraging and/or nesting woodland birds in southern box-ironbark woodlands* and the Brigalow Belt.

Species	Box-ironbark woodlands	Brigalow Belt
Bush Stone-curlew	E	P
Red-rumped Parrot	S	S
Brown Treecreeper	V (NSW), NT (Vic)	P
Speckled Warbler	V	P
Restless Flycatcher	S	S
Grey-crowned Babbler	V (NSW), E (Vic)	P
Diamond Firetail	V	P

Status: E-Endangered, V-Vulnerable, P-Priority species (Environment Protection Agency 2002b), S-secure

3.7.6 Fauna of semi-arid and tropical woodlands

The semi-arid and tropical woodland zones are less suitable for intensive agriculture and extensive areas of woodland remain in these areas. However, they are not as relevant for conservation of the fauna communities that once occupied the now extensively cleared woodlands of southern and eastern Australia. Semi-arid woodlands have several key differences and have also lost a significant number of mammal fauna. Tropical woodlands are relatively intact but their fauna communities are also fundamentally different with an absence of many species shared by the Brigalow Belt and the temperate woodlands.

The fauna communities of semi-arid woodlands are different to sub-humid woodlands in a number of ways. Lorikeets are virtually absent, and while a diversity of honeyeaters is present nectarivore movements are not driven by winter-flowering eucalypts to any great extent. Large gliding marsupials are generally absent, with the Sugar Glider the only species to enter semi-arid woodlands to any meaningful extent, and large owls such as the Powerful and Masked Owl are absent. Barking Owls are present but are probably largely restricted to riparian woodlands only. The avifauna has a significant Eyrean element, with species such as Mallee Ringneck, Mulga Parrot and Splendid Fairy-wren prominent. In contrast to the Brigalow Belt, the mammal fauna of the semi-arid eucalypt woodlands in eastern Australia are impoverished with the total extinction of species in the quoll (Western Quoll), bandicoot (Bilby and Western Barred Bandicoot) and bettong (Burrowing Bettong) groups.

The largely intact tropical woodlands that extend unbroken across northern Australia from the Einasleigh Uplands to northern Western Australia are of great conservation significance but the fauna are vastly different to the sub-humid woodlands. Eucalypts generally do not develop into very large trees (i.e. more than 1 metre in diameter) as climate, frequent fires or termites may arrest their development. The understorey is dominated by tall grasses and frequent fires shape the landscape (Woinarski *et al.* 1997). A large number of species and some genera that characterise sub-humid woodlands of the Brigalow Belt and temperate southern Australia are absent from the tropical north. These include the quail-thrushes (*Cinclosoma* spp.), whitefaces (*Aphelocephala* spp.), Red Wattlebird, Speckled Warbler, Yellow-tufted Honeyeater, White-eared Honeyeater, Brown-headed Honeyeater, Red-rumped Parrot, Turquoise Parrot, Swift Parrot, Diamond Firetail, Chestnut-rumped Thornbill, Regent Honeyeater, Brown Treecreeper (south-eastern), Hooded Robin (south-eastern), White-browed Babbler, Powerful Owl, Yellow-footed Antechinus and Common Dunnart. Large gliding marsupials are absent except for the Sugar Glider.

3.7.7 Actions required for woodland birds in the Brigalow Belt

The Action Plan of Australian Birds (Garnett and Crowley 2000) identified the "Subtropical woodlands", as a priority area requiring a Co-ordinated Conservation Plan. Garnett and Crowley (2000) noted that the subtropical woodlands shared many species with temperate woodlands but were distinguished by the presence (or former presence) of the Paradise Parrot, Black-throated Finch (southern), Squatter Pigeon and Australian Bustard. They recognized the threat of extensive clearing, particularly on the more fertile areas, but also that remnant woodland "*continues to be degraded by inappropriate fire regimes, weed invasion, and, particularly during drought, sheep and rabbit grazing*". They stated that "*local extinctions are likely to continue for many decades to come*".

The area outlined encompasses most of Brigalow Belt South and extends south into NSW, covering most of the Nandewar and New England bioregions. The area includes Barakula and Allies Creek State Forests, the eastern Carnarvon Ranges Subregion (including Expedition and Isla Gorge National Parks and Theodore, Presho and Belington Hut State Forests), the Inglewood Sandstones Subregion, the State Forests of the Auburn Ranges and Yuleba State Forest.

A total of 26 species were identified by Garnett and Crowley (2000) as core taxa. Of these, three are extinct, three are waterbirds, two occur in grassland and very open woodland, two have contracted from former distributions in the Brigalow Belt but still occur on the New England Tableland, one is marginal to the bioregion and one is not generally found in Queensland. All 14 remaining species have significant populations in State Forests in the Co-ordinated Conservation Plan area (Table 3.32).

Garnett and Crowley (2000) recommend placing significant habitat on public land under secure conservation management. Secure conservation management for these species would entail the removal of processes that threaten their persistence, which include loss of floristic integrity on the ground layer (native grasses) (Diamond Firetail), attrition of fallen timber (Speckled Warbler, Brown Treecreeper, Bush Stone-curlew), loss of understorey integrity (shrub layer) (Speckled Warbler, Hooded Robin, Glossy Black-Cockatoo), attrition of hollows (Barking Owl, Masked Owl) and predation by feral animals (Squatter Pigeon, Bush Stone-curlew).

Table 3.32 Relevance of core areas in the Brigalow Belt for conservation of species targeted in Conservation Plan for Subtropical Woodlands region (Garnett and Crowley 2000). Species for which core areas relevant to Conservation Plan are highlighted in bold text.

Species	Status (EPBC)	State Status	Comment
Paradise Parrot	X	X	Globally Extinct
Star Finch (southern)	CE	E	Extinct in plan area
Swift Parrot	E	E	Margins of Brigalow Belt, but in New England Tableland
Regent Honeyeater	E	E	Margins of Brigalow Belt, but in Durikai SF in New England Tableland
Australasian Bittern	V	C	Waterbird
Painted Snipe	V	C	Waterbird
Black-throated Finch	V	V	Extinct in plan area
Little Bittern	NT	C	Waterbird
Grey Falcon	NT	R	Species of open country
Australian Bustard	NT	C	Species of open country
Bush Stone-curlew	**NT**	**P**	**Barakula, Carnarvon Ranges Subregions**
Squatter Pigeon	**NT**	**V**	**Carnarvon Ranges Subregion**
Glossy Black-Cockatoo	**NT**	**V**	**Barakula, Carnarvon Ranges, Inglewood Sandstones and Woorabinda Subregions and Coominglah SF**
Superb Parrot	NT	-	Not present in Queensland part of plan area
Turquoise Parrot	**NT**	**R**	**Barakula and Inglewood Sandstones Subregions**
Barking Owl	**NT**	**P**	**Barakula and Carnarvon Ranges Subregions**
Masked Owl	**NT**	**P**	**Peak Range and Carnarvon Ranges Subregions**
White-browed Treecreeper	NT	C	Eastern margin of Brigalow Belt
Brown Treecreeper	**NT**	**P**	**Inglewood Sandstones Subregion**
Speckled Warbler	**NT**	**P**	**Barakula and Inglewood Sandstones Subregions**
Black-chinned Honeyeater	**NT**	**R**	**Barakula, Inglewood Sandstones and Carnarvon Ranges Subregions**
Painted Honeyeater	**NT**	**R**	**Barakula and Inglewood Sandstones Subregions**
Hooded Robin	**NT**	**P**	**Barakula and Inglewood Sandstones Subregions**
Grey-crowned Babbler	**NT**	**P**	**Barakula, Carnarvon Ranges, Inglewood Sandstones and Woorabinda Subregions and Coominglah SF**
Crested Bellbird	**NT**	**C**	**Inglewood Sandstones Subregion (Bracker SF)**
Diamond Firetail	**NT**	**P**	**Barakula and Inglewood Sandstones Subregions**

X-Extinct, E-Endangered, V-Vulnerable, P-Priority species (Environment Protection Agency 2002b), S-secure, NT-Near Threatened

3.8 The Eastern Australian Bird Migration System: Importance of the Study Area as a wintering ground

The Eastern Australian Bird Migration System is the mass northward movement of Australian forest birds to escape cold winter temperatures and the associated dearth of nectar and insects in south-eastern Australia. Nix (1993) identified five major seasonal bird movement patterns in Australia, and considered the Eastern Australian Bird Migration System to be the most important because of the number of species involved and the rate of habitat loss.

The Brigalow Belt is a vital component of the Eastern Australian Bird Migration System both as a transit zone and as the largest area of winter habitat in the System. The winter visitors, mainly nectarivores and insectivores, are attracted to regions with positive winter plant growth indices. These regions occur on a long narrow strip along the east coast but also extend several hundred kilometres inland in Queensland and northern NSW. Nix (1993) mapped the area of positive winter plant growth conditions in eastern Australia and the inland extension virtually mirrors the Brigalow Belt bioregion.

Insectivores probably attracted by greater numbers of insects (especially flying insects) in the milder winter temperature regimes of the Brigalow Belt. The most numerous migrant insectivore is probably the Grey Fantail (*Rhipidura fuliginosa*). Nectarivores also move into the bioregion in large numbers, especially small honeyeaters such as the Yellow-faced Honeyeater. Nix (1993) discussed the specific importance of Brigalow Belt habitats, describing the broad-scale destruction of important winter habitats such as the *Eucalyptus tereticornis* woodlands and Brigalow (*Acacia harpophylla*), Gidgee (*A. cambagei*) and Blackwood (*A. argyrodendron*) forests.

The large-scale losses that Nix described cannot be reversed within any meaningful timeframe, but examples of what Nix described as "*important open forest habitat with winter-flowering eucalypt species*" are still relatively extensive, albeit degraded. Winter-flowering eucalypts are keystone elements for birds in the East Australian Bird Migration System, providing an important resource when food elsewhere is limiting. They are also important for species that move regionally (e.g. Little Lorikeet) and as a drought refuge for Eyrean species (e.g. Masked Woodswallow).

3.9 Eucalypt flowering patterns and rich patch species

3.9.1 The patterns and the species

The distribution of eucalypt flowering resources in the Brigalow Belt varies greatly in time and space. A given stand of eucalypts could be in full flower in one year and not flowering at all twelve months later. Some eucalypts only flower profusely once every 3–6 years in the Brigalow Belt (Blake and Roff 1988). These fluctuations are well known by apiarists; the term 'migratory beekeepers' has been used to describe their commercial activities in inland Queensland (Blake and Roff 1988).

Many nectarivorous birds and the Little Red Flying-fox have adapted to this spatial and temporal variability in resources. These species have developed high mobility and gregarious behavior, traits that enable them to locate and capitalize on 'resource pulses'. The term 'rich patch fugitives' was coined by Ford *et al.* (1993) for such species, referred to herein as 'rich patch' species. The 'resource pulses' pursued by 'rich patch' species could be seeding grasses, fruit, rodent plagues or eucalypt flowering events, but this discussion is restricted to nectarivores. Nectarivores in the Eastern Australian Bird Migration System may undertake regular long distance movements between denser forests and the Brigalow Belt, but then adopt 'rich patch' strategies to locate resources once they reach the Study Area.

Nectarivore aggregations at major flowering events in woodlands are a natural spectacle, supporting what must be some of the highest bird densities in wooded habitat in Australia. Oliver (1998) recorded as many as 183 nectarivores/ha in winter-flowering ironbark woodland on the New England Tableland. These aggregations may also be diverse, with as many as 15 bird species foraging within an area of a few hectares. Species present usually include a large number of honeyeaters, two or three lorikeet species and possibly facultative nectarivores such as woodswallows, Olive-backed Oriole and Silvereye.

Major aggregations such as this create an impression of great abundance, but species that visit a succession of sources are vulnerable. Each "stepping stone" may only be a small area, but the loss or degradation of that "stepping stone" may have an effect highly disproportionate to the percentage of total suitable habitat lost (Ford *et al*. 1993). Eby *et al.* (1999), in a paper investigating flying-fox populations wrote: "*Patterns of migration characteristically include periods of concentration in which an intensive resource flush at a time of general scarcity results in large proportions of the population congregating into restricted areas*." Sites which attract these large nectarivore aggregations are critical for rich-patch species in times of scarcity.

Identification of rich-patch species is an important step in determining conservation priorities. Contrasting life history responses among nectarivores can be seen in data collected from bird censuses in the Brigalow Belt in Figure 3.10.

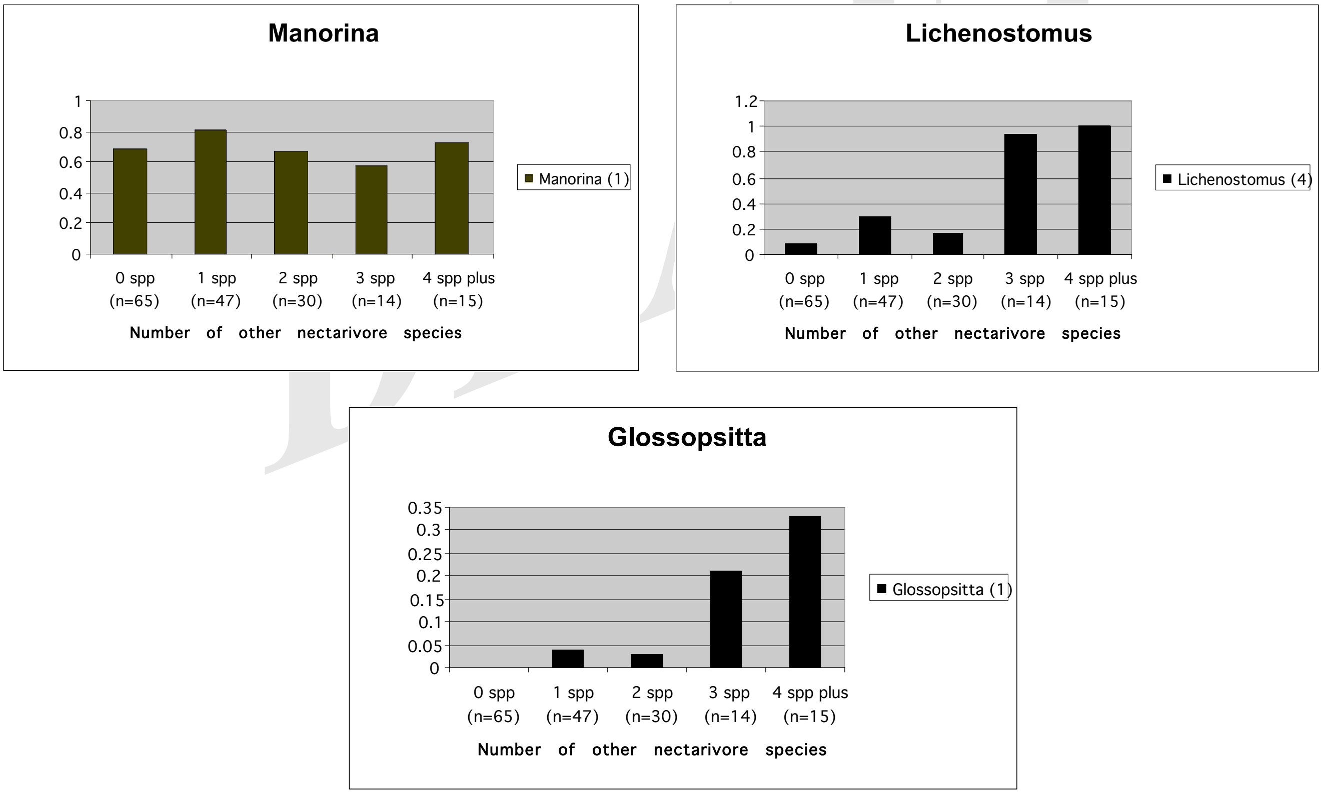


Figure 3.10 Relationship between reporting rate of nectarivore genera and the total number of nectarivores present at the site.

Honeyeaters of the *Lichenostomus* genus and the Little Lorikeet (*Glossopsitta pusilla*) appear to be rich patch species. They were at least three times as likely to be recorded where three or more other nectarivore species were present, suggesting they preferred sites with abundant resources. Other likely 'rich patch' species in the Brigalow Belt include the Little Red Flying-fox, Scarlet Honeyeater and Masked Woodswallow, which was observed congregating in large numbers at flowering events by Environment Protection Agency surveys (M. Haseler pers. comm.) and ARCS surveys (S. Kennedy pers. obs.). By contrast, The Noisy Miner (*Manorina melanocephala*) is not a rich patch species. The species was frequently recorded regardless of the total number of nectarivores present. The Noisy Miner is colonial, and if no nectar is available, the miners switch to lerps, another carbohydrate resource provided largely by eucalypts. Colonies are even thought to ensure a continuous supply of lerps by 'farming' them, as they consume the sugary secretion the insect (a psyllid) produces for protection but not the insect itself, which then produces another sugary covering for the miner to eat (Loyn 1983). Hence, the Noisy Miner is not threatened by the loss or degradation of nectar resources.

The most sensitive rich patch species in the Brigalow Belt have already declined. The Regent Honeyeater (Endangered) and Swift Parrot (Endangered) were both recorded by Barnard and Barnard (1925) in the Dawson Range area and by Broadbent in the Chinchilla area in the 1880s. Neither species has been seen in these areas for decades and they are now scarce in the bioregion, with the most recent Australian Bird Atlas (1998–2001) recording the Regent Honeyeater once in a Dalby town park and the Swift Parrot six times, all on the escarpment edge at Toowoomba. The remaining rich patch species are relatively common, but perform an important ecosystem function in maintaining bird-plant pollination systems in the Study Area. Population declines remain a concern for these species, as bird-plant pollination systems can be disrupted by reduced pollinator density even where no pollinator species become extinct. This has been observed by Paton (1997), who found reduced fruit production in some bird pollinated plants at study sites in southern Australia. Paton attributed this disruption to a reduction in honeyeater *density*, rather than species loss. This illustrates that maintaining the integrity of the nectarivore community is not only relevant for species conservation, but also for maintenance of ecosystem processes.

3.9.2 Reserve implications of eucalypt flowering patterns

The irregular flowering behaviour of eucalypts in the Brigalow Belt has major conservation implications. Rich patch species with an ostensibly broad range actually occupy a restricted and continuously changing habitat area. Rich patch species in a forest as large as Barakula SF could easily be reliant on a single eucalypt species at a given time. For example, *E. fibrosa* subsp. *nubila* (Blue-leaved Ironbark) is a major winter-flowering eucalypt. *E. fibrosa* subsp. *nubila* woodland occurs only as scattered small patches in Barakula SF, covering well under 10 per cent of the landscape. However these patches are likely to be critical in years when *E. fibrosa* subsp. *nubila* flowers and flowering of the far more extensive *C. citriodora* (Spotted Gum) fails. A coincidence of these events would restrict rich patch species to a very small percentage of Barakula SF. Dale and Hawkins (1983) studied Spotted Gum flowering in Barakula SF over four years, recording extensive flowering in some years and virtually none in others, suggesting that *C. citriodora* failure is sufficiently frequent to make this example a realistic scenario.

Major nectar producers (Blake and Roff 1988) from the Study Area are generally from the *Symphyomyrtus* subgenus of *Eucalyptus* and the genus *Corymbia*. Together, these eucalypts cover a large area and flower sequentially over the entire year (Table 3.33). As a general rule, lowland eucalypts on richer soil flower in summer and the upland eucalypts on skeletal soils flower in autumn, winter and early spring. This important finding highlights that responses in eucalypt phenology to low fertility may result in nutrient-poor habitats becoming winter refuges for fauna. There are exceptions to this trend, notably *Eucalyptus tereticornis* (Forest Red Gum) of alluvial flats which begins flowering in winter, and *Angophora leiocarpa* (Smooth-barked Apple) and *E. crebra* (Narrow-leaved Ironbark) of stony soils which flower in summer.

Table 3.33 Flowering periods of dominant eucalypts in the Brigalow Belt

N-Flowering period in NSW, Q-Flowering period in south-eastern Queensland from Blake (1988). *NB-Definition of "South-eastern Queensland" in this text includes a large section of Brigalow Belt South, extending west to the Auburn Ranges and the Gurulmundi area.*

Species	Frequency	Major bird tree	Site preference	J	F	M	A	M	J	J	A	S	O	N	D
Angophora floribunda		No	lowland	NQ	N										Q
Angophora leiocarpa	5	No	upland	Q											Q
Corymbia tessellaris		No	lowland	Q	Q									Q	Q
Corymbia trachyphloia		No	upland	N	NQ	NQ	Q								
Corymbia citriodora	3 to 4	No	upland						Q	Q	Q	Q			
Eucalyptus albens		Yes	lowland			N	NQ	NQ	NQ	NQ	N	N	N		
Eucalyptus caleyi			upland						Q	Q	Q	Q	Q		
Eucalyptus camaldulensis	2	Yes	lowland	Q								N	N	NQ	NQ
Eucalyptus cambageana			lowland	Q										Q	Q
Eucalyptus crebra	4 to 5	No	upland								Q	NQ	NQ	NQ	Q
Eucalyptus dealbata	3 to 4	No	upland										N	NQ	NQ
Eucalyptus decorticans		No	upland		Q	Q	Q	Q							
Eucalyptus fibrosa subsp. fibrosa		Yes	upland	N			Q	Q	Q	Q	Q	Q	Q	NQ	NQ
Eucalyptus fibrosa subsp. nubila	5 to 6	Yes	upland					Q	Q	Q	Q	Q			
Eucalyptus melanophloia	2	No	upland	NQ	Q									N	NQ
Eucalyptus melliodora		Yes	lowland	N							N	NQ	NQ	NQ	NQ
Eucalyptus microcarpa		No	lowland	Q	NQ	N									
Eucalyptus microtheca			lowland	Q	Q									Q	Q
Eucalyptus moluccana		No	lowland		Q	Q	Q								
Eucalyptus orgadophila			upland				Q	Q	Q	Q	Q	Q			
Eucalyptus populnea	2 to 3	No	lowland	Q											Q
Eucalyptus sideroxylon		Yes	upland			N	N	NQ	NQ	NQ	NQ	NQ	Q	Q	
Eucalyptus tereticornis	3 to 4	Yes	lowland						Q	Q	Q	Q	Q	Q	
Lophostemon suavolens		No	lowland	Q										Q	Q

Of the species in Table 3.33, *Corymbia citriodora*, *E. tereticornis* and *E. fibrosa* subsp. *nubila* are known to be particularly important nectar sources and should be the focus of study into movements of 'rich patch' species. All are geographically extensive (although they may occur on relatively restricted areas such as alluvial flats or stony ridges) and all have been observed to attract large numbers of birds and/or flying-foxes (S. Kennedy pers. obs., P. Birt, P. Grimshaw, M. Mathieson pers. comm.). A reserve system that samples a notional 'representative' percentage of these types may not be adequate for conservation of rich-patch species, as 'resource pulses' may occur entirely outside the reserve system in some years, exposing the 'rich patch' aggregations to threatening processes. The management of these habitat types as a whole will be important for the future health of populations of 'rich patch' species and the eucalypts that depend on them for adequate pollination.

3.10 The Glossy Black-Cockatoo: a unique casuarina specialist

3.10.1 Introduction

The Glossy Black-Cockatoo has one of the most specialized foraging ecologies of any Australian parrot (Pepper 1996). It only occurs in open forest and woodland with extensive stands of particular species of *Casuarina* and *Allocasuarina,* the seeds of which are the sole food source. It occurs disjunctly in the Brigalow Belt, with populations in the Inglewood Sandstones Subregion, Barakula-Allies Creek State Forests, Southern Downs, Moonie, Carnarvon Range, Chesterton Range NP, Bigge Range, Blackdown Tableland and Coominglah SF and, in NSW, the Pilliga and Goonoo forests. Active and ongoing speciation has resulted in two distinct subspecies in the Study Area. *Calyptorhynchus lathami lathami* occurs in southern Queensland and along the Great Divide to about 25°S, whilst *C. l. erebus* occurs north of 25°S in the Dawson-Mackenzie-Isaac sub-basins (Schodde *et al*. 1993).

3.10.2 Ecological specificity

The primary food species for the Glossy Black-Cockatoo in the Study Area are *Allocasuarina inophloia*, *A. torulosa, A. littoralis* and *Casuarina cristata* (Table 3.34). Stands of the widespread *A. luehmannii* are only occasionally used. This species is not mentioned as a food source by Garnett and Crowley (2000) or Schodde *et al.* (1993) and other observers have seen only occasional use of *A. luehmannii* and at a lower level than other *Allocasuarinas* (M. Cameron pers. comm., P. Grimshaw pers. comm.).

Glossy Black-Cockatoo populations in the Study Area are most closely allied to those of *Allocasuarina inophloia*, *A. torulosa* and *A. littoralis*, with subspecies dominance reflecting the regional distribution and relative abundances of their specific food preferences, particularly *A. inophloia* and *A. torulosa*. *C. l. erebus* is centred at Blackdown Tableland and Coominglah SF where *A. torulosa* is more abundant, and *C. l. lathami* favours the Barakula-Allies Creek and Inglewood Sandstone region where *A. inophloia* is the major foraging species. Areas where *A. torulosa* and *A. inophloia* co-dominate (e.g. Bigge Range, Carnarvon Range) are also the areas where the taxonomic identity of the Glossy Black-Cockatoo is most unclear (See Schodde *et al*. 1993.). Schodde *et al*. (1993) suggested cone size may have led to differentiation in bill size or else "stochastic genetic drift" in isolated populations may account for the variation.

Table 3.34 Glossy Black-Cockatoo populations and presence of potential or known major food sources.

Population	Subspecies	*A. torulosa*	*A. littoralis*	*A. inophloia*	*C. cristata*	*A. diminuta*	*A. gymnanthera*
Coominglah	*erebus*	■	■	□			
Blackdown T	*erebus*	■		□			
Bigge Range	*erebus?*	■	□	■			
Carnarvon Range	*lathami?*	■	□	■			
Barakula-Allies Ck	*lathami*		□	■■[3]			
Inglewood Sandstones	*lathami*		□	■■[3]			
Southern Downs	*lathami*				■■[1]		
Moonie	*lathami*				■■[3]		
Pilliga (NSW)	*lathami*					■■[2]	
Goonoo (NSW)	*lathami*					■■[2]	■■[2]

Allocasuarina and *Casuarina* species in the Brigalow Belt have regionally restricted, edaphically correlated distributions. Within this framework, ■ - implies more extensive and dominant occurrence; □ - less extensive with sparse occurrences; ■■ - Glossy Black-Cockatoos known to use species in area — sources, [1]- Environment Protection Agency (2002b), [2]- M. Cameron pers. comm., [3]-P. Grimshaw, M. Mathieson pers. comm.

3.10.3 Reserve design implications

The specialized foraging ecology of the Glossy Black-Cockatoo highlights the care needed in designing reserves for viability and ongoing evolution.

Given the localized and disjunct nature of food resources, e.g. *A. torulosa* populations in RE 11.10.5 at Blackdown Tableland, more work is needed to clarify possible seasonal or drought-stress dependence of *C. l. erebus* on normally suboptimal *A. luehmannii* resources in the lower reaches of Mimosa Creek (RE 11.5.1 and RE 11.5.2).

Parapatric associations of *A. inophloia* and *A. luehmannii* in the Barakula–Inglewood Sandstone region may provide similar ecosystem services for *C. l. lathami*. *A. inophloia* (a high quality resource), is associated with relictual floras on old duricrusted Tertiary surfaces — diverse assemblages of old eucalypt lineages including *Eucalyptus tenuipes*, *E. panda, E. fibrosa* subsp. *nubila* and *Corymbia watsoniana* (primarily RE 11.7.4). *A. luehmannii* (normally a low quality resource), occurs with *E. crebra* and *Callitris glaucophylla* on sandy duplex soils (RE 11.5.1). Both ecosystems are intricately intermingled and reflect the progressive dismemberment of very old and deeply weathered landforms of the Tertiary. Thus the landforms, soils, floristic communities and dependent fauna have had a long evolutionary history in the Brigalow Belt. Recognition of these relationships is essential if viability and ongoing evolution of the bioregion's outstanding biodiversity is to be ensured.

3.11 The Brigalow Belt and avifaunal lineages from the Neogene

Abstract: The geographical patterns of 'old', 'medium-aged' and 'recent' bird species were investigated in the Brigalow Belt and South-East Queensland. It was found that old and recent species were more prominent in South-East Queensland, and medium-aged species were more prominent in the Brigalow Belt. Species from the medium-aged group belong to monophyletic lineages that arose during the Neogene period.

Given the prominence of the Neogene lineages in the Study Area compared to South-East Queensland, patterns in endemism, adaptive traits and habitat preferences among this group were investigated. The endemism at a generic level among the Neogene lineages is comparable that of older lineages. The Neogene lineage has the largest number of genera that utilize eucalypt habitat rather than rainforest. A major characteristic trait of Neogene species is cooperative breeding, which is far more prevalent among passerines from this period than from older or younger lineages. Cooperative breeders are more prevalent in eucalypt forest and woodland than in rainforest, and are richest in inland eastern Australia, including the Brigalow Belt.

Cooperative breeding is strongly associated with sedentariness but not all sedentary species breed cooperatively. Cooperative breeders were found to have declined at a greater rate than sedentary passerines in general in the Study Area and the NSW woodlands, suggesting cooperative breeding may increase vulnerability. However, investigation of breeding strategy and foraging substrate found that a significant proportion of bark and litter foragers are in decline but there are few or no declines among other major groups such as foliage gleaners and flower feeders. This is despite the fact that all of these foraging substrate groups have a significant component of cooperative breeders. Hence, foraging substrate may be a stronger indicator of decline than cooperative breeding *per se*. Bark and litter foragers had the highest old and medium-aged element among the species studied, but there were also significant older elements among the relatively secure foliage gleaners and flower feeders.

These results are indicative only, with many bird lineages unresolved and some difficulties in separating correlation and causality for some of the observed relationships. However it appears that older lineages are more vulnerable to decline than newer species, but this is especially so for birds foraging on bark and litter, resources that are diminished by a number of threatening processes such as attrition of large trees and increased fire frequency associated with management for wood production and grazing.

3.11.1 Introduction

The geographical patterns among birds with 'old', 'recent' and 'medium-aged' origins were investigated in the Brigalow Belt and South-East Queensland. This study utilised the method of Fjeldsa (1994) in his study of geographical patterns of relict and young species in Africa and South America. The major worldwide study of avian DNA by Sibley and Ahlquist (1990) was used as a basis for categorisation of bird species as belonging to old, medium-aged or recent lineages as in Fjeldsa (1994).

Old genera are those that appear to have originated in the Early Miocene or earlier. Medium-aged genera belong to monophyletic groups considered to have arisen between 6 MYA and the Early Miocene, closely corresponding to the Neogene period (See Section 3.1.). Recent genera are those that were part of a radiation of 10 or more species in the last 6 MY. Many groups of birds were omitted, as the age of some radiations could not be determined in sufficient detail (cf. Fjeldsa 1994). A total of 91 genera were categorised (Table 3.35).

3.11.2 Spatial patterns of species richness in lineage groups

The number of species in each age category was calculated for 20-km grid cells across the Brigalow Belt, Central Queensland Coast and South-East Queensland. It was found that total species richness (i.e. all species for which an age could be determined) was highest in South-East Queensland, although richness was also high in the Study Area at Blackdown Tableland NP, Carnarvon NP, Expedition NP, Isla Gorge-Precipice NP area and some grid cells in the Barakula and Inglewood Sandstones Subregions (Figure 3.11).

Table 3.35 Bird genera of Australia grouped by phylogenetic age

Recent	Medium-aged (Neogene)	Old
Non-passerines		
Accipiter	*Cuculus*	*Aegotheles*
Alcedo	*Dromaius*	*Alectura*
Cacatua	*Merops*	*Caprimulgus*
Cacomantis	*Nymphicus*	*Centropus*
Falco		*Chalcophaps*
		Chrysococcyx
		Coturnix
		Eudynamys
		Eurostopodus
		Eurystomus
		Macropygia
		Ninox
		Phaps
		Scythrops
		Todhiramphus
		Turnix
		Tyto
Passerines		
Anthochaera	*Acanthiza*	*Acanthorhynchus*
Chlamydera	*Ailuroedus*	*Atrichornis*
Coracina	*Aphelocephala*	*Certhionyx*
Corvus	*Aplonis*	*Climacteris*
Dicaeum	*Chthonicola*	*Conopophila*
Eopsaltria	*Colluricincla*	*Cormobates*
Epthianura	*Corcorax*	*Daphoenositta*
Hirundo	*Dicrurus*	*Dasyornis*
Lalage	*Entomyzon*	*Falcunculus*
Monarcha	*Gerygone*	*Melanodryas*
Myiagra	*Grallina*	*Menura*
Pachycephala	*Hylacola*	*Microeca*
Phylidonyris	*Lichenostomus*	*Myzomela*
Ptiloris	*Lichmera*	*Oreoica*
Rhipidura	*Malurus*	*Orthonyx*
Sericornis	*Meliphaga*	*Pardalotus*
Zoothera	*Melithreptus*	*Petroica*
Zosterops	*Oriolus*	*Pitta*
	Plectorhyncha	*Psophodes*
	Pomatostomus	
	Ptilonorhynchus	
	Pyrrholaemus	
	Ramsayornis	
	Smicrornis	
	Sphecotheres	
	Strepera	
	Struthidea	

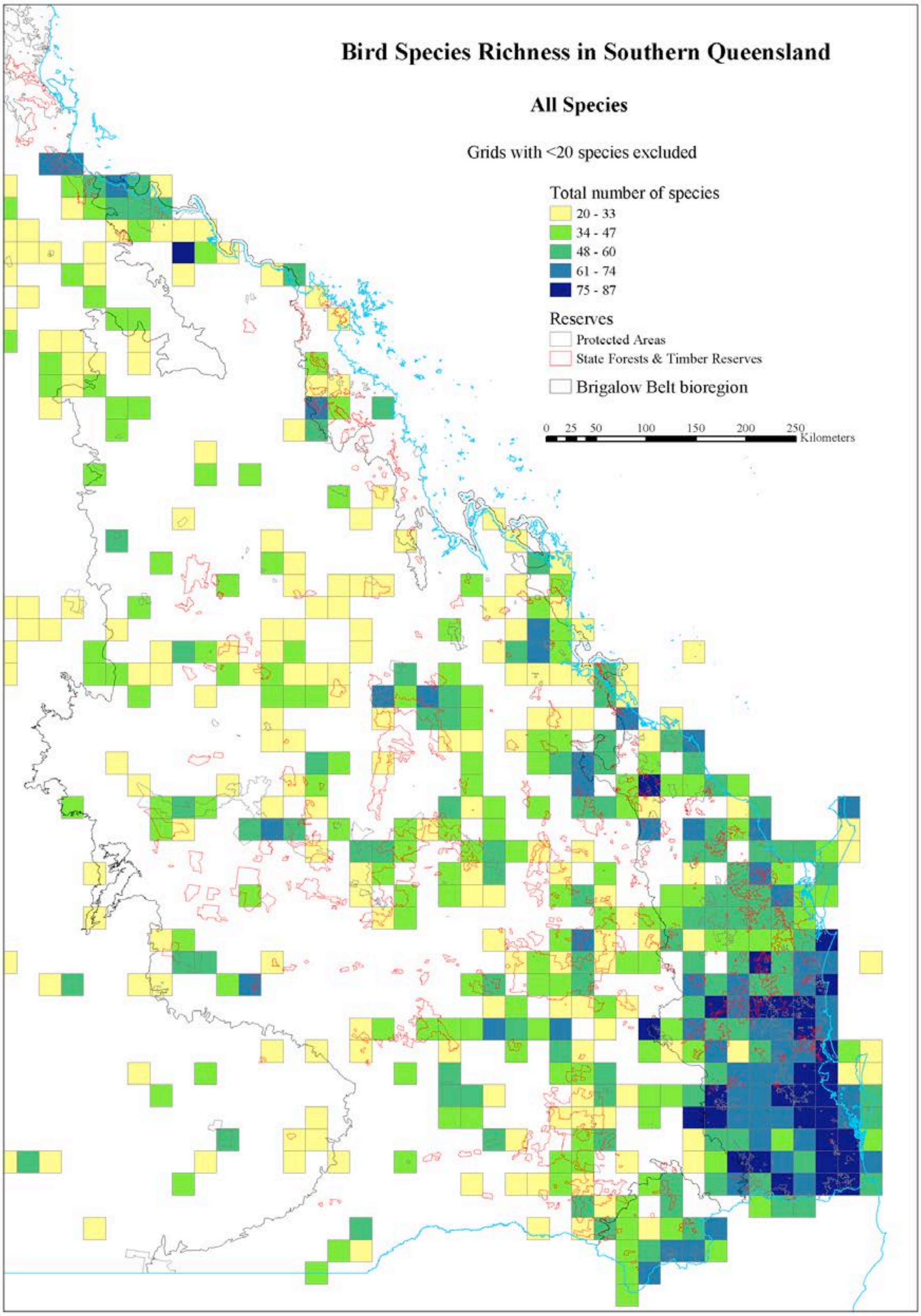


Figure 3.11 Bird species richness across South-East Queensland, Central Queensland Coast and the Brigalow Belt

The pattern of richness among "old" and "recent" species closely followed the overall pattern, while "Neogene" species were more diffusely distributed (Figures 3.12–3.14). Some areas of low total richness are likely to be an artefact of survey effort.

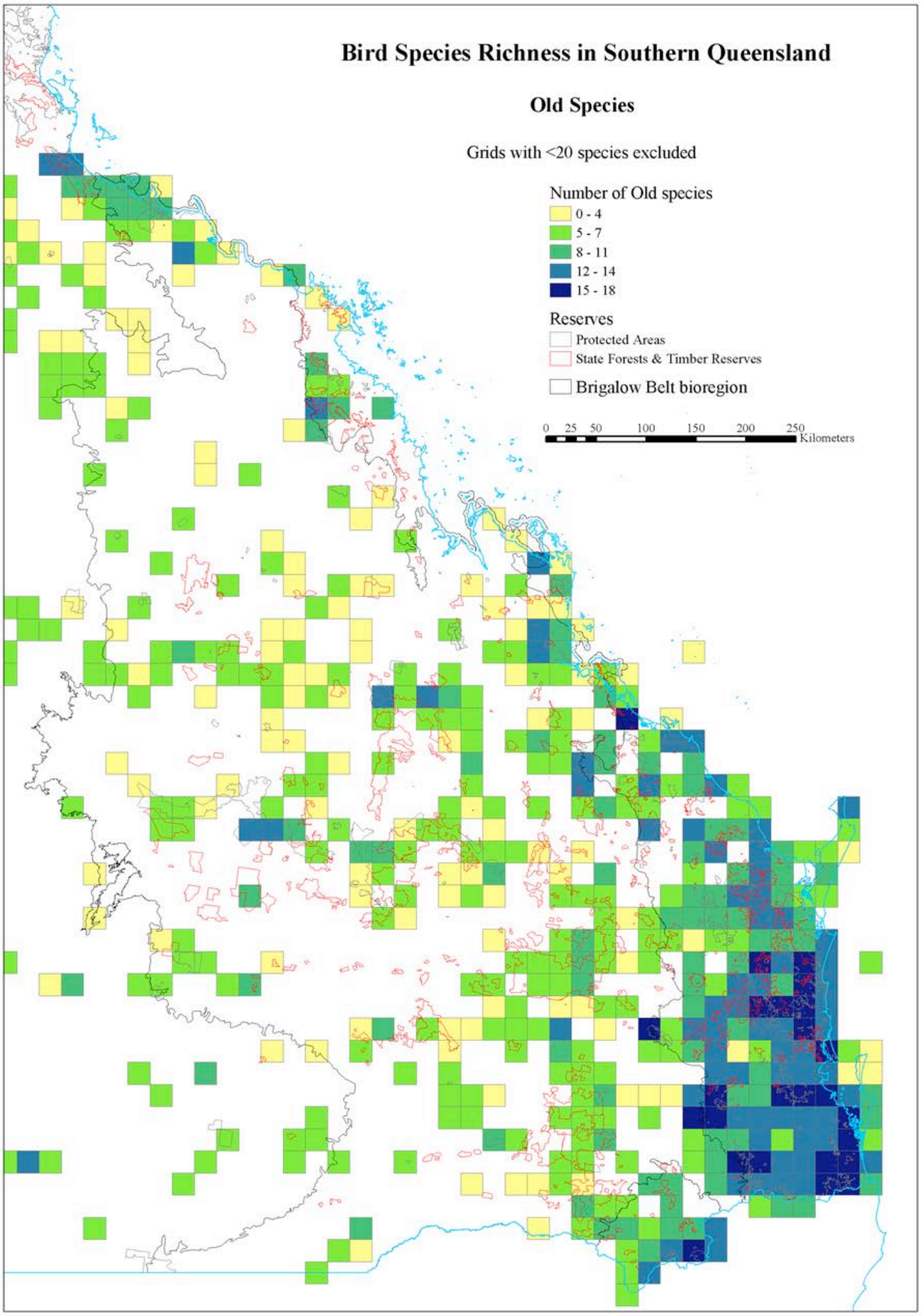


Figure 3.12 Species richness of birds of old lineages across South-East Queensland, Central Queensland Coast and the Brigalow Belt

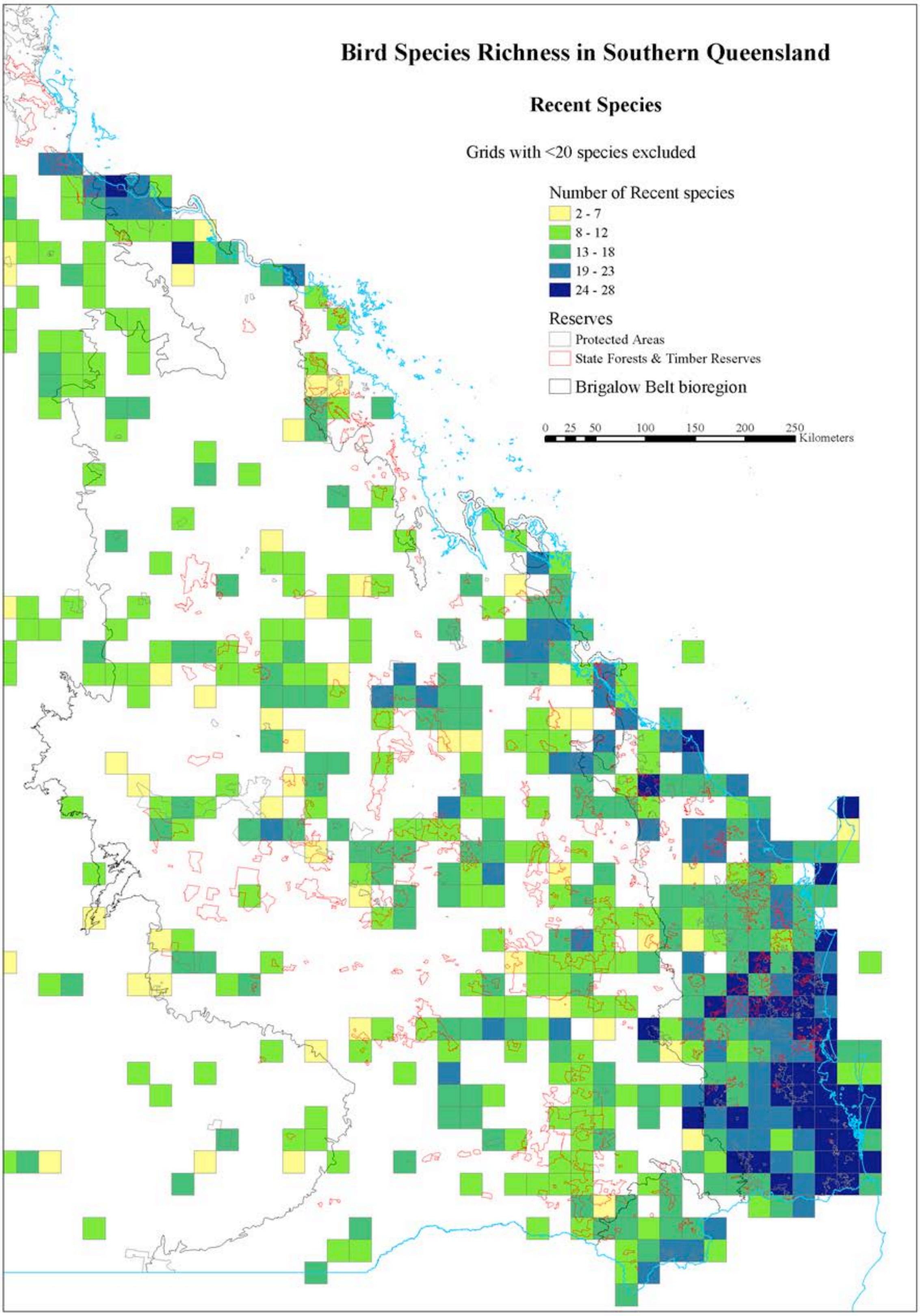


Figure 3.13 Species richness of birds of recent lineages across South-East Queensland, Central Queensland Coast and the Brigalow Belt

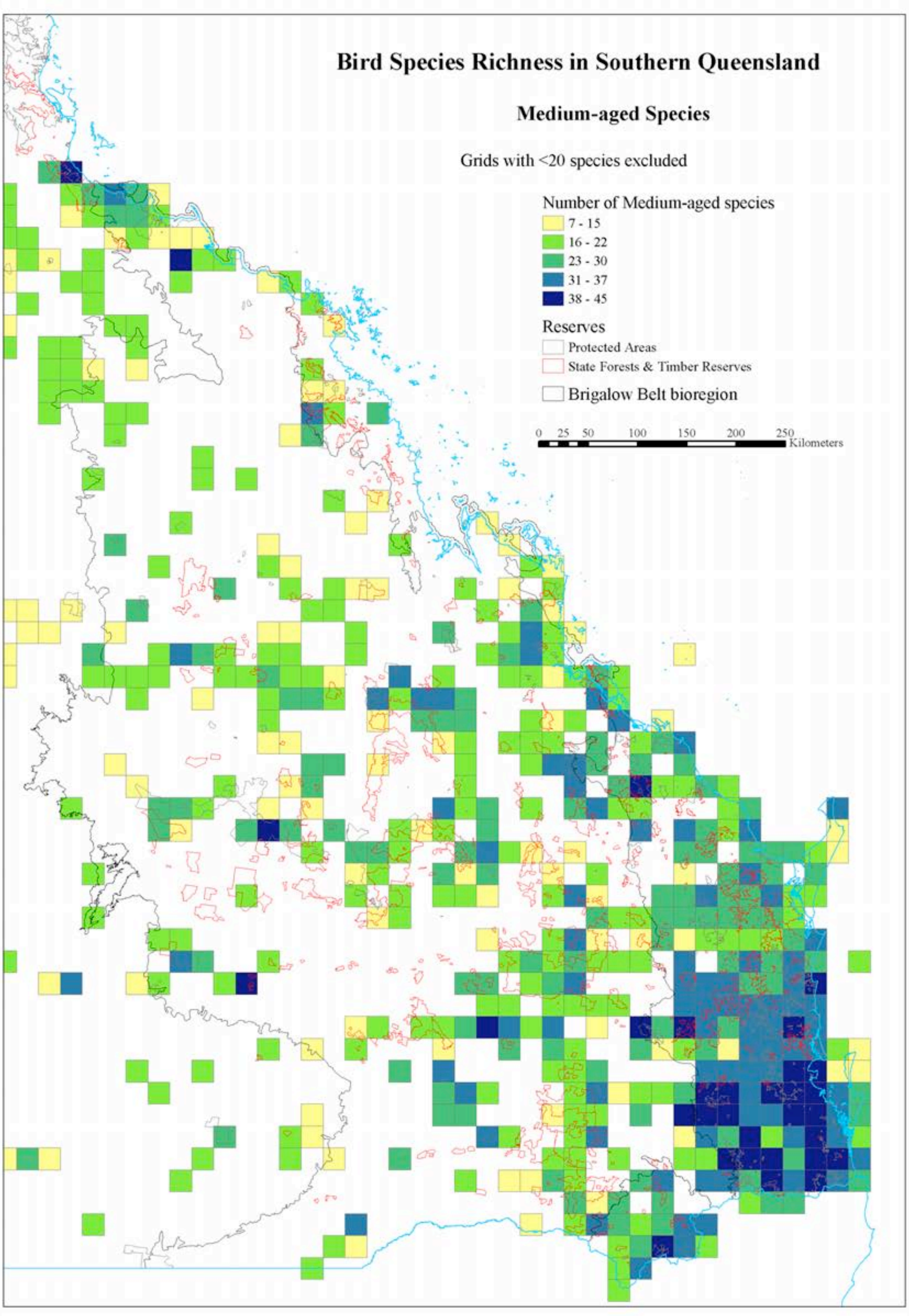


Figure 3.14 Species richness of birds of medium-aged (Neogene) lineages across South-East Queensland, Central Queensland Coast and the Brigalow Belt

3.11.3 Relationship between the age of avifaunal lineages and their geographical distribution

In order to partially overcome the biases in survey effort towards densely populated areas and well known national parks, the proportion of old, medium-aged and recent species was calculated for each 20-km grid cell.

Birds with old origins were more predominant in the avifauna of South-East Queensland, New England Tableland and the Clarke Range (Figure 3.15). Birds from recent lineages were more predominant on the coastal fringe with high proportions in some grid cells in the Brigalow Belt, especially in lowlands (Figure 3.16).

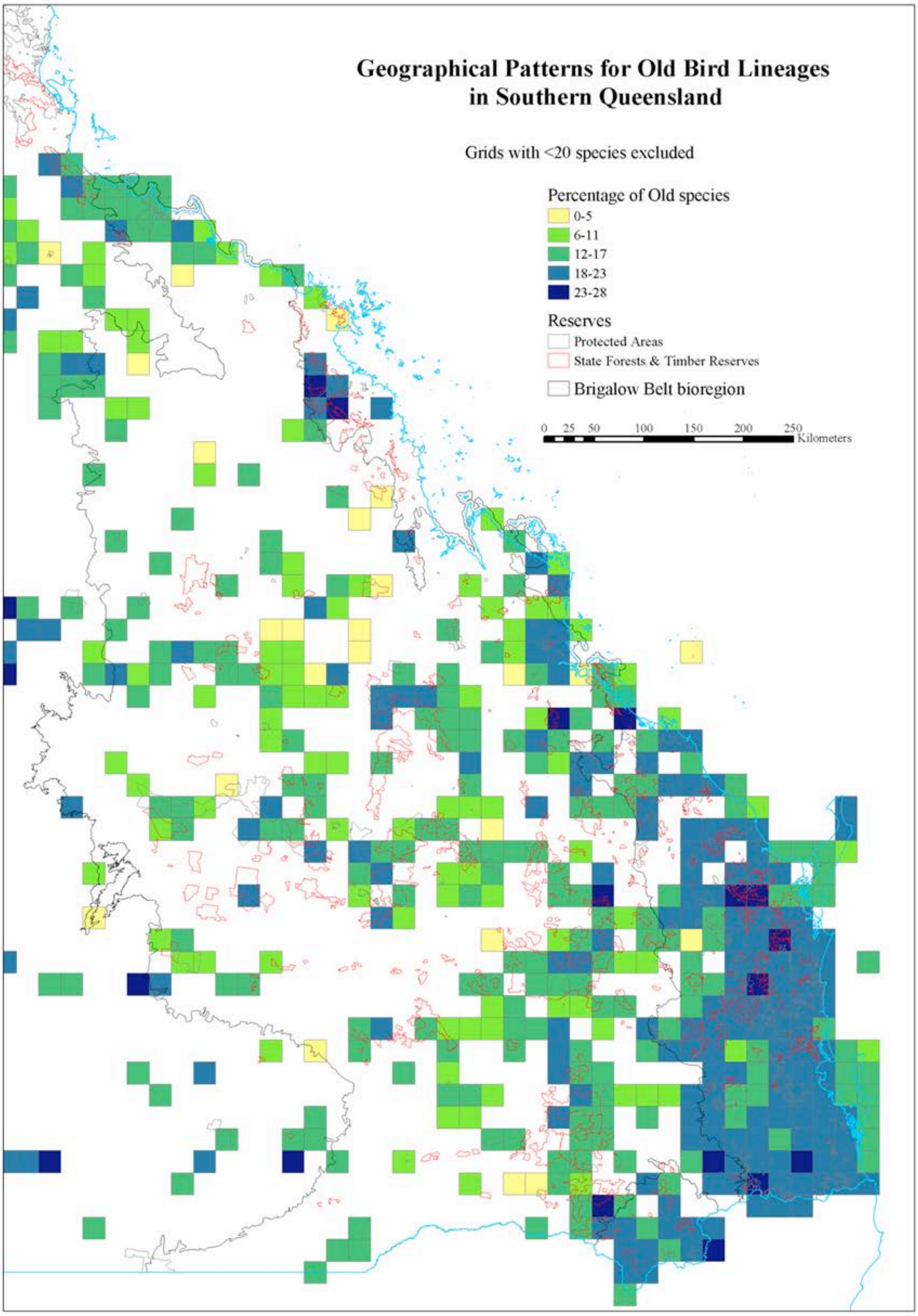


Figure 3.15 Areas of predominance of old lineages of birds in South-East Queensland, Central Queensland Coast and the Brigalow Belt

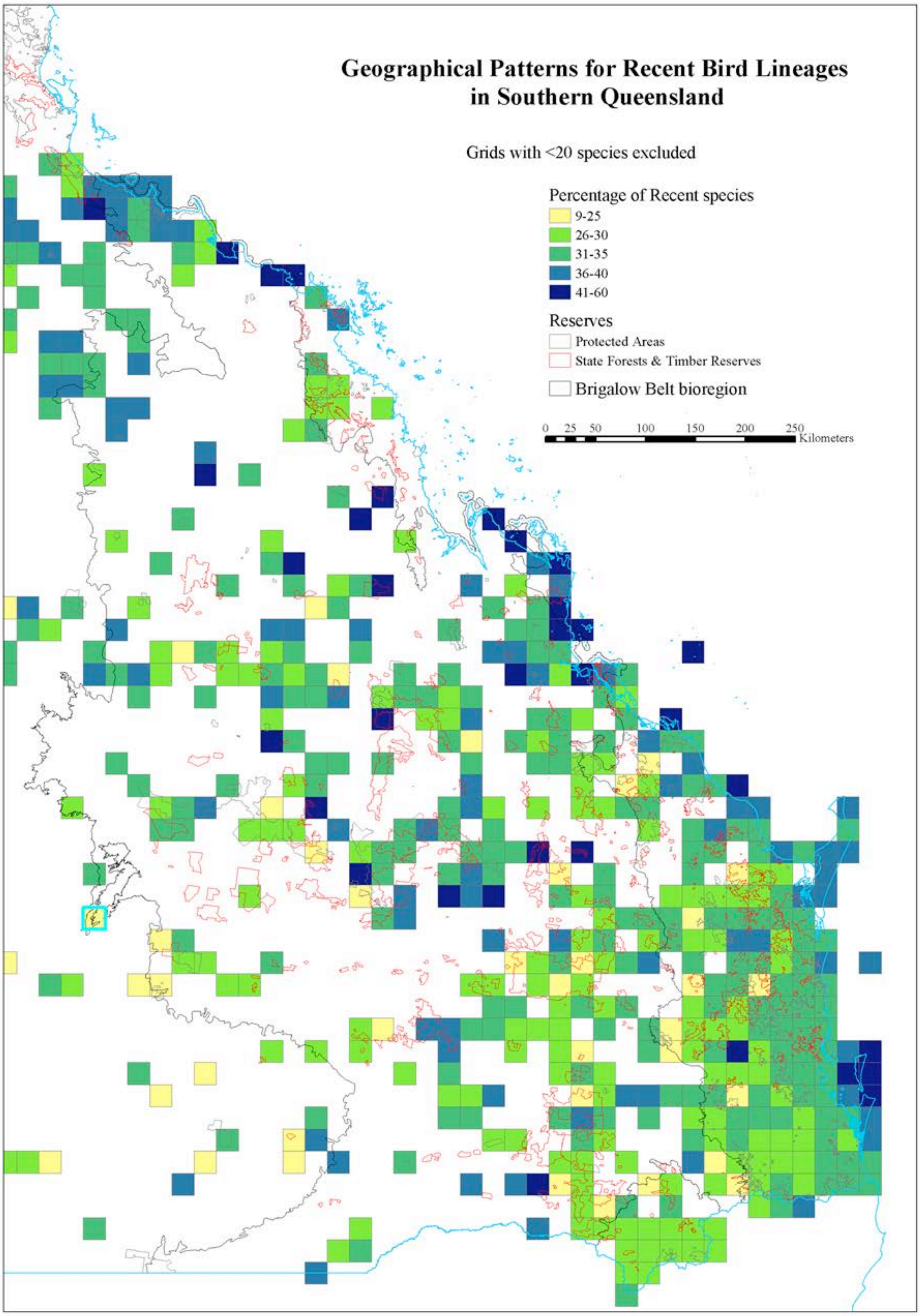


Figure 3.16 Areas of predominance of recent lineages of birds in South-East Queensland, Central Queensland Coast and the Brigalow Belt

Medium-aged genera were more prominent in the Brigalow Belt avifauna than in South-East Queensland (Figure 3.17).

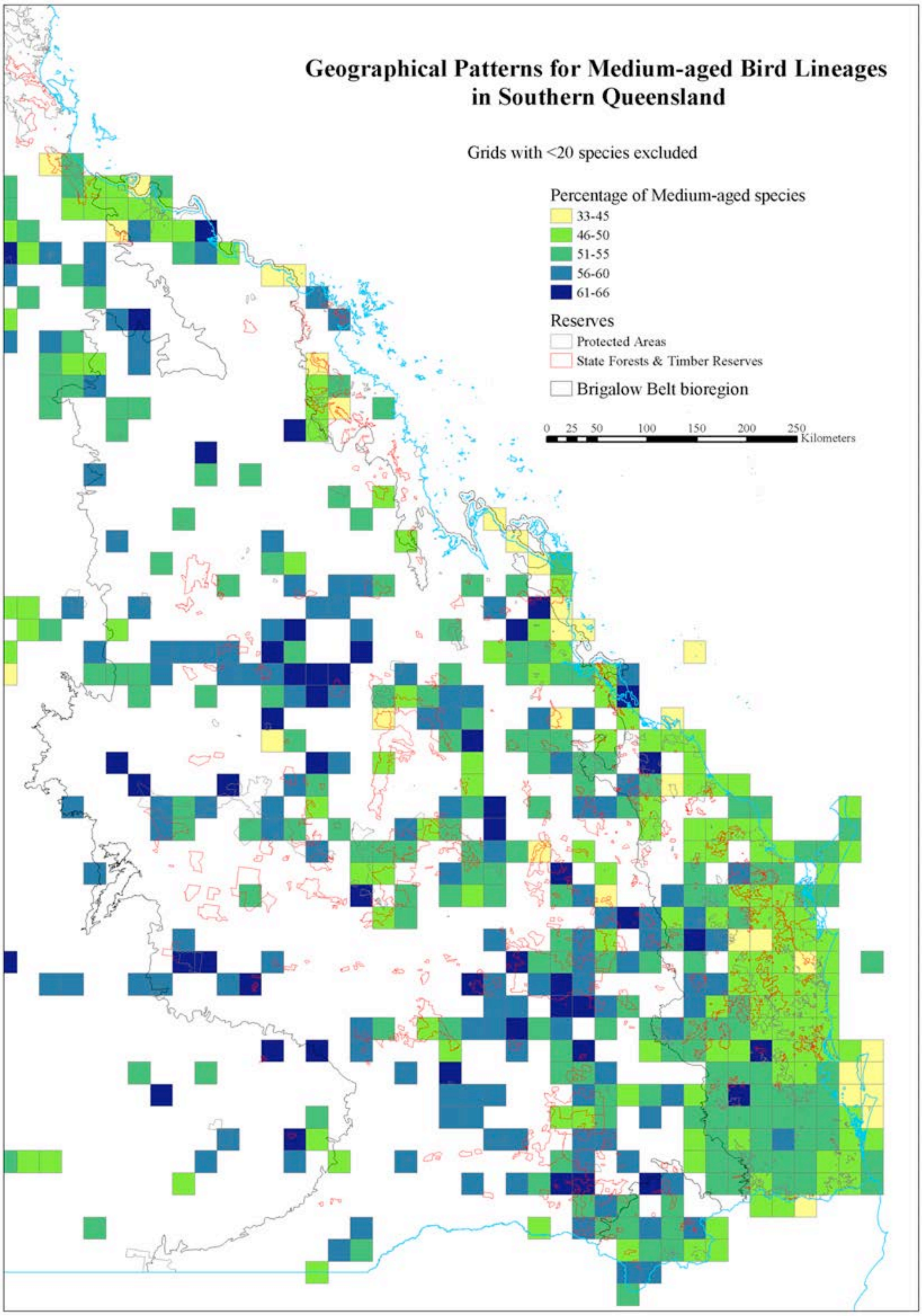


Figure 3.17 Areas of predominance of old lineages of birds in South-East Queensland, Central Queensland Coast and the Brigalow Belt

Many distinctive monotypic woodland genera arose in this period, including the Speckled Warbler (*Chthonicola*), the eucalypt foliage specialist Weebill (*Smicrornis*), and the cooperative breeding mud-nest builders the Apostlebird (*Struthidea*) and White-winged Chough (*Corcorax*). The most eucalypt-dependent genus of the honeyeaters, *Melithreptus*, also has its origins in this period. Their prominence in the avifauna of the Brigalow Belt led to the investigation of distinctive features, which are discussed in sections 3.11.4 and 3.11.5.

These conclusions are tentative, with many phylogenetic origins and relationships still to be resolved and investigated. A major group omitted from this analysis was a large proportion of the Australian parrots, a distinctive, important and morphologically diverse group. A number of the medium-aged species are from the large *Lichenostomus* genus of honeyeaters, which may actually represent a recent radiation. Christidis and Schodde (1993), on the basis of protein electrophoretic studies, considered there to be significant radiations among these honeyeaters associated with the climatic fluctuations of the Pleistocene.

3.11.4 Distinctive features of birds from Neogene lineages

The avifaunal group identified in this study as having arisen in the Neogene has a number of distinctive features. This group has more endemic bird genera than either the old or recent lineages. Sixty-nine per cent of the Neogene group are endemic to Australia (40 per cent) or are Australo-Papuan endemics (29 per cent). By comparison, 50 per cent of the old genera are Australian or Australo-Papuan endemics, and there are no Australian and few Australo-Papuan endemic genera (20 per cent) among the recent lineages (Figure 3.18).

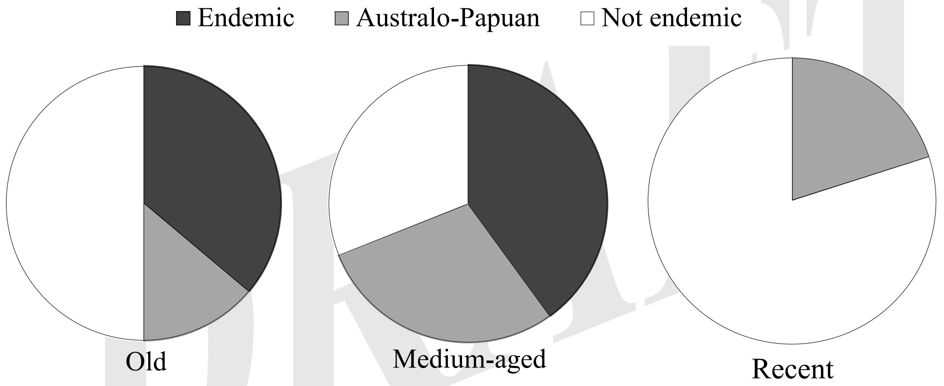


Figure 3.18 Endemicity of old, medium-aged and recent genera among Australian birds for which a time of origin could be determined

However, the difference between Neogene and old genera can be explained by the predominance of non-passerines (very few of which are endemic) in old genera. Passerines as a whole are more highly endemic to Australia, with recent investigations suggesting all oscine passerines have an Australo-Papuan origin (Barker *et al.* 2002). When non-passerines are excluded, 84 per cent of old lineages are Australian or Australo-Papuan endemics. Neogene passerine lineages follow with 71 per cent being Australian or Australo-Papuan endemics compared with only 27 per cent among the recent lineages (Figure 3.19).

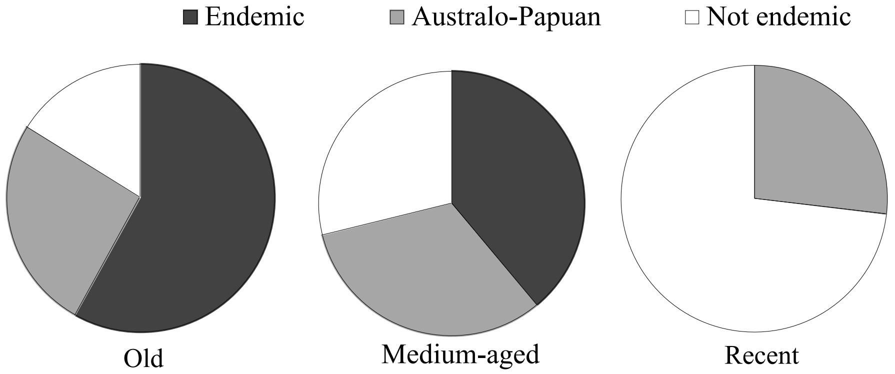


Figure 3.19 Endemicity of old, medium-aged and recent genera among Australian passerines for which a time of origin could be determined

The use of eucalypt forest habitat is more common among members of Neogene genera. Within Neogene passerine lineages, there are 12 genera (44 per cent) that occur in eucalypt forest but have no rainforest representatives, compared to seven old genera (37 per cent) and two recent genera (11 per cent).

Neogene lineages have a particularly high representation of cooperative breeders. Arnold and Owens (1999) and Cockburn (2003) concluded that cooperative breeding, where offspring remain in a territory with the parents in subsequent seasons to help rear the next brood was probably an ancestral trait in a number of taxa within the Corvida, a major songbird lineage that originated in Australia (Sibley and Ahlquist 1995, Barker *et al.* 2002, Ericson *et al.* 2003).

Arnold and Owens (1999) found that conditions that facilitate cooperative breeding include a relatively low seasonal variation in temperature and mild winters, and found that species must have certain inherent traits to develop cooperative breeding such as sedentariness and low annual mortality. Ford *et al.* (1988) found that areas of low seasonal plant growth index corresponded with the areas of highest richness among cooperative breeders as mapped by Dow (1980).

Cockburn (2003) concluded that recent advances in our knowledge shed little light on the influence of environmental factors on cooperative breeding. Cockburn (2003) noted that seasonality, aseasonality and unpredictability had all been suggested as reasons for the high incidence of cooperative breeding in Australia, although he did not refer to the patterns reported by Ford *et al.* (1988). Cockburn (2003) suggested that sedentariness among cooperative breeders negated the likelihood of them developing migration, and that the relationship between low annual mortality and cooperative breeding in Arnold and Owens (1999) was an artefact of uneven sampling of survival data among the passerine groups.

Identification of cooperatively breeding species among the Australian passerines by Geffen and Yom-Tov (1999)(See Appendix 5.) allowed for assessment in the present study of the relationship between breeding strategy and other factors. Genera with both cooperative breeding and pair breeding species were identified as “part” cooperatively breeding genera. At a genus level, the present study revealed that cooperative breeding among Australian passerines is most prominent among Neogene lineages, with species across 60 per cent of genera employing the strategy, compared to 39 per cent of old genera and 27 per cent of recent genera (Figure 3.20). The ancestral nature of cooperative breeding in corvids (Russell 1989; Arnold and Owens 1999; Cockburn 2003) implies that its origins are likely to have preceded the Neogene. However the trait is particularly well expressed among birds from Neogene lineages.

The relationship between co-operative breeding, age and habitat (i.e. rainforest and eucalypt forest and woodland) was investigated. This investigation was carried out at a species level as some genera include both eucalypt and rainforest species. The highest incidence of cooperative breeding was among species that utilize eucalypt habitat rather than rainforest (Figures 3.21–3.24). This result concurs with Ford *et al.* (1988) who recorded a higher level of cooperative breeding in eucalypt woodland and semi-arid woodland than in rainforest or arid habitat. The incidence of cooperative breeding in species of eucalypt habitat was especially high among Neogene species (Figure 3.23).

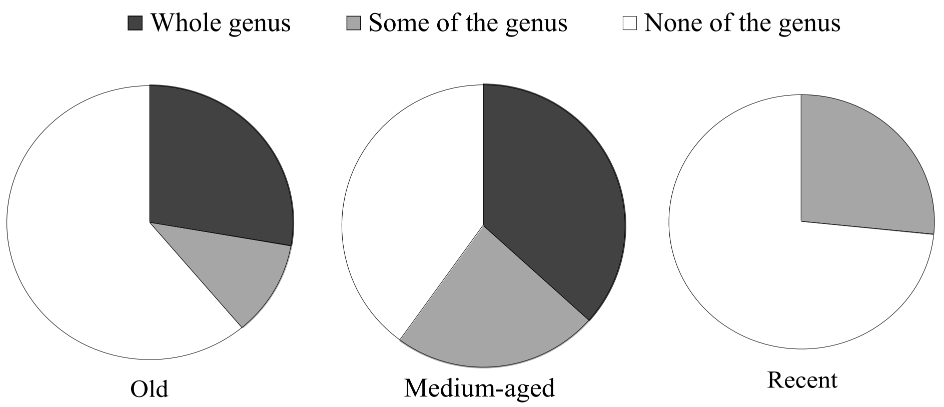


Figure 3.20 Incidence of cooperative breeding among old, medium-aged and recent genera among Australian passerines

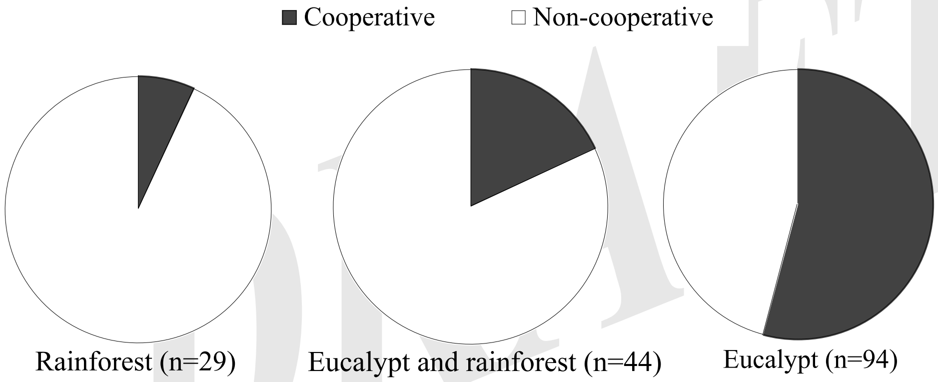


Figure 3.21 Incidence of cooperative breeding among species of Australian passerines that utilize rainforest, eucalypt habitat and both habitats

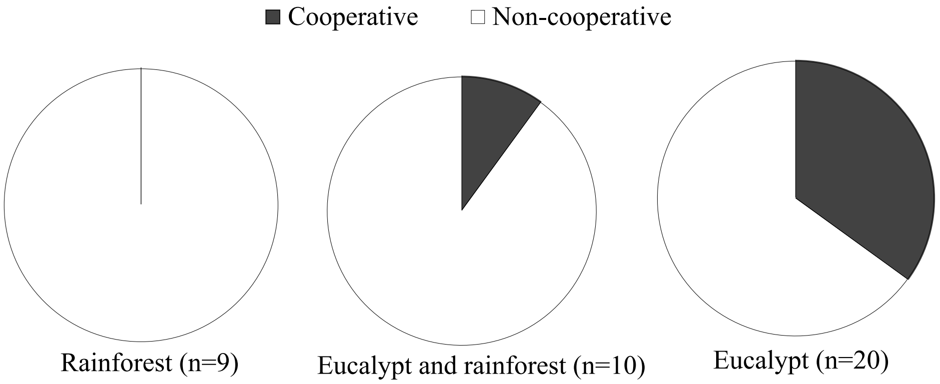


Figure 3.22 Incidence of cooperative breeding among recent Australian passerines that utilize rainforest, eucalypt habitat and both habitats

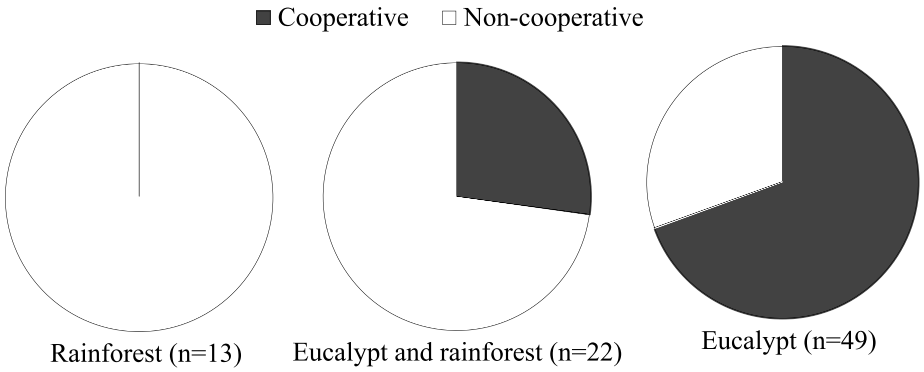


Figure 3.23 Incidence of cooperative breeding among medium-aged (Neogene) Australian passerines that utilize rainforest, eucalypt habitat and both habitats

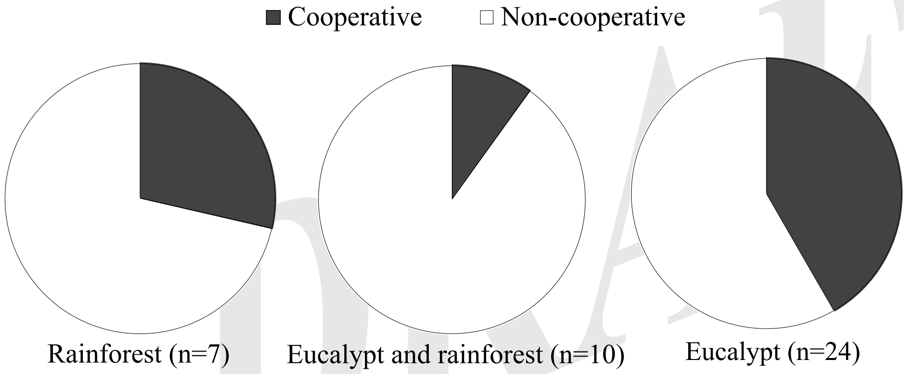


Figure 3.24 Incidence of cooperative breeding among old Australian passerines that utilize rainforest, eucalypt habitat and both habitats

The lower incidence of cooperative breeding in rainforest appears to contradict the premise that low seasonal variation in temperature and mild winters facilitate the strategy. Ford *et al.* (1988) suggested eucalypt habitats may have lower seasonal variation in invertebrate abundance than rainforest, citing a number of invertebrate studies as evidence.

Dow (1980) found that the highest number of cooperative breeders in Australia (>18 species) occur in the Brigalow Belt and across most of the temperate and semi-arid woodland zones of inland eastern Australia, with small areas inside this zone within the NSW section of the Brigalow Belt supporting >22 species. Ford *et al.* (1988) found the pattern of richness among cooperative breeders mapped by Dow (1980) corresponded closely with the pattern of seasonal plant growth index mapped by Nix (1976), with an inverse correlation between the seasonality of plant growth and richness of cooperative breeders. Hence the areas with the most equable seasonal growth indices (e.g. the Brigalow Belt) have the largest assemblages of cooperative breeders in Australia.

To investigate whether the large assemblage of cooperative breeders in the Brigalow Belt was merely an artefact of high richness generally, the proportion of cooperatively breeding and non-cooperatively breeding species was calculated for each 20-km grid cell.

Cooperative breeders are more prominent in the Brigalow Belt avifauna than in the avifauna of South-east Queensland or the Central Queensland Coast (Figure 3.25). The eastern Mulga and Desert Uplands and southern Einasleigh Uplands also appear to be high, although study of these bioregions as a whole would be needed to confirm whether co-operative breeding is as prevalent as it is in the Brigalow Belt.

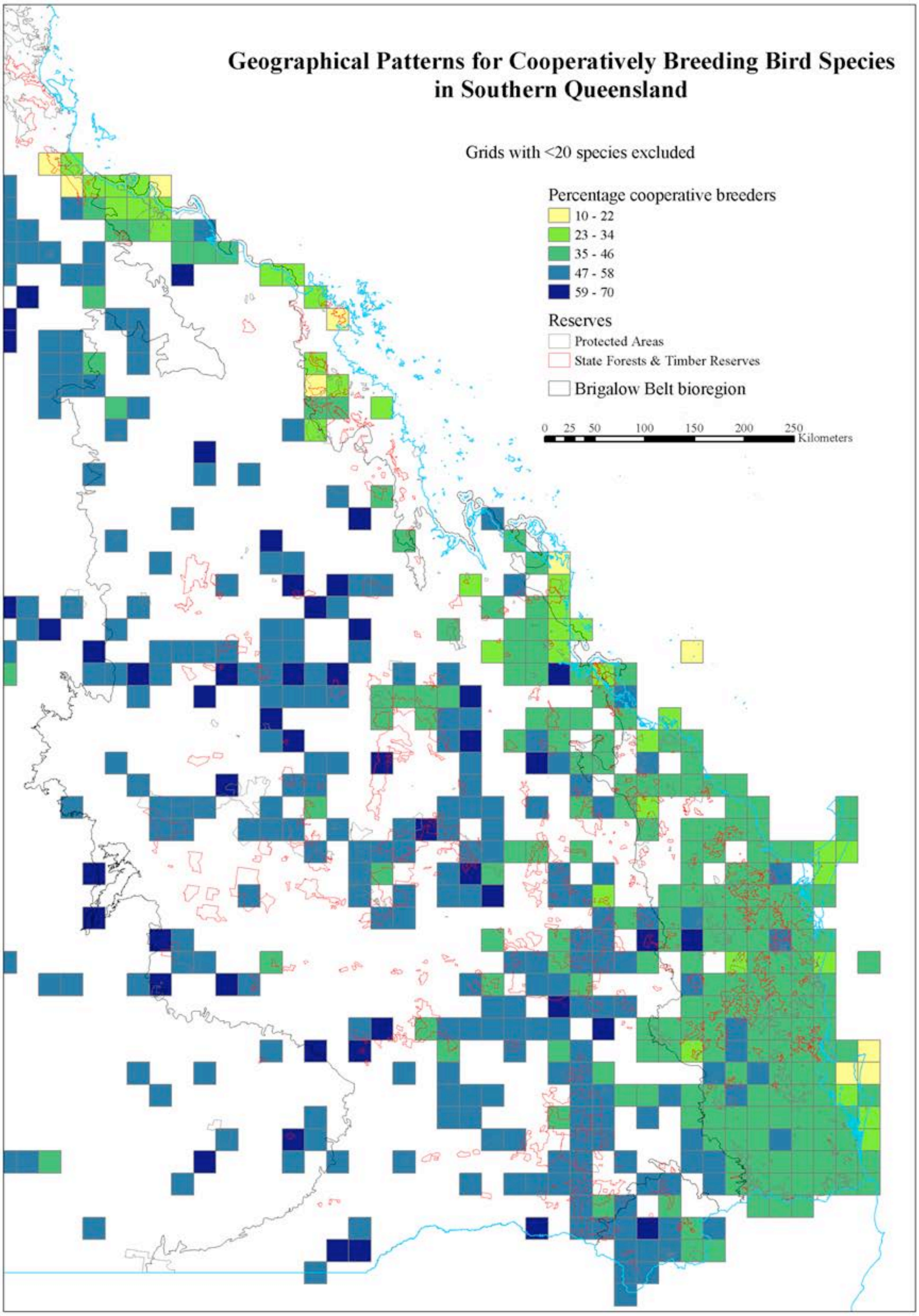


Figure 3.25 Geographical distribution patterns for cooperatively breeding bird species in southern Queensland

3.11.5 Relevance of phylogeny and traits to incidence of decline

The decline of woodland birds in Australia is outlined in detail in Sections 3.4.2.5 and 3.6.4. Investigation of the relationship between decline and phylogeny found a greater incidence of decline in old and Neogene lineages in both NSW woodland birds and Brigalow Belt birds (Figures 3.26 and 3.27). Reid (1999) considered “Old Australasian and Gondwanan lineages” and monotypic genera to be predisposed to extinction given their over-representation among declining woodland birds in NSW.

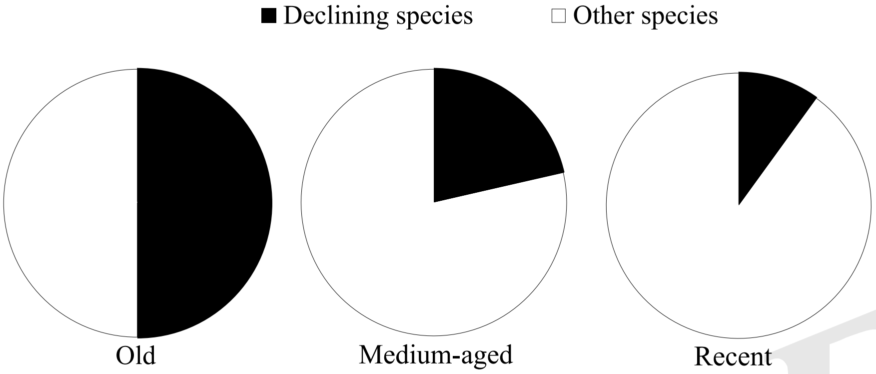


Figure 3.26 Incidence of decline in different age groups among passerines in NSW woodland belt

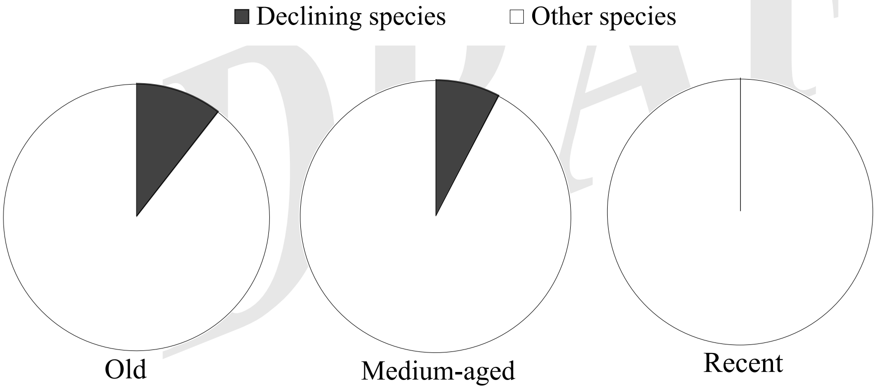


Figure 3.27 Incidence of decline in different age groups among passerines in Brigalow Belt South

The prevalence of cooperative breeders among Neogene species (Section 3.11.4) is of particular interest as they are over-represented among the declining birds of both the Study Area and the NSW woodlands. The high level of sedentariness among cooperative breeders, where natal dispersal is the only major movement an individual is ever likely to undertake (Ford *et al*. 1999), may be a factor that makes them vulnerable to fragmentation. However, sedentariness *per se* is not the explanation for the prevalence of cooperative breeders among declining species, as cooperative breeders are declining at a higher rate than sedentary species overall. Of the 74 species categorised by Geffen and Yom-Tov (1998) that occur in the NSW woodlands (Reid 1999), 37 per cent of sedentary cooperatively breeding passerines were in decline compared to 22 per cent of sedentary non-cooperative breeders. In Brigalow Belt South, where relatively few species have been formally recognized as being in decline, 14 per cent of sedentary cooperative breeders are listed as Of Concern or Near Threatened nationally compared to 4 per cent of sedentary non-cooperative breeders.

Despite the prevalence of cooperative breeders among declining sedentary birds in these areas, some of Australia's most successful birds (e.g. Noisy Miner, Grey Butcherbird, Australian Magpie) also use this strategy. It is evident that a cooperative breeding strategy can be successful in a degraded environment. The success of these birds suggests that cooperative breeding is a not risk factor *per se* but a correlate with other potential risk factors, e.g. foraging niche, sensitivity to disturbance, habitat preference.

The relationship between incidence of decline, foraging substrate and breeding strategy was investigated. No pattern emerged between breeding strategies and foraging preferences at a broad level (ground, canopy, shrub), possibly because of further differentiation within each group. For example, at this level of categorisation a canopy forager could be a nest raider (Grey Butcherbird), bark gleaner (Brown Treecreeper) or foliage gleaner (Striated Pardalote).

Finer-scale foraging preferences (foraging substrates) were analysed in relation to breeding strategies and incidence of decline in NSW woodlands and the Study Area. Cooperative breeders occurred in similar proportions on most foraging substrates, but declines were more prevalent among bark and leaf litter foragers, while generalist canopy foragers and foliage gleaners were relatively secure (Tables 3.36 and 3.37).

The incidence of cooperative and non-cooperative breeders within foraging substrates was compared and related to conservation status (Tables 3.36 and 3.37). However, the influence of breeding strategy on vulnerability of birds using a particular foraging substrate is unclear at this level of detail. Only cooperatively breeding bark foragers are in decline, but there are only two species in each study area that are pair breeders. There are declines among both cooperatively breeding and pair breeding litter and ground feeders. Hence it appears that while cooperative breeders are more likely to be in decline overall, foraging substrate is a better indicator of risk of decline.

The relationship between foraging substrate and phylogenetic age was examined to ascertain whether birds utilizing the 'high risk' (i.e. bark and litter) foraging substrates were significantly older or younger than passerines generally. Bark and litter foragers had the highest proportion of old species, but old and Neogene lineages were also prominent among species foraging 'low risk' substrates such as flowers and foliage (Table 3.38).

It is appropriate to examine the relevant threats that exist within the Study Area. Clearly, land clearing is an indiscriminate threat and it is being addressed by legislation about to be introduced in Queensland. Other threats exist within land that is essentially protected from clearing by tenure, legislation or management decisions. These threats include changes to overall forest structure, understorey structure and composition and ground layer structure and composition.

Litter and bark feeders may be particularly vulnerable because habitat degradation (e.g. attrition of large trees, simplification of ground structure) may have a greater impact on their resource. In the Study Area, foliage gleaners, for example, forage largely on eucalypt leaves, the total abundance of which may not be as greatly affected by management practices, e.g. selective logging and 'thinning', as are other foraging substrates. Bark is generally abundant in eucalypt habitat, but the volume of loose and decorticating bark, the primary foraging site of most bark foraging birds, may be diminished in forests dominated by smaller and younger trees (Recher 1991). Species that forage among litter are vulnerable to simplification of the ground layer. Litter, including woody debris and logs, is an important element of forest structure, providing foraging, perching and nesting sites for birds. Litter also provides significant refuges for invertebrates (Recher 1991). Unnaturally frequent burning and grazing are likely to simplify the ground layer to the detriment of litter foragers.

Table 3.36 Foraging substrates, breeding strategy and incidence of decline among sedentary passerines in NSW woodlands.

Age group	Foraging substrate	Total No. of species	Cooperative breeders (%)	Declining species (%)	Declining cooperative breeders (%)	Other declining species (%)
Old	air					
Medium-Aged	air	2	100	0		
Recent	air					
Total	Air	2	100	0	0	0
Old	bark	5	80	80		
Medium-Aged	bark	2	50	50		
Recent	bark					
Total	Bark	7	71	71	100	0
Old	canopy					
Medium-Aged	canopy	5	40	20		
Recent	canopy	2	100	0		
Total	Canopy	7	57	14	25	0
Old	flowers					
Medium-Aged	flowers	1	100	0		
Recent	flowers	1	0	0		
Total	Flowers	2	50	0	0	0
Old	foliage	2	50	0		
Medium-Aged	foliage	3	100	0		
Recent	foliage					
Total	Foliage	5	80	0	0	0
Old	fruit					
Medium-Aged	fruit					
Recent	fruit					
Total	Fruit	0	0	0	0	0
Old	ground	1	0	100		
Medium-Aged	ground	5	100	20		
Recent	ground	7	14	14		
Total	Ground	13	46	23	17	29
Old	litter	3	0	67		
Medium-Aged	litter	8	87	38		
Recent	litter	1	100	100		
Total	Litter	12	67	50	50	50
Old	all	11	45	64		
Medium-Aged	all	26	81	23		
Recent	all	11	36	18		
Total	All	48	63	31	37	22

Table 3.37 Foraging substrates, breeding strategy and incidence of decline among sedentary passerines in the Brigalow Belt

Age Group	Foraging substrate	Total No. of species	Cooperative breeders (%)	Declining species (%)	Declining cooperative breeders (%)	Other declining species (%)
Old	air					
Medium-aged	air	4	50	0		
Recent	air					
Total	Air	4	50	0	0	0
Old	bark	4	75	25		
Medium-aged	bark	2	50	50		
Recent	bark					
Total	Bark	6	67	33	50	0
Old	canopy					
Medium-aged	canopy	5	40	0		
Recent	canopy	3	67	0		
Total	Canopy	8	50	0	0	0
Old	flowers	1	100	0		
Medium-aged	flowers	3	67	0		
Recent	flowers	2	0	0		
Total	Flowers	6	50	0	0	0
Old	foliage	3	33	0		
Medium-aged	foliage	4	100	0		
Recent	foliage					
Total	Foliage	7	71	0	0	0
Old	fruit					
Medium-aged	fruit	2	50	0		
Recent	fruit					
Total	Fruit	2	50	0	0	0
Old	ground	1	0	100		
Medium-aged	ground	8	100	0		
Recent	ground	6	11	0		
Total	Ground	15	60	7	0	17
Old	litter	5	0	0		
Medium-aged	litter	9	89	33		
Recent	litter	1	100	0		
Total	Litter	15	60	20	33	0
Old	all	14	36	64		
Medium-aged	all	36	78	23		
Recent	all	13	31	18		
Total	All	63	59	10	14	4

Table 3.38 Foraging substrate of old, medium and recent Australian passerines

Foraging Substrate	Total	Percentage of species by age category		
		old	medium	recent
air	**18**	0	56	44
bark	**19**	42	47	11
canopy	**28**	7	57	36
flowers	**27**	37	33	30
foliage	**16**	31	69	0
fruit	**10**	0	80	20
ground	**40**	28	33	40
litter	**41**	51	41	10

3.12 The Brigalow Belt and reptile lineages from the Neogene

3.12.1 Introduction

A number of reptiles now endemic or largely restricted to the Brigalow Belt exemplify significant episodes in the evolution of Australia's reptile fauna. There are five Australian lizard families: Gekkonidae (geckoes), Pygopodidae (legless lizards), Varanidae (goannas), Agamidae (dragons) and Scincidae (skinks). The Brigalow Belt is the home of the antecedents of major radiations within three of these five families. *Strophurus taenicauda* (Gekkonidae)*, Paradelma orientalis* (Pygopodidae) *and Menetia timlowi* (Scincidae) are all antecedents of speciose and/or geographically widespread Australian reptile radiations.

There are two major groups of reptiles that are of phylogenetic importance in the Brigalow Belt. One group consists of species endemic or nearly endemic to the Brigalow Belt that are basal to major reptile radiations into drier habitats. The radiations subsequent to these basal taxa are major elements of the composition of the contemporary Australian reptile fauna in eucalypt habitats and drier semi-arid shrublands and deserts. Core areas for these species are "upland" Subregions on old surfaces, such as Banana-Auburn Ranges, Barakula, Carnarvon Ranges, Inglewood Sandstones, and Woorabinda Subregions. They are not closely restricted to mesic microhabitats such as water or rock crevices, but are found in open eucalypt forests and woodlands that characterise the Study Area.

The other group consists of species that represent evolutionary shifts of rainforest forms into mesic microhabitats. These species represent the evolutionary outcome of the progressive contraction of rainforest since the mid-Miocene. There are no apparent subsequent radiations directly from these species, although this does not mean further radiation into other forms has not occurred. These species are closely restricted to mesic microhabitats, particularly rock crevices.

Molecular phylogenetic studies have drawn attention to another small reptile genus (3 species) of which one species has its distribution centred in the Brigalow Belt. The elapid snake genus, *Hoplocephalus*, was found by Keogh *et al*. (2000) to be most closely related to

“*Echiopsis*” *atriceps*, an extremely localised species from semi-arid woodlands in Western Australia.

3.12.2 Geckoes (Gekkonidae)

3.12.2.1 Introduction

The geckoes are the second largest group of Australian lizards (18 per cent of species and 24 per cent of genera). Twenty species from seven genera occur in the Brigalow Belt. The Australian members of the family Gekkonidae belong to two subfamilies, Gekkoninae and Diplodactylinae.

The Gekkoninae are widespread across Australia and the world. There are more than 900 species (nearly 90 per cent of all geckoes) in approximately 70 genera. Twenty-nine species from six genera occur in Australia and two genera are endemic.

The smaller Diplodactylinae (approximately 120 species and 17 genera worlwide) are restricted to Australo-Papua, New Caledonia and New Zealand, and form the predominant group of geckoes in Australia with more than 80 species from eleven genera. The Diplodactylinae are divided into two subgroups or “tribes”, Diplodactylini and Carphodactylini (Melville *et al*. 2004).

The gecko fauna that now occupies the bulk of Australia (outside the far north and the rainforests of the east) are from the Gekkoninae (*Gehyra, Christinus* and *Heteronotia*, 21 species), and from both subgroups of the Diplodactylinae: the Carphodactylini (*Nephrurus*, 9 species) and the Diplodactylini (*Diplodactylus, Strophurus, Crenadactylus, Oedura* and *Rhynchoedura*, 54 species).

3.12.2.2 Subgroup Carphodactylini

Pseudothecadactylus is a basal member of the Diplodactylinae, and is the Australian species with the closest links to the old lineages that occupy New Caledonia and New Zealand (Greer 1989). It is now found only in far north Queensland and in caves in the Northern Territory and Western Australia (Cogger 2000).

The tropical and sub-tropical rainforests of eastern Australia are occupied by old lineages of leaf-tailed geckoes from *Orraya*, *Saltuarius* and *Phyllurus*. *Orraya occultus* of the McIlwraith Range is considered to be the oldest of these, representing a sister lineage to all *Saltuarius* and *Phyllurus*. *Saltuarius* and *Phyllurus* diverged 74–58 MYA (Hoskin *et al.* 2003), corresponding to the Palaeocene Epoch when Australia was still connected to Antarctica and the vegetation was dominated by podocarpous gymnosperms with a minor component of *Myrtaceae* and *Casuarinaceae* (Martin 1994; MacPhail *et al.* 1994). *Saltuarius* and *Phyllurus* now have a highly relictual distribution in eastern Australia, especially in the Wet Tropics, the Central Queensland Coast rainforests and the CERRA World Heritage Area. The direct descendants of the leaf-tailed geckoes are the “thick-tailed” and “knob-tailed” geckoes of the genus *Nephrurus*, a terrestrial group which occur in wetter eucalypt forests through to the arid zone (Figure 3.28)

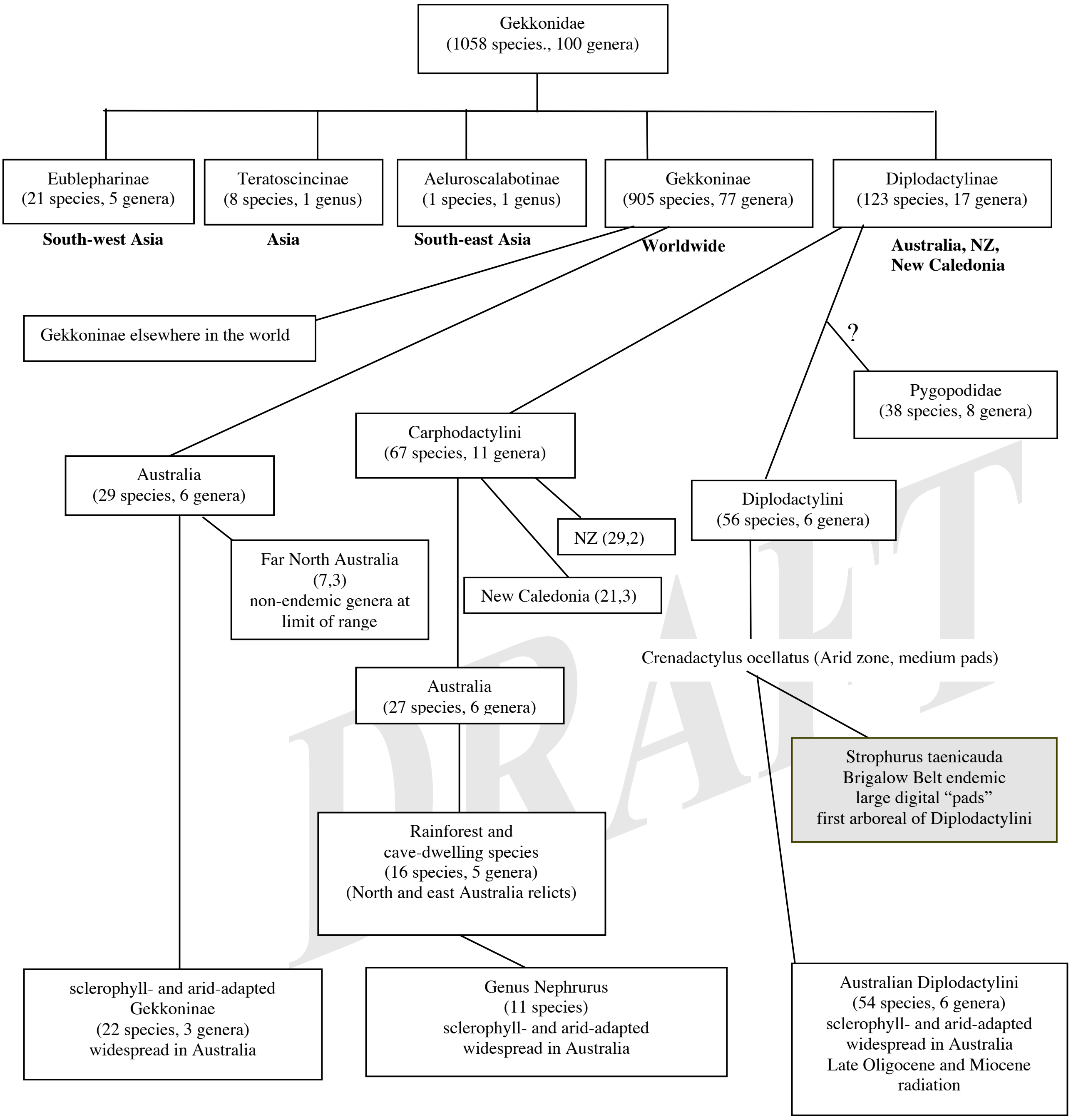


Figure 3.28 World gecko groups and position of Australian sclerophyll and arid-adapted forms

3.12.2.3 Subgroup Diplodactylini

The Diplodactylini arose from a common ancestor (possibly *Pseudothecadactylus*) of the leaf-tailed gecko lineage and their descendants. The Late Oligocene/Early Miocene witnessed the first eucalypts, the commencement of the Neogene period and the appearance of basal lineages of the Diplodactylini, the largest radiation of geckoes into the drier vegetation that now characterises most of Australia. The Diplodactylini now account for nearly 50 per cent of the Australian gecko fauna. The Diplodactylini geckoes are “dry country” reptiles; there are no living rainforest representatives, and indeed few species in wetter eucalypt forests (Wilson and Knowles 1988). The results of Melville *et al.* (2004) suggest that many species in this subgroup arose during the Neogene. A pivotal basal species in the development of this major radiation of dry-adapted geckoes, *Strophurus taenicauda* (Golden-tailed Gecko), is endemic to the Brigalow Belt (Figure 3.28).

Strophurus taenicauda (Golden-tailed Gecko)

Strophurus taenicauda (Golden-tailed Gecko) represents the oldest extant example of evolutionary adaptations to aridity and arboreality in the *Diplodactylus*/*Strophurus* group, and possibly the Diplodactylini as a whole. Melville *et al.* (2004) placed *S. taenicauda* as either a basal or a sister group to the genus *Oedura* depending on the method of analysis used, with neither result considered to be more strongly indicative. If *S. taenicauda* is basal to *Oedura*, it is a basal lineage to all of Australia’s arboreal Diplodactylini. If it is a sister group to *Oedura*, both *S. taenicauda* and *Oedura* are basal to the *Diplodactylus*/*Strophurus* group, or about 75 per cent of the Diplodactylini.

From these origins, the *Diplodactylus*/*Strophurus* group (37 species) radiated largely during the Neogene with species generally arising 28–8 MYA (Melville *et al.* 2004). The group entered more xeric habitats within which further speciation occurred, particularly in arid and semi-arid Western Australia, and now occupies virtually the entire Australian mainland (Cogger 2000).

S. taenicauda is the oldest extant species with a broad “pad” on each digit which all subsequent arboreal *Strophurus* possess. The rainforest-dwelling arboreal geckoes of the Carphodactylini that evolved much earlier than *S. taenicauda* have narrow, “bird-like” feet (Cogger 2000, Hoskin *et al.* 2003). The development of broad “pads” may be of major significance, as it appears to have enabled the “first step” of the diplodactyline geckoes into trees in non-rainforest habitats. All Australian non-rainforest dwelling arboreal geckoes (including those of the distantly related *Gehyra*, which evolved digital “pads” independently) have broad “pads”, suggesting such an adaptation might be necessary to enable arboreality in drier habitats (rainforests have few smooth-barked trees).

3.12.2.4 Distribution patterns of geckoes in the Brigalow Belt

Saltuarius salebrosus, *Oedura tryoni* and *Nephrurus milii* have the closest association with upland Subregions, and *Diplodactylus conspicillatus*, *D. steindachneri* and *Gehyra catenata* had the closest association with the downs (Queensland Fauna Database). Of the seven genera present in the Brigalow Belt, *Gehyra*, *Oedura*, *Diplodactylus*, *Strophurus* and *Nephrurus* all have “upland” and “lowland” representatives, whilst the monotypic generalist *Heteronotia binoei* is widespread throughout the Study Area. Intrageneric phylogenies for *Gehyra*, *Oedura*, *Diplodactylus* and *Nephrurus* are not sufficiently detailed to determine the relationship of upland species with their lowland counterparts.

Strophurus taenicauda occurs in the Brigalow Belt with the relatively recently derived *S. williamsi*. *Strophurus taenicauda* has a stronger upland association than the more widespread *S. williamsi*, with 73 per cent of precise (≤500 m) records on the uplands compared to 22 per cent for *S. williamsi*. The upland associated taxon *N. milii* is basal to four other *Nephrurus* species studied by Melville *et al*. (2004) but they did not assay *N. asper*, which is the lowland species in the Brigalow Belt.

Saltuarius is a much older lineage than the aforementioned genera (See Hoskin *et al*. 2003 and Melville *et al*. 2004.). One species is present, with the most relict upland distribution of all the Brigalow Belt's geckoes. *S. salebrosus* appears to be a true pre-Miocene relict, restricted to the refuges offered by sandstone overhangs and crevices. These refuges are often at high altitudes, but populations in Nathan Gorge where the Dawson River cuts through the Carnarvon Ranges Subregion are at around 200 metres asl, and a record from Roundstone Creek in Theodore State Forest is at about 250 metres asl. Populations are known from Blackdown Tableland-Shotover SF, Carnarvon Ranges (especially the east including Presho, Belington Hut and Theodore State Forests) and the Monto area including Grevillea SF, where individuals have been recorded on the trunks of *Eucalyptus decorticans* (Gum-topped Ironbark)(S. Kennedy pers. obs.). *S. salebrosus* is unique in the genus in that it extends up to 300 km inland. The remaining *Saltuarius* are restricted to rainforest and heathland and all display a highly relictual distribution, with species endemic to the New England Tableland, the Mt Warning-Scenic Rim rainforests and the higher parts of the Wet Tropics.

Study of *S. salebrosus* populations in the Brigalow Belt compared to those in South-East Queensland may offer an insight into the timing of the contraction of suitable habitat for this species. The events that caused the retreat of *S. salebrosus* may have been climatic (contraction of rainforest) or geological (erosion of the old surfaces or "scarp retreat"). In either case, the antiquity of *S. salebrosus* makes it a unique element of the herpetofauna and one that may be informative about the climatic history of the Study Area.

The genus *Oedura* is more species rich in the Brigalow Belt than anywhere else, with a range of species from the most temperate form, *O. lesueurii*, which is found only in mesic refugia in the Brigalow Belt, upland associated species, *O. tryoni*, lowland sub-humid species, *O. monilis*, through to the most arid-adapted form, *O. marmorata*. *Oedura* is made up entirely of arboreal and saxicolous species, with a number of species displaying a close affinity to eucalypts. The species present may represent a catena reflecting evolution of forms in response to declining moisture regimes but this hypothesis is subject to intrageneric study of *Oedura* phylogeny. Phylogenetic study of *Oedura tryoni, O. monilis and O. marmorata* is currently being conducted by Conrad Hoskin at the University of Queensland (C. Hoskin pers. comm.).

3.12.3 Legless lizards (Pygopodidae)

The Pygopodids, a group of 38 legless lizards, are Gondwanan in origin and confined to Australia and New Guinea (Jennings *et al*. 2003). They are currently placed in their own family, Pygopodidae, but recent molecular study indicates that they are geckoes (family Gekkonidae) and may represent a sister group to the gecko subfamily Diplodactylinae (Donnellan *et al*. 1999).

The first pygopodid appeared in the late Eocene (timed at 37 MYA), and all genera arose in the Eocene, Oligocene or early Miocene but most extant species have evolved during the

Neogene, commencing around 25 MYA (Jennings *et al*. 2003). There are no extant rainforest pygopodids in Australia, but *Lialis jicari* of New Guinea may use rainforest, and the little known *Delma mitella* of the Atherton Tableland has been recorded at the open forest-rainforest ecotone (Queensland Fauna Database).

There may be a link between the commencement of the Neogene and a major acceleration in the development of today's pygopodid fauna, but Jennings *et al*. (2003) caution that "*Although our profile shows two possible upturns in speciation rate, one between 23 and 33 MYA and the other between 17 and 23 MYA, any attempt to link these putative upturns to specific environmental events is premature until independent comparisons with Australian lizard clades can be made. If a number of such profiles are found to agree with one another, this agreement may provide further evidence that Australian lizard diversity has tracked large-scale environmental changes in Australia*." Nevertheless the current composition of the pygopodid fauna was largely developed in the Neogene even if an actual upturn in speciation cannot be linked to its commencement.

The Pygopodidae are split at a deep level between the *Delma* group (17 species) and all other pygopodids. The basal genus to the species other than *Delma* is *Lialis*, which includes a highly successful and widespread Australian species and a New Guinean species that may be a rainforest dweller. The next group to diverge was the *Paradelma*/*Pygopus* clade (five species) which occupies the entire Australian mainland. Two localized endemics *Ophidiocephalus taeniatus* (central Australia) and *Pletholax gracilis* (Western Australia) are basal to the genus *Aprasia* (12 species) which occupies winter-rainfall areas across southern Australia (Figure 3.29).

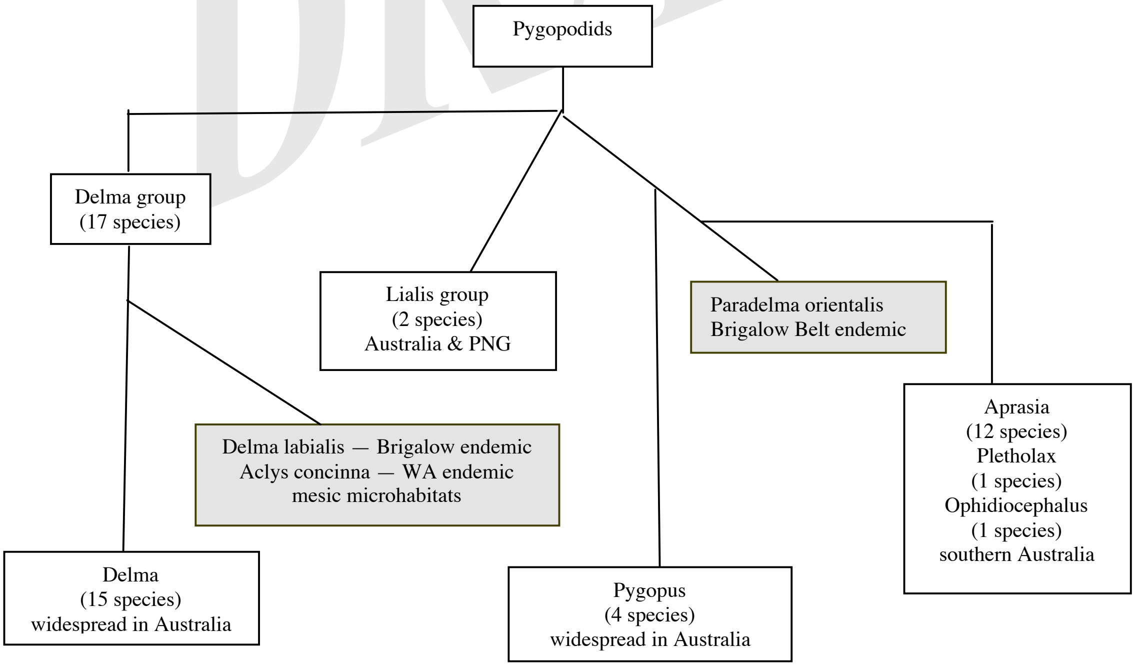


Figure 3.29 Relationships among the pygopodids

The Brigalow Belt has nine pygopodid species, which is fewer than many regions in South Australia and Western Australia, but these nine species represent seven lineages extending back approximately 20 million years. This diversity of early Miocene lineages is found nowhere else, and two of the oldest lineages among the pygopodids are endemic to the Brigalow Belt. These two endemics are basal to two of the three pygopodid lineages that are now widespread across mainland Australia. *Paradelma orientalis* is basal to *Pygopus* while *Delma labialis* and its sister taxon *Aclys concinna* (coastal Western Australia) are basal to *Delma* (Jennings *et al*. 2003).

Paradelma orientalis ***(Brigalow Scaly-foot)***

The monotypic endemic *Paradelma orientalis* (Brigalow Scaly-foot) arose about 23 MYA, corresponding with the commencement of the Neogene period. As noted above, *P. orientalis* is basal to *Pygopus*. *Pygopus* is not speciose, with recent revision suggesting there are four species (James *et al*. 2001), but is evidently a successful lineage as it occupies the entire Australian mainland (Cogger 2000).

Delma labialis

Delma labialis of the Townsville area in Brigalow Belt North appears to be a sister species to *Aclys concinna*, a species of coastal Western Australia. Together, these two species form a sister group to the remainder of the *Delma* genus, the largest pygopodid genus and one which occupies the entire Australian mainland. The disjunction of these two species spans the continent, a remarkable 3500 km. Their evolutionary separation appears to have occurred prior to the isolation (by aridity or rising sea levels) of the fauna of eastern and south-western Australia in the mid-Miocene. The results of Jennings *et al*. (2003) indicated a divergence between 22 and 30 MYA, and they suggested that increasing aridity across the interior of Australia has created the relictual distributions of these two relatively mesic-adapted species.

Other **Delma** ***in the Brigalow Belt***

The genus *Delma* is represented in the Brigalow Belt by *D. labialis, D. inornata*, *D. plebeia*, *D. torquata*, and *D. tincta*. *D. plebeia* was not studied by Jennings *et al*. (2003), but the other four species were found to be deeply divergent and were separate as long as 18 MYA. One species is basal to a group of southern species, and two others are highly disjunct from sister species in southern and western Australia.

Delma torquata was considered to be a sister species to *D. australis*, which has a southern Bassian and semi-arid distribution. *D. torquata* has the most relict distribution of the Brigalow Belt representatives in the genus, with a close association to the uplands including Blackdown Tableland and the Carnarvon Ranges Subregion (Presho SF and Expedition NP). *D. australis* is found in sandy arid areas across southern Australia, at least 1000 km from the western edge of the range of *D. torquata.*

Delma inornata was considered basal to a group (*Delma petersoni, D. fraseri and D. grayii*) that otherwise has a southern Bassian distribution. It is a lowland grassland species, with a broader range than *D. torquata.* Unlike *D. torquata* it ranges south into Victoria to within 300 km of the nearest taxon in the group.

Delma tincta has the broadest distribution of any *Delma* (Cogger 2000) and was grouped with a clade covering much of northern Australia, for which *D. pax* (northern Western Australia) is the basal species. *D. tincta* is the only Brigalow Belt *Delma* to occur sympatrically with other members of its group.

3.12.4 Dragons (Agamidae)

Macey *et al*. (2000) proposed that the Australo-Papuan agamids are a monophyletic group of Gondwanan origin, having "rafted" on the Australia-New Guinea plate as it crossed the Tethys Sea, evolving in isolation. The Australo-Papuan agamids display a deep divergence to agamids of other continents, and Macey *et al*. (2000) proposed the name Amphibolurinae for this subfamily. A dispersal event from Asia followed by a rapid radiation is considered unlikely by Macey *et al*. (2000) on the ground that such dispersal could not have predated 10 MYA. Macey *et al*. (2000) found that DNA sequence data for taxa of the Australo-Papuan plate and a species from a fragment of the plate suggest a vicariant split at least 20 million years ago. Further investigation of agamid and varanid phylogeny by Schulte *et al*. (2003) suggested divergence of these groups either side of Wallace's Line occurred 128 to 160 MYA. Their studies support the conclusion of Macey *et al*. (2000) that south-east Asian varanids and agamids rafted on a fragment (or fragments) of Gondwana that separated from the northern margin of Australia or the subcontinent (See Section 3.12.6.1.). The alternative hypothesis of a late tertiary dispersal event introducing these groups to Australia was clearly rejected.

Physignathus lesueurii is basal to all other Brigalow Belt species. It is found on watercourses throughout the Brigalow and much of coastal and sub-coastal eastern Australia. *P. lesueurii* is basal to two major groups of agamids. One is the large *Ctenophorus* genus, a largely arid-zone dwelling genus which is absent from the Brigalow Belt. The other major group includes all other agamid genera of eucalypt habitats in Australia. The most basal group to this "non-*Ctenophorus*" group includes four species, *Chlamydosaurus kingii*, *Lophognathus gilberti*, *Amphibolurus muricatus* and *A. norrisi* (Schulte *et al*. 2003). Three of these four species overlap in the Brigalow Belt, the only place where this occurs. *A. norrisi* is a geographically isolated sister taxon to *A. muricatus,* and occurs in the mallee of southern Australia. From shared ancestors with the aforementioned group, major genera such as *Diporiphora* (15 species), *Tympanocryptis* (six species) and *Pogona* (seven species) radiated and occupied a range of habitats from open forests and woodlands, to rocky areas and arid scrubs.

3.12.5 Skinks (Scincidae)

3.12.5.1 Introduction

The skinks represent the largest group of Australian lizards (62 per cent of species and almost 50 per cent of genera). Greer (1989) defined three major groups of Australian skinks: *Sphenomorphus*, *Eugongylus* and *Mabuya*. The *Mabuya* group was found to be paraphyletic by Reeder (2003) who proposed subdivision of the group with the Australian members (*Egernia*, *Tilqua*) placed in the new group, *Egernia*. Each group displays an evolutionary progression from basal rainforest taxa through to sclerophyll and arid-adapted forms that extend across much of Australia (see Reeder 2003). The genera *Anomalopus* and *Eulamprus* (*Sphenomorphus* group), *Lampropholis* and *Carlia* (*Eugongylus* group) and *Egernia* (*Egernia* group) are well represented in the Brigalow Belt.

3.12.5.2 *Eugongylus* group

The *Eugongylus* group includes a morphologically distinct group of four genera with a hemipenal structure found in no other skinks (Greer 1989). This group of about 40 species accounts for about 10 per cent of Australian skinks. The basal genus is the largely rainforest-dwelling *Saproscincus* of eastern Australia. Four of the five species occur as rainforest relicts in the Wet Tropics (two species), the rainforests of the Central Queensland

Coast (one species), and the rainforests of CERRA (one species) (Cogger 2000). The subsequent genus to diverge, *Lampropholis* (five species), has a greater number of species with wider ranges in eucalypt forests but is still largely restricted to mesic microhabitats (Relict populations occur in mesic refugia in the Study Area.). From these origins, the group underwent a major radiation in drier habitats, with a variety of forms that are not restricted to mesic microhabitats. *Menetia timlowi*, a pivotal basal species to the transition of this distinct group of skinks into dry habitats and their subsequent radiation, is found largely in the Brigalow Belt (Figure 3.30).

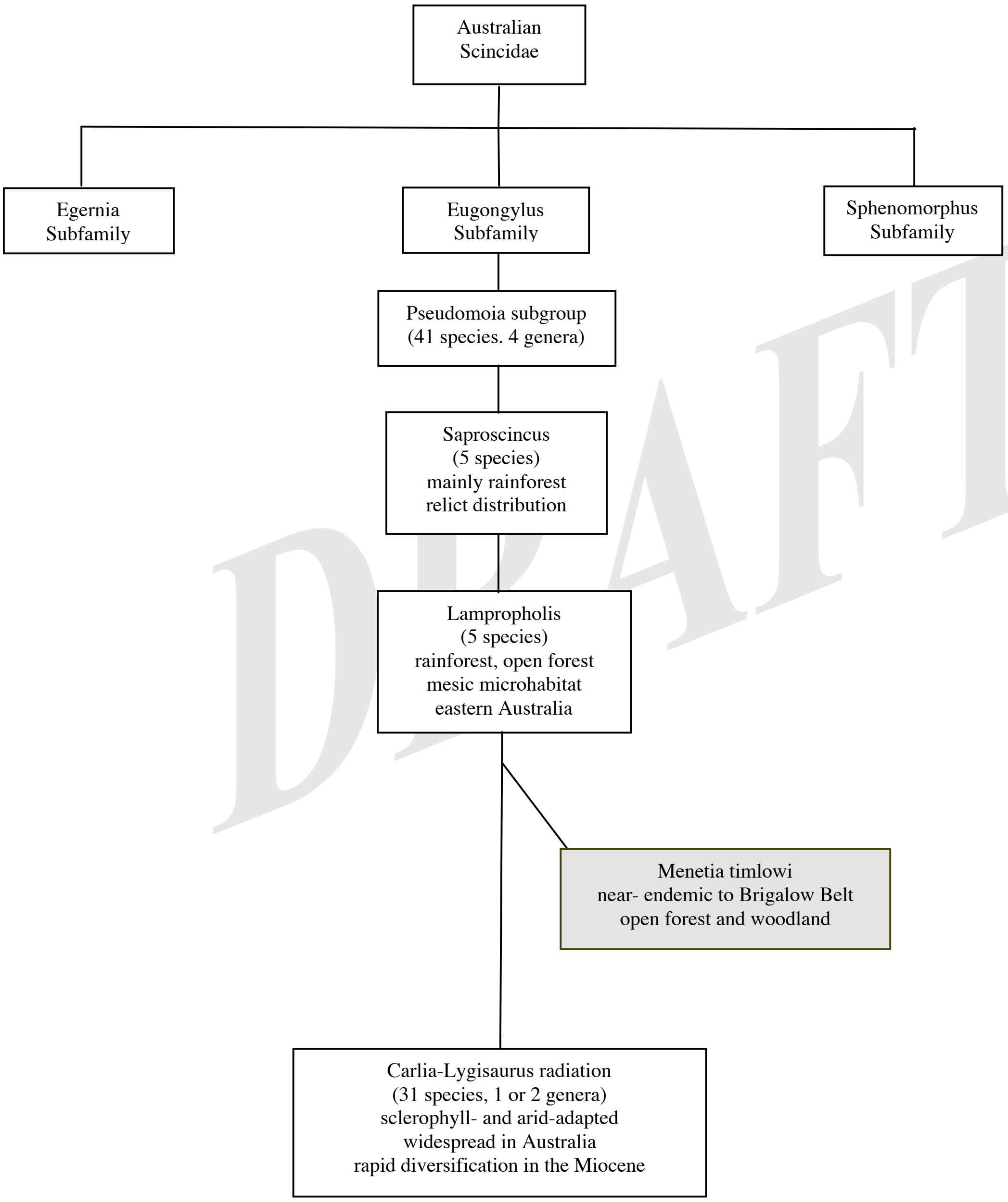


Figure 3.30 Australian skink subfamilies and position of *Menetia timlowi*

Menetia timlowi (Scincidae)

Menetia timlowi is basal to the radiation of the *Carlia-Lygisaurus* group (31 Australian species) (Stuart-Fox *et al*. 2002). The *Carlia-Lygisaurus* group is a group of litter-dwelling skinks now widespread across Australia (especially the tropical north) and Papua New

Guinea. The group is most speciose in north Queensland, particularly the Wet Tropics but 12 species have been recorded in the Brigalow Belt. The group occurs in a variety of habitats from rainforest to spinifex grasslands, although the bulk of species occur in woodland and open eucalypt forest (Cogger 2000).

The timing of the divergence of the skink *Menetia timlowi* was not discussed by Stuart-Fox *et al*. (2002), but the subsequent radiation among the *Carlia-Lygisaurus* group was considered to have been a "*relatively rapid diversification sometime during the Miocene*". *M. timlowi* evidently appeared earlier than this radiation, and so probably originated in the Miocene or Oligocene. Stuart-Fox *et al*. (2002) suggest that *M. timlowi* does not belong in "*Menetia*", but in a separate genus, possibly with *M. sadlieri* which is endemic to Brigalow Belt North (Magnetic Island) and *M. koshlandae* of woodlands in the Palmer River area of the Wet Tropics. This classification would give a clear taxonomic identity to a lineage which appears to have been of great evolutionary significance in the development of the *Carlia-Lygisaurus* radiation.

3.12.5.3 *Sphenomorphus* group

Eulamprus genus

The skinks of the genus *Eulamprus* (sensu Cogger 2000) are likely to represent three genera which diverged "well back" into the Miocene (O'Connor and Moritz 2003). They are the rainforest-dependent *E. murrayi* group of South-East Queensland and the Central Queensland Coast, the *E. tenuis* group which includes *Gnypetoscincus queenslandicus* and *Nangura spinosa* and relictual representatives in the Brigalow Belt, and the *E. quoyii* group, which is basal to the other groups and includes a single Brigalow Belt representative, the water-dependent *E. quoyii*. The *E. quoyii* clade is basal to the *E. tenuis* group. The *E. quoyii* skinks are quite ecologically distinct, with a close association with water. This clade is recommended to be the "new" *Eulamprus* by O'Connor and Moritz (2003).

Eulamprus tenuis subgroup or "Concinnia"

The *E. tenuis* group is proposed as the genus *Concinnia* by O'Connor and Moritz (2003). The study by O'Connor and Moritz (2003) suggests "Concinnia" displays a trend of evolutionary adaptation to declining moisture regimes. The basal lineages of the group are relict rainforest specialists, including *Gnypetoscincus queenslandiae* of the Wet Tropics *Eulamprus amplus* of the Central Queensland Coast rainforests and *Nangura spinosa* of dry rainforests in two highly localized areas in South-East Queensland. Subsequently, *E. tenuis* diverged and is found in coastal eastern Australia in both rainforests and rocky habitats in open eucalypt forest. The next clade includes *E. tigrinus* of Wet Tropics rainforest as a sister taxon to *E. brachysoma, E. martini* and *E. sokosoma*, which appear to represent a relatively recent shift of the *"Concinnia"* into rocky and creekline habitats in drier areas (O'Connor and Moritz 2003). A large proportion of the range of *E. sokosoma* is in the Brigalow Belt, and *E. brachysoma* also occurs in eastern parts of the Study Area (Figure 3.31).

O'Connor and Moritz (2003) stated that "*For both flora and fauna, rainforest contractions since the mid-Miocene may have caused the extinction of rainforest specialists or, for species persisting in now drier forests, promoted ecological shifts towards mesic microhabitats. The shifts towards such habitat preferences on both the* quoyii *and* martini/sokosoma/brachysoma *lineages may reflect this trend*".

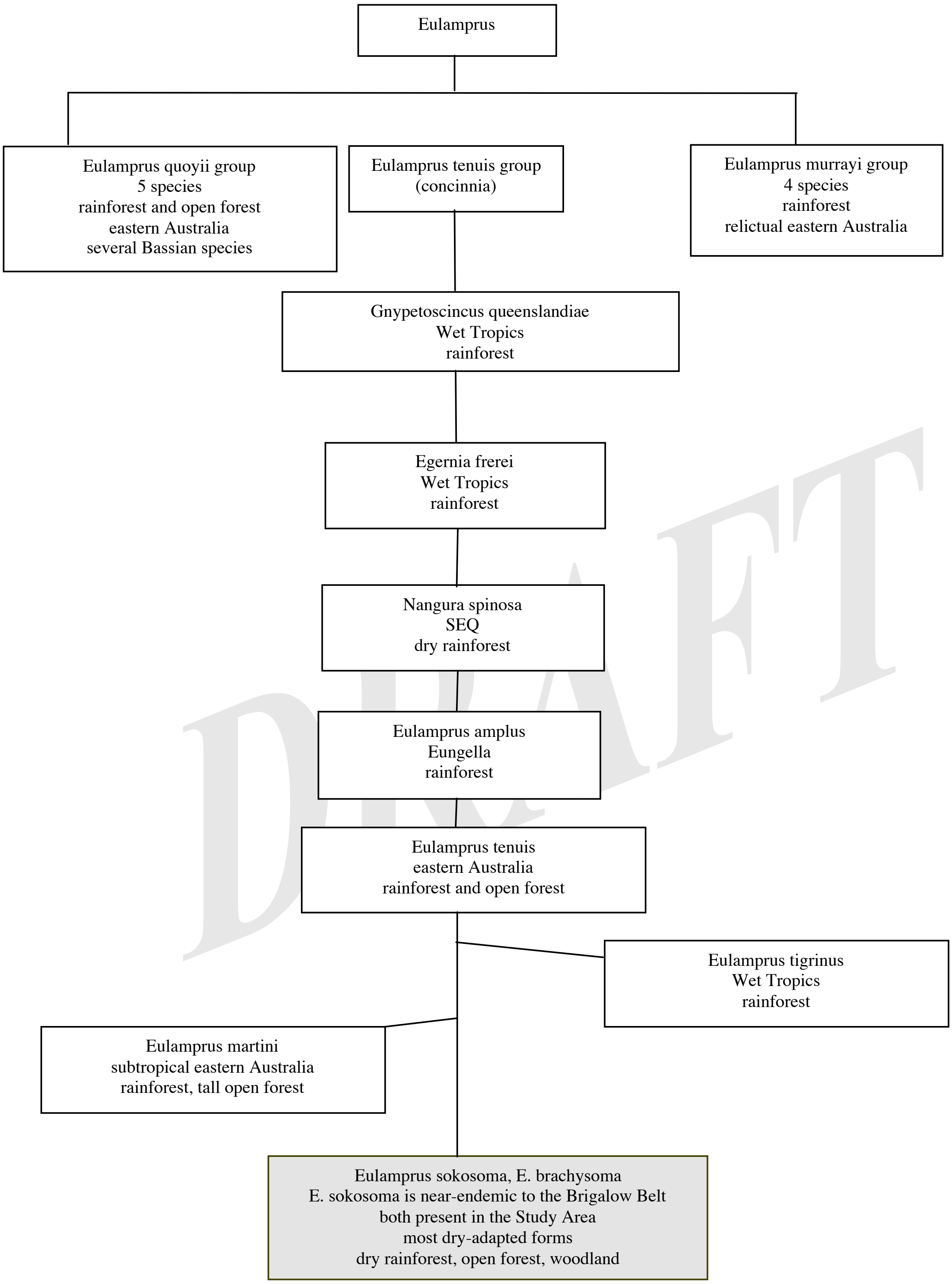


Figure 3.31 Relationships within *Eulamprus* and the position of *Eulamprus sokosoma*

Eulamprus sokosoma has a relict distribution in the Brigalow Belt, with populations on uplands in Blackdown Tableland, Belington Hut SF, Isla Gorge NP and Moonlight SF near Rockhampton. It is the most inland member of "*Concinnia*", and is therefore presumably the most evolutionarily "advanced" extant member of a lineage that has been gradually adapting to declining moisture regimes since the Miocene. It is evident from the current relict distribution of *E. sokosoma* that even the relatively dry microhabitats it uses have contracted from their former extent.

Cryptoblepharus

Cryptoblepharus is a genus of arboreal and saxicoline skinks. In Cogger (2000), there are three arboreal species, which all overlap in the Brigalow Belt and on the central east coast of Queensland. There is little scope to identify patterns among *Cryptoblepharus* with these three taxa, which are very widespread. However, Horner (2003) has reviewed the taxonomy of *Cryptoblepharus* and described 13 new taxa. This work has yet to be published, but may elucidate the role of the Brigalow Belt in the development of this genus. Given the major adaptations of the genus to arboreality (Greer 1989), and the importance of the Brigalow Belt for the antecedents of other non-rainforest arboreal reptiles, the work of Horner (2003) will be of great interest.

3.12.5.4 Distribution patterns of skinks in the Brigalow Belt

The most upland restricted taxa in the Brigalow Belt include two species each from the genera *Eulamprus* and *Lampropholis* as well as a population of the saxicolous *Carlia mundivensis* in the Nathan Gorge area. *Egernia modesta* and *E. cunninghami* also have disjuncts on the uplands, with the *E. cunninghami* population in Carnarvon NP more than 400 km from the nearest known population.

3.12.6 Elapids (Elapidae)

3.12.6.1 Introduction

Fifteen of the 20 elapid genera occur in the Brigalow Belt. This is the largest number of elapid genera in a bioregion in Australia (shared with South-East Queensland)(Section 2.4.5.2), and hence one the most genus rich areas in the world as other continents have relatively poor elapid diversity at this higher level.

Elapid phylogeny in Australia is still poorly resolved, despite the large number of authors seeking to redress this deficiency (Keogh *et al.* 2000). Keogh (1998) found that divergence events among the elapids occurred a long time ago and within a brief period. Keogh's results suggest that the basal branches of the Australo-Papuan radiation are genera from Melanesia. Keogh concluded that the elapids "invaded" Australia with the collision of the Australian and Asian plates 15 million years ago. The elapids then radiated rapidly, but have since stabilized. Macey *et al.* (2000) found a similar sister-group relationship between agamids on the Australian plate and those on Southeast Asian blocks but offered a different explanation. They suggest that the Southeast Asian agamids, elapids and varanid lizards "rafted" on Gondwanan blocks that broke away from the northern margin of the Australia-New Guinea plate and accreted to Asia more than a hundred million years ago.

If the explanation of Macey *et al.* (2000) is correct, the possibility arises that the rapid radiation of Australian elapid snakes since the Miocene was triggered by climatic and vegetation changes rather than resulting from an "invasion" from the north. Further phylogenetic work and accurate measurement of the timing of radiation may elucidate this.

A significant discovery by Keogh *et al.* (2000) was that *"Echiopsis" atriceps*, an extremely localized species from woodlands in Western Australia, is most closely related to the arboreal snakes of *Hoplocephalus*. *Hoplocephalus* is the most arboreally adapted elapid genus and the oldest extant species is *H. bitorquatus,* with a distribution centred on the Brigalow Belt (Section 2.4.5.2). This is a remarkable disjunction in the group, the common ancestors of which evidently once spanned the continent (as did the arboreal gecko genus *Oedura*, which has also has one arboreal woodland species in south-west WA, disjunct from other arboreal species in the genus). *"Echiopsis" atriceps* (Lake Cronin Snake) is so little known (there are only five museum specimens) that arboreality cannot be confirmed other than a mention in Ehmann (1993) that it may be a tree-climber (Keogh *et al.* 2000). This discovery indicates that *H. bitorquatus* is perhaps the oldest extant form of a lineage that once covered much of Australia (rather than just eastern Australia where *Hoplocephalus* currently occurs), but is now much more restricted. The possible timing of the vicariance event between the *"Echiopsis" atriceps* lineage and *Hoplocephalus* is not discussed by Keogh *et al.* (2000), but would be of great interest.

3.12.6.2 Distribution patterns of elapids in the Brigalow Belt

Nearly all elapids have a closer affinity to lowlands than uplands (Queensland Fauna Database). A major exception is the Eastern Tiger Snake (*Notechis scutatus*) has been recorded in the Mount Moffatt section of Carnarvon NP, some 400 kilometres from the nearest populations in the Bunya Mountains. This population is a northerly outlier of an otherwise Bassian genus, a pattern of disjunction mirrored by other fauna (e.g. *Egernia cunninghami*, the moth genus *Paralaea*) and many plant taxa.

3.13 Biodiversity Planning Assessments

The Environmental Protection Agency (EPA) has conducted Biodiversity Planning Assessments in the Brigalow Belt North, Brigalow Belt South and New England Tableland Bioregions using the Biodiversity Assessment Mapping Methodology (BAMM)(Environmental Protection Agency 2002a).

BAMM comprises two components: (1) a computer-based data analysis using a set of Diagnostic Criteria to provide a 'first cut' of Biodiversity Significance of remnant Regional Ecosystem polygons, and (2) an Expert Panel based review of the 'first-cut' assessment using a set of Other Essential Criteria. Three separate panels were convened for flora, fauna and landscape assessments.

Biodiversity Significance (Biosignificance) was rated as 'State Significance', 'Regional Significance', 'Non Bioregional Ecosystem' or 'Local Significance or Other Values'.

Of the 12.2 million ha of remnant vegetation in the Brigalow Belt, 11.7 million ha (95 per cent) were classified as being of 'State Significance' for biodiversity (Environmental Protection Agency 2003a). This included around 2.1 million ha (91 per cent) of State Forest and Timber Reserve land in the WHWD Area, including all of the larger reserves.

The final result of the assessments is shown in Figure 3.32.

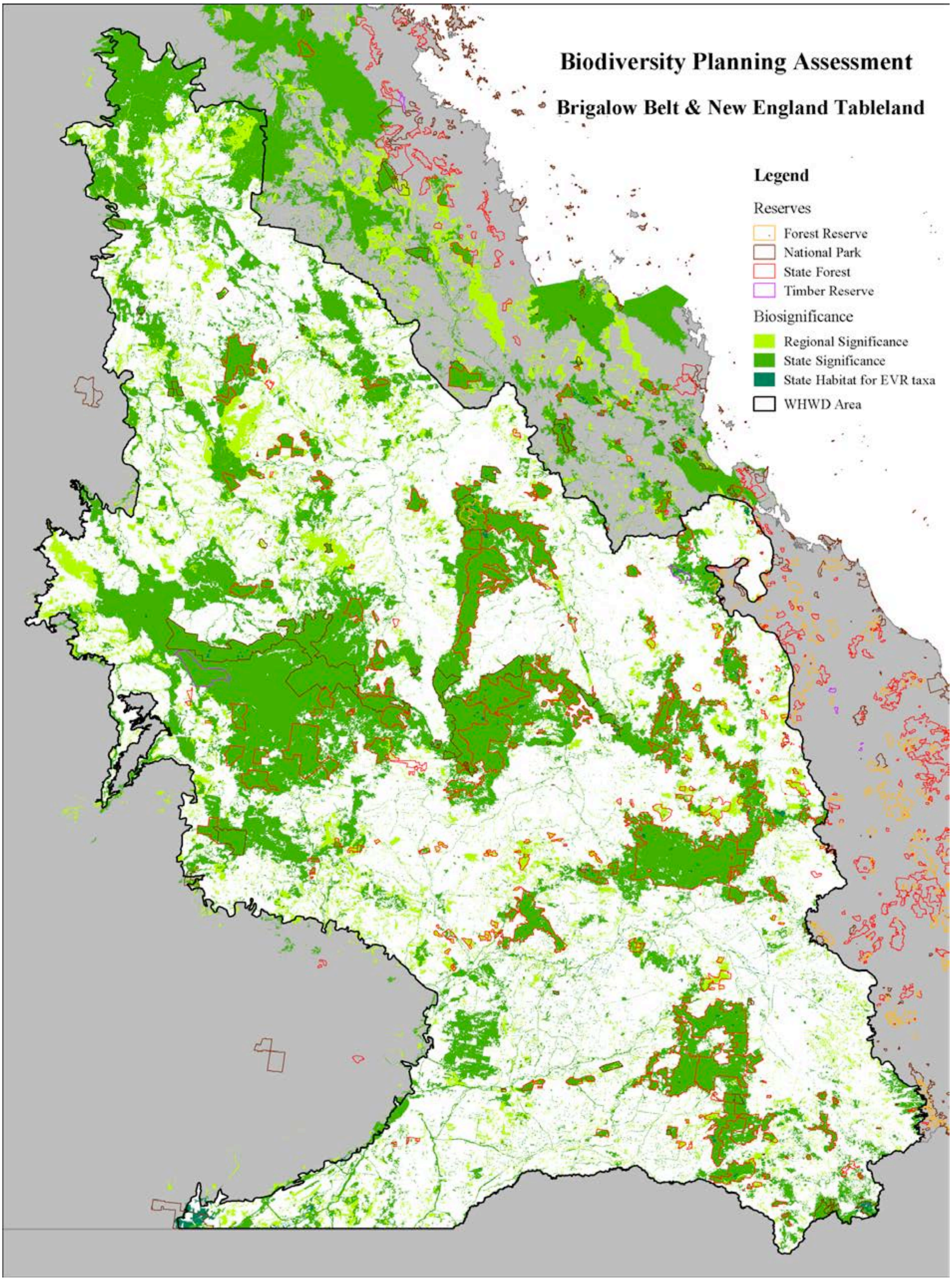


Figure 3.32 Biodiversity Planning Assessment, Brigalow Belt and New England Tableland

3.14 Wilderness

Wilderness quality data for the WHWD Area were derived from National Wilderness Inventory data originally provided by Environment Australia (April 2001).

A Wilderness Quality Index is derived by summing standardised values for the three distance-based wilderness quality indicators, Remoteness from Settlement, Remoteness from Access and Apparent Naturalness (truncated at a maximum of class 5) and the Biophysical Naturalness value (http://www.heritage.gov.au/anlr/nwi/nwihtm/chap_4/chap_4_4.html). The index has a maximum value of 20.

For the purposes of Regional Forest Agreement assessment processes, a Wilderness Quality Index threshold of 12 and a minimum patch size of 8000 ha were used to define ‘wilderness’. Areas within the WHWD Area meeting this definition were mapped and are shown in Figure 3.33.

It should be noted that the original data were generated at a continental scale and have not been refined on the basis of current information on roading and land use in the WHWD Area.

It is apparent from Figure 3.xx that the major areas of wilderness occur in national parks and state forests on the Carnarvon, Bigge, Murphy, Lynd and Expedition Ranges and Blackdown Tableland.

Of a total area of wilderness of approximately 2.2 million ha, around 535000 ha occur on state forests and 417000 ha on national parks. The central occurrence extending from Belington Hut SF to Blackdown Tableland and Dawson Range SF is a largely continuous area covering nearly 600000 ha.

State Forests with major areas of wilderness are Belington Hut, Expedition, Presho, Oakvale, Shotover and Boxvale State Forests.

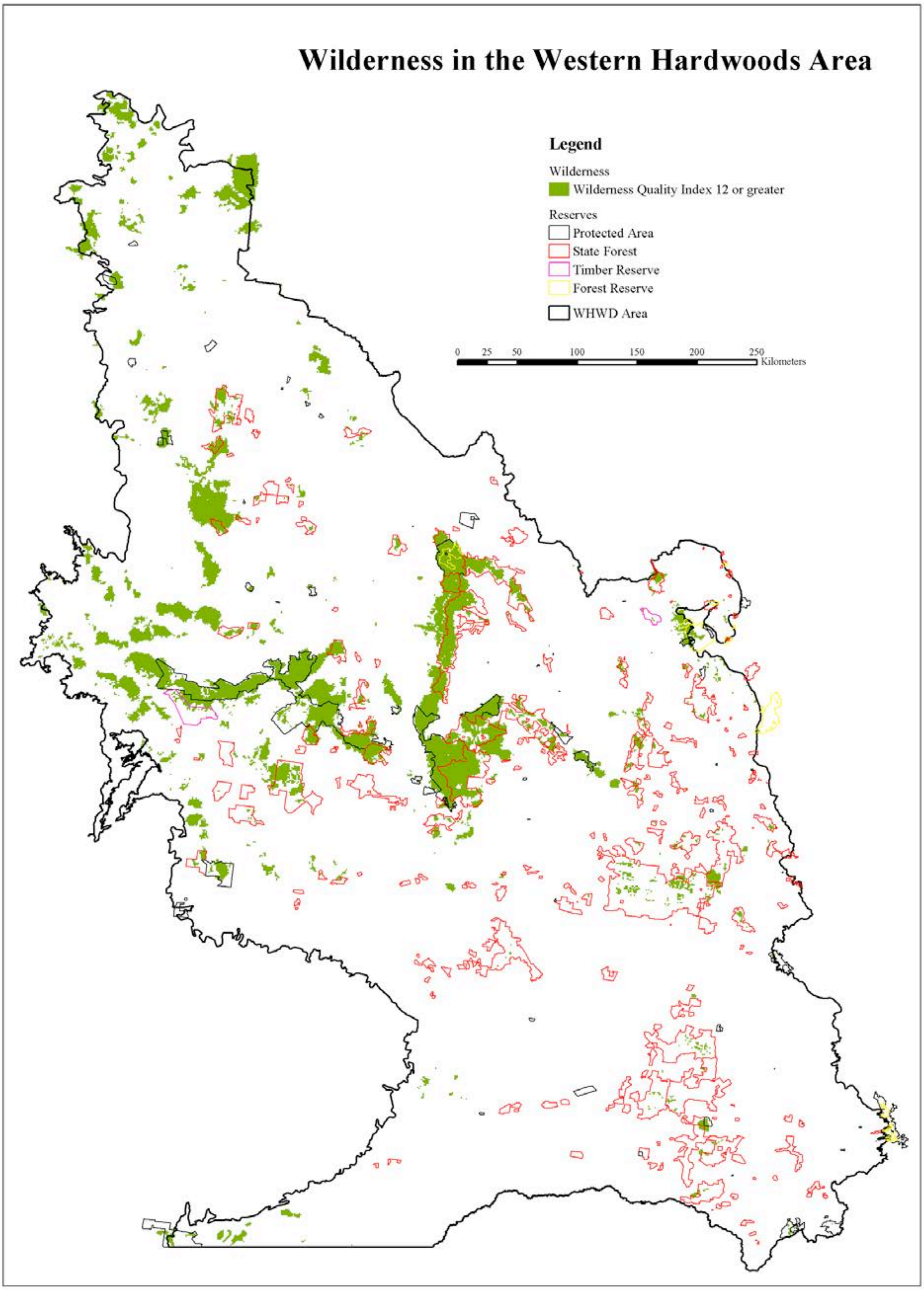


Figure 3.33 Wilderness quality in the WHWD Area. Source: National Wilderness Inventory

4 Threatening Processes

4.1 Processes affecting flora

to be completed

4.2 Processes affecting fauna

4.2.1 Overview

The Study Area has large, unfragmented areas of woodland and open forest, but even large tracts are of little value to a species if they do not provide the essential resources for its persistence. Species vulnerable to broad-scale attrition of old-growth elements, heavy grazing of riparian zones, or frequent burning are by no means secure in the 98 per cent of the Study Area that is outside reserves. The Brigalow Belt's forests and woodlands have lost a significant proportion of large trees in the overstorey as a result of logging, and there has been a considerable alteration of the structure and floristics of the understorey as a result of grazing and associated burning. Species such as the Yellow-bellied Glider, Speckled Warbler and *Paradelma orientalis* (Brigalow Scaly-foot) are ostensibly widespread in several large areas of habitat but documented threats to their persistence continue to pressure virtually their entire populations in the Brigalow Belt. The higher grazing pressure in alluvial areas and on watercourses disproportionately affects many species. The more easterly forests are criss-crossed with literally dozens of roads, and the presence of extensive road networks in forest landscapes is considered a threatening process in itself (Mackey *et al*. 1998).

"*Landscapes that are being managed to restore the ecological integrity will, amongst other things, aim to reduce the impact of threatening processes associated with modern technological society*."

(Mackey *et al*. 1998)

Land clearing has removed about 60 percent of the Brigalow Belt's vegetation cover, and has undoubtedly had a catastrophic effect on fauna largely found in brigalow, vine-thickets, fertile box woodlands and grasslands. Threatening processes affecting fauna in the remaining intact areas cannot be considered in isolation to this changed landscape. What were single large populations of some species are now a number of relatively fragile small populations, increasing the risk to the population as a whole. Some fauna (e.g. lorikeets, flying-foxes) are capable of traversing the barriers created by clearing, but others are not (e.g. Yellow-bellied Glider, *Acanthophis antarcticus* (Common Death Adder), Spotted Quail-thrush).

The following are primary issues regarding the context in which threatening processes operate in the Brigalow Belt:

- The very low percentage of the area reserved (1.9 per cent), much lower than most of Australia's forested bioregions, and hence the high percentage of habitat subject to modification.
- The low productivity of the Study Area compared to coastal areas. This means the area needed to sustain a Brigalow Belt population of a species is larger than it would be in a coastal bioregion. This is relevant for species for which abundance is known to be dependent on productivity (e.g. Yellow-bellied Glider, Greater Glider, Koala,

Powerful Owl). It also means the forest and woodland requires a longer time to recover habitat integrity after a disturbance.

- The greater vulnerability of species with poor dispersal ability in fragmented habitat. The extensive clearing has created a series of isolated populations of such species and consequently increases the likelihood of threatening processes extirpating them from part or all of the Study Area.
- The presence of naturally disjunct populations, some of which are small and therefore vulnerable. Some disjunct populations, especially reptiles, have proven to be separate species in recent years after further taxonomic investigation. Disjunct populations that are not taxonomically distinct may still have distinct genetic features that could be required by the species to evolve in response to future change.

Eight threatening processes are listed in Table 4.1, which combined are considered to affect 156 taxa (Appendix 6) in the Study Area. These processes illustrate the number of different aspects of management that require attention.

Table 4.1 Summary of threatening processes and number of taxa considered to be affected.

Threatening Process	No. of species affected
Attrition of hollows	40
Loss of nectar resources	6
Loss of understorey integrity (shrub layer)	43
Loss of ground layer structure and integrity (floristics)	18
Loss of ground layer structure and integrity (coarse woody debris and litter)	75
Drying out and silting of waterholes	25
Desiccation of dry rainforests	27
Predation by feral animals	9

4.2.2 Attrition of hollows

4.2.2.1 The process

This section describes the attrition of hollow-bearing trees that occurs when loss exceeds replacement of large trees in the landscape. Hollows take a very long time to develop (Gibbons and Lindenmayer 2002), especially in drier habitats (Soderquist and Lee 1994). These important fauna shelter resources, especially large hollows, appear to have been greatly diminished given the substantial losses of large trees from the forests and woodlands of the Brigalow Belt, especially in the Spotted Gum-Ironbark open forests. The first commercial sawlog harvesting cycle removed many of the largest old trees in keeping with the silvicultural objectives for "*virgin stands of overmature trees*" at the time (DPI 1998). Habitat tree retention rules have been introduced more recently, but logging still removes most of the largest remaining trees, and hence a significant percentage of the maturing trees *before* they form hollows. This aspect of selective logging is of serious concern and is not resolved by current habitat tree prescriptions.

ARCS (unpub. data) found that logged stumps >60 cm diameter were more numerous than live trees >60 cm diameter at breast height (DBH) in logged *Corymbia citriodora* (Spotted Gum) forests across the Western Hardwoods Area (Table 4.2). There were 1 to 4 live trees/ha >60 cm DBH at most of the one-hectare sites. However it is estimated (by applying a "reverse" growth rate of 2mm/year to existing trees and trees logged after the initial logging) that most sites supported 6–10 trees/ha >60 cm diameter before logging, and nearly a third of the sites surveyed supported >10 such trees (Figure 4.1).

Table 4.2 Density of trees and logged stumps >60 cm diameter at 37 1-ha sites in logged Spotted Gum dominated forests in the Western Hardwoods area.

State Forest	Sites	>60 cm DBH trees/ha (average)	>60 cm diameter stumps/ha (average)	Total (average)
Coominglah	9	3.2	9.6	12.8
Grevillea	3	10.0	1.3	11.3
Jarrah	4	6.3	4.8	11.0
Allies Creek	6	3.5	7.2	10.7
Belington Hut	2	5.0	5.0	10.0
Tuturin	7	2.6	6.6	9.1
Barakula	6	1.2	6.7	7.8

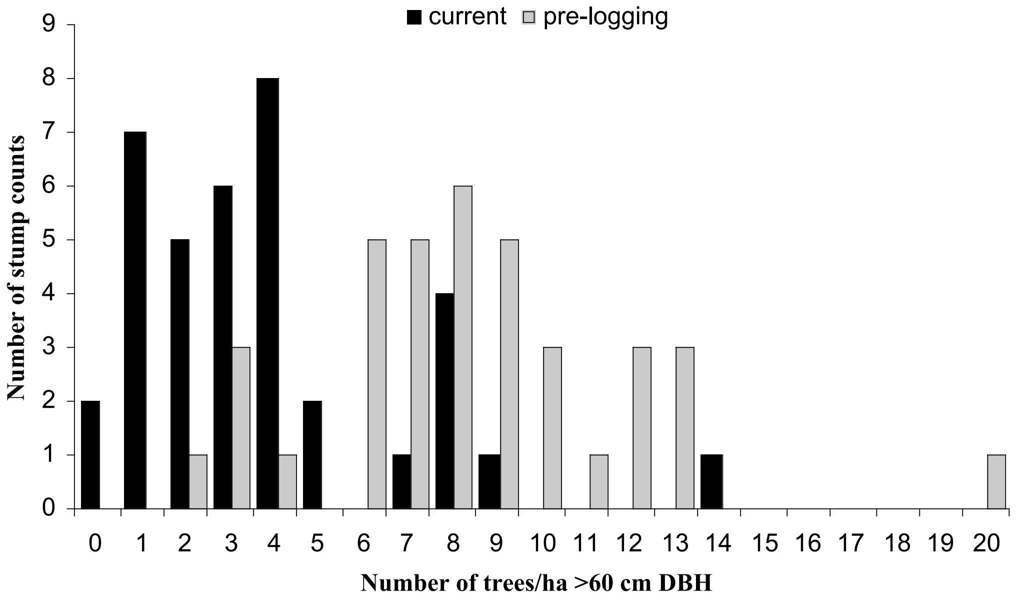


Figure 4.1 Current and pre-logging distribution of large tree densities at 37 1-ha plots in commercial forests in the Western Hardwoods Area.

A depletion of large trees has been an outcome of selective logging for sawlogs and sleepers in slow-growing, low-productivity forests in eastern inland Australia generally. This pattern has been documented in the Pilliga forest in NSW (Paull 2001) and the Victorian box-ironbark forests (ECC 2001). Agencies in Victoria and NSW have responded to this landscape-level depletion by protecting what is left of the largest trees (ECC 2001). Soderquist *et al*. (2002) recommended the sympathetic management of the Victorian box-ironbark forests as a whole to return them to a more natural state to achieve conservation of the Powerful Owl in that area.

4.2.2.2 Impacts

The Yellow-bellied Glider and Greater Glider are known to decline with a loss of large trees (Eyre 2002). Loss of large trees may also impact on many other hollow-dependent species (there are more than 100 in the Study Area) but study of relationships between abundance and habitat quality for relatively wide-ranging species (e.g. bats, black-cockatoos) is difficult and has not been carried out. In the case of large hollow-dependent, forest-dependent and low-density species such as the Powerful Owl, Barking Owl and Yellow-bellied Glider, it is not known whether the post-logging populations are viable in the long-term or what their rates of recovery might be. It is even more uncertain whether populations of these species will tolerate further attrition of large trees.

The Powerful Owl (Vulnerable) may have already disappeared from many areas where logging has been extensive (e.g. Barakula SF has only one record despite extensive surveys). The presence of large gliders, a primary food source, a number of records from the Chinchilla district and areas of a forest type (Spotted Gum/Narrow-leaved Ironbark open forest) that the Powerful Owl are known to use elsewhere in Queensland are all evidence that the species would have occurred in Barakula SF. The species was recorded at five out of 249 playback sessions in the Study Area by the Environmental Protection Agency, only one of which was in a landscape with widespread recent logging. Kelly *et al.* (2003) observed that Powerful Owls were only found where arboreal marsupials were numerous. If the observations by Eyre (2002) and conclusions drawn from ARCS stump counts are correct, then the original forests had more large trees and therefore more Greater and Yellow-bellied Gliders, and ultimately higher densities of the Powerful Owl. Gliders are still present but possibly at insufficient densities to maintain breeding pairs of the Powerful Owl at sites such as the Barakula and Allies Creek forests. It would be expected that a top-level predator such as the Powerful Owl would disappear before the prey (in this case large gliders) does.

Two previously common arboreal marsupials have gone into an alarming decline as a result of logging in the Pilliga forest in the NSW section of Brigalow Belt South. There has been a major attrition of large trees and therefore hollows in Narrow-leaved Ironbark/cypress woodland that dominates the Pilliga landscape (Paull 2001). The Common Brushtail Possum has declined dramatically, whilst the Common Ringtail Possum seems to have virtually retreated altogether from the Narrow-leaved Ironbark/cypress woodland and is now largely confined to the relatively scarce *Eucalyptus albens* and *E. blakelyi* woodlands (Paull and Kerle in press.).

The Brigalow Belt has the richest arboreal reptile fauna in Australia. Some of these are hollow-dependent while many others frequently shelter under decorticating bark, another resource provided primarily by large trees. Many arboreal reptiles (e.g. geckoes) occur at higher densities than any hollow-dependent marsupial or bird, but may require a high density of large trees to maintain social structures. There have been no studies investigating impacts of attrition of large trees on arboreal reptiles in Queensland, but the hollow-sheltering arboreal snake *Hoplocephalus bitorquatus* (Pale-headed Snake) has been considered likely to be affected (Date and Paull 2000). *H. bitorquatus* is sometimes found under rocks, suggesting that the species may be able to rely on these for shelter. However a congener, *H. bungaroides* (Broad-headed Snake), was also thought to be a saxicolous species, but when a population was radio-tracked by Webb and Shine (1997) it was found that many individuals ‘switched’ from rock shelters to tree hollows in dead and live trees depending on the time of year. *H. bungaroides* actively selected large live and dead trees with multiple hollows, where individuals often remained for around a week and as long as one and a half months (Webb and Shine 1997).

4.2.3 Loss of nectar resources

4.2.3.1 The process

This process describes the reduction in reliability and volume of nectar resources that is likely to accompany attrition in the density of large trees, alteration of the species composition of a forest, or introduction of bees to consume nectar.

4.2.3.2 Impacts

Investigations into the relationship between tree diameter and flowering frequency in eucalypts (Wilson and Bennett 1999; Eyre 2002) have found statistically significant relationships between likelihood of flowering and diameter, i.e. large trees are more reliable nectar sources. The attrition of large trees is likely to reduce the overall available nectar resource, and reduce the reliability of the resource. The consequence is increased competition among nectarivores for scant resources. Increased competition pressure among nectarivores will affect community composition, which in turn may disrupt bird-plant pollination systems. A link between reduced nectarivore populations and altered bird-pollination systems has been identified in southern Australia (Paton 1997; 2000).

4.2.4 Loss of understorey integrity (shrub layer)

4.2.4.1 The process

This section describes significant alteration of the structure and/or floristics of the shrub layer. A general management objective in State Forest managed for both timber production and cattle grazing is to maintain a predominantly grassy understorey for cattle. This requires frequent burning of the understorey vegetation, which may be detrimental to the forest or woodland structure.

4.2.4.2 Impacts

Habitat fragmentation caused by land clearing is considered the main driving factor for decline and extinction of woodland birds, but the ongoing decline in habitat quality at the patch level is "*equally as serious*" and stock grazing has been identified as the biggest single risk factor in a number of NSW studies (Reid 1999, Seddon *et al.* 2003). Data from surveys by the Environmental Protection Agency suggest grazing and associated fire management in the Study Area benefits generalist species already common in much of the agricultural landscape (e.g. Noisy Miner, Grey Butcherbird, Torresian Crow) at the expense of small forest and woodland-dependent insectivores (e.g. Rufous Whistler, Buff-rumped Thornbill). Figure 4.2 displays the average density of Noisy Miners on bird censuses at sites in forest designated as "commercial hardwood" (these were almost always Spotted Gum forests) with either "moderate", "light" or "no" prescribed burning evidence. This suggests a positive response in Noisy Miner densities to increased severity of prescribed burning.

Tables 4.3 and 4.4 display the reporting frequency of a number of bird species at sites in "commercial hardwood" forest where Noisy Miners were present and absent. Species in Table 4.3 were more frequently recorded at sites where Noisy Miners were present, and those in Table 4.4 were more frequently recorded at sites with no Noisy Miners. All species in Table 4.3 are canopy or ground feeding species and several are common in agricultural landscapes, but those in Table 4.4 are all small forest- and woodland-dependent insectivores

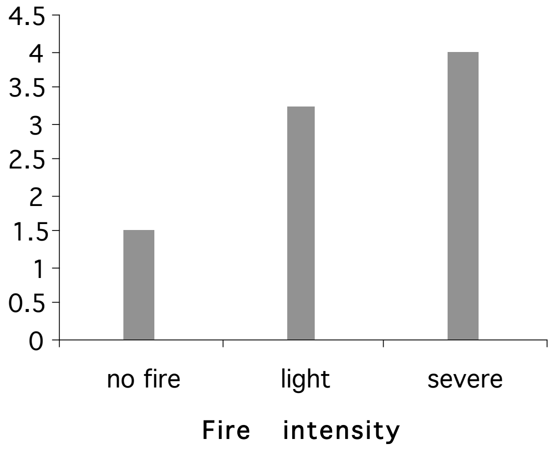


Figure 4.2 Noisy Miner density and prescribed fire intensity in commercial forest types in the Brigalow Belt. *Source: EPA data*

Table 4.3 Bird species that were more common where Noisy Miners were present. *Source: EPA data*

Species	% sites miners present (n=86)	% sites miners absent (n=20)
Grey Butcherbird	53	20
Scaly-breasted Lorikeet	49	5
Pale-headed Rosella	28	10
Little Lorikeet	26	5
Australian Magpie	19	5
Torresian Crow	13	5
Apostlebird	10	0

Table 4.4 Bird species that were more common where Noisy Miners were absent.

Species	% sites miners present (n=86)	% sites miners absent (n=20)
White-naped Honeyeater	14	50
Rufous Whistler	7	30
Grey Fantail	3	65
Striped Honeyeater	3	15
White-throated Gerygone	3	20
Yellow-faced Honeyeater	2	25
Buff-rumped Thornbill	1	40
White-eared Honeyeater	1	20
White-throated Treecreeper	1	25

and nectarivores. This stark contrast within a single forest type suggests significant alteration of the bird community where Noisy Miners are present. The effect of Noisy Miners on other birds has been well documented in woodlands in other parts of Australia (Loyn 1987, Grey *et al*. 1998, Mac Nally *et al*. 2000). These other studies also document a negative association between Noisy Miners and small insectivores.

The changes brought about by fire are temporary and shrub-foraging and ground-nesting birds may recover within a few years. However, the primary issue is that the forest is often burnt again before such a recovery occurs and large areas of habitat are in an early post-fire seral stage at any point in time.

4.2.5 Loss of ground layer structure and integrity (floristics)

4.2.5.1 The process

This process describes the alteration of the species composition or structure of the grasses and herbs, and/or the disruption of seed production by grasses. These changes are of particular concern in grassy woodlands, which are prime habitat (along with grasslands) of granivorous fauna. This is a widespread problem in the Study Area and across northern Australia. This process is a concern even in landscapes with "intact" vegetation. The tree layer may be intact but resources required by granivorous birds can still be absent.

4.2.5.2 Impacts

The introduction of cattle has altered the floristics of the grass layer across a large area of Queensland. One of the major changes has been the broad-scale replacement of cattle sensitive species such as *Themeda triandra* with species that can withstand defoliation by grazing animals, notably the Black Spear-grass (*Heteropogon contortus*) (Woinarski 1993b; Todd *et al*. 2003). Seeds of grasses from the genus *Themeda* were eaten by the Star Finch and Crimson Finch in a study by Todd *et al*. (2003) on the Cape York Peninsula, but *H. contortus* was never used, and is not known to be used by either species. Todd *et al*. (2003) speculated that this process, and therefore the cause (cattle grazing) may be a long-term threat to the Star Finch and Crimson Finch on the Cape York Peninsula. However it may also give us an insight into losses of these species (the Star Finch in particular) from other areas, including the Brigalow Belt, as much of eastern Queensland was altered in the same way (Woinarski 1993b).

Another major concern is the spread of the Buffel Grass (*Cenchrus ciliaris*). This African perennial was introduced as a productive pasture grass, but it is known to invade remnant vegetation, competing with native grasses and reducing floristic diversity (Fairfax and Fensham 2000). Where Buffel Grass invades native vegetation and displaces native grass species, it is effectively destroying the habitat for granivorous birds that cannot use Buffel Grass as a seed source. Even if all granivorous birds could use Buffel Grass the seasonality of seed resources, a crucial factor in the study of Star and Crimson Finches by Todd *et al*. (2003), is likely to be greatly altered, unbalancing or eliminating species populations.

Granivorous species have already been lost from the Brigalow Belt (See Section 3.4.2.3.), but healthy grassy woodlands may still be indicated by species such as the Squatter Pigeon, Plum-headed Finch, Diamond Firetail and Peaceful Dove. The *Eucalyptus tereticornis*, *E. populnea* and *E. melanophloia* grassy woodlands that occur on the edges of State Forests and on alluvial flats within them are often heavily grazed and granivorous birds other than generalists (e.g. Crested Pigeon) are absent.

4.2.6 Loss of ground layer structural integrity (coarse woody debris and litter)

4.2.6.1 The process

This process describes attrition of the natural volume and size distribution of coarse woody debris and litter on the forest floor.

4.2.6.2 Impacts

The attrition of coarse woody debris and the effect of this on fauna has received a great deal of attention in recent years, especially in slow-growing, low-productivity forests (Driscoll *et al*. 2000; Mac Nally *et al*. 2001). Scientific Advisory Committees in Victoria and New South Wales have proposed the listing of removal of coarse woody debris as a threatening process (C. Tzaros pers. comm.) as it is thought to affect a large number of fauna including birds, reptiles and mammals. These nominations have arisen from concerns about unsustainable levels of firewood collection in the southern states and effect of this on habitat quality. Firewood collection is not as severe in the Study Area as in NSW or Victoria (with the exception of the ironbark woodlands of the Inglewood Sandstones Subregion, see Sattler and Creighton (2002)). However, fuel reduction burning is more extensive and frequent than in the southern states (S. Kennedy pers. obs.), and importantly is also implicated as a threat by the Victorian and New South Wales Scientific Advisory Committees.

The process is noteworthy for the significant number of fauna species thought to be affected. Driscoll *et al*. (2000) identified 54 species considered to be affected by firewood collection in Regional Forest Agreement processes in Australia, and 38 of these occur in the Study Area. The Victorian SAC listed 90 species affected by loss of coarse woody debris of which 59 occur in the Study Area, although this figure includes species affected by loss of standing dead trees (a serious biodiversity issue in southern states). The fauna list presented by the NSW SAC concentrated on species requiring dead old trees, although the nomination explicitly included loss of fallen timber as a threatening process as well.

Coarse woody debris needs to have cavities to be used as shelter by many species, such as *Varanus gouldii* (Gould's Goanna) (Plate 20) and *Paradelma orientalis*. Dense litter is required for *Acanthopis antarcticus* (Death Adder) (Plate 21), which unlike most Australian snakes has an ambush strategy to capture prey.

Plate 20 The Common Death Adder (*Acanthopis antarcticus*) (Rare) requires dense leaf litter as part of its prey capture strategy. The dramatic decline of the species in the Brigalow Belt has been attributed to changes in fire regimes, altering the structure of the understorey vegetation. There are populations in proposed reserves in Bracker and Coominglah State Forests. *Photo: D. Williams*

Plate 21 The Gould's Monitor (*Varanus gouldi*) shelters in coarse woody debris. The species grows to 1.6 metres long so it needs a substantial shelter, which is only afforded by structural elements formed by the decay of large, old trees. It is fairly common in the Brigalow Belt, but could become rare in the long-term if attrition of large trees and therefore larger coarse woody debris continues. *Photo: P. Robertson*

4.2.7 Drying out and silting of waterholes

4.2.7.1 The process

This process describes the loss of once-permanent or semi-permanent waterholes as a result of changes to vegetation and pressure for the remaining water.

4.2.7.2 Impacts

A small but significant component of the Brigalow Belt's fauna is reliant on the persistence of surface water and in some cases healthy riparian vegetation on waterways. Grazing and feral animals may cause silting and drying of once permanent waterholes, with a significant impact on these fauna. The process and impacts are ably described by Nix (1993):

> *"The most critical time in the year is at the end of the dry season, when food availability depends on plant growth response to soil water or groundwater. Unfortunately, livestock and feral grazing animals have the same requirements as native species and all converge on these narrow strips of riparian habitat at this most critical time. Over very large areas both livestock and wildlife numbers are dictated by this resource more than any other. Consequently, even where very little change has occurred in tree and shrub cover, domestic and feral grazing animals have had and continue to have the major impact".*
>
> (Nix 1993)

There is a number of amphibians, reptiles (notably *Physignathus lesueurii* (Eastern Water Dragon), which is common in South-East Queensland but 'Of Concern' in the Study Area), birds (notably the Azure Kingfisher), the Platypus and even a bat (the Large-footed Myotis forages on the water surface) that are reliant on permanent creeks and waterholes. Many of these species persist on the major rivers of the Study Area such as the Dawson and Burnett Rivers, but degradation of riparian habitat threatens populations in State Forests in the upper reaches of the catchments. These species are indicators of the ecological integrity that should be maintained for the overall health of forested landscapes.

Frogs that rely on permanent water may also be lost through heavy browsing of the vegetation around waterholes. A study by Healey *et al.* (1997) in *E. camaldulensis* (River Redgum) woodland in NSW found that the nature of riparian vegetation had a great influence on adult frog abundance, with various species exhibiting significant associations to the availability of riparian trees, rushes, sedges and grasses. Healey *et al.* (1997) therefore concluded that the extent of disturbance to riparian vegetation by domestic stock was the major determinant of the composition of adult frog populations. Given that similar patterns are likely in the Study Area the maintenance of healthy frog populations requires protection of both permanent waterholes and the vegetation they support. This is important in the Brigalow Belt where some frogs that rely on permanent water occur as isolated and possibly genetically distinct inland populations (e.g. *Adelotus brevis, Litoria lesueuri*) (See Section 2.4.4.2.).

4.2.8 Desiccation of dry rainforests and brigalow

4.2.8.1 The process

This process describes the degradation of dry rainforest and brigalow remnants by fire or incursions by grazing animals seeking shelter, resulting in damage to vegetation, greater exposure to drying conditions, reduction in habitat quality and possibly weed invasion. The issues and concerns regarding management of dry rainforest presented here are not new; they were raised by Horsup *et al.* (1993) after their extensive fauna survey of dry rainforests in the eastern Brigalow Belt and South-East Queensland.

4.2.8.2 Impacts

Fragments of the once extensive areas of brigalow and dry rainforest are dispersed through much of the public land estate in the Study Area. These pockets of vegetation among the state forests support a fauna community that is starkly different (especially among birds) to the surrounding eucalypt forest. The process of desiccation degrades habitat for some specialist species, notably the Black-breasted Button-quail (Vulnerable). Hamley *et al.* (1997) systematically searched for the species in the Brigalow Belt and cited habitat degradation as the likely reason for the absence of the species at some sites. The condition of many remnants is a concern, with even examples designated as Scientific Areas still grazed by cattle (S. Kennedy pers. obs.).

Woinarski (1993a) surveyed monsoon rainforest avifaunas in the Northern Territory and noted that some bird species were often found in the interior of these fragmented habitats but rarely at the edges. These ‘interior species’ included five dry rainforest specialists that are also found in the Study Area. They have been included in Appendix 6 as species affected by processes that Horsup *et al.* (1993) described as “eating away” at dry rainforest edges.

4.2.9 Predation by feral animals

4.2.9.1 The process

Many fauna are probably subject to at least some predation by introduced mammals, but for critical weight range mammals and some of the large and medium-sized ground-dwelling birds it can be a major threatening process, even in otherwise relatively undisturbed landscapes. These two fauna groups represent a small number of species but their continued presence is critical to the integrity of the fauna community in the Study Area. These two groups have declined significantly in Australia. Woodlands (semi-arid or sub-humid) with a healthy complement of critical weight range mammals and large and medium-sized ground-dwelling birds are now found in the Study Area only.

4.2.9.2 Impacts

The Northern Quoll, Spotted-tailed Quoll, Bush Stone-curlew, Squatter Pigeon and Rufous Bettong (Plate 22) are among the species that appear to decline with increased fox numbers. All species have contracted dramatically from their pre-European range and the Study Area is now the southernmost location where Squatter Pigeons and Northern Quolls remain locally common.

It has been suggested that populations of the Rufous Bettong, Bush Stone-curlew (Environmental Protection Agency 2002b) and Squatter Pigeon are more common north of the Dingo fence, which is a large fence erected across central Queensland to keep Dingoes out of agricultural areas. It is thought that the higher populations of Dingoes north of the fence suppress fox populations and benefit the aforementioned species (Environmental Protection Agency 2002b). The hypothesis is probably impossible to test, given that the landscapes on each side of the fence are different. However, the increase in populations of the Australian Bustard, Bush Stone-curlew, Rufous Bettong, Squatter Pigeon and Northern Quoll north of the Dingo fence is certainly noteworthy.

Plate 22 Extinct in Victoria and Vulnerable in New South Wales, the Rufous Bettong (*Aepyprymnus rufescens*) is still locally common in the Study Area, and is thought to be more common where there are dingoes and fewer red foxes. *Photo: Ian McCann/NRE*

5 Integrity of the Forests of the Study Area

5.1 Landscape Level

Of the 31 million hectares of land in the WHWD Area, more than 18 million hectares (60 per cent) have been cleared (Figure 5.1).

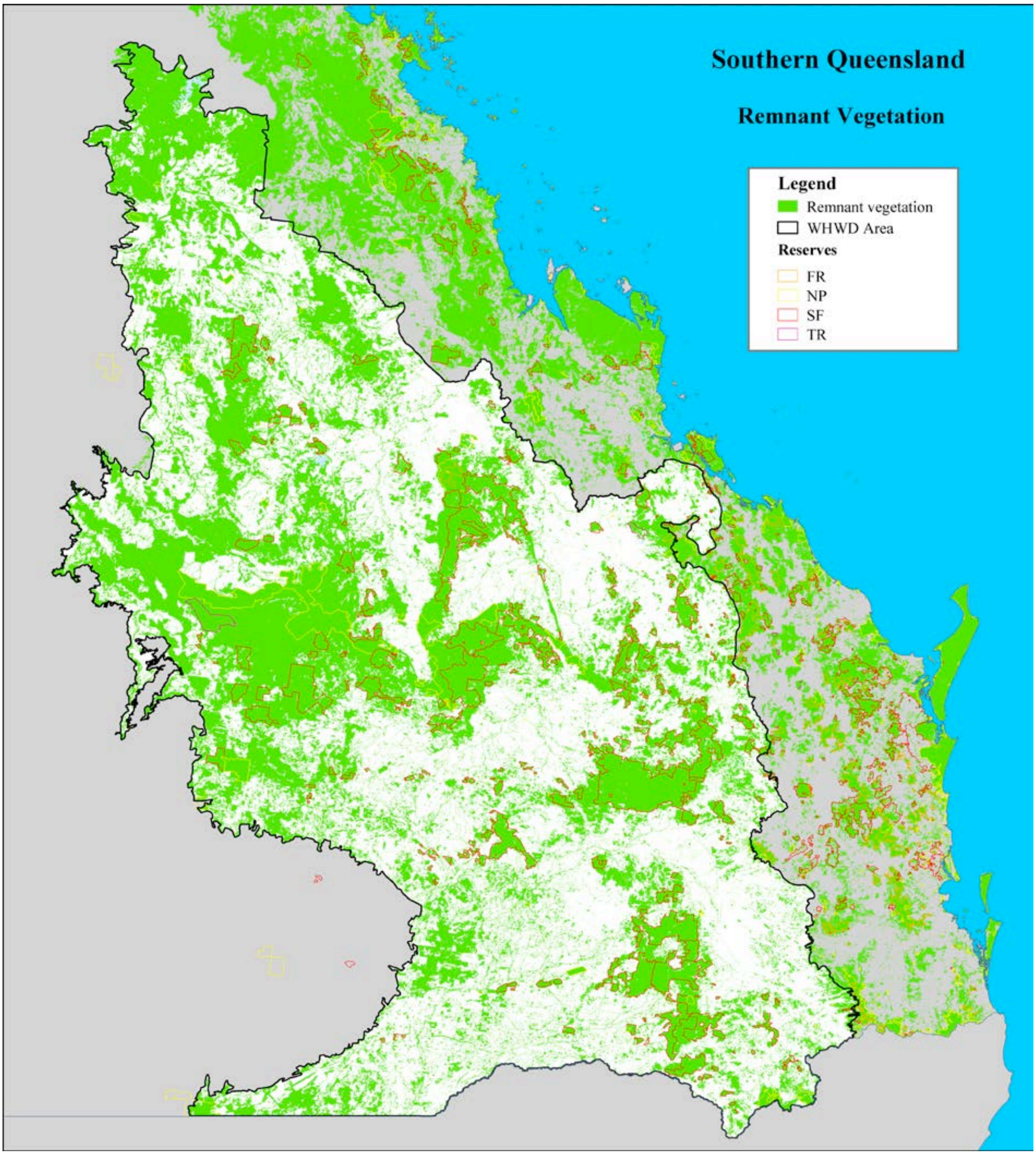


Figure 5.1 Remnant vegetation in southern Queensland

5.2 The Losses

While outstanding for its diverse biological values, the Brigalow Belt is highly threatened and poorly conserved. More than 60 per cent of the WHWD Area has been cleared and only 1.9 per cent is protected in conservation reserves (See Figure 5.1 and Map 3.).

Brigalow

There have been various estimates of the extent of brigalow vegetation prior to European settlement. Nix (1994) concludes that there were at least 5 million hectares of brigalow-dominant vegetation and another 10 million hectares of vegetation in which brigalow was codominant or a significant element. While some clearing had occurred prior to 1950, large-scale development began in the southern Brigalow Belt in the 1950s. Development began in earnest in the central and northern Brigalow Belt in the 1960s under the Fitzroy Basin (Brigalow) Land Development Scheme, and several million hectares were cleared in “one of the greatest land clearing ventures in Australia” (Webb 1984).

The preclearing and 2001 distributions of brigalow communities are shown in Figure 5.2.

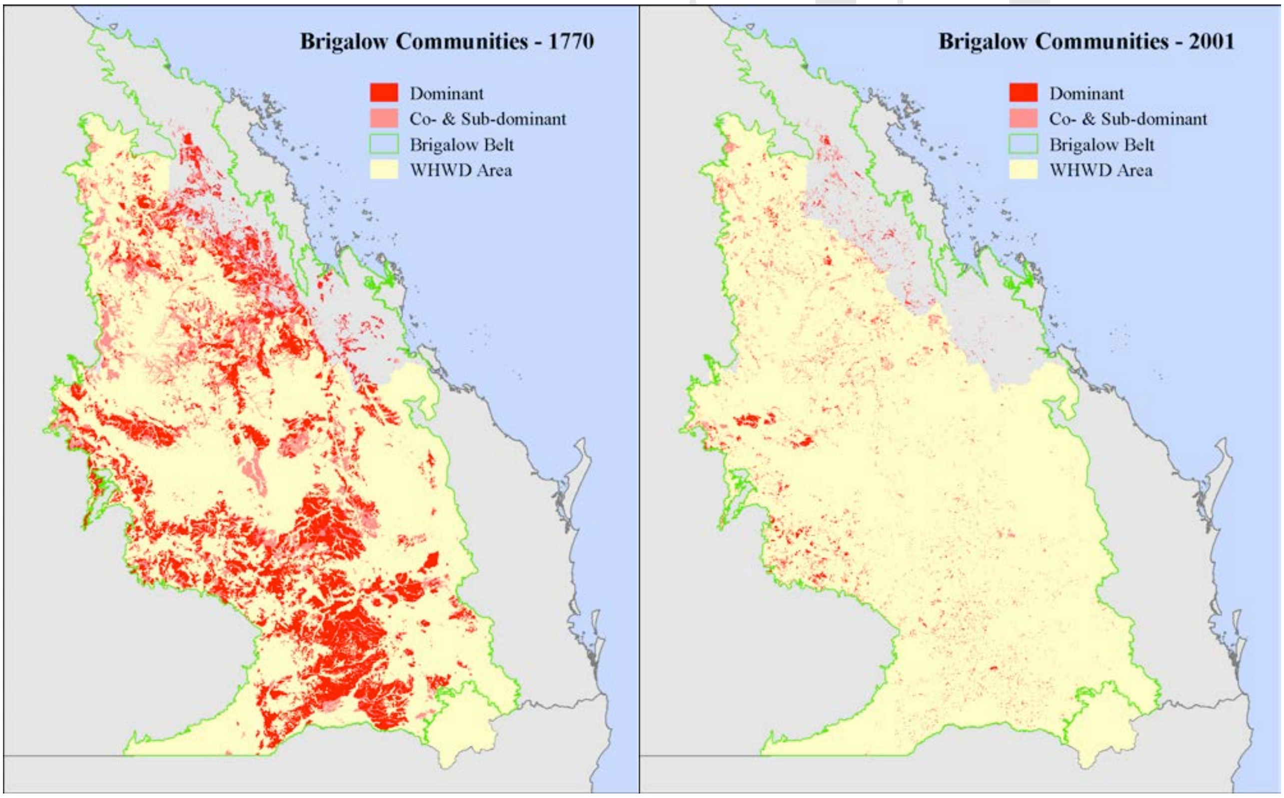


Figure 5.2 Extent of brigalow communities in 1770 and 2001

“I think it impossible for any man to go through this country between Dalby and Roma — to pass through the horrible brigalow — and say it is not a good object to get rid of that curse. I say it would pay the country handsomely to give that land away to any person that would cut the scrub and let the grass grow on it”
Samuel Griffith, Premier of Queensland, [Hansard 32:365(1884); quoted in Ramsay (1984)]

No more than around 1 million hectares remain of vegetation communities in which brigalow is dominant or a significant element. Of the 17 Regional Ecosystems in the WHWD Area in which *A. harpophylla* is dominant, 11 are Endangered and 3 are Of

Concern. Ecological communities in which *A. harpophylla* is dominant or codominant are listed as endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (See Section 5.6.)

Relatively large remnants of brigalow occur on leasehold land to the north-west of Carnarvon National Park and in an area centred around Mitchell. Approximately 37 000 ha occur on Mantuan Downs, adjoining Carnarvon National Park.

Clearing of brigalow lands also meant clearing of rainforest communities including 'bottle tree scrubs'.

Rainforests

Prior to clearing, there were around 1.1 million hectares of rainforest in the Brigalow Belt. In 2001, the area had been reduced to 272 000 hectares. The preclearing and 2001 distributions of rainforest in the Brigalow Belt are shown in Figure 5.3.

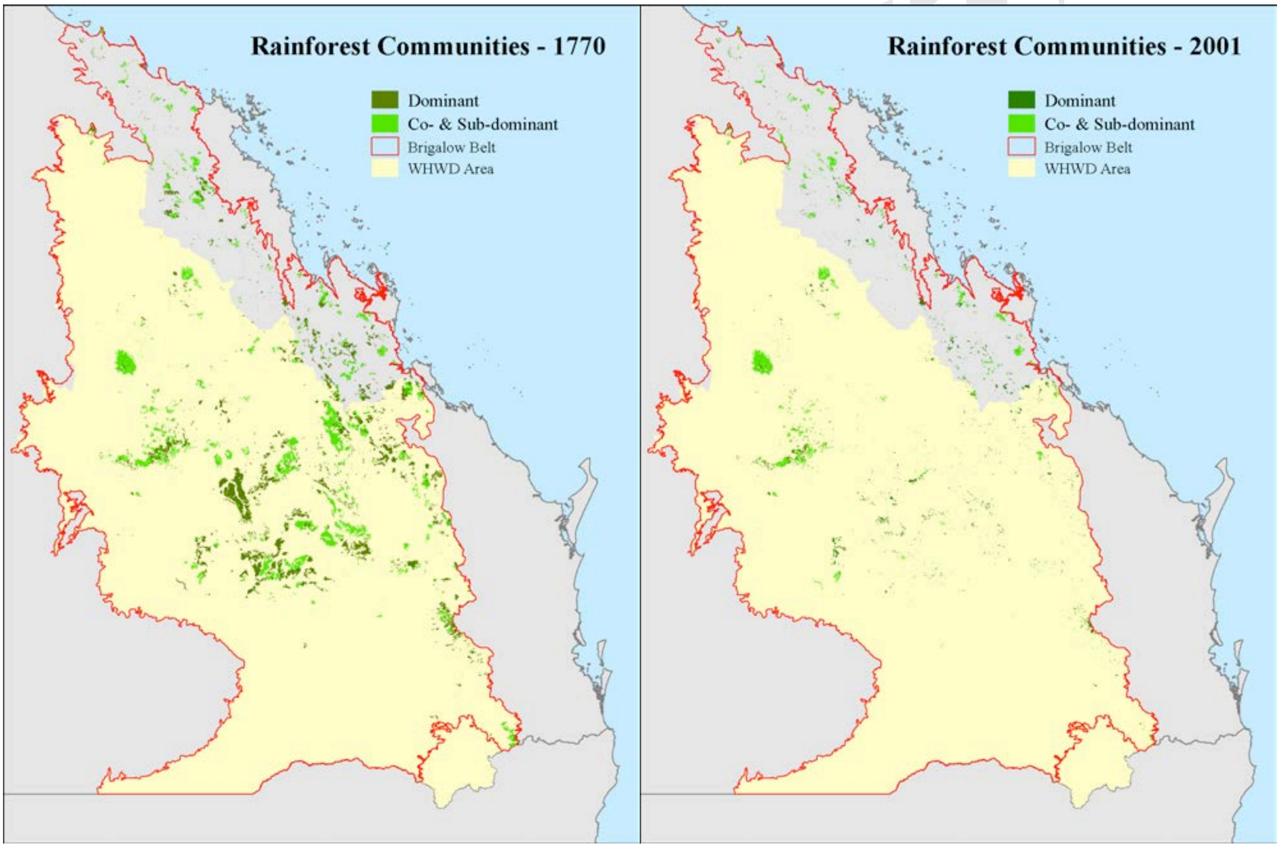


Figure 5.3 Extent of rainforest communities in 1770 and 2001

The rainforest type that has suffered most from clearing is RE 11.9.4, Semi-evergreen vine thicket on Cenozoic fine-grained sedimentary rocks. This rainforest type, which covered 522 000 ha and represented 48 per cent of rainforest vegetation in the Brigalow Belt, has been reduced to 48 000 ha or just 9 per cent of its preclearing extent. It is classified as 'Endangered'. The major former occurrence in Arcadia Valley has been almost completely cleared. The largest remnants on public land occur in Palmgrove NP, Expedition NP, Belington Hut SF and Hurdle Gully in Coominglah SF. A major remnant occurs on leasehold and freehold land on the Great Divide around Mount Hutton.

The apparently large areas of sub-dominant rainforest shown on Figure 5.3 in the north and north-west of the WHWD Area have been mapped as mixed polygons in which the proportion of rainforest ranges between 5 and 25 per cent.

5.3 Australia's Biodiversity Hotspots

On 3 October 2003, the Federal Minister for the Environment and Heritage, Dr David Kemp, announced a national identification of biodiversity hotspots (Figure 5.4). The following is an extract from the Fact Sheet released by the Minister.

> **What are biodiversity hotspots?**
>
> Australia is one of the most biologically diverse countries in the world, with a large portion of our species found nowhere else. But that biodiversity — the plants, animals, micro-organisms and their ecosystems — is threatened by the impact of human activities.
>
> Biodiversity hotspots are areas under immediate threat from impacts such as salinity, land clearing, weeds and feral animals, and are strongholds for large numbers of Australia's unique plants and animals. The hotspots are home to 'endemic' species — in other words, native flora and fauna that are mostly restricted to one geographic locality.
>
> Australia is one of the most megadiverse countries on the planet. It is home to more than one million species of plants and animals, many of which are found nowhere else in the world. Eighty five per cent of flowering plants, 84 per cent of mammals, more than 45 per cent of birds and 89 per cent of inshore freshwater fish are endemic to Australia. Since European settlement, more than 50 species of Australian animals and over 60 species of Australian plants are known to have become extinct.
>
> Whilst international biodiversity hotspots have been identified for some time (with South-West Western Australia on the international list), this is the first identification of Australia's biodiversity hotspots. The National Biodiversity Hotspots were identified to raise public awareness of our environmental heritage at risk, and to support strategic action to conserve it.
>
> The National Biodiversity Hotspots were identified by the Australian Government's Threatened Species Scientific Committee, with input from recognised experts in the field of biodiversity conservation from each Australian State and Territory.
>
> **2. Brigalow North and South (Queensland and New South Wales)**
>
> The inland plains of the Brigalow belt originally supported vast vegetation communities dominated by Brigalow (*Acacia harpophylla*). On the western slopes of the Great Dividing Range there are large tracts of eucalypt woodlands and the hotspot is also a stronghold for large numbers of endemic invertebrates. This hotspot includes populations of the endangered Bridled Nailtail Wallaby and the only remaining wild population of the endangered Northern Hairy-nosed Wombat, now limited to around 110 individuals. The area contains important habitat for rare and threatened species including the Bulloak Jewel Butterfly, Brigalow Scaly-foot, Glossy Black-Cockatoo, Greater Long-eared Bat, Large Pied Bat, Eastern Long-eared Bat and the threatened community of semi evergreen vine thickets The hotspot provides important habitat for star finches and golden tailed geckos.

Broad-scale clearing for agriculture and unsustainable grazing is fragmenting the original vegetation, particularly on lowland areas, encouraging weed invasion and putting at risk woodland and grassland birds and the natural water cycle. Inappropriate fire regimes and predation by feral animals, in particular pigs, cats and foxes, pose additional threats to local biodiversity.

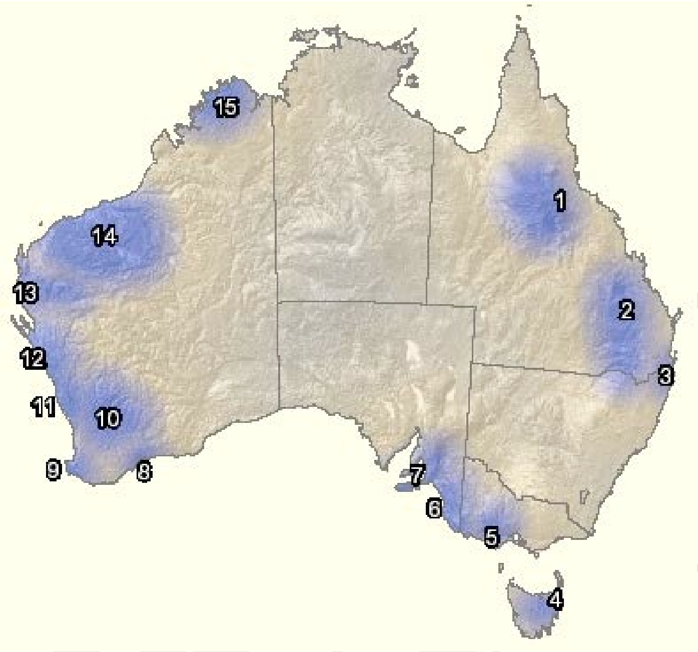
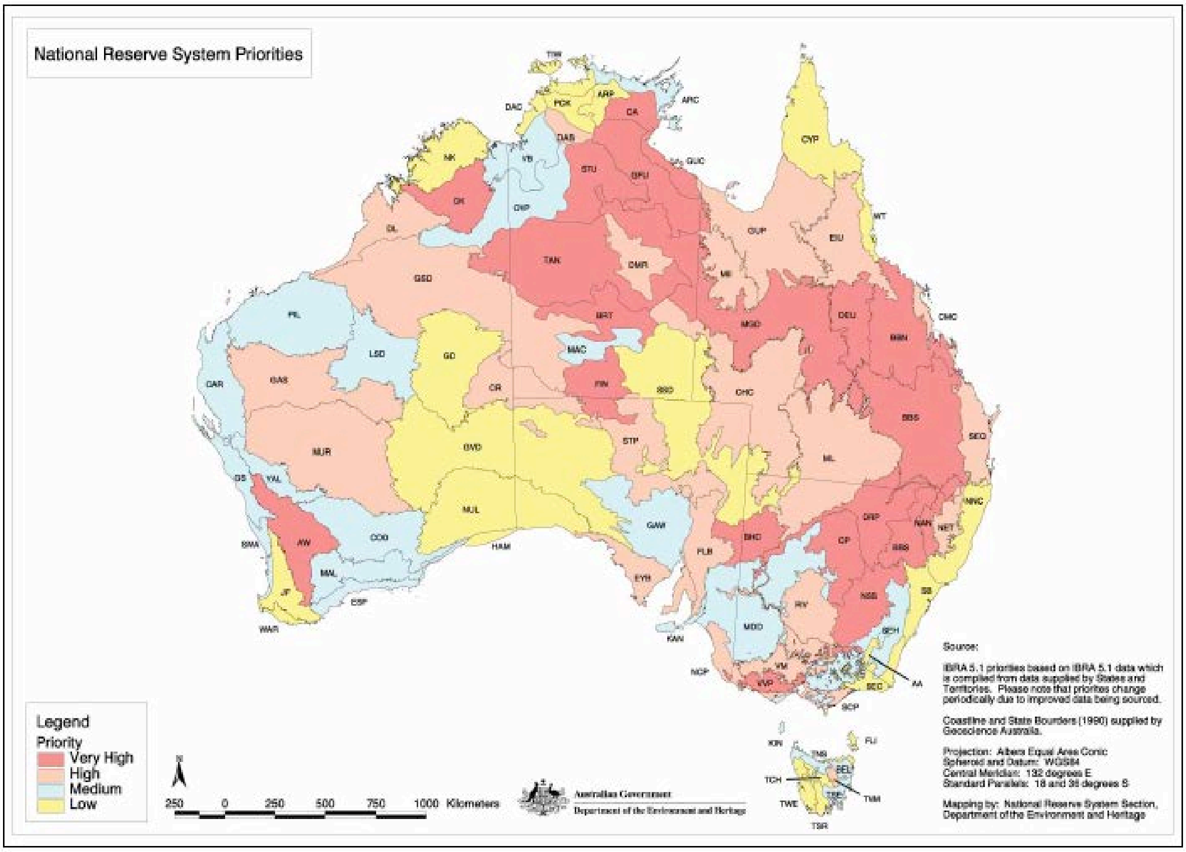


Figure 5.4 Australia’s Biodiversity Hotspots. 1, Einasleigh and Desert Uplands; 2, Briglow North and South; 3, Border Ranges North and South; 4, Midlands of Tasmania; 5, Victorian Volcanic Plain; 6, South-East of South Australia and South-West Victoria; 7, Mt Lofty/Kangaroo Island; 8, Fitzgerald River Ravensthorpe; 9, Busselton Augusta; 10, Central and Eastern Avon Wheat Belt; 11, Mount Lesueur Eneabba; 12, Geraldton to Shark Bay sand plains; 13, Carnarvon Basin; 14, Hamersley/Plibara; 15, North Kimberley

5.4 A priority area for protection

In their Australian Terrestrial Biodiversity Assessment, Sattler and Creighton (2002) comment on the Brigalow Belt South bioregion noting “The limited area reserved, the bias in the ecosystems sampled and the degree of threatening processes means that this region is classified as priority 1 (at the national level) for consolidation of the protected area system.”

The Commonwealth of Australia has identified the Brigalow Belt North, Brigalow Belt South and Nandewar as “Very High” priority (highest rating given) bioregions for purposes of the National Reserve System (Figure 5.5)



Source:

IBRA 5.1 priorities based on IBRA 5.1 data which is compiled from data supplied by States and Territories. Please note that priorities change periodically due to improved data being sourced.

Coastline and State Bourders (1990) supplied by Geoscience Australia.

Projection: Albers Equal Area Conic
Spheroid and Datum: WGS84
Central Meridian: 132 degrees E
Standard Parallels: 18 and 36 degrees S

Mapping by: National Reserve System Section, Department of the Environment and Heritage

Figure 5.5 Priority bioregions for developing the National Reserve System based on the IBRA bioregions
Source: Department of the Environment and Heritage, Australian Government

Referring to the Brigalow Belt, Young *et al*. (1999) recommended “consolidation of the reserve system to include the remaining significant large areas, especially on the more fertile landscapes”. Not surprisingly, the more fertile landscapes such as those supporting Brigalow (*Acacia harpophylla*) were the focus for past clearing and the opportunity for reserving large areas in those landscapes is essentially gone. However, there are opportunities to reserve other significant large areas of remaining vegetation in the Brigalow Belt. As shown in Figure 5.1, major large areas of remnant vegetation that occur on public land in State Forests and Timber Reserves represent the major occurrences of remnant vegetation in the Brigalow Belt South. Whereas existing national parks in the Brigalow Belt protect important aspects of Queensland’s biodiversity, species that exist primarily in the large areas of eucalypt forest and woodland that now form the major core areas of the remaining vegetation are very poorly represented in the reserve system, and still exposed to many or all of the primary threatening processes.

On a broader scale, the larger State Forests and Timber Reserves in the Brigalow Belt represent the last opportunity in Southern Queensland to reserve relatively large areas of forest (Figure 5.1).

5.5 Regional Ecosystem Status

Regional Ecosystems, as mapped by the Environmental Protection Agency, are used as the basis for biodiversity conservation planning and strategy.

Of the 369 Regional Ecosystems (REs) in the WHWD Area, 54 (14.6 per cent) are 'endangered' and 88 (23.8 per cent) are 'of concern' based on the *Vegetation Management Act 1999* status. Using the Biodiversity Status defined by the Environmental Protection Agency, 67 (18.2 per cent) of the REs are 'endangered' and 123 (33.3 per cent) are 'of concern', i.e. just over half of the REs in the WHWD Area are threatened.

The Biodiversity Status of remnant vegetation in the Study Area is shown in Map 3.

The Brigalow Belt bioregion has the highest number of 'endangered' REs of all bioregions in Queensland. Comparing bioregions with respect to the percentage of REs that are threatened ('endangered' and 'of concern'), New England Tableland has the highest percentage, followed by Central Queensland Coast, South East Queensland and the Brigalow Belt (Figure 5.6).

Communities in which Brigalow (*Acacia harpophylla*) is dominant are particularly threatened. Of the 17 that occur in the WHWD Area, 11 are 'endangered' and 3 are 'of concern' (Biodiversity Status).

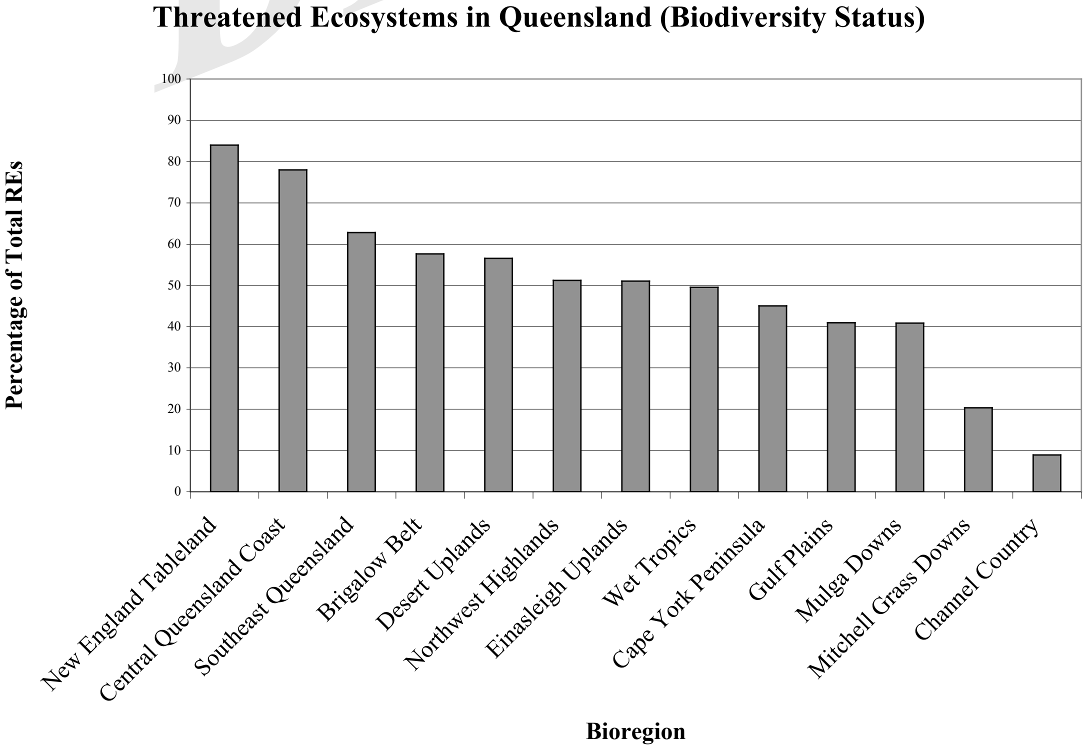


Figure 5.6 Percentage of Threatened Regional Ecosystems in Queensland Bioregions

5.6 Endangered ecological communities

The Commonwealth of Australia has listed three Brigalow Belt ecological communities as endangered under the provisions of the *Environment Protection and Biodiversity Conservation Act 1999*. These communities and the regional ecosystems they comprise are shown in Table 5.1.

Table 5.1 Endangered ecological communities in the Brigalow Belt (*Environment Protection and Biodiversity Conservation Act 1999*)

Endangered ecological community	Regional ecosystems
Blue grass (*Dichanthium* spp.) dominant grasslands of the Brigalow Belt Bioregions (North and South)	11.8.11, 11.4.4, 11.3.21, 11.9.12
Brigalow (*Acacia harpophylla* dominant and codominant)	6.4.2, 11.3.1, 11.4.3, 11.4.7, 11.4.8, 11.4.9, 11.4.10, 11.5.16, 11.9.1, 11.9.5, 11.9.6, 11.11.14, 11.12.21, 12.8.23, 12.9-10.6, 12.12.26
Semi-evergreen vine thickets of Brigalow Belt (North and South) and Nandewar Bioregions	11.3.11, 11.4.1, 11.5.15, 11.8.13, 11.9.4, 11.11.18, 11.2.3, 11.8.3, 11.8.6, 11.9.8

6 Current State of Reservation in the Western Hardwoods Area

6.1 Broad reservation levels

Of the 31 million ha of land in the WHWD Area, only 609 000 ha (just under 2 per cent) are protected in conservation reserves. This compares with the Statewide figure of 4.1 per cent and the national figure of around 7 per cent (IUCN Categories I to IV)(Australian Government 2002). Table 6.1 provides a tenure breakdown across the Area. A total of 54 per cent of the WHWD Area is government-owned, but the major part is leasehold tenure.

Table 6.1 Land tenure in the WHWD Area

Tenure	Area ('000 ha)	Percentage of Total
National Park	609	1.97
State Forest	2191	7.09
Timber Reserve	76	0.25
Forest Reserve	7	0.02
Crown leasehold with government timber rights	9550	30.91
Crown leasehold with no government timber rights	4124	13.35
Freehold	13 610	44.06
No tenure	726	2.35
Total	30 892	100.00

More than 60 per cent of the vegetation in the WHWD Area has been cleared. Around 12.3 million ha of vegetation remain. Table 6.2 shows the area of remaining vegetation by tenure. The great majority (74 per cent) of the vegetation occurs on Crown land including leasehold. Whereas 79 per cent and 77 per cent of freehold land and leasehold land *without* government timber rights, respectively, has been cleared, only 46 per cent of leasehold land *with* government timber rights has been cleared.

Table 6.2 Area of remnant vegetation in the WHWD Area by tenure

Vegetated Area ('000 ha) (Percentage of Total Vegetation)								
National Park	**State Forest**	**Timber Reserve**	**Forest Reserve**	**Leasehold: Crown timber rights**	**Leasehold: No Crown timber rights**	**Freehold**	**Other**	**Total**
587 (4.8)	2091 (17.0)	71 (0.6)	7 (<0.1)	5367 (43.6)	969 (7.9)	2893 (23.5)	317 (2.6)	12303 (100)

6.2 Representation of Regional Ecosystems in Protected Areas in the Western Hardwoods Area

As noted above, National Parks and other Protected Areas in the WHWD Area cover 609 000 hectares or less than two per cent of the area. This figure is less than half the average across the State (4.1 per cent at June 2001; QPWS Master Plan) and falls far short of the IUCN Commission on National Parks and Protected Areas minimum target of 10 per cent.

Given this situation, it is not surprising that Regional Ecosystems of the WHWD Area are poorly represented in the Protected Area estate. Of the 213 Brigalow Belt and New England Tableland REs that occur in the WHWD Area, 84 (39 per cent) have no representation. A further 10 are represented by less than 20 hectares.

The Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-Committee (JANIS) set a reservation target of 15 per cent of the pre-clearing area of each ecosystem. In the case of endangered ecosystems, the target was set at 100 per cent, and for ‘of concern’ (vulnerable) ecosystems, at 80 per cent.

In the WHWD Area, only 12 per cent of REs meet the JANIS target. The value rises to just 13 per cent if the IUCN target of 10 per cent is applied. Eighty four per cent of the REs have less than five per cent of their pre-clearing area in Protected Areas. Reservation levels are shown in Figure 6.1.

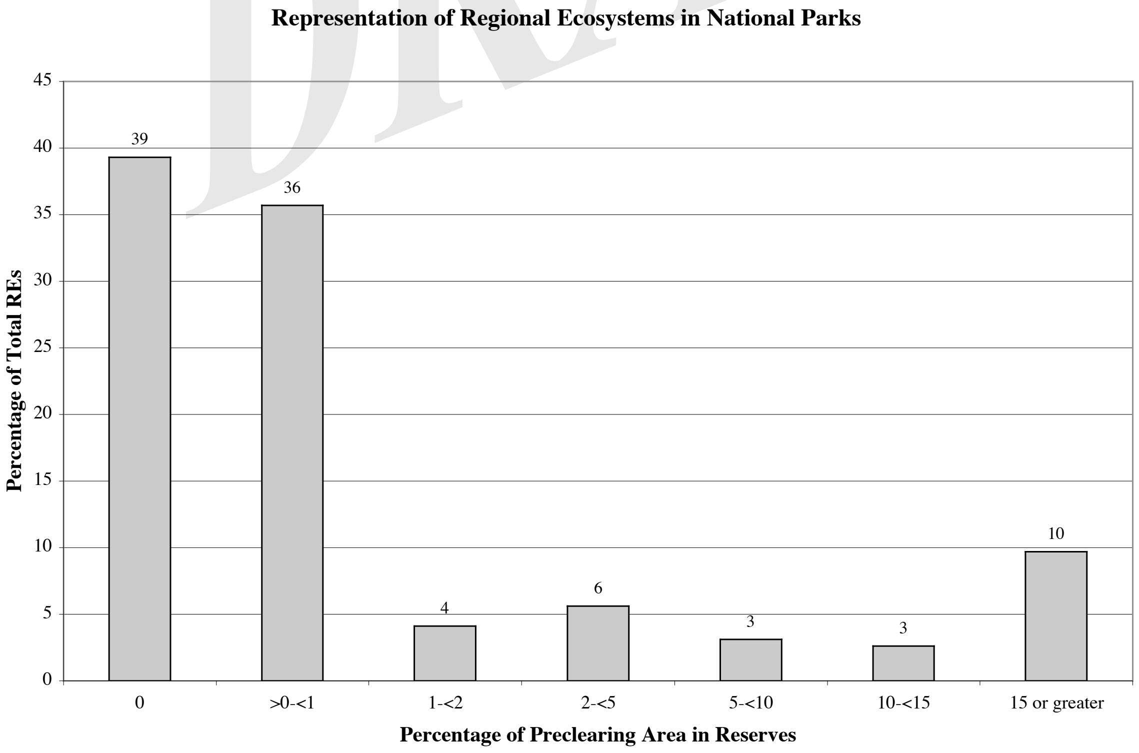


Figure 6.1 Representation of WHWD Area Regional Ecosystems in Protected Areas

7 Conservation Values of State Forests, Timber Reserves and Some Leasehold Lands in the Western Hardwoods Area

7.1 Data sources

The following datasets were used to assess conservation values:

- Wildnet flora and fauna database (incorporating HERBRECS and CORVEG records, EPA Sustainable Forest Sciences WHWD survey records and ARCS fauna survey records)
- ARCS flora survey records
- Brigalow Belt interim 2001 Regional Ecosystem Mapping
- New England Tableland Regional Ecosystem mapping (version 3.1)
- Brigalow Belt North Biodiversity Planning Assessment v. 1.2
- Brigalow Belt South Biodiversity Planning Assessment v. 1.2
- New England Tableland Biodiversity Planning Assessment v. 1.2
- Modelled high-quality habitat for the Yellow-bellied Glider and Greater Glider (provided by Teresa Eyre, Environmental Protection Agency)(Eyre 2002)

7.2 Landscape level

7.2.1 Overview

At the broader landscape level, there are areas that have suffered greatly from clearing and where there is an urgent need to protect remnant vegetation occurrences. One such area is the Arcadia valley (Figures 7.1 and 7.2). Prior to the 1960s, this area contained the largest occurrences of rainforest in the Brigalow Belt. It also contained areas of brigalow.

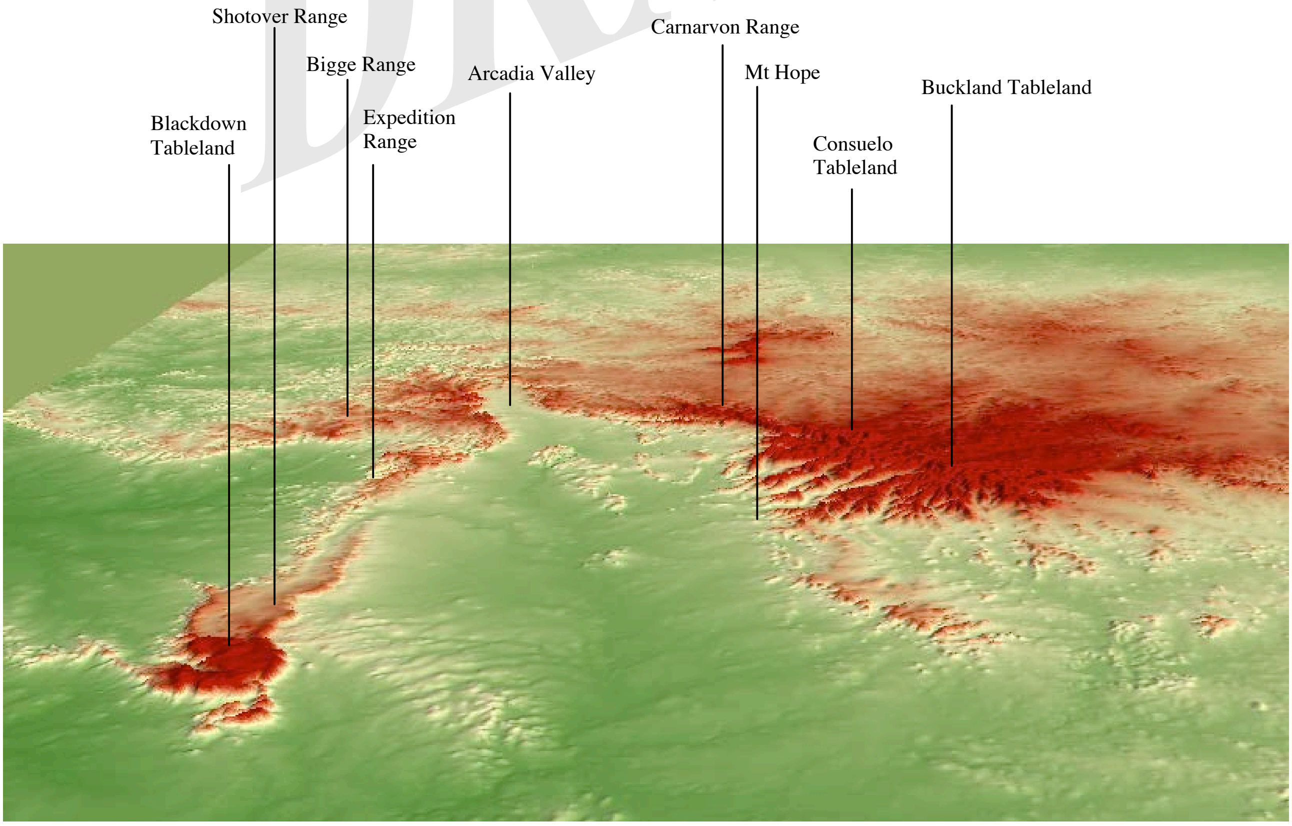


Figure 7.1 Looking southwards to the head of the Comet River and Arcadia Valley which supported the largest area of rainforest in the Brigalow Belt. It was cleared under the Brigalow Land Development Scheme in the 1960s.

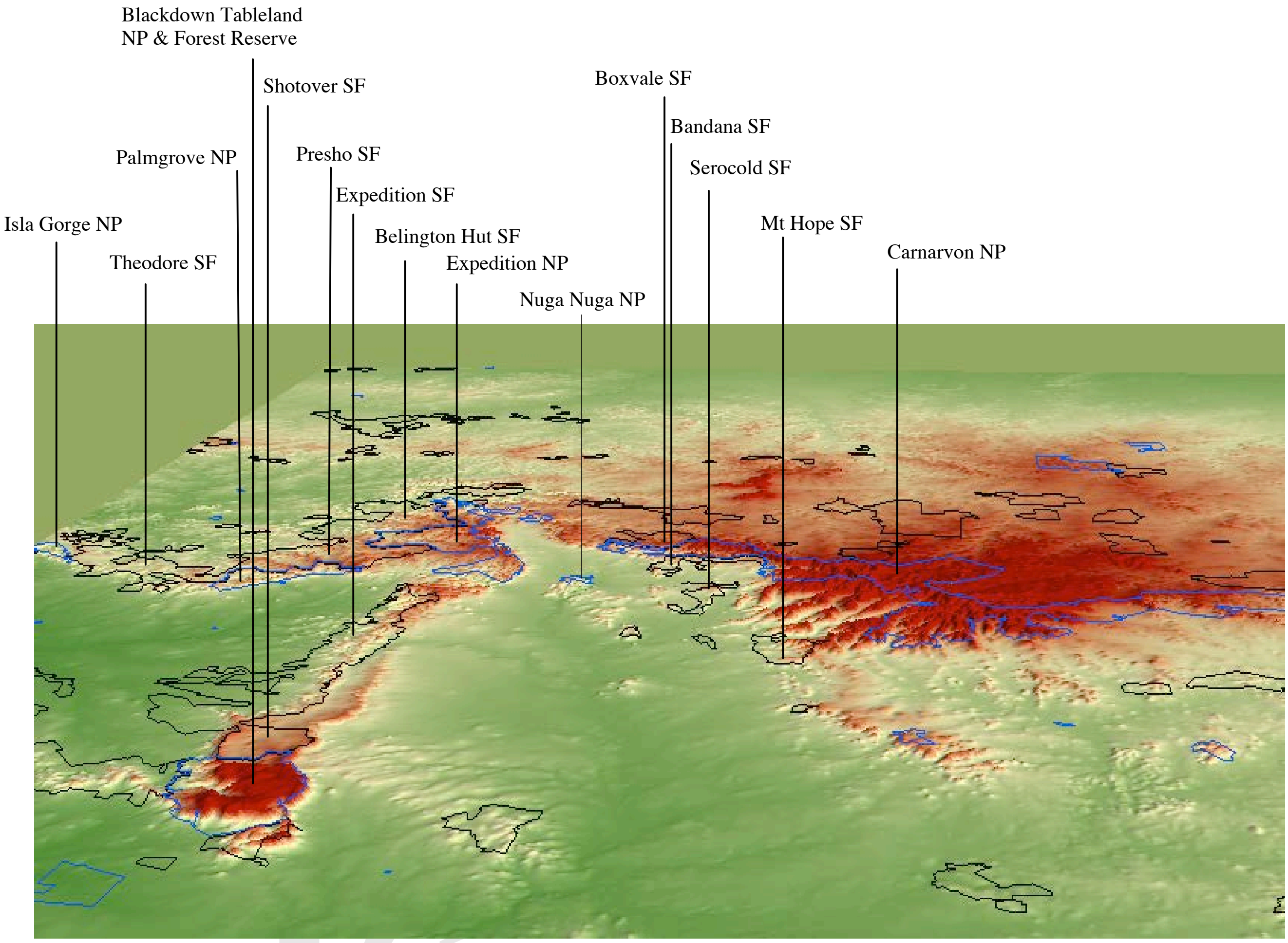


Figure 7.2 Looking southwards to the head of the Comet River and Arcadia Valley showing State Forests and National Parks

Virtually all Arcadia valley has been cleared, but brigalow remnants remain on leasehold land between Nuga Nuga NP and Serocold SF, and at the head of the valley adjoining the isolated section of Expedition NP. There are also remnants along the upper eastern slopes adjoining Expedition NP. The leasehold land at the head of the valley linking the isolated section of Expedition NP with the main block also supports significant brigalow remnants.

Despite the level of clearing in the Brigalow Belt, the remaining intact areas of forest are the largest in Southern Queensland (Figure 5.1). They represent the last opportunity to create large forest reserves in the southern half of the State.

7.2.2 Areas of State Significance for Biodiversity

The Biodiversity Planning Assessments carried out by the Environmental Protection Agency (EPA) were considered in the assessment of conservation values. The assessments are described in Section 3.13 and illustrated in Figure 3.27.

Around 2.1 million hectares (91 per cent) of State Forest and Timber Reserve land in the WHWD Area, including all of the larger reserves, were assessed as having State Significance for biodiversity (Environmental Protection Agency 2003a).

The fauna expert panel identified five areas in the Brigalow Belt South as being of State Significance for fauna (Environmental Protection Agency 2002b). Two of these overlap to a major extent and together cover the area from Expedition National Park to Isla Gorge and Precipice National Parks, taking in Belington Hut, Presho and Theodore State Forests and adjoining leasehold land (See Figures 7.5 and 7.6.). The other areas were (1) the area around Carnarvon National Park including Boxvale and McLeay State Forests and leasehold land to the south of the park and Bandana, Serocold and Mount Hope State Forests and connecting leasehold blocks to the north of the park (See Figures 7.3 and 7.4.), (2) Blackdown Tableland including a major part of Shotover State Forest and Arthurs Bluff State Forest, and (3) Mount Hutton (leasehold).

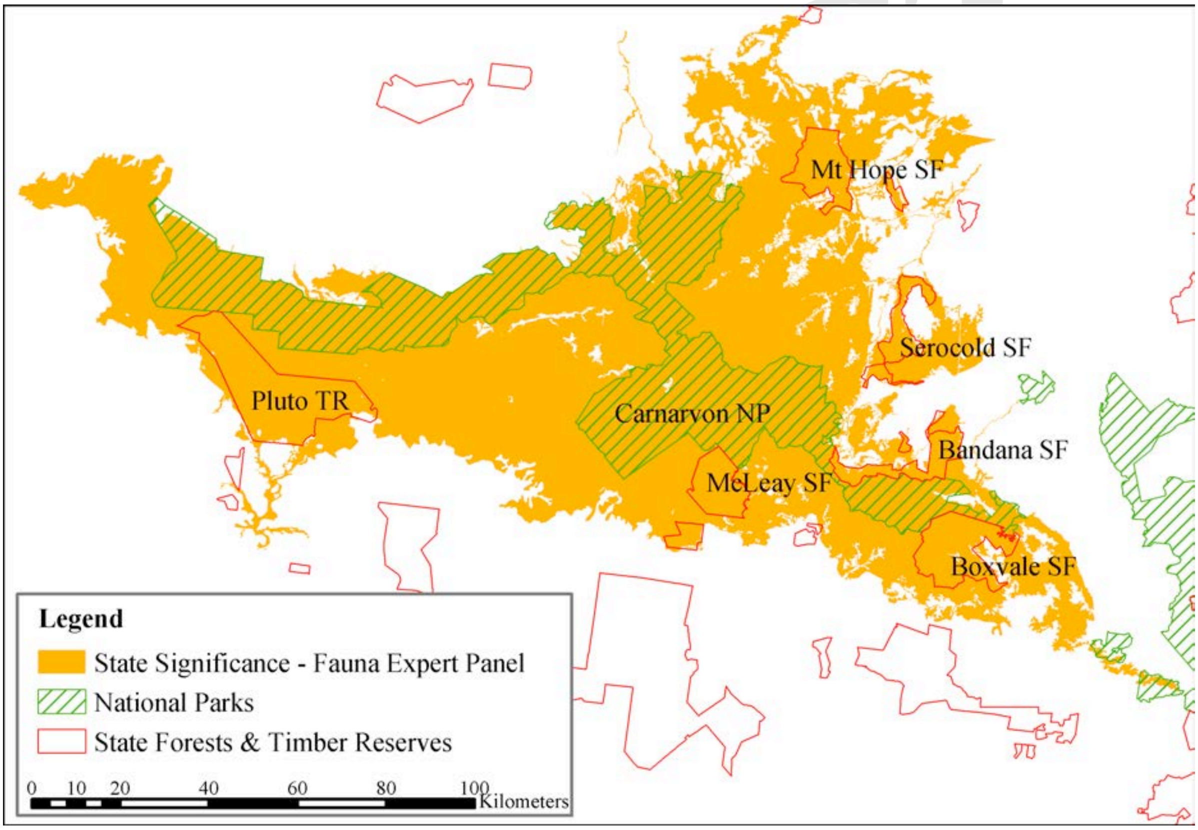


Figure 7.3 Areas around Carnarvon National Park identified by the Brigalow South Fauna Expert Panel as being of State Significance for fauna

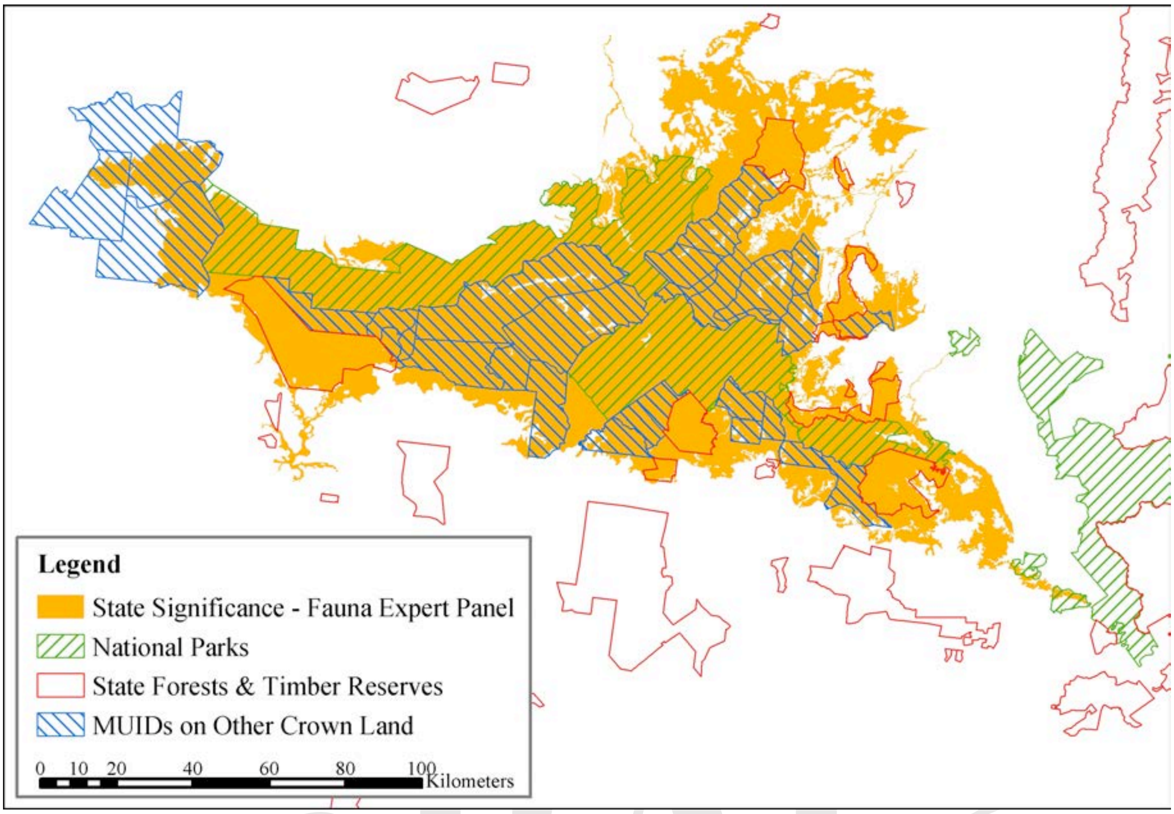


Figure 7.4 Areas around Carnarvon National Park identified by the Brigalow South Fauna Expert Panel as being of State Significance for fauna, showing leasehold land on which the Crown holds timber rights (MUIDs)

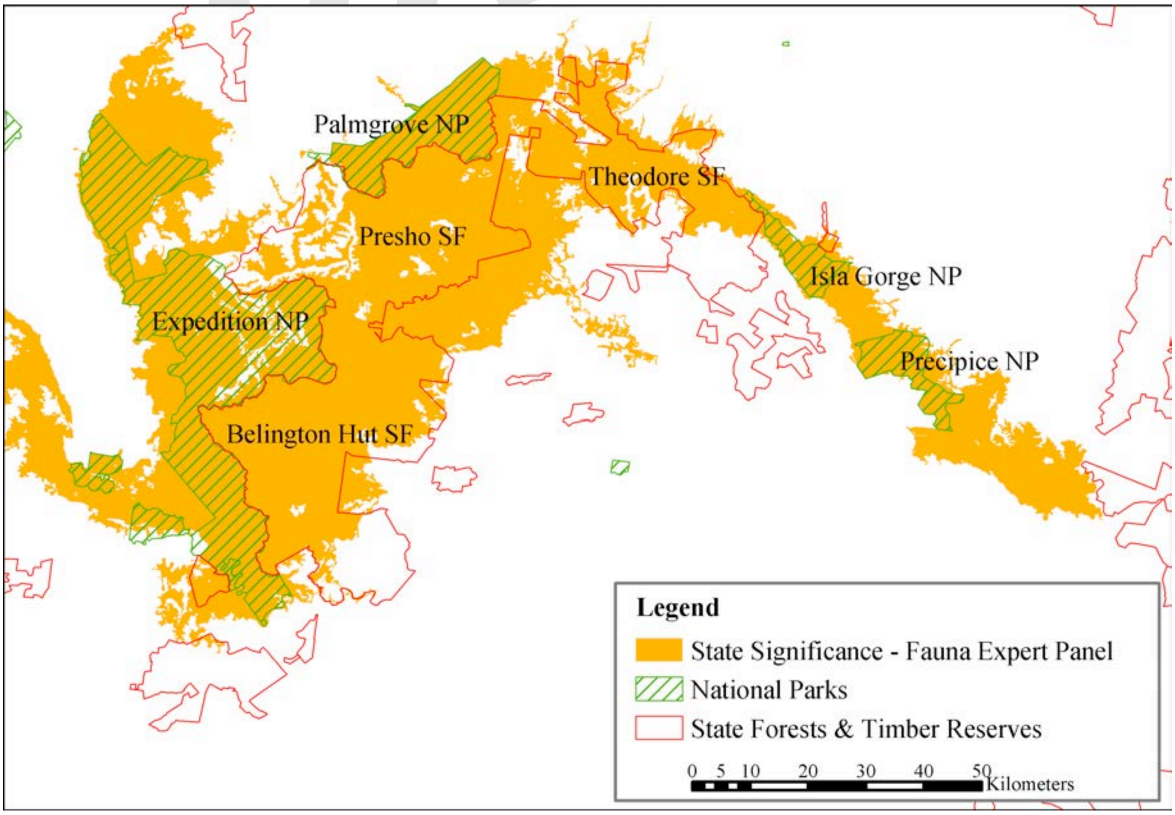


Figure 7.5 Areas around Carnarvon Range–Bigge Range identified by the Brigalow South Fauna Expert Panel as being of State Significance for fauna

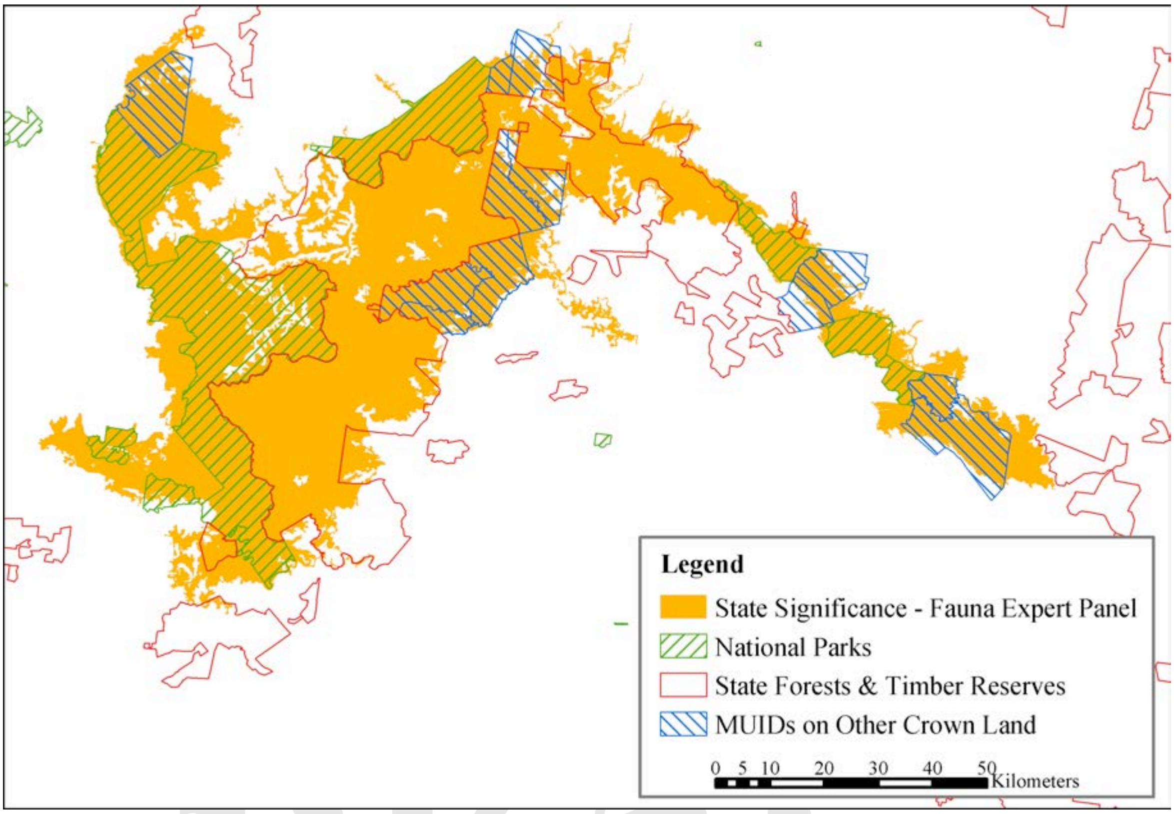


Figure 7.6 Areas around Carnarvon Range–Bigge Range identified by the Brigalow South Fauna Expert Panel as being of State Significance for fauna, showing leasehold land over which the Crown holds timber rights (MUIDs)

7.2.3 Glider Habitat

The habitat models for the Yellow-bellied Glider and Greater Glider provided by Teresa Eyre, Environmental Protection Agency, were considered in the development of this reserve proposal. They are shown in Figures 7.7 and 7.8.

The models indicate the major significance of State Forests and leasehold land to the north of Carnarvon National Park, Barakula State Forest, Carnarvon Range–Bigge Range (Expedition National Park, Belington Hut, Presho and Theodore State Forests, Palmgrove and Isla Gorge National Parks) and Expedition Range.

Eyre notes that the areas of high-quality habitat for the Greater Glider on the western edge of the region should be viewed with caution (Eyre 2002). It is also likely that moderate-quality habitat for the Yellow-bellied Glider in Barakula State Forest is over-estimated in that it includes some cypress and mixed ironbark-cypress forests, which are unsuitable habitats, in the western section.

Figure 7.9 shows the major areas of high- and moderate-quality habitat for the Yellow-bellied Glider on public lands in Southern Queensland. While, as noted above, the area of moderate-quality habitat in Barakula State Forest is over-estimated by the model, it is likely that this State Forest has the largest area of habitat of any area of public land in Southern Queensland.

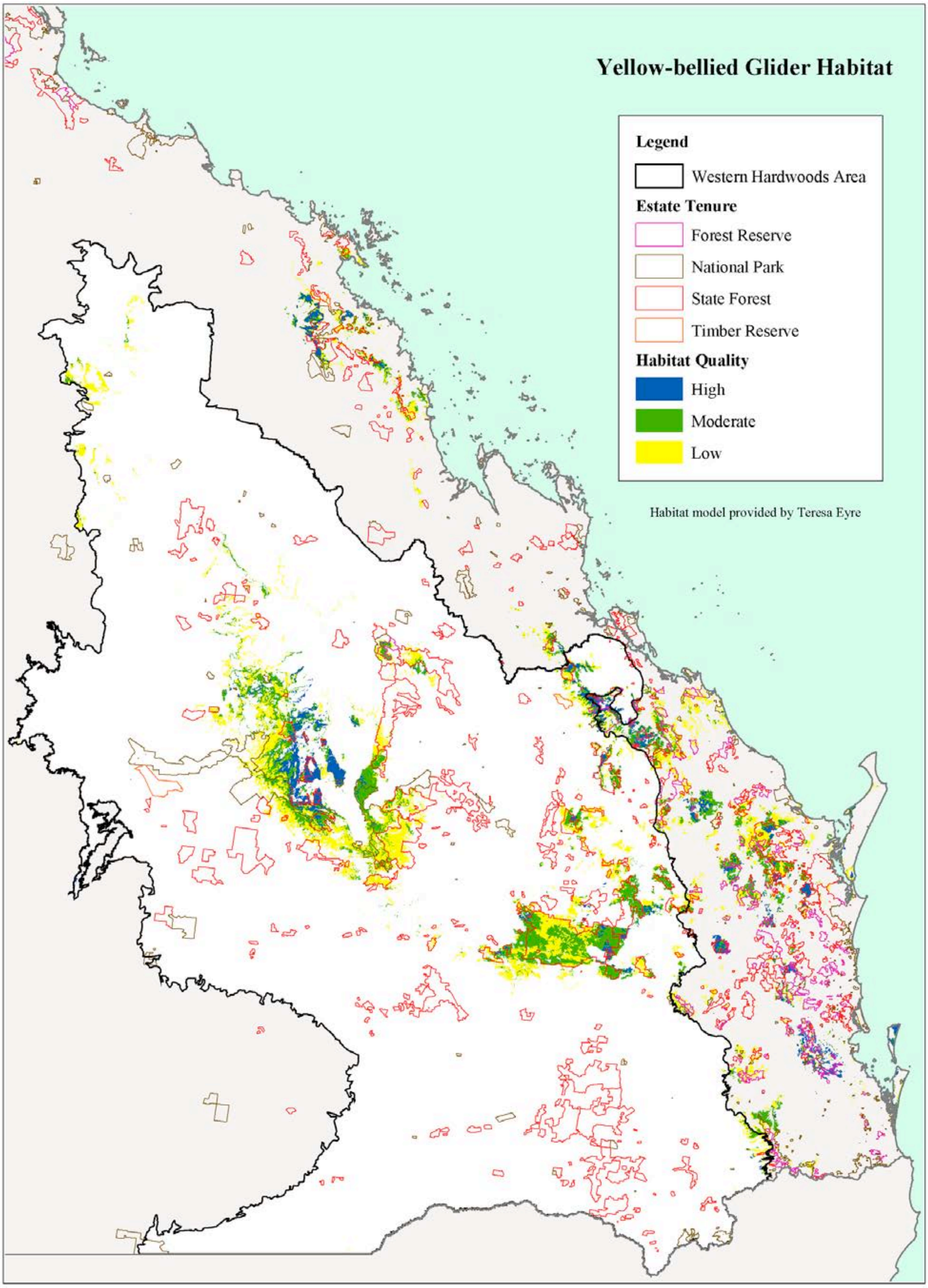


Figure 7.7 Modelled habitat quality for the Yellow-bellied Glider (Eyre 2003)

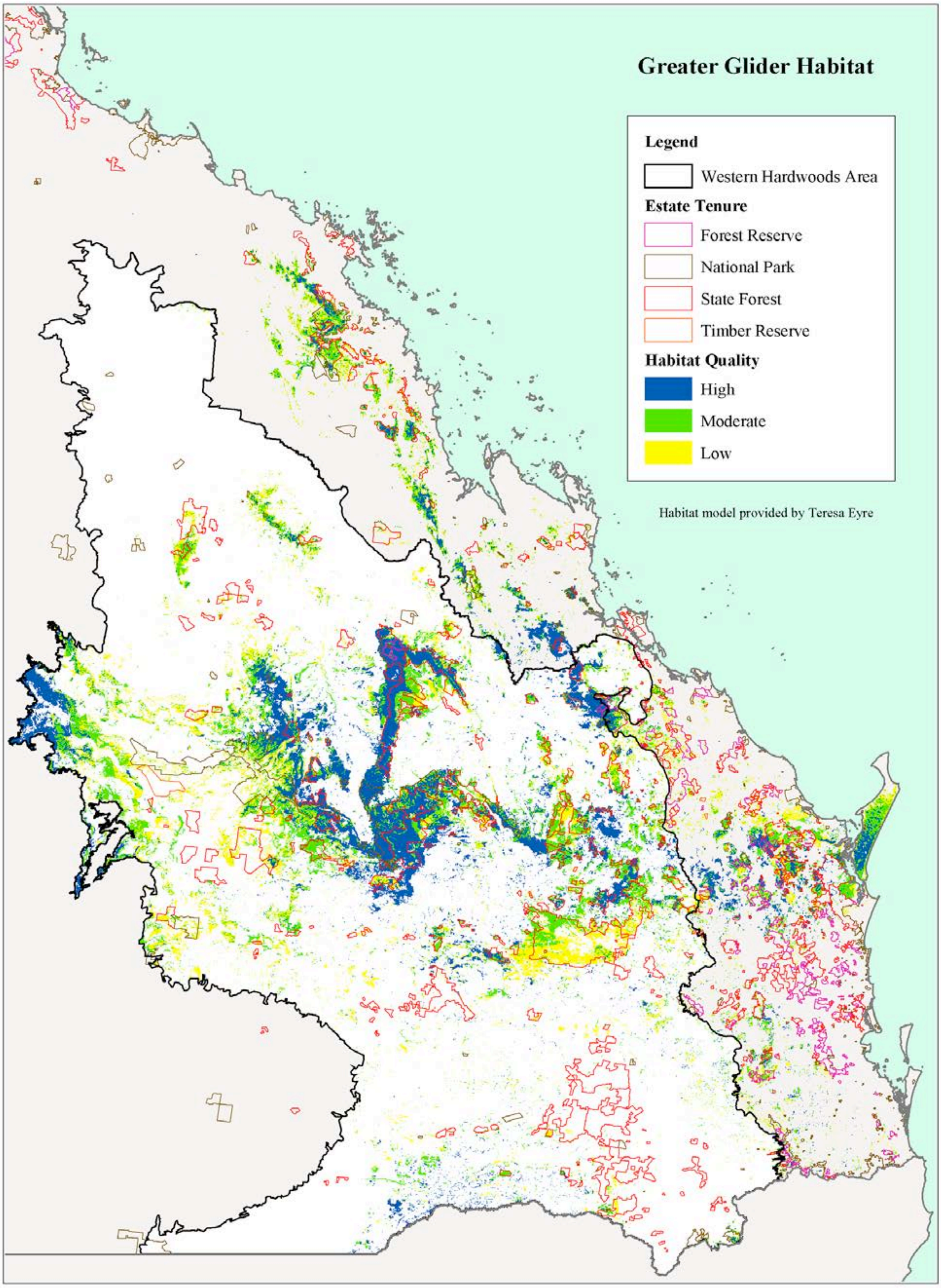


Figure 7.8 Modelled habitat quality for the Greater Glider

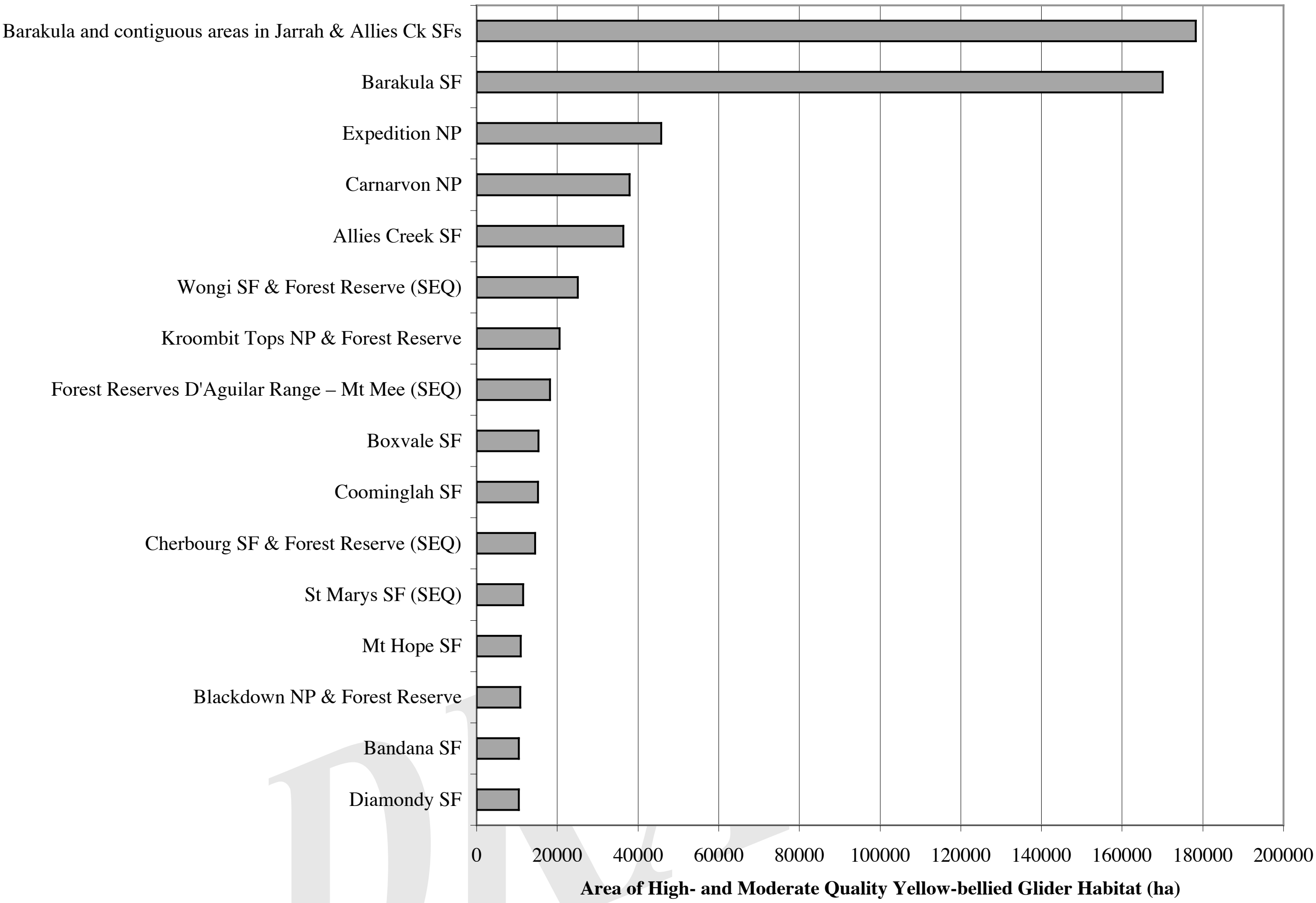


Figure 7.9 High- and Moderate-quality Yellow-bellied Glider habitat in selected areas of public land in Southern Queensland

When leasehold land is included in the assessment, the most significant area of habitat for the Yellow-bellied Glider is the area around Carnarvon National Park extending northwards to Mount Hope State Forest. The total area of high- and moderate-quality habitat is around 270 000 hectares. The area includes a number of blocks of leasehold land with Crown timber rights. Only 37 500 hectares are included in the national park, with 46 600 hectares on State Forest and the remainder on leasehold land.

Another significant block connects Expedition National Park with Mount Nicholson State Forest. The two reserves, together with the connecting leasehold land, include around 80 000 hectares of high- and moderate-quality habitat for the Yellow-bellied Glider.

The area around Carnarvon National Park, including the leasehold land, is also significant for the Greater Glider (Figure 7.8). The largest essentially continuous area of high-quality habitat for the Greater Glider is on the Carnarvon Range–Bigge Range, stretching from Expedition National Park through Belington Hut, Presho and Theodore State Forests to Palmgrove National Park. Another major area extends from Expedition National Park through the connecting leasehold block to Mount Nicholson State Forest and along the Expedition Range to Blackdown Tableland and the Dawson Range.

The expert fauna panel set up by the Environmental Protection Agency for the Brigalow Belt South Biodiversity Planning Assessment identified the area around Carnarvon National Park extending to Mount Hope State Forest and the area extending from Expedition National Park across the Bigge Range to Palmgrove and Isla Gorge National Parks as areas of State Significance for fauna biodiversity (See Figures 7.3 to 7.6.)

7.2.4 Centres of floral endemism in the Study Area

7.2.4.1 Introduction

Distribution patterns of floral endemism in the Study Area were investigated using three measures: (1) areas of high endemic species richness for all flora and specific floral groups, (2) centres of endemism reflecting richness of species with restricted ranges and (3) areas grouped together by similar endemic species composition. For these analyses, flora taxa were considered endemic to the Study Area where at least 75 per cent of their range falls within the Area (Queensland CRA/RFA Steering Committee 1998). Records from the Wildnet database (current at February 2003) were supplemented by more recent records from the Queensland Herbarium and ARCS field surveys (Figure 7.10).

7.2.4.2 Areas of high endemic species richness

For this analysis, records were intersected with a 10-km grid and the number of taxa attributed to each grid cell. The preliminary results for all endemic species are shown in Figure 7.11, for eucalypts (*Corymbia* and *Eucalyptus*) in Figure 7.12, *Eucalyptus* in Figure 7.13, *Corymbia* in Figure 7.14 and *Acacia* in Figure 7.15.

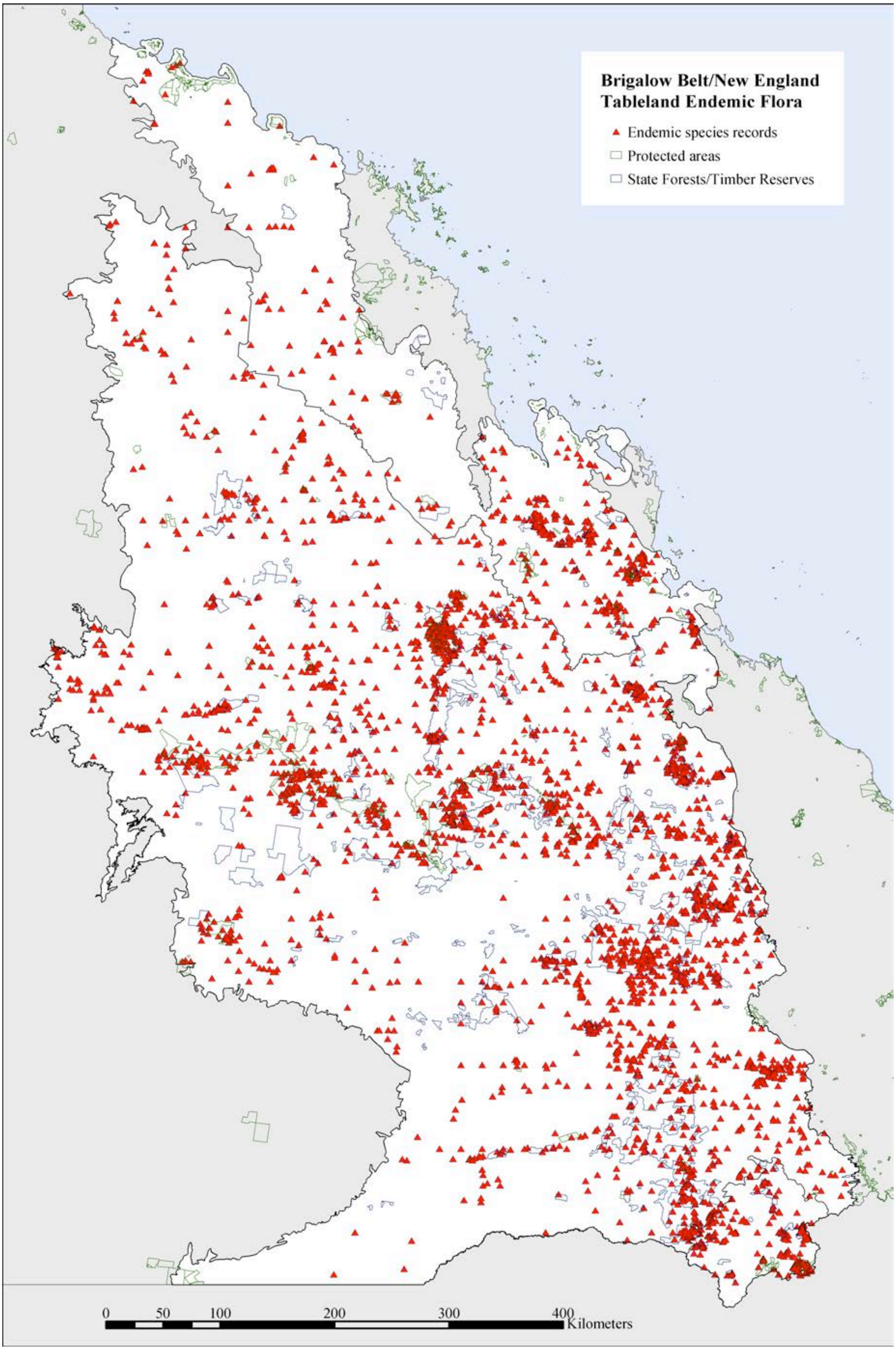


Figure 7.10 Endemic species records in the Brigalow Belt and New England Tableland

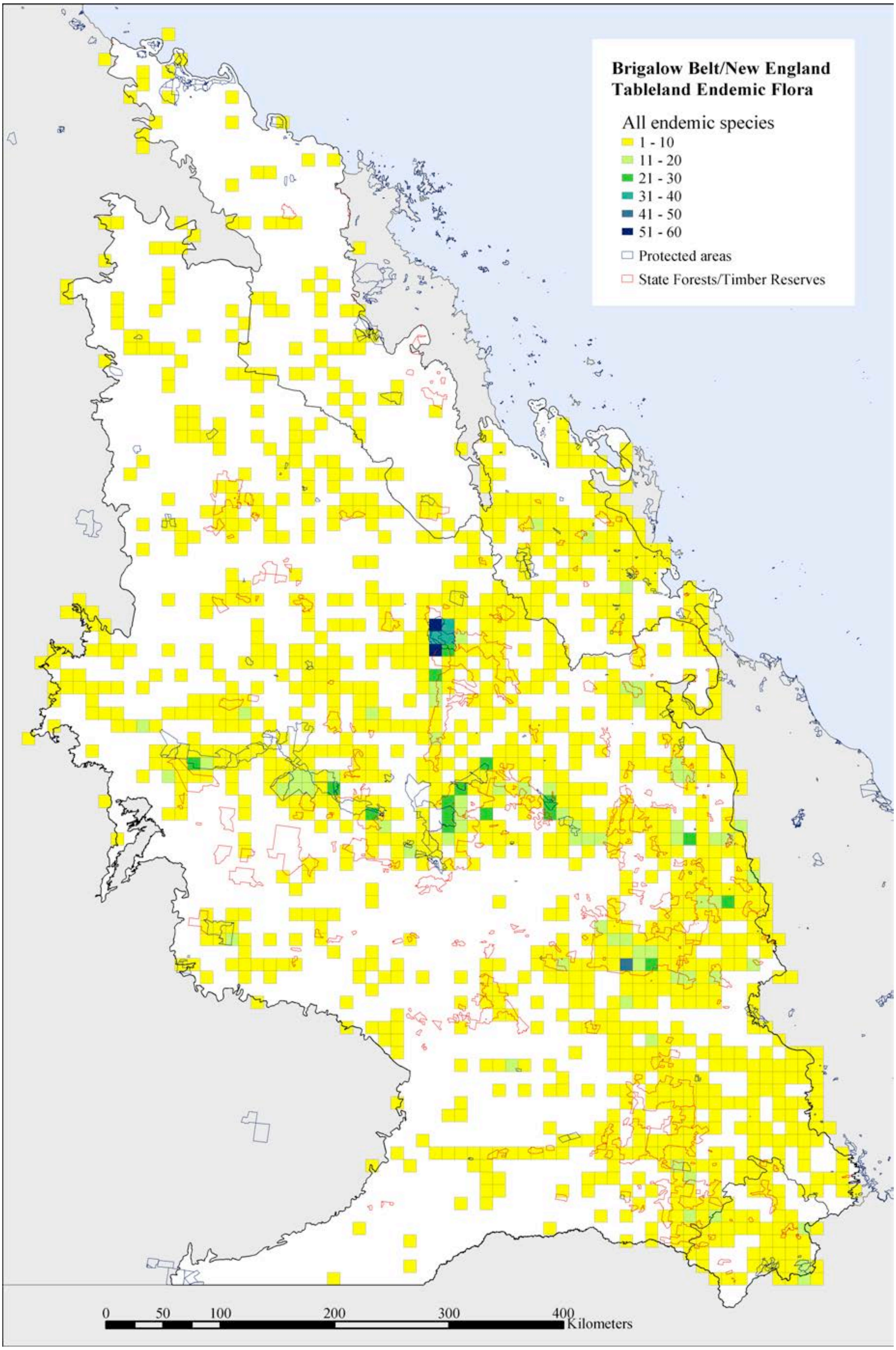


Figure 7.11 Endemic flora richness in the Study Area, based on number of taxa per 10-km grid cell

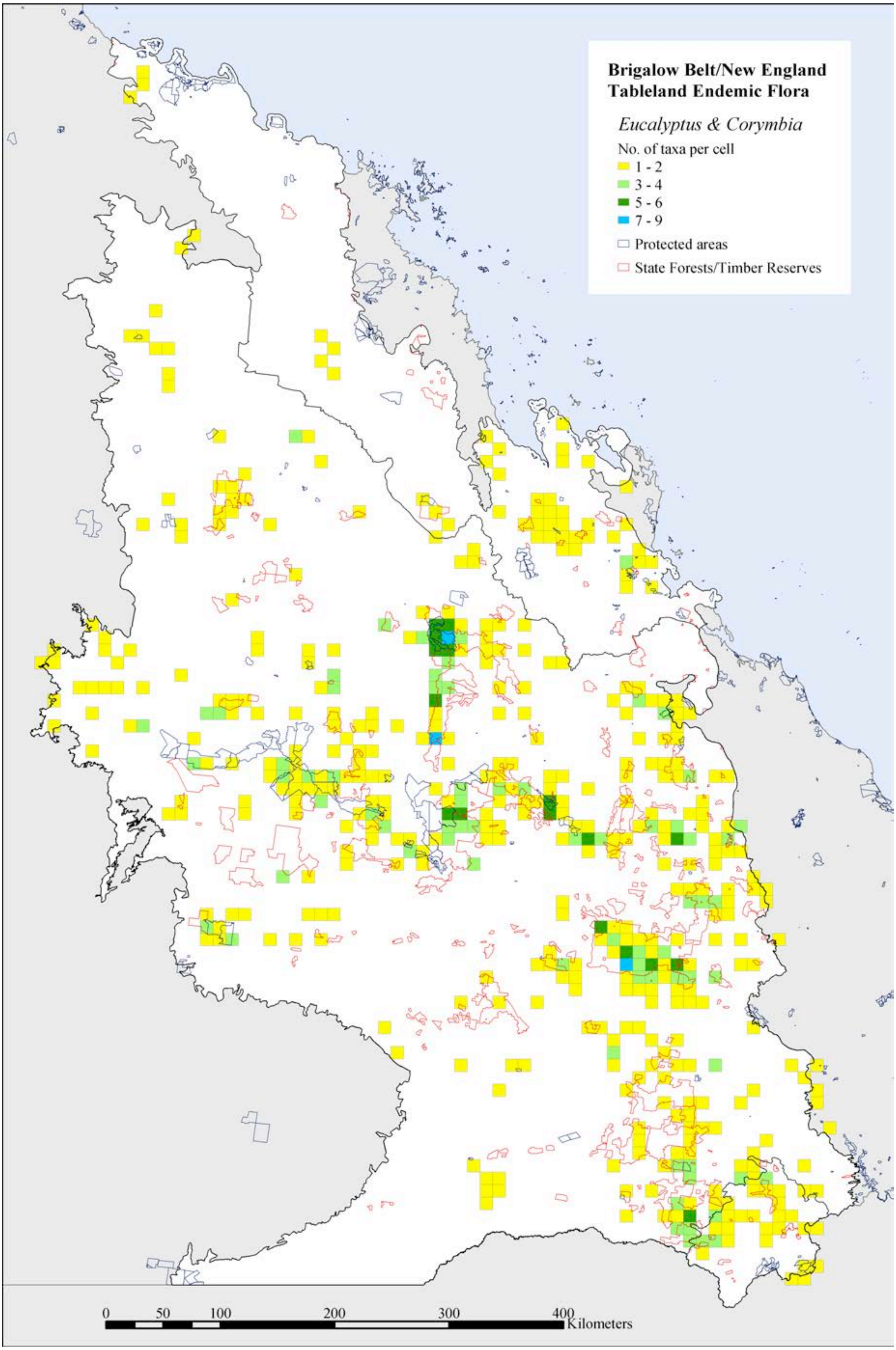


Figure 7.12 Endemic eucalypt richness in the Study Area, based on number of taxa per 10-km grid cell

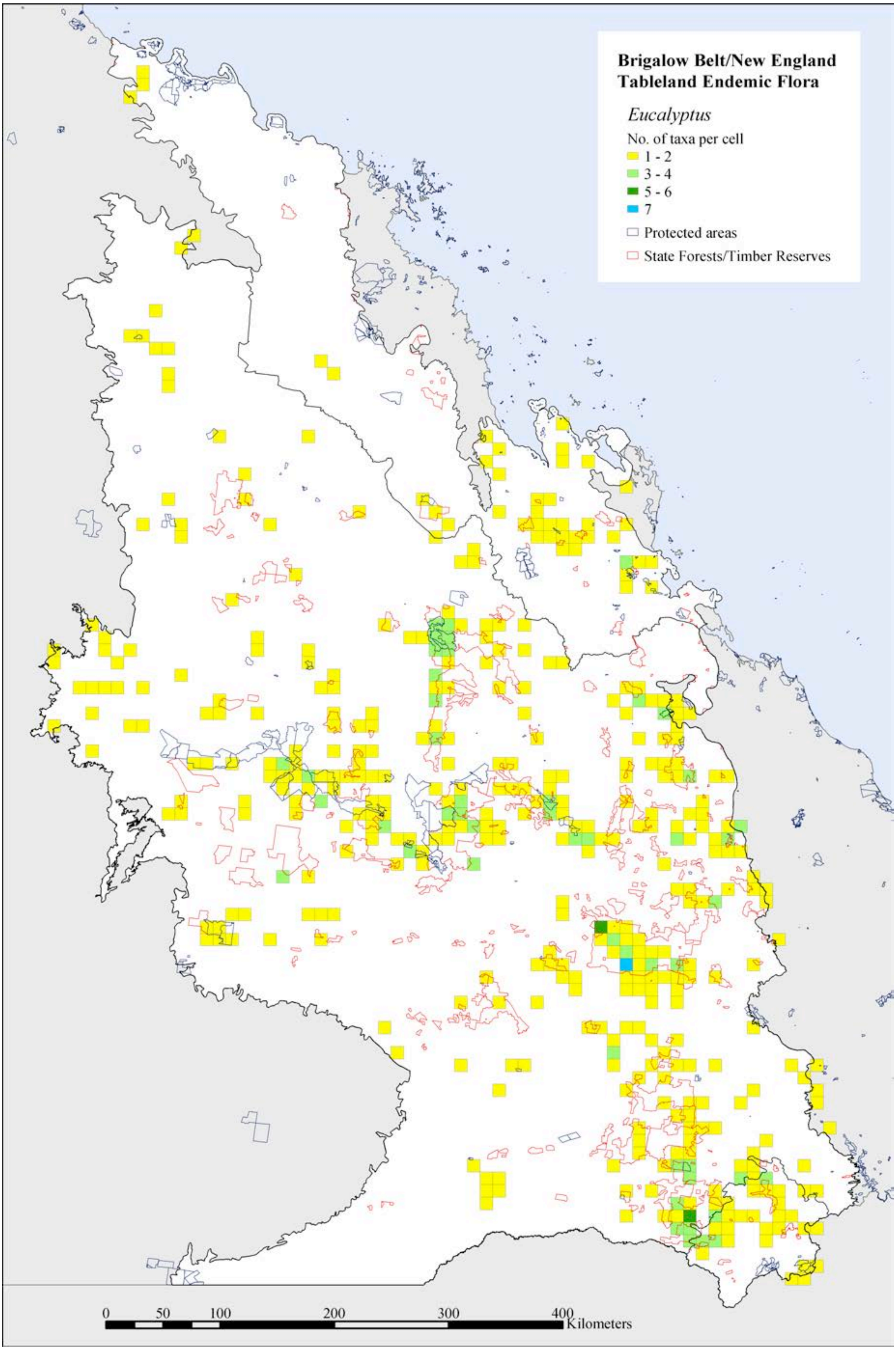


Figure 7.13 Endemic *Eucalyptus* richness in the Study Area, based on number of taxa per 10-km grid cell

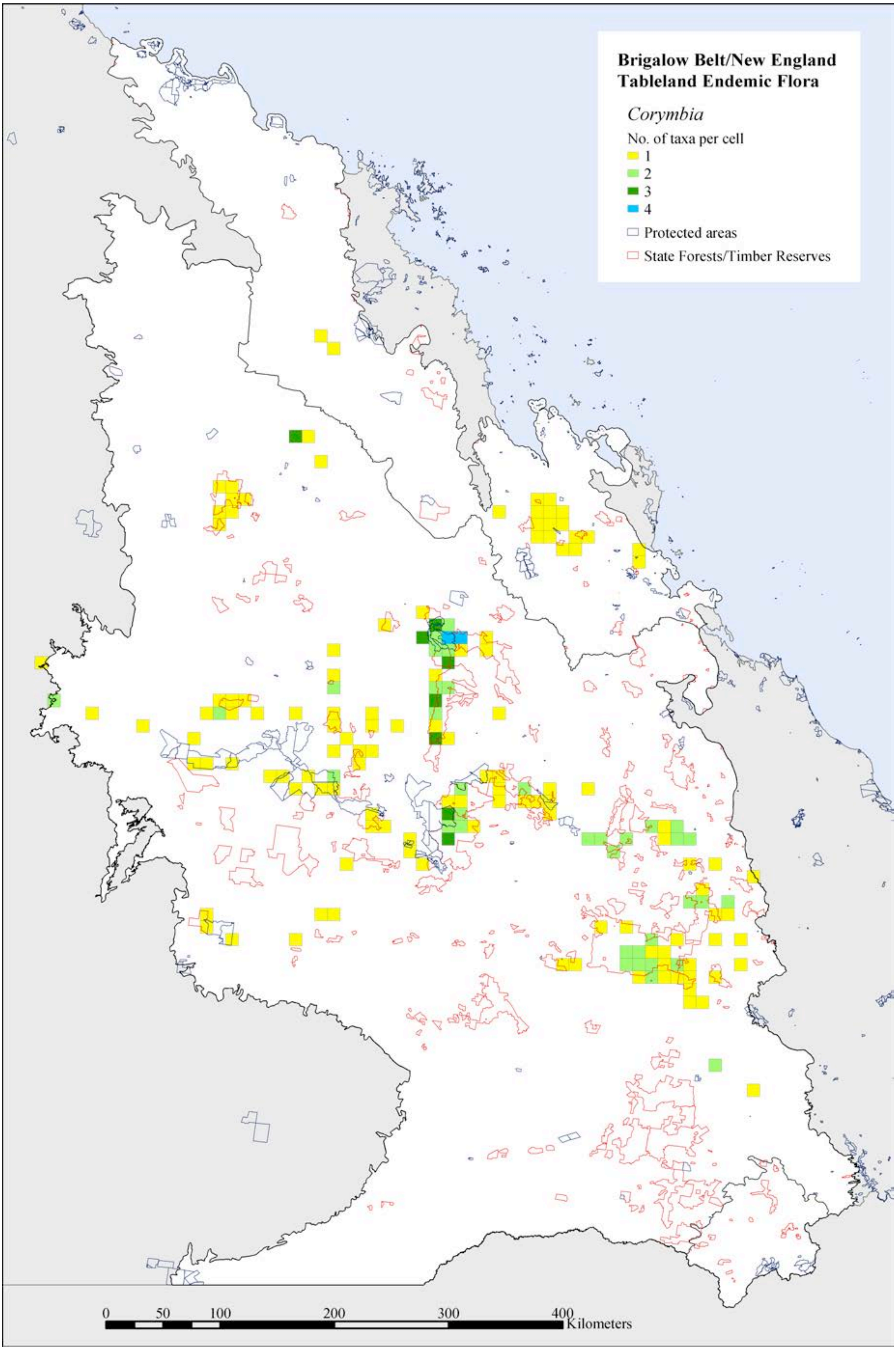


Figure 7.14 Endemic *Corymbia* richness based on number of taxa per 10-km grid cell

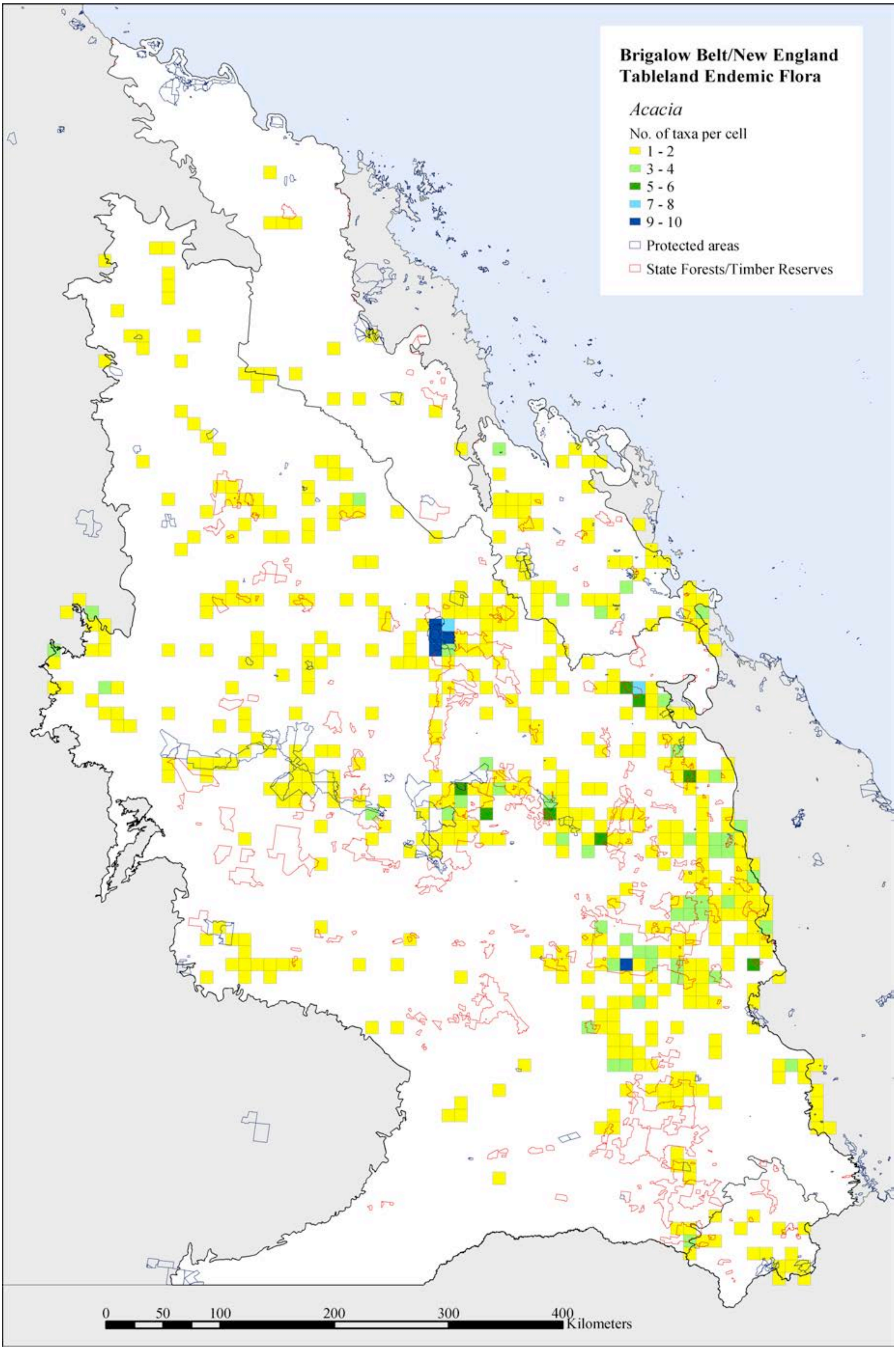
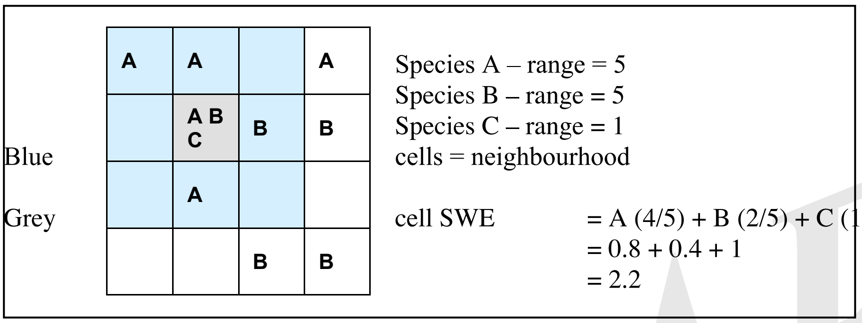


Figure 7.15 Endemic acacia richness based on number of taxa per 10-km grid cell

7.2.4.3 Richness of species with restricted ranges

For this analysis, records of endemic species were intersected with a 10-km grid. To gain an indication of the richness of species with restricted ranges within a cell, a 'spatial weighted endemism' (SWE) index value was calculated. The $SWE_{species}$ index value within a given grid cell was calculated by adding the number of immediately neighbouring cells in which the species also occurs, and dividing by the species' range (the total number of cells in which it occurs across the Study Area) (Figure 7.16). Essentially, a species is weighted in a particular neighbourhood of cells by the proportion of its occurrence in that neighbourhood. The SWE_{cell} value is calculated by summing $SWE_{species}$ values. The SWE_{cell} index values for the 10-km grid are shown in Figure 7.17.



A	A		A
	A B C	B	B
	A		
		B	B

Blue

Grey

Species A – range = 5
Species B – range = 5
Species C – range = 1
cells = neighbourhood

cell SWE = A (4/5) + B (2/5) + C (1/1)
= 0.8 + 0.4 + 1
= 2.2

Figure 7.16 Worked example for determining a cell's spatial weighted endemism (SWE) index

The method was modified from that developed by Laffan and Crisp (2003) to calculate a 'spatial corrected weighted endemism' (SCWE) index. The first deviation from Laffan and Crisp (2003) was omission of the correction for species richness, which divides the SWE_{cell} value by the total number of species. Laffan and Crisp derived the SCWE index using all species, whereas this analysis used a dataset of species already determined to be endemic. If the correction for species richness was made for index values derived only from endemic species, cells with a few narrow-range species could have relatively high values, whilst cells with many species (including species with both narrow and wider ranges) could relatively decrease in significance despite having more narrow endemics than the aforementioned cell. Hence, a raw summed score was preferred. Although sampling intensity and consistency may be raised as a bias in the analysis, the intent was initially to detect areas of endemism.

The second deviation from Laffan and Crisp (2003) relates to cell selection. Where the SCWE index only involved four surrounding cells (north, south, east and west) due to square neighbourhoods of 100-km cells including too much extra data at longer spatial lags. This was deemed not to be as significant a problem with 10-km cells, and so all eight surrounding cells were considered to include species records within a realistic radius of the central cell.

A limitation of the method is apparent when considering the range restriction of two species which only occur in one neighbourhood. A species occurring in a single cell will contribute the same index value to that cell as a species occurring in a group of nine neighbouring cells will to the central cell of that group (1/1 vs 9/9 = 1). It is evident that the species restricted to one cell should be assigned greater weight. Further analysis could address this issue in a revised methodology.

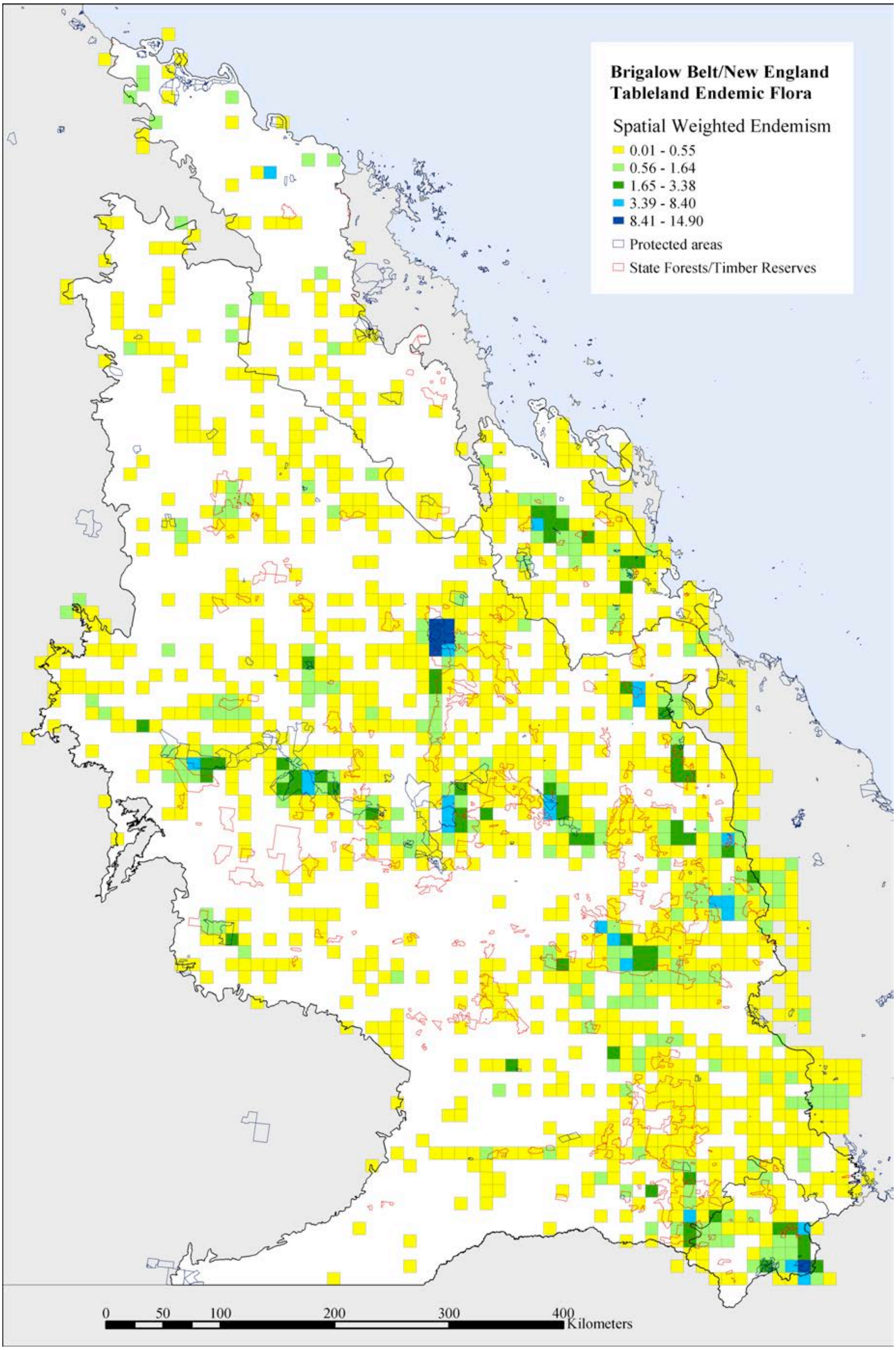


Figure 7.17 Spatial Weighted Endemism index values for 10km grid cells

7.2.4.4 Areas with similar endemic species composition

Cluster analysis was used to group cells with similar species composition. However, it was undertaken prior to the endemic species dataset being complete, so that significantly fewer species (269 versus 355) and associated records were used than the final version of the data. Time constraints have to date precluded re-analysis using the full data set. Despite apparent limitations in detecting and resolving finer scale endemism, it was useful to compare the results with those of the SWE index analysis, which confirmed the core centres of endemism described above.

PC-ORD 4.27 (McCune and Mefford 1999) was used to cluster grid cells with similar endemic species composition. This was done using the Sorensen (Bray-Curtis) distance measure and a flexible beta linkage value of = -0.25 on species presence or absence. In order to minimise distortion in clustering due to insufficient data, only cells with species counts greater than one standard deviation from the mean (≥ 5 species) were analysed. The resulting groups can be seen in Figures 7.18 and 7.19.

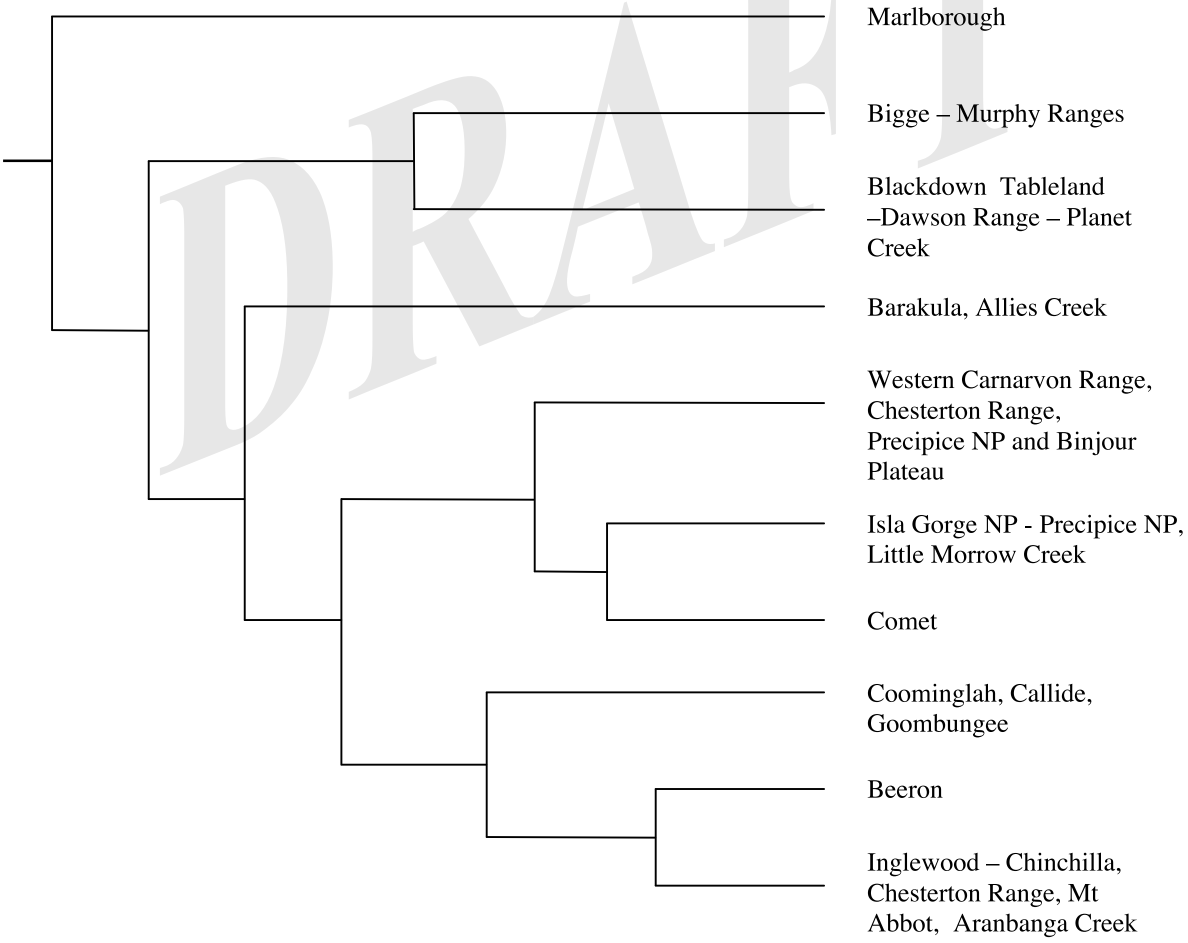


Figure 7.18 Areas of high endemic species richness grouped according to similarity in species composition as indicated by cluster analysis

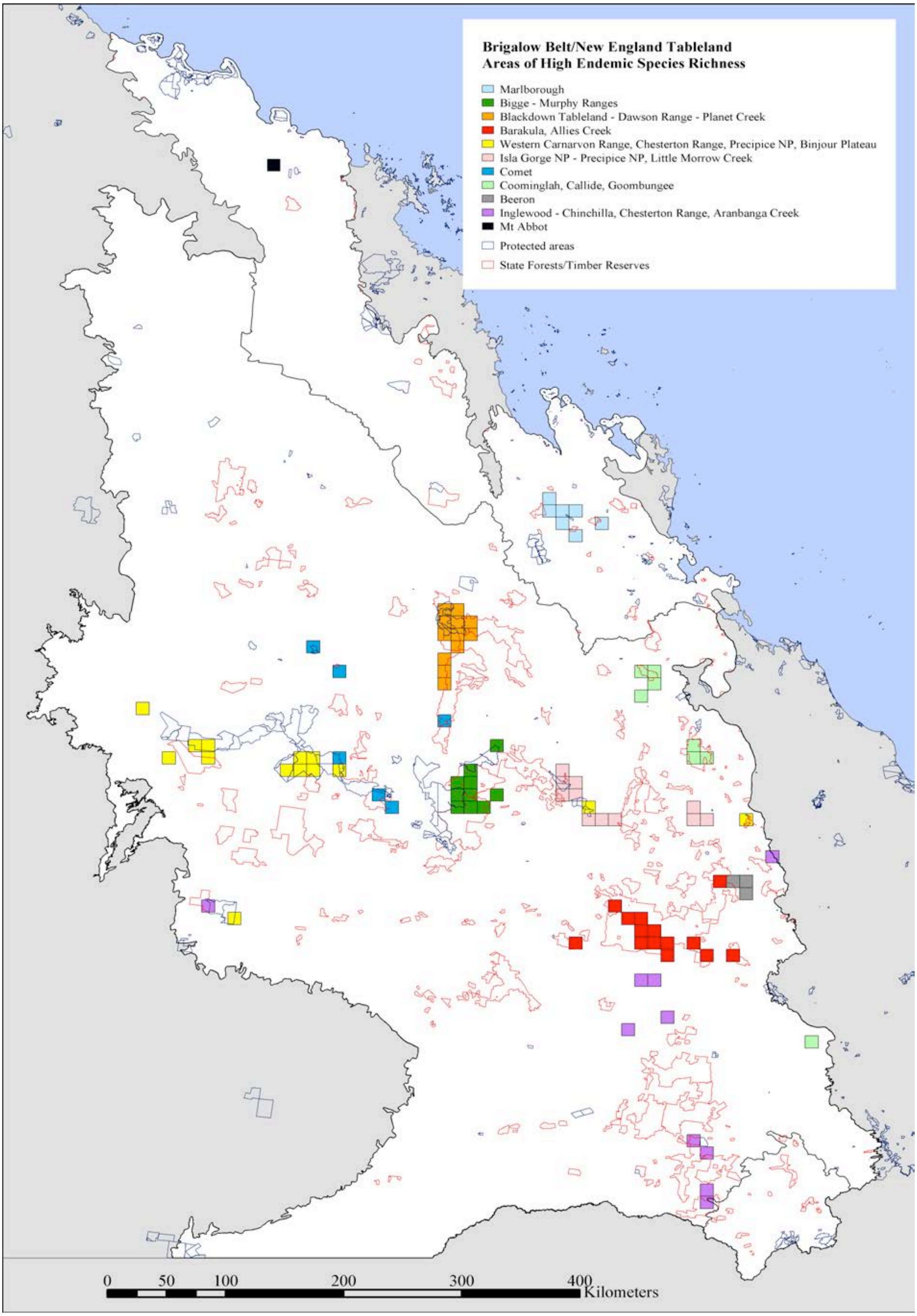


Figure 7.19 Distribution of areas of high endemic species richness with similar species compositions in the Brigalow Belt and New England Tableland

It is important to highlight that grouping of cells provided a broad measure of similarity based on species composition. The combination of inaccurate species locations and limitations in the clustering method meant that finer scale endemism of highly restricted species was not sufficiently detected or resolved. Although the clustering strategy utilised an algorithm resulting in groups being weighted proportionally to the number of cells they contain, some cells were clearly misclassified, i.e. the last group to split in the dendogram (Figure 7.18). These cells typically contained a majority of species that were not recorded in other cells, and so were grouped more on similarity with widespread but minor component species within the misclassified cells. For example, although the Mt Abbot cell in the far north of the bioregion clustered with this group, almost all the species present are entirely restricted to that area. This highlighted some of the limitations of the analytical method; re-analysis using the alternative UPGMA linkage method split this cell into its own group, justifying treatment as such in Figure 7.19.

Furthermore, the cluster group distributions were subject to sampling intensity bias as a result of collector preference and land use patterns; many areas still require further comprehensive survey. Future analysis will address these limitations by refining the classification methods after incorporating the results of new surveys and correction of erroneous locations of records.

For example, a disjunct cell at Binjour Plateau was clustered with areas further to the west, but arguably should be a group in its own right. Of the six species recorded in the single cell, four are restricted or near restricted to the area and only two are shared with other members of the group. The closest cell geographically is at Precipice National Park, but it does not share any common species. However, each shares different species with the core western group of cells. Furthermore, ongoing work to correct inaccurate locality records of species in surrounding cells is likely to affect the classification and ranking of the Binjour area. This highlights the limitations of the analytical method in determining differences in species composition and also weaknesses in some of the underlying source data.

7.2.4.5 Specific areas of endemism

The majority of the centres of endemism occur on the skeletal soils of sandstone ranges and plateaus of Jurassic-Triassic origin. However, one centre occurs in low coastal ranges on serpentinite. Barakula and surrounding State Forests make up a core area of endemism on lower parts of the Great Divide.

Blackdown Tableland – Planet Creek

Blackdown Tableland is an isolated sandstone plateau and provides a major refugium for many restricted species, especially within the Myrtaceae and Mimosaceae. Exceeding 900 m altitude in places, it receives higher annual rainfall (over 850 mm) than most of the surrounding areas. This refugium is characterised by a central plateau and dissected topography of adjoining areas in the Dawson and Shotover Ranges and Planet Creek. The centre has more endemic species than anywhere else in the Study Area (Figure 7.11), is the most species rich for endemic acacias (Figure 7.15), and has one of the highest numbers of endemic eucalypts (Figure 7.12). It also has the highest index values indicating richness of range-restricted species (Figure 7.17). Some of the species that are restricted to or have core distributions in the area include *Acacia storyi* (R)*, A. gittinsii* (R), *A. hendersonii, Eucalyptus mensalis* (R)*, E. sphaerocarpa* (R), *Corymbia bunites, Callistemon* sp. (Blackdown Tableland S.G.Pearson 287), *Callistemon* sp. (Rainbow Falls P.I.Forster PIF13786), *Macrozamia platyrhachis* (E), *Baeckea trapeza* (V), *Daviesia quoquoversus* (V) and *Kunzea opposita* var. *leichhardtii*.

Stanthorpe – Wallangarra

The important Stanthorpe Wallangarra centre is located on the New England Tableland and includes Girraween National Park, a locality renowned for floral endemism. Elevation ranges from 700 m to over 1250 m in the highest parts of Girraween, with annual rainfall of up to 1100 mm. There area is also somewhat of a transition zone between cooler southern temperate areas and the subtropical zone of southern Queensland. Although not as rich in endemic species as other parts of the Study Area, it is an extremely important refuge for many highly restricted species. It has a SWE index value second only to the Blackdown Tableland – Planet Creek area (Figure 7.17). Restricted species include *Boronia amabilis* (R), *B. repanda* (E), *Phebalium whitei* (V), *Zieria* sp. (Amiens L.Pedley 1518), *Z. arborescens* subsp. *glabrifolia*, *Prostanthera* sp. (Wallangarra T.D.Stanley 7876), *Acacia pubifolia* (V), *Bertya recurvata* (R), *Callistemon* sp. (Bald Rock Creek I.R.Telford 11840), *Craspedia* sp. (Girraween NP S.T.Blake 23643), *Eucalyptus scoparia* (V) and *Macrozamia viridis* (E).

Beeron

Beeron Holding, an elevated area of up to 500 m adjoining the eastern boundary of Allies Creek State Forest, is a small exposed surface within an area of the largest outcropping of Upper Palaeozoic granitoids in Queensland, representing key elements of the State's original crustal development. Edaphic specialization on nutrient-deficient substrates associated with granites and annual rainfall of over
750 mm (wetter than the Barakula group and most parts of the adjacent Allies Creek State Forest) most likely underpins the differentiation of this centre of endemism and its refugial status for many threatened and endemic species of flora. The restricted occurrence of *Acacia porcata*, which represents an ancient lineage of the genus and has no close relatives , elevates the significance of this area. This centre of endemism may be one of the most important areas in Australia for conserving the ancestral elements of acacias.

The area has a relatively high level of endemic species richness (Figure 7.11), and stands out as one of the significant centres for species with restricted ranges (Figure 7.17) – for example, *Acacia porcata, A. eremophiloides*, *Newcastelia velutina*, *Bertya* sp. (Beeron Holding P.I.Forster+ PIF5753), *B. granitica* (E) and *Commersonia* sp. (Beeron P.I.Forster PIF4658) have not been recorded anywhere else.

Marlborough

The most outstanding characteristic of the Marlborough area in the north-east of the Study Area is its occurrence on some of the most nutrient-depleted soils known, associated with the largest serpentinite deposit in the southern hemisphere. This has resulted in a specialised suite of nickel-accumulating plants of global significance. The area also receives a comparatively high annual rainfall of more than 900 mm. It is a centre for range restricted species in the Study Area (Figure 7.17), and a level of formal protection is required commensurate with the outstanding significance of this unique, highly restricted and threatened flora. Narrowly endemic species include *Callistemon* sp. (Marlborough Creek G.N.Batianoff+ MC9108006), *Eucalyptus fibrosa* subsp. (Glen Geddes M.I.Brooker 10230), the endangered *Macrozamia serpentina* and *Olearia* sp. (Glenavon P.I.Forster+ PIF15039), and the vulnerable *Bursaria reevesii*, *Capparis thozetiana* and *Corymbia xanthope*.

Bigge–Murphy Ranges

The Bigge–Murphy Ranges area lies on parts of the inland elevated sandstone ranges which receive greater annual rainfall than the surrounding lowlands. Presho SF, the northern part of Belington Hut SF and Palmgrove NP support the core area of endemism. Throughout this area both the Bigge and Murphy Ranges have been dissected by watercourses feeding the Dawson River, with the resultant elevations varying from 300 to 600 m. The skeletal soils on ridges and slopes support relatively high numbers of endemic species generally (Figure 7.11), and also endemic *Corymbia* (Figure 7.14) and *Acacia* (Figure 7.15) species. Species include the endangered *Acacia* sp. (Ruined Castle Creek P.I.Forster+ PIF17848), and core populations of *Corymbia bunites*, *Macrozamia fearnsidei* (V), *Homoranthus decasetus* (R), *Boronia forsteri*, *Conospermum sphacelatum*, *Pseudanthus* sp. (Salvator Rosa NP M.E.Ballingall MEB450), *Pseudanthus* sp. (Tylerville P.I.Forster+ PIF11510) and *Dendrobium kingianum* subsp. *carnarvonense*.

In addition to it being an area of endemic eucalypt richness (Figure 7.12), it is important for ancestral *Eucalyptus* lineages, in particular the area bounded by Presho and northern Belington Hut State Forests and eastern Expedition NP. There, four of the six monotypic subgenera, *Idiogenes*, *Cuibodea*, *Primitiva* and *Acerosae* co-occur, representing a remarkable diversity of basal genetic lineages in one of the most speciose genera in Australia.

As large parts of the area have not been surveyed, further investigation may reveal an even greater level of endemism.

Carnarvon Range

Core centres on Carnarvon Range with high richness of endemics species include Boxvale SF, Carnarvon Gorge through the Consuelo Tableland to Bull Creek Gorge west of the Salvator Rosa section of Carnarvon NP (Figure 7.11). The area is characterised by the highest annual rainfall (up to 850 mm) in that part of the bioregion, comparable only with Blackdown Tableland. Although some locations have relatively high numbers of eucalypt endemics (Figure 7.12), it is the areas of range-restricted species that heighten its significance (Figure 7.17). The narrowly endemic species include *Eucalyptus grisea*, *Glycine* sp. (Mt Moffatt K.A.Williams 86060) *Diuris luteola*, *Swainsona sejuncta* and *Pseudanthus* sp. (Salvator Rosa NP M.E.Ballingall MEB450). Disjunctions also characterise this area – for example, *Eucalyptus pachycalyx* subsp. *waajensis* in Bull Creek Gorge is separated by a gap of over 370 km from its nearest population south of Cracow, and the closest record of *Pterostylis woollsii* on the New England Tableland is a distance of almost 550 km.

Although some species such as the vulnerable *Bertya* sp. (Winneba D.Jermyn 31) are restricted to the Chesterton Range about 150 km to the south, many of the endemics there have small, restricted ranges and occur disjunctly in the western Carnarvon Range. Examples of these species include *Homoranthus zeteticorum*, *Boronia eriantha* (also disjunct in White Mountains NP), *Lomandra teres* (R) and *Micromyrtus leptocalyx*. The apparent geographical separation of this area may be due to a comparatively low survey effort between the Carnarvon and Chesterton Range National Parks on the Murphy Tableland (between the upper reaches of the Warrego and Maranoa Rivers). Alternatively, the disjunctions may reflect the pattern of radiations and contractions of species' ranges during the Pleistocene climatic oscillations. Thus, increased focus on this area would clarify the nature of this area of endemism.

The Mantuan Downs area at the headwaters of the Nogoa River to the north of the Ka Ka Mundi section of Carnarvon NP also contains several important endemic species and disjunct occurrences. The restricted endemic species include *Teucrium micranthum*, *Corymbia scabrida* (R), while *Acacia tindaliae* represents an extraordinary disjunction of over 650 km from its only other occurrence in the Pilliga of NSW. Future work will more closely evaluate the significance of this epi-centre of endemism, particularly taking into account the significant presence of narrowly disjunct but non-endemic taxa.

Barakula, Allies Creek

The Barakula–Allies Creek area encompasses the large central core of moderately elevated and dissected topography in Barakula State Forest, together with nearby Gurulmundi, Nudley, Diamondy and Allies Creek State Forests. The core cells in Barakula track the line of equable seasonality of soil moisture (Figure 2.5), allowing plants to survive under lower rainfall regimes than those towards the east or on the other higher sandstone ranges and tablelands to the north and west. This soil moisture equability coupled with the low nutrient levels associated with skeletal sandstone soils of the old, lower eroded sections of the Great Divide may be major contributing factors to the exceptional levels of endemism present. Around 80 species of endemic plants are present in Barakula, with the richest areas shown in Figure 7.11. Barakula, with Blackdown Tableland, supports the highest levels of endemism in the Brigalow Belt in regard to the acacias (Figure 7.15) and eucalypts (Figure 7.12). It is also a significant area of restricted endemism (Figure 7.17), supporting species such as *Acacia barakulensis* (V), *A. handonis* and *Calytrix gurulmundensis*. Other important species include the endangered *Micromytrus patula* and representatives of ancient eucalypt lineages – *E. rubiginosa, E. tenuipes* and *E. curtisii*. Important species in nearby areas include a core disjunct population of *Eucalyptus taurina* in Allies Creek and *Micromyrtus carinata* in Gurulmundi.

Isla Gorge NP – Precipice NP

The diversity of topography in and around the areas of Isla Gorge, Precipice National Park, Nathan Gorge and Cracow Creek provides for floral refugial niches, reflected by the richness of all endemic species (Figure 7.11), eucalypts (Figure 7.12) and acacias (Figure 7.15). Despite supporting widely disjunct endemic species, the presence of more narrower range species such as *Acacia hockingsii, A. islana, Calytrix islensis* and *Cryptandra* sp. (Isla Gorge P.Sharpe 627) also make it a core centre of restricted endemism in the Study Area (Figure 7.17). Skeletal soils on the rocky ridges support several threatened eucalypts — *E. rubiginosa* (R) from the monotypic subgenus *Primitiva*, *E. pachycalyx* subsp. w*aajensis* (E) and *Eucalyptus beaniana* (V).

Callide–Coominglah

TheCallide–Coominglah area occurs on a convergence zone of coastal ranges and dissected remnants of ancient peneplains, namely the western slopes of the Calliope Range around Callide Timber Reserve, and Coominglah sits on a mostly elevated section of the Dawes Range between the Banana Range and Kroombit Tops. Due to this easterly distribution and elevation, annual rainfall is between 700 and 800 mm. Although not as abundant in endemic species as some centres, these areas support one of the highest numbers of acacias in the Study Area (Figure 7.15) and are important for restricted range species (Figure 7.17). *Grevillea hockingsii* (V), *Boronia palasepala* are restricted to the two areas, *Acacia* sp. (Biloela T.Shepard A32) just to the Callide area and *Pomaderris coomingalensis*, *Solanum* sp. (Coominglah A.R.Bean 10389) and *Zieria* sp. (Coominglah A.R.Bean+ 8959) to Coominglah.

Inglewood

The Inglewood group is based around the undulating hills and low ranges up to 450 m of the Inglewood Sandstones complex. This area derives from Jurassic-Cretaceous sediments which have been deeply weathered and laterised. The group is characterised by its occurrence in some of the drier areas of the bioregion. Typically, annual rainfall is less than 650 mm. Furthermore, the mean moisture index is generally higher in winter than in summer, compared to more equable seasonality or summer dominance in other group areas. Soil moisture represents one of the strongest influences on plant distributions and abundances. The southern Inglewood Sandstones area supports one of the highest levels of endemic *Eucalyptus* taxa within the Brigalow Belt (Figure 7.12), and is also important for narrow range species (Figure 7.17). Species restricted to the area near Inglewood include *Acacia argyrotricha*, *Cheiranthera* sp. (Inglewood R.W.Johnson 2940), *Eucalyptus* sp. (Inglewood P.Grimshaw+ PG846), *Westringia parvifolia* (V) and *Prasophyllum campestre* (R).

Binjour Plateau

This elevated area of Binjour Plateau near the eastern boundary of the Study Area supports several endemic acacias (Figure 7.15), and is also important as an area of restricted endemism (Figure 7.17). Examples of species with narrow ranges occurring there include *Acacia rubricola*, *Acacia* sp. (Nantglyn P.I.Forster+ PIF5741) and *Fontainea fugax*.

Mt Abbot

This Mt Abbott cell, in the far north of the Study Area, has elevations over 1000 m and receives up to 1750 mm annual rainfall. Although not rich in the total number of endemic species, the proportion of narrow endemics in the small area make it an important location (Figure 7.17). The restricted species include *Acacia abbatiana, Hemigenia* sp. (Mt Abbot A.R.Bean 4204), *Plectranthus cyanophyllus* and *Triplarina calophylla*. *Callistemon* sp. (Mt Abbot A.R.Bean 5186) has only one other record to the north-west in Bowling Green Bay National Park.

Little Morrow Creek

Little Morrow Creek on the eastern slopes of the Auburn Range shares some of the widespread species that also occur in Isla Gorge and Precipice NP, and is a relatively rich area of endemic species (Figure 7.11). It is also important for endemic eucalypts (Figure 7.12). Narrow range species make it a significant location for restricted endemism (Figure 7.17) – *Leptospermum venustum* (V) is restricted to the area, and the only other places that *Corymbia petalophylla* occurs in are nearby Beeron Holding and Allies Creek State Forest.

Comet

The Comet area is based around the elevated sandstone ranges in the upper catchment of the Comet River, where the highly restricted species *Commersonia* sp. (Zamia Range R.W.Johnson 1398) and *Eucalyptus sicilifolia* occur around Springsure in the Staircase Range. Many of the taxa in this area of refugia are considered to be actively evolving, with this region likely to represent a contact zone for allopatric populations and sister taxa.

7.2.5 Priority Areas (Environmental Protection Agency)

In June 2003, the Queensland Timber Board (now Timber Queensland) invited the Environmental Protection Agency to identify State Forests and Timber Reserves in the WHWD Area considered to be priority areas for reservation.

A total of 25 areas were identified, incorporating 33 State Forests or Timber Reserves (Queensland Timber Board 2003). The reserves are listed in Table 7.1.

Table 7.1 State Forests and Timber Reserves identified by the EPA as priority areas for reservation

Subregion	**State Forest/Timber Reserve**	
Anakie Inlier	Blair Athol SF Copperfield SF	Redrock SF
Anakie Inlier & Isaac–Comet Downs	Kettle SF (part)	
South Drummond Basin	Zamia SF Keilambete SF	Withersfield SF
Isaac–Comet Downs	Crystal Creek SF Burn SF	Llandillo SF
Basalt Downs	Fairbairn SF	
Carnarvon Ranges	Presho SF (part) Theodore SF	Mebir SF
Banana Ranges–Auburn Ranges	Belmont SF	Grevillea SF
Mount Morgan Ranges	Callide TR Mundrowan SF Binjour SF	Gurgeena SF Reid SF Mountain View SF
Barakula	Cominglah SF Koko SF	Barakula SF (part)
Southern Downs	Gurulmundi SF Yuleba SF (part)	Binkey SF
Inglewood Sandstones	Condamine SF Wondul Creek SF Bracker (Yelarbon) SF	Wyaga SF (part) Bendidee SF

7.3 State Forests and Timber Reserves

7.3.1 Regional Ecosystem diversity

Carnarvon National Park, with its topographic and climatic diversity, has the highest level of Regional Ecosystem diversity of all reserves in the WHWD Area. The park covers an area of 298 000 ha, extends east-west over 200 km and, within the park, elevation ranges from around 400 to 1200 m. Next in rank to Carnarvon with respect to RE diversity are Allies Creek SF (70 900 ha) and Barakula SF (283 000 ha)(Figure 7.20). In contrast to Carnarvon, Barakula has an elevation range of 300 to 450 m, and an east-west range of 100 km.

Other state forests and timber reserves with high ecosystem diversity include Pluto TR and Kettle, Theodore, Mt Hope, Dawson Range, Expedition, Squire, Coominglah, Bringalily and Blair Athol State Forests.

For their size, Mt Pleasant SF (3440 ha) and Grevillea SF (4000 ha) have outstanding ecosystem diversity with 19 and 17 REs, respectively.

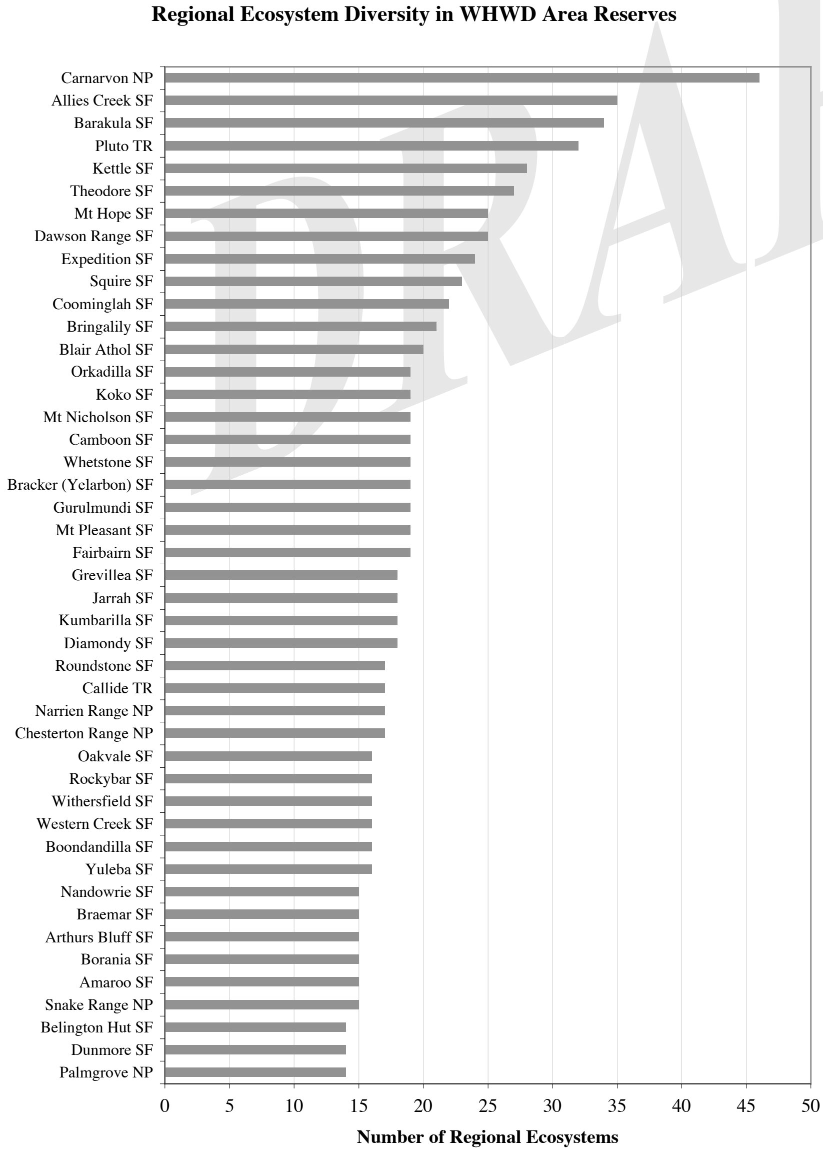


Figure 7.20 Regional Ecosystem diversity in areas of public land in the WHWD Area

7.3.2 Flora values

7.3.2.1 All flora

Figure 7.21 compares the flora species richness of a range of State Forests, Timber Reserves and National Parks. Barakula State Forest (283 000 ha) compares favourably with Carnarvon National Park (298 000 ha). Given the climatic and edaphic differences, it is not surprising that around 400 (55 per cent) of the taxa recorded from Barakula State Forest are not recorded from Carnarvon National Park.

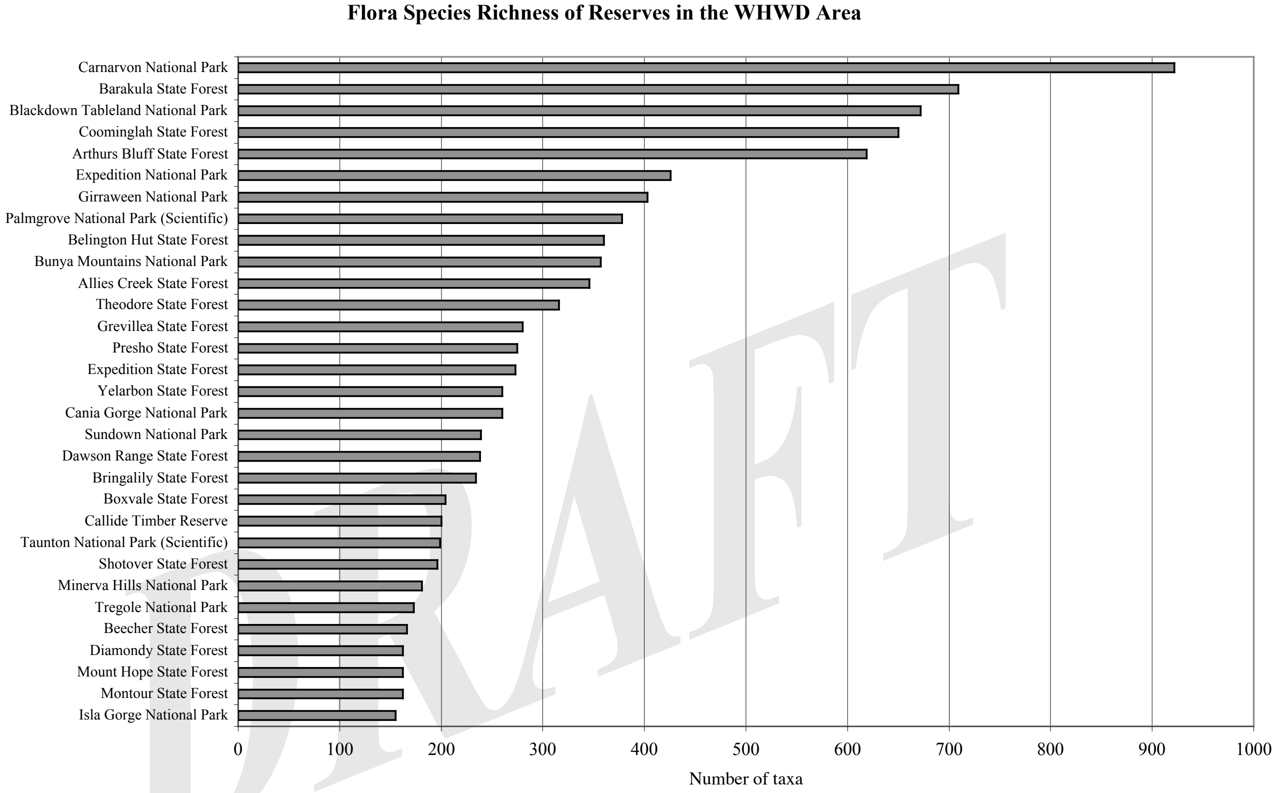


Figure 7.21 Flora species richness in reserves in the WHWD Area

Considering their size compared to Carnarvon and Barakula, Arthurs Bluff (9350 ha) and Coominglah (41 043 ha) State Forests are outstandingly rich in flora with 620 and 650 taxa, respectively. Of particular significance with respect to flora richness is Grevillea State Forest. With an area of just 4000 ha, Grevillea SF is home to 280 taxa, including the largest known population of the highly restricted and endangered *Cossinia australiana* (Plate 23).

Plate 23 *Cossinia australiana*, Grevillea SF

The area extending from the eastern section of Carnarvon Range across Bigge Range has been identified as part of an area of State Significance both as a large core area and for fauna biodiversity (See Sections 3.13 and 7.2.2, and Figures 3.27 and 7.3 to 7.6.). This encompasses Belington Hut, Presho and Theodore State Forests. Belington Hut and Presho State Forests adjoin the eastern boundary of Expedition National Park. The combined flora of Belington Hut and Presho State Forests totals around 500 taxa. Of these taxa, 273 (55 per cent) are not recorded from the adjoining Expedition National Park.

A similar situation applies to Allies Creek and Barakula State Forests. Allies Creek State Forest has records for around 350 taxa, but 120 (34 per cent) of these are not recorded from the adjoining Barakula State Forest.

7.3.2.2 Rare and threatened (EVR) flora

Figure 7.22 compares the flora species richness of a range of State Forests and National Parks with respect to rare and threatened species (EVR Taxa). Again, Carnarvon, Blackdown and Expedition National Parks and Barakula, Arthurs Bluff, Coominglah and Allies Creek State Forests are outstanding.

And again, Grevillea State Forest with nine EVR taxa is particularly significant given its size of just 4000 ha.

Note: Further details on the flora of each State Forest will be included in the final report.

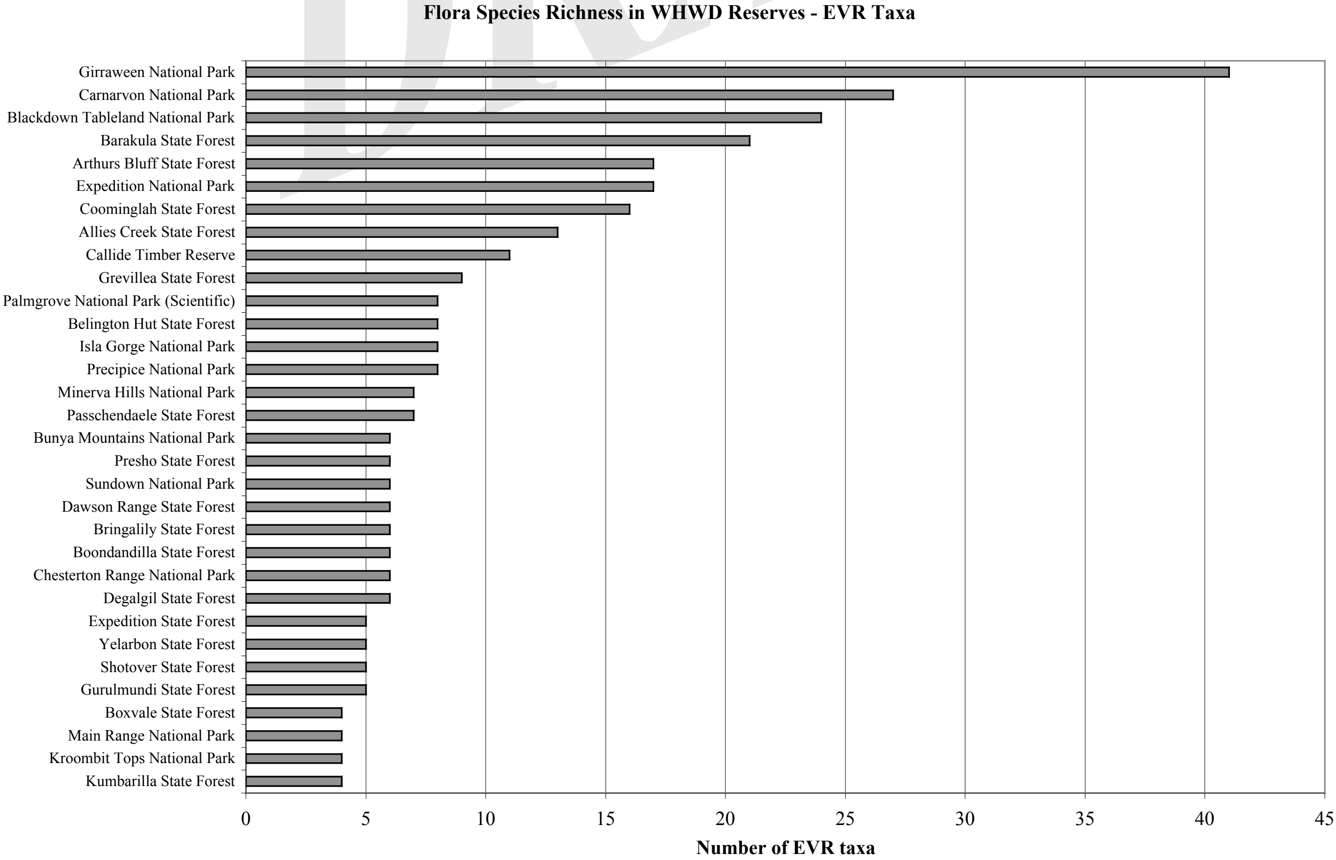


Figure 7.22 EVR species richness in reserves in the WHWD Area

7.3.2.3 Endemic flora

There are 270 flora taxa endemic to the Study Area, of which 104 are rare or threatened. Figure 7.23 compares a range of State Forests, Timber Reserves and National Parks with respect to richness in these endemic flora.

Note: State Forests and Timber Reserves that fall within centres of endemism are identified in Section 7.1.4.

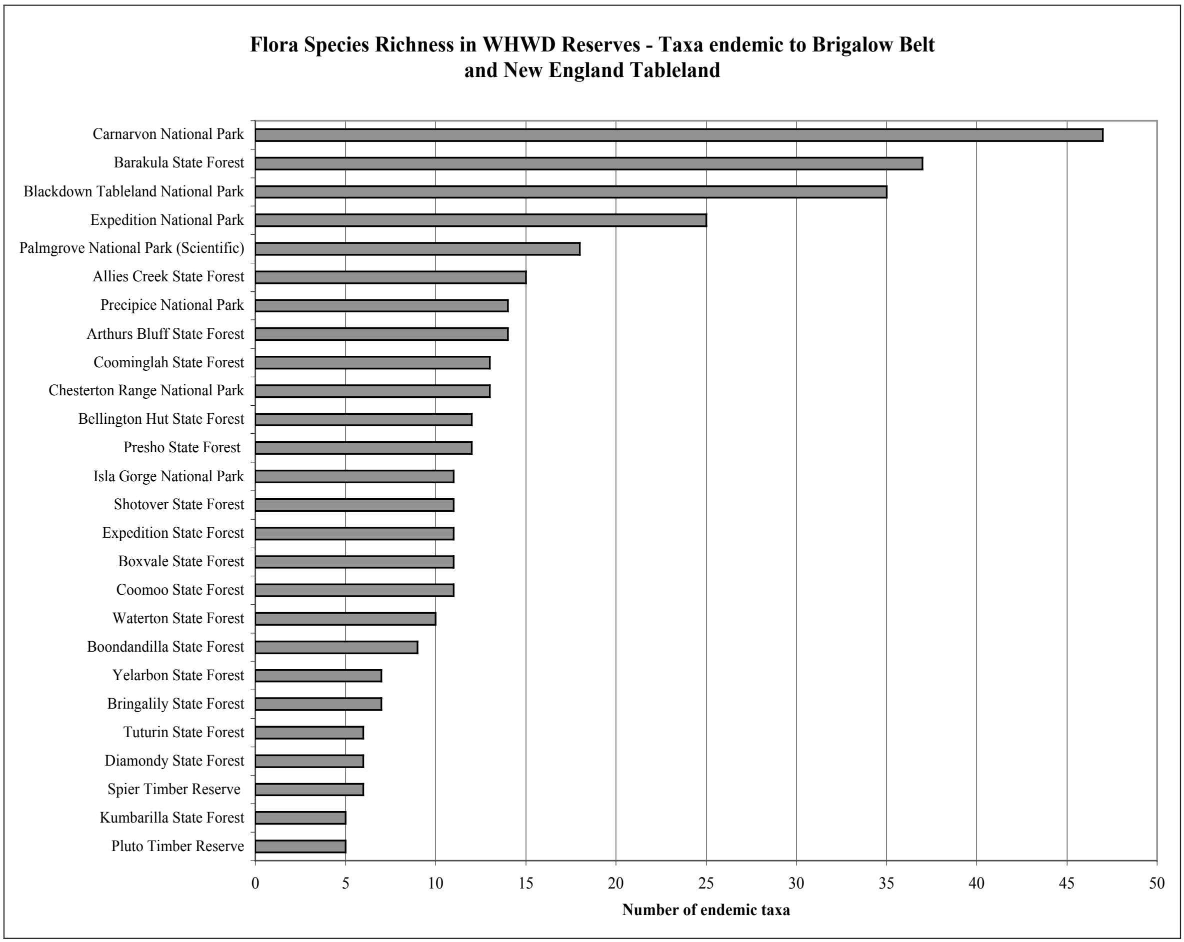


Figure 7.23 Endemic species richness in reserves in the WHWD Area

7.3.2.4 Eucalypt diversity

In the current context, 'eucalypt' includes species of *Eucalyptus*, *Corymbia* and *Angophora*. A total of 171 eucalypt taxa have been recorded from the WHWD Area.

The Brigalow Belt is of major significance for eucalypts (See Section 3.2.1.). This is particularly true at the level of the subgenus.

Of the 13 eucalypt subgenera, 12 are recorded from the WHWD Area. This exceeds the number occurring in every other bioregion in Queensland and every other State in Australia. The Greater Blue Mountains World Heritage Area, which was listed partly for its outstanding eucalypt diversity, has only four subgenera present. The Wet Tropics World Heritage Area has 9 subgenera.

Subgenera containing only one species occupy a very significant place in eucalypt phylogeny. There are six such monotypic subgenera, and four are found in the WHWD Area. Belington Hut, Presho, Expedition, Barakula, Allies Creek, Theodore, Dawson Range and Shotover State Forests have more than or equal to the number of monotypic subgenera in any State of Australia (excluding, obviously, Queensland)(Figure 7.24).

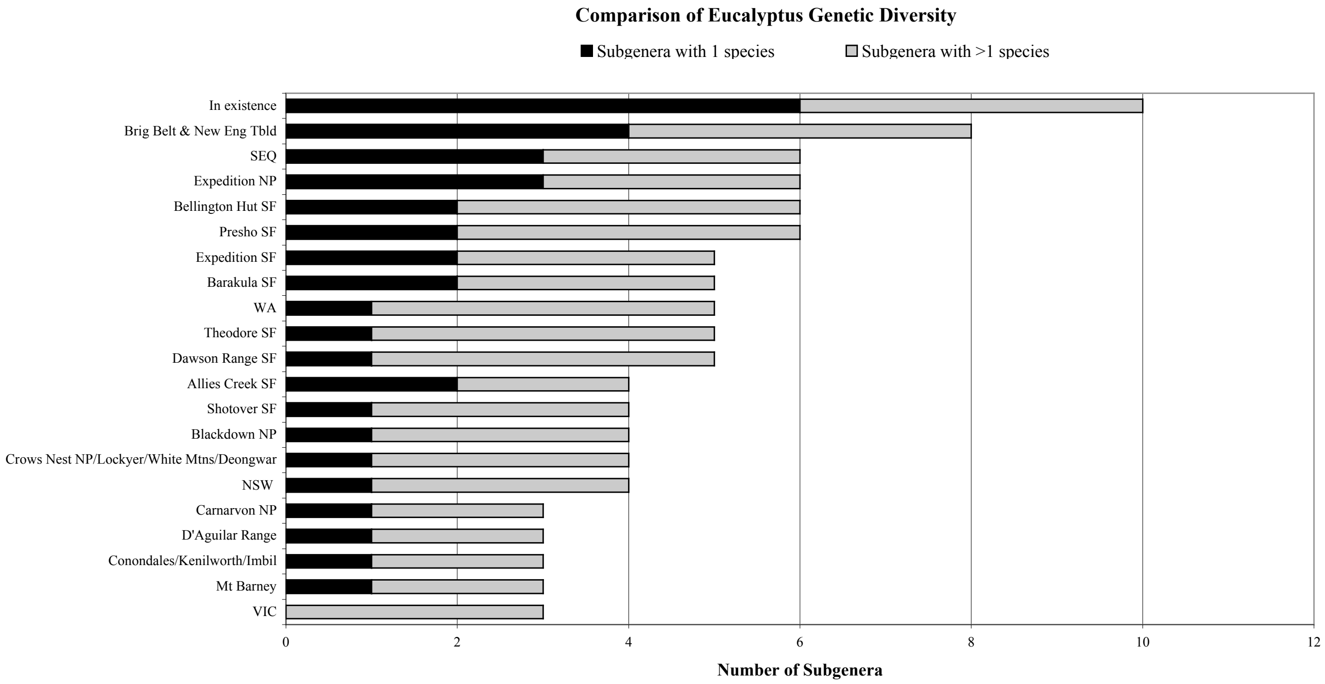


Figure 7.24 *Eucalyptus* genetic diversity within WHWD Area reserves and other regions in Australia

With respect to overall eucalypt species richness, Barakula SF has a higher level than any national park in the WHWD Area or in South-East Queensland (Figure 7.25). Other State Forests with high eucalypt species richness include Bracker (Yelarbon), Belington Hut, Bringalily, Allies Creek, Western Creek, Coominglah, Theodore, Presho, Expedition, Dawson Range, and Shotover.

When the national parks and state forests that form a continuous area of forest from Carnarvon NP to Isla Gorge NP and north to Blackdown Tableland together with Barakula are considered as a unit (1 195 670 ha), the number of eucalypt taxa totals 85. This compares favourably with the Greater Blue Mountains World Heritage Area (1 032 649 ha) which has 90 eucalypt taxa and for which World Heritage listing was based significantly on eucalypt diversity.

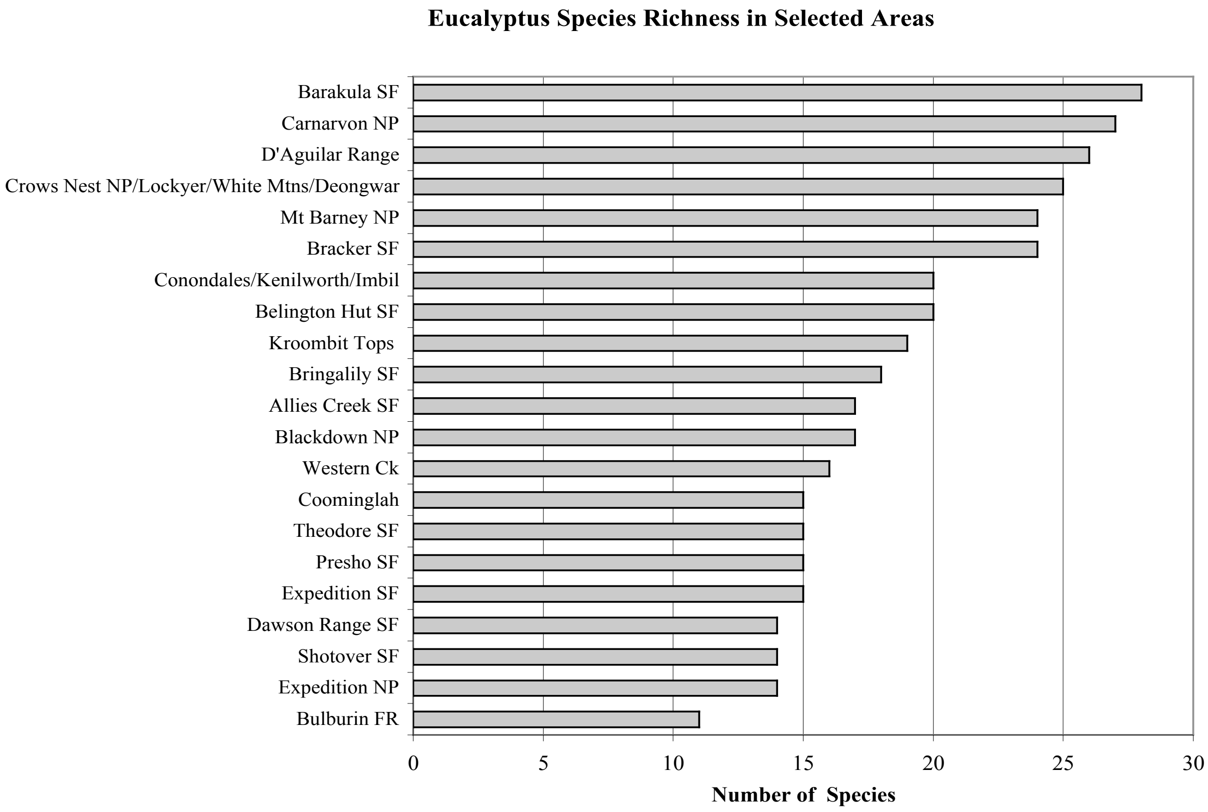


Figure 7.25 *Eucalyptus* species richness within reserves in southern Queensland

7.3.3 Fauna values

7.3.3.1 All fauna

Figure 7.26 compares the total species richness of a range of reserves in the WHWD Area. The comparison significantly reflects survey effort. Lake Broadwater NP has been the subject of regular surveys by local naturalists, partly owing to its close proximity to Dalby. Similarly, Carnarvon and Blackdown Tableland have been intensively surveyed.

Apart from those areas, State Forests with the highest fauna species richness include Barakula, Dawson Range, Whetstone, Coominglah, Durikai, Bracker (Yelarbon) and Belington Hut State Forests.

As noted in Section 7.2.2 and illustrated in Figures 7.3 to 7.6, the Fauna Expert Panel for the Brigalow Belt South Biodiversity Planning Assessment identified the sweep of land from Carnarvon NP through Boxvale SF, Expedition NP, Belington Hut SF, Presho SF, Palmgrove NP, Theodore SF and Isla Gorge NP to Precipice NP as having State Significance for fauna biodiversity.

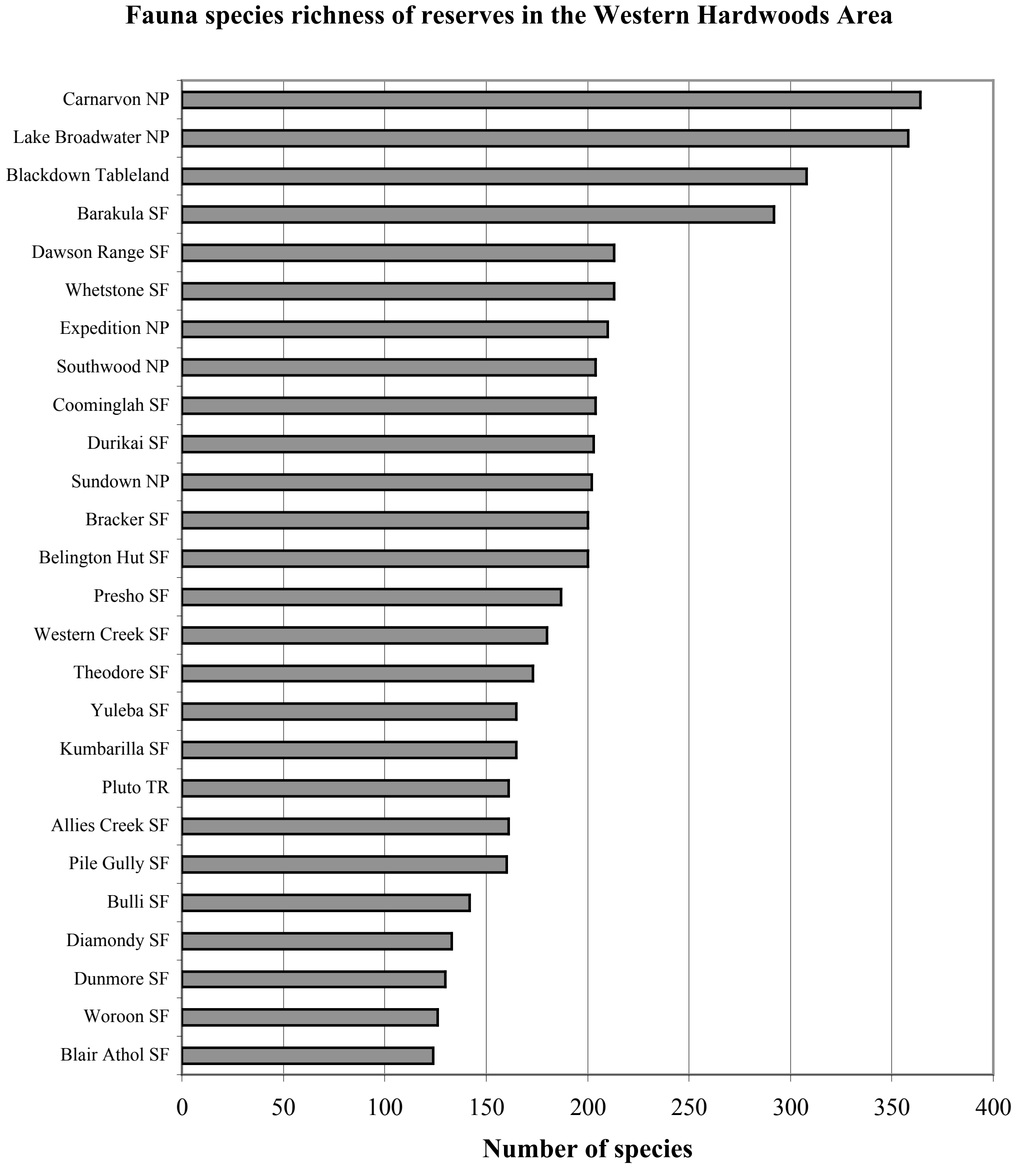


Figure 7.26 Fauna species richness of reserves in the WHWD Area

7.3.3.2 Rare and threatened (EVR) and priority fauna

As in the case of total species richness, Carnarvon, Lake Broadwater and Blackdown Tableland are outstanding with respect to EVR fauna, partly reflecting survey effort.

Barakula, Coominglah, Whetstone, Allies Creek, Presho, Durikai and Bracker State Forests all record significant numbers of EVR and priority species.

Comparative data are illustrated in Figure 7.27.

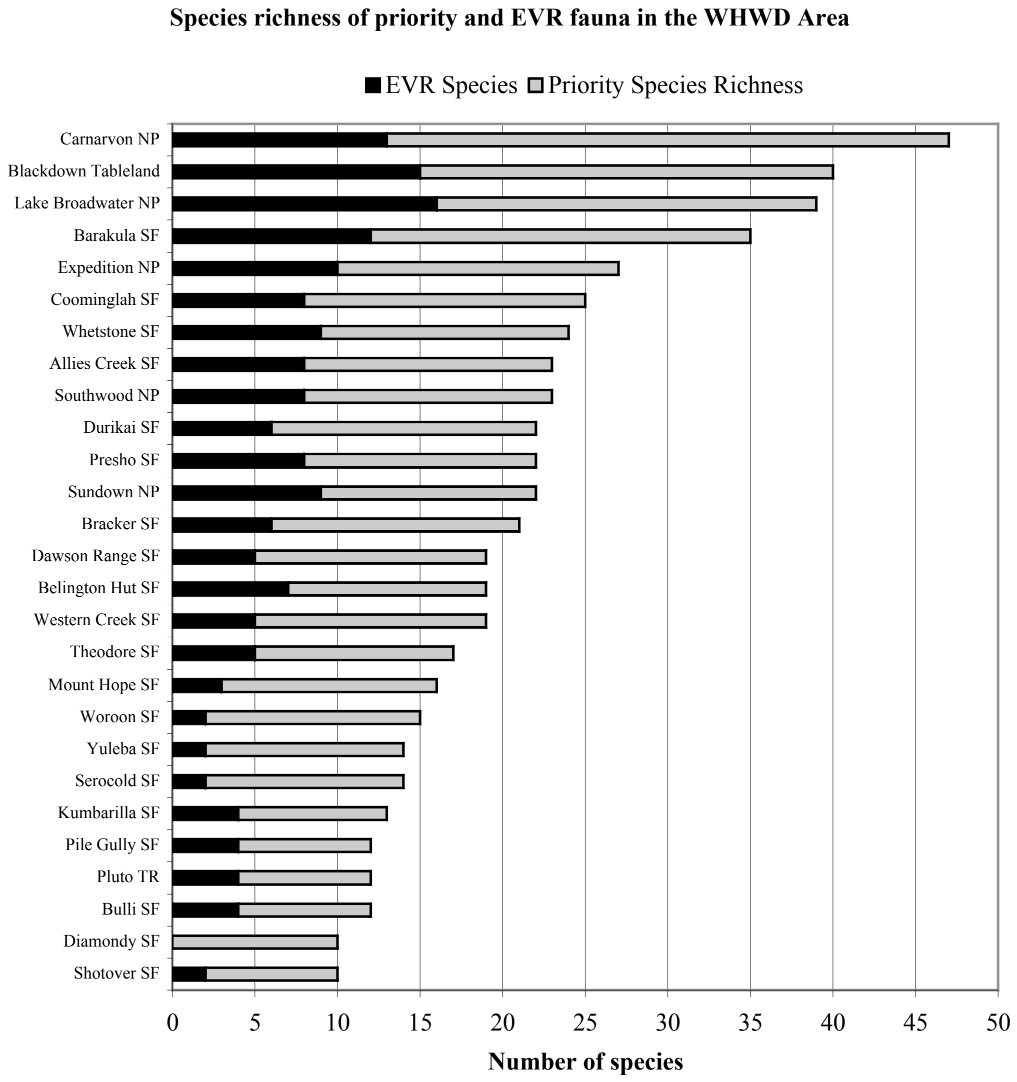


Figure 7.27 Species richness for EVR and priority fauna in reserves in the WHWD Area

With respect to rare and threatened fauna species, a comparison can be made between four major areas — Carnarvon NP, the Bigge Range (Belington Hut, Presho and Theodore State Forests), Barakula–Allies Creek and Inglewood Sandstones. The comparison is shown in Table 7.2.

In these four major areas, there is a total of 23 rare or threatened species of fauna. Carnarvon National Park conserves populations of only 12 (52 per cent) of these species.

Table 7.2 Rare and threatened fauna in four major areas in the WHWD Area (Shaded cell indicates presence of species)

Species	Status	Carnarvon	Bigge Range Arc[1]	Barakula-Allies Creek	Inglewood Sandstones
Tiger Quoll	V	■			
Little Pied Bat	R	■	■	■	■
Large-eared Pied Bat	R		■	■	
Greater Long-eared Bat	R			■	■
Glossy Black-cockatoo	V	■	■	■	■
Black-chinned Honeyeater	R	■	■	■	■
Squatter Pigeon	V	■	■		■
Turquoise Parrot	R	■		■	■
Painted Honeyeater	R	■		■	■
Powerful Owl	V	■		■	
Grey Goshawk	R	■		■	
Square-tailed Kite	R		■	■	■
Black-breasted Button-quail	V			■	
Cotton Pygmy-goose	R				■
Brigalow Scaly-foot	R	■	■	■	■
Golden-tailed Gecko	R	■	■	■	
Anomalopus brevicollis	R	■			
Collared Delma	V		■		■
Yakka Skink	V		■		
Dunmall's Snake	V		■		
Common Death Adder	R				■
Rough Frog	R			■	
Fitzroy Tortoise	V		■		

[1] Bigge Range Arc comprises Belington Hut, Presho and Theodore State Forests

7.3.3.3 Further notes on individual State Forests

Belington Hut-Presho-Theodore State Forests

This area covers about 240 000 hectares and supports the same number of EVR species (12) as the similarly sized Carnarvon NP (298 000 ha) and Barakula SF (285 000 ha). This forest complex is a centre of endemism, supporting disjunct populations of fauna from coastal regions, including *Adelotus brevis* (Tusked Frog), Grey Goshawk and Eastern Whipbird (Environmental Protection Agency 2002b). Investigation of Wildnet records suggest *Eulamprus sokosoma*, Striated Thornbill, White-cheeked Honeyeater and Large-eared Pied Bat (Rare) are also disjunct in this area. One of the most important disjuncts is the Large-eared Pied Bat (Rare), one of the rarest bats in Queensland. There are only 25 records of the species in the whole state, of which 13 are from these forests.

There are fewer roads here than the other large forest complexes, particularly in the western half of Belington Hut SF and the southern part of Presho SF. The presence of extensive road networks in forest landscapes is considered a threatening process (Mackey *et al.* 1998) so this is a significant value. The low number of roads has meant large areas have not been logged and while grazing continues throughout the roadless areas there are fewer opportunities to create artificial watering points to increase grazing pressure in these areas.

It is at the core of the largest unbroken area of suitable habitat for Greater Gliders in Queensland. This contrasts with Carnarvon NP, most of which is unsuitable for the species. The suitability of habitat for Greater Glider means that these forests are also a significant site for Powerful Owls, which rely heavily on large gliders for food. The grassy woodlands of the valleys in these forests are prime habitat for the Squatter Pigeon (southern race), a bioregional endemic subspecies that has now contracted largely to the Carnarvon Ranges Subregion.

Barakula-Allies Creek

Barakula is one of the largest areas of sub-humid woodland in Australia, and is large enough to absorb large-scaled perturbations. Barakula differs from the other large areas in the Carnarvon subregion in that it is low altitude. A diverse mosaic of forest types occurs across the gentle topography, with subtle edaphic variation often resulting in significant changes in eucalypt species composition. Some ridges support old-growth *Eucalyptus fibrosa* subsp. *nubila* woodland. Old-growth ironbark woodland of any description is rare in Australia, with pressures for fencing timber and firewood resulting in the virtual total loss of old-growth ironbark woodland in Victoria and New South Wales (ECC 1997, Date and Paull 2000).

The presence of the Dingo, Bush Stone-curlew and Rufous Bettong indicate a relatively high integrity woodland fauna assemblage, a feature shared with the Carnarvon Ranges Subregion, the Auburn Ranges and Coominglah. However Barakula-Allies Creek also supports a number of significant species not found in the aforementioned areas. These include declining woodland birds such as the Turquoise Parrot (Rare), Hooded Robin and Diamond Firetail.

Barakula is of national interest as a key refuge for the southern Barking Owl, and the size of this forest may ensure that a population of 100 or more birds could persist there. The species is of great concern in Queensland (Environmental Protection Agency 2002b).

Barakula has some the largest intact populations in Australia of the Barking Owl (southern) (Of Concern), *Paradelma orientalis* (Brigalow Scaly-foot) (Vulnerable), Turquoise Parrot (Rare), Glossy Black-cockatoo (Vulnerable), *Strophurus taenicauda* (Golden-tailed Gecko) (Rare), Grey-crowned Babbler (eastern) (Of Concern), Rufous Bettong (Of Concern), Speckled Warbler (Of Concern) and Square-tailed Kite (Rare). The importance of Barakula-Allies Creek is almost certain to increase in coming decades as species disappear from heavily cleared regions where isolated populations are simply too small to persist. Painted Honeyeaters (Rare) were observed in old-growth *Eucalyptus decorticans-Acacia blakei* woodland and nearby in *Eucalyptus crebra* woodland on granite (RE 11.12.1) in Allies Creek SF by ARCS in 2002.

Barakula and Allies Creek include some of the largest remnants of dry rainforest remaining in the region (remnants of the forest of the Cadarga Creek area, once a forest of several thousand hectares now reduced to small fragments). These notably support populations of the Black-breasted Button-quail (Vulnerable). Other specialists such as the Black-faced Monarch, Varied Triller and Rufous Fantail also occur. The 'Auburn River' population of Black-breasted Button-quails occurs in Brigalow vine scrubs and Brigalow and Belah ‘closed forest’ in both Allies Creek and Barakula State Forests. It is one of 14 population groups of Black-breasted Button-quails in Queensland identified by Hamley *et al*. (1997). The area covered by these habitats is small, but their occurrence in a matrix of open eucalypt and cypress forest may allow a greater degree of dispersal than would the cleared landscapes that surround many dry rainforest remnants. This is particularly important in the context of the total population, which still occupies much of its former geographic range but now occurs in a number of isolated populations, many of which are isolated by clearing.

Coominglah

The Red Goshawk (Endangered) was recorded in Coominglah SF in 1994, and a pair is known from the adjacent Cania Gorge NP (3000 ha), but it has been estimated that a pair of Red Goshawks require a range of approximately 20 000 hectares (Garnett and Crowley 2000). Hence Cania Gorge NP is too small to support a single pair so the goshawks may still utilise Coominglah. There is likely to be interchange between these individuals and those on nearby Kroombit Tops NP (30 000 ha) but the whole population is still likely to represent only a few pairs. Other major areas of woodland and forest in the Study Area have no recent records or are not suitable habitat.

A number of rainforest and wet forest species that occur in Coominglah SF have not been found in State Forest further inland. These include Fawn-footed Melomys, Regent Bowerbird, White-eared Monarch, Brown Cuckoo-dove, Little Shrike-thrush, Emerald Dove, Noisy Pitta, Large-billed Scrubwren, *Ctenotus eurydice* and *Lampropholis amiculata*.

A population of the Yellow-bellied Glider (Of Concern) exists in Coominglah SF. Models by Eyre (2002) suggested the minimum patch size for a viable population of Yellow-bellied Gliders in Queensland was 31 600 hectares although the area could be as small as 9750 hectares if all habitat was highly suitable. Coominglah State Forest covers about 40 000 hectares, and is tenuously linked by vegetation to Kroombit Tops in SEQ. Of this area, the glider habitat mapping by Eyre (2002) suggests that less than 4000 hectares of Coominglah is highly suitable habitat, and approximately 15 000 hectares is moderately suitable habitat. The vegetation link to Kroombit Tops is either low quality habitat or unsuitable for the species (and much of the link is severed by the Cania Dam), so there is a high likelihood this population is isolated. Hence it appears likely it is “borderline” whether the Coominglah Yellow-bellied Glider population is viable, and habitat quality is therefore particularly important.

Inglewood Sandstones province

The Bringalily, Bulli, Bracker and Whetstone State Forests together protect habitat for 12 EVR species in an area of 115–120 000 hectares. This area is therefore comparable to Carnarvon NP or Barakula SF for threatened species conservation.

The Inglewood Sandstones is the most important large area of habitat in the Brigalow Belt for declining woodland birds. The Inglewood Sandstones province receives less rainfall than Barakula, Coominglah or the Carnarvon and Expedition Ranges, and the woodlands here are relatively dry and open. Relatively open habitats are favoured by a number of woodland bird species that are absent or uncommon in Spotted Gum-Ironbark forests, such as the Crested Bellbird (nominate race, nationally Near Threatened), Hooded Robin (south-eastern race, Of Concern) and Brown Treecreeper (south-eastern race, Of Concern). The Inglewood Sandstones are also home to a disproportionate percentage of the Study Area’s populations of woodland birds such as the Speckled Warbler (Of Concern), Southern Whiteface, Red-capped Robin, Turquoise Parrot (Rare), Painted Button-quail and Diamond Firetail (Of Concern). Reid (1999; 2000) identified 24 woodland species as being in decline in NSW. All of these extend into Queensland where it is presumed they are subject to many of the same pressures (indeed six were listed as ‘Of Concern’ in Brigalow Belt South by the fauna expert panel (Environmental Protection Agency 2002b) and the Black-chinned Honeyeater is listed as Rare). Of the 24 species listed by Reid (2000), 20 are known to occur in Bracker SF, the highest number for any State Forest or reserve in Queensland (the much larger Carnarvon NP also has 20 species).

Significantly, the Inglewood Sandstones woodlands are now the Queensland stronghold for three taxa (Crested Bellbird (nominate race, nationally Near Threatened), Diamond Firetail (Of Concern) and Hooded Robin (south-eastern) (Of Concern)) that are known to have contracted considerably within the Study Area. These three taxa are now largely found in this province and the relatively fragmented New England Tableland bioregion. An area of *Eucalyptus crebra-Triodia vella* woodland (P. Grimshaw *pers. comm.*) in Bracker SF supports the most easterly Crested Bellbird population in Queensland.

This province also supports important habitat for a number of reptiles that are either absent or localized elsewhere in the Study Area. The Inglewood Sandstones is a potential refuge for declining species of the fertile ‘downs’ areas, offering relatively well-connected lowland grassy woodland for species. For example, there are only 14 records of the lowland specialist *Pseudechis guttatus* (Spotted Black Snake) (Of Concern) on public land in South-East Queensland and the Brigalow Belt combined. Of these, seven records are from the Inglewood Sandstones province. Most other records are in the fragmented Darling Downs and the Lockyer Valley, where it has declined (Environmental Protection Agency 2002b). Other terrestrial reptiles also have strongholds in the Inglewood Sandstones, including *Paradelma orientalis* (Brigalow Scaly-foot) (Vulnerable) and *Acanthophis antarcticus* (Common Death Adder) (Rare), both of which have been recorded more frequently in Whetstone State Forest than in any other State Forest or reserve in the Brigalow Belt.

7.3.3.4 Yellow-bellied Glider Habitat

Modelled habitat for Yellow-bellied Glider was discussed in Section 7.2.3 and illustrated in Figure 7.7. Several State Forests are of major significance for this species. Figure 7.28 shows the area of high- and moderate-quality habitat in a number of State Forests.

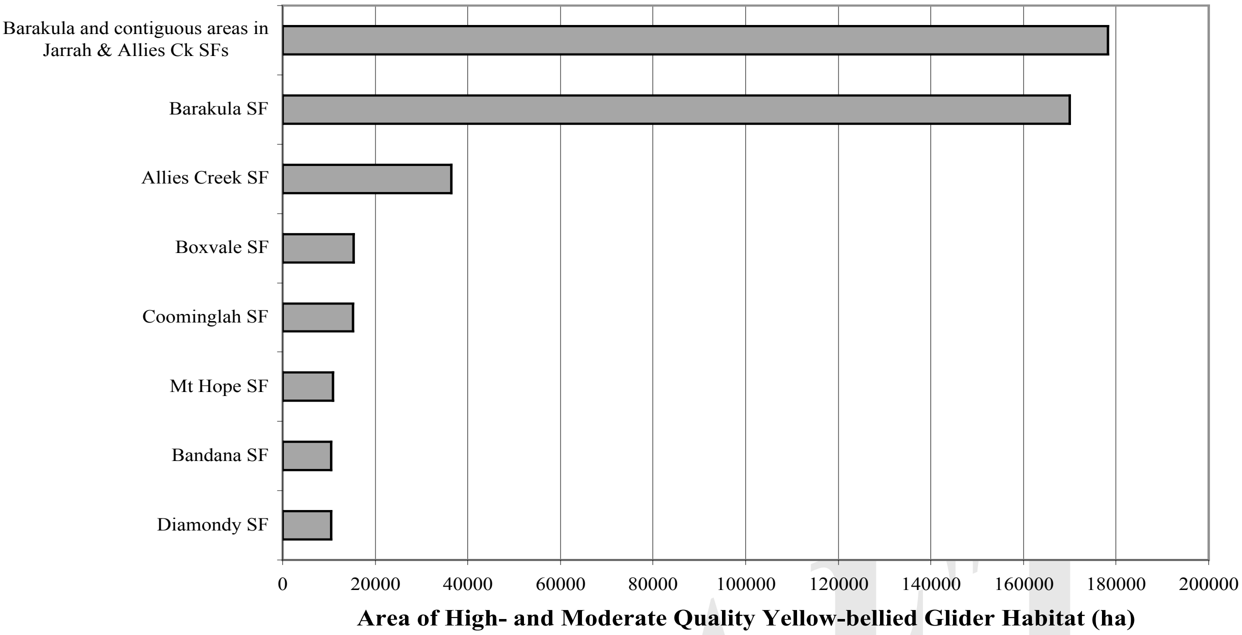


Figure 7.28 High- and moderate-quality Yellow-bellied Glider habitat in selected State Forests in the WHWD Area. Data from Eyre (2002)

Of outstanding significance are the contiguous areas of Barakula, Jarrah and Allies Creek State Forests. Whereas Mt Hope and Bandana State Forests have relatively small, though significant, areas of habitat, they contribute to a much larger area incorporating parts of Boxvale State Forest and Carnarvon National Park and a major area of leasehold land.

7.3.4 Wilderness

As noted in Section 3.13, the majority of the area indicated by National Wilderness Inventory data as being wilderness in the WHWD Area is in State Forests. Table 7.3 lists the area of wilderness in a number of reserves in the WHWD Area.

Table 7.3 Area of wilderness in National Park and State Forest in the WHWD Area

Reserve	Area of Wilderness (ha)
Carnarvon NP	215 500
Expedition NP	97 200
Belington Hut SF	75 400
Expedition SF	62 500
Blackdown Tableland NP & FR	50 000
Presho SF	48 200
Dawson Range SF	39 200
Oakvale SF	31 300
Palmgrove NP	24 600
Shotover SF	17 800

The largely continuous area of wilderness in the central part of the WHWD Area, extending over nearly 600 000 ha, includes Theodore, Presho. Belington Hut, Mt Nicholson, Expedition, Shotover, Arthurs Bluff and Dawson Range State Forests.

7.4 Leasehold land

In a number of sections of this report, the conservation values of various areas of leasehold land have been noted. These areas are listed in Table 7.4.

Table 7.4 Leasehold land of high conservation value in the WHWD Area

Area	Conservation values	Section of this report
Beeron Holding	Major centre of endemism; high concentration of rare and threatened plants, including species of outstanding scientific significance	3.5.1.7
Land adjoining Carnarvon NP to the south and north, extending to and around Mt Hope SF	Fauna expert panel, area of State Significance for fauna; High-quality habitat for Yellow-bellied Glider	3.3 and 3.4 Figure 3.3
Land linking Expedition NP and Mt Nicholson SF	Fauna expert panel, area of State Significance for fauna; Moderate-quality habitat for Yellow-bellied Glider and high-quality habitat for Greater Glider	3.3 and 3.4 Figure 3.3
Land adjoining Belington Hut, Presho and Theodore State Forests	Fauna expert panel, area of State Significance for fauna;	3.3 and 3.4 Figure 3.5
Land linking Isla Gorge and Precipice National Parks and extending south-eastwards from Precipice NP	Fauna expert panel, area of State Significance for fauna;	3.3 and 3.4 Figure 3.5
Mantuan Downs	Major remnants of brigalow; adjoins Carnarvon NP	2.2.1.1
Leasehold land centred around Mitchell	Major remnants of brigalow	2.2.1.1

8 Reserve Design and Selection Principles

8.1 Approaches to Reserve requirements and Reserve Design.

8.1.1 General

Reserves are specifically devised to minimise loss of biodiversity or extinction risk (Crozier 1997, Gaston *et al*. 2002) but approaches differ vastly in their explicit goals, underpinning value systems (paradigms) and likely effectiveness.

The existing level of reservation in the Western Hardwoods Area (1.97 per cent) is less than half the State's average and less than 30 per cent of the national average. Eighty-three per cent of all regional ecosystems have less than two per cent of pre-clearing areas in conservation reserves. Only seven per cent of regional ecosystems meet minimal JANIS reservation targets. Diversity of vascular plants, and vertebrate fauna on the other hand is high, comparable with that found in the World Heritage listed areas of the Wet Tropics and Central Eastern Rainforest Reserves of Australia. Threats to biodiversity, on the other hand are high. Twenty one million hectares of vegetation in the Brigalow Belt have been cleared, 14 million hectares of which has been in Brigalow Belt South (67 per cent of the bioregion). This is among the highest levels of land clearing in the 85 bioregions of Australia (National Land and Water Resources Audit 2001).

In reality there has always been and still is great pressure to commit only minimal and remote, inaccessible or unproductive areas to conservation reserves (Saxon and Tracey 1988, Pressey *et al.* 1996, Margules and Pressey 2000, Neel and Cummings 2003). Attention in the past has largely been directed to short-term crisis reservation of threatened species and communities (Hopper 2000) or small-scale sampling of otherwise healthy patches, biodiversity 'hotspots' or 'beautiful and untouched' areas identified within a static temporal framework. The best and most representative areas are selected 'efficiently' or otherwise to include in showcase reserves. The net result has been a collection of mostly small, isolated protected areas biased to those elements most likely to go extinct. The presence of high numbers of threatened species is even translated into an intrinsic conservation 'value' rather than a management imperative, with 'value' ratings in Multi Criteria Analysis models scaled in proportion to 'richness' of threatened species.

Most reserve selection models today (Margules and Nicholls 1987, Margules *et al.* 1987, Austin *et al.* 1996, Gaston *et al.* 2002) are still based on minimum-set algorithms or complementarity approaches to 'representative' sampling of patterns of biological variation in the least possible area. Whilst some use average bioclimatic parameters to predict abundance or distribution of particular species, they ignore phylogenetic relationships and genetic variability at the population level. They all inadequately deal with the number or persistence of populations within species or numbers of individuals within populations or genetic structure between populations, even though reduced variability putatively reduces a species' potential to evolve and increases its extinction risk. Even if a minimum area approach is accepted, there is a general tendency to subvert conservation objectives by reserving the least productive and least threatened landscapes thus misleading the public about the adequacy of even these limited initiatives (Soulé and Sanjayan 1998). At the same time as demands are made for maximum efficiency in reserve selection algorithms, much natural resource use continues to be wasteful, inefficient and unsustainable, responsible for escalating land degradation and lowered productivity, 'locking up' ever-increasing areas for the exclusive ‘terminal’ use of present generations, thereby foreclosing options for future generations.

With respect to the major issue of vegetation clearing, the Queensland Government has recently introduced new legislation. Even though broadscale land clearing of remnant vegetation will be halted in Queensland within two years, some clearing of regrowth areas can continue and a major proportion of remnant vegetation designated as ‘not of concern’ will continue to be fragmented and modified until eventually the broad spectrum of biological diversity, other than generalists and weedy species, reaches extinction thresholds.

Ironically, failure to achieve the broader goals of maintaining persistence and evolutionary capacity of biodiversity by placing a higher priority on natural resource extraction or utilization over protection, or a low priority on allocation of public funding to expansion of reserves, could be putting at risk the health and welfare of future generations (Ehrlich 2001). The Queensland Government’s current Biodiversity Policy Framework (2003) recognizes Queensland’s biodiversity underpins industries of critical significance to our economy (agriculture, forestry, ecotourism, bioprospecting, biotechnology). Bioprospecting, and the native floriculture industry in Queensland especially, rest on biodiversity as the source of novel products. The expected foregone annual loss of sales value to the United States alone when plants become extinct before any chance of assay has been estimated at US $3.5 billion (Principe 1995, Crozier 1997). Eucalypts are exploited worldwide for fibre (Eldridge *et al*. 1993), phytochemicals including medicinal and industrial chemical products (Boland *et al.* 1991) and floriculture. Acacias likewise are globally exploited for food, fodder, fibre, resins, flowers, foliage and medicines (Orchard and Wilson 1999, Midgley and Turnbull 2003). Natural populations are the reservoir of base genetic material for all plantation and domestication programmes (Eldridge *et al.* 1993, Brown and Brubaker 2000). Conservation of this reservoir will depend upon understanding the patterns and distribution of genetic variation, breeding systems, the impact of inbreeding, gene flow and the nature of selective forces acting upon populations (Moran and Hopper 1987, Hopper and Coates 1990, Hopper 1993, Brown and Brubaker 2000, MORE). Recent studies in Western Australia have recognised the potential importance of some native *Acacia* species for biological control of *Phytophthora cinnamomi*, a root pathogen with enormous destructive impacts on horticultural industries and native plant communities worldwide (D’Souza *et al.* 2004).

Escalation in costs of management of small, isolated reserves within the current interventionist paradigm of *control* of current human pressures and the ongoing cumulative impacts of past fragmentation and modification, also continue to be used as an argument against new reserves. However, these costs can be reduced substantially if instead the focus changes to large, connected reserves and the *facilitation* of natural ecosystem and population processes and dynamics (ecosystem services) to deliver the long-term goal of restoration to healthy, viable and evolving natural landscapes encompassing as much of Queensland’s biodiversity as feasibly achievable.

8.2 Reserve selection and design for persistence and maintenance of evolutionary capacity

8.2.1 Reserve selection: capturing patterns of variation

8.2.1.1 General

The ultimate aim of conservation broadly and reserve selection in particular is ensuring the persistence and evolutionary capacity of biodiversity at all levels of organisation from genes to landscapes (Frankel and Soule 1981, Harrison et al. 1984, Barrett and Kohn 1991, Holsinger and Gottlieb 1991, Elstrand and Elam 1993, Falk 1992, Newman and Pilson 1997, Hogbin *et al.* 2000).

A comprehensive concept of biodiversity encompasses all hierarchical levels: (1) variation among and within ecosystems across landscapes, (2) variation among and within species of a given ecosystem, and (3) genetic variability within species (analysing populations, individuals or genes). Capturing one type of diversity does not necessarily capture other types (Neel and Cummings 2003) and the capturing of any or all level(s) of biodiversity alone does not ensure persistence or ongoing evolution. An understanding of both spatial patterns of biodiversity and evolutionary and ecological processes at multiple temporal and spatial scales is essential for ensuring viability and evolutionary capacity.

Given the WHWD Area contains 41 subregions, 10 land zones, 365 regional ecosystems (including subunits), 5100 native vascular plant taxa (61per cent of the State total), 111 (47 per cent) mammals, 384 (62 per cent) species of birds, 178 (40 per cent) reptiles, and 49 (41 per cent) frog species, the challenge to adequately and viably conserve ecosystems, species and genetic variation across their respective geographic ranges becomes an enormous challenge.

All reserve selection procedures variously use surrogates or partial measures of elements of biodiversity. Much debate exists on the pertinence and meaning of terms such as “surrogate” or “umbrella”. All have inadequacies, but the term “surrogate” is both defined as “a substitute” and mostly used as such in practice, with no scientific substantiation of its relevance to stated goals or to the ultimate aim of safeguarding the persistence and evolution of life. The paradigm underlying choices (regardless of how many measures are used) is rarely but should always be explicitly stated by proponents or practitioners. Two basic extreme paradigms involve (1) “playing god” to pick winners and losers because “we can’t afford to save it all”, and (2) “saving it all” because we can’t afford not to (Wilson 1984). The former places the onus of ‘efficiency’ on conservation reserves whereas the latter also places an emphasis on areas for human use to reduce the human ecological ‘footprint’ — doing more with less land.

Paradigm 2 includes consideration of direct economic and opportunity costs. Present and future agricultural systems will be unsustainable unless genetic resources are preserved in situ to (a) maintain productivity and pest and disease resistance in domesticated “stocks”, (b) deliver new crop species for changed climate conditions (c) drive product innovation in industries such as floriculture where product life cycles are relatively short or dynamic, or such as the pharmaceutical industry where drug design must outpace resistance to infectious diseases, and (d) support remediation of degraded lands (Bhatia *et al.* 2002). For example, the genetic information contained in a rare provenance of *Eucalyptus camaldulensis* from

Lake Abacutya in Victoria with exceptional salt tolerance may be important in arresting dryland salinity predicted to affect 25 per cent of Australia's agricultural land within the next 35 years at costs close to a billion dollars annually in lost production and $840 million in damaged infrastructure and lost environmental assets. Edaphically adapted species such as those restricted to serpentinite soils may play significant roles in remediation of toxic sites and removal of toxic metal contamination (Bhatia *et al.* 2002).

An intermediate paradigm makes on/off-reserve allocations on the basis of relative extinction risk but equally suffers from an inability to comprehensively quantitate this risk other than for a small number of select species.

The level of biological organization focussed on in reserve selection criteria will have a major bearing on outcomes. The following considers various approaches and their intrinsic limitations.

8.2.1.2 Ecosystem level

Whilst persistence and evolution of species are dependent on health and integrity of ecosystems, it is unlikely that coarsely defined and delineated filters such as vegetation communities can be used principally either as reserve selection tools or to test the effectiveness of reserve options in comprehensively capturing biodiversity. However, the cornerstone of the State's biodiversity strategy has been based on regional ecosystems across bioregions as surrogates for biodiversity — the "80/5 rule"— which aspires to represent 80 per cent of the state's regional ecosystems in five per cent of its landmass: "By conserving the ecosystems and their essential ecosystem processes, most of the diversity of plants and animals can also be protected" (Environmental Protection Agency 2001).

National parks are purported to currently protect about 70 per cent of the state's regional ecosystems across 13 bioregions or broad "landscapes", the aim being to increase representation to eighty per cent (Environmental Protection Agency 2001: Section 1.1: p. 18), the estimated maximum possible without major compulsory land acquisitions (Environmental Protection Agency 2001: p.17). The above parameter of regional ecosystem representation within national parks is used in the Government's annual report "Priorities in Progress", as its primary index for monitoring progress on one of its five key policy priorities, "valuing the environment". The implication is that the State has achieved close to 90 per cent of its target.

Yet, in the Brigalow Belt and New England Tableland (an area of 36.5 million hectares representing almost 21 per cent of the State's land area), 39 per cent of regional ecosystems have no representation, and a further 40 per cent have less than one per cent of their pre-clearing area within conservation reserves.

The extent to which biodiversity is capable of being captured through selective representation of regional ecosystems defined primarily by dominant canopy species, quite apart from issues of viability, is clearly critically dependent upon the sample size and distribution. Many of the regional ecosystems in the Brigalow Belt, as currently prescribed, are very large. Nine woodland types, each between 0.5 and 2.0 million hectares in original extent, collectively represented 20 per cent of the bioregion and are assessed as "not of concern" (Environmental Protection Agency 2003b). Because of the sheer size of the Brigalow Belt bioregion spanning 1150 km north to south, annual mean temperature differences can exceed 10°C, and mean annual rainfall gradients range from 800 mm to 350 mm. Within a single regional ecosystem, significant geographic variation can occur within the flora of the lower strata, even where those strata are dominated by species with wide ecological amplitudes. Refinements in classification of regional ecosystems to better reflect actual geographic variability based on a broader complement of species other than canopy dominants will have a significant impact on sampling strategies adopted for reserve selection (See Section 2.2.2.). The problem of using widespread regional ecosystems as surrogates for biodiversity is compounded further by the failure to attribute an appropriate conservation status to recognised subunits. (A significant number of regional ecosystems are divided into subunits.) All subunits currently retain the biodiversity status (NCA) of the parent regional ecosystem regardless of species differences, range-restrictedness of component species or degree of threat through depletion, fragmentation, isolation, or other impacting processes.

To illustrate the problem, whilst overall almost 60 per cent of the vegetation in the Brigalow Belt and New England Tableland has been cleared, the 41 subregions have been disproportionately affected. Those most heavily impacted include Dulacca Downs (16 per cent remnant vegetation remaining) Eastern Darling Downs (15 per cent), Dawson River Downs (10 per cent), Callide Creek (10 per cent), Tara Downs (7 per cent), and Taroom Downs (7 per cent). Even such percentages camouflage the impacts of fragmentation. The Eastern Darling Downs Subregion, for example, covering an area of 1.7 million hectares (thus larger than many entire bioregions including the Wet Tropics and Central Queensland Coast), retains 251 233 ha of remnant vegetation. However, the two largest extant remnants comprise only 10 848 ha in Nudley SF and 14 378 ha in Diamondy SF. The remaining 226 000 ha are distributed in variously spaced fragments significantly smaller than 10 000 ha. Analogous treatment should urgently be afforded suitably resolved subunits of regional ecosystems as given to infraspecific taxons of animals and plants which are recognized and attributed their own conservation status.

Ecosystem processes are likely to have been significantly disrupted in such fragmented environments. No records have been reported in the Eastern Darling Downs subregion over the last 10 to 30 years for a range of fauna species with habitat requirements above 10 000–14 000 ha to support minimum viable population sizes, such as Barking Owl (OC), Diamond Firetail (OC), Glossy Black-Cockatoo (V), Hooded Robin (OC), Brown Treecreeper (OC), Turquoise Parrot (R), and Black-chinned Honeyeater (R). Whilst the Yellow-bellied Glider (OC) has been recently recorded in Diamondy SF, the population is unlikely to be viable. On the other hand viable populations of Golden-tailed Gecko (R), Rufous Bettong (OC) and Squirrel Glider (OC) in the subregion will now be restricted only to either Nudley or Diamondy State Forests.

A major component of Nudley and Diamondy State Forests is RE11.10.1 (Biodiversity Status “not of concern”). This previously totalled one million hectares, and ranged over 800 km north–south and 500 km east–west. Ordination and cluster analysis of CORVEG sites within this regional ecosystem (Section 2.2.2) indicates considerable complexity across its geographic range. Given the known higher levels of genetic diversity associated with wide-ranging species and increasing genetic differentiation between populations increasing with distance (ref), some subdivision of regional ecosystems such as this at a subregional level would be warranted.

In summary, no scientific studies have yet been published that validate the use of regional ecosystems as a primary or sufficient surrogate for biodiversity, especially since they are defined primarily on the basis of the dominant canopy components, not understorey species.

The majority of range-restricted vascular plant species and more than 90 per cent of those that are rare and/or threatened in the Brigalow Belt and New England Tableland bioregions occur in the shrub or ground layers. Thus no “presence/absence” or minimalist measure of representation of regional ecosystems within the reserve system can seriously hope to ensure the persistence or even representation of most species in the WHWD Area.

In general, reserve selection protocols for any wide-ranging vegetation communities/ecosystems should take into account ordination and cluster analyses of species-site data that warrants further differentiation of regional ecosystems into subunits, which, if extensively depleted or modified within parts of their range, should be afforded a biodiversity status that specifically reflects their state of integrity not that of the parent regional ecosystem.

Whilst vegetation communities can be helpful in interpreting patterns of variation at a broad scale, they obviously should not be the primary or sole determinant of reserve requirements. Quite apart from being too coarse to reflect variation in composition, they represent a static descriptor of dynamic associations changing over a range of temporal and spatial scales. They represent a snapshot in time of random and non-random species associations resulting from climatic, edaphic fluxes. The vegetation communities that exist today are very different from those that existed in even the past few thousand years, and will differ from those in the next. It is the persistence and capacity of biodiversity to evolve that is the prime objective of conservation.

Thus community level assessments need to be supplemented with consideration of all other levels of biological organization and function in order to better understand reserve requirements.

8.2.1.3 Species level

Species have traditionally been the prime focus of conservation activity, especially the most threatened, specialized, rare or range-restricted, because they are the most recognisable (scientifically and socially) and, until recently, quantifiable units of biodiversity. Whilst the typological species concept (invariable in space and time) is generally recognised as outdated and flawed, the biological species concept (actually or potentially interbreeding natural populations) is also limited because it ignores (a) asexual reproduction that maintains genetic variability in populations through apomixis, (b) variation in degrees of interbreeding that make it difficult to objectively distinguish definitional thresholds between species, and (c) the difficulties of observing interbreeding in nature between geographically separated groups, and that even if such groups can breed in artificial conditions they may not do so in the wild.

In the absence of direct evidence for non-interbreeding, and despite the growing evidence of inconsistencies between morphological and molecular systematics and phylogenies (Byrne 1999, Coates 2000, Hopper 2000, Pharmawati *et al.* 2004), the morphological species concept dominates many reserve selection schemes. This places additional limitations based both on (a) differences in the degree to which different systematists have split or ranked ‘species’ and (b) the critical deficit in taxonomists so that some plant and animal groups are bedevilled by a lack of comprehensive analysis.

Taxonomy is not an irrelevant abstraction but the essential foundations of conservation as illustrated by the classic example of the New Zealand tuatara (*Sphenodon*), the only surviving genus of an entire order of reptiles. Not until the perceived wide ranging monotype was recognised as comprising two geographically restricted species was there sufficient incentive to protect further loss of populations (Daugherty *et al.* 1990). Extra reference re plants. Within the Asteraceae, the potential existed for elimination of native fireweed (*Senecio* species, including members of the *S. lautus* complex occurring in the Brigalow Belt) through ill-advised introduction of biological control agents from Madagascar against the introduced weed, *Senecio madagascariensis*, and was largely avoided through molecular studies of the genetic relationships between and geographic origins of closely related *Senecio* species (Radford et al. 2000).

Despite the relatively intense historical focus on *Acacia*, the most speciose of Australian genera (Maslin 2001), 80 (37 per cent) of the 217 species occurring in the Brigalow Belt are referred to as geographically variable, some extremely, with many identified as specifically in need of further taxonomic work (Flora of Australia 2001). On the basis of variable performances of provenances in plantation trials, McDonald and Maslin (2000) recently split *Acacia aulacocarpa* into five new taxa. The work also illustrates the vital importance of taxonomy in species/provenance selection processes for plantation establishment or reforestation that can mean the difference between economic success and failure.

Notwithstanding inadequate taxonomic resolution of species ‘complexes’, floras rich in species present computational difficulties that have spawned a number of approaches that either prioritise species or aggregate them into super groups or measures.

Further aggregated measures include species diversity or richness, or higher-taxon richness (e.g. families or genera), or partial measures using indicator groups of species where one group of organisms is used to estimate the biodiversity of unstudied groups.

The other approach is to prioritise species in terms of proneness to local or total extinction followed by an aggregation of geographically restricted, rare, endemic or threatened species into “hot spots” on the basis of comparative analysis using grid-based matrices or other planning units.

These aggregation approaches generally treat all species as having equal value, are crucially affected by scale, and do not always rigorously substantiate the validity of underlying assumptions. Again, whilst being a useful adjunct tool for conservation of extant species diversity they do not necessarily address the needs of future biodiversity.

Phylogenetic approaches can better reflect the evolutionary potential of species (Erwin 1991) and allow focus on areas with sets of species that represent as much ‘evolutionary history’ as possible (May 1990, Linder 1991, Vane-Wright *et al.* 1991, Krajewski 1991, Williams *et al.* 1991, Faith 1992, 1996, Nee and May 1997, Mooers and Heard 1997, McKinney 1998, Vazqiez amd Gittlemam 1998)

In some of these approaches species represented within phylogenetic trees are weighted for phylogenetic distinctiveness according to their evolutionary history, with basal ‘monotypic’ taxa weighted more heavily than ‘terminal’ taxa (Vane-Wright *et al.* 1991). Erwin (1991) on the other hand favours the more rapidly evolving clades as representing greater evolutionary potential. Others prioritise taxa with the greatest character combinations (Faith 1992, Humphries *et al.* 1995) with character richness replacing species richness as a concept. A range of different algorithms has been developed to guide reserve selection for prioritising or maximizing the number of clades (evolutionary lineages) protected where the emphasis is on uniqueness or diversity of clades rather than species. Whatever the emphasis, cladistic phylogenetic assessments provide the best opportunity for including evolutionary information in reserve selection procedures (Crandall *et al.* 2000).

The cautionary results of these types of studies are that areas of species endemism and phylogenetic diversity are not necessarily overlapping. Phylogenetic relicts and neo-endemics may have vastly different geographical patterns contrary to intuition or prevalent theories, and both palaeo- and neo-endemics can be clustered and restricted to the same areas (Fjeldsa and Lovett 1997, Byrne *et al.* 2001).

The nationally agreed criteria developed for implementation of the National Forest Policy (1992) identified categories of species that need to be individually addressed in reserve selection protocols: threatened, rare, declining, migratory, specialized (e.g. dependent on old-growth forest), phylogenetically distinct, bioregionally endemic or more narrowly range-restricted, disjunct, indicators of broad groupings of species, or those that are functionally, economically or culturally important (JANIS 1996).

8.2.1.4 Importance of genetic diversity

Most scientific approaches to reserve selection and design still focus on the conveniently recognisable species level (Crozier 1992, Humphries *et al.* 1995, Pharo *et al.* 1998) or on communities and ecosystems despite recognition of the importance of intra-specific taxonomic and genetic variation to the persistence and ongoing evolution of species (Prober and Brown 1994, Richter *et al.* 1994, McCue *et al.* 1996, Ledig *et al.* 1997, Palacios and Gonzales-Candelas 1997, Brown *et al*. 1997, Byrne Radford *et al*. 2004).

Maintaining diversity within species is vital because it encompasses variation in adaptive traits evolved through natural selection and which influence an individual organism's capacity to survive and reproduce (Falconer and Mackay 1996). Loss of variability in adaptive traits reduces the rate at which species can evolve and respond to future environmental change, thereby increasing the likelihood of extinction and reduction of diversity at the higher levels of species and ecosystems. Reduced genetic diversity effectively decreases evolutionary potential but also has a negative impact on short-term viability (Burgmann *et al.* 1988, Holsinger and Gottlieb 1991, Ellstrand and Elam 1993, Namkoong 1993, Storfer 1996, Hogbin *et al.* 2000). Recent studies using microsatellite genetic markers have begun to quantify how much genetic diversity can be lost before impacts are realized or extinction made inevitable (Young 2003). However, until further studies on other species and different breeding systems are carried out, no biological justification can be made for an acceptable level of loss. Whilst some researchers postulate no more than one to five populations are required to capture genetic diversity over a species' range (Falk 1991), the data overwhelming support the need for large population numbers.

Measurement of genetic diversity and adaptive traits

Studies of variation in physiological responses of species across their geographic range reveal significant adaptive variation, especially where wide ranges extend from mesic to dry, infertile and unpredictable environments (Ngugi *et al*. 2003a, b). Recognising this variation has significant implications for both conservation and provenance selection for plantation stock.

Three main approaches have been developed in an attempt to measure genetic diversity and adaptive traits relating to species survival and evolutionary potential: (1) fitness-related adaptive traits, (2) ecological surrogates, and (3) allelic diversity.

Fitness-related adaptive traits

Direct estimates of adaptive variability (essential for maintaining evolutionary potential in response to selective environmental pressures) are difficult and often impractical, even for one species, requiring data from large numbers of populations across a range of environments. As a result, phenotypic performance or fitness-related adaptive traits are frequently used or advocated as surrogates (Marshall and Brown 1975, Milligan *et al.* 1994, Storfer 1996, Doran and Skelton 1982, Midgley and Turnbull 2003).

Most traits of ecological significance, especially those that are fitness related, are considered to be under quantitative genetic control (Libby and Critchfield 1987), but the spatial scale at which selection operates over a species' range (potentially variably ranging from fine-scale micro-habitat to broad-scale climatic domains) and the genetic basis and adaptive significance of phenotypic variation are complex and unresolved issues (Potts and Wiltshire 1997). Garnier-Gere and Ades (2001), using growth rates of trees as a fitness-related trait linked to juvenile survival, found a high genetic correlation between tree diameter and survival. Solar radiation variables appeared to be strong quantitative predictors, with populations in locations receiving higher insolation, particularly in the warmest quarter, showing greater average growth across all sites. Solar radiation and other associated factors thus appear to have a significant effect on differentiation of most populations for growth.

Ecological surrogates

Ecological "surrogate characters" such a climatic or edaphic data have been used to predict adaptive variation within species (Waples 1991, Millar and Libby 1991, Ennos *et al.* 1998). Variation in mean radiation indices was used for predicting species richness and between-population genetic variability in eucalypts (Austin *et al.* 1996). Differences in habitat among conspecific populations have been taken to imply adaptive differences (Waples 1991) with the existence of unusual or distinctive habitat features allowing for the possibility of unique adaptations in the local population (Dimmick *et al.* 2001).

Protection of environments encompassing maximum variability in average rainfall and temperature as well as topography, geological substrate and understorey type is likely to ensure more stable populations based on optimising a species' adaptive variability.

Population size has been shown to be an effective surrogate for genetic variability in wild animal populations (Frankham 1996, Montgomery *et al.* 2000) and in some plants (Ellstrand and Elam 1993, Frankel *et al.* 1995), but knowledge of breeding systems and genetic structure and clonality of populations becomes more important, e.g. *Eucalyptus curtisii* (Smith *et al.* 2003).

Allelic diversity

Neutral molecular markers for estimating allelic diversity, are a relatively cheap and informative tool for estimating (a) changes in genetic structure from reduced gene flow due to isolation, (b) extinction risks due to small population size from habitat reduction, and (c) the minimum number of populations needed for survival and ongoing evolution (Namkoong 1993, Schoen and Brown 1993, Petit *et al.* 1998, Young and Brown 1999). Patterns of genetic diversity for neutral markers generally provide information on historical and contemporary patterns of gene flow and co-ancestry while differentiation for adaptive traits may reflect environmental variation (Murray and Young 2001). Methods based on allelic diversity are less likely to underestimate population requirements than those based on fitness-related adaptive traits where multiple fitness-related traits are likely to be correlated with different environmental gradients across heterogeneous landscapes. Neel and Cummings (2002) found the number of populations required to capture all alleles increases with the total number of alleles and large numbers of populations were required to capture all alleles or common alleles even for species with little differentiation among populations. The genetic diversity measure chosen (e.g. all alleles versus common alleles) strongly influences results with twice as many populations required to capture all alleles as opposed to common alleles. The frequently advocated limits of capturing 10-12 percent of populations, or five populations, failed to capture all alleles. Even with population sampling intensities of 45 per cent recommended by Sanjayan and Soule (1998) and Noss (1996), up to 30 per cent of all alleles could be lost. Where extreme genetic divergence or extensive clonality among populations is demonstrated, the capture of all populations becomes an imperative (Peakall and Sydes 1996, Hogbin *et al.* 2000).

Given the lack of data on levels of genetic diversity within and between populations of most species, it is generally assumed that genetic diversity will be automatically captured by capturing broader patterns of diversity using ecological reserve selection and design principles based on island biogeography, community ecology, population genetics and biology including habitat requirements and species demography (Murphy and Noon 1992, Burgman *et al*. 2001). Neel and Cummings (2003) have shown that such protocols on their own were ineffective in capturing genetic diversity or no better than random selection procedures The number of populations selected appears to be much more important than how those populations were selected. Focusing on ecological features for selecting sites for conservation will ensure representation of genetic diversity only when sufficient numbers of populations are included in reserves (Neel and Cummings 2003).

The important conclusions from this work were that whilst conservation of the geographic and ecological ranges of species provides some measure of buffering against environmental and human-mediated stochasticity, protecting large proportions or numbers of populations will be necessary for effective capture of genetic diversity to ensure persistence and ongoing evolution of species, communities and ecosystems (Neel and Cummings 2003).

Recent work recognises clustering of populations putatively derived from a common ancestor that are monophyletic for mitochondrial DNA alleles, whilst allowing for differences in the frequency of alleles at their nuclear loci (Moritz *et al*. 1995). These have been defined as Evolutionarily Significant Units (ESUs). In view of the importance of populations as the fundamental drivers of evolution (Waples 1991, Millar and Libby 1991, Crozier 1992, Baverstock *et al*. 1993, Crozier and Kusmierski 1994, Mallet 1994, 1996), moves exist to give such populations a legal status comparable to that of species under the US Endangered Species Act (Moritz *et al.* 1995).

Alternative grouping of plant species based on similar mating systems, population structure and size, habitat and geographical range, factors which appear to be key determinants of population genetic diversity and differentiation, have been suggested as fruitful avenues for determining and conserving adaptive genetic variability (Lynch 1995, Brown and Schoen 1992, Linhart and Grant 1996).

In summary, considering species' genetic variability rather than species distribution alone will dramatically affect the type of reserves necessary. Reserve-selection procedures based on maximizing population genetic variability, while allowing sufficient gene flow between populations of species, should increase the probability of persistence.

Thus viability of populations within species has to be given special attention in the interests of ecosystem viability (Soule and Mills (1992). Species richness is a necessary but not sufficient requirement for biodiversity conservation.

9 Conclusions

Biodiversity conservation has to take account of the processes that create and maintain biodiversity.

This report addresses the significance and origins of biodiversity within the Study Area and some of the key underlying factors relevant to its persistence and ongoing evolution.

Many of the analyses in this report were made possible by the recent worldwide explosion in phylogenetic studies which, with the advent of increasingly sophisticated molecular marker techniques and computing capability, have enormously advanced our understanding of the evolutionary relationships among large groups of plants and animals. Traditional morphological taxonomic classifications are being radically reworked in the light of the recent molecular advances. Plant group systematics are being revolutionised by these advances.

The advances in phylogeny in turn have facilitated major advances in related fields such as biogeography and ecology, spawning new fields such as phylogeography and molecular ecology. Basal lineages within 'the tree of life' and its branches are more reliably being identified and can be correlated with their geographic distributions within a broader context of fossil histories, plate tectonics, climate and sea level change, and soil and landscape evolution. These relevant and necessary scales of analysis range from local to continental and decadal to millennial.

Increasingly, through this multidisciplinary approach, the origins and early radiations of basal lineages within major groups of the world's fauna and flora are being traced to the Australasian region. It is becoming clear that the Australian plate through its final rifting from Antarctica then docking with the Pacific and Asian plates, changed the world climates and its biota. The Neogene and subsequent Quaternary Period, particularly the last 10 million years, represents the most unstable of the past 100 million years and the transformation of ancient mesic floras to their modern, dry-adapted counterparts.

The persistence of so many phylogenetic and biogeographic relict taxa in this region can be traced to the unique tectonic and geomorphological history of the Australian continent. More than in any other country ancient landforms have been able to persist, providing buffering, in refugia, against climatic and environmental instability.

However, these ancient surfaces persist only as residual, isolated plateaus and ranges that have survived the normal erosional planation processes responsible for Australia otherwise being the flattest continent on earth. The Great Divide of eastern Australia, the ranges and residual 'uplands' of the southwest, Pilbara and Kimberley regions of Western Australia, the Arnhem Land plateau and Macdonnell and Musgrave Ranges of Northern Territory, and the Flinders, Mt Lofty, Barrier and Gawler Ranges of South Australia have to be seen in this light to make sense of the congruent patterns of continental disjunctions, relictual distributions of congeners and sister taxa across a range of classes of animals and plant groups.

Central to an understanding of the likely history of these elevated areas is an understanding of the age and origin of the underlying rocks and geological structures, the age and style of erosion, and the age and causes of uplift. Whilst most work in this regard is heavily biased to southeast Australia, evidence points to the Neogene and Quaternary as the major landscape-forming periods generating the landscapes of today. Low sea levels coupled with off-shore subsidence10 million years ago, followed by wet/dry cycles of increasing frequency and intensity, accelerated fluvial processes that removed the protective Tertiary basalt capping to the softer underlying Palaeozoic sedimentary strata.

Distributions of phylogenetic and biogeographic relicts among the reptiles, birds and vascular plants are highly clumped and concentrated in the elevated areas of the Brigalow Belt and adjoining bioregions.

The Study Area has retained basal lineages of radiations that now characterise the ‘dry country’ reptile fauna of Australia. Approximately 50 per cent of geckoes and more than 10 per cent of the skinks and legless lizards arose in Neogene radiations that can be traced back to basal lineages that are endemic or near endemic to the Brigalow Belt and most heavily concentrated in upland areas.

The Brigalow Belt has not only the greatest diversity of arboreal reptiles in Australia but also many key basal taxa in this group. The endemic Golden-tailed Gecko (*Strophurus taenicauda*) is basal to most of Australia’s dry adapted arboreal geckoes. The Pale-Headed Snake (*Hoplocephalus bitorquatus*) with the major part of its range in the Brigalow Belt is the oldest extant member of Australia’s only genus of truly arboreal snakes. Arboreality in reptiles is likely to have been an important adaptation to the increasing dry and seasonal climates of the Neogene and subsequent Quaternary.

On the other hand amphibians in the Brigalow Belt adapted to aridity and highly seasonal rainfall by burrowing into the water retentive clays of the lowlands. The Brigalow Belt has the largest assemblage of burrowing frogs in Australia, with representatives from all four of the independent evolutions of this habit.

The revolution in molecular systematics has recent revealed that the whole world’s oscine songbirds (some 4500 species or about half the world’s birds) arose in East Gondwana (Australasia), as almost all basal lineages of oscine songbirds are endemic to Australia or Australo-Papua. Whilst the oldest songbird lineages remain in the rainforests to the east, a wide range of old and Neogene Australo-Papuan songbird lineages occur in the eucalypt forests and woodlands of the Brigalow Belt. As a group, the older and more unique basal songbirds that arose and evolved within Australia are more vulnerable to woodland disturbance and fragmentation than woodland-inhabiting birds as a whole. Thus the largest areas of unfragmented woodland in the Brigalow, now restricted almost entirely to the uplands, provide an unparalleled opportunity to maintain ecologically functional populations of those woodland birds with the longest history of evolution in the Australian environment and which are members of some of the oldest extant songbird families in the world.

With respect to vascular plants the Brigalow Belt has outstanding concentrations of basal taxa associated with Neogene radiations of major flowering plant groups such as the rosids, asterids and monocots.

Within the rosids, the Euphorbiaceae is one of the world’s six largest vascular plant families having experienced explosive radiations in and since the Neogene. The two most basal subfamilies (Phyllanthoideae, Oldfieldioideae) are most diverse, at all taxonomic levels, in the Gondwanan African and Australasian floristic regions. Queensland has the most diverse representation of the family in Australia, with the Brigalow Belt a major refuge for relictual and disjunct basal taxa closely linked to Neogene radiations. Fifteen species are endemic to the Brigalow Belt. Other families included in this group such as the Casuarinaceae, Myrtaceae, Stackhousiaceae, Rutaceae, Mimosaceae and Sterculiaceae are either ancient Gondwanan, East Gondwanan, or endemic families that have played a major role in the evolution of Australia's flora. The Brigalow Belt contains the highest diversity of ancient or basal lineages of eucalypts, acacias and arborescent casuarinas with narrowly endemic or range-restricted species predominantly restricted to elevated ancient landforms. The Brigalow Belt, Cape York and southeast Queensland have comparable high diversities of relict species of *Brachychiton* (Sterculiaceae), a dominant species of dry rainforest ecosystems that first emerged during the Neogene from their mesic ancestral forms. The Brigalow Belt represented the most extensive development of this type. Very little remains. The Sterculiaceae has been considered the most primitive family in the Malvales with the tribe Sterculieae the closest to the ancestral type.

The asterid group of flowering plants is one the largest, most successful and phylogenetically specialized of all flowering plants comprising up to one third of their total numbers. The Asteraceae (23000 species) is the largest of all plant families and dominant in the northern hemisphere. It radiated explosively during the most arid phases of the Neogene and Pleistocene to dominate entire floras. However Australasia (East Gondwanan) again has been identified as the origin of many of the basal lineages of the Asteraceae and closely related Campanulaceae, The near endemic Goodeniaceae and Stylidaceae, and the Pittosporaceae which originated from here have high levels of endemism within the Study Area.

Within the monocots, grasses (Poaceae) are one of the largest, most cosmopolitan and economically significant of the flowering plant families of the world. They too came to dominance in the Neogene now numbering up to 20 per cent of the worlds vascular flora. Phylogenetic studies based on morphological and molecular characters show the grasses are closely related to the Restionaceae, a Southern Hemisphere family most diverse in Australia and South Africa. The Brigalow Belt is a major refugium for relict, disjunct and endemic taxa of both older and recently radiated lineages of the Poaceae and Restionaceae.

The values of the Brigalow Belt thus derive from unparalleled concentrations of basal lineages that diversified, often explosively, during the Neogene to shape the modern flora and fauna of Australia and other parts of the world. The Neogene was a major stage in the earth's evolutionary history marking the transition from relatively stable 'greenhouse' climatic conditions in the early half of the Tertiary to the increasingly unstable 'icehouse' conditions of the Quaternary.

The recognition of the outstanding significance of this bioregion has been fundamentally underpinned by taxonomy and phylogenetics. Queensland is seriously under-resourced in these two areas. The Queensland Herbarium relies on five full-time botanical staff and an equivalent number of retired specialists to describe a flora that is recognised as the most diverse in Australia. Almost a third of the acacias occurring in the state are recorded as being highly geographically variable and likely to comprise new species or genetic variants. Most of the molecular phylogenetic work is conducted outside the State, ensuring a southern bias in sample selections and, potentially, the resultant phylogenies.

The most important implication of this report are that palaeoecologically stable elevated areas such as Tertiary surfaces capped with lateritic duricrust, stony granitic outctops or sandstone ridges and plateaus with oligotrophic soils have accumulated narrowly endemic species by virtue of their relative stability compared to the more dynamic and unstable floodplain environments at lower altitudes. The former tend to coincide with either higher rainfall levels, annually or during the driest quarter, or more equable soils moisture regimes. If the high aggregations of phylogenetic or biogeographic relic taxa are attributable to past environmental stability, severe biomass depletion and unnatural fire regimes may threaten the persistence of these species and the ongoing evolution of the unique and relatively ancient flora and fauna of the Brigalow Belt.

10 References

Adams, J.M. (1997). Preliminary vegetation maps of the world since the Last Glacial Maximum: an aid to archaeological understanding. *Journal of Archaeological Science* 24: 623–647.

Adams, M.J. (1987). Butterfly search and research in the Northern Andes. *Proc. Trans. British Entomological and Natural History Society* 20: 35–40.

Adams, W.T., Griffin, A.R. and Moran, G.F. (1992). Using paternity analysis to measure effective pollen dispersal in plant populations. *American Naturalist* 140: 762–780.

Ahmed, A.K. and Johnson, K.A. (2000). Horticultural development of Australian native edible plants. *Australian Journal of Botany* 48: 417–426.

Allem, A.C. (2003). Optimization theory in plant evolution: an overview of long-term evolutionary prospects in the angiosperms. *The Botanical Review* 69: 225–252.

Allen, C.M., Wyborn, D. and Chappell, B.W. (1998). Plutonic rocks of the New England orogen north of Rockhampton: are they cordilleran style? http://www.es.mq.edu.au/GEMOC/Abstrfull98/Allen982.htm - pp. 1–3.

Al-Shammary, K.I.A. and Gornall, R.J. (1994). Trichome anatomy of the Saxifragaceae s.l. from the southern hemisphere. *Botanical Journal of the Linnean Society* 114: 99-131.

Ambrose, J.P. and Bratton, S.P. (1990). Trends in Landscape Heterogeneity Along the Borders of Great Smoky Mountains National Park. *Conservation Biology* 4: 135–143.

Anderberg, A.A. (1993). Cladistic interrelationships and major clades of the Ericales. *Plant Systematics and Evolution* 184: 207–231.

Andersen, N.M. and Weir, T.A. (2003). The genus *Microvelia* Westwood in Australia (Hemiptera: Heteroptera: Veliidae). *Invertebrate Systematics* 17: 261–348.

Andersson, S. (2001). The Genetic Basis of Floral Variation in *Senecio jacobaea* (Asteraceae). *The American Genetic Association* 92: 409–414.

Andrew, R.L., Miller, J.T., Peakall, R., Crisp, M.D. and Bayer, R.J. (2003). Genetic, cytogenetic and morphological patterns in a mixed mulga population: evidence for apomixis. *Australian Systematic Botany* 16: 69–80.

Araujo, M.B. and Williams, P.H. (2001). The bias of complementarity hotspots toward marginal populations. *Conservation Biology* 15: 1710–1720.

Armstrong, J.A. (2002). *Zieria* (Rutaceae): a systematic and evolutionary study. *Australian Systematic Botany* 15: 277–463.

Arnold, K.E. and Owens, I.P.F. (1999). Cooperative breeding in birds: the role of ecology. *Behavioural Ecology* 10: 465–471.

Ash, J. (1983). Tree rings in tropical *Callitris macleayana* F. Muell. *Australian Journal of Botany* 31: 227–281.

Astarini, I.A., Yan, G. and Plummer, J.A. (1999). Interspecific hybridisation of boronias. *Australian Journal of Botany* 47: 851-864.

Atahan, P., Dodson, J.R. and Itzstein-Davey, F. (2004). A fine-resolution Pliocene pollen and charcoal record from Yallalie, south-western Australia. *Journal of Biogeography* 31: 199–205.

Auld, T.D. (2001). The ecology of the Rutaceae in the Sydney region of south-eastern Australia: poorly known ecology of a neglected family. *Cunninghamia* 7: 213–239.

Austin, M.P. and Meyers, J.A. (1996). Current approaches to modelling the environmental niche of eucalypts: implication for management for forest biodiversity. *Forest Ecology and Management* 85: 95–106.

Austin, M.P., Pausas, J.G. and Nicholls, A.O. (1996). Patterns of tree species richness in relation to environment in southeastern New South Wales, Australia. *Australian Journal of Ecology* 21: 154–164.

Austin, M.P., Pausas, J.G. and Noble, I.R. (1997). Modelling environmental and temporal niches of eucalypts. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press, Cambridge. pp. 129–150.

Australian Government (2002). Collaborative Australian Protected Area Database (CAPAD2002). Department of Environment and Heritage, Canberra.

Baehr, M. (1993). New species and new records of the genus *Sphallomorpha* Westwood from Australia: Supplement to the *Revision of the Pseudomorphinae of the Australian region 1. Spixiana* 16: 25–42.

Ballard, J.W.O. and Whitlock, M.C. (2004). The incomplete natural history of mitochondria. *Molecular Ecology* 13: 729–744.

Band, L.E., Peterson, D.L., Running, S.W., Coughlan, J., Lammers, R., Dungan, J. and Nemani, R. (1991). Forest ecosystem processes at the watershed scale: basis for distributed simulation. *Ecological Modelling* 56: 171–196.

Barber, H.N. (1965). Selection in natural populations. *Heredity* 20: 551–572.

Barker, F.K., Barrowclough, G.F. and Groth, J.G. (2001). A phylogenetic hypothesis for passerine birds: taxonomic and biogeographic implications of an analysis of nuclear DNA sequence data. *Proc. R. Soc. Lond.* 269: 295–308.

Barlow, B.A. (1959a). Chromosome numbers in the Casuarinaceae. *Australian Journal of Botany* 7: 230–237.

Barlow, B.A. (1959b). Polyploidy and apoxixis in the Casuarina distyla species group. *Australian Journal of Botany* 7: 238–251

Barnard, C.A., and Barnard, H.G. (1925). A review of the bird life on Coomooboolaroo Station, Duaringa, Queensland, during the past fifty years. *Emu* 24: 252–65.

Bartolome, M., Walsh, N.G., James, E.A. and Ladiges, P.Y. (2002). A new, rare species of *Acacia* from north-eastern Victoria. *Australian Systematic Botany* 15: 465–475.

Batianoff. G.N. and Pearson, S.G. (1990). Further notes on *Bertya sharpeana* Guymer (Euphorbiaceae): a significant extension of its range in Queensland. *Austrobaileya* 3: 327–328.

Batianoff, G.N., Reeves, R.D. and Specht, R.L. (1990). *Stackhousia tryonii* Bailey: a nickel-accumulating Serpentinite-endemic species of Central Queensland. *Australian Journal of Botany* 38: 121–130.

Batianoff, G.N. and Specht, R.L. (1992), Queensland (Australia) Serpentine Vegetation The Vegetation of Ultramafic (Serpentine) Soils: Proceedings of the First International Conference on Serpentine Ecology. Andover Publishing, Hampshire, United Kingdom.

Bauer, L.M., Johnston, M.E. and Williams, R.R. (2001). Rate and timing of vegetative growth, flowering and fruit development of *Persoonia virgata* (Proteaceae). *Australian Journal of Botany* 49: 245–251.

Bayly, M. (1999). A name change for most eriostemons. http://farrer.riv.csu.edu.au/ASGAP/APOL13/mar99-3.html

Beadle, N.C.W. (1981). *The Vegetation of Australia*. Cambridge University Press. 490 pp.

Bean, A.R. (1994). *Eucalyptus clandestina* (Myrtaceae), a new bloodwood from central Queensland. *Austrobaileya* 4: 205–208.

Bean, A.R. (1995a). A new species and new combination in *Ochrosperma* Trudgen (Myrtaceae) *Austrobaileya* 4: 387–390.

Bean, A.R. (1995b). Reinstatement and revision of *Triplarina* Raf. (Myrtaceae). *Austrobaileya* 4: 353–367.

Bean, A.R. (1997a). Notes on *Eucalyptus* ser. *Psathyroxyla* Blakely (Myrtaceae) and other ‘Ash group’ eucalypts. *Austrobaileya* 5: 125–135.

Bean, A.R. (1997b). Reinstatement of the genus *Babingtonia* Lindl. (Myrtaceae, Leptospermoideae). *Austrobaileya* 4: 619–626.

Bean, A.R. (1999). *Ochrosperma obovatum* (Myrtaceae), a new species from south-eastern Queensland. *Austrobaileya* 5: 499–501.

Bean, A.R. (2000). A revision of *Stylidium* subg. Andersonia (R.Br.ex G. Don) Mildbr. (Stylidiaceae). *Austrobaileya* 5: 589–649.

Bean, A.R. (2001). Pappus morphology and terminology in Australian and New Zealand thistles (Asteraceae, tribe Cardueae) *Austrobaileya* 6: 139–152.

Beaumont, M.A. and Balding, D.J. (2004). Indetifying adaptive genetic divergence among populations from genome scans. *Molecular Ecology* 13: 969–980.

Becker, A. and Theiben, G. (2003). The major clades of MADS-box genes and their role in the development and evolution of flowering plants. *Molecular Phylogenetics and Evolution* 29: 464–489.

Begon, M., Harper, J.L. and Townsend, C.R. (1986). *Ecology, Individuals, Populations and Communities*. Blackwell Scientific Publications, Oxford. pp. 762–783.

Bell, D.T. (1999). Australian trees for the rehabilitation of waterlogged and salinity-damaged landscapes. *Australian Journal of Botany* 47: 697–716.

Bell, D.T. and Williams, J.E. (1997). Eucalypt ecophysiology. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 168–186.

Bell, K.L., Yeates, D.K., Moritz, C., and Monteith, G.B. (2004). Molecular phylogeny and biogeography of the dung beetle genus *Temnoplectron* Westwood (Scarabaeidae: Scarabaeinae) from Australia's wet tropics. *Molecular Phylogenetics and Evolution* 31: 741–753.

Bennett, P.M. and Owens, I.P.F. (2000). Ecological basis of extinction risk in birds: habitat loss versus human persecution and introduced predators. *Proceedings of the National Academy of Sciences* 97: 12144–12148.

Benson, J. and Redpath, P.A. (1997). The nature of pre-European native vegetation in south-eastern Australia: A critique of Ryan, D.G., Ryan J.R. and Starr, B.J. (1995), *The Australian Landscape — Observations of Explorers and Early Settlers*. *Cunninghamia* 5: 285–328.

Bhatia, N.P., Bhatia, P. and Ashwath, N. (2002). Asexual propagation of *Stackhousia tryonii*: a step towards restoration of a rare metallophyte. *Australian Journal of Botany* 50: 577–582.

Bickford, S. and Mackey, B. (2004). Reconstructing pre-impact vegetation cover in modified landscapes using environmental modelling, historical surveys and remnant vegetation data: a case study in the Flurieu Peninsula, South Australia. *Journal of Biogeography* 31: 787–805.

Blackburn, T.M., Jones, K.E., Cassey P. and Losin N. (2004). The influence of spatial resolution on macroecological patterns of range size variation: a case study using parrots (Aves: Psittaciformes) of the world. *Journal of Biogeography* 31: 285–293.

Blake, S. T. and Roff, C. (1988). *Honey Flora of Queensland*. Queensland Department of Primary Industries.

Blakers, M., Davies, S.J.J.F. and Reilly, P.N. (1984). *The Atlas of Australian Birds*. Royal Australasian Ornithologists Union, Melbourne Univ. Press, Melbourne.

Bond, G., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J. and Bonani, G. (1993). Correlations between climate records from North Atlantic sediments and Greenland ice. *Nature* 365: 143–147.

Borchsenius, F. (1997). Patterns of plant species endemism in Ecuador. *Biodiversity and Conservation* 6: 379–399.

Bowman, D.M.J.S. (2001). Future eating and country keeping: what role has environmental history in the management of biodiversity? *Journal of Biogeography* 28: 549–564.

Bowman, D.M.J.S. (2001b). On the elusive definition of 'Australian rainforest': response to Lynch and Neldner (2000). *Australian Journal of Botany* 49: 1–3.

Bowman, D.M.J.S. (2002). Preface. *Australian Journal of Botany* 50: i–iii.

Braithwaite, R.W. and Griffiths, A.D. (1994). Demographic variation and range contraction in the Northern Quoll *Dasyurus hallucatus*. *Wildl. Res.* 21: 203–217.

Bremer, B., Bremer, K., Heidari, N., Erixon, P., Olmstead, R.G., Anderberg, A.A., Kallersjo, M. and Barkhordarian, E. (2002). Phylogenetics of asterids based on 3 coding and 3 non-coding chloroplast DNA markers and the utility of non-coding DNA at higher taxonomic levels. *Molecular Phylogenetics and Evolution* 24: 274–301.

Bremer, K. and Gustafsson, M.H.G. (1997). East Gondwana ancestry of the sunflower alliance of families. *Proceedings of the National Academy of Sciences* 94: 9188–9190.

Brennan, A.C., Harris, S.A. and Hiscock, S.J. (2003). Population genetics of sporophytic self-incompatibility in *Senecio squadilis* L. (Asteraceae). II: a spatial autocorrelation approach to determining mating behaviour in the presence of low S allele diversity. *Heredity* 91: 502–509.

Brennan, A.C., Harris, S.A., Tabah, D.A. and Hiscock, S.J. (2002). The population genetics of sporophytic self-incompatibility in *Senecio squalidus* L. (Asteraceae). I: S allele diversity in a natural population. *Heredity* 89: 430–438.

Brook, B.W. and Bowman, D.M.J.S. (2004). The uncertain blitzkrieg of Pleistocene megafauna. *Journal of Biogeography* 31: 517–523.

Brooker, M.I.H. (2000). A new classification of the genus *Eucalyptus* L'Her. (Myrtaceae). *Australian Systematic Botany* 13: 79–148.

Brooker, M.I.H. and Bean, A.R. (1991). A revision of the yellow bloodwoods (Myrtaceae: *Eucalyptus* ser. *Naviculares* Maiden). *Austrobaileya* 3: 409–437.

Bros, U., Ostling, A., Harrison, K. and Martinez, N.D. (2004). Unified spatial scaling of species and their trophic interactions. *Nature* 428: 167–171.

Brown, A.G., Turnbull, J.W. and Booth, T.H. (1997). The Australian Environment. In: J.C. Doran and J.W. Turnbull (eds), *Australian Trees and Shrubs: species for land rehabilitation and farm planting in the tropics*. ACIR Monograph No. 2. Australian Centre for Agricultural Research, Canberra. pp. 1–18.

Brown, A.H.D. and Brubaker, C.L. (2000). Genetics and the conservation and use of Australian wild relatives of crops. *Australian Journal of Botany* 48: 297–303.

Brown, A.H.D and Schoen, D.J. (1992). Plant population genetic structure and biological conservation. In: O.T. Sandlund, K.Hindar and A.H.D. Brown (eds), *Conservation of Biodiversity for Sustainable Development*. Scandinavian University Press, Oslo.

Brown, A.H.D., Young, A., Burdon, J., Christidis, L., Clarke, G., Coates, D. and Sherwin, W. (1997). *Genetic indicators for state of environment reporting*. State of the environment technical paper series. Department of the Environment, Canberra, Australia.

Brown, G.K., Udovicic, F. and Ladiges, P.Y. (2001). Molecular phylogeny and biogeography of *Melaleuca*, *Callistemon* and related genera (Myrtaceae). *Australian Systematic Botany* 14: 565–585.

Brumfield, R.T., Beerli, P., Nickerson, D.A. and Edwards, S.V. (2003). The utility of single nucleotide polymorphisms in inferences of population history. *Trends in Ecology and Evolution* 18: 249–256.

Brummitt, N. and Lughadha, E.N. (2003). Biodiversity: where's hot and where's not. *Conservation Biology* 17: 1442–1448.

Bull, N.J., Schwarz, M.P. and Cooper, S.J.B. (2003). Phylogenetic divergence of the Australian allodapine bees (Hymenoptera: Apidae). *Molecular Phylogenetics and Evolution* 27: 212–222.

Bullock, S.H. (1994). Wind pollination of neotropical dioecious trees. *Biotropica* 26: 172–179.

Burbank, E.W. and Pinter, N. (1999). Landscape evolution: the interactions of tectonics and surface processes. *Basin Research* 11: 1–6.

Burbidge, A.A. and McKenzie, N.L. (1989). Patterns in the modern decline of western Australia's vertebrate fauna: Causes and conservation implications. *Biol. Cons.* 50: 143–198.

Burgman, M.A. (1988). Spatial analysis of vegetation patterns in southern Western Australia: implications for reserve design. *Australian Journal of Ecology* 13: 415–429.

Burgman, M.A. (2002). Turner Review No. 5 — Are listed threatened plant species actually at risk? *Australian Journal of Botany* 50: 1–13.

Burgman, M.A., Akcakaya, H.R. and Loew, S.S. (1988). The use of extinction models for species conservation. *Biological Conservation* 43: 9–25.

Burton, T.C. (2001). Variation in the foot muscles of frogs of the family Myobatrachidae. *Australian Journal Zoology.* 201: 539–559.

Butcher, P.A., Moran, G.F. and Perkins, H.D. (1996). Genetic resources and domestication of *Acacia mangium*. In: M.J. Dieters, A.C. Matheson, D.G. Nikles, C.E. Harwood and S.M. Walker (eds), *Tree Improvement for Sustainable Tropical Forestry*. Proceedings of QFRI-IUFRO Conference, Caloundra, Australia, October–Novermber 1996. pp. 467–471.

Butler, D.W. and Fairfax, R.J. (2003). Buffel Grass and fire in a Gidgee and Brigalow woodland: a case study from central Queensland. *Ecological Management and Restoration* 4: 120–125.

Byrne, M. (1999). High genetic identities between three oil mallee taxa, *Eucalyptus kochii* ssp. *kochii*, ssp. *plenissima* and *E. horistes*, based on nuclear RFLP analysis. *Heredity* 82: 205–211.

Byrne, M. (2002). Phylogenetics and the conservation and utilisation of *Acacia* in Western Australia. *Conservation Science Western Australia* 4: 10–18.

Byrne, M., Tischler, G., Macdonald, B., Coates, D.J. and McComb, J. (2001). Phylogenetic relationships between two rare acacias and their comon, widespread relatives in south-western Australia. *Conservation Genetics* 2: 157–166.

Campbell, L.D. and Holden, A.M. (1984). Miocene Casuarinaceae fossils from Southland and Central Otago, New Zealand. *New Zealand Journal of Botany* 22: 159–167.

Cantrill, D.J. and Webb, J.A. (1998). Permineralized pleuromeid lycopsid remains from the Early Triassic Arcadia Formation, Queensland, Australia. *Review of Palaeobotany and Palynology* 102: 189–211.

Cardillo, M. and Bromham, L. (2001). Body size and risk of extinction in Australian mammals. *Cons. Biol.* 15: 1435–1440.

Carpenter, R.J., Hill, R.S. and Jordan, G.J. (1994). Cenozoic vegetation in Tasmania: macrofossil evidence. In: R.S. Hill (ed.), *History of the Australian Vegetation: Cretaceous to recent*. Cambridge University Press, Cambridge. pp. 276–298.

Carr, D.E. and Dudash, M.R. (1996). Inbreeding depression in two species of *Mimulus* (Scrophulariaceae) with contrasting mating systems. *American Journal of Botany* 83: 586–593.

Carr, D.J., Carr, S.G.M., Hyland, B.P.M., Wilson, P.G. and Ladiges, P.Y. (2002). *Stockwellia quadrifida* (Myrtaceae), a new Australian genus and species in the eucalypt group. *Botanical Journal of the Linnean Society* 139: 415–421.

Catling, P.C. (1991). Ecological effects of prescribed burning practices on the mammals of southeastern Australia. In: D. Lunney (ed.), *Conservation of Australia's Forest Fauna.* Royal Zoological Society of New South Wales, Sydney. pp. 237–244.

Cayzer, L.W., Crisp, M.D. and Telford, I.R.H. (1999). *Bursaria* (Pittosporaceae): a morphometric analysis and revision. *Australian Systematic Botany* 12: 117–143.

Cayzer, L.W., Crisp, M.D. and Telford, I.R.H. (2000a). *Auranticarpa*, a new genus of Pittosporaceae from northern Australia. *Australian Systematic Botany* 13: 903–917.

Cayzer, L.W., Crisp, M.D. and Telford, I.R.H. (2000b). Revision of *Pittosporum* (Pittosporaceae) in Australia. *Australian Systematic Botany* 13: 845–902.

Celebrezze, T. and Paton, D.C. (2004). Do introduced honeybees (*Apis mellifera*, Hymenoptera) provide full pollination service to bird-adapted Australian plants with small flowers? An experimental study of *Brachyloma ericoides* (Epacridaceae). *Austral Ecology* 29: 129–136.

Chandler, G.T., Bayer, R.J. and Crisp, M.D. (2001). A molecular phylogeny of the endemic Australian genus *Gastrolobium* (Fabaceae Mirbelieae) and allied genera using chloroplast and nuclear markers. *American Journal of Botany* 88: 1675–1687.

Chase, M.W. and Cox, A.V. (1998). Gene sequences, collaboration and analysis of large data sets. *Australian Systematic Botany* 11: 215–229.

Chase, M.W., Soltis, D.E., Olmstead, R.G., Morgan, D., Les, D.H., Mishler, B.D., Duvall, M.R., Price, R.A., Hills, H.G., Qiu, Y.L., Kron, K.A., Rettig, J.H., Conti, E., Palmer, J.D., Manhart, J.R., Sytsma, K.J., Michaels, H.J., Kress, W.J., Karol, K.G., Clark, W.D., Hedren, M., Gaut, B.S., Jansen, R.K., Kim, K.J., Wimpee, C.F., Smith, J.F., Furnier, G.R., Strauss, S.H., Xiang, Q.Y., Plunkett, G.M., Soltis, P.S., Swensen, S.M., Williams, S.E., Gadek, P.A., Quinn, C.J., Eguiarte, L.E., Golenberg, E., Learn, G.H., Graham, S.W., Barrett, S.C.H., Dayanandan S. and Albert, V.A. (1993). Phylogenetics of seed plants: an analysis of nucleotide sequences from the plastid gene rbcL1. *Annals of the Missouri Botanical Gardens* 80: 528–580.

Chazdon, R.L., Careaga, S., Webb, C. and Vargas, O. (2003). Community and phylogenetic structure of reproductive traits of woody species in wet tropical forests. *Ecological Monographs* 73: 331–348.

Chiarucci, A. (2003). Vegetation ecology and conservation on Tuscan ultramafic soils. *The Botanical Review* 69: 252–269.

Choisy, M., Franck, P. and Cornuet, J.-M. (2004). Estimating admixture proportions with microsatellites: comparison of methods based on simulated data. *Molecular Ecology* 13: 995–968.

Christidis, L. and Schodde, R. (1993). Relationships and radiations in the meliphagine honeyeaters, *Meliphaga*, *Lichenostomus* and *Xanthotis* (Aves: Meliphagidae): Protein evidence and its integration with morphology and ecogeography. *Australian Journal of Zoology* 41: 293–316.

Christophel, D.C. (1989). Evolution of the Australian flora through the Tertiary. *Plant Systematics and Evolution* 162: 63–78.

Claridge, A.W. and Barry, S.C. (2000). Factors influencing the distribution of medium-sized ground-dwelling mammals in southeastern mainland Australia. *Austral Ecology* 25: 676–688.

Clark, G.M. and Spier, F. (2003). A review of the conservation status of selected Australian non-marine invertebrates. Australian Non-Marine Invertebrates — Species Synopses (1), http://www.deh.gov.au/biodiversity/threatened/action/non-marine-invertebrates/species1.html#boggomoss

Clark, J.R. (1990). The ecosystem approach from a practical point of view. *Conservation Biology* 13: 679–681.

Clarke, P.J. and Knox, K.J.E. (2002). Post-fire response of shrubs in the tablelands of eastern Australia: do existing models explain habitat differences? *Australian Journal of Botany* 50: 53–62.

Clawson, M.L., Bourret, A. and Benson, D.R. (2004). Assessing the phylogeny of *Frankia*-actinorhizal plant nitrogen-fixing root nodule symbioses with *Frankia* 16S rRNA and glutamine synthtase gene sequences. *Molecular Phylogenetics and Evolution* 31: 131–138.

Clayton, S. (1998). Supporting bushland with science. http://www.treesforlife.org.au/ReLeaf/archives/science/html

Clemann, N., and Loyn, R. (2003). *Barking Owl* Ninox connivens. *Action Statement No. 116*, Department of Sustainability and Environment, Melbourne.

Clemens, S., Wang, P. and Prell, W. (2003). Monsoons and global linkages on Milankovitch and sub-Milankovitch time scales. *Marine Geology* 201: 1–3.

Coates, D.J. (2000). Defining conservation units in a rich and fragmented flora: implications for the management of genetic resources and evolutionary processes in south-west Australian plants. *Australian Journal of Botany* 48: 329–339.

Coates, D.J. and Hopper, S.D. (2000). Preface. *Australian Journal of Botany* 48: i–iii.

Coates, F. and Kirkpatrick, J.B. (1999). Is geographic range correlated with climatic range in Australian *Spyridium* taxa? *Australian Journal of Botany* 47: 755–767

Coates, F., Kirkpatrick, J.B. and Minchin, P.R. (1999). Towards an explanation of the causes of the rarity of two *Tasmanium spyridium* species. *Australian Journal of Ecology* 24: 11–17.

Coates, F., Walsh, N.G. and James, E.A. (2002). Threats to the survival of the Grampians pincushion lily (*Borya mirabilis*, Liliaceae) — a short-range endemic from western Victoria. *Australian Systematic Botany* 15: 477–483.

Cockburn, A. (2003). Cooperative breeding in oscine passerines: does sociality inhibit speciation? *Proceedings of the Royal Society, Lond. series B* 270: 2207–2214.

Cogger, H.G. (1992). *Reptiles and Amphibians of Australia*, 5th ed. Reed Books, Melbourne.

Cogger, H.G. (2000). *Reptiles and Amphibians of Australia,* 6th ed. Reed Books, Melbourne.

Cohen, J.E. and Briand, F. (1984). Trophic links of community food webs. *Proceedings of the National Academy of Sciences* 81: 4105–4109.

Collins, B.G. and Newland, C. (1986). Honeyeater population changes in relation to food availability in the Jarrah forest of Western Australia. *Australian Journal of Ecology* 11: 63–76.

Collinson, M.E. (1990). Plant evolution and ecology during the early Cainozoic diversification. *Advances in Botanical Research* 17: 1–98.

Collinson, M.E. (2002). The ecology of Cainozoic ferns. *Review of Palaeobotany and Palynology* 119: 51–68.

Collinson, M.E. and van Konijnenburg-van Cittert, J.H.A. (2002). Ecology of ferns through time (IOPC-VI). *Review of Palaeobotany and Palynology* 2427: vii–viii.

Common, I.F.B. and Waterhouse, D.F. (1981). *Butterflies of Australia*, 2nd ed. Angus and Robertson, Sydney.

Comport, S.S., Ward, S.J. and Foley, W.J. (1996). Home ranges, time budgets and food-tree use in a high density tropical population of Greater Gliders, *Petauroides volans minor*. *Wildl. Res.* 23: 401–419.

Connor, E.F. and McCoy, E.D. (1979). The statistics and biology of the species-area relationship. *The American Naturalist* 113: 791-833

Considine, J.A. (1996). Emerging indigenous crops of Australia. In: J. Janick (ed.), *Progress in New Crops*. ASHS Press, Alexandria, VA. pp. 26–36.

Contreras-Medina, R. and Luna Vega, I. (2002). On the distribution of gymnosperm genera, their areas of endemism and cladistic biogeography. *Australian Systematic Botany* 15: 193–203.

Cooper, C.B. and Walters, J.R. (2002). Experimental evidence of disrupted dispersal causing decline of an Australian passerine in fragmented habitat. *Conservation Biology* 16: 471–478.

Correge, T., Gagan, M.K., Beck, J.W., Burr, G.S., Cabloch, G. and Le Cornec, F. (2004). Interdecadal variation in the extent of South Pacific tropical waters during the Younger Dryas event. *Nature* 428: 927–929.

Couvet, D. (2002). Deleterious effects of restricted gene flow in fragmented populations. *Conservation Biology* 16: 369–376.

Covacevich, J.A., Couper, P.J. and McDonald, K.R. (1996). *Lerista allanae* (Scincidae: Lygosominae): 60 years from exhibition to extinction? *Memoirs of the Queensland Museum* 39: 247–256.

Covacevich, J.A., Couper, P.J. and McDonald, K.R. (1998). Reptile diversity at risk in the Brigalow Belt, Queensland. *Memoirs of the Queensland Museum* 42: 475–486.

Cracraft, J. and Prum, R.O. (1988). Patterns and processes of diversification: speciation and historical congruence in some neotropical birds. *Evolution* 42: 603–620.

Crandall, K.A., Bininda-Emonds, O.R.P., Mace, G.M. and Wayne, R.K. (2000). Considering evolutionary processes in conservation biology. *Trends in Ecology and Evolution* 15: 290–295.

Crane, M.A. and Molnar, P. (2001). Closing of the Indonesian seaway as a precursor to east African aridification around 3–4 million years ago. *Nature* 411: 157–162.

Crayn, D.M., Brown, E.A. and Powell, J.M. (2003). A revision of *Lissanthe* (Styphelioideae: Ericaceae). *Australian Systematic Botany* 16: 595–619.

Cremer, K.W. (1966). Dissemination of seed form *Eucalyptus regnans*. *Australian Forestry* 30: 33–37.

Cresser, M.S., Smart, R., Billet, M.F., Soulsby, C., Neal, C., Wade, A., Langan, S. and Edwards, A.C. (2000). Modelling water chemistry for a major Scottish river from catchment attributes. *Journal of Applied Ecology* 37 (Supplement 1): 171–184.

Crisp, M. (2003). Evolution of bird pollination among Australian legumes. http://www.anu.edu.au/BoZo/Crisp/Postgrad%20info/Brd-poll.html

Crisp, M.D., Laffan, S., Linder, H.P. and Monro, A. (2001). Endemism in the Australian flora. *Journal of Biogeography* 28: 183–198.

Cronk, Q.C.B. (1997). Islands: stability, diversity, conservation. *Biodiversity and Conservation* 6: 477–493.

Cronk, Q.C.B. and Fuller, J.L. (1995). *Plant Invaders — the Threat to Natural Ecosystems*. Chapman and Hall, London.

Cross, E.W., Quinn, C.J. and Wagstaff, S.J. (2002). Molecular evidence for the polyphyly of *Olearia* (Astereae: Asteraceae). *Plant Systematics and Evolution* 235: 99–120.

Crossman, D.G. and Reimer, D.S. (1986). Mammals, birds, reptiles and amphibians of the Taroom Shire, Central Queensland. *Queensland Journal of Agricultural and Animal Sciences* 43: 55–72.

Crouch, S. (1998). Mt Archer and Berserker Range. *Rocks and Landscape Notes*. Geological Society of Australia, Queensland Division.

Crozier, R.H. (1992). Genetic diversity and the agony of choice. *Biological Conservation* 61: 11–15.

Crozier, R.H. (1997). Preserving the information content of species: genetic diversity, phylogeny, and conservation worth. *Annual Review of Ecology and Systematics* 28: 243–268.

D'Souza, N.K., Colquhoun, I.J., Shearer, B.L. and Hardy, G.E.St.J. (2004). The potential for five Western Australian native *Acacia* species for biological control of *Phytophthora cinnamomi. Australian Journal of Botany* 52: 267–279.

Dale, J.A and Hawkins, P.J. (1983). *Phenological studies of Spotted Gum in southern inland Queensland* Technical Paper number 35. Department of Forestry. S.R. Hampson, Government Printer, Queensland.

Danielsen, F. (1997). Stable environments and fragile communiteis: does history determine the resilience of avian rain-forest communities to habitat degradation? *Biodiversity and Conservation* 6: 423–433.

Dansgaard, W., Johnsen, S.J., Clausen, H.B., Dahl-Jensen, D., Gundestrup, N.S., Hammer, C.J., Hvidberg, C.S., Steffensen, J.P., Sveinbjörnsdottir, A.E., Jouzel, J. and Bond, G. (1993). Evidence for general instability of past climate from a 250-kyr ice-core record. *Nature* 364: 218–220.

Date, E.M, and Paull, D.C. (2000). *Fauna survey of the north-west cypress/ironbark forests.* State Forests of New South Wales, Western Region.

Daugherty, C.H. and Allendorf, F.W. (2002). The numbers that really matter. *Conservation Biology* 16: 283–284.

Davey, S. (1993). Notes on the habitat of four Australian owl species. In: P. Olsen and J. Olsen (eds). *Proceedings of the 10th Anniversary Conference of the Australian Raptor Association, Canberra, 1993*. ARA Canberra.

Davis, B.K. and Henderson, R.A. (1996). Rift-phase extensional fabrics of the back-arc Drummond Basin, eastern Australia. *Basin Research* 8: 371–381.

Davis, C.C., Bell, C.D., Fritsch, P.W. and Mathews, S. (2002). Phylogeny of *Acridocarpus-Brachylophon* (Malpighiaceae): implications for Tertiary tropical floras and Afroasian biogeography. *Evolution* 56: 2395–2405.

de Candolle, A.P. (2003). Phylogenetic biogeography deconstructed. *Journal of Biogeography* 30: 1285–1296.

de Kok, R.P.J. and West, J.G. (2002). A revision of *Pultenaea* (Fabaceae) 1. Species with ovaries glabrous and/or with tufted hairs. *Australian Systematic Botany* 15: 81–113.

de Kok, R.P.J. and West, J.G. (2003). A revision of the genus *Pultenaea* (Fabaceae). 2. Eastern Australian species with velutinous ovaries and incurved leaves. *Australian Systematic Botany* 16: 229–273.

DeAngelis, D.L. and Waterhouse, J.C. (1987). Equilibrium and nonequilibrium concepts in ecological models. *Ecological Monographs* 57: 1–21.

DeCelles, P.G. and Giles, K.A. (1996). Foreland basin systems. *Basin Research* 8: 105–123.

Dennerlein, C. (1997). Lines to hold, lines to ignore: the paradox of areas. In: J.J. Pigram and R.C. Sundell (eds), *National Parks and Protected Areas Selection, Delimitation and Management*. Centre for Water Policy Research, Armidale, New South Wales, Australia. pp. 45–59.

Despres, L., Gielly, L., Redoutet, B. and Taberlet, P. (2003). Using aflP to resolve phylogenetic relationships in a morphologically diversified plant species complex when nuclear and chloroplast sequences fail to reveal variability. *Molecular Phylogenetics and Evolution* 27: 185–196.

Dettmann, M.E. and Clifford, H.T. (2000). Monocotyledon fruits and seeds, and an associated palynoflora from Eocene-Oligocene sediments of coastal central Queensland, Australia. *Review of Palaeobotany and Palynology* 110: 141–173.

Dettmann, M.E. and Clifford, H.T. (2002). *Spondylostrobus* F.Mueller: operculate fruits of an extinct dictotyledon from the mid-Tertiary of Australia. *Review of Palaeobotany and Palynology* 122: 219–237.

Dickison, W.C., Hils, M.H., Lucansky, T.W. and Stern, W.L (1994). Comparative anatomy and systematics of woody Saxifragaceae. *Aphanopetalum* Endl. *Botanical Journal of the Linnean Society* 114: 167–182.

Dickman, C.R., Leung, L. K.-P. and Van Dyck, S.M. (2000). Status, ecological attributes and conservation of native rodents in Queensland. *Wildl. Res.* 27: 333–346.

Dieckmann, U. and Moebeli, M. (1999). On the origin of species by sympatric speciation. *Nature* 400: 354–357.

Dimmick, W.W., Ghedotti, M.J., Grose, M.J., Maglia, A.M., Meinhardt, D.J. and Pennock, D.S. (2001). The evolutionarily significant unit and adaptive crieria: a response to Young. *Conservation Biology* 15: 788–790.

Dodson, J.R. and Ramrath, A. (2001). An Upper Pliocene lacustrine environmental record from south-western Australia: preliminary results. *Palaeogeography, Palaeoclimatology, Palaeoecology* 167: 309–320.

Donald, P.F. (2004). Biodiversity impacts of some agricultural commodity production sytems. *Conservation Biology* 18: 17–37.

Donnellan, S.C., Hutchinson, M.N., Dempsey, P. and Osborne, W.S. (1988). Systematics of the *Egernia whitii* species group (Lacertilia: Scincidae) in south-eastern Australia. *Australian Journal of Zoology* 50: 439-459.

Donnellan, S.C., Hutchinson, M.N. and Saint, K.M. (1999). Molecular evidence for the phylogeny of Australian gekkonoid lizards. *Biological Journal of the Linnean Society* 67: 97–118.

Donnellan, S.C. and Mahony, M.J. (2004). Allozyme, chromosomal and morphological variability in the *Litoria lesueuri* species group (Anura: Hylidae), including a description of a new species. *Australian Journal of Zoology* 52: 1-28.

Doran, J.C. and Skelton, D.J. (1982). *Acacia mangium* seed collections for international provenance trials. *Forest Genetic Resources Information* 11: 47–53.

Doran, J.C. and Turnbull, J.W. (1997). *Australian Trees and Shrubs: Species for Land Rehabilitation and Farm Planting in the Tropics*. Australian Centre for International Agricultural Research, Canberra. p. 9.

Doremus, H. and Pagel, J.E. (2001). Why listing may be forever: perspectives on delisting under the U.S. Endangered Species Act. *Conservation Biology* 15: 1258–1268.

DPI (1998). *Wood Availability Estimates for Allocation Zones in the SEQ RFA Region*. Queensland Department of Primary Industries – Forestry, Brisbane.

Drinnan, A.N. and Ladiges, P.Y. (1991). Floral development and systematic position of *Eucalyptus curtisii* (Myrtaceae). *Australian Systematic Botany* 4: 539–551.

Driscoll, D., Milkovits, G. and Freudenberger, D. (2000). *Impact and Use of Firewood in Australia*. CSIRO Sustainable Ecosystems, Canberra.

Driskell, A.C. and Christidis, L. (2004). Phylogeny and evolution of the Australo-Papuan honeyeaters (Passeriformes, Meliphagidae). *Molecular Phylogenetics and Evolution* 31: 943–960.

Ducousso, M., Bena, G., Bourgeois, C., Buyck, B., Eyssartier, G., Vincelette, M., Rabevohitra, R., Randrihasipara, L., Dreyfus, B. and Prin, Y. (2004). The last common ancestor of Sarcolaenaceae and Asian dipterocarp trees was ectomycorrhizal before the India-Madagascar separation, about 88 million years ago. *Molecular Ecology* 13: 231–236.

Dufrene, M. and Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* 67: 345–366

Dunn, K. (1993). The distribution, status and management of the piceatus jewel butterfly. *Entomological Society of Queensland news bulletin* 21: 155–159.

Duvall, M.R. and Ervin, A.. (2004). 18S gene trees are positively misleading for monocot/dicot phylogenetics. *Molecular Phylogenetics and Evolution* 30: 97–106.

Eby, P., Richards, G., Collins, L. and Parry-Jones, K. (1999). The distribution, abundance and vulnerability to population reduction of a nomadic nectarivore, the Grey-headed Flying-fox *Pteropus poliocephalus* in New South Wales, during a period of resource concentration. *Australian Zoologist* 31: 240–253.

ECC (1997). *Box-Ironbark Forests and Woodlands Investigation Resources and Issues Report*. Environment Conservation Council, Melbourne.

ECC (2001). *Box-Ironbark Forests and Woodlands Investigation Final Report.* Environment Conservation Council, Melbourne.

Edwards, K.J. and Gadek, P.A. (2000). Evolution and biogeography of *Alectryon* (Sapindaceae). *Molecular Phylogenetics and Evolution* 20: 14–26.

Ehmann, H. (1993). A field observation on the Lake Cronin Snake (Denisonia atriceps) and mineral exploration within its range. In D. Lunney and D. Ayers (eds.) *Herpetology in Australia. A diverse discipline.* pp 346-348. Royal Zoological Society of New South Wales, Mosman.

Ehrlich, P.R. (2001). Intervening in evolution: ethics and actions. *Proceedings of the National Academy of Sciences* 98: 5477–5480.

Eklund, H. (2003). First Cretaceous flowers from Antarctica. *Review of Palaeobotany and Palynology* 127: 187–217.

Eldridge, K,, Davidson, J., Harwood, C. and van Wyk, G. (1993). *Eucalypt Domestication and Breeding*. Clarendon Press, Oxford.

Elliott, C.P. and Byrne, M. (2004). Phylogenetics and the conservation of rare taxa in the *Eucalyptus angustissima* complex in Western Australia. *Conservation Genetics* 5: 39–47.

Elliott, C.P., Yates, C.J., Ladd, P.G. and Coates, D.J. (2002). Morphometric, genetic and ecological studies clarify the conservation status of a rare *Acacia* in Western Australia. *Australian Journal of Botany* 50: 63–73.

Ellstrand, N.C. (1992). Gene flow by pollen: implications for plant conservation genetics. *Oikos* 63: 77–86.

Ellstrand, N.C. and Elam, D.R. (1993). Population genetic consequences of small population size: implications for plant conservation. *Annual Review Ecology and Systematics* 24: 217–242.

Ennos, R.A., Worrell, R. and Malcolm, D.C. (1998). The genetic management of native species in Scotland. *Forestry* 71: 1–23.

Enright, N.J. (1995). Conifers of tropical Australasia. In: N.J. Enright and R.S. Hill (eds.), *Ecology of the Southern Conifers*. Melbourne University Press, Melbourne. pp. 197–222.

Enright, N.J. and Ogden, J. (1995). The southern conifers — a synthesis. In: N.J. Enright and R.S. Hill (eds), *Ecology of the Southern Conifers*. Melbourne University Press, Melbourne. pp. 271–287.

Environment Australia (2000). *Response to disturbance of forest species in CRA regions in NSW-southern region.* NSW CRA/RFA Steering Committee, Sydney.

Environmental Protection Agency (2001). *Master Plan for Queensland's Parks System*. Queensland Parks and Wildlife Service, Environmental Protection Agency, Brisbane.

Environmental Protection Agency (2002a). *Biodiversity Assessment Mapping Methodology*, Version 2.1, July 2002. Environmental Protection Agency, Brisbane.

Environmental Protection Agency (2002b). *Biodiversity Planning Assessment, Brigalow Belt South Fauna Expert Panel Report*, September 2002. Environmental Protection Agency, Brisbane.

Environmental Protection Agency (2003a). *Brigalow Belt South*, *Biodiversity Planning Assessment*, *Version 1.2*, April 2003. Environmental Protection Agency, Brisbane.

Environmental Protection Agency (2003b). *Regional Ecosystem Description Database (REDD)*. Version 4.0. Updated September 2003. Environmental Protection Agency, Brisbane.

Ericson, P.G.P., Irestedt, M. and Johansson, U. S. (2003). Evolution, biogeography and patterns of diversification in passerine birds. *Journal of Avian Biology* 34: 3–15.

Estabrook, G.F., Winsor, J.A., Stephenson, A.G. and Howe, H.F. (1982). When are two phenological patterns different? *Botanical Gazette* 143: 374–378.

Excoffier, L. (2004a). Patterns of DNA sequence diversity and genetic structure after a range expansion: lessons from the infinite-island model. *Molecular Ecology* 13: 853–864.

Excoffier, L. (2004b). Special issue: analytical methods in phylogeography and genetic structure. *Molecular Ecology* 13: 727.

Eyre, T.J. (2002). *Habitat preferences and management of large gliding possums in southern Queensland*, PhD thesis, Southern Cross University.

Faith D.P. (1994). Genetic diversity and taxonomic priorities for conservation. *Biological Conservation* 68: 69–74.

Faith, D.P. (2004). L.A.S. Johnson Review No. 1 — From species to supertrees: Popperian corroboration and some current controversies in systematics. *Australian Systematic Botany* 17: 1–16.

Faith, D.P., Reid, C.A.M. and Hunter, J. (2003). Integrating phylogenetic diversity, complementarity and endemism for conservation assessment. *Conservation Biology* 19: 255–261.

Falconer, D.S. and Mackay, T.F.C. (1996). *Introduction to Quantitative Genetics*. 4th Edition. Wiley, New York.

Falk, D.A. (1990). Endangered forest resources in the U.S.: Integrated Strategies for Conservation of Rare Species and Genetic Diversity. *Forest Ecology and Management* 35: 91–117.

Falk, D.A. (1992). From conservation biology to conservation practice: strategies for protecing plant diversity. In: P.L Fiedler and S.K. Jain (eds), *Conservation Biology: Theory and Practice of Nature Conservation and Management*. Chapman and Hall, New York. pp. 396–431.

Fensham, R.J. and Butler, D.W. (2004). Spatial pattern of dry rainforest colonizing unburnt *Eucalyptus* savanna. *Austral Ecology* 29: 121–128.

Fensham, R.J., Fairfax, R.J., Butler, D.W. and Bowman, D.M.J.S. (2003). Effects of fire and drought in a tropical eucalypt savanna colonized by rain forest. *Journal of Biogeography* 30: 1405–1414.

Fergusson, Chris (1998). School of Geosciences - Anakie Inlier. School of Geosciences - Research.

Ferraro, P.J. (2001). Global habitat protection: limitations of development interventions and a role for conservation performance payments. *Conservation Biology* 15: 990–1000.

Fiala, B. and Linsenmair, K.E. (1995). Distribution and abundance of plants with extrafloral nectaries in the woody flora of a lowland primary forest in Malaysia. *Biodiversity and Conservation* 4: 165–182.

Field, C.B. (1990). Review. *Ecology* 71: 2397–2398.

Fielding, C.R., Stephens, C.J. and Holcombe, R.J. (1993). Submarine mass-wasting deposits as an indicator of the onset of foreland thrust loading: Late Permian Bowen Basin, Queensland, Australia. http://www.earthsciences.uq.edu.au/~rodh/publications/Moah.html - pp. 1–7.

Figge, F. (2004). Bio-folio: applying portfolio theory to biodiversity. *Biodiversity and Conservation* 13: 827–849.

Fiz, O., Valcarcel, V. and Vargas, P. (2002). Phylogenetic position of Mediterranean Astereae and character evolution of daisies (Bellis, Asteraceae) inferred from nrDNA ITS sequences. *Molecular Phylogenetics and Evolution* 25: 157–171.

Fjeldsa, J. (1994). Geographical patterns for relict and young species of birds in Africa and South America and implications for conservation priorities. *Biodiversity and Conservation* 3: 207–226.

Fjeldsa, J., Ehrlich, D., Lambin, E. and Prins, E. (1997). Are biodiversity 'hotspots' correlated with current ecoclimatic stability? A pilot study using the NOAA-AVHRR remote sensing data. *Biodiversity and Conservation* 6: 401–422.

Fjeldsa, J. and Lovett, J.C. (1997a). Biodiversity and environmental stability. *Biodiversity and Conservation* 6: 315–323.

Fjeldsa, J. and Lovett, J.C. (1997b). Geographical patterns of old and young species in African forest biota: the significance of specific montane areas as evolutionary centres. *Biodiversity and Conservation* 6: 325–346.

Florence, R.G. (1964). A comparative study of flowering and seed production in six blackbutt (*Eucalyptus pilularis* Sm.) forest stands. *Australian Forestry* 28: 23–33.

Ford, H.A. (1989). *Ecology of Birds*. Surrey Beatty & Sons, Chipping Norton, NSW. p. 57.

Ford, H.A., Barrett, G.W., Saunders, D.A. and Recher, H.F. (2001). Why have the birds in the woodlands of Southern Australia declined? *Biological Conservation* 97: 71–88.

Ford, H.A., Bell, H., Nias, R. and Noske, R. (1988). The relationship between ecology and the incidence of cooperative breeding in Australian birds. *Behavioral Ecology and Sociobiology* 22: 239–250.

Forest Ecosystem Research and Assessment (2001). *Preliminary Assessment of Forest Values within the Western Queensland Hardwood Zone.* Queensland National Parks and Wildlife Service, Environment Protection Agency, Indooroopilly.

Forey, P.L., Humphries, C.J. and vane-Wright, E.I. (eds) (1994). *Systematics and Conservation Evaluation*. Clarendon Press, Oxford.

Forster, P.I. (1995a). *Omphalea celata*, a new species of Euphorbiaceae from central Queensland. *Austrobaileya* 4: 381–385.

Forster, P.I. (1995b). *Sankowskya*, a new genus of Euphorbiaceae (Dissiliariinae) from the Australian Wet Tropics. *Austrobaileya* 4: 329–335.

Forster, P.I. (1997a). A taxonomic revision of *Dissiliaria* F.Muell. ex Baill. (Euphorbiaceae) *Austrobaileya* 5: 9–27.

Forster, P.I. (1997b). Three new species of *Fontainea* Heckel (Euphorbiaceae) from Australia and Papua New Guinea. *Austrobaileya* 5: 29–37.

Forster, P.I. (1999). A taxonomic revision of *Bridelia* willd. (Euphorbiaceae) in Australia. *Austrobaileya* 5: 405–419.

Forster, P.I. (1999b). A taxonomic revision of *Mallotus* Lour. (Euphorbiaceae) in Australia. *Austrobaileya* 5: 457–497.

Forster, P.I. (2000). *Chamaesyce ophiolitica* P.I.Forst. (Euphorbiaceae), a new and endangered species endemic to serpentine vegetation in central Queensland. *Austrobaileya* 5: 711–714.

Forster, P.I. (2003). A taxonomic revision of *Croton* L. (Euphorbiaceae) in Australia. *Austrobaileya* 6: 349–436.

Forsyth, A. and Nott, J. (2003). Evolution of drainage patterns on Cape York Peninsula, northeast Queensland. *Australian Journal of Earth Sciences* 50: 145–155.

Fox, C.W., Roff, D.A. and Fairbairn, D.J. (2001). *Evolutionary Ecology*. Oxford University Press, New York.

Fox, M.D. (1999). Present environmental influences on the Australian flora. *Flora of Australia* 1: 205–241.

Francois, R. (2004). Cool stratification. *Nature* 428: 31–32.

Frank, K. (2004). Ecologically diferentiated rules of thumb for habitat network — lessons from a formula. *Biodiversity and Conservation* 13: 189–206.

Frankel, O.H., Brown, A.H.D. and Burdon, J.J. (1995). *The Conservation of Plant Biodiversity*. Cambridge University Press, Cambridge, United Kingdom.

Frankham, R. (1996). Relationship of genetic variation to populations size in wildlife. *Conservation Biology* 10: 1500–1508.

Franklin, D. (2000). *Trouble in the never-never. Wingspan* 10(1): 14–21.

Franklin, D.C., Menhorst, P.W. and Robinson, J.L. (1989). Ecology of the Regent Honeyeater *Xanthomyza phrygia*. *Emu* 89: 140–54.

Fraser, D.J. and Bernatchez, L. (2001). Adaptive evolutionary conservation: towards a unified concept for defining conservation units. *Molecular Ecology* 10: 2741–2752.

Freudenberger, D. and Brooker, L. (2004). Development of the focal species approach for biodiversity conservation in the temperate agricultural zones of Australia. *Biodiversity and Conservation* 13: 253–274.

Gabbe, A.P., Robinson, S.K. and Brawn, J.D. (2002). Tree-species preferences of foraging insectivorous birds: implications for floodplain forest restoration. *Conservation Biology* 16: 462–470.

Gaggiotti, O.E., Brooks, S.P., Amos, W. and Harwoods, J. (2004). Combining demographic, environmental and genetic data to test hypotheses about colonization events in metapopulations. *Molecular Ecology* 13: 811–825.

Garcia-Jacas, N., Susanna, A., Garnatje, T. and Vilatersana, R. (2001). Generic Delimitation and phylogeny of the Subtribe Centaureinae (Asteraceae): a combined nuclear and chloroplast DNA analysis. *Annals of Botany* 87: 503–515.

Garnett, S. and Crowley, G. (2000). *The Action Plan for Australian Birds*. Environment Australia, Canberra.

Garnier-Gere, P.H. and Ades, P.K. (2001). Environmental surrogates for predicting and conserving adaptive genetic variability in tree species. *Conservation Biology* 15: 1632–1644.

Gaston, K.J., Pressey, R.L. and Margules, C.R. (2002). Persistence and vulnerability: retaining biodiversity in the landscape and in protected areas. *Journal of Biosciences* 27 Supplement 2: 361–384

Geffen, E. and Yom-Tov, Y. (1999). Old endemics and new invaders: alternative strategies of passerines for living in the Australian environment. *Behavioral Ecology and Sociobiology* 47: 250–257.

Gemmill, C.E.C., Allan, G.J., Wagner, W.L. and Zimmer, E.A. (2002). Evolution of insular Pacific *Pittosporum* (Pittosporaceae): origin of the Hawaiian radiation. *Molecular Phylogenetics and Evolution* 22: 31–42.

Gentry, A.H. (1986). Endemism in tropical versus temperate plant communities. In: M.E. Soule (ed.), *Conservation Biology: The Science of Scarcity and Diversity*. Sinauer Associates, Inc., Sunderland, Massachusetts. Chapter 8

Gering, J.C. (2004). Reply to Magnusson. *Conservaiton Biology* 18: 5–6.

Gering, J.C., Crist, T.O. and Veech, J.A. (2003). Additive partioning of species diversity across multiple spatial scales: implications for regional conservation of biodiversity. *Conservation Biology* 17: 88–499.

Gibbons, P. and Lindenmayer, D. (2002). *Tree Hollows and Wildlife Conservation in Australia.* CSIRO Publishing, Collingwood, Australia.

Gill, A.M. (1997). Eucalypts and fires: interdependent or independent? In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 151–167.

Gill, M.A. (2001). Economically destructive fires and biodiversity conservation: an Australian perspective. *Conservation Biology* 15: 1558–1560.

Gillespie, G.R. and Hines, H.B. (1999). Status of temperate riverine frogs in south-eastern Australia*.* In: Campbell, A. (ed.) *Declines and Disappearances of Australian Frogs*. Environment Australia, Canberra. pp. 109–130.

Gilmore, A. (1999). Hard Science, Soft Science or Pseudoscience: an assessment of “Towards reserve options for forest taxa in South-East Queensland: Taxa at risk, threats, conservation requirements and recovery planning.” Australian Rainforest Conservation Society (unpublished).

Gitzendanner, M.A. and Soltis, P.S. (2000). Patterns of generic variation in rare and widespread plant congeners. *American Journal of Botany* 87: 783–792.

Given, D.R. (1993). Changing aspects of endemism and endangerment in Pteridophyta. *Journal of Biogeography* 20: 293–302.

Goel, S, Raina, S.N. and Ogihara, Y. (2002). Molecular evolution and phylogenetic implications of internal transcribed spacer sequences of nuclear ribosomal DNA in the *Phaseolus-Vigna* complex. *Molecular Phylogenetics and Evolution* 22: 1–19.

Goldblatt, P. (1997). Floristic diversity in the Cape flora of South Africa. *Biodiversity and Conservation* 6: 359–377.

Goldingay, R.L and Kavanagh, R.P. (1991). The yellow-bellied glider: a review of its ecology, and management considerations. In: D. Lunney (ed.), *Conservation of Australia's Forest Fauna*. Royal Zoological Society of New South Wales. pp. 365–375.

Goldingay, R.L. and Possingham, H.P. (1995). Area requirements for viable populations of the Australian gliding marsupial *Petaurus australis*. *Biol. Cons.* 73: 161–167.

Gray, J.S. (1989). Effects of environment stress on species rich assemblages. *Biological Journal of the Linnean Society* 37: 19–32.

Greer, A. E. (1989). *Australian Lizards*. Surrey Beatty and Sons Pty Ltd, Chipping Norton, NSW, Australia.

Grey, M.J., Clarke, M.F., and Loyn, R.H. (1998). Influence of the Noisy Miner *Manorina melanocephala* on avian diversity and abundance in remnant Grey Box woodland. *Pacific Conservation Biology* 4: 55–69.

Griffin, A.R., Moran, G.F. and Fripp, Y.J. (1987). Preferential outcrossing in *Eucalyptus regnans* F. Muell. *Australian Journal of Botany* 35: 465–475.

Guerin, G. (2001). Plant megafossils from the Oligocene of Riversleigh, Queensland and Little Rapid River, Tasmania. B.Sc. Hons. Thesis, Department of Environmental Biology, University of Adelaide.

Gugerli, F., Sperisen, C., Buchler, U., Brunner, I., Brodbeck, S., Palmer, J.D. and Qiu, Y-L. (2001). The evolutionary split of Pinaceae from other conifers: evidence from an intron loss and a multigene phylogeny. *Molecular Phylogenetics and Evolution* 21: 167–165.

Gunn, R.H. (1984). Soil Landscapes of the Brigalow Belt in Queensland. In: A. Bailey (ed.) *The Brigalow Belt of Australia*. Royal Society of Queensland, Brisbane. pp. 7–21.

Gunnell, Y. (2000). Apatite fission track thermochronology: an overview of its potential and limitations in geomorphology. *Basin Research* 12: 115–132.

Gupta, S. and Cowie, P. (2000). Processes and controls in the stratigraphic development of extensional basins. *Basin Research* 12: 185–194.

Guymer, G.P. (1979). The genus *Brachychiton* Schott et Endl. (Sterculiaceae): Taxonomic revision, pollen morphology, wood anaotmy, seedling morphology and evolution. PhD Thesis, University of New England.

Hackett, S.J., Griffiths, C.S., Bates, J.M. and Klein, N.K. (1995). Letter to the Editor — Re: A commentary on the use of sequence data for phylogeny reconstruction. *Molecular Phylogenetics and Evolution* 4: 350–356.

Hadden, S.A. and Westbrooke, M.E. (1996). Habitat relationships of the herpetofauna of remnant buloke woodlands of the Wimmera Plains, Victoria. *Wildl.Res.* 23: 363–372.

Haffer, J. (1982). General aspects of the refuge theory. In: G.T. Prance (ed.), *Biological Diversification in the Tropics*. Clarendon and Oxford University Press, Oxford. pp. 6–24.

Haffer, J. (1997). Alternative models of vertebrate speciation in Amazonia: an overview. *Biodiversity and Conservation* 6: 451–476.

Hahn, W.J. (2002). A phylogenetic analysis of the Arecoid line of palms based on plastid DNA sequence data. *Molecular Phylogenetics and Evolution* 23: 189–204.

Halford, D.A. and Henderson, R.J.F. (2002a). Studies in Euphorbiaceae A.L.Juss. sens. lat. 3. A revision of *Bertya* Planch. (Ricinocarpeae Mull.Arg., Bertyinae Mull.Arg.). *Austrobaileya* 6: 187–245.

Halford, D.A. and Henderson, R.J.F. (2002b). Studies in Euphorbiaceae A.L.Juss. sens. lat. 4. A revision of *Monotaxis* Brongn. (Acalyphoideae Ascherson, Ampereae Mull.Arg.) *Austrobaileya* 6: 273–292.

Halford, D.A. and Henderson, R.J.F. (2003). Studies in Euphorbiceae A.L.Juss. sens. lat. 5. A revision of *Pseudanthus* Sieber ex spreng. and *Stachystemon* Planch. (Oldfieldioideae Kohler and Webster, Caletieae Mull.Arg.). *Austrobaileya* 6: 445–496.

Hamley, T., Flower, P. and Smith, G.C. (1997). Present and past distribution of the Black-breasted Button-quail *Turnix melanogaster* in Queensland. *Sunbird* 27: 1–21.

Hansman, D.J. (2001). Floral biology of dry rainforest in north Queensland and a comparison with adjacent savanna woodland. *Australian Journal of Botany* 49: 137–153.

Harden, G.J., Hardin, D.W. and Godden, D.C. (2000). *Proteaceae of New South Wales*. UNSW Press, Royal Botanic Gardens, Sydney.

Harrington, M.G. and Gadek, P.A. (2004). Molecular systematics of the *Acmena* alliance (Myrtaceae): phylogenetic analyses and evolutionary implications with reference to Australian taxa. *Australian Systematic Botany* 17: 63–72.

Harrington, G.N. and Sanderson, K.D. (1994). Recent contraction of wet sclerophyll forest in the wet tropics of Queensland due to invasion by rainforest. *Pacific Conservation Biology* 1: 319–327.

Harris, M.R. Lamb, D. and Erskine, P.D. (2003). An investigation into the possible inhibitory effects of white cypress pine (*Callitris glaucophylla*) litter on the germination and growth of associated ground cover species. *Australian Journal of Botany* 51: 93–102.

Harrison, J., Miller, K. and McNeely, J. (1984). The world coverage of protected areas: development goals and environmental needs. In: J.A. McNeely and K.R. Miller (eds), *National Parks, Conservation and Development: The Role of Protected Areas in Sustaining Society*. Smithsonian Institution, Washington, D.C. pp. 24–33.

Harte, J. (1996). Feedbacks, threshholds and synergies in global change: population as a dynamic factor. *Biodiversity and Conservation* 5: 1069–1083.

Harte, J. and Kinzig, A.P. (1997). On the implications of species-area relationships for endemism, spatial turnover, and food web patterns. *Oikos* 80: 417–427.

Hartley, T.G. (2003). Neoschmidia, a new genus of Rutaceae from New Caledonia. *Adansonia* ser. 3, 25 (1): 7–12.

Hartley, T.G. (2001a). Morphology and biogeography in Australasian-Malesian Rutaceae. *Malayan Nat. J.* 55: 197–219.

Hartley, T.G. (2001b). On the taxonomy and biogeography of Euodia and Melicope (Rutaceae). *Allertonia* 8: 1–319.

Harwood, C. *Aspects of Species and Provenance Selection*. CSIRO Division of Forestry and Forest Products, A.C.T.

Hauk, W.D., Parks, Clifford R. and Chase, M.W. (2003). Phylogenetic studies of Ophioglossaceae: evidence from rbcL and trnL-F plastid DNA sequences and morphology. *Molecular Phylogenetics and Evolution* 28: 131–151.

Healey, M., Thompson, D. and Robertson, A. (1997). Amphibian communities associated with billabong habitats on the Murrumbidgee floodplain, Australia. *Australian-Journal-of-Ecology* 22: 270–278.

Heatwole, H.F. and Taylor, J. (1987). *Ecology of Reptiles*. Surrey Beatty & Sons Pty Limited, Chipping Norton, Australia.

Heinsohn, R.G., Cockburn, A. and Mulder, R.A. (1990). Avian cooperative breeding: old hypotheses and new directions. *Trends in Ecology and Evolution* 5: 403–407.

Heinsohn, R. and Double, M.C. (2004). Cooperate or speciate: new theory for the distribution of passerine birds. *Trends in Ecology and Evolution* 19: 55–57.

Henle, K., Davies, K.F., Kleyer, M., Margules, C. and Settele, J. (2004). Predictors of species sensitivity to fragmentation. *Biodiversity and Conservation* 13: 207–251.

Henle, K., Lindenmayer, D.B., Margules, C.R., Saunders, D.A. and Wissel, C. (2004). Species survival in fragmented landscapes: where are we now? *Biodiversity and Conservation* 13: 1–8.

Henle, K., Sarre, S. and Wiegand, K. (2004). The role of density regulation in extinction processes and population viability analysis. *Biodiversity and Conservation* 13: 9–52.

Hennequin, S., Ebihara, A., Ito, M., Iwatsuki, K. and Dubuisson, J-Y. (2003). Molecualr systematics of the fern genus *Hymenophyllum* s.l. (Hymenophyllaceae) based on chloroplastic coding and noncoding regions. *Molecular Phylogenetics and Evolution* 27: 283–301.

Henry, R.J. (1997). *Practical Applications of Plant Molecular Biology*. Chapman & Hall, London.

Hermanutz, L., Innes, D., Denham, A. and Whelan, R. (1998). Very low fruit: flower rations in *Grevillea* (Poteaceae) are independent of breeding system. *Australian Journal of Botany* 46: 465–478.

Heyerdahl, E.K. and Card, V. (2000). Implications of paleorecords for ecosystem management. *Trends in Ecology and Evolution* 15: 49–50.

Higgins, P.J. and Davies, S.J.J.F. (eds)(1999). *Handbook of Australian, New Zealand and Antarctic Birds — Vol. 4*. Oxford University Press, Melbourne.

Higgins, S.I., Pickett, S.T.A. and Bond, W. (2000). Predicting extinction risks for plants: environmental stochasticity can save declining populations. *Trends in Ecology and Evolution* 15: 515–520.

Hill, C.J. (1995). Linear strips of rainforest vegetation as potential dispersal corridors for rain forest insects. *Conservation Biology* 9: 1559–1566.

Hill, J.L. and Curran, P.J. (2003). Area, shape and isolation of tropical forest fragments: effects on tree species diversity and implications for conservation. *Journal of Biogeography* 30: 1391–1403.

Hill, K.D. (1992). A preliminary account of *Cycas* (Cycadaceae) in Queensland. *Telopea* Vol. 5(1)

Hill, K.D. (1999). A taxonomic revision of the White Mahoganies, *Eucalyptus* series *Acmenoideae* (Myrtaceae). *Telopea* 8: 219–247.

Hill, K.D. and Johnson, L.A.S. (1991). Systematic studies in the eucalypts. 4. New taxa in Eucalyptus (Myrtaceae). Telopea 4: 321–349.

Hill, K.D. and Johnson, L.A.S. (1994). Systematic studies in the eucalypts. 6. A revision of the coolibahs, *Eucalyptus* subgenus *Symphyomyrtus* section *Adnataria* series *Oliganthae* subseries *Microthecosae* (Myrtaceae). *Telopea* 5: 743–771.

Hill, K.D. and Johnson, L.A.S. (1995). Systematic studies in the eucalypts. 7. A revision of the bloodwoods, genus *Corymbia* (Myrtaceae). *Telopea* 6: 185–504.

Hill, K.D. and Johnson, L.A.S. (2000). Systematic studies in the eucalypts. 10. New tropical and subtropical eucalypts from Australia and New Guinea (*Eucalyptus*, Myrtaceae). Telopea 8: 503–539.

Hill, R.S. and Brodribb, T.J. (1999). Turner Review No. 2: Southern Conifers in time and space. *Australian Journal of Botany* 47: 639–696.

Hill, R.S. and Christophel, D.C. (1988). Tertiary leaves of the Tribe Banksieae (Proteaceae) from south-eastern Australia. *Botanical Journal of the Linnean Society* 97: 205–227.

Hill, R.S. and Scriven, L.J. (1995). The angiosperm-dominated woody vegetation of Antarctica: a review. *Review of Palaeobotany and Palynology* 86: 175–198.

Hilu, K.W. (2004). Phylogenetics and chromosomal evolution in the Poaceae (grasses). *Australian Journal of Botany* 52: 13–23.

Hnatiuk, R.J. and Maslin, B.R. (1988). Phytogeography of *Acacia* in Australia in relation to climate and species-richness, *Australian J. Bot.* 36: 361–383.

Hobbs, R.J. (2001). Synergisms among habitat fragmentation, livestock grazing, and biotic invasions in Southwestern Australia. *Conservation Biology* 15: 1522–1528.

Hobbs, R.J. and Saunders, D.A. (1994). Effects of landscape fragmentation in agricultural areas. In: C. Moritz and J. Kikkawa (eds), *Conservation Biology in Australia and Oceania*. Surrey Beatty & Sons, Chipping Norton. pp. 77–95.

Hobbs, R.J. and Yates, C.J. (2003). Turner Review No. 7 — Impacts of ecosystem fragmentation on plant populations: generalising the idiosyncratic. *Australian Journal of Botany* 51: 471–488.

Hoffman, E.A. and Bouin, M.S. (2004). Historical data refute recent range contraction as cause of low genetic diversity in isolated frog populations. *Molecular Ecology* 13: 271–276.

Hogbin, P.M. and Crisp, M.D. (2003). Evolution of the coastal neospecies *Zieria prostrate* (Rutaceae) and its relationship to the *Zieria smithii* species complex. *Australian Systematic Botany* 16: 515–525.

Hogbin, P.M., Peakall, R. and Sydes, M.A. (2000). Achieving practical outcomes from genetic studies of rare Australian plants. *Australian Journal of Botany* 48: 375–382.

Holcombe, R.J., Stephens, C.J., Fielding, C.R., Gust, D., Little, T.A., Sliwa, R., McPhie, J. and Ewart, A. Tectonic evolution of the northern New England Fold Belt: Carboniferous to Early Permian transition from active accretion to extension.

Holloway, J.D. (1987). Macrolepidoptera diversity in the Indo-Australian tropics: geographic, biotopic and taxonomic variations. *Biological Journal of the Linnean Society* 30: 325–341.

Holloway, J.D. (2003). An addiction to Southeast Asian biogeography. *Journal of Biogeography* 30: 161–163.

Holt. R.D. (2002). On the interplay of dynamic instability and spatial processes. *Ecological Research* 17: 261–273.

Holt, R.D., Lawton, J.H., Polis, G.A. and Martinez, N.D. (1999). Trophic rank and the species-area relationship. *Ecology* 80: 1495–1504.

Hopper, S.D. (2000). How well do phylogenetic studies inform the conservation of Australian plants? *Australian Journal of Botany* 48: 321–328.

Hopper, S.D. and Brown, A.P. (2004). Robert Brown's *Caladenia* revisited, including a revision of its sister genera *Cyanicula*, *Ericksonella* and *Phyladenia* (Caladeniinae: Orchidaceae). *Australian Systematic Botany* 17: 171–240.

Hopper, S.D., Brown, A.P. and Marchant, N.G. (1997). Plants of Western Australian granite outcrops. *Journal of the Royal Society of Western Australia* 80: 141–158.

Horner, P. (2003). '*Cryptic Cryptos'-A taxonomic revision of Australian* Cryptoblepharus *(Scincidae)*. Australian Society of Herpetologists Conference, Mary River, Northern Territory, December 2003.

Horsup, A. (1999). *Northern Hairy-nosed Wombat* (Lasiorhinus krefftii) *Recovery Plan 1998–2002*. Report to Environment Australia, Canberra. Queensland Parks and Wildlife Service, Brisbane.

Horsup, A., James, C. and Porter, G. (1993). Vertebrates of dry rainforest of south and mideastern Queensland. *Mem. Qld. Mus.* 34: 215–228.

Hoskin, C.J., Couper, P.J. and Schneider, C.J. (2003). A new species of *Phyllurus* (Lacertilia: Gekkonidae) and a revised phylogeny and key for the Australian leaf-tailed geckos. *Australian Journal of Zoology*. 51: 153-164.

House, S.M. (1997). Reproductive biology of eucalypts. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 30–55.

House, J.I., Archer, S., Breshears, D.D., Scholes, R.J. and NCEAS Tree-Grass Interactions Participants (2003). Conundrums in mixed woody-herbaceous plant systems. *Journal of Biogeography* 30: 1763–1777.

Howarth, D.G. and Baum, D.A. (2002). Phylogenetic utility of a nuclear intron from nitrate reductase for the study of closely related plant species. *Molecular Phylogenetics and Evolution* 23: 525–528.

Hudson, N.J. and Franklin, C.E. (2002). Effect of aestivation on muscle characteristics and locomotor performance in the Green-striped burrowing frog, *Cyclorana alboguttata*. *Journal of Comparative Physiology* 172: 177–182.

Humphries, C.J., Williams, P.J. and Vane-Wright, R.I. (1995). Measuring biodiversity value for conservation. *Annual Review of Ecology and Systematics* 26: 93–111.

Hurt, C.R., Meredith, S. and Hamilton, P. (2003). Evolutionary ecology: integrating Theory, Technology, and Ecology. *Conservation Biology* 17: 342-343.

Hutchinson, M.F., Nix, H.A. and McMahon, J.P. (1992). Climate constraints on cropping systems. In: *Ecosystems of the World Vol. 18*: *field crop ecosystems*. Elsevier, Amsterdam.

Iddles, T.L., Read, J. and Sanson, G.D. (2003). The potential contribution of biomechanical properties to anti-herbivore defence in seedlings of six Australian rainforest trees. *Australian Journal of Botany* 51: 119–128.

Isern, A.R., McKenzie, J.A. and Feary, D.A. (1996). The role of sea-surface temperature as a control on carbonate platform development in the western coral Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology* 124: 247–272.

Jackson, J.B.C. (2001). What was natural in the coastal oceans? *Proceedings of the National Academy of Sciences* 98: 5411–5418.

Jaffre, T. (1995). Distribution and ecology of the conifers of New Caledonia. In: N.J. Enright and R.S. Hill (eds), *Ecology of the Southern Conifers*. Melbourne University Press, Melbourne. pp. 171–196.

Jaffre, T., Reeves, R.D. and Becquer, T. (eds) (1997). The ecology of ultramafic and metalliferous areas. The ecology of ultramafic and metalliferous areas. Proceedings of the Second International Conference on Serpentine Ecology (ORSTOM: Noumea: New Caledonia July 31-August 5 1995).

James, B.H., Donnellan, S.C. and Hutchinson, M.N. (2003). Taxonomic revision of the Australian lizard *Pygopus nigriceps* (Squamata: Gekkonoidea). *Records of the South Australian Museum*. 34: 37-52.

James, E.A. (2002). Preface for papers on short-range endemism. *Australian Systematic Botany* 15: i.

James, S.H. and Kennington, W.J. (1993). Selection against homozygotes and resource allocation in the mating system of *Eucalyptus camaldulensis* Dehn. *Australian Journal of Botany* 41: 381–391.

James, S.J. (2000). Genetic systems in the south-west flora: implications for conservation strategies for Australian plant species. *Australian Journal of Botany* 48: 341–347.

JANIS (1997). *Nationally Agreed Criteria for the Establishment of a Comprehensive, Adequate and Representative Reserve System for Forests in Australia.* A Report by the Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee. Commonwealth of Australia, Canberra.

Jansen, A. and Healey, M. (2003). Frog communities and wetland condition: relationships with grazing by domestic livestock along an Australian floodplain river. *Cons. Biol.* 109: 207–219.

Jansen, A. and Robertson, A.I. (2001). Riparian bird communities in relation to land management practices in floodplain woodlands of south-eastern Australia. *Biol. Cons.* 100: 173–185.

Jansen, S., Dessein, S., Piesschaert, F., Robbrecht, E. and Smets, E. (2000). Aluminium accumulation in leaves of Rubiaceae: systematic and phylogenetic implications. *Annals of Botany* 85: 91–101.

Jansen, S., Watanabe, R. and Smets, E. (2002). Aluminium accumulation in leaves of 127 species in Melastomataceae with comments on the Order Myrtales. *Annals of Botany* 90: 53–64.

Jennings, W.B., Pianka, E.R. and Donnellan, S. (2003). Systematics of the lizard family Pygopodidae with implications for the diversification of Australian temperate biotas. *Systematic Biology* 52: 757–780.

Johnson, K.P. (2004). Deletion bias in avian introns over evolutionary timescales. *Molecular Biology and Evolution* 21: 599–602.

Johnson, R.W. (1984). Flora and vegetation of the Brigalow Belt. In: A. Bailey (ed.), *The Brigalow Belt of Australia*. Royal Society of Queensland, Brisbane. pp. 41–59.

Jones, C.G., Lawton, J.H. and Shachak, M. (1994). Organisms as ecosystem engineers. *Oikos* 69: 373–386.

Jones, C.G., Lawton, J.H. and Shachak, M. (1997). Positive and negative effects of organisms as physical ecosystem engineers. *Ecology* 78: 1946–57.

Jones, R. (1964). The Mountain Mallee Heath of the McPherson Ranges. University of Queensland papers: Department of Botany 4(12): 159–208.

Jordan, G.J. (1995). Extinct conifers and conifer diversity in the Early Pleistocene of western Tasmania. *Review of Palaeobotany and Palynology* 34: 375–387.

Jordan, G.J. (1997). Evidence of plant extinction and diversity from Regatta Point, western Tasmania. *Botanical Journal of the Linnean Society* 123: 45–71.

Kato, M., Takimura, A. and Kawakita, A. (2003). An obligate pollination mutualism and reciprocal diversification in the tree genus Glochidion (Euphorbiaceae). *Proceedings of the National Academy of Sciences* 100: 5264–5267.

Kavanagh, R.P. and Murray, M. (1996). Home range, habitat and behaviour of the Masked Owl *Tyto novaehollandiae* near Newcastle, New South Wales. *Emu* 96: 158–165.

Keast, A. (1981). The evolutionary biogeography of Australian birds. In: A. Keast (ed.), *Ecological Biogeography of Australia.* D.W. Junk, The Hague, Netherlands. pp. 1587–1635.

Keast, A., Recher, H.F., Ford, H. and Saunders, D. (eds)(1985). *Birds of Eucalypt Forests and Woodlands: Ecology, Conservation, Management.* Surrey Beatty & Sons, Chipping Norton.

Keatley, M.R., Hudson, I.L. and Fletcher, T.D. (2004). Long-term flowering synchrony of box–ironbark eucalypts. *Australian Journal of Botany* 52: 47–54.

Keeley, J.E. and Fotheringham, C.J. (2003). Species-area relationships in Mediterranean-climate plant communities. *Journal of Biogeography* 30: 1629–1657.

Keith, H. (1997). Nutrient cycling in eucalypt ecosystems. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 197–226.

Kelly, A., Haseler, M., Ferguson, D., Wang, J., Mathieson, M., Venz, M. and Lawrence, A. (2003). *Assessment of Forest Values within the Western Queensland Hardwood Region*. Sustainable Forestry Sciences Unit, Environmental Protection Agency, Brisbane.

Kennedy, S.J. (2003). A four-year study of a bird community in a woodland remnant near Moyston, Western Victoria. *Corella* 27: 33–44.

Kenrick, J. (2003). Review of pollen-pistil interactions and their relevance to the reproductive biology of *Acacia*. *Australian Systematic Botany* 16: 119–130.

Keogh, J.S. (1998). Molecular phylogeny of elapid snakes and a consideration of their biogeographic history. *Biological Journal of the Linnaean Society.* 67: 177–203.

Keogh, J.S., Scott, I.A.W. and Scanlon, J.D. (2000). Molecular phylogeny of viviparous elapid snakes: affinities of *Echiopsis atriceps* (Storr, 1980) and *Drysdalia coronata* (Schlegel, 1837), with description of a new genus. *J. Zool. Lond.* 252: 317-326.

Keogh, J.S., Scott, I.A.W., Fitzgerald, M. and Shine, R. (2003). Molecular phylogeny of the Australian venomous snake genus *Hoplocephalus* (Serpentes, Elapidae) and conservation genetics of the threatened *H. stephensii*. *Conservation Genetics* 4: 57–65.

Keogh, J.S., Shine, R. and Donnellan, S. (1998). Phylogenetic relationships of terrestrial Australo-Papuan elapid snakes (Subfamily Hydrophiinae) based on Cytochrome b and 16S rRNA sequences. *Molecular Phylogenetics and Evolution* 10: 67–81.

Kerr, R.A. (1984). Climate since the ice began to melt. *Science* 226: 326–327.

Kershaw, A.P., Martin, H.A. and McEwen Mason, J.R.C. (1994). The Neogene: a period of transition. In: R.S. Hill (ed.), *History of the Australian Vegetation: Cretaceous to Recent*. Cambridge University Press, Cambridge. pp. 299–327.

Kershaw, A.P. and McGlone, M.S. (1995). The Quaternary history of the southern conifers. In: N.J. Enright and R.S. Hill (eds), *Ecology of the Southern Conifers*. Melbourne University Press, Melbourne. pp. 30–63.

Kershaw, A.P., McKenzie, G.M. and McMinn, A. (1993). 9. A Quaternary vegetation history of Northeastern Queensland from pollen analysis of ODP Site 820. *Proceedings of the Ocean Drilling Program, Scientific Results* 133: 107–114.

Kershaw, A.P., van der Kaars, S. and Moss, P.T. (2003). Late Quaternary Milankovitch-scale climatic change and variability and its impact on monsoonal Australasia. *Marine Geology* 201: 81–95.

Kershaw, A.P., van der Kaas, S., Moss, P. and Wang, S. (2002). Quaternary records of vegetation, biomass burning, climate and possible human impact in the Indonesian-Northern Australian region. In: P. Kershaw, B. David, N. Tapper, D. Penny and J. Brown (eds), *Bridging Wallace's Line: The Environment and Cultural History and Dynamics of the SE-Asian-Australian Region*. Advances in Geoecology 34. A Cooperating Series of the International Union of Soil Science (IUSS). pp. 97–118.

Khedr, A-H., Cadotte, M.W., El-Keblawy, A. and Lovett-Doust, J. (2002). Phylogenetic diversity and ecological features in the Egyptian flora. *Biodiversity and Conservation* 11: 1809–1824.

Kim, S., Soltis, D.E., Soltis, P.S., Zanis, M.J. and Suh, Y. (2004). Phylogenetic relationships among early-diverging eudicots based on four genes: were the eudicots ancestrally woody? *Molecular Phylogenetics and Evolution* 31: 16–30.

Kimpton, S.K., James, E.A. and Drinnan, A.N. (2002). Reproductive biology and genetic marker diversity in *Grevillea infecunda* (Proteaceae), a rare plant with no known seed production. *Australian Systematic Botany* 15: 485–492.

King, J.R., Adersen, A.N. and Cutter, A.D. (1998). Ants as bioindicators of habitat disturbance: validation of the functional group model for Australia's humid tropics. *Biodiversity and Conservation* 7: 1627–1638.

Kirkpatrick, J.B. (1997). Vascular plant-eucalypt interactions. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 227–245.

Kluth, C. and Bruelheide, H. (2004). Using standardized sampling designs from population ecology to assess biodiversity patterns of therophyte vegetation across scales. *Journal of Biogeography* 31: 363–377.

Kokubugata, G. and Holland, a.E. (2002). Cytotaxonomic studies in five species of *Rutidosis* (Asteraceae) endemic to south-eastern Queensland. *Australian Journal of Botany* 50: 237–240.

Korall, P. and Kenrick, P. (2004). The phylogenetic history of Selaginellaceae based on DNA sequences from the plastid and nucleus: extreme distribution rates and rate heterogeneity. *Molecular Phylogenetics and Evolution* 31: 852–864.

Kruckeberg, A.R. and Rabinowitz, D. (1985). Biological aspects of endemism in higher plants. *Annual Reviews in Ecological Systematics* 16: 447–479.

Krupnick, G.A., and Kress, W.J. (2003). Hotspots and ecoregions: a test of conservation priorities using taxonomic data. *Biodiversity and Conservation* 12: 2237–2253.

Kunich, J.C. (2002). World Heritage in Danger in the Hotspots. *Indiana Law Journal* 78: 619–658.

Lacey, C.J. and Johnston, R.D. (1990). Woody clumps and clumpwoods. *Australian Journal of Botany* 38: 299–234.

Ladd, P.G. (1989). The status of Casuarinaceae in Australian forests. In: K.J. Frawley and N.M. Semple (eds), *Australia's Ever Changing Forests*. Special Publication No. 1, Department of Geography and Oceanography, Aust. Defence Force Academy, Camberr, ACT, Australia. pp. 63–85.

Ladiges, P.Y. (1997). Phylogenetic history and classification of eucalypts. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 16–29.

Ladiges, P.Y. (1998). Biogeography after Burbidge. *Australian Systematic Botany* 11: 231–242.

Ladiges, P.Y. and Udovicic, F. (2000). Comment on a new classification of the eucalypts. *Australian Systematic Botany* 13: 149–152.

Ladiges, P.Y., Udovicic, F. and Drinnan, A.N. (1995). Eucalypt phylogeny — molecules and morphology. *Australian Systematic Botany* 8: 483–497.

Ladiges, P.Y., Udovicic, F. and Nelson, G. (2003). Australian biogeographic connections and the phylogeny of large genera in the plant family Myrtaceae. *Journal of Biogeography* 30: 989–998.

Laffan, S.W. and Crisp, M.D. (2003). Assessing endemism at multiple spatial scales, with an example from the Australian vascular flora. *Journal of Biogeography* 30: 511–520.

Lake, J.A. and Rivera, M.C. (2004). Deriving the genomic tree of life in the presence of horizontal gene transfer: conditioned reconstruction. *Molecular Biology and Evolution* 21: 681–690.

Lam, N., Wilson, P.G., Heslewood, M.M. and Quinn, C.J. (2003). A phylogenetic analysis of the *Chamelaucium* alliance (Myrtaceae). *Australian Systematic Botany* 15: 535–543.

Lamont, B.B. and Connell, S.W. (1996). Biogeography of *Banksia* in southwestern Australia. *Journal of Biogeography* 23: 295–309.

Landsberg, J.J. and Cork, S.J. (1997). Herbivory: interactions between eucalypts and the vertebrates and invertebrates that feed on them. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 342–372.

Laplaze, L., Gherbi, H., Frutz, T., Pawlowski, K., Franche, C., Macheix, J-J., Auguy, F., Bogusz, D. and Duhoux, E. (1999). Flavan-containing cells delimit Frankia-infected compartments in *Casuarina glauca* nodules. *Plant Physiology* 121: 113–122.

Laurance, W. F. Distributional records for two “relict” dasyurid marsupials, with notes on forest destruction in a centre of tropical mammalian endemism. *Journal of Mammalogy* 71. Laurance, W.F. (1990). Distributional records for two 'relict' dasyurid marsupials (Marsupialia: Dasyuridae) in north Queensland rainforest. *Aust. Mamm.* 13: 215-218 ???????

Laurance, W.F. (2001). Synergistic effects in fragmented landscapes. *Conservation Biology* 15: 1488–1499.

Laurance, W.F. (2004). Future shock for foresters. *Trends in Ecology and Evolution* 19: 172–173.

Laurance, W.F., Oliveira, A.A., Laurance, S.G., Condit, R., Nascimento, H.E.M., Sanchez-Thorin, A.C., Lovejoy, T.E., Andrade, A., D’angelo, S., Ribeiro, J.E. and Dick, C.W. (2004). Pervasive alternation of tree communities in undisturbed Amazonian forests. *Nature* 428: 171–175.

Laurance, W.F. and Williamson, G.B. (2001). Positive feedbacks among forest fragmentation, drought, and climate change in the Amazon. *Conservation Biology* 15: 1529–1535.

Lavorel, S., Gardner, R.H. and O’Neill, R.V. (1995). Dispersal of annual plants in hierarchically structured landscapes. Landscape Ecology 10: 277–289.

Lazarides, M. and Hince, B. (eds) (1993). *Handbook of Economic Plants of Australia*. CSIRO, Melbourne.

Leeson, K.E. and Kirkpatrick, J.B. (2004). Ecological and physiological explanations for the restriction of a Tasmanian species of *Ozothamnus* to a single population. *Australian Journal of Botany* 52: 39–45.

Leffingwell, J.C. (2002). *Boronia*. *Leffingwell Reports* 2: 1–6.

Leitch, E.C., Fergusson, C.L. and Henderson, R.A. (2003). Arc to craton provenance switching in a Late Palaeozoic subduction complex, Wandilla and Shoalwater terranes, New England Fold Belt, eastern Australia. *Australian Journal of Earth Sciences* 50: 919–929.

Levin, G.A. and Simpson, M.G. (1994). Phylogenetic implications of pollen ultrastructure in the Oldfieldioideae (Euphorbiaceae). *Annals of the Missouri Botanic Gardens* 81: 203–238.

Lev-Yadun, S. (2000). Why are underground flowering and fruiting more common in Israel than anywhere else in the world? *Current Science* 79: 289.

Lewis, H.T. and Anderson, M.K. (eds) (2002). Forgotten fires: native Americans and transient wilderness by Omer C. Stewart. University of Oklahoma Press, Norman, USA.

Libby, W.J. and Critchfield, W.B. (1987). Patterns of genetic architecture. *Annales Forestales* 13: 77–91.

Lindenmayer, D.B., Manning, A.D., Smith, P.L., Possingham, H.P., Fischer, J., Oliver, I. and McCarthy, M.A. (2002). The focal-species approach and landscape restoration: a critique. *Conservation Biology* 16: 338–345.

Lindsay, J.F. (2002). Supersequences, superbasins, supercontinents — evidence from the Neoproterozoic-early Palaeozoic basins of central Australia. *Basin Research* 14: 207–223.

Linhart, Y.B. and Grant, M.C. (1996). Evolutionary significance of local genetic differentiation in plants. *Annual Review of Ecology and Systematics* 27: 237–277.

Lloyd, P.L. (1984). Agricultural and pastoral land use in the Brigalow Belt of Queensland. In: A. Bailey (ed.), *The Brigalow Belt of Australia*. Royal Society of Queensland, Brisbane. pp. 23–40.

Lockwood, J.L. and McKinney, M.L. (eds). (2001). *Biotic Homogenization*. Kluwer Academic/Plenum Publishers, New York. 289 pp.

Lomolino, M.V. (2000). Ecology's most general, yet protean pattern: the species-area relationship. *Journal of Biogeography* 27: 17–26.

Losos, J.B. and Glor, R.E. (2003). Phylogenetic comparative methods and the geography of speciation. *Trends in Ecology and Evolution* 18: 220– 227.

Lovett, J.C., Clarke, G.P., Moore, R. and Morrey, G.H. (2001). Elevational distribution of restricted range forest tree taxa in eastern Tanzania. *Biodiversity and Conservation* 10: 541–550.

Lovett, J.C., Rudd, S., Taplin, J. and Frimodt-Moller, C. (2000). Patterns of plant diversity in Africa south of the Sahara and their implications for conservation management. *Biodiversity and Conservation* 9: 37–46.

Loyn, R.H. (1987). Effects of patch area and habitat on bird abundances, species numbers and tree health in fragmented Victorian forests. In: D.A. Saunders, G.W. Arnold, A.A. Burbidge and A.J.M. Hopkins (eds), *Nature Conservation: The Role of Remnants of Native Vegetation*. Surrey Beatty and Sons, Sydney. pp. 65–77.

Loyn, R. H., Runnalls, R. G., Forward, G. Y. and Tyers, J. (1983). Territorial Bell Miners and other birds affecting populations of insect prey. *Science* 221: 1411–1413.

Lucas, Y., Luizao, F.J., Chauvel, A., Rouiller, J. and Nahon, D. (1993). The relation between biological activity of the rain forest and mineral composition of soils. *Science* 260: 521–523.

Luckow, M., Miller, J.T., Murphy, D.J. and Livshultz, T. (2002). A cladistic analysis of the subfamily Mimosoideae, Leguminosae, based on data from the chloroplast genes trnL and matK. http://www.botany2002.org/section12/abstracts/117.shtml

Lundie-Jenkins, G. (2001). *Recovery plan for the bridled nailtail wallaby (*Onychogalea fraenata*)* 1997–2001. Report to Environment Australia, Canberra. Queensland Parks and Wildlife Service, Brisbane.

Lynch, A.J.J., Gilfedder, L. and Kirkpatrick, J.B. (1999). The Tasmanian endemic shrub *Acacia axillaris*: conservation ecology applied to the question of rarity or vulnerability. *Australian Journal of Botany* 47: 97–109.

Lynch, M. (1995). A quantitative genetic perspective on conservation issues. In: J.C. Avise and J.L. Hamrick (eds), *Conservation Genetics: Case History from Nature*. Springer Verlag, New York. pp. 471–501.

Ma, X., Considine, J.A. and Han, G. (2004). Chloroplast DNA variation and inheritance in waxflowers (Myrtaceae). *Australian Journal of Botany* 52: 55–61.

Mac Nally, R., Parkinson, A., Horrocks, G., Conole L. and Tzaros, C. (2001). *Relationships between terrestrial vertebrate diversity, abundance and availability of coarse woody debris on south-eastern Australian floodplains*. Report No. R7007, Murray-Darling Basin Commission, Riverine Program, Canberra.

Mac Nally, R.C., Soderquist T.R. and Tzaros, C.L. (2000). The conservation value of mesic gullies in dry forest landscapes: avian assemblages in the box-ironbark ecosystem of southern Australia. *Biological Conservation* 93:293–302.

MacArthur, R.H. and Wilson, E.O. (1962). *The Theory of Island Biogeography*. Princeton University Press, Princeton, New Jersey.

MacDonald, M.A. and Kirkpatrick, J.B. (2003). Explaining bird species composition and richness in eucalypt-dominated remnants in subhumid Tasmania. *Journal of Biogeography* 30: 1415–1426.

Macey, R.J., Schulte, J.A., Larson, A., Ananjeva, N.B., Wang, Y., Pethiyagoda, R., Rastegar-Pouyani, N. and Papenfuss, T.J. (2000). Evaluating trans-Tethys migration: an example using Acrodont lizard phylogenetics. *Systematic Biology* 49: 233–256.

Mackensen, J., Bauhus, J. and Webber, E. (2003). Decomposition rates of coarse woody debris — a review with particular emphasis on Australian tree species. *Australian Journal of Botany* 51: 27–37.

Mackey, B.G., Lesslie, R.G., Lindenmayer, D.B., Nix, H.A. and Incoll, R.D. (1998). *The Role of Wilderness in Nature Conservation*. Report to the Australian and World Heritage group, Environment Australia. Australian National University, Canberra.

Macphail, M.K. (1996). Neogene environments in Australia, 1: re-evaluation of microfloras associated with important Early Pliocene marsupial remains at Grange Burn, southwest Victoria. *Review of Palaeobotany and Palynology* 92: 307–328.

Macphail, M.K., Alley, N.F., Truswell, E.M. and Sluiter, I.R.K. (1994). Early tertiary vegetation: evidence from spores and pollen. In: R.S. Hill (ed.) *History of the Australian Vegetation: Cretaceous to Recent,* pp. 189–261.

Maekawa, K., Lo, N., Rose, H.A. and Matsumoto, T. (2003). The evolution of soil-burrowing cockroaches (Blattaria: Blaberidae) from wood-burrowing ancestors following an invasion of the latter from Asia into Australia. *Proc. R. Soc. Lond.* 270: 1301–1307.

Maggs, J. (1991). Nitrogen mineralization and nitrification in rainforests of contrasting nutrient status and physiognomic structure near Lake Eacham, Northeast Queensland. *Australian Journal of Ecology* 16: 47–51.

Magnusson, W.E. (2001). Catchments as basic units of management in conservation biology courses. *Conservation Biology* 15: 1464–1465.

Magnusson, W.E. (2004). Ecoregion as a pragmatic tool. *Conservation Biology* 18: 4–10.

Magri, D. (1989). Interpreting long-term exponential growth of plant populations in a 250 000-year pollen record from Valle di Castiglione. *New Phytology* 112: 123–128.

Majer, J.D., Recher, H.F., Wellington, A.B., Woinarski, J.C.Z. and Yen, A.L. (1997). Invertebrates of eucalypt formations. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 278–302.

Major, R.E., Christie, F.J. and Gowing, G. (2001). Influence of remnant and landscape attributes on Australian woodland bird communities. *Biological Conservation* 102: 47–66.

Margules, C.R. and Nicholls, A.O. (1987). Assessing the conservation value of remnant habitat islands: mallee patches on the western Eyre peninsula, South Australia. In: D.A. Saunders, G. Arnold, A.A. Burbidge, A.J.M. Hopkins (eds), *Nature Conservation: The Role of Remnants in Native Vegetation*. Surrey Beatty and Sons, Chipping Norton, New South Wales, Australia.

Margules, C.R. and Pressey, R.L. (2000). Systematic conservation planning. *Nature* 405: 243–253.

Margules, C.R., Nicholls, A.O. and Austin, M.P. (1987). Diversity of Eucalyptus species predicted by a multi-variable environmental gradient. *Oecologia* 71: 229–232.

~~Markgraf, V., McGlone. M. (2000). Southern Temperate Ecosystems.~~ Markgraf, V. and McGlone, M. (2003). Southern temperate ecosystems. In: T.E. Lovejoy and L. Hannah (eds), *Climate Change and Biodiversity*. Yale University Press. **OR** Markgraf V., McGlone, M. and Hope G. (1995). Neogene paleoenvironmental and paleoclimatic change in southern temperate ecosystems - a southern perspective. *Trends in Ecology and Evolution* 10: 143-147.

Martin, H.A. (1994). Australian tertiary phytogeography: evidence from palynology. In R.S. Hill (ed.) *History of the Australian Vegetation: Cretaceous to Recent*, pp. 104-142. Cambridge University Press, Melbourne.

Martin, H.A. (2001). The family Convolvulaceae in the Tertiary of Australia: evidence from pollen. *Australian Journal of Botany* 49: 221–234.

Martin, H.A. (2002). History of the family Malpighiaceae in Australia and its biogeographic implications: evidence from pollen. *Australian Journal of Botany* 50: 171–182.

Martin, P.G. and Jennings, A.C. (1983). The study of plant phylogeny using amino acid sequences of ribulose-1, 5-bisphosphate carboxylase. I. Biochemical methods and the patterns of variability. *Australian Journal of Botany* 31: 395–409.

Maslin, B.R. (2001). Introduction to *Acacia*. In: A.E. Orchard and A.J.G. Wilson (eds) *Flora of Australia*, volume 11A, Mimosaceae, Acacia part 1. CSIRO Publishing, Melbourne. pp. 3–13.

Maslin, B.R., Miller, J.T. and Seigler, D.S. (2003). Overview of the generic status of *Acacia* (Leguminosae: Mimosoideae), *Australian Systematic Botany* 16: 1–18.

Maslin, B.R. and Pedley, L. (1998). Patterns of distribution of *Acacia* in Australia. *Australian Journal of Botany* 36: 385–393.

May, R.M. (1990). Taxonomy as destiny. *News and Views* 347: 129–130.

May, T.W. and Simpson, J.A. (1997). Fungal diversity and ecology in eucalypt ecosystems. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 246–277.

McCarthy, D. (2003). The trans-Pacific zipper effect: disjunct sister taxa and matching geological outlines that link the Pacific margins. *Journal of Biogeography* 30: 1545–1561.

McCarthy, F.M.G., Gostlin, K.E., Mudie, P.J. and Pedersen, R.O. (2004). The palynological record of terrigenous flux to the deep sea: late Pliocene-Recent examples from 41degN in the abyssal Atlantic and Pacific oceans. *Review of Palaeobotany and Palynology* 128: 81–95.

McCosker, J.C. (1997). *The ecology and conservation of Spectacled Hare-wallabies (*Lagorchestes conspicillatus*) in Central Queensland.* Masters Thesis, The University of Queensland.

McCoy, M. (1990). Pollination of eucalypts by flying-foxes in northern Australia. In: S.M. Slack (ed.), Flying Fox Workshop, Wollongbar Agricultural Institute 22 August 1990. NSW Agriculture and Fisheries. pp. 33–37.

McCune, B. and Mefford, M.J. (1999). *PC-ORD version 4.27. Multivariate Analysis of Ecological Data*. MJM Software Design, Gleneden Beach, Oregon, USA.

McDonald, M.W. and Maslin, B.R. (2000). Taxonomic revision of the Salwoods: *Acacia aulacocarpa* Cunn. ex Benth. and its allies (Leguminosae: Mimosoideae: section Juliflorae). *Australian Systematic Botany* 13: 21–78.

McDonald, M.W., Butcher, P.A., Bell, J.C. and Larmour, J.S. (2000). Intra- and interspecific allozyme variation in eucalypts from the Spotted Gum Group, *Corymbia*, Section ‘Politaria’ (Myrtaceae). *Australian Systematic Botany* 13: 491–507.

McDowall, R.M. (2004). What biogeography is: a place for process. *Journal of Biogeography* 31: 345–351.

McFarland, D.C., Haseler, M., Venz, M., Reis, T., Ford, G. and Hines, H. (1999). *Terrestrial Vertebrate Fauna of the Brigalow Belt South Bioregion: Assessment and Analysis for Conservation Planning*. Biodiversity Planning, Queensland Environmental Protection Agency, Brisbane.

McIntosh, B.A., Sedell, J.R., Thurow, R.F., Clarke, S.E. and Chandler, G.L. (2000). Historical changes in pool habitats in the Colombia River Basin. *Ecological Applications* 10: 1478–1496.

McKay, I.J. (1991). Cretaceous Promecognathinae (Coleoptera: Carabidae): a new genus, phylogenetic reconstruction and zoogeography. *Biological Journal of the Linnean Society* 44: 1–12.

McKenzie, N.L. and Burbidge, A.A. (2002). *Australian Mammal Audit*. A report to the National Land and Water Resources Audit, Canberra.

McQuillan, P.B., Young, C.J and Richardson, A.M.M. (2001). A revision of the Australian moth genus *Paralaea* Guest (Lepidoptera: Geometridae: Ennominae). *Invertebrate Taxonomy* 15: 277–317.

Medellin, R.A. (1994). Seed dispersal of Cecropia obtusifolia by two species of opossums in the Selva Lacandona, Chiapas, Mexico. *Biotropica* 26: 400–407.

Meiri, S., Dayan, T. and Simberloff, D. (2004). Carnivores, biases and Bergmann’s rule. *Biological Journal of the Linnean Society* 81: 579–588.

Melbourne, B.A., Davies, K.F., Margules, C.R., Lindenmayer, D.B., Saunders, D.A., Wissel, C. and Henle, K. (2004). Species survival in fragmented landscapes: where to from here? *Biodiversity and Conservation* 13: 275–284.

Melville, J., Schulte II, J.A. and Larson, A. (2004). A molecular study of phylogenetic relationships and evolution of antipredator strategies in Australian *Diplodactylus* geckos, subgenus *Strophurus*. *Biological Journal of the Linnean Society* 82: 123–138.

Memarian, H. and Fergusson, C.L. (2003). Multiple fracture sets in the southeastern Permian-Triassic Sydney Basin, New South Wales. *Australian Journal of Earth Sciences* 50: 49–61.

Menkhorst, P. (2001). *Field Guide to the Mammals of Australia*. Oxford University Press, South Melbourne.

Menkhorst, P. (ed.)(1995). *Mammals of Victoria: Distribution, Ecology and Conservation.* Oxford University Press, Melbourne.

Merenlender, A.M., Huntsinger, L., Guthery, G. and Fairfax, S.K. (2004). Land trusts and conservation easements: who is conserving what for whom? *Conservation Biology* 18: 65–75.

Midgley, S.J. and Turnbull, J.W. (2003). Domestication and use of Australian acacias: case studies of five important species. *Australian Systematic Botany* 16: 89–102.

Millar, C.I. (1996). *Tertiary Vegetation History*. Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. Davis: University of California, Centres for Water and Wildland Resources, 1996.

Millar, C.I. and Libby, W.J. (1991). Strategies for conserving clinal, ecotypic, and disjunct population diversity in widespread species. In: D.A. Falk and K.E. Holsinger (eds), *Genetics and Conservation of Rare Plants*. Oxford University Press, New York. pp. 149–170.

Miller, J.S. and Venable, D.L. (2000). Polyploidy and the evolution of gender dimorphism in plants. *Science* 289: 2335–2338.

Miller, J.T., Andrew, R. and Bayer, R.J. (2003a). Molecular phylogenetics of the Australian acacias of subg. Phyllodineae (Fabaceae: Mimosoideae) based on the trnK intron. *Australian Journal of Botany* 51: 167–177.

Miller, J.T. and Bayer, R.J. (2001). Molecualr phylogenetics of *Acacia* (Fabaceae: Mimosoideae) based on the chloroplast matK coding sequence and flanding trnK intron spacer regions. *American Journal of Botany* 88: 697–705.

Miller, J.T. and Bayer, R.J. (2003). Molecular phylogenetics of Acacia subgenera Acacia and Aculeiferum (Fabaceae: Mimosoideae), based on the chloroplast matK coding sequence and flanking trnK intron spacer regions. *Australian Systematic Botany* 16: 27–33.

Miller, J.T., Grimes, J.W., Murphy, D.J., Bayer, R.J. and Ladiges, P.Y. (2003b). A phylogenetic analysis of the Acacieae and Ingeae (Mimosoideae: Fabaceae) based on trnK, matK, psbA-trnH, and trnL/trnF sequence data. *Systematic Botany* 28: 558–566.

Mlot, C. (1989). Blueprint for conserving plant diversity. *BioScience* 39: 364–368.

Mokany, K. and Adam, P. (2000). The biogeographical attributes of the threatened flora of New South Wales. *Cunninghamia* 6: 873–1203.

Moles, A.T. and Westoby, M. (2003). Latitude, seed predation and seed mass. *Journal of Biogeography* 30: 105–128.

Molnar, S. (2001). Angiosperm origins and evolution. http://www.geocities.com/we_evolve/Plants/angiosperm.html

Monteith, G.M. (1999). Wingless dung beetle. *Nature Australia* 26(7): 22–23.

Montgomery, M.E., Woodworth, L.M., Nurthen, R.K., Gilligan, D.M., Briscoe, D.A. and Frankham, R. (2000). Relationships between population size and loss of genetic diversity: comparison of experimental results with theoretical predictions. *Conservation Genetics* 1: 33–43.

Moran, G.F. (1992). Patterns of genetic diversity in Australian tree species. *New Forests* 6: 49–66.

Moran, G.F., Butcher, P.A. and Glaubitz, J.C. (2000). Application of genetic markers in the domestication, conservation and utilisation of genetic resources of Australasian tree species. *Australian Journal of Botany* 48: 313–320.

Moran, G.F. and Hopper, S.D. (1987). Conservation of the genetic resources of rare and widespread eucalypts in remnant vegetation. In: D.A. Saunders, G. Arnold, A.A. Burbidge, A.J.M. Hopkins (eds), *Nature Conservation: The Role of Remnants of Native Vegetation*. Surrey Beatty and Sons, Chipping Norton. pp. 151–162.

Morin, P.A., Luikart, G., Wayne, R.K. and the SNP workshop group. (2004). SNPs in ecology, evolution and conservation. *Trends in Ecology and Evolution* 19: 208–216.

Moritz, C. (1994). Defining 'evolutionarily significant units' for conservation. *Trends in Ecology and Evolution* 9: 373–375.

Moritz, C., Joseph, L. and Adams, M. (1993). Cryptic diversity in an endemic rainforest skink (Gnypetoscincus queenslandiae). *Biodiversity and Conservation* 2: 412–425.

Moritz, C. and Playford, J. (1998). *Genetic diversity and the design of a Comprehensive, Adequate and Representative reserve system for forests in South-East Queensland*. Queensland Department of Environment, Brisbane.

Morley, R.J. (1998). Palynological evidence for Tertiary plant dispersals in the SE Asian region in relation to plate tectonics and climate. In: R. Hall and J.D. Holloway (eds), *Biogeography and Geological Evolution of SE Asia*. Backbuys Publishers, Leiden, The Netherlands. pp. 211–234.

Morley, R.J. (2003). Interplate dispersal paths for megathermal angiosperms. *Perspectives in Plant Ecology, Evolution and Systematics* 6: 5–20.

Morris, R.J., Lewis, O.T. and Godfray, H.C.J. (2004). Experimental evidence for apparent competition in a tropical forest food web. *Nature* 428: 310–313.

Morrison, D.A., McDonald, M., Bankoff, P. and Quirico, P. (1994). Reproductive isolation mechanisms among four closely related species of *Conospermum* (Proteaceae). *Botanical Journal of the Linnean Society* 116: 13–31.

Moss, P.T. and Kershaw, A.P. (2000). The last glacial cycle from the humid tropics of northeastern Australia: comparison of a terrestrial and a marine record. *Palaeogeography, Palaeoclimatology, Palaeoecology* 155: 155–176.

Moss, P.T. and Kershaw, P. (1999). Evidence from marine ODP Site 820 of fire/vegetation/climate patterns in the humid tropics of Australia over the last 250 000 years. Conference proceedings, Australian Bushfire Conference, Albury, July 1999, Charles Sturt University.

Muller, R.D., Lim, V.S.L. and Isern, A.R. (2000). Late Tertiary tectonic subsidence on the northeast Australian passive margin: response to dynamic topography? *Marine Geology* 162: 337–352.

Munasinghe, D.H.N., Burridge, C.P and Austin, C.M. (2004). Molecular phylogeny and zoogeography of the freshwater crayfish genus *Cherax* Erichson (Decapoda: Parastacidae) in Australia. *Biological Journal of the Linnean Society* 81: 553–563.

Murphy, D.J., Miller, J.T., Bayer, R.J. and Ladiges, P.Y. (2003). Molecular phylogeny of *Acacia* subgenus *Phyllodineae* (Mimosoideae: Leguminosae) based on DNA sequences of the internal transcribed spacer region. *Australian Systematic Botany* 16: 19–26.

Murray, B.G. and Young, A.G. (2001). Widespread chromosome variation in the endangered grassland forb *Rutidosis leptorrhynchoides* F. Muell. (Asteraceae: Ganphalieae). *Annals of Botany* 87: 83–90.

Murray, B.R., Brown, A.H.D., Dickman, C.R. and Crowther, M.S. (2004). Geographical gradients in seed mass in relation to climate. *Journal of Biogeography* 31: 379–388.

Murray, C.G., Blake, P.R., Hutton, L.J., Withnall, I.W., Hayward, M.A., Simpson, G.A. and Fordham, B.G.; Bryan, S.E., Holcombe, R.J. and Fielding, C.R. (2003). Discussion and reply — Yarrol terrane of the northern New England Fold Belt: forearc or backarc? *Australian Journal of Earth Sciences* 50: 271–293.

Myers, N. and Mittermeier, R.A. (2003). Impact and acceptance of the hotspots strategy: response to Ovadia and to Brummitt and Lughadha. *Conservation Biology* 17: 1449–1450.

Nagalingum, N.S., Drinnan, A.N., Lupia, R. and McLoughlin, S. (2002). Fern spore diversity and abundance in Australia during the Cretaceous. *Review of Palaeobotany and Palynology* 119: 69–92.

Nandi, O.I., Chase, M.W. and Endress, P.K. (1998). A combined cladistic analysis of angiosperms using rbcL and non-molecular data sets. *Annals of the Missouri Botanic Gardens* 85: 137–212.

National Forest Inventory (2003). *Australia's State of the Forests Report 2003*. Bureau of Rural Sciences, Canberra.

National Land and Water Resources Audit (2001). *Australian Native Vegetation Assessment 2001.* Commonwealth of Australia.

Nativ, R., Ephrath, J.E., Berliner, P.R. and Saranga, Y. (1999). Drought resistance and water use efficiency in Acacia saligna. *Australian Journal of Botany* 47: 577–586.

Natural Resource Management Ministerial Council (2004). *Directions For The National Reserve System — A Partnership Approach*. Commonwealth of Australia, Canberra.

Neel, M.C. and Cummings, M.P. (2003). Genetic consequences of ecological reserve design guidelines: an empirical investigation. *Conservation Genetics* 4: 427–439.

Neldner, V.J. and Lynch, A.J.J. (2001). In defence of a workable national rainforest definition in Australia: response to Bowman (2001). *Australian Journal of Botany* 49: 789–790.

Nepokroeff, M., Sytsma, K.J., Wagner, W.L. and Zimmer, E.A. (2003). Reconstructing ancenstral patterns of colonization and dispersal in the Hawaiian understory tree genus *Psychotria* (Rubiaceae): a comparison of parsimony and likelihood approaches. *Systematic Biology* 52: 820–838.

Newsome, J.C. (1999). Pollen-vegetation relationships in semi-arid southwestern Australia. *Review of Palaeobotany and Palynology* 106: 103–119.

Ngugi, M.R., Hunt, M.A., Doley, D., Ryan, P. and Dart, P.J. (2003a). Photosynthetic light and temperatures responses of *Eucalyptus cloeziana* and *Eucalyptus argophloia*. *Australian Journal of Botany* 51: 573–583.

Ngugi, M.R., Hunt, M.A., Doley, D., Ryan, P. and Dart, P.J. (2003b). Effects of soil water availability on water use efficiency of *Eucalyptus cloeziana* and *Eucalyptus argophloia* plants. *Australian Journal of Botany* 51: 159–166.

Nickerson, J. and Drouin, G. (2004). The sequence of the largest subunit of RNA polymerase II is a useful marker for inferring seed plant phylogeny. *Molecular Phylogenetics and Evolution* 31: 403–415.

Niklas, K.J. (1998). The influence of gravity and wind on land plant evolution. *Review of Palaeobotany and Palynology 102: 1–14.*

Nix, H. (1994). *The Brigalow*. In: S. Dovers (ed.), *Australian Environmental History*. Oxford University Press, Melbourne. pp. 198–233.

Nix, H.A. (1993). Bird distributions in relation to imperatives for habitat conservation in Queensland. In: C.P. Catterall, P.V. Driscoll, K. Hulsman, D. Muir and A. Taplin (eds), *Birds and Their Habitats: Status and Conservation in Queensland*. Queensland Ornithological Society Inc., St. Lucia, Queensland. pp. 12–21.

Nix, H.A. (1997). Management of parks and reserves for the conservation of biological diversity In: J.J. Pigram and R.C. Sundell (eds), *National Parks and Protected Areas Selection, Delimitation and Management.* Centre for Water Policy Research, Armidale, New South Wales, Australia. pp. 11–36.

Nix, H.A. and Mackey, B.G. Conservation principles and criteria for the Brigalow Belt South Bioregion in N.S.W. Unpublished Report.

Nix, H.A. and Switzer, M.A. (1991). *Rainforest Animals: Atlas of Vertebrates Endemic to Australia's Wet Tropics*. Australian National Parks and Wildlife Service, Canberra.

Noble, I.R. (1989). Ecological traits of *Eucalyptus* L'Herit. Subgenera *Monocalyptus* and *Symphyomyrtus*. *Australian Journal of Botany* 37: 207–24.

Norton. T.W. (1997). Conservation and management of eucalypt ecosystems. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 373–401.

Nowicke, J.W. and Takahashi, M. (2002). Pollen morphology, exine structure and systematics of *Acalyphoideae* (Euphorbiaceae), Part 4. Tribes *Acalypheae* pro parte (*Erythrococca*, *Claoxylon*, *Claoxylopsis*, *Mareya*, *Mareyopsis*, *Discoclaoxylon*, *Micrococca*, *Amyrea*, *Lobanilia*, *Mallotus*, *Deuteromallotus*, *Cordemoya*, *Cococceras*,*Trewia*, *Neotrewia*, *Rockinghamia*, *Octospermum*, *Acalypha*, *Lasiococca*, *Spathiostemon*, *Homonoia*), *Plukenetieae* (*Haematostemon*, *Astrococcus*, *Angostyles*, *Romanoa*, *Eleutherostigma*, *Plukenetia*, *Vigia*, *Cnesmone*, *Megistostigma*, *Sphaerostylis*, *Tragiella*, *Platygyna*, *Tragia*, *Acidoton*, *Pachystylidium*, *Dalechampia*), *Omphalaea* (*Omphalea*), and discussion and summary of the complete subfamily. *Review of Palaeobotany and Palynology* 121: 231–336.

Nowicke, J.W., Takahashi, M. and Webster, G.L. (1998). Pollen morphology, exine structure and systematics of *Acalyphoideae* (Euphorbiaceae) Part 1. Tribes *Clutieae* (*Clutia*), *Pogonophoreae* (*Pogonophora*), *Chaetocarpeae* (*Chaetocarpus*, *Trigonopleura*), *Perea* (*Pera*), *Cheiloseae* (*Cheilosa*, *Neoscortechinia*), *Erismantheae* pro parte (*Erismanthus*, *Moultonianthus*), *Dicoelieae* (*Dicoelia*), *Galearieae* (*Galearia*, *Microdesmis*, *Panda*) and *Ampereae* (*Amperea*, *Monotaxis*). *Review of Palaeobotany and Palynology* 102: 115–152.

Nowicke, J.W., Takahashi, M. and Webster, G.L. (1999). Pollen morphology, exine structure and systematics of *Acalyphoideae* (Euphorbiaceae). Part 2. Tribes *Agrostistachydeae* (*Agrostistachys*, *Pseudagrostistachys*, *Cyttaranthus*, *Chondrostylis*), *Chrozophoreae* (*Speranskia*, *Caperonia*, *Philyra*, *Ditaxis*, *Argythamnia*, *Chiropetalum*, *Doryxylon*, *Sumbaviopsis*, *Thyrsanthera*, *Melanolepis*, *Chrozophora*), *Caryodendreae* (*Caryodendron*, *Discoglypremna*, *Alchorneopsis*), *Bernardieae* (*Bernardia*, *Necepsia*, *Paranecepsia*, *Discocleidion*, *Adenophaedra*) and *Pycnocomeae* (*Pycnocoma*, *Droceloncia*, *Argomuellera*, *Blumeodendron*, *Podadenia*, *Ptychopyxis*, *Botryophora*). *Review of Palaeobotany and Palynology* 105: 1–62.

Noyes, R.D. and Rieseberg, L.H. (1999). ITS sequence data support a single origin for North American *Astereae* (Asteraceae) and reflect deep geographic divisions in *Aster* s.l. *American Journal of Botany* 86: 398–412.

NSW National Parks and Wildlife Service (2002). *Approved Recovery Plan for the Red Goshawk* (Erythrotriorchis radiatus), NSW National Parks and Wildlife Service, Hurstville.

NSW National Parks and Wildlife Service (2003). *Recovery Plan for the Yellow-bellied Glider* (Petaurus australis). NSW National Parks and Wildlife Service, Hurstville.

NSW National Parks and Wildlife Service (2003b). *Draft Recovery Plan for the Barking Owl* (Ninox connivens). NSW National Parks and Wildlife Service, Hurstville.

Nybom, H. (2004). Comparison of different nuclear DNA markers for estimating intraspecific genetic diversity in plants. *Molecular Ecology* 13: 1143–1155.

O'Brien, M.M., Quinn, C.J. and Wilson, P.G. (2000). Molecular systematics of the *Leptospermum* suballiance (Myrtaceae). *Australian Journal of Botany* 48: 621–628.

O'Connor, D. and Moritz, C. (2003). A molecular phylogeny of the Australian skink genera *Eulamprus*, *Gnypetoscincus*, and *Nangura*. *Australian Journal of Zoology*. 51: 317-330.

Oakwood, M. (2000). Reproduction and demography of the northern quoll, *Dasyurus hallucatus,* in the lowland savanna of northern Australia. *Australian Journal of Zoology* 48: 519–539.

Olden, J.D., LeRoy Poff, N., Douglas, M.R., Douglas, M.E. and Fausch, K.D. (2004). Ecological and evolutionary consequences of biotic homogenization. *Trends in Ecology and Evolution* 19: 18–24.

Oliver, D. L. (1998). *Ecology and conservation of the endangered Regent Honeyeater* Xanthomyza phrygia *in northern New South Wales*. Ph.D thesis, University of New England, Armidale, New South Wales.

Ollier, C. and Pain, C. (1996). *Regolith, Soils and Landforms*. John Wiley and Sons, England.

Ollier, C. and Pain, C. (2000). *The Origin of Mountains*. Routledge, London.

Ollier, C.D. (1982). The Great Escarpment of eastern Australia: tectonic and geomorphic significance. *J. Geol. Soc. Aust.* 29: 13–23.

Ollier, C.D. and Pain, C.F. (1994). Landscape evolution and tectonics in southeastern Australia. *Journal of Australian Geology and Geophysics* 15: 335–345.

Orr, D.W. (2002). Four challenges of sustainability. *Conservation Biology* 16: 1457–1460.

Osborne, M.J. and Christidis, L. (2001). Molecular phylogenetics of Australo-Papuan possums and gliders (Family Petauridae). *Molecular Phylogenetics and Evolution* 20: 211–224.

Pacey, T.L., Baverstock, P.R. and Jerry, D.R. (2001). The phylogenetic relationships of the Bilby, *Macrotis lagotis* (Peramelimorphia: Thylacomyidae), to the bandicoots — DNA sequence evidence. *Molecular Phylogenetics and Evolution* 21: 26–31.

Page, C.N. (2002). Ecological strategies in fern evolution: a neopteridological overview. *Review of Palaeobotany and Palynology* 119: 1–33.

Page, C.N. and Clifford, H.T. (1981). Ecological biogeography of Australian conifers and ferns. In: A. Keast (ed.), *Ecological Biogeography of Australia*. Dr. W. Junk, The Hague – Boston – London. pp. 473–497.

Pardon, L.G., Brook, B.W., Griffiths, A.D. and Braithwaite, R.W. (2003). Determinants of survival of the Northern Brown Bandicoot under a landscape-scale fire experiment. *Journal of Animal Ecology* 72: 106–115.

Parnaby, H. (2002). "*Pilliga bats — no time to lose*", excerpt from "Revealing the Pilliga" seminar, Royal Botanical Gardens, Sydney, April 2002.

Pate, J.S., Verboom, W.H. and Galloway, P.D. (2001). Co-occurrence of Proteaceae, laterite and related oligotrophic soils: coincidental associations or causative inter-relationships? *Australian Journal of Botany* 49: 529–560.

Paton, D.C. (1986). Evolution of bird pollination in Australia. In: H.A. Ford and D.C. Paton (eds), *The Dynamic Partnership. Birds and Plants in Southern Australia*. Government Printer, Adelaide. pp. 32–41.

Paton, D.C. (1996). Overview of Feral and Managed Honeybees in Australia — Distribution, Abundance, Extent of Interactions with Native Biota, Evidence of Impacts and Future Research. Department of Zoology, The University of Adelaide for Australian Nature Conservation Agency, Environment Australia

Paton, D.C. (1997). Honey Bees *Apis mellifera* and the disruption of plant-pollinator systems in Australia. *Victorian Naturalist* 114: 23–29.

Paton, D.C. (2000). Disruption of bird-plant pollination systems in southern Australia. *Cons. Biol.* 14: 1232–1234.

Paton, D., Carpenter, G. and Sinclair, R. (1994). A second bird atlas of the Adelaide region. Part 1: changes in the distribution of birds: 1974–75 vs 1984–85. *S.A. Orn.* 31: 151–193.

Patterson, C., Williams, D.M. and Humphries, C.J. (1993). Congruence between molecular and morphologicl phylogenies. *Annual Reviews in Ecological Systematics* 24: 154–188.

Paull, D.C (2001). Stump-count analysis of the pre-European Pilliga forests. In: J. Dargavel, D. Hart and B. Libbis (eds), *Perfumed Pineries: Environmental History of Australia's Callitris Forests.* Centre for Environmental Resource Studies, Australian National University, Canberra. pp. 63–70.

Paull, D.C. and Kerle, A. (in press.). Recent decline of Common Brushtail and Common Ringtail Possums in the Pilliga forests, New South Wales.

Paull, R. and Hill, R.S. (2003). *Nothofagus kiandrensis* (Nothofagaceae subgenus Brassospora), a new macrofossil leaf species from Miocene sediments at Kiandra, New South Wales. *Australian Systematic Botany* 16: 549–559.

Pavey, C.R., Smyth, A.K. and Mathieson, M.T. (1993). The breeding season diet of the Powerful Owl *Ninox strenua* at Brisbane, Queensland. *Emu* 94: 278–284.

Pepper, J.W. (1996). *The Behavioral Ecology of the Glossy Black-Cockatoo* (Calyptorhynchus lathami halmaturinus), Ph.D. thesis, Biology Department, The University of Michigan.

Percy, D.M., Page, R.D.M. and Cronk, Q.C.B. (2004). Plant-insect interactions: double-dating associated insect and plant lineages reveals asynchronous radiations. *Systematic Biology* 53: 120–127.

Perrie, L.R., Brownsey, P.J., Lockhart, P.J., Brown, E.A. and Large, M.F. (2003). Biogeography of temperate Australasian *Polystichum* ferns as inferred from chloroplast sequence and AFLP. *Journal of Biogeography* 30: 1729–1736.

Perry, D.A., Borchers, J.G., Borchers, S.L. and Amarantus, M.P. (1990). Species migrations and ecosystem stability during climate change: the belowground connection. *Conservation Biology* 4: 266–273.

Peters, M.D. (1985). A taxonomic analysis of a middle Cretaceous megafossil plant assemblage from Queensland, Australia. PhD thesis, University of Adelaide.

Peters, R.L. and Darling, J.D.S. (1985). The greenhouse effect and nature reserves. *BioScience* 35: 707–717.

Petraitis, P.S., Latham, R.E. and Niesenbaum, R.A. (1989). The maintenance of species diversity by disturbance. *The Quarterly Review of Biology* 64: 393–418.

Pettigrew, C.J. and Watson, L. (1975). On the classification of Australian acacias. *Australian Journal of Botany* 23: 833–847.

Pettit, N.E. and Froend, R.H. (2001). Availability of seed for recruitment of riparian vegetation: a comparison of a tropical and a temperate river ecosystem in Australia. *Australian Journal of Botany* 49: 515–528.

Pharmawati, M., Yan, G. and McFarland, I.J. (2004). Application of RAPID and ISSR markers to analyse molecular relationships in *Grevillea* (Proteaceae). *Australian Systematic Botany* 17: 49–61.

Pharo, E.J, Beattie, A.J. and Binns, D. (1998). Vascular plant diversity as a surrogate for bryophyte and lichen diversity. *Conservation Biology* 13: 282–292.

Philippe, M., Bamford, M., McLoughlin, S., Alves, L.S.R., Falcon-Lang, H.J., Gnaedinger, S., Ottone, E.G., Pole, M., Rajanikanth, A., Shoemaker, R.E., Torres, T and Zamuner, A (2004). Biogeographic analysis of Jurassic-Early Cretaceous wood assemblages from Gondwana. *Review of Palaeobotany and Palynology* 129: 141–173.

Pickett, E.J. and Newsome, J.C. (1997). *Eucalyptus* (Myrtaceae) pollen and its potential role in investigations of Holocene environments in southwestern Australia. *Review of Palaeobotany and Palynology* 98: 187–205.

Pigg, K.B. and McLoughlin, S. (1997). Anatomically preserved Glossopteris leaves from the Bowen and Sydney basins, Australia. *Review of Palaeobotany and Palynology* 97: 339–350.

Platnick, N.I. (2000). *A relimitation and revision of the Australasian ground spider family Lamponidae (Araneae: Gnaphosoidea).* American Museum of Natural History, online at http://research.amnh.org/entomology/lamponid/

Platnick, N. I. (2003). *The World Spider Catalog, Version 3.5*. American Museum of Natural History, online at http://research.amnh.org/entomology/spiders/catalog81–87/index.html

Playford, J., Bell, J.C. and Moran, G.F. (1993). A Major disjunction in genetic diversity over the geographic range of *Acacia melanoxylon*. *Australian Journal of Botany* 41: 355–368.

Plunkett, G.M. and Lowry, P.P. (2001). Relationships among “Ancient Araliads” and their significance for the systematics of Apiales. *Molecular Phylogenetics and Evolution* 19: 259–276.

Pole, M. (1992). Early Miocene flora of the Manuherikia Group, New Zealand. 2. Conifers. *Journal of the Royal Society of New Zealand* 22: 287–302.

Pole, M. (1993a). Keeping in touch: vegetation prehistory on both sides of the Tasman. *Australian Systematic Botany* 6: 387–397.

Pole, M.S. (1993b). Early Miocene flora of the Manuherikia Group, New Zealand. 10. Paleoecology and stratigraphy. *Journal of the Royal Society of New Zealand* 23: 393–426.

Pole, M. (1994). The New Zealand flora — entirely long-distance dispersal? *Journal of Biogeography* 21: 625–635.

Pole, M.S., Hill, R.S., Green, N. and Macphail, M.K. (1993). The Oligocene Berwick Quarry flora — rainforest in a drying environment. *Australian Systematic Botany* 6: 399–427.

Pollock, A.B. (1999). Notes on status, distribution and diet of Northern Quoll *Dasyurus hallucatus* in the Mackay-Bowen area, mideastern Queensland. *Aust. Zool.* 31: 388–395.

Pollock, A.B. (2002). Rediscovery of *Glossocardia orthochaeta* (F.Muell.) Veldk. (Asteraceae) from north-east Queensland. *Austrobaileya* 6: 341–343.

Poole, I. (2002). Systematics of Cretaceous and Tertiary *Nothofagoxylon*: implications for Southern Hemisphere biogeography and evolution of the Nothofagaceae. *Australian Systematic Botany* 15: 247–276.

Poole, I., Cantrill, D.J., Hayes, P. and Francis, J. (2000). The fossil record of Cunoniaceae: new evidence from Late Cretaceous wood of Antarctica? *Review of Palaeobotany and Palynology* 111: 127–144.

Posadas, P., Esquivel, D.R.M. and Crisci, J.V. (2001). Using phylogenetic diversity measures to set prioriteis in conservation: an example from southern South America. *Conservation Biology* 15: 1325–1334.

Posadas, P., Miranda-esquivel, D.R. and Crisci, J.V. (2004). On words, tests, and applications: reply to Faith *et al*. *Conservation Biology* 18: 262–266.

Possingham, H.P. and Field, S.A. (2001). Regional bird extinctions and their implications for vegetation clearance policy. Community Biodiversity Network website, 7 May 2001. http://nccnsw.org.au/member/cbn/projects/LifeLines7.2/NatVeg_Ext.html

Potts, B.M. (1990). The response of eucalypt populations to a changing environment. *Tasforests* 2: 179–193.

Potts, B.M. (2003). Genetic pollution of native eucalypt gene pools — identifying the risks. *Australian Journal of Botany* 51: 333.

Potts, M.D., Ashton, P.S., Kaufman, L.S. and Plotkin, J.B. (2002). Habitat patterns in tropical rainforests: a comparison of 105 plots in northwest Borneo. Ecology 83: 2782-2797.

Potts, B.M. and Jackson, W.D. (1986). Evolutionary processes in the Tasmanian high altitude eucalypts. In: Barlow, B.A. (ed), *Flora and Fauna of Alpine Australasia*. Ages and Origins. CSIRO, Melbourne. pp. 511–527.

Prance, G.T. (1982). A review of the phytogeographic evidences for Pleistocene climate changes in the Neotropics. *Annals of the Missouri Botanic Gardens* 69: 594–624.

Prendergast, J.R., Quinn, R.M. and Lawton, J.H. (1999). The gaps between theory and practice in selecting nature reserves. *Conservation Biology* 13: 484–492.

Pressey, R.L. and Logan, V.S. (1995). Reserve Coverage and Requirements in Relation to Partitioning and Generalization of Land Classes: Analyses for western New South Wales. *Conservation Biology* 9: 1506–1517.

Prober, S.M., Thiele, K.R. and Lunt, I.D. (2002). Identifying ecological barriers to restoration in temperate grassy woodlands: soil changes associated with different degradation states. *Australian Journal of Botany* 50: 699–712.

Purvis, A. (2003). Book Review: Implications of the “Homogecene Debt”. *Conservation Biology* 17: 337–343.

Pye, M.G., Gadek, P.A. and Edwards, K.J. (2003). Divergence, diversity and species of the Australasian *Callitris* (Cupressaceae) and allied genera: evidence from ITS sequence data. *Australian Systematic Botany* 16: 505–514.

Queensland CRA/RFA Steering Committee (1998). *Flora Data Analysis EH 1.1.4*. A report by the Forest Assessment Unit, Queensland Department of Environment and Heritage, Brisbane.

Quinn, C.J., Crayn, D.M., Heslewood, M.M., Brown, E.A. and Gadek, P.A. (2003). A molecular estimate of the phylogeny of *Styphelieae* (Ericaceae). *Australian Systematic Botany* 16: 581–594.

Radford, I.J., Cousens, R.D. and Michael, P.W. (2004). Morphological and genetic variation in the *Senecio pinnatifolius* complex: are variants worthy of taxonomic recognition? *Australian Systematic Botany* 17: 29–48.

Radford, I.J., Muller, P., Fiffer, S. and Michael, P.W. (2000). Genetic relationships between Australian Fireweed and South African and Madagascan populations of *Senecio madagascariensis* Poir. and closely related *Senecio* species. *Australian Systematic Botany* 13: 409–423.

Ramsay, J. (1984). *Official Opening Address*. In: A. Bailey (ed.), *The Brigalow Belt of Australia*, Royal Society of Queensland, Brisbane. pp. 1–4.

Rapport, D.J., Regier, H.A. and Hutchinson, T.C. (1985). Ecosystem behavior under stress. *The American Naturalist* No. 5: 617–640.

Raymond, J., Siefert, J.L., Staples, C.R. and Blankenship, R.E. (2004). The natural history of nitrogen fixation. *Molecular Biology and Evolution* 21: 541–554.

Read, K., Keogh, J.S., Scott, I.A.W., Roberts, J.D. and Doughty, P. (2001). Molecular phylogeny of the Australian frog genera *Crinia*, *Geocrinia*, and allied taxa (Anura: Myobatrachidae). *Molecular Phylogenetics and Evolution* 21: 294–308.

Reed, D.H. and Frankham, R. (2001). How closely correlated are molecular and quantitative measures of genetic variation? a meta-analysis. *Evolution* 55: 1095–1103.

Reeder, T.W. (2003). A phylogeny of the Australian *Sphenomorphus* group (Scincidae: Squamata) and the phylogenetic placement of the crocodile skinks (*Tribolonotus*): Bayesian approaches to assessing congruence and obtaining confidence in maximum likelihood inferred relationships. *Molecular Phylogenetics and Evolution* 27: 384–397.

Reid, J.R.W. (1999). *Threatened and declining birds in the New South Wales Sheep-Wheat belt: I. Diagnosis, characteristics and management.* Consultancy report to NSW National Parks and Wildlife Service. CSIRO Wildlife and Ecology, Canberra.

Renner, S.S., Foreman, D.B. and Murray, D. (2000). Timing transantarctic disjunctions in the Atherospermataceae (Laurales): evidence from coding and noncoding chloroplast sequences. *Systematic Biology* 49: 579–591.

Richardson, D.M, Cowling, R.M. and Lamont, B.B. (1996). Non-linearities, synergisms and plant extinctions in South African fynbos and Australian kwongan. *Biodiversity and Conservation* 5: 1035–1046.

Richardson, P.M. and Young, D.A. (1982). The phylogenetic content of flavonoid point scores. *Biochemical Systematics and Ecology* 10: 251–255.

Ricklefs, R.E. (2003). Global diversification rates of passerine birds. *Proceedings of the Royal Society, London Series B Biological Sciences* 270: 2285–2291.

Roberge, J-M. and Angelstam, P. (2004). Usefulness of the umbrella species concept as a conservation tool. *Conservation Biology* 18: 76–85.

Robertson, A., Hollingsworth, P.M., Kettle, C.J., Ennos, R.A. and Gardner, F. (2004). Characterization of nuclear microsatellites in New Caldeonian *Araucaria* species. *Molecular Ecology Notes* 4: 62–63.

Robinson, D. and Traill, B.J. (1996). *Conserving woodland birds in the wheat and sheep belts of southern Australia*. RAOU Conservation Statement No. 10. RAOU, Melbourne.

Rojas, M. (1992). The species problem and conservation: what are we protecting? *Conservation Biology* 6: 170–178.

Romero, C. and Andrade, G.I. (2004). International conservation organizations and the fate of local tropical forest conservation initiatives. *Conservation Biology* 18: 578–580.

Rosenzweig, M.L. (1995). *Species Diversity in Space and Time*. Cambridge University Press, Cambridge, United Kingdom.

Ruggiero, L.F., Hayward, G.D. and Squires, J.R. (1994). Viability analysis in biological evaluations: concepts of population viability analysis, biological population, and ecological scale. *Conservation Biology* 8: 364–372.

Rye, B.L. and James, S.H. (1992). The relationship between dysploidy and reproductive capacity in Myrtaceae. *Australian Journal of Botany* 40: 829–48.

Salamin, N., Chase, M.W., Hodkinson, T.R. and Savolainen, V. (2003). Assessing internal support with large phylogenetic DNA matrices. *Molecular Phylogenetics and Evolution* 27: 528–539.

Salomon, M. (2004). Speciation centres and sustainable development. *Journal of Biogeography* 31: 675–678.

Sampson, J.F., Hopper, S.D. and James, S.H. (1989). The mating system and population genetic structure in a bird-pollinated mallee, *Eucalyptus rhodantha*. *Heredity* 63: 383–393.

Sands, D.P.A. and New, T.R. (2002). *The Action Plan for Australian Butterflies*. Environment Australia, Canberra.

Santiago, L.J.M., Louro, R.P., Emmerich, M. and Barth, O.M. (2004). The pollen morphology of *Phyllanthus* (Euphorbiaceae) section *Choretropsis*. *Biological Journal of the Linnean Society* 144: 243–250.

Sattler, P. and Creighton, C. (2002). *Australian Terrestrial Biodiversity Assessment*, National Land and Water Resources Audit, Canberra.

Sattler, P.S. and Williams, R.D. (eds)(1999). *The Conservation Status of Queensland's Regional Ecosystems*. Environmental Protection Agency, Brisbane.

Saunders, D.A. (1989). Changes in the avifauna of a region, district and remnant as a result of fragmentation of native vegetation: the wheatbelt of Western Australia. A case study. *Biol. Cons.* 50: 99–135.

Saxon, E.C. and Tracey, J.G. (1988). Origin and evolution of rainforest biogeographic diversity using evidence from the Proteaceae. In: R.L. Kitching (ed.), *The Ecology of Australia's Wet Tropics*. *Proceedings of the Ecological Society of Australia.* Volume 15: pp. 89–98.

Schauble, C.S. (2004). Variation in body size and sexual dimorphism across geographical and environmental space in the frogs *Limnodynastes tasmaniensis* and *L. peronii*. *Biological Journal of the Linnean Society* 82: 39–56.

Schneider, H., Schuettpeiz, E., Pryer, K.M., Cranfill, R., Magallon, S. and Lupia, R. (2004). Ferns diversified in the shadow of angiosperms. *Nature* 428: 553–557.

Schneider, S.H. and Root, T.L. (1996). Ecological implications of climate change will include surprises. *Biodiversity and Conservation* 5: 1109–1119.

Schodde, R. (1989). *Origins, Radiations and Sifting in the Australasian Biota — Changing Concepts from New Data and Old*. Nancy Burbidge Memorial Lecture.

Schodde, R. and Calaby, J. H. (1972). The biogeography of the Australo-Papuan bird and mammal faunas in relation to Torres Strait. In: D. Walker (ed.), *Bridge and Barrier: The Natural and Cultural History of Torres Strait*. Australian National University Press, Canberra. pp. 257–300.

Schodde, R. and Mason, I.J. (1999). *The Directory of Australian Birds: Passerines.* CSIRO Publishing, Canberra.

Schodde, R., Mason, I.J. and Wood, J.T (1993). Geographical differentiation in the Glossy Black-Cockatoo *Calyptorhynchus lathami* (Temminck) and its history. *Emu* 93: 156–166.

Schulte II, J.A., Melville, J. and Larson, A. (2003). Molecular phylogenetic evidence for ancient divergence of lizard taxa on either side of Wallace's Line. *Proceedings of the Royal Society, Lond*. 270: 597–603.

Schutz, W., Milberg, P. and Lamont, B.B. (2002). Seed dormancy, after-ripening and light requirements of four annual Asteraceae in south-Western Australia. *Annals of Botany* 90: 707–714.

Scott, G.A.M. (1988). Australasian bryogeography: fact, fallacy and fantasy. *Botanical Journal of the Linnean Society* 98: 203–210.

Scott, K.M. and Mustard, R. (2003). Police Creek Gold Deposit, Drummond Basin, NE Queensland. CRC LEME, CSIRO Exploration and Mining, North Ryde. pp. 1–3.

Scott, M.L., Skagen, S.K. and Merigliano, M.F. (2003). Relating geomorphic change and grazing to avian communities in riparian forests. *Conservation Biology* 17: 284–296.

Seddon, J.A., Briggs, S.V. and Doyle, J. (2003). Relationships between bird species and characteristics of woodland remnants in central New South Wales. *Pac. Cons. Biol.* 9: 95–119.

Seidl, M.A., Weissel, J.K. and Pratson, L.F. (1996). The kinematics and pattern of escapment retreat across the rifted continental margin of SE Australia. *Basin Research* 12: 301–316.

Seigler, D.S. (1994). Phytochemistry and systematics of the Euphorbiaceae. *Annals of the Missouri Botanic Gardens* 81: 380–401.

Shapcott, A. (1997). Population Genetics of the long-lived Huon Pine *Lagarostrobos franklinii*: an endemic Tasmanian temperate rainforest tree. *Biological Conservation* 80: 169–179.

Shapcott, A. (1998a). Taxonomy, genetics and conservation: a preliminary study of the variation in *Actephila lindleyi* (Euphorbiaceae) a rainforest shrub. *Pacific Conservation Biology* 4: 105–110.

Shapcott, A. (1998b). The genetics of *Ptychosperma bleeseri*, a rare palm form the Northern Territory, Australia. *Biological Conservation* 85: 203–209.

Shapcott, A. (1998c). The patterns of genetic diversity in *Carpentaria acuminata* (Arecaceae), and rainforest history in northern Australia. *Molecular Ecology* 7: 833–847.

Sharp, K.R. (2004). Cenozoic volcanism, tectonism and steam derangement in the Snowy Mountains and northern Monaro of New South Wales. *Australian Journal of Sciences* 51: 67–83.

Shugart, H.H & West, D.C. (1977). Development of an Appalachian Deciduous Forest Succession Model and its application to assessment of the impact of the Chestnut Blight. *Journal of Environmental Management* 5: 161–179.

Sibley, C.G. and Ahlquist, J. E. (1985). The phylogeny and classification of the Australo-Papuan passerine birds. *Emu* 85: 1–14.

Sibley, C.G. and Ahlquist, J.E. (1990). *Phylogeny and Classification of Birds. A Study in Molecular Evolution*. Yale University Press, New Haven, London.

Sibley, C.G. and Monroe, B. L., Jr. (1990). *Distribution and Taxonomy of Birds of the World*. Yale University Press, New Haven, Connecticut.

Sigman, D.M., Jaccard, S.L. and Huag, G.H. (2004). Polar ocean stratification in a cold climate. *Nature* 428: 59–63.

Simmons, M.P., Savolainen, V., Clevinger, C.C., Archer, R.H. and Davis, J.I. (2001). Phylogeny of the Celastraceae inferred from 26S nuclear ribosomal DNA, Phytochrome B, rbcL, atpB, and morphology. *Molecular Phylogenetics and Evolution* 19: 353–366.

Sivertsen, D. (1993). Conservation of remnant vegetation in the box and ironbark lands of New South Wales. *Vic. Nat.* 110: 24–29.

Small, R.L., Cronn, R.C. and Wendel, J.F. (2004). L.A.S. Johnson Review No. 2 — Use of nuclear genes for phylogeny reconstruction in plants. *Australian Systematic Botany* 17: 145–170.

Smith, J.M.B. and Cleef, A.M. (1988). Composition and origins of the world's tropicalpine floras. *Journal of Biogeography* 15: 631–645

Smith, S., Hughes J. and Wardell-Johnson, G. (2003). High population differentiation and extensive clonality in a rare mallee eucalypt: *Eucalyptus curtisii*. *Conservation Genetics* 4: 289–300.

Snow, N. and Simon, B. (1997). *Leptochloa southwoodii* (Poaceae: Chloridoideae), a new species from south-east Queensland. *Austrobaileya* 5: 137–143.

Soderquist, T.R. and Lee, A.K. (1994). *Ontogeny of tree hollows in Box-Ironbark Forest*. Report to Department of Conservation and Natural Resources, Melbourne.

Soderquist, T.R., Lowe, K.W., Loyn, R.H. and Price, R. (2002). Habitat quality in Powerful Owl (*Ninox strenua*) territories in the Box-Ironbark Forest of Victoria, Australia. In: I. Newton, R.P. Kavanagh, J. Olsen and I.R Taylor (eds), *Ecology and Conservation of Owls: Proceedings of the Owls 2000 Conference*. CSIRO Publishing. pp 91–99.

SoE (1996). *Australia: State of the Environment 1996*. An independent report presented to the Commonwealth Minister for the Environment by the State of the Environment Advisory Council. CSIRO Publishing, Melbourne.

Sogo, A., Setoguchi, H., Noguchi, J., Jaffre, T. and Tobe, H. (2001). Molecular phylogeny of Casuarinaceae based on rbcL and matK gene sequences. *Journal of Plant Research* 114: 259–465.

Soule, M.E., Estes, J.A., Berger, J. and Martinez del Rio, C. (2003). Ecological effectiveness: conservation goals for interactive species. *Conservation Biology* 17: 1238–1250.

Soule, M.E. and Mills, L.S. (1992). Conservation genetics and conservation biology: a troubled marriage. In: O.T. Sandlund, K. Hindar and A.H.D. Brown (eds), *Conservation of Biodiversity for Sustainable Development*. Scandinavian University Press, Oslo. pp.

Spector, S. (2002). Biogeographic crossroads as priority areas for biodiversity conservation. *Cons. Biol.* 16: 1480–1490.

Spjut, R.W. (1985). Limitations of a random screen: search for new anticancer drugs in higher plants *Economic Botany* 39: 266–288

Stanisic, J. (1990). Systematics and biogeography of Eastern Australian Charopidae (Mollusca, Pulmonata) from subtropical rainforests. *Mem. Qld. Mus.* 30: 1–241.

Stanisic, J. (1996). New land snails from boggomoss environments in the Dawson valley, southeastern Queensland (Eupulmonata: Charopidae and Camaenidae). *Memoirs of the Queensland Museum* 39: 343–354.

Steane, D.A., Nicolle, D., McKinnon, G.E., Vaillancourt, R.E. and Potts, B.M. (2002). Higher-level relationships among the eucalypts are resolved by ITS-sequence data. *Australian Systematic Botany* 15: 49–62.

Steane, D.A., Wilson, K.L. and Hill, R.S. (2003). Using matK sequence data to unravel the phylogeny of Casuarinaceae. *Molecular Phylogenetics and Evolution* 28: 47–59.

Stein, W.E. (1998). Developmental logic: establishing a relationship between developmental process and phylogenetic pattern in primitive vascular plants. *Review of Palaeobotany and Palynology* 102: 15–42.

Stern, H., de Hoedt, G. and Ernst, J. (2000). Objective classification of Australian climates. *Aust. Met. Mag.* 49: 87–96.

Stevens, P.F. (1986). Evolutionary classification in botany, 1960–1985. *Journal of the Arnold Arboretum* 67: 313–339.

Stockwell, C.A. and Ashley, M.V. (2004). Diversity: rapid adaptation and conservation. *Conservation Biology* 18: 272–273.

Stone, G.N. (2003). Preface. *Australian Systematic Botany* 16: i–ii.

Stone, G.N., Raine, N.E., Prescott, M. and Willmer, P.G. (2003). Pollination ecology of acacias (Fabaceae, Mimosoideae). *Australian Systematic Botany* 16: 103–118.

Stone, L. and Ezrati, S. (1996). Chaos, cycles and spatiotemporal dynmics in plant ecology. *Journal of Ecology* 84: 279–291.

Stork, N.E. and Eggleton, P. (1992). Invertebrates as determinants and indicators of soil quality. *American Journal of Alternative Agriculture* 7: 38–47.

Stow, A.J. and Sunnucks, P. (2004a). High mate and site fidelity in Cunningham's skinks (*Egernia cunninghami*) in natural and fragmented habitat. *Molecular Ecology* 13: 419–430.

Stow, A.J. and Sunnucks, P. (2004b). Inbreeding avoidance in Cunningham's skinks (*Egernia cunninghami)* in natural and fragmented habitat. *Molecular Ecology* 13: 443–447.

Stow, A.J., Sunnucks, P., Briscoe, D.A. and Gardner, M.G. (2001). The impact of habitat fragmentation on dispersal of Cunningham's skink (*Egernia cunninghami*): evidence from allelic and genotypic analyses of microsatellites. *Molecular Ecology* 10: 867–878.

Strahan, R. (ed.)(1983). *The Mammals of Australia*. Reed Books, Sydney.

Su, J.C., Debinski, D.M., Jakubauskas, M.E. and Kindscher, K. (2004). Beyond species richness: community similarity as a measure of cross-taxon congruence for coarse-filter conservation. *Conservation Biology* 18: 167–173.

Sumner, J., Jessop, T., Paetkau,D. and Moritz, C. (2004). Limited effect of anthropogenic habitat fragmentation on molecular diversity in a rainforest skink, *Gnypetoscincus queenslandiae*. *Molecular Ecology* 13: 259–269.

Swenson, U., Backlund, A., McLoughlin, S. and Hill, R.S. (2001). *Nothofagus* biogeography revisited with special emphasis on the enigmatic distribution of Subgenus *Brassospora* in New Caledonia. *Cladistics* 17: 27–47.

Swenson, U., Hill, R.S. and McLoughlin, S. (2000). Ancestral area analysis of *Nothofagus* (Nothofagaceae) and its congruence with the fossil record. *Australian Systematic Botany* 13: 469–478.

Takahashi, M., Nowicke, J.W., Webster, G.L., Orli, S.S. and Yankowski, S. (2000). Pollen morphology, exine structure, and systematics of *Acalyphoideae* (Euphorbiaceae), Part 3. Tribes *Epiprineae* (*Epiprinus*, *Symphyllia*, *Adenochlaena*, *Cleidiocarpon*, *Koilodepas*, *Cladogynos*, *Cephalocrotonopsis*, *Cepalocroton*, *Cephalomappa*), *Adelieae* (*Adelia*, *Crotonogynopsis*, *Enriquebeltrania*, *Lasiocroton*, *Leucocroton*), *Alchorneae* (*Orfilea*, *Alchornea*, *Coelebogyne*, *Aparisthmium*, *Bocquillonia*, *Conceveiba*, *Gavarretia*), *Acalypheae* pro parte (*Ricinus*, *Adriana*, *Mercurialis*, *Leidesia*, *Dysopsis*, *Wetria*, *Cleidion*, *Sampantaea*, *Macaranga*). *Review of Palaeobotany and Palynology* 110: 1–66.

Tang, Y., Boulter, S.L. and Kitching, R.L. (2003). Heat and smoke effects on the germination of seeds from soil seed banks across forest edges between subtropical rainforest and eucalypt forest at Lamington National Park, south-eastern Queensland, Australia. *Australian Journal of Botany* 51: 227–237.

Taylor, G. and Shirtliff, G. (2003). Weathering: cyclical or continuous? An Australian perspective. *Australian Journal of Earth Sciences* 50: 9–17.

Templeton, A.R. (2004). Statistical phylogeography: methods of evaluating and minimizing inference errors. *Molecular Ecology* 13: 789–809.

ter Steege, H., Pitman, N., Sabatier, D., Castellanos, H. van der Hout, P., Daly, D.C., Silveira, M., Phillips, O., Vasquez, R., van Andel, T., Duivenvoorden, J., de Oliveira, A.A., Ek, R., Lilwah, R., Thomas, R., van Essen, J., Baider, C., Maas, P., Mori, S., Terborgh, J., Vargas, P.N., Mogollon, H. and Morawetz, W. (2003). A spatial model of tree alpha-diversity and tree density for the Amazon. *Biological Conservation* 12: 2255–2277.

Terborgh, J. (1974). Preservation of natural diversity: the problem of extinction-prone species. *BioScience* 24: 715–722.

Tero, N., Aspi, J., Siikamaki, P. Jakalaniemi, A. and Tuomi, J. (2003). Genetic structure andgene flow in a metapopulation of an endangered species, *Silene tatarica*. *Molecular Ecology* 12: 2073–2085.

Tews, J., Brose, U., Grimm, V., Teilborger, K, Wichmann, M.C., Schwager, M. and Jeltsch, F. (2004). Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. *Journal of Biogeography* 31: 79–92.

Theischinger, D. (2001). Regions of taxonomic disjunction in Australian Odonata and other freshwater insects: Second addendum, with the description of *Austroaeschna unicornis pinheyi* ssp. nov. (Anisoptera: Aeshnidae). *Odonatologica* 30: 87–96.

Thomas, C.D. (1994). Extinction, Colonization, and Metapopulations: Environmental Tracking by Rare Species. *Conservation Biology* 8: 373–378.

Thomas, C.D., Cameron, A., Green, R.E., Makkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., Ferrelra de Siquelra, M., Grainger, A., Hannah, L., Huges, L., Buntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Townsend Peterson, A., Phillips, O.L. and Williams, S.E. (2004). Extinction risk from climate change. *Nature* 427: 145–148.

Thomsom, V.P. and Leishman, M.R. (2004). Survival of native plants of Hawkesbury Sandstone communities with additional nutrients: effect of plant age and habitat. *Australian Journal of Botany* 52: 141–147.

Thorburn, P.J., Cowie, B.A. and Lawrence, P.A. (1991). Effect of land development on groundwater recharge determined from non-steady chloride profiles. Journal of Hydrology 124: 43-58.

Tierney, D.A. (2004). Towards an understanding of population change for the long-lived resprouting tree *Angophora inopina* (Myrtaceae). *Australian Journal of Botany* 52: 31–38.

Tilman, D., May, R.M., Lehman, C.L. and Nowak. M.A. (1994). Habitat destruction and the extinction debt. *Nature* 371: 65–66.

Tilman, D., Wedin, D. and Knops, J. (1996). Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature* 397: 718–720.

Tindale, M.D. and Roy, S.K. (2002). A cytotaxonomic survey of the Pteridophyta of Australia. *Australian Systematic Botany* 15: 839–937.

Todd, M.K., Felton, A. and Garnett, S.T. (2003). Morphological and dietary differences between common and uncommon subspecies of Crimson Finch *Neochmia phaeton* and Star Finch *Neochmia ruficauda*, in northern Australia. *Emu* 103: 141–148.

Tokuoka, T. and Tobe, H. (2001). Ovules and seeds in subfamily *Phyllanthoideae* (Euphorbiaceae): structure and systematic implications. *Journal of Plant Research* 114: 75–92.

Tokuoka, T. and Tobe, H. (2002). Ovules and seeds in subfamily *Euphorbioideae* (Euphorbiaceae): structure and systematic implications. *Journal of Plant Research* 115: 361–374.

Tokuoka, T. and Tobe, H. (2003). Ovules and seeds in subfamily *Acalyphoideae* (Euphorbiaceae): structure and systematic implications. *Journal of Plant Research* 116: 355–380.

Traill, B.J. (1995). *Competition and co-existence in a community of forest vertebrates.* PhD thesis, Monash University.

Traill, B.J., Collins, E., Peake, P. and Jessup, S. (1996). Current and past status of the birds of Chiltern — a box-ironbark forest in north-eastern Victoria. *Aust. Bird Watcher* 16: 309–326.

Traill, B.J. and Duncan, S. (2000). *Status of birds in the New South Wales temperate woodlands region*. Consultancy report to the NSW National Parks and Wildlife Service. Australian Woodlands Conservancy.

Traverse, A. (1982). Response of world vegetation to Neogene tectonic and climatic events. *Alcheringa* 6: 197–209.

Triantis, K.A., Mylonas, M., Lika, K. and Vardinoyannis, K. (2003). A model for the species-area-habitat relationship. *Journal of Biogeography* 30: 29–27.

Tuomisto, H. and Poulsen, A.D. (1996). Influence of edaphic specialization on pteridophyte distribution in neotropical rain forests. *Journal of Biogeography* 23: 283–293.

Tuomisto, H. and Ruokolainen, K. (1997). The role of ecological knowledge in explaining biogeography and biodiversity in Amazonia. *Biodiversity and Conservation* 6: 347–357.

Turnbull, J.W. and Martensz, P.N. (1983). Seed production, collection and germination in Casuarinaceae. In: S.J. Midgley, W.W. Turnbull, and R.D. Johnston (eds), *Casuarina Ecology, Management and Utilization: Proceedings of an International Workshop, Canberra, Australia, 17–21 August 1981.* CSIRO, Australia. pp. 126–132.

Turney, C.S.M., Kershaw, A.P., Clemens, S.C., Branch, N., Moss, P.T. and Fifield, L.K. (2004). Millenial and orbital variations of El Nino/Southern Oscillation and high-latitude climate in the last glacial period. *Nature* 428: 306–310.

Tyler, M.J. (1989). *Australian Frogs*. Penguin Books, Victoria.

Udovicic, F., McFadden, G.I. and Ladiges, P.Y. (1995). Phylogeny of *Eucalyptus* and *Angophora* based on 5S rDNA spacer sequence data. *Molecular Phylogenetics and Evolution* 4: 247–256.

Valdecasas, A.G. and Camacho, A.I. (2003). Conservation to the rescue of taxonomy. *Biodiversity and Conservation* 12: 1113–1117.

van Beurden (1982). Desert adaptations of *Cyclorana platycephalus*: an holistic approach to desert-adaptation in frogs. In: W.R. Barker and P.J.M. Greenslade (eds.), *Evolution of the Flora and Fauna of Arid Australia*, Peacock Publications, Adelaide. pp. 235–240.

Van der Beek, P. and Braun, J. (1998). Numerical modelling of landscape evolution on geological time-scales: a parameter analysis and comparison with the south-eastern highlands of Australia. *Basin Research* 10: 49–68

van der Kaars, S. and Decker, P.D. (2002). A Late Quaternary pollen record from deep-sea core Fr10/95, GC17 offshore Cape Range Peninsula, northwestern Western Australia. *Review of Palaeobotany and Palynology* 120: 17–39.

Van der Kaars, S., Wang, X., Kershaw, P., Guichard, F. and Setiabudi, D.A. (2000). A Late Quaternary palaeoecological record from the Banda Sea, Indonesia: patterns of vegetation, climate and biomass burning in Indonesia and northern Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 155: 135–153.

Van Dyck, S.M. (1997). Queensland pebble-mound mice … up from the tailings. *Nature Australia* 25(10): 40–47.

Van Welzen, P.C., Turner, H. and Roos, M.C. (2001). New guinea: a correlation between accreting areas and dispersing Sapindaceae. *Cladistics* 17: 242–247.

Vanderwoude, C., Andersen, A.N. and House, A.P.N. (1997). Community organisation, biogeography and seasonality of ants in an open forest of South-eastern Queensland. *Australian Journal of Zoology* 45: 523–537.

Vane-Wright, R.I., Humphries, C.J. and Williams, P.H. (1991). What to protect? — Systematics and the agony of choice. *Biological Conservation* 55: 235–254.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130–137.

Vardon, M.J. and Tidemann, C.R. (1999). The ecology and management of flying-foxes in the Northern Territory. *Australian Biologist* 12: 91–95.

Vazquez, D.P. and Gittleman, J.L. (1998). Biodiversity conservation: does phylogeny matter? Current Biology 8: R379–R381.

Vekemans, X. and Hardy, O.J. (2004). New insights from fine-scale spatial genetic structure analyses in plant populations. *Molecular Ecology* 13: 921–935.

Veldkamp, J.F. (1992). Notes on Australian *Coreopsidinae* (Compositae). *Austrobaileya* 3: 741–744.

Venosta, M. (2001). *Forest structure and ecological management in Victoria's box-ironbark forests.* Honours thesis, School of Ecology and Environment, Deakin University, Melbourne.

Vijverberg, K., Kuperus, P., Breeuwer, J.A.J. and Bachmann, K. (2000). Incipient adaptive radiation of New Zealand and Australian *Microseris* (Asteraceae): an amplified fragment length polymorphism (AFLP) study. *Journal of Evolution and Biology* 13: 997–1008.

Vijverberg, K., Lie, L. and Bachmann, K. (2002). Morphological, evolutionary and taxonomic aspects of Australian and New Zealand *Microseris* (Asteraceae). *Australian Journal of Botany* 50: 127–143.

Vijverberg, K., Mes, T.H.M. and Bachmann, K. (1999). Chloroplast DNA evidence for the evolution of *Microseris* (Asteraceae) in Australia and New Zealand after long-distance dispersal from western North America. *American Journal of Botany* 86: 1448–1462.

Von Dohlen, C.D. and Teulon, D.A.J. (2003). Phylogeny and historical biogeography of New Zealand indigenous Alphidini Aphids (Hemiptera, Aphididae): an hypothesis. *Annals of the Entomological Society of America* 96: 107–116.

Wakeley, J. (2004). Metapopulation models for historical inference. *Molecular Ecology* 13: 865–875.

Walker, B. (1995). Conserving biological diversity through ecosystem resilience. *Conservation Biology* 9: 747–752.

Walker, D. (2000). Pollen input to, and incorporation in, two crater lakes in tropical northeast Australia. *Review of Palaeobotany and Palynology* 111: 253–283.

Wallis, L. (2003). An overview of leaf phytolith production patterns in selected northwest Australian flora. *Review of Palaeobotany and Palynology* 125: 201–248.

Walter, D.E. and Beard, J.J. (1997). A review of the Australian Phytoseiinae (Acari: Mesostigmata: Phytoseiidae). *Invertebrate Taxonomy* 11: 823–860.

Wardell-Johnson, G. and Horwitz, P. (1996). Conserving biodiversity and the recognition of heterogeneity in ancient landscapes: a case study from south-western Australia. *Forest Ecology and Management* 85: 219–238.

Wardell-Johnson, G.W., Williams, J.E., Hill, K.D. and Cumming, R. (1997). Evolutionary biogeography and contemporary distribution of eucalypts. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 92–128.

Warren, M.S., Hill, J.K., Thomas, J.A., Asher, J., Fox, R., Huntley, B., Roy, D.B., Telfer, M.G., Jeffcoate, S., Willis, S.G., Greatorex-Davies, J.N., Moss, D. and Thomas, C.D. (2001). Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature* 414: 65–69.

Waters, E.R. (2003). Molecular adaptation and the origin of land plants. *Molecular Phylogenetics and Evolution* 29: 456–463.

Waters, J.M. and Roy, M.S. (2004). Out of Africa: the slow train to Australasia. *Systematic Biology* 53: 18–24.

Watson, A., Freudenberger, D. and Paull, D. (2001). An assessment of the focal-species approach for conserving birds in variegated landscapes in southeastern Australia. *Conservation Biology* 15: 1364–1373.

Watson, L. and Dallwitz, M.J. (1994). *The Grass Genera of the World.* CAP International, Wallingford. 1081 pp.

Watson, L.E., Evans, T.M. and Boluarte, T. (2000). Molecular phylogeny and biogeography of Tribe *Anthemideae* (Asteraceae), based on chloroplast gene ndhF. *Molecular Phylogenetics and Evolution* 15: 59–69.

Webb, A.A. (1984). Consequences of agricultural land use in the Brigalow Belt. In: A. Bailey (ed.), *The Brigalow Belt of Australia*. Royal Society of Queensland, Brisbane. pp. 131–147.

Webb, J. and Shine R. (1997). Out on a limb: Conservation implications of tree-hollow use by a threatened snake species (*Hoplocephalus bungaroides*: Serpentes, Elapidae). *Biol. Cons*. 81: 21–33.

Westman, W.E. (1990). Park Management of Exotic Plant Species: Problems and Issues. Conservation Biology 4: 251–259.

Westphal, M.I. and Possingham, H.P. (2003). Applying a decision-theory framework to landscape planning for biodiversity: follow-up to Watson *et al*. *Conservation Biology* 17: 327–329.

Whelan, R.J. (1995). *The Ecology of Fire*. Cambridge University Press, Cambridge, United Kingdom.

White, P.S. and Miller, R.I. (1988). Topographic Models of Vascular Plant Richness in the Southern Appalachian High Peaks. *Journal of Ecology* 76: 192–199.

Wikstrom, N. and Kenrick. P. (2001). Evolution of Lycopodiaceae (Lycopsida): estimating divergence times from rbcL gene sequences by use of nonparametric rate smoothing. *Molecular Phylogenetics and Evolution* 19: 177–186.

Wikstron, N., Kenrick, P. and Vogel, J.C. (2002). Schizaeaceae: a phylogenetic approach. *Review of Palaeobotany and Palynology* 119: 35–50.

Wilf, P., Cuneo, N.R., Johnson, K.R., Hicks, J.F., Wing, S.L. and Obradovich, J.D. (2003). High plant diversity in Eocene South America: evidence from Patagonia. *Science* 300: 122–125.

Wilkinson, D.M. (2003). Dispersal cladistics and the nature of biogeography. *Journal of Biogeography* 30: 1779–1780.

Williams, D.M. and Ebach, M.C. (2004). The reform of palaeontology and the rise of biogeography — 25 years after 'ontogeny, phylogeny, palaeontology and the biogenetic law' (Nelson, 1978). *Journal of Biogeography* 31: 685–712.

Williams, J.E. and Brooker, M.I.H. (1997). Eucalypts: an introduction. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 1–15.

Williams, J.E. and Woinarski, J.C.Z. (1997). Eucalypt ecology: overview and outlook. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 402–411.

Williams, R.F. and Metcalf, R.A. (1985). The genesis of form in Casuarinaceae. *Australian Journal of Botany* 33: 563–578.

Wills, K.E., Whalley, R.D.B. and Bruhl, J.J. (2000). Systematic studies in *Paniceae* (Poaceae): *Homopholis* and *Whalleya* gen. et sp. nov. *Australian Systematic Botany* 13: 437–468.

Wilson, J. and Bennett, A.F. (1999). Patchiness of a floral resource: flowering of red ironbark *Eucalyptus tricarpa* in a box and ironbark forest. *Victorian Naturalist* 116: 48–53.

Wilson, P.G. (1998). A taxonomic review of the genera *Eriostemon* and *Philotheca* (Rutaceae: Boronieae). *Nuytsia* 12: 239–265.

Wilson, P.G. (1998). New species and nomenclatural changes in *Phebalium* and related genera (Rutaceae). *Nuytsia* 12: 267–288.

Wilson, P.G., O'Brien, M.M. and Quinn, C.J. (2000). *Anetholea* (Myrtaceae), a new genus for *Backhousia anisata*: a cryptic member of the *Acmena* alliance. *Australian Systematic Botany* 13: 429–435.

Wilson, S.K. and Knowles, D.G. (1988). *Australia's Reptiles; A Photographic Reference to the Terrestrial Reptiles of Australia*. Collins, Sydney.

Winston, M.R. and Angermeier, P.L. (1995). Assessing conservation value using centres of population density. *Conservation Biology* 9: 1518–1527.

Winterton, S.L. and Irwin, M.E. (1997). Phylogenetic revision of *Agapophytus* Guerin (Diptera: Therevidae: Agapophytidae). *Invertebrate Taxonomy* 15: 467–526.

Woinarski, J.C.Z. (1993a). A cut-and-paste community: Birds of monsoon rainforests in Kakadu National Park, Northern Territory. *Emu* 93: 100–120.

Woinarski, J.C.Z. (1993b). Australian tropical savannas, their avifauna, conservation status and threats. In: C.P. Catterall, P.V. Driscoll, K. Hulsman, D. Muir and A. Taplin (eds), *Birds and Their Habitats: Status and Conservation in Queensland*. Queensland Ornithological Society Inc., St. Lucia, Queensland. pp. 45–63.

Woinarski, J.C.Z. and Recher, H.F. (1997). Impact and response: a review of the effects of fire on the Australian avifauna. *Pacific Conservation Biology* 3: 183–205.

Woinarski, J.C.Z., Recher, H.F. and Majer, J.D. (1997). Vertebrates of eucalypt formations. In: J.E. Williams and J.C.Z. Woinarski (eds), *Eucalypt Ecology: Individuals to Ecosystems*. Cambridge University Press. pp. 303–341.

Woolfrey, A.R. and Ladd, P.G. (2001). Habitat preferene and reproductive traits of a major Australian riparian tree species (*Casuarina cunninghamiana*). *Australian Journal of Botany* 49: 705–715.

Worboys, G.L., DeLacy, T. and Lockwood, M. (2000). Chapter 1. Australia's natural heritage. Weblinks. Weblink 1.1 - Formation and evolution of earth, with special reference to Australia. Protected Area Management Principles and Practice, Oxford University Press, Sydney. (http://www.nrsm.uq.edu.au/iucn).

Wright, J.D. (2001). Climate change: the Indonesian valve. *Nature* 411: 142–143.

Wright, S. (1982). Character change, speciation, and the higher taxa. *Evolution* 36: 427–443.

Yates C.J. and Hobbs R.J. (2000). Temperate eucalypt woodlands in Australia — an overview. In: R.J. Hobbs and C. Yates (eds), *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration*. Surrey Beatty & Sons, Sydney. pp. 1–5.

Yen, A.L. (2002). Short-range endemism and Australian Psylloidea (Insecta: Hemiptera)in the genera *Glycaspis* and *Acizzia* (Psyllidae) *Invertebrate Systematics* 16: 631–636.

Young, A. (2003). Monitoring, molecules and models — integrating genetics and demography in the analysis of plant population viability. *Australian Frontiers of Science Conference, Australian Academy of Science, Canberra, 31 July 2003.*

Young, A., Miller, C., Gregory, E. and Langston, A. (2000). Sporophytic self-incompatibility in diploid and tetraploid races of *Rutidosis leptorrhynchoides* (Asteraceae). *Australian Journal of Botany* 48: 667–672.

Young, A.G. and Murray, B.G. (2000). Genetic bottlenecks and dysgenic gene flow into re-established populations of the grassland daisy, *Rutidosis leptorrhynchoides*. *Australian Journal of Botany* 48: 409–416.

Young, P.A.R., Wilson, B.A., McCosker, J.C., Fensham, R.J., Morgan, G. and Taylor, P.M. (1999). Brigalow Belt. In: P.S. Sattler and R.D. Williams (eds), *The Conservation Status of Queensland's Bioregional Ecosystems*. Environmental Protection Agency, Brisbane. pp. 11/1–11/14.

Yu, P., Prakash, N. and Whalley, R.D.B. (2003). Sexual and apomictic seed development in the vulnerable grass *Bothriochloa biloba*. *Australian Journal of Botany* 51: 75–84.

Zhang, M., Stephenson, P.J., O'Reilly, S.Y., McCulloch, M.T. and Norman, M. (2001). Petrogenesis and geodynamic implications of Late Cenozoic Basalts in North Queensland, Australia: trace-element and Sr-Nd-Pb isotope evidence. *Journal of Petrology* 42: 685–719.

Zhang, W. (2000). Phylogeny of the grass family (Poaceae) from rpl16 Intron sequence data. *Molecular Phylogenetics and Evolution* 15: 135–146.

Ziegler, A.M., Eshel, G., McAllister Rees, P., Rothfus, R.A., Rowley, D.B. and Sunderlin, D. (2003). Tracing the tropics across land and sea: Permian to present. *Lethaia* 36: 227–254.

Zimmerman, M. (1988). Nectar production, flowering phenology, and strategies for pollination. In: J. Lovett Doust and L. Lovett Doust (eds), *Plant Reproductive Ecology*. Oxford University Press, Oxford.

Appendix 1

Regional Ecosystems in the Western Hardwoods Area

Regional Ecosystem	Short Description
Brigalow Bioregion	
11.1.4	Mangrove forest/woodland on marine clay plains.
11.3.1	Acacia harpophylla and/or Casuarina cristata open forest on alluvial plains
11.3.2	Eucalyptus populnea woodland on alluvial plains. Texture contrast and deep clay soils.
11.3.2a	E. conica woodland in the central highlands subregions (15, 24)
11.3.3	Eucalyptus coolabah woodland on alluvial plains.
11.3.3a	Melaleuca bracteata
11.3.3x1	low open-shrubland of Sclerolaena spp. with scalding and sometimes emergent trees or shrubs including Eucalyptus coolabah, Acacia harpophylla, Lysiphyllum hookeri and Alectryon oleifolius and Eremophila mitchellii, which are often associated with E. coolibah woodlands
11.3.4	Eucalyptus tereticornis and/or Eucalyptus spp. woodland on alluvial plains.
11.3.5	Acacia cambagei woodland on alluvial plains.
11.3.6	Eucalyptus melanophloia woodland on alluvial plains.
11.3.7	Corymbia spp. woodland on alluvial plains. Sandy soils.
11.3.8	Acacia argyrodendron woodland on alluvial plains.
11.3.9	Eucalyptus platyphylla, Corymbia spp. woodland on alluvial plains.
11.3.10	Eucalyptus brownii woodland on alluvial plains.
11.3.11	Semi-evergreen vine thicket on alluvial plains.
11.3.14	Eucalyptus spp., Angophora spp., Callitris spp. woodland on alluvial plains. Sandy soils.
11.3.15	Eucalyptus coolabah, Acacia stenophylla, Muehlenbeckia florulenta open woodland - woodland on alluvial plains.
11.3.15a	Muehlenbeckia florulenta low shrubland +/- scattered E. coolabah trees
11.3.16	Eucalyptus largiflorens +/- Acacia cambagei woodland on alluvial plains
11.3.17	Eucalyptus populnea woodland with shrubby Acacia harpophylla and/or Casuarina cristata on alluvial plains.
11.3.18	Eucalyptus populnea, Callitris glaucophylla, Allocasuarina luehmannii shrubby woodland on alluvial plains.
11.3.19	Callitris glaucophylla, Corymbia spp. and/or Eucalyptus melanophloia woodland on Cainozoic alluvial plains. Deep sands.
11.3.20	Forb/grassland with scattered Atalaya hemiglauca, Flindersia maculosa, Acacia spp. on alluvial plains.
11.3.21	Dichanthium sericeum and/or Astrebla spp. grassland on alluvial plains. Cracking clay soils.
11.3.23	Eucalyptus conica, E. nobilis, E. tereticornis, Angophora floribunda on alluvial plains. Basalt derived soils.
11.3.24	Themeda avenacea grassland on alluvial plains. Basalt derived soils.
11.3.25	Eucalyptus tereticornis or E. camaldulensis, Casuarina cunninghamiana fringing woodland on alluvial plains.
11.3.26	Eucalyptus moluccana or E. microcarpa woodland to open forest on margins of alluvial plains.
11.3.27	Freshwater wetlands.
11.3.27a	Larger ephemeral - permanent water bodies (lakes).
11.3.28	Casuarina cristata +/- Eucalyptus coolabah open woodland on alluvial plains.
11.3.29	Eucalyptus crebra, E. exserta, Melaleuca spp. woodland on alluvial plains.
11.3.30	Eucalyptus crebra, Corymbia dallachiana woodland on alluvial plains.
11.3.33	Eremophila mitchellii open woodland on alluvial plains.
11.3.34	Acacia tephrina woodland on alluvial plains
11.3.35	Eucalyptus platyphylla, Corymbia clarksoniana woodland on alluvial plains.
11.3.37	Eucalyptus coolabah fringing woodland on alluvial plains.
11.3.39	Eucalyptus melanophloia +/- E. chloroclada woodland on undulating plains and valleys with sandy soils
11.4.1	Semi-evergreen vine thicket +/- Casuarina cristata on Cainozoic clay plains.
11.4.2	Eucalyptus-Corymbia grassy or shrubby woodland on Cainozoic clay plains.
11.4.3	Acacia harpophylla and/or Casuarina cristata shrubby open forest on Cainozoic clay plains.
11.4.3a	Melaleuca bracteata woodland associated with Acacia harpophyla communities
11.4.3b	Eucalyptus argophloia, A. harpophylla open-forest.
11.4.3c	Acacia omalophylla low open-forest ± A. harpophylla.
11.4.4	Dichanthium spp., Astrebla spp. grassland on Cainozoic clay plains.
11.4.5	Acacia argyrodendron woodland on Cainozoic clay plains.
11.4.6	Acacia cambagei woodland on Cainozoic clay plains.
11.4.7	Woodland to open forest of Eucalyptus populnea with Acacia harpophylla and/or Casuarina cristata on Cainozoic clay plains.
11.4.8	Eucalyptus cambageana woodland to open forest with Acacia harpophylla on Cainozoic clay plains
11.4.9	Acacia harpophylla shrubby open forest with Terminalia oblongata on Cainozoic clay plains.

Regional Ecosystem	Short Description
11.4.9a	Acacia harpophylla, Lysiphyllum carronii ± Casuarina cristata open-forest to woodland.
11.4.9b	Acacia harpophylla, Eucalyptus cambagiana open-forest to woodland.
11.4.10	Eucalyptus populnea or E. pilligaensis, Acacia harpophylla, Casuarina cristata woodland to open forest on margins of Cainozoic clay plains.
11.4.11	Dichanthium sericeum, Astrebla spp. and patchy Acacia harpophylla, Eucalyptus coolabah on Cainozoic clay plains.
11.4.12	Eucalyptus populnea woodland on eroding edge of Cainozoic clay plains.
11.4.12a	Acacia maranoensis ± E. populnea woodland.
11.4.13	Eucalyptus orgadophila open woodland on Cainozoic clay plains.
11.5.1	Eucalyptus crebra, Callitris glaucophylla, Angophora leiocarpa, Allocasuarina luehmannii woodland on Cainozoic sand plains/remnant surfaces.
11.5.1a	E. populnea woodland with Allocasuarina luehmannii low tree layer.
11.5.2	Eucalyptus crebra, Corymbia spp., with E. moluccana on lower slopes of Cainozoic sand plains/remnant surfaces.
11.5.2a	Allocasuarina luehmannii low tree layer with or without emergent woodland.
11.5.3	Eucalyptus populnea and/or E. melanophloia and/or Corymbia clarksoniana on Cainozoic sand plains/remnant surfaces.
11.5.4	Eucalyptus crebra, Callitris glaucophylla, C. endlicheri, E. chloroclada, Angophora leiocarpa on Cainozoic sand plains/remnant surfaces.
11.5.4a	Callitris glaucophylla ± Eucalyptus spp. And corymbia spp. woodland.
11.5.4x1	Corymbia bloxsomei ± Callitris glaucophylla ± Eucalyptus crebra ± Angophora leiocarpa woodland on Cainozoic sand plains/remnant surfaces
11.5.5	Eucalyptus melanophloia +/- Callitris glaucophylla +/- E. populnea woodland on Cainozoic sand plains/remnant surfaces.
11.5.5a	Callitris glaucophylla, Eucalyptus melanophloia, Eucalyptus populnea ± Corymbia tessellaris woodlands that occur in northern parts of the bioregion.
11.5.5b	Callitris glaucophylla, Eucalyptus melanophloia, Eucalyptus populnea ± Corymbia tessellaris woodlands that occur in northern parts of the bioregion.
11.5.5c	E. melanophloia ± Callitris glaucophylla ± E. populnea woodlands that occur in northern parts of the bioregion.
11.5.6	Triodia spp. grassland on Cainozoic sand plains/remnant surfaces.
11.5.7	Eucalyptus acmenoides, Angophora leiocarpa on Cainozoic sand plains/remnant surfaces.
11.5.9	Eucalyptus crebra and other Eucalyptus and Corymbia spp. woodland on Cainozoic sand plains/remnant surfaces. Plateaus and broad crests with deep red loams.
11.5.10	Melaleuca tamariscina shrubland on Cainozoic sand plains/remnant surfaces.
11.5.12	Corymbia clarksoniana woodland and other Corymbia, Eucalyptus species on Cainozoic sand plains/remnant surfaces.
11.5.13	Eucalyptus populnea +/- Acacia aneura +/- E. melanophloia woodland on Cainozoic sand plains/remnant surfaces.
11.5.14	Triodia sp. grassland with emergent trees on Cainozoic sand plains/remnant surfaces. Highly alkaline soils.
11.5.14a	Eucalyptus crebra and Allocasuarina luehmannii woodland with a ground layer of Triodia vella.
11.5.15	Semi-evergreen vine thicket on Cainozoic sand plains/remnant surfaces. Deep red loams.
11.5.16	Acacia harpophylla and/or Casuarina cristata open forest in depressions on Cainozoic sand plains/remnant surfaces.
11.5.17	Eucalyptus tereticornis woodland in depressions on Cainozoic sand plains/remnant surfaces.
11.5.18	Micromyrtus capricornia shrubland on Cainozoic sand plains/remnant surfaces.
11.5.20	Eucalyptus moluccana and/or E. microcarpa/pilligaensis +/- E. crebra woodland on Cainozoic sand plains
11.7.1	Acacia harpophylla and/or Casuarina cristata and Eucalyptus thozetiana or E. microcarpa woodland on lower scarp slopes on Cainozoic lateritic duricrust.
11.7.2	Acacia spp. woodland on Cainozoic lateritic duricrust. Scarp retreat zone.
11.7.3	Eucalyptus persistens, Triodia mitchellii open woodland on stripped margins of Cainozoic lateritic duricrust.
11.7.4	Eucalyptus decorticans and/or Eucalyptus spp., Corymbia spp., Acacia spp., Lysicarpus angustifolius on Cainozoic lateritic duricrust.
11.7.5	Shrubland on natural scalds on Cainozoic coarse-grained sedimentary rocks.
11.7.6	Corymbia citriodora and/or Eucalyptus crebra woodland on Cainozoic lateritic duricrust.
11.7.7	Eucalyptus fibrosa subsp. nubila ± Corymbia spp. ± Eucalyptus spp. on Cainozoic lateritic duricrust.
11.8.1	Eucalyptus laevopinea tall open forest on Cainozoic igneous rocks. Elevated plateaus
11.8.2	Eucalyptus tereticornis, E. melliodora woodland on Cainozoic igneous rocks.
11.8.2a	Eucalyptus tereticornis and E. melliodora occurring on low hills in subregion 31.
11.8.3	Semi-evergreen vine thicket on Cainozoic igneous rocks. Steep hillsides
11.8.4	Eucalyptus melanophloia woodland on Cainozoic igneous rocks. Hillsides.
11.8.5	Eucalyptus orgadophila open woodland on Cainozoic igneous rocks.
11.8.6	Macropteranthes leichhardtii thicket on Cainozoic igneous rocks

Regional Ecosystem	Short Description
11.8.7	Shrubland (heath) on Cainozoic igneous rocks. Rocky outcrops.
11.8.8	Eucalyptus albens, E. crebra woodland on Cainozoic igneous rocks. Hillsides.
11.8.9	Callitris spp. +/- vine thicket on Cainozoic igneous rocks. Hillsides.
11.8.10	Themeda triandra grassland on Cainozoic igneous rocks.
11.8.11	Dichanthium sericeum grassland on Cainozoic igneous rocks. Lowlands.
11.8.12	Eucalyptus microcarpa, E. exserta woodland on Cainozoic igneous rocks.
11.8.13	Semi-evergreen vine thicket and microphyll vine forest on Cainozoic igneous rocks. Lowlands.
11.8.15	Eucalyptus brownii or Eucalyptus populnea woodland on Cainozoic igneous rocks. Lowlands.
11.9.1	Acacia harpophylla-Eucalyptus cambageana open forest on Cainozoic fine-grained sedimentary rocks.
11.9.2	Eucalyptus melanophloia +/- E. orgadophila woodland on Cainozoic fine-grained sedimentary rocks.
11.9.3	Dichanthium spp., Astrebla grassland on Cainozoic fine-grained sedimentary rocks.
11.9.3a	Eucalyptus spp., and/or Acacia spp. open-woodland which often occur on rises.
11.9.4	Semi-evergreen vine thicket on Cainozoic fine-grained sedimentary rocks.
11.9.4a	Semi-evergreen vine thicket that occur on crests and mid-slopes of steep hills.
11.9.5	Acacia harpophylla and/or Casuarina cristata open forest on Cainozoic fine-grained sedimentary rocks.
11.9.6	Acacia melvillei +/- A. harpophylla open forest on Cainozoic fine-grained sedimentary rocks.
11.9.7	Eucalyptus populnea shrubby woodland on Cainozoic fine-grained sedimentary rocks.
11.9.7a	E. populnea woodland with a distinct shrubby layer dominated by species such as Eremophila mitchellii, Archidendropsis basaltica and Acacia excelsa.
11.9.8	Macropteranthes leichhardtii thicket on Cainozoic fine-grained sedimentary rocks. Lowlands.
11.9.9	Eucalyptus crebra woodland on Cainozoic fine-grained sedimentary rocks. Lowlands.
11.9.9a	Eucalyptus albens ± E. crebra ± E. tereticornis ± Callitris baileyi.
11.9.10	Acacia harpophylla, Eucalyptus populnea open forest on Cainozoic fine-grained sedimentary rocks.
11.9.11	Acacia harpophylla shrubland on Cainozoic fine-grained sedimentary rocks.
11.9.12	Dichanthium sericeum grassland with clumps of Acacia harpophylla on Cainozoic fine-grained sedimentary rocks.
11.9.13	Eucalyptus moluccana or E. microcarpa open forest on Cainozoic fine-grained sedimentary rocks
11.9.14	Lysiphyllum carronii, Atalaya hemiglauca + Eucalyptus melanophloia + Acacia excelsa open woodland
11.10.1	Corymbia citriodora and/or Eucalyptus crebra open forest on Cainozoic coarse-grained sedimentary rocks.
11.10.1a	Corymbia watsoniana +/- C. citriodora, +/- C. trachyphloia +/- C. henryi
11.10.2	Tall open forest in sheltered gorges on Cainozoic coarse-grained sedimentary rocks.
11.10.3	Acacia catenulata or A. shirleyi open forest on Cainozoic coarse-grained sedimentary rocks. Crests and scarps.
11.10.4	Eucalyptus decorticans, Lysicarpus angustifolius +/- Eucalyptus spp., Corymbia spp., Acacia spp. woodland on coarse-grained sedimentary rocks. Crests and scarps.
11.10.5	Eucalyptus sphaerocarpa +/- E. mensalis, E. saligna, tall open forest on Cainozoic coarse-grained sedimentary rocks. Tablelands.
11.10.6	Angophora leiocarpa, Callitris glaucophylla open woodland on Cainozoic coarse-grained sedimentary rocks. Broad valleys.
11.10.7	Eucalyptus crebra woodland on Cainozoic coarse-grained sedimentary rocks.
11.10.8	Semi-evergreen vine thicket in sheltered habitats on Cainozoic medium to coarse-grained sedimentary rocks.
11.10.9	Callitris glaucophylla woodland on Cainozoic coarse-grained sedimentary rocks.
11.10.11	Eucalyptus melanophloia and/or E. populnea, Callitris glaucophylla woodland on Cainozoic coarse-grained sedimentary rocks.
11.10.11a	Eucalyptus moluccana and/or E. microcarpa woodland on lower slopes. 11.10.11b; Eucalyptus crebra ± Callitris glaucophylla ± Angophora leiocarpa ± Eucalyptus spp woodland.
11.10.11b	Eucalyptus crebra ± Callitris glaucophylla ± Angophora leiocarpa ± Eucalyptus spp
11.10.12	Eucalyptus populnea woodland on Cainozoic medium to coarse-grained sedimentary rocks.
11.10.13	Mixed Eucalyptus-Corymbia open forest on scarps and sandstone tablelands.
11.10.13b	Corymbia leichhardtii woodland.
11.11.1	Eucalyptus crebra +/- Acacia rhodoxylon woodland on old sedimentary rocks with varying degrees of metamorphism and folding.
11.11.1a	Eucalyptus crebra and/or Acacia rhodoxylon + Corymbia dallachiana + Acacia catenulata on land zone 12
11.11.2	Acacia shirleyi or A. catenulata low open forest on old sedimentary rocks with varying degrees of metamorphism and folding.
11.11.3	Corymbia citriodora, Eucalyptus crebra, E. acmenoides open forest on old sedimentary rocks with varying degrees of metamorphism and folding. Coastal ranges.
11.11.4	Eucalyptus crebra woodland on old sedimentary rocks with varying degrees of metamorphism and folding. Coastal ranges.
11.11.4a	E. tereticornis woodland.
11.11.4c	Eucalyptus thozetiana
11.11.5	Microphyll vine forest +/- Araucaria cunninghamii on old sedimentary rocks with varying degrees of metamorphism and folding.
11.11.5a	vine thicket, usually with no Araucaria cunninghamii emergents,

Regional Ecosystem	Short Description
11.11.6	Corymbia leichhardtii, C. clarksoniana woodland on deformed and metamorphosed sediments and interbedded volcanics.
11.11.7	Eucalyptus fibrosa subsp. (Glen Geddes M.I. Brooker 10230) +/- Corymbia xanthope +/- Corymbia spp.woodland on serpentinite.
11.11.8	Eucalyptus shirleyi woodland on deformed and metamorphosed sediments and interbedded volcanics.
11.11.9	Eucalyptus populnea or E. brownii woodland on deformed and metamorphosed sediments and interbedded volcanics.
11.11.10	Eucalyptus melanophloia woodland on deformed and metamorphosed sediments and interbedded volcanics.
11.11.10a	Eucalyptus moluccana woodland on lower slopes.
11.11.11	Eucalyptus orgadophila woodland on deformed and metamorphosed sediments and interbedded volcanics.
11.11.12	Eucalyptus persistens low woodland on deformed and metamorphosed sediments and interbedded volcanics.
11.11.13	Acacia harpophylla or A. argyrodendron, Terminalia oblongata low open forest on deformed and metamorphosed sediments and interbedded volcanics.
11.11.14	Acacia harpophylla open forest on deformed and metamorphosed sediments and interbedded volcanics.
11.11.15	Eucalyptus crebra woodland on deformed and metamorphosed sediments and interbedded volcanics; undulating plains.
11.11.15a	E. crebra, E. exserta woodland.
11.11.16	Eucalyptus cambageana, Acacia harpophylla woodland on old sedimentary rocks with varying degrees of metamorphism and folding; lowlands.
11.11.18	Semi-evergreen vine thicket on old sedimentary rocks with varying degrees of metamorphism and folding. Lowlands
11.11.19	Eucalyptus thozetiana, Acacia harpophylla woodland on old sedimentary rocks with varying degrees of metamorphism and folding; lowlands and footslopes
11.12.1	Eucalyptus crebra woodland on igneous rocks
11.12.1a	Eucalyptus crebra ± E. exserta woodland on undulating rises.
11.12.1b	Eucalyptus persistens low woodland.
11.12.2	Eucalyptus melanophloia woodland on igneous rocks
11.12.2a	E. melanophloia and/or E. orgadophila ± Corymbia erythrophloia on undulating plains.
11.12.2b	E. moluccana woodland on lower slopes.
11.12.3	Eucalyptus crebra, E. tereticornis, Angophora leiocarpa woodland on igneous rocks especially granite.
11.12.4	Semi-evergreen vine thicket and microphyll vine forest on igneous rocks
11.12.4a	Semi-evergreen vine thicket with open patches of Acacia fasciculifera, Archidendropsis thozetiana, Pleiogynium timorense and various other species.
11.12.5	Corymbia spp., Lysicarpus angustifolius, Eucalyptus crebra, E. cloeziana woodland on igneous rocks (granite).
11.12.5a	Corymbia watsoniana., Lysicarpus angustifolius, Eucalyptus crebra, E. cloeziana woodland on igneous rocks (granite).
11.12.6	Corymbia citriodora open forest on igneous rocks (granite)
11.12.6a	Eucalyptus crebra + Corymbia citriodora and/or E. acmenoides + Lophostemon suaveolens woodland to open-forest that occurs mainly in subregions 11, 14 and 18.
11.12.7	Eucalyptus crebra woodland with patches of semi-evergreen vine thicket on igneous rocks (boulder-strewn hillsides).
11.12.8	Eucalyptus shirleyi woodland on igneous rocks
11.12.14	Lophostemon spp. woodland on igneous rocks; coastal hills
11.12.17	Eucalyptus populnea woodland on igneous rocks; colluvial lower slopes
11.12.18	Montane shrubland on igneous rocks; mountain tops.
11.12.20	Corymbia spp., Eucalyptus baileyana, E. dura, E. exserta woodland on igneous rocks; hills.
11.12.21	Acacia harpophylla open forest on igneous rocks; colluvial lower slopes.
New England Tableland	
13.3.1	Eucalyptus blakelyi woodland on alluvial plains
13.3.2	Eucalyptus nova-anglica open forest on alluvial plains
13.3.3	Eucalyptus nobilis open forest on alluvial plains
13.3.4	Eucalyptus conica, E. microcarpa, E. melliodora woodland on alluvial plains
13.3.5	Eucalyptus camaldulensis fringing open forest
13.3.6	Sedgeland on igneous rocks
13.3.7	Eucalyptus tereticornis, Angophora floribunda open forest on alluvial plains
13.9.2	Eucalyptus moluccana open forest on fine-grained sedimentary rocks
13.11.1	Eucalyptus youmanii, E. dealbata, E. caleyi, Callitris endlicheri woodland on metamorphics
13.11.2	Eucalyptus laevopinea open forest on metamorphics
13.11.3	Eucalyptus crebra woodland on metamorphics
13.11.3a	E.crebra, E.tereticornis, Angophera leiocarpa woodland.
13.11.3b	Eucalyptus caleyi woodland.
13.11.4	Eucalyptus melanophloia woodland on metamorphics
13.11.5	Eucalyptus sideroxylon, E. fibrosa subsp. nubila open forest on metamorphics

Regional Ecosystem	Short Description
13.11.6	Corymbia citriodora, Eucalyptus crebra open forest on metamorphics
13.11.7	Low microphyll vine forest on metamorphics
13.11.7a	Low microphyll vine forest on metamorphics on small patches of sandstone south of Warwick
13.11.8	Eucalyptus melliodora and/or Eucalyptus microcarpa/E.moluccana woodland on metamorphics.
13.11.8a	E. pilligaensis or E. moluccana woodland in the west of the bioregion.
13.12.1	Eucalyptus campanulata open forest on igneous rocks
13.12.2	Eucalyptus andrewsii, E. youmanii woodland on igneous rocks.
13.12.3	Eucalyptus scoparia woodland on igneous rocks.
13.12.4	Eucalyptus caliginosa, E. tereticornis open forest on igneous rocks.
13.12.5	Eucalyptus youmanii on igneous rocks.
13.12.6	Shrubland on igneous rocks.
13.12.8	Eucalyptus melliodora and/or Eucalyptus moluccana/E. microcarpa and/or E. conica woodland on igneous rocks.
13.12.9	Eucalyptus blakelyi and/or Eucalyptus caliginosa woodland to open forest on igneous rocks.
13.12.10	Eucalyptus crebra, E. tereticornis, Angophora leiocarpa woodland on igneous rocks
South East Queensland Bioregion	
12.3.3	Eucalyptus tereticornis woodland to open forest on alluvial plains.
12.3.7	Eucalyptus tereticornis, Callistemon viminalis, Casuarina cunninghamiana fringing forest.
12.3.9	Eucalyptus nobilis tall open forest on alluvial plains.
12.5.1	Mixed forest with Corymbia citriodora on subcoastal remnant Tertiary surfaces. Deep red soils.
12.5.5	Eucalyptus portuensis, Corymbia intermedia woodland on remnant Tertiary surfaces. Deep red soils.
12.5.6	Eucalyptus siderophloia, E. propinqua, E. microcorys +/- E. pilularis tall open forest on remnant Tertiary surfaces. Deep red soils.
12.5.6a	Eucalyptus saligna or E. grandis open forest, often with rainforest understorey,
12.8.1	Eucalyptus campanulata tall open forest on Cainozoic igneous rocks
12.8.4	Complex notophyll vine forest with Araucaria spp. on Cainozoic igneous rocks
12.8.5	Complex notophyll vine forest on Cainozoic igneous rocks. Altitude >600m.
12.8.8	Eucalyptus saligna or E. grandis tall open forest on Cainozoic igneous rocks.
12.8.9	Lophostemon confertus tall open forest on Cainozoic igneous rocks.
12.8.12	Eucalyptus obliqua tall open forest on Cainozoic igneous rocks.
12.8.13	Araucarian Complex microphyll vine forest on Cainozoic igneous rocks.
12.8.13x1	Microphyll and microphyll/notophyll vine forest ± Araucaria cunninghamii associated with areas that have been subject to deep weathering (land zone 5).
12.8.14	Eucalyptus eugenioides, E. biturbinata, E. melliodora open forest on Cainozoic igneous rocks.
12.8.14x1	Woodland of Eucalyptus eugenioides, E. biturbinata/longirostrata,E. crebra, and Corymbia trachyphloia occurring on land zone 9
12.8.15	Poa labillardieri grassland on Cainozoic igneous rocks.
12.8.16	Eucalyptus crebra, E. tereticornis woodland on Cainozoic igneous rocks.
12.8.17	Eucalyptus crebra, E. melanophloia woodland on Cainozoic igneous rocks.
12.8.19	Montane shrubland on Cainozoic igneous rocks.
12.8.21	Semi-evergreen vine thicket with Brachychiton rupestris on Cainozoic igneous rocks; southern half of bioregion.
12.8.23	Acacia harpophylla open forest on Cainozoic igneous rocks.
12.8.26	Corymbia trachyphloia and Eucalyptus major woodland on igneous rocks.
12.9-10.2	Corymbia citriodora-Eucalyptus crebra open forest on sedimentary rocks.
12.9-10.3	Eucalyptus moluccana on sedimentary rocks.
12.9-10.5a	Eucalyptus helidonica, Corymbia trachyphloia, C. citriodora, E. taurina in the Helidon hills region
12.9-10.6	Acacia harpophylla open forest on sedimentary rocks.
12.9-10.7	Eucalyptus crebra woodland on sedimentary rocks.
12.9-10.14	Eucalyptus pilularis tall open forest on sedimentary rocks.
12.9-10.15	Semi-evergreen vine thicket with Brachychiton rupestris on sedimentary rocks.
12.9-10.16	Araucarian microphyll to notophyll vine forest on sedimentary rocks.
12.9-10.17a	
12.9-10.19	Eucalyptus fibrosa subsp. fibrosa open forest on sedimentary rocks.
12.9-10.21	Eucalyptus acmenoides or E. portuensis open forest usually with Corymbia trachyphloia +/- Angophora leiocarpa, E. major, E. moluccana, E. exserta, Lophostemon sp. aff. L. confertus on Cainozoic to Proterozoic sediments.
12.9-10.23	Eucalyptus melanoleuca open forest on sedimentary rocks.
12.9-10.24	Eucalyptus suffulgens open forest on sedimentary rocks.
12.11.4	Semi-evergreen vine thicket on metamorphics and interbedded volcanics.
12.11.5	Mixed tall open forest with Corymbia citriodora, Eucalyptus siderophloia, E. major on metamorphics and interbedded volcanics.
12.11.6	Corymbia citriodora, Eucalyptus crebra open forest on metamorphics and interbedded volcanics.

Regional Ecosystem	Short Description
12.11.7	Eucalyptus crebra woodland on metamorphics and interbedded volcanics.
12.11.8	Eucalyptus melanophloia, E. crebra woodland on metamorphics and interbedded volcanics
12.11.9	Eucalyptus tereticornis, Corymbia intermedia open forest on metamorphics and interbedded volcanics at higher altitudes.
12.11.12	Araucarian complex microphyll vine forest on metamorphics and interbedded volcanics; northern half of bioregion
12.11.14	Eucalyptus crebra, E. tereticornis woodland on metamorphics and interbedded volcanics.
12.11.17	Eucalyptus acmenoides or E. portuensis open forest on metamorphics and interbedded volcanics
12.12.10	Shrubland of rocky peaks on Mesozoic to Proterozoic igneous rocks
12.11.18	Eucalyptus moluccana tall open forest on metamorphics and interbedded volcanics.
12.12.3	Mixed open forest with Corymbia citriodora, Eucalyptus siderophloia or E. crebra or E. decolor, E. major and/or E. longirostrata, E. acmenoides or E. portuensis on Mesozoic to Proterozoic igneous rocks
12.12.4	Eucalyptus acmenoides +/- Syncarpia glomulifera tall open forest on Mesozoic to Proterozoic igneous rocks, especially granite
12.12.5	Corymbia citriodora, Eucalyptus crebra open forest on Mesozoic to Proterozoic igneous rocks.
12.12.7	Eucalyptus crebra woodland on Mesozoic to Proterozoic igneous rocks
12.12.8	Eucalyptus melanophloia woodland on Mesozoic to Proterozoic igneous rocks
12.12.9	Shrubby woodland with Eucalyptus dura on rocky peaks on Mesozoic to Proterozoic igneous rocks
12.12.11	Eucalyptus portuensis or E. acmenoides, Corymbia trachphloia open forest on Mesozoic to Proterozoic igneous rocks
12.12.12	Eucalyptus tereticornis, E. crebra or E. siderophloia, Lophostemon suaveolens open forest on granite
12.12.13	Araucarian Complex microphyll to notophyll vine forest on Mesozoic to Proterozoic igneous rocks
12.12.16	Notophyll vine forest on Mesozoic to Proterozoic igneous rocks
12.12.18	Semi-evergreen vine thicket on Mesozoic to Proterozoic igneous rocks; north of bioregion
12.12.24	Angophora leiocarpa, Eucalyptus crebra woodland on Mesozoic to Proterozoic igneous rocks
12.12.24x1	Angophora leiocarpa, Eucalyptus crebra ± Corymbia intermedia, E. longirostrata, E. major, E. tereticornis, E. acmenoides or E. portuensis, C. citriodora woodland to open-forest on areas that have been subject to deep weathering (land zone 5).
12.12.27	Corymbia trachyphloia, Eucalyptus crebra and Callitris endlicheri woodland on Mesozoic to Proterozoic igneous rocks
12.12.28	Eucalyptus moluccana tall open forest on Mesozoic to Proterozoic igneous rocks
Desert Uplands Bioregion	
10.3.3a	Eucalyptus cambageana open woodland with or without Acacia harpophylla understorey on alluvium
10.3.3b	Acacia harpophylla low woodland to woodland on alluvium
10.3.6a	Eucalyptus brownii open woodland to woodland on alluvium
10.3.12a	Corymbia plena and C. dallachiana open woodland on alluvium
10.3.13a	Eucalyptus camaldulensis open woodland to woodland along river channels
10.3.13b	Melaleuca fluviatalis open woodland to woodland along river channels
10.3.14a	Eucalyptus coolabah open woodland on flood plains and channels
10.3.14b	Eucalyptus coolabah mostly with E. camaldulensis open woodland to woodland along streams
10.3.27a	Eucalyptus populnea open woodland to woodland on alluvium
10.3.28a	Eucalyptus melanophloia open woodland to woodland on alluvium
10.4.8	Astrebla spp. and/or Dichanthium sericeum grassland on clay downs
10.4.9	Corymbia terminalis low open woodland on downs
10.5.1	Eucalyptus similis woodland or open woodland on deep red earths
10.5.1a	Eucalyptus similis low open woodland
10.5.1c	Eucalyptus similis and Corymbia setosa low open woodland
10.5.1d	Corymbia setosa low open woodland on sand plain
10.5.2	Corymbia plena and C. dallachiana +/- Eucalyptus populnea woodland on red earths and texture contrast soils
10.5.2a	Corymbia dallachiana and C. plena open woodland on sand plain
10.5.5	Eucalyptus whitei or E. melanophloia +/- E. populnea and bloodwood woodland on loamy yellow earths and texture contrast soils
10.5.5a	Eucalyptus melanophloia open woodland on sand plain
10.5.7c	Acacia salicina and Acacia excelsa low open woodland on sand plains
10.5.12	Eucalyptus populnea open woodland to woodland on undulating terrain with sandy loam to sandy clay soils
10.7.2	Eucalyptus persistens +/- E. thozetiana low open woodland on skeletal soils
10.7.2b	Triodia pungens and/or Eriachne mucronata or Amphipogon caricinus grasslands on ferricrete
10.7.2d	Eucalyptus persistens low open woodland on shallow duplex soil
10.7.3a	Acacia catenulata low woodland and sometimes with Acacia shirleyi woodland on skeletal soil
10.7.3c	Corymbia lamprophylla and/or C. leichhardtii woodland on ferricrete
10.7.5	Eucalyptus thozetiana woodland on texture contrast soils on pediments below scarps
10.7.7	Open-shrubland to low open woodland of Melaleuca tamariscina or M. uncinata or M. nervosa or M. pallescens and/or Acacia leptostachya or A. julifera on skeletal soils and shallow earths

Regional Ecosystem	Short Description
10.7.11a	Eucalyptus melanophloia open woodland on Tertiary surface
10.7.12a	Eucalyptus sp. (Caldervale D. Jermyn AQ 582304) open woodland on Tertiary surfaces
Mulga Downs Bioregion	
6.3.1	Eucalyptus camaldulensis woodland on alluvium within Acacia aneura associations
6.3.3	Eucalyptus camaldulensis +/- E. coolabah +/- E. populnea, Acacia stenophylla woodland on alluvium
6.3.7	Eucalyptus coolabah, Acacia stenophylla low open woodland on alluvium
6.3.14	Astrebla spp., Dichanthium spp. open grassland on alluvium
6.3.17	Callitris glaucophylla, Corymbia tessellaris, Acacia excelsa +/- C. clarksoniana open woodland on old alluvial dunes and sand plains
6.3.18	Eucalyptus populnea +/- Eremophila mitchellii +/- Acacia aneura +/- E. melanophloia woodland on flat alluvial plains
6.3.20	Angophora floribunda +/- Eucalyptus melanophloia, open woodland with Triodia spp. on old alluvial levees
6.4.1	Acacia cambagei + Casuarina cristata open forest on clay plains
6.4.2	Casuarina cristata + Acacia harpophylla open forest on clay plains
6.4.3	Eucalyptus populnea, Casuarina cristata or Acacia harpophylla +/- Geijera parviflora woodland on clay plains
6.4.4	Acacia harpophylla +/- A. cambagei +/- Atalaya hemiglauca, Flindersia maculosa low woodland on old alluvial plains
6.5.1	Acacia aneura, Eucalyptus populnea, E. melanophloia open forest on undulating lowlands
6.5.2	Eucalyptus populnea, Acacia aneura and/or E. melanophloia woodland on Quaternary sediments
6.5.3	Eucalyptus populnea, Acacia aneura +/- Eremophila mitchellii woodland
6.5.4	Eucalyptus populnea +/- Eremophila mitchellii +/- Acacia aneura +/- Callitris glaucophylla woodland on Quaternary sediments
6.5.5	Eucalyptus intertexta +/- E. populnea +/- Acacia aneura +/- Callitris glaucophylla woodland on Quaternary sediments
6.5.8	Acacia aneura, Eucalyptus populnea +/- Eremophila gilesii low woodland
6.5.9	Acacia aneura, Eucalyptus populnea +/- E. melanophloia shrubby low woodland on Quaternary sediments
6.5.13	Acacia aneura +/- Eucalyptus populnea +/- E. melanophloia +/- Brachychiton populneus low woodland on sand plains
6.5.17	Eucalyptus populnea, E. melanophloia +/- Callitris glaucophylla +/- Acacia aneura woodland on sand plains
6.5.18	Acacia aneura +/- Eucalyptus populnea +/- E. melanophloia +/- Eremophila mitchellii low open woodland on plains
6.7.1	Acacia catenulata +/- Eucalyptus spp. open forest on crests and slopes
6.7.2	Acacia microsperma open forest on upper and footslopes
6.7.5	Eucalyptus thozetiana or E. cambageana, Acacia harpophylla woodland on scarps
6.7.6	Eucalyptus thozetiana +/- Acacia aneura open woodland on scarps and slopes
6.7.11	Acacia aneura +/- Eucalyptus cambageana +/- E. thozetiana +/- Eremophila latrobei tall shrubland on residuals
6.9.3	Acacia harpophylla woodland with emergent Eucalyptus cambageana in valleys with stony soils derived from Cretaceous sediments
Einasleigh Uplands Bioregion	
9.3.1c	Eucalyptus camaldulensis or Eucalyptus tereticornis ± Casuarina cunninghamiana ± Melaleuca spp. fringing woodland on channels and levees
9.3.1d	Eucalyptus camaldulensis or Eucalyptus tereticornis ± Casuarina cunninghamiana ± Melaleuca spp. fringing woodland on channels and levees
9.3.1x3	Waterholes and lagoons in the bed of larger rivers containing aquatic vegetation.
9.3.6	Poplar gum (Eucalyptus platyphylla) woodland on podsolics in drainage depressions
9.5.3x1	Corymbia peltata or C. setosa ± C. clarksoniana and Eucalyptus melanophloia open woodland on laterised and deeply weathered surfaces
9.5.3x9	Eucalyptus crebra (sens. lat.) +/- Corymbia clarksoniana +/- C. dallachiana +/- C. tessellaris +/- E. platyphylla +/- C. setosa +/- C. erythrophloia woodland to open woodland
9.7.1	Normanton box (Eucalyptus persistens) low open woodland on texture contrast soils on plains
9.7.2a	Acacia shirleyi low open forest to dense woodland.
9.11.1b	Eucalyptus sp. (Mt Hope) +/- Corymbia peltata +/- E. dallachiana +/- E. brownii +/- E. drepanophylla low open woodland with no mid layer and a tussock grass ground layer.
9.11.2a	Eucalyptus exilipes and Corymbia erythrophloia open-woodland with a sparse tussock grass ground layer.
9.11.2g	Eucalyptus crebra (sens. lat.), Corymbia peltata ± Eucalyptus shirleyi woodland to open woodland on metamorphic hills
9.11.5x5	Eucalyptus exserta and Lysicarpus angustifolius low open woodland with Triodia bitextura ground layer on sandy soils on acid volcanics
9.12.1a	Eucalyptus xanthoclada +/- Corymbia erythrophloia open-woodland.
9.12.1d	Eucalyptus crebra (sens. lat.) +/- Corymbia erythrophloia +/- C. dallachiana +/- E. persistens +/- E. brownii +/- E. microneura +/- C. clarksoniana open woodland or woodland.
9.12.4	Broad-leaved ironbark (Eucalyptus shirleyi) low open woodland on skeletal soils of hills and ranges
9.12.4x4	Eucalyptus persistens low woodland to woodland on granites and rhyolites

Regional Ecosystem	**Short Description**
9.12.5x2	Eucalyptus crebra (sens. lat.) +/- Corymbia erythrophloia +/- C. dallachiana +/- E. persistens +/- E. brownii +/- E. microneura +/- C. clarksoniana open woodland or woodland.
9.12.5x3	Eucalyptus crebra (sens. lat.) +/- Corymbia erythrophloia +/- C. dallachiana +/- E. persistens +/- E. brownii +/- E. microneura +/- C. clarksoniana open woodland or woodland.
9.12.7a	Eucalyptus culleni and Corymbia leichhardtii +/- E. shirleyi or E. melanophoia +/- E. pachycalyx +/- Erythrophleum chlorostachys +/- C. erythrophloia open woodland to low open woodland.
9.12.8	Dry vine forest on igneous outcrops
Mitchell Grass Downs Bioregion	
4.3.2	Eucalyptus camaldulensis +/- E. coolabah woodland on drainage lines
4.3.4	Eucalyptus coolabah open woodland on drainage lines/plains
4.3.3	Eucalyptus coolabah, E. camaldulensis +/- Lysiphyllum gilvum open woodland on drainage lines
4.3.14	Astrebla lappacea, Astrebla spp. +/- Eulalia aurea grassland on alluvium
4.3.19	Dichanthium spp., Eulalia aurea, Astrebla spp. grassland on alluvium
4.3.20	Atriplex spp. and Sclerolaena spp. +/- Astrebla spp. +/- short grasses +/- forbs, open herbland on braided or flat alluvial plains
4.5.9	Acacia cambagei, Archidendropsis basaltica and mixed species open woodland on sand plains
4.9.1	Astrebla lappacea +/- Aristida latifolia +/- Panicum decompositum grassland on Cretaceous sediments
4.9.6	Astrebla spp. grassland wooded with mixed tree species on Cretaceous sediments
4.9.7	Astrebla spp. grassland wooded with Acacia tephrina +/- A. cambagei and Atalaya hemiglauca on Cretaceous sediments
4.9.8	Astrebla spp. grassland wooded with Atalaya hemiglauca +/- Alectryon oleifolius +/- Flindersia maculosa on Cretaceous sediments
4.9.11	Acacia cambagei low woodland with scattered shrubs such as Eremophila mitchellii and Geijera parviflora on fresh Cretaceous sediments
4.9.15	Acacia harpophylla tall shrubland with scattered emergent Atalaya hemiglauca +/- Eucalyptus spp. on Cretaceous sediments
4.9.17	Acacia harpophylla +/- A. cambagei low woodland on undulating clay plains.
4.9.18	Archidendropsis basaltica and mixed species including Ventilago viminalis and Lysiphyllum carronii on Cretaceous sediments

Appendix 2

Assessment of diversity within Regional Ecosystems of the Western Hardwoods Area

Introduction

A discussion of the Regional Ecosystem classification system used in Queensland can be found in Section 2.2.2 of this report.

Method

Species data were sourced from the Queensland Herbarium's CORVEG systematic survey sites. Sites recorded as being of 'secondary' sampling level or with 'comprehensive' floristics sampled were used as the best indication of species presence or absence.

The statistical analysis software PC-ORD 4.27 (McCune and Mefford 1999) was used for multivariate analysis. The total species composition data from sites for which the RE was recorded were transformed into a site by species presence-absence matrix. Weeds, indeterminate species and single species records were excluded. Sites were then clustered using the Sorensen distance measure with UPGMA (group average) linkage, and a dendrogram was produced to show site groupings. Significant group-associated species were determined by PC-ORD's indicator species analysis which uses the method of Dufrene and Legendre (1997) for calculating indicator values, then runs a Monte Carlo significance test.

A nonmetric multidimensional scaling (NMS) ordination of the sites in two dimensions was also conducted using the Sorensen (Bray-Curtis) distance measure. The site groups and significant indicator species were plotted on the ordination diagram. In some instances it was convenient to reduce the stress levels associated with ordination of the full data set, and so only indicator species were used to ordinate the sites. Selected bioclimatic parameters (Table A2.1) assigned to sites using the BIOCLIM module of ANUCLIM (CRES Australian National University 1999) were then overlaid onto the ordination plot. Many of the 35 available BIOCLIM parameters are interrelated, and so several indicators were selected as being potentially limiting climatic conditions during seasonal extremes (Nix and Switzer 1991). A derived season equability moisture index (after Nix 1994; See Section 2.1.1.) and altitude were also included.

Table A2.1 Selected bioclimatic parameters for NMS ordination plot

Code	**Variable/Parameter**
MTWP	Maximum Temperature of Warmest Period
MTCP	Minimum Temperature of Coldest Period
PWQ	Precipitation of Wettest Quarter
PDQ	Precipitation of Driest Quarter
PHQ	Precipitation of Warmest Quarter
PCQ	Precipitation of Coldest Quarter
Altitude	Altitude
Nix MMI	% Deviation from Equal Summer-Winter Mean Moisture Index

A slightly different approach was taken for REs with similar composition and distribution. In discussions with Queensland Herbarium staff, it was suggested that similar REs and their related subunits be analysed together (B. Wilson pers. comm.). To take into account large numbers of sites, the analysis method was altered to gain a broader indication of dominant woody species rather than total species composition. Sites were clustered on basal areas of woody species using a relativised Sorensen distance measure and flexible beta linkage value of -0.25. Species with records for basal area at fewer than six sites were excluded.

Results

The full results are given for one RE (11.5.1) and end results for three others (11.12.1, 11.7.4 and 11.10.1/11.10.13). These preliminary findings indicate strong potential for dividing a number of existing REs into separate communities and reassessing their conservation status. This would result in the recognition of greater RE richness in both the Brigalow Belt as a whole and in specific parts of the bioregion. Furthermore, there would be greater significance placed on reclassified communities with occurrences on public land which are deemed to be threatened. However, it is apparent from investigating several REs that large areas still require further comprehensive field survey.

Example 1

RE 11.5.1: This RE is broadly described as *Eucalyptus crebra*, *Callitris glaucophylla*, *Angophora leiocarpa*, *Allocasuarina luehmannii* woodland on Cenozoic sand plains/remnant surfaces. It is currently mapped as spreading through the Inglewood, Barakula and Yuleba forests, with disjunct patches in and around Woorabinda Subregion and the Auburn Ranges (Figure A2.3). Its Vegetation Management Status under the *Vegetation Management Act 1999* and Biodiversity Status defined by the Queensland Herbarium are 'not of concern' (Environmental Protection Agency 2003b).

Six groups of sites representing differences in species composition were determined through the analysis, with a single site ('group' 3) clustering out by itself (Figure A2.1, Table A2.2). Group 6 did not have any significantly associated indicator species.

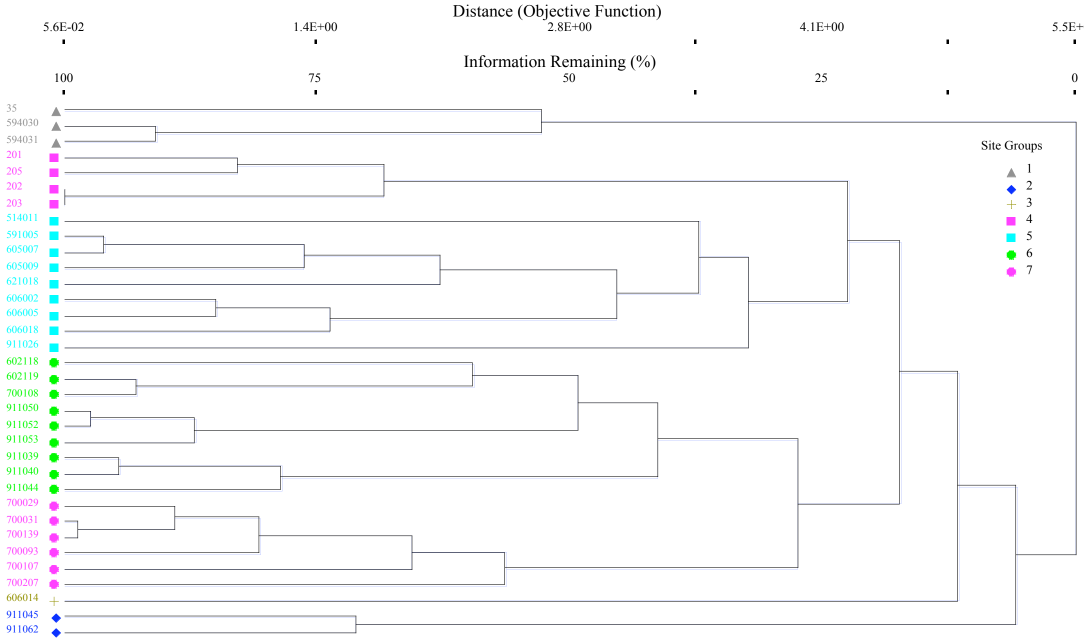


Figure A2.1 Sorensen/UPGMA dendrogram representing 11.5.1 site groupings for total species composition

Table A2.2 Group percentage indicator species analysis for RE 11.5.1 calculated using the method of Dufrene and Legendre (1997) and Monte Carlo significance of observed maximum indicator value for each species (1000 permutations); only significant ($p < 0.05$) species are shown.

Namecode	Species	Group	% Indication	Mean	St Dev	*P*
ANGOLEIO	*Angophora leiocarpa*	1	36	22.4	7.86	0.043
CHRYAPIC	*Chrysocephalum apiculatum*	1	69	20.8	11.72	0.002
EUCATERE	*Eucalyptus tereticornis*	1	67	18.8	11.69	0.009
EXOCCUPR	*Exocarpos cupressiformis*	1	67	19.6	11.83	0.011
HIBBCIST	*Hibbertia cistifolia*	1	67	18.8	11.69	0.009
JACKSCOP	*Jacksonia scoparia*	1	62	20.6	11.66	0.022
LAXMGRAC	*Laxmannia gracilis*	1	52	21.2	10.27	0.007
MELIISLA	*Melichrus* sp. (Isla Gorge P.Sharpe+ 601)	1	90	19.7	10.82	0.001
SCHIFRAG	*Schizachyrium fragile*	1	67	18.8	11.69	0.009
ACACMUEL	*Acacia muelleriana*	2	100	18.5	11.1	0.002
CYMBREFR	*Cymbopogon refractus*	2	45	21.7	10.04	0.035
MELADECO	*Melaleuca decora*	2	62	19.8	10.88	0.015
	(none – single site group)	3				
ACACJUJL	*Acacia julifera* subsp. *curvinervia*	4	50	19.1	11.94	0.021
ACACSHIR	*Acacia shirleyi*	4	50	18.9	11.27	0.011
ARISCAPU	*Aristida caput-medusae*	4	29	23	3.2	0.011
ARISJESU	*Aristida jerichoensis* var. *jerichoensis*	4	38	20.4	10.98	0.05
BABIDENS	*Babingtonia densifolia*	4	41	19.7	11	0.041
BOROBIPI	*Boronia bipinnata*	4	75	20	11.06	0.009
CALLGLAU	*Callitris glaucophylla*	4	30	22.6	2.72	0.001
CALYMICR	*Calytrix microcoma*	4	50	19.1	11.94	0.021
CORYLAMP	*Corymbia lamprophylla*	4	75	20	11.06	0.009
CORYLEIC	*Corymbia leichhardtii*	4	100	19.8	10.65	0.001
DODOSTEN	*Dodonaea stenophylla*	4	50	18.9	11.27	0.011
EUCACREB	*Eucalyptus crebra*	4	20	18.3	0.85	0.018
EUCACHIN	*Eucalyptus* sp. (Chinchilla L.Pedley 4022)	4	75	20	11.06	0.009
GREVSESS	*Grevillea sessilis*	4	50	19.1	11.94	0.021
GREVSTRI	*Grevillea striata*	4	41	19.7	10.91	0.04
LOMALEUC	*Lomandra leucocephala*	4	56	20.4	11	0.026
LYSIANGU	*Lysicarpus angustifolius*	4	75	19.9	10.72	0.006
PERSFALC	*Persoonia falcata*	4	50	19.1	11.94	0.021
SCHOKENN	*Schoenus kennyi*	4	75	19.8	10.85	0.007
SOLANEMO	*Solanum nemophilum*	4	75	19.7	10.48	0.003
TRIOPUNG	*Triodia pungens*	4	100	19.8	10.65	0.001
ERAGLACU	*Eragrostis lacunaria*	5	53	20.4	11.25	0.044
ERAGSORO	*Eragrostis sororia*	5	56	22.1	10.4	0.001
PANIEFSI	*Panicum effusum* var. *simile*	5	56	19.8	11.03	0.024
	(none)	6				
ACACIXIO	*Acacia ixiophylla*	7	90	20.6	11.99	0.001
ACACSEMI	*Acacia semilunata*	7	50	20.5	11.49	0.029
AMYEMIQU	*Amyema miquelii*	7	57	20.4	11.54	0.024
LOMAFILI	*Lomandra filiformis*	7	49	22.6	10.42	0.011
LOMAMUMU	*Lomandra multiflora* subsp. *multiflora*	7	75	21.5	11.39	0.001
OLEAELLI	*Olearia elliptica*	7	50	20.3	11.28	0.024

The distribution of the main groups can be generally described as northern (group 1), southern (group 7), mid-northern (groups 4 and 5) and mid-southern (groups 2 and 6) (Figure A2.3). The single site of group 3 and the disjunct northern site in group 5 appear to be misclassified. Ordination of the sites highlighted groups 1 and 7 as the most floristically different when considering all sites based on species composition (Figure A2.2). These two groups are also towards the opposite ends of the RE's geographic range (Figure A2.3), with differing bioclimatic and altitudinal characteristics (Figure A2.2, Table A2.3). Whereas the related pair of group 6 and 7 had discernable differences in bioclimatic attributes, the pair of group 4 and 5 were bioclimatically similar with the variables tested. Depending on necessary surveys in areas indicated in Table A2.4, reclassification of 11.5.1 into five separate communities (excluding group 2) and reassessment of conservation status would better reflect biodiversity (Table A2.3). In addition, a potentially threatened community type may also result from comprehensive surveys in the northern disjunct patch around Woorabinda Subregion.

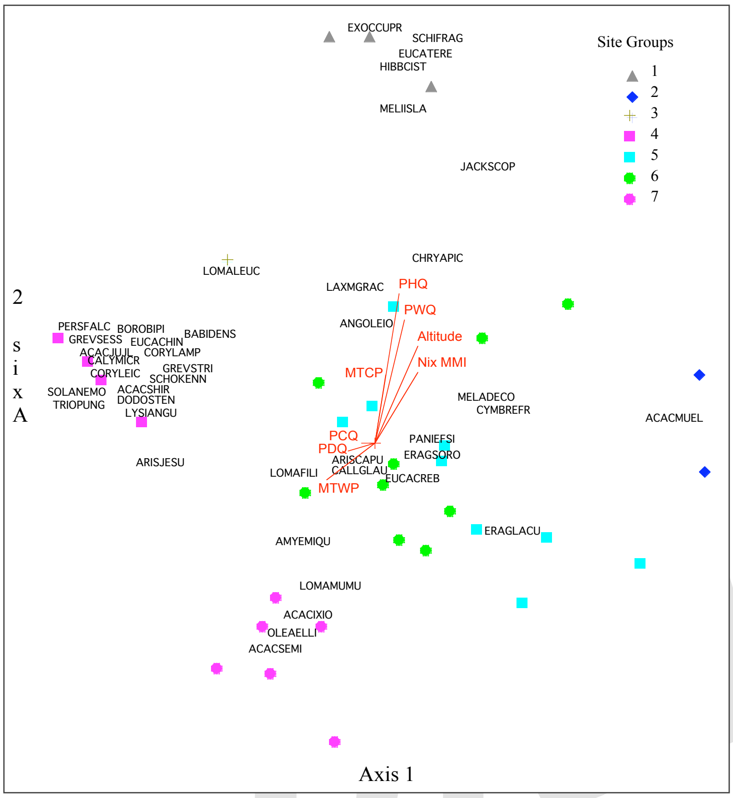


Figure A2.2 Two-dimensional Nonmetric Multidimensional Scaling (NMS) ordination plot (stress = 21.5%) of site groups from Figure A2.1 superimposed with the relative ordinal position of the bioclimatic variables and significantly associated indicator species (codes as per Table A2.2).

Table A2.3 Summary of site groups resulting from species composition analysis; ranking represents level of difference from other sites (1 = most different); group 3 consists of a single site and is not included

Group	Bioclimatic variable comparison between groups	State Forests/Timber Reserves with significant occurrences
1	Higher altitude, higher minimum temperature during the coldest period, higher moisture index and rainfall in summer than winter	SFs 227 and 228; requires more sites to confirm as separate community
2	Intermediate between Gps 1 and 7, but closer to 7 and higher altitude and moisture index than 4	SF 155 and other northern Inglewood forests
4	Intermediate between Gps 1 and 7, lower altitude and moisture index than 2, lower moisture index than 5	SF 161 Condamine
5	Intermediate between Gps 1 and 7, similar to 6 with ranging site attributes, higher moisture index than 4	SF 302 Barakula and southern SF 132 Allies Ck; potentially Yuleba SF
6	Intermediate between Gps 1 and 7, similar to 5 with ranging site attributes, and higher altitude and moisture index than 7	All of the Inglewood Sandstones SFs (341, 189, 79, 168, 161, 150, 154, 155)
7	Lower altitude, lower min temp during coldest period and higher moisture index in winter than summer, lower rainfall in summer	SF 81, 79, 341; possibly a transition to a New England Tableland community

Table A2.4 Core areas of 11.5.1 that have no comprehensive flora survey sites

Core Area	Comment	Potential Grouping
Woorabinda Subregion	Disjunct and has been subject to clearing	Either separate group (if so, probably threatened) or include with Gp 1; SFs 62 and 212 significant
Auburn Range	Approx 70km disjunct from closest occurrence in Barakula	Clarify extent of Gp 1

Yuleba SF	Probably largest remnant patch	With Gp 4 or 5 to refine transition between Barakula, Condamine SF and the Inglewood forests
Whetstone and Boondandilla SFs	Largest dominant remnant patches in the south are on public land as fragmented by clearing in surrounding areas	Clarify relationship between Gps 6 and 7, and validate occurrences of Gp 2

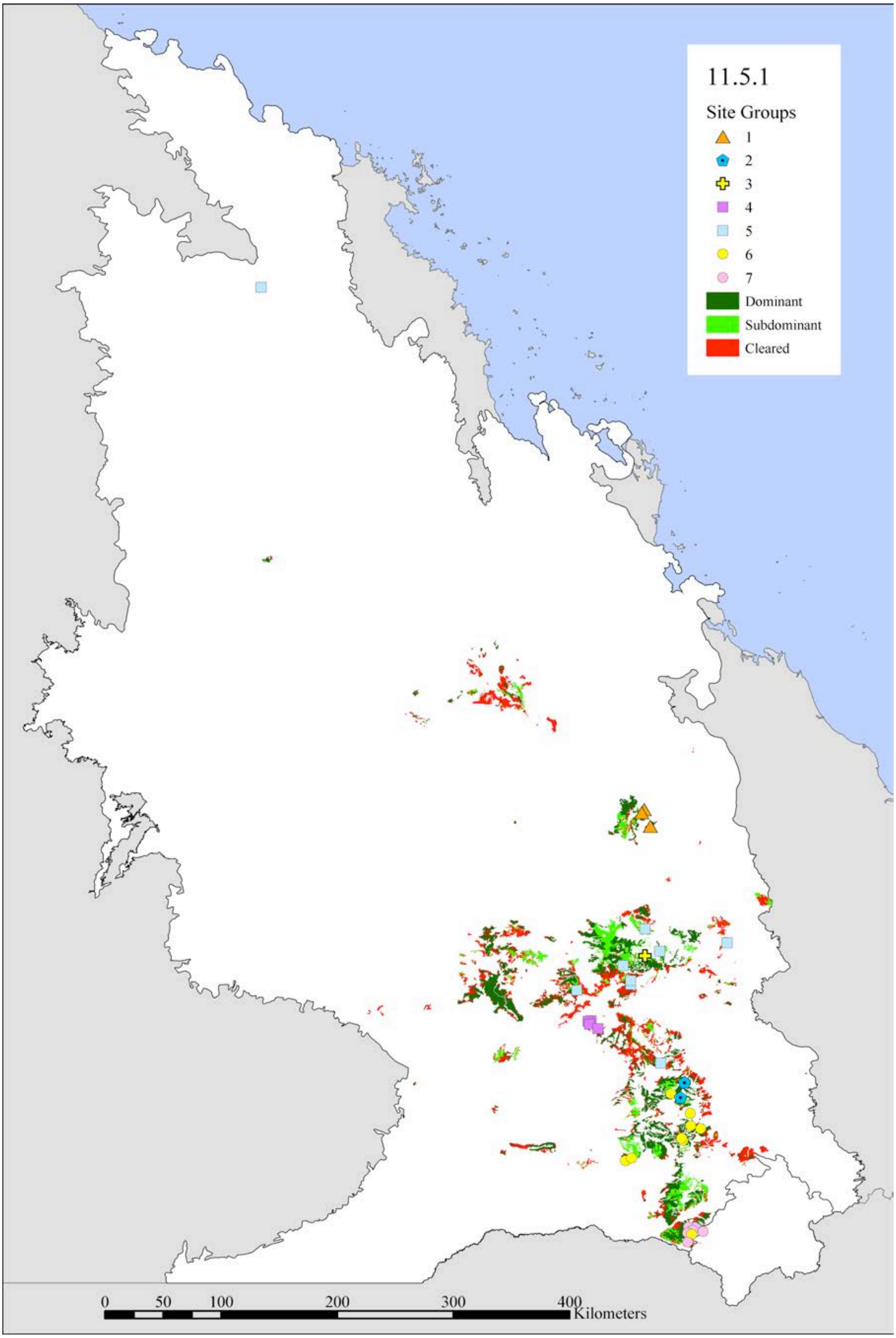


Figure A2.3 Distribution of 11.5.1 site groups in the Brigalow Belt, with remnant and cleared vegetation shown

Further investigation into site classification, sampling and species composition is necessary to determine the validity of communities suggested by groups 2 and 3.

Example 2

RE 11.12.1: This RE is broadly described as *Eucalyptus crebra* and/or *E. melanophloia* +/- *Corymbia erythrophloia* shrubby woodland on ranges on Mesozoic to Proterozoic igneous rocks. It is currently mapped as spreading from the eastern Brigalow Belt boundary south of Gayndah through the Banana-Auburn Ranges Subregion to the north of the bioregion along the eastern side, but with a patchy distribution west of Gladstone (Figure A2.4). The southern areas have been extensively cleared, with larger patches remaining in the north. Both its status under the Vegetation Management Act and Biodiversity Status are 'not of concern' (Environmental Protection Agency 2003b).

Two clear groups of sites with differing bioclimatic attributes resulted from the analysis: a northern group (group 1) and a southern group which also splits into a southerly subgroup (group 2) and northerly subgroup (group 3) (Table A2.5, Figure A2.4). Based on these findings, the large remnant patches in the north of the bioregion are probably a separate community to the small patches remaining in the Banana-Auburn Ranges area. It is likely that the southern community is highly threatened and should have its conservation status amended in light of further comprehensive surveys in core areas (Table A2.6). This also places greater significance on the remnant patches of the reclassified, threatened RE that are on public land (Table A2.5).

Table A2.5 Summary of site groups resulting from species composition analysis for RE 11.12.1; ranking represents level of difference from other sites (1 = most different)

Group	Bioclimatic variable comparison between groups	State Forests/Timber Reserves with significant occurrences
1	Higher moisture index in summer than winter, average minimum temperature in the coldest period = 9.9°C, average rain in wettest quarter = 535mm	SF 71
2	Higher moisture index in winter than summer, avg min temperature in the coldest period = 6.3°C, avg rain in wettest quarter = 353mm	SFs 119, 40, 28 (Coominglah), 69, 132 (Allies Ck), 227, 228, 220, 249, 96; community could be endangered as extensively cleared
3	Intermediate between gps 1 and 2	SFs 100, 298, 871, 878

Table A2.6 Core areas that have no comprehensive flora survey sites; RE 11.12.1

Core Area	Comment	Potential Grouping
Wyarra Hills Subregion (BBN)	Large remnant patch	Either Gp 1 or a separate RE at higher altitude
South-west of Proserpine	Large remnant patch	Gp 1
West of St Lawrence	Relatively intact patch in transitional area between northern and southern groups	Gp 3 – will help in clarifying the relationship between Gps 1 and 2
Small remnant patches in Banana-Auburn Ranges Subregion	SFs 249, 119, 219, 230, 231, 249, 96, 132 require comprehensive survey	Gp 2

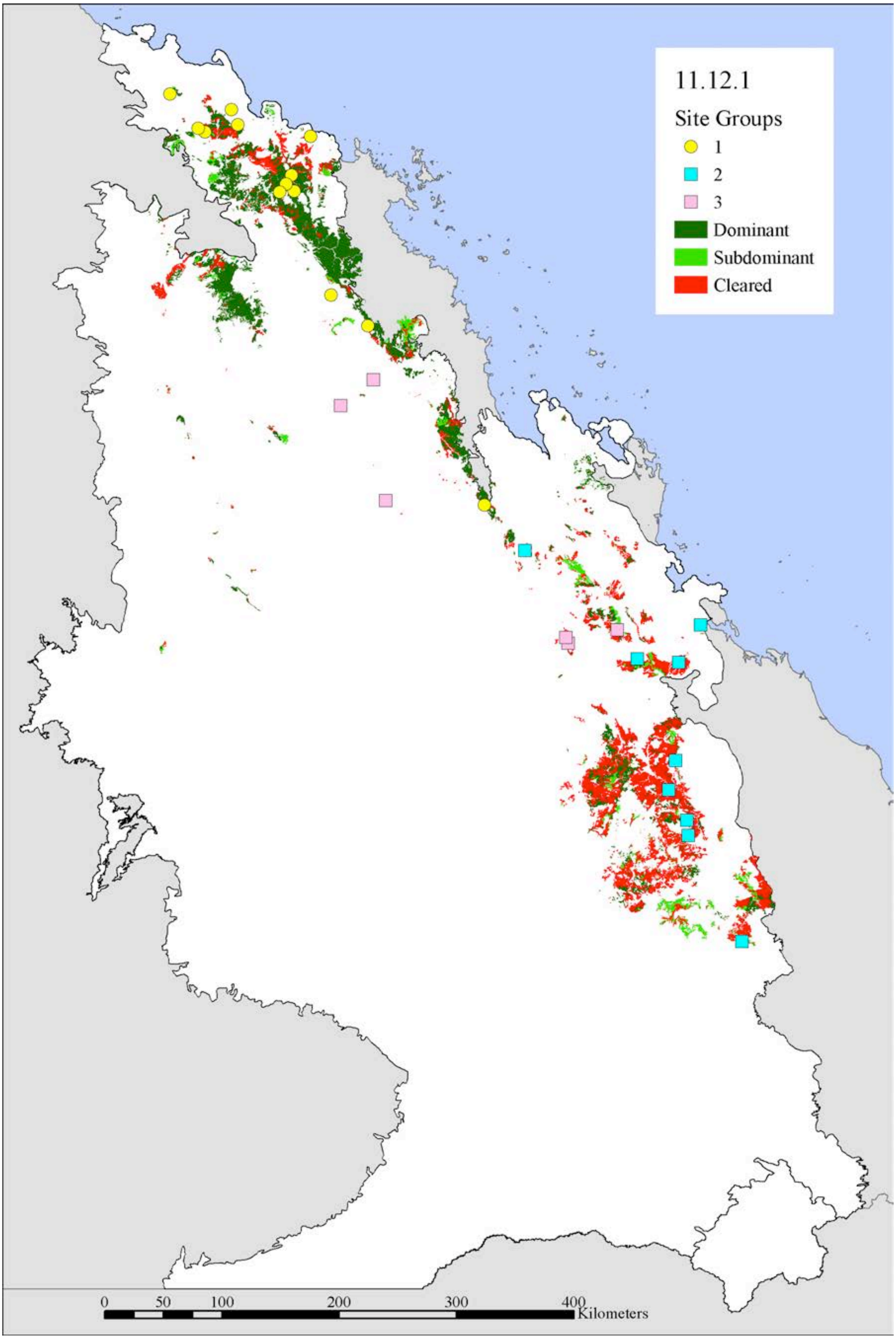


Figure A2.4 Distribution of 11.12.1 site groups in the Brigalow Belt, with remnant and cleared vegetation shown

Example 3

RE 11.7.4: This RE is broadly described as mixed *Eucalyptus* spp. woodland on Cenozoic lateritic duricrusts and can include *Eucalyptus crebra*, *E. decorticans*, *Corymbia trachyphloia*, *E. tenuipes*, *C. watsoniana* and *Callitris glaucophylla* usually with a distinct understorey of *Lysicarpus angustifolius*, *Acacia* spp. or *E. exserta*. It is currently mapped as patches through the Inglewood forests and west to near Surat, and from the Barakula area through the Auburn Ranges to Coominglah State Forest; there are also some small areas north of the Blackdown Tableland (Figure A2.5). Both the Vegetation Management Status and Biodiversity Status are ‘not of concern’ (Environmental Protection Agency 2003b).

The analysis revealed that the most different group (group 1) consisted of a single site in Allies Creek State Forest which had species in common with other sites but a unique composition. This may be indicative of a transitional community yet to be further surveyed. The other sites split broadly into two groups, with one sub-splitting to form groups 3 and 4. The distribution of group 2 and group 4 sites was similar around the northern Auburn Ranges and Coominglah State Forest area (Figure A2.5) and was not distinguishable by the bioclimatic parameters investigated (Table A2.7). Group 3 had generally a more southerly distribution (Figure A2.5).

Despite most surveys of this RE having been conducted within the Banana-Auburn Ranges area, the analysis indicates that finer-scale mapping and reclassification of 11.7.4 in this area is still required to better represent the species diversity present. The significance of remnants on public land is greatly accentuated because many of the surrounding areas have been largely cleared of other vegetation communities (Table A2.7). In addition, there have been very few surveys in the major distribution areas in the south-west where it has been subject to clearing (Figure A2.5, Table A2.8). Further attention would clarify group distribution and the possibility that patches in different bioregions have differing species compositions warranting reclassification and reassessment of conservation status.

Table A2.7 Summary of site groups resulting from species composition analysis for RE 11.7.4; ranking represents level of difference from other sites (2 = most different); group 1 consists only of one site and is excluded

Group	Bioclimatic variable comparison between groups	State Forests/Timber Reserves with significant occurrences
2	Higher altitude than 3, but very similar to 4	SFs 28 (Coominglah), SF 227, 228, 40, 42, 64, 268, 295
3	Lower altitude and slightly higher temperature in hottest period than 2 and 4	SFs 161, 132 (Allies Ck), 302, 130, 172, 417, 81, 341, 93, 235, 154, 155, 22?
4	Higher altitude than 3, but very similar to 2	SFs 28 (Coominglah), 227, 228, 40, 42, 64, 268, 295

Table A2.8 Core areas of 11.7.4 that have no comprehensive flora survey sites

Core Area	Comment	Potential Grouping
NW of Blackdown Tableland	Disjunct dominant patch; also patches in SFs 22 and 179 east of Blackdown	Possible separate community, otherwise maybe Gp 3 as lower altitude
Subdominant patches north of Allies Ck	Most surrounding vegetation is cleared	Gps 1 or 3
SF 302 and SW Barakula Subregion	Largest dominant patches remaining	Gp 3, maybe add to Gp 1
Remnant patch west of Yuleba SF and patches through to Inglewood	Largest south westerly patch near bioregion boundary; traverse different subregions	Potentially different, otherwise linked with Barakula and Inglewood area groups
Inglewood Sandstone patches and SF 161	Scattered dominant and subdominant patches	Northern areas with Gp 3 or Barakula/Yuleba community types; southern areas separate group?

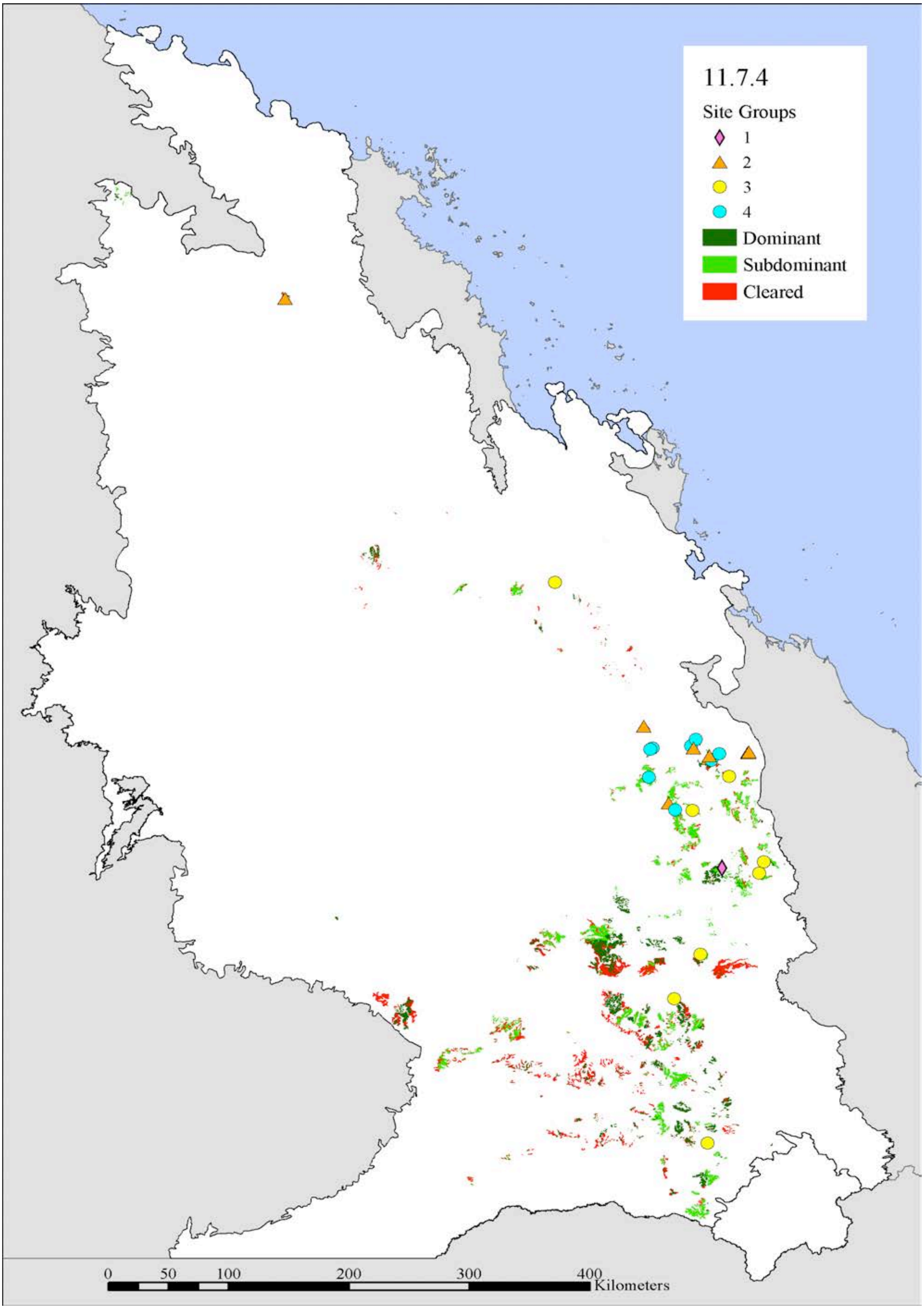


Figure A2.5 Distribution of 11.7.4 site groups in the Brigalow Belt with remnant and cleared 11.7.4 vegetation

Example 4

REs 11.10.1 and 11.10.13 and associated subunits: RE 11.10.1 is described as *Corymbia citriodora* and/or *Eucalyptus crebra* open forest on hills and ranges, particularly colluvial lower slopes. RE 11.10.13 is open forest of mixed *Eucalyptus*/*Corymbia* canopy species on scarps and sandstone tablelands. Both of these REs occur on soils formed from Cenozoic to Proterozoic consolidated, medium to coarse-grained sediments, and the two often merge and intermix. These REs also have several subunits (Table A2.9). Both REs have a ‘not of concern’ Vegetation Management Status and Biodiversity Status (Environmental Protection Agency 2003b).

Table A2.9 Currently described subunits for 11.10.1 and 11.10.13, and whether mapped by the Queensland Herbarium (Environmental Protection Agency 2003b)

Subunit	Description	Mapped?
11.10.1a	*Corymbia watsoniana* ± *C. citriodora*, ± *C. trachyphloia* ± *C. henryi* woodland.	Yes
11.10.1b	*Eucalyptus mediocris* woodland	No
11.10.1c	*Eucalyptus fibrosa*, *Eucalyptus* spp. woodland	No
11.10.1d	*Eucalyptus crebra* woodland	No
11.10.13a	*Eucalyptus cloeziana* ± *E. melanoleuca* ± *E. bunites* ± *E. sphaerocarpa* woodland to open-forest	No
11.10.13b	*Corymbia leichhardtii* woodland	Yes

The analysis produced two broad groups with descriptions similar to the main REs: one with dominance of *C. citriodora*/*E. crebra* (groups 1-3), and the other with mixed *Eucalyptus*/*Corymbia* dominant species (groups 4-8). However, sites did not necessarily fall into the group that corresponded to their existing classification. The groups are described in Table A2.10, with group distributions shown in Figures A2.6 and A2.7.

Table A2.10 Groups resulting from cluster analysis of sites using woody species basal area; group number is categorical only

Group	Significant Indicator Woody Species	Existing RE	State Forests/Timber Reserves with significant occurrences
1	*C. citriodora*	11.10.1	SFs 160, 89, 93, 197, 44, 46, 69, 28 (Shotover) TR 170, 77, 212, 43
2	*E. decorticans*, *E. melanophloia*	11.10.4 for *E. decorticans*?	SFs 160, 46, 197
3	*E. crebra*	11.10.1d	SFs 11, 89, 46, 44, 93, TR 170, 21, 77, 212
4	*E. cloeziana*	11.10.1 or 11.10.13a	SFs 28 (Coominglah), 44, 28 (Shotover), 29, 21; TR 170
5	*C. leichhardtii*	11.10.13b	TR 1, SFs 160, 21, 236
6	*E. suffulgens*, *E. tenuipes*, *C. trachyphloia*	11.10.13	SFs 46, 29, 93, 212 TR 170
7	*C. bunites*, *E. baileyana*, *E. melanoleuca*, *C. hendersonii*	11.10.13a	SFs 28 (Shotover) and 29; maybe SF 47, 212
8	*E.* sp. (Rewan), *C. watsoniana*, *E. mediocris*, *C. trachyphloia*, *Lysicarpus angustifolius*, *Angophora leiocarpa*, *Lophostemon suaveolens*, *Acacia longispicata*	11.10.1b or 11.10.1a	SFs 28 (Coominglah), 160, 28 (Shotover), 44, 50, 46, 89, 43, 212

Groups 4 and 7 suggest a further split within 11.10.13a to separate out communities dominated by *E. cloeziana* from those with a mix of *C. bunites*, *E. melanoleuca*, *E. baileyana*, *C. hendersonii* and/or *E. sphaerocarpa*. Group 7 is distributed on the edges of Blackdown Tableland and northern section of the Expedition Range in Expedition SF (Figure A2.7). Group 5 was strongly represented by the dominance of *C. leichhardtii* and supports the existence of 11.10.13b. Furthermore, its reclassification as a new RE may be warranted as the sites of this group reflect the principal distribution of *C. leichhardtii* in the Desert Uplands and Einasleigh Uplands bioregions, being north and west of the core areas of the main REs. The dominance of *E. crebra* in group 3 sites also supports current subunit 11.10.1d.

None of the tested bioclimatic variables assisted in distinguishing the groups, and so underlying reasons for differences in the relative abundances of woody species may be more related to soils or geology. However, the analysis did show that current mapping does not adequately represent the floral diversity present in these two REs, even of the woody species. Areas with several groups represented such as Callide TR, the northern Expedition Range, and Belington Hut, Presho and Theodore State Forests indicate the need for finer scale classification. Other core areas with no surveys demand attention, especially those that have been subject to clearing (Table A2.11).

Table A2.11 Core areas of 11.10.1 and 11.10.13 that have few or no flora survey sites

Code	Core Area	Comment	Potential Grouping
A	West of Eungella NP	Northernmost patch of 11.10.1 and disjunct	Gps 1 or 3?
B	Peak Range east of Clermont	Large patch of 11.10.1 over 100km long and about 30km wide	Gps 3-5
C	Western part of Carnarvon Ranges Subregion	Corridor of core most westerly distribution of 11.10.13	Gps 3-5 or 8
D	Expedition Range: southern SF 29, SF 47 and northern Expedition NP	Important for connectivity; SF 29 11.10.13 patch may be gradient to areas of 11.10.1 as move south to Expedition NP	Gps 7 or 8 SF 29; Gps 1 or 2
E	SF 50 Presho	Broadly mapped as complex of 11.10.1 and 11.10.13	Gps 1-4, 6 or 8
F	SF 55 and to the east	Southern edge of principal core area of 11.10.1; subject to clearing	Gps 1, 3 or 8
G	SF 164 Gurulmundi	One of the larger southern, disjunct patches of 11.10.1; subject to clearing	Gps 1, 3 or 6
H	SE of Precipice NP	Large intact patch of 11.10.13 important for connectivity to Auburn Ranges	Gps 3, 6 or 8
I	Northern parts of SFs 40 and 132 Allies Ck	Large intact patch of 11.10.1 with somewhat disjunct southeast location	Gps 1-3 or 6

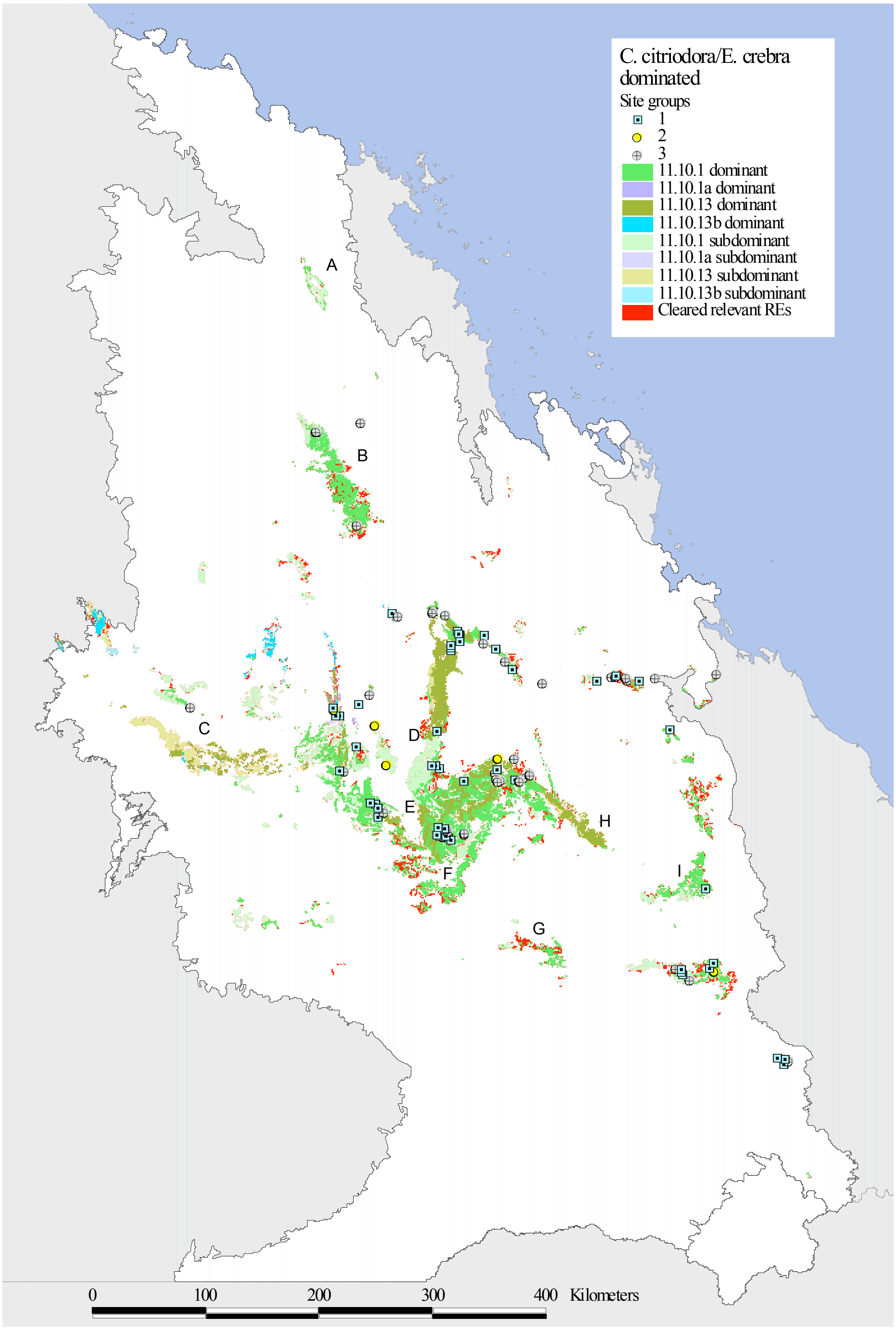


Figure A2.6 Distribution of remnant and cleared 11.10.1, 11.10.13 and related subunits, with *C. citriodora*/*E. crebra* dominated site groups in the Brigalow Belt; letter codes represent core areas for further survey (See Table 2.11.)

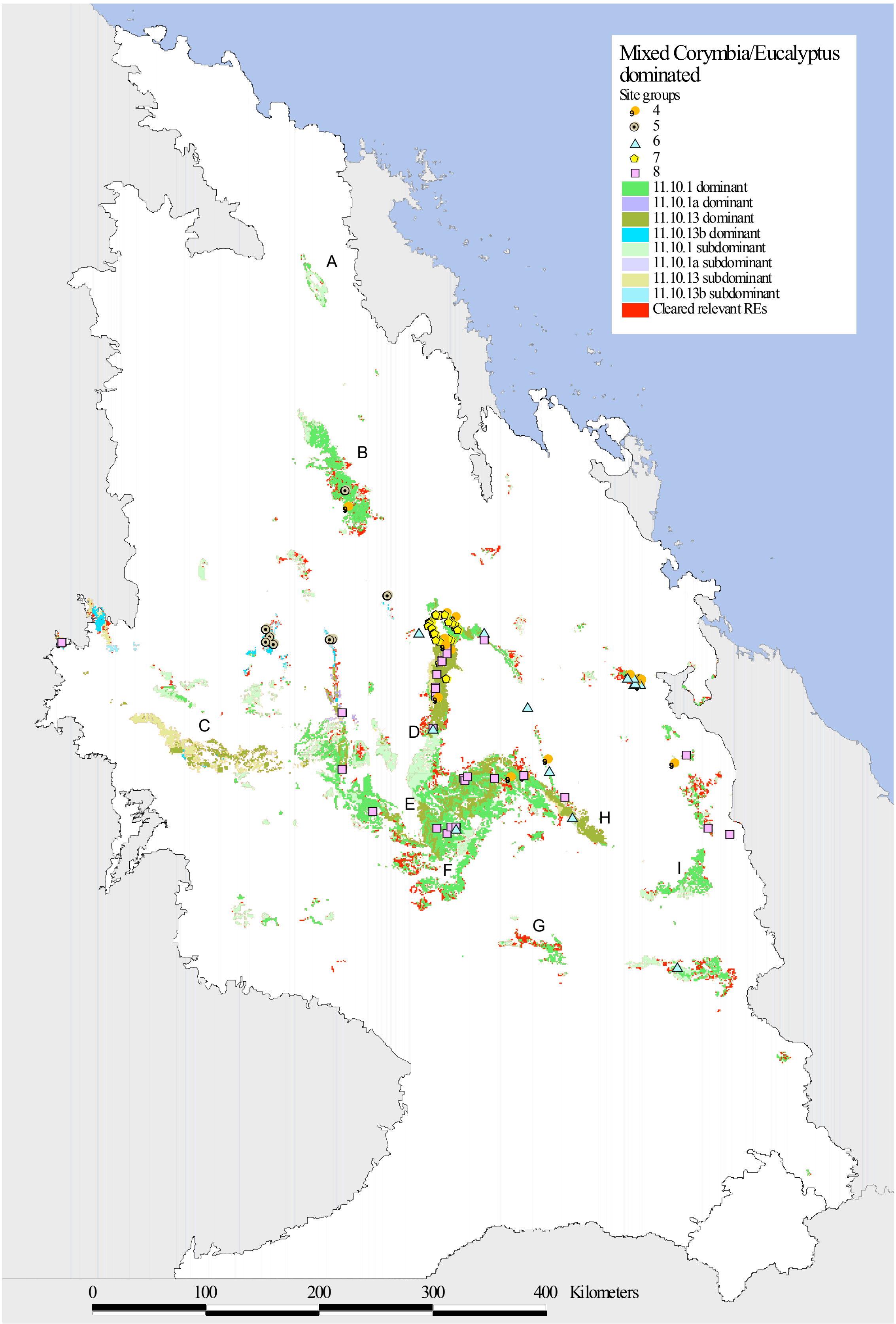


Figure A2.7 Distribution of remnant and cleared 11.10.1, 11.10.13 and related subunits, with mixed *Corymbia*/*Eucalypt* dominated site groups in the Brigalow Belt; letter codes represent core areas for further survey (See Table 2.14.)

Further analysis

Many other REs have similarly wide or disjunct distributions over several subregions and require investigation if they are continued to be used as surrogates for biodiversity (Table A2.12).

Further analyses under this project will involve the following:

- Soils and geology as environmental variables to explain variation in species composition
- Additional use of basal areas of woody species from sites which have not been comprehensively surveyed to cluster sites
- Clustering all sites of two or more intermixing and/or similar REs and investigating spatial distributions of the resulting site groups

Table A2.12 Examples of key REs for further survey and review

RE	Comment	Number of comprehensive sites
11.5.4	Disjunct patches in Barakula SF and Inglewood forests; also Yuleba SF; few sites in northern area	6
11.5.5	2 disjunct core areas which have both been subject to clearing: central far west BB around Alpha, and near Yuleba in the south-west	3
11.5.20	Widespread patches through the Inglewood, Barakula and Auburn Range forests, with disjunct areas in western Carnarvons and Woorabinda Subregion; extensively grazed; less than 1% in NP	4
11.8.4	Core area in the Buckland Basalts Subregion has no comprehensive sites; disjuncts in the Eastern Darling Downs Subregion and near Kroombit Tops	8
11.9.7	'Of concern'; northern disjunct south of Eungella is largest remnant core area; largely cleared in central and southern Brigalow Belt	2
11.10.3	Core areas in central western Brigalow Belt have very few sites; disjuncts on Dawson Range and Northern Bowen Basin subregion have max of 2 sites	8
11.10.7	Core patchy distribution in central west; largest dominant patches are disjunct in the north; also disjunct and cleared near Precipice NP, Allies Ck	1
11.12.2	Large disjunct patch in the west of the bioregion	2

Appendix 3

Rare and threatened plants of the Study Area

Acanthaceae	
Graptophyllum excelsum (F.Muell.) Druce	R
Graptophyllum ilicifolium (F.Muell.) F.Muell. ex Benth.	V
Rhaphidospora bonneyana (F.Muell.) R.M.Barker	V
Xerothamnella herbacea R.M.Barker	E
Amaranthaceae	
Ptilotus blakeanus Benl	R
Ptilotus extenuatus Benl	R
Anthericaceae	
Sowerbaea subtilis D.A.Stewart	V
Apiaceae	
Actinotus paddisonii R.T.Baker	R
Apocynaceae	
Alyxia magnifolia F.M.Bailey	R
Alyxia sharpei P.I.Forst.	R
Cerbera dumicola P.I.Forst.	R
Neisosperma kilneri (F.Muell.) Fosberg & Sachet	V
Parsonsia kroombitensis J.B.Williams	V
Parsonsia larcomensis J.B.Williams	V
Parsonsia lenticellata C.T.White	R
Aponogetonaceae	
Aponogeton queenslandicus H.Bruggen	R
Araliaceae	
Astrotricha roddii Makinson	E
Arecaceae	
Livistona drudei F.Muell. ex Becc.	V
Livistona fulva Rodd	R
Livistona lanuginosa Rodd	V
Livistona nitida Rodd	R
Livistona sp. (Eungella A.N.Rodd 3798)	R
Aristolochiaceae	
Pararistolochia praevenosa (F.Muell.) Michael J.Parsons	R
Asclepiadaceae	
Marsdenia brevifolia (Benth.) P.I.Forst.	V
Marsdenia hemiptera Rchb.	R
Marsdenia pumila P.I.Forst.	V
Tylophora linearis P.I.Forst.	E
Tylophora woollsii Benth.	E
Aspleniaceae	
Asplenium normale D.Don	R
Asteraceae	
Angianthus brachypappus F.Muell.	R
Calocephalus sonderi F.Muell.	R
Calotis glabrescens C.T.White	R
Olearia gravis (F.Muell.) Benth.	R
Olearia sp. (Glenavon P.I.Forster+ PIF15039)	E
Ozothamnus eriocephalus (J.H.Willis) Anderb.	V
Peripleura scabra (DC.) G.L.Nesom	R
Picris conyzoides Lack & S.Holzapfel	R
Picris evae Lack	V
Rutidosis crispata A.E.Holland	R
Rutidosis glandulosa A.E.Holland	R
Rutidosis lanata A.E.Holland	E
Stemmacantha australis (Gaudich.) Dittrich	V
Trioncinia retroflexa (F.Muell.) Veldkamp	E
Blechnaceae	
Blechnum ambiguum (C.Presl) Kaulf. ex C.Chr.	R
Caesalpiniaceae	
Cassia sp. (Paluma Range G.Sankowsky+ 450)	R
Senna acclinis (F.Muell.) Randell	R
Campanulaceae	
Pratia podenzanae S.Moore	R
Wahlenbergia glabra P.J.Sm.	R
Wahlenbergia islensis P.J.Sm.	R
Capparaceae	
Capparis humistrata (F.Muell.) F.Muell.	E
Capparis sp. (Gloucester Island G.N.Batianoff 920912)	R
Capparis thozetiana (F.Muell.) F.Muell.	V
Casuarinaceae	
Allocasuarina rupicola L.A.S.Johnson	R
Celastraceae	
Apatophyllum sp. (Bull Creek A.R.Bean 2225)	R
Apatophyllum sp. (Expedition Range E.J.Thompson AQ440723)	R
Denhamia parvifolia L.S.Sm.	V
Chenopodiaceae	
Sclerolaena everistiana (Ising) A.J.Scott	R
Combretaceae	
Dansiea elliptica Byrnes	R
Macropteranthes fitzalanii F.Muell.	R
Macropteranthes leiocaulis P.I.Forst.	R
Commelinaceae	
Cartonema brachyantherum Benth.	R
Connaraceae	
Rourea brachyandra F.Muell.	R
Convolvulaceae	
Bonamia dietrichiana Hallier f.	R
Cupressaceae	
Callitris baileyi C.T.White	R
Callitris monticola J.Garden	R
Cycadaceae	
Cycas megacarpa K.D.Hill	E
Cycas ophiolitica K.D.Hill	E
Cyperaceae	
Carex cruciata var. rafflesiana (Boott) Noot.	R
Cyperus clarus S.T.Blake	V
Eleocharis blakeana L.A.S.Johnson & O.D.Evans	R
Fimbristylis vagans S.T.Blake	R
Dilleniaceae	
Hibbertia elata Maiden & Betche	R
Hibbertia monticola Stanley	R
Dryopteridaceae	
Dryopteris sparsa (Buch.-Ham. ex D.Don) Kuntze	V
Lastreopsis silvestris D.A.Sm. ex Tindale	R
Tectaria devexa (Kunze ex Mett.) Copel. var. devexa	E
Epacridaceae	
Leucopogon grandiflorus Pedley	R
Leucopogon sp. (Coolmunda D.Halford Q1635)	E
Lissanthe brevistyla A.R.Bean	V
Eriocaulaceae	
Eriocaulon carsonii F.Muell.	E
Euphorbiaceae	
Actephila sessilifolia Benth.	R
Actephila sp. (Koumala I.G.Champion 870)	V
Bertya calycina Halford & R.J.F.Hend.	V
Bertya glandulosa Gruening	R
Bertya granitica Halford & R.J.F.Hend.	E
Bertya pedicellata F.Muell.	R
Bertya recurvata Halford & R.J.F.Hend.	R
Bertya sharpeana Guymer	R
Beyeria sp. (Bull Creek Gorge B.O'Keeffe 573)	R
Cleistanthus discolor Summerh.	R
Croton magneticus Airy Shaw	V
Fontainea fugax P.I.Forst.	E
Fontainea venosa Jessup & Guymer	V
Neoroepera buxifolia Muell.Arg. & F.Muell.	V
Omphalea celata P.I.Forst.	V
Ricinocarpos speciosus Muell.Arg.	V
Trigonostemon inopinatus Airy Shaw	V
Fabaceae	
Daviesia discolor Pedley	V
Daviesia quoquoversus Crisp	V
Desmodium macrocarpum Domin	R
Indigofera baileyi F.Muell.	R
Leptosema chapmanii Crisp	R
Mirbelia confertiflora Pedley	R
Pultenaea pycnocephala F.Muell. ex Benth.	R

Pultenaea setulosa Benth.	V
Pultenaea stuartiana H.B.Will.	V
Sophora fraseri Benth.	V
Swainsona murrayana Wawra	V
Tephrosia baueri Benth.	R
Zornia pallida Mohlenbr.	R
Flacourtiaceae	
Xylosma ovatum Benth.	R
Grossulariaceae	
Argophyllum nullumense R.T.Baker	R
Haloragaceae	
Gonocarpus urceolatus Orchard	V
Haloragis exalata subsp. velutina Orchard	V
Myriophyllum implicatum Orchard	R
Myriophyllum artesium Halford & Fensham	E
Hernandiaceae	
Hernandia bivalvis Benth.	R
Hydrocharitaceae	
Hydrocharis dubia (Blume) Backer	V
Lamiaceae	
Callicarpa thozetii Munir	R
Newcastelia velutina Munir	V
Plectranthus blakei P.I.Forst.	R
Plectranthus graniticola P.I.Forst.	R
Prostanthera sp. (Dunmore D.M.Gordon 8A)	V
Prostanthera sp. (Wallangarra T.D.Stanley 7876)	R
Westringia amabilis B.Boivin	R
Westringia parvifolia C.T.White & W.D.Francis	V
Lauraceae	
Cryptocarya floydii Kosterm.	R
Loganiaceae	
Logania cordifolia Hook.	R
Logania diffusa R.J.F.Hend.	V
Lomariopsidaceae	
Elaphoglossum callifolium (Blume) T.Moore	R
Loranthaceae	
Lysiana filifolia Barlow	R
Muellerina myrtifolia (A.Cunn. ex Benth.) Barlow	R
Lycopodiaceae	
Huperzia squarrosa (G.Forst.) Trevis.	E
Huperzia varia (R.Br.) Trevis.	R
Malvaceae	
Abutilon tubulosum var. breviflorum Benth.	
Gossypium sturtianum J.H.Willis	R
Gossypium sturtianum J.H.Willis var. sturtianum	R
Gossypium sturtianum var. nandewarense (Derera) Fryxell	R
Mimosaceae	
Acacia arbiana Pedley	R
Acacia argyrotricha Pedley	P
Acacia barakulensis Pedley	V
Acacia brunioides A.Cunn. ex G.Don subsp. brunioides	R
Acacia brunioides subsp. granitica Pedley	R
Acacia calantha Pedley	R
Acacia centrinervia Maiden & Blakely	R
Acacia chinchillensis Tindale	V
Acacia curranii Maiden	V
Acacia deuteroneura Pedley	V
Acacia eremophiloides Pedley & P.I.Forst.	V
Acacia gittinsii Pedley	R
Acacia handonis Pedley	V
Acacia hockingsii Pedley	R
Acacia islana Pedley	R
Acacia jackesiana Pedley	R
Acacia latisepala Pedley	R
Acacia lauta Pedley	V
Acacia orites Pedley	R
Acacia pedleyi Tindale & Kodela	R
Acacia polyadenia (Pedley) Pedley	R
Acacia porcata P.I.Forst.	E
Acacia pubicosta C.T.White	R
Acacia pubifolia Pedley	V
Acacia ramiflora Domin	E
Acacia rubricola Pedley	E
Acacia ruppii Maiden & Betche	V
Acacia sp. (Gwambagwine F.Carter 2)	V
Acacia sp. (Ruined Castle Creek P.I.Forster+ PIF17848)	E
Acacia spania Pedley	R
Acacia storyi Tindale	R
Acacia tenuinervis Pedley	R
Acacia tingoorensis Pedley	V
Acacia wardellii Tindale	V
Molluginaceae	
Macarthuria ephedroides C.T.White	R
Myrtaceae	
Babingtonia brachypoda A.R.Bean	R
Babingtonia granitica A.R.Bean	E
Babingtonia papillosa A.R.Bean	E
Babingtonia silvestris A.R.Bean	E
Baeckea trapeza A.R.Bean	V
Callistemon chisholmii Cheel	R
Callistemon flavovirens Cheel	R
Callistemon formosus S.T.Blake	R
Callistemon pearsonii R.D.Spencer & Lumley	R
Callistemon pungens Lumley & R.D.Spencer	V
Calytrix gurulmundensis Craven	V
Calytrix islensis Craven	R
Choricarpia subargentea (C.T.White) L.A.S.Johnson	R
Corymbia clandestina (A.R.Bean) K.D.Hill & L.A.S.Johnson	V
Corymbia petalophylla (Brooker & A.R.Bean) K.D.Hill & L.A.S.Johnson	R
Corymbia scabrida (Brooker & A.R.Bean) K.D.Hill & L.A.S.Johnson	R
Corymbia xanthope (A.R.Bean & Brooker) K.D.Hill & L.A.S.Johnson	V
Decaspermum struckoilicum N.Snow & G.Guymer	E
Eucalyptus argophloia Blakely	V
Eucalyptus beaniana L.A.S.Johnson & K.D.Hill	V
Eucalyptus broviniensis A.R.Bean	E
Eucalyptus codonocarpa Blakely & McKie	R
Eucalyptus curtisii Blakely & C.T.White	R
Eucalyptus decolor A.R.Bean & Brooker	R
Eucalyptus howittiana F.Muell.	R
Eucalyptus infera A.R.Bean	V
Eucalyptus magnificata L.A.S.Johnson & K.D.Hill	V
Eucalyptus mensalis L.A.S.Johnson & K.D.Hill	R
Eucalyptus pachycalyx Maiden & Blakely subsp. pachycalyx	R
Eucalyptus pachycalyx subsp. waajensis L.A.S.Johnson & K.D.Hill	E
Eucalyptus paedoglauca L.A.S.Johnson & Blaxell	V
Eucalyptus raveretiana F.Muell.	V
Eucalyptus rubiginosa Brooker	R
Eucalyptus scoparia Maiden	V
Eucalyptus sicilifolia L.A.S.Johnson & K.D.Hill	R
Eucalyptus sphaerocarpa L.A.S.Johnson & Blaxell	R
Eucalyptus taurina A.R.Bean & Brooker	V
Eucalyptus virens Brooker & A.R.Bean	V
Homoranthus decasetus Byrnes	R
Homoranthus decumbens (Byrnes) Craven & S.R.Jones	V
Homoranthus montanus Craven & S.R.Jones	V
Homoranthus papillatus Byrnes	R
Homoranthus zeteticorum Craven & S.R.Jones	R
Kunzea bracteolata Maiden & Betche	R
Kunzea flavescens C.T.White & W.D.Francis	R
Kunzea sp. (Dicks Tableland A.R.Bean 3672)	R
Leptospermum venustum A.R.Bean	V
Melaleuca groveana Cheel & C.T.White	R
Micromyrtus carinata A.R.Bean	E
Micromyrtus patula A.R.Bean	E
Micromyrtus rotundifolia A.R.Bean	V
Ochrosperma obovatum A.R.Bean	V
Rhodamnia glabrescens Guymer & Jessup	R
Rhodamnia pauciovulata Guymer	R
Ristantia waterhousei Peter G.Wilson & B.Hyland	R
Oleaceae	
Notelaea pungens Guymer	R
Orchidaceae	
Acianthus sublestus Dockrill	R
Aphyllorchis anomala Dockrill	R
Bulbophyllum weinthalii subsp. striatum D.L.Jones	V
Caladenia atroclavia D.L.Jones & M.A.Clem.	E
Dendrobium phalaenopsis Fitzg.	V
Dendrobium schneiderae F.M.Bailey var. schneiderae	R
Diuris parvipetala (Dockrill) D.L.Jones & M.A.Clem.	R
Eulophia bicallosa (D.Don) P.Hunt & Summerh.	R
Gastrodia crebriflora D.L.Jones	R
Genoplesium pedersonii D.L.Jones	R

Genoplesium validum D.L.Jones	R
Habenaria xanthantha F.Muell.	R
Liparis simmondsii F.M.Bailey	R
Phaius tancarvilleae (Banks ex L'Her.) Blume	E
Prasophyllum campestre R.J.Bates & D.L.Jones	R
Prasophyllum incompositum D.L.Jones	R
Pterostylis longicurva Rupp	R
Pterostylis setifera M.A.Clem., Matthias & D.L.Jones	R
Pterostylis woollsii Fitzg.	R
Sarcochilus weinthalii F.M.Bailey	E
Phormiaceae	
Dianella fruticans R.J.F.Hend.	R
Thelionema grande (C.T.White) R.J.F.Hend.	R
Pittosporaceae	
Bursaria reevesii L.W.Cayzer, Crisp & I.Telford	V
Poaceae	
Amphibromus whitei C.E.Hubb.	X
Aristida annua B.K.Simon	V
Aristida forsteri B.K.Simon	R
Aristida granitica B.K.Simon	E
Arthraxon hispidus (Thunb.) Makino	V
Bambusa forbesii (Ridl.) Holttum	R
Bothriochloa bunyensis B.K.Simon	V
Dichanthium queenslandicum B.K.Simon	V
Dichanthium setosum S.T.Blake	R
Digitaria porrecta S.T.Blake	R
Homopholis belsonii C.E.Hubb.	E
Paspalidium scabrifolium S.T.Blake	R
Paspalidium udum S.T.Blake	V
Paspalum batianoffii B.K.Simon	X
Sporobolus pamelae B.K.Simon	E
Sporobolus partimpatens R.Mills ex B.K.Simon	R
Polygalaceae	
Comesperma oblongatum (R.Br. ex Benth.) Pedley	V
Proteaceae	
Conospermum burgessiorum L.A.S.Johnson & McGill.	R
Grevillea cyranostigma McGill.	R
Grevillea hockingsii Molyneux & Olde	V
Grevillea scortechinii F.Muell. subsp. scortechinii	V
Grevillea singuliflora F.Muell.	R
Grevillea venusta R.Br.	V
Hakea macrorrhyncha W.R.Barker	R
Hakea trineura (F.Muell.) F.Muell.	V
Macadamia integrifolia Maiden & Betche	V
Persoonia amaliae Domin	R
Persoonia daphnoides A.Cunn. ex R.Br.	R
Ranunculaceae	
Clematis fawcettii F.Muell.	V
Rhamnaceae	
Cryptandra lanosiflora F.Muell.	R
Cryptandra sp. (Gurulmundi G.W.Althofer 8418)	R
Cryptandra sp. (Thulimbah C.Schindler 6)	R
Discaria pubescens (Brongn.) Druce	R
Pomaderris clivicola E.M.Ross	E
Pomaderris coomingalensis N.G.Walsh & Coates	E
Pomaderris crassifolia N.G.Walsh & Coates	V
Trymalium minutiflorum E.M.Ross	V
Rutaceae	
Acronychia eungellensis T.G.Hartley & B.Hyland	R
Boronia amabilis S.T.Blake	R
Boronia eriantha Lindl.	R
Boronia granitica Maiden & Betche	E
Boronia grimshawii Duretto	V
Boronia repanda (F.Muell. ex Maiden & Betche) Maiden & Betche	E
Leionema ambiens (F.Muell.) Paul G.Wilson	R
Medicosma obovata T.G.Hartley	V
Phebalium glandulosum subsp. eglandulosum (Blakely) Paul G.Wilson	V
Phebalium whitei Paul G.Wilson	V
Philotheca sporadica (Bayly) Paul G.Wilson	V
Zieria sp. (Binjour P.I.Forster PIF14134)	E
Zieria verrucosa J.A.Armstr.	V
Zieria sp. (Mt Larcom N.Gibson TOI8)	V
Santalaceae	
Thesium australe R.Br.	V
Sapindaceae	
Alectryon semicinereus (F.Muell.) Radlk.	R
Atalaya calcicola S.T.Reynolds	R
Atalaya collina S.T.Reynolds	E
Atalaya rigida S.T.Reynolds	R
Cossinia australiana S.T.Reynolds	E
Cupaniopsis shirleyana (F.M.Bailey) Domin	V
Dodonaea biloba J.G.West	R
Dodonaea hirsuta (Maiden & Betche) Maiden & Betche	R
Dodonaea macrossanii F.Muell. & Scort.	R
Sarcotoechia heterophylla S.T.Reynolds	R
Scrophulariaceae	
Derwentia arenaria (A.Cunn. ex Benth.) B.G.Briggs & Ehrend.	R
Scrophulariaceae	
Euphrasia orthocheila subsp. peraspera W.R.Barker	R
Euphrasia orthocheila W.R.Barker subsp. orthocheila	R
Microcarpaea agonis A.R.Bean	E
Rhamphicarpa australiensis Steenis	R
Simaroubaceae	
Quassia bidwillii (Hook.f.) Noot.	V
Solanaceae	
Solanum adenophorum F.Muell.	E
Solanum papaverifolium Symon	E
Solanum sp. (Dalby R.F.Kelsey 56)	V
Solanum sporadotrichum F.Muell.	R
Stackhousiaceae	
Stackhousia tryonii F.M.Bailey	R
Sterculiaceae	
Brachychiton compactus Guymer	R
Brachychiton sp. (Blackwall Range R.J.Fensham 971)	E
Commersonia sp. (Beeron P.I.Forster PIF4658)	V
Rulingia hermanniifolia (J.Gay) Endl.	R
Surianaceae	
Cadellia pentastylis F.Muell.	V
Symplocaceae	
Symplocos stawellii var. montana C.T.White	R
Thelypteridaceae	
Thelypteris confluens (Thunb.) C.V.Morton	V
Thymelaeaceae	
Pimelea leptospermoides F.Muell.	R
Tiliaceae	
Corchorus hygrophilus A.Cunn. ex Benth.	R
Corchorus thozetii Halford	X
Grewia graniticola Halford	R
Xanthorrhoeaceae	
Lomandra teres T.D.Macfarl.	R
Zamiaceae	
Macrozamia conferta D.L.Jones & P.I.Forst.	V
Macrozamia cranei D.L.Jones & P.I.Forst.	E
Macrozamia crassifolia P.I.Forst. & D.L.Jones	V
Macrozamia fearnsidei D.L.Jones	V
Macrozamia machinii P.I.Forst. & D.L.Jones	V
Macrozamia occidua D.L.Jones & P.I.Forst.	V
Macrozamia platyrhachis F.M.Bailey	E
Macrozamia serpentina D.L.Jones & P.I.Forst.	E
Macrozamia viridis D.L.Jones & P.I.Forst.	E

Appendix 4

Plant taxa endemic to the Study Area

Acanthaceae	
Harnieria sp. (Lornesleigh E.J.Thompson+ CHA75)	
Xerothamnella herbacea R.M.Barker	E
Amaranthaceae	
Ptilotus extenuatus Benl	R
Apiaceae	
Hydrocotyle sp. (Lake Broadwater K.A.Williams AQ230829)	
Araliaceae	
Astrotricha biddulphiana F.Muell.	
Astrotricha brachyandra A.R.Bean	
Astrotricha cordata A.R.Bean	
Arecaceae	
Livistona fulva Rodd	R
Livistona nitida Rodd	R
Asclepiadaceae	
Marsdenia pumila P.I.Forst.	V
Tylophora linearis P.I.Forst.	E
Asteraceae	
Blumea benthamiana Domin	
Calotis cuneata (F.Muell. ex Benth.) G.L.R.Davis var. cuneata	
Calotis glabrescens C.T.White	R
Craspedia sp. (Girraween NP S.T.Blake 23643)	
Hemisteptia lyrata (Bunge) Fisch. & C.A.Mey.	P
Olearia gordonii Lander	
Olearia sp. (Carnarvon NP W.Morley AQ249966)	
Olearia sp. (Glenavon P.I.Forster+ PIF15039)	E
Ozothamnus diotophyllus (F.Muell.) Anderb.	
Picris barbarorum Lindl.	P
Picris evae Lack	V
Rutidosis crispata A.E.Holland	R
Rutidosis glandulosa A.E.Holland	R
Rutidosis lanata A.E.Holland	E
Senecio sp. (Blackdown Tableland R.J.Henderson+ H1171)	
Sigesbeckia fugax Pedley	
Trioncinia retroflexa (F.Muell.) Veldkamp	E
Caesalpiniaceae	
Labichea digitata Benth.	
Callitrichaceae	
Callitriche sonderi Hegelm.	
Campanulaceae	
Isotoma fluviatilis subsp. borealis McComb	
Wahlenbergia celata P.I.Forst.	
Wahlenbergia islensis P.J.Sm.	R
Capparaceae	
Capparis humistrata (F.Muell.) F.Muell.	E
Capparis shanesiana F.Muell.	
Capparis thozetiana (F.Muell.) F.Muell.	V
Caryophyllaceae	
Stellaria sp. (Cooyar A.R.Bean 10622)	
Celastraceae	
Apatophyllum flavovirens A.R.Bean & Jessup	R
Apatophyllum teretifolium A.R.Bean & Jessup	R
Denhamia parvifolia L.S.Sm.	V
Denhamia sp. (Junee Tableland T.J.McDonald 553)	
Maytenus sp. (Mt Coolon D.Corr PA409)	
Combretaceae	
Macropteranthes leichhardtii F.Muell. ex Benth.	
Macropteranthes leiocaulis P.I.Forst.	R
Commelinaceae	
Aneilema sclerocarpum F.Muell.	
Aneilema sp. (Tower LA P.I.Forster+ PIF14846)	
Cycadaceae	
Cycas cupida P.I.Forst.	P
Cycas ophiolitica K.D.Hill	E
Cyperaceae	
Caustis sp. (Robinson Gorge P.I.Forster+ PIF11256)	
Eleocharis blakeana L.A.S.Johnson & O.D.Evans	R
Lepidosperma tuberculatum var. grande Kuek.	
Dilleniaceae	
Hibbertia sp. (Barakula V.Hando 122)	
Hibbertia sp. (Blackdown Tableland S.G.Pearson 279)	
Hibbertia stricta var. fruticosa Domin	
Hibbertia tenuifolia Toelken	
Dryopteridaceae	
Tectaria devexa (Kunze ex Mett.) Copel. var. devexa	E
Epacridaceae	
Leucopogon blakei Pedley	
Leucopogon flexifolius R.Br.	
Leucopogon grandiflorus Pedley	R
Leucopogon pleiospermus (F.Muell.) Benth.	
Leucopogon pluriloculatus F.Muell.	
Leucopogon sp. (Coolmunda D.Halford Q1635)	E
Lissanthe brevistyla A.R.Bean	V
Melichrus erubescens A.Cunn. ex DC.	
Melichrus sp. (Inglewood A.R.Bean 1652)	
Melichrus sp. (Isla Gorge P.Sharpe+ 601)	
Melichrus sp. (Tara D.Halford Q2259)	
Euphorbiaceae	
Bertya calycina Halford & R.J.F.Hend	V
Bertya recurvata Halford & R.J.F.Hend.	R
Bertya sp. (Beeron Holding P.I.Forster+ PIF5753)	E
Bertya sp. (Oakey Creek B.O'Keeffe 822)	
Beyeria sp. (Bull Creek Gorge B.O'Keeffe 573)	R
Chamaesyce ophiolitica P.I.Forst.	P
Fontainea fugax P.I.Forst.	E
Neoroepera buxifolia Muell.Arg. & F.Muell.	V
Petalostigma pachyphyllum Airy Shaw	
Phyllanthus occidentalis J.T.Hunter & J.J.Bruhl	
Phyllanthus triandrus subsp. (Blackdown Tableland R.J.Henderson+ H950)	
Pseudanthus sp. (Salvator Rosa NP M.E.Ballingall MEB450)	
Pseudanthus sp. (Tylerville P.I.Forster+ PIF11510) subsp. (Blackdown Tableland R.J.Henderson H722)	R
Ricinocarpos sp. (Blackdown Tableland R.J.Henderson H610)	
Ricinocarpos sp. (Cania Gorge K.A.Wiliams 80221)	
Ricinocarpos sp. (Planet Downs A.R.Bean 14223)	
Fabaceae	
Daviesia quoquoversus Crisp	V
Daviesia ulicifolia subsp. (Bybera C.T.White 12612)	
Glycine sp. (Aldinga Grace+ 228)	
Glycine sp. (Laglan Station L.S.Smith 10302)	
Glycine sp. (Melaleuca Creek Scrub P.I.Forster+ PIF7949)	
Glycine sp. (Mt Moffatt K.A.Williams 86060)	
Hovea angustissima I.Thomps.	
Hovea planifolia (Domin) J.H.Ross	
Hovea tholiformis I.Thomps.	
Indigofera sp. (St Anns Homestead E.J.Thompson+ BUC500)	
Kennedia procurrens Benth.	
Kennedia sp. (Blackdown Tableland R.J.Henderson+ H747)	
Pultenaea millarii var. angustifolia H.B.Will.	
Pultenaea setulosa Benth.	V
Pultenaea sp. (Cracow P.I.Forster PIF7010)	
Pultenaea sp. (Eidsvold D.Halford Q1783)	
Pultenaea sp. (Narrabri R.G.Coveny+ 8811)	
Swainsona sejuncta Joy Thomps.	
Tephrosia sp. (Georgetown G.N.Batianoff+ 900402H)	
Tephrosia sp. (Keppel Bay R.Brown AQ253335)	
Goodeniaceae	
Goodenia racemosa F.Muell. var. racemosa	
Goodenia racemosa var. latifolia Carolin	
Haemodoraceae	
Haemodorum planifolium R.Br.	
Haloragaceae	
Gonocarpus urceolatus Orchard	V
Myriophyllum gracile var. laeve Orchard	
Lamiaceae	
Hemigenia biddulphiana F.Muell.	
Hemigenia sp. (Mt Abbot A.R.Bean 4204)	

Mentha grandiflora Benth.	
Newcastelia interrupta Munir	
Lamiaceae (continued)	
Newcastelia velutina Munir	V
Plectranthus actites P.I.Forst.	
Plectranthus blakei P.I.Forst.	R
Plectranthus cyanophyllus P.I.Forst.	
Prostanthera cryptandroides subsp. euphrasioides (Benth.) B.J.Conn	
Prostanthera lithospermoides F.Muell.	
Prostanthera sp. (Baking Board V.Hando 135)	
Prostanthera sp. (Blackdown Tableland K.A.W.Williams 79071)	
Prostanthera sp. (Dunmore D.M.Gordon 8A)	V
Prostanthera sp. (Moonie Highway K.A.Williams 89011)	
Prostanthera sp. (Wallangarra T.D.Stanley 7876)	R
Teucrium sp. (Ka Ka Mundi NP A.R.Bean 2170)	
Westringia parvifolia C.T.White & W.D.Francis	V
Loganiaceae	
Logania diffusa R.J.F.Hend.	V
Malvaceae	
Abutilon oxycarpum (F.Muell.) F.Muell. ex Benth. forma oxycarpum	
Abutilon tubulosum Hook. var. tubulosum	
Abutilon tubulosum var. breviflorum Benth.	
Gossypium sturtianum var. nandewarense (Derera) Fryxell	R
Hibiscus sp. (Barambah Creek P.Grimshaw+ PG2484)	
Sida sp. (Rockhampton T.Stanley 8024)	
Meliaceae	
Owenia x reliqua P.I.Forst.	
Mimosaceae	
Acacia abbatiana Pedley	
Acacia angusta Maiden & Blakely	
Acacia arbiana Pedley	R
Acacia argyrotricha Pedley	P
Acacia barakulensis Pedley	V
Acacia brachycarpa Pedley	
Acacia calantha Pedley	R
Acacia chinchillensis Tindale	V
Acacia crassa subsp. longicoma Pedley	
Acacia cretata Pedley	
Acacia debilis Tindale	
Acacia deuteroneura Pedley	V
Acacia eremophiloides Pedley & P.I.Forst.	V
Acacia everistii Pedley	
Acacia fodinalis Pedley	
Acacia gittinsii Pedley	R
Acacia grandifolia Pedley	
Acacia handonis Pedley	V
Acacia hendersonii Pedley	
Acacia hockingsii Pedley	R
Acacia holotricha Pedley	
Acacia islana Pedley	R
Acacia jucunda Maiden & Blakely	
Acacia lauta Pedley	V
Acacia leichhardtii Benth.	
Acacia loroloba Tindale	
Acacia maranoensis Pedley	
Acacia pedleyi Tindale & Kodela	R
Acacia polifolia Pedley	
Acacia porcata P.I.Forst.	E
Acacia pubicosta C.T.White	R
Acacia pubifolia Pedley	V
Acacia pustula Maiden & Blakely	
Acacia rhodoxylon Maiden	
Acacia rubricola Pedley	E
Acacia semirigida Maiden & Blakely	
Acacia sp. (Biloela T.Shepard A32)	
Acacia sp. (Comet L.Pedley 4091)	
Acacia sp. (Gayndah P.I.Forster+ PIF24863)	
Acacia sp. (Gwambagwine F.Carter 2)	V
Acacia sp. (Jericho G.R.Beeston 1065C)	
Acacia sp. (Mt Beaufort E.J.Thompson+ JER164)	
Acacia sp. (Nantglyn P.I.Forster+ PIF5741)	
Acacia sp. (Ruined Castle Creek P.I.Forster+ PIF17848)	E
Acacia spania Pedley	R
Acacia storyi Tindale	R
Acacia striatifolia Pedley	
Acacia tenuinervis Pedley	R
Acacia wardellii Tindale	V
Molluginaceae	
Macarthuria ephedroides C.T.White	R
Myoporaceae	
Myoporum tenuifolium subsp. (Marlborough R.J.Chinnock+ 8435)	
Myrtaceae	
Babingtonia brachypoda A.R.Bean	R
Baeckea trapeza A.R.Bean	V
Callistemon sp. (Bald Rock Creek I.R.Telford 11840)	
Callistemon sp. (Blackdown Tableland S.G.Pearson 287)	
Callistemon sp. (Carnarvon NP M.B.Thomas 115)	
Callistemon sp. (Chinchilla D.M.Gordon 401)	
Callistemon sp. (Marlborough Creek G.N.Batianoff+ MC9108006)	
Callistemon sp. (Mt Abbot A.R.Bean 5186)	
Callistemon sp. (Mt Coolon T.D.Stanley+ 78374)	
Callistemon sp. (Rainbow Falls P.I.Forster PIF13786)	
Calytrix gurulmundensis Craven	V
Calytrix islensis Craven	R
Corymbia aureola (Brooker & A.R.Bean) K.D.Hill & L.A.S.Johnson	
Corymbia bloxsomei (Maiden) K.D.Hill & L.A.S.Johnson	
Corymbia bunites (Brooker & A.R.Bean) K.D.Hill & L.A.S.Johnson	
Corymbia clandestina (A.R.Bean) K.D.Hill & L.A.S.Johnson	V
Corymbia hendersonii K.D.Hill & L.A.S.Johnson	
Corymbia petalophylla (Brooker & A.R.Bean) K.D.Hill & L.A.S.Johnson	R
Corymbia scabrida (Brooker & A.R.Bean) K.D.Hill & L.A.S.Johnson	R
Corymbia sp. (Springsure M.I.Brooker 9786)	
Corymbia trachyphloia subsp. carnarvonica K.D.Hill & L.A.S.Johnson	
Corymbia watsoniana (F.Muell.) K.D.Hill & L.A.S.Johnson subsp. watsoniana	
Corymbia watsoniana subsp. capillata (Brooker & A.R.Bean) K.D.Hill & L.A.S.Johnson	
Corymbia xanthope (A.R.Bean & Brooker) K.D.Hill & L.A.S.Johnson	V
Decaspermum sp. (Mt Morgan N.Hoy AQ455657)	E
Eucalyptus apothalassica L.A.S.Johnson & K.D.Hill	
Eucalyptus argophloia Blakely	V
Eucalyptus bakeri Maiden	
Eucalyptus beaniana L.A.S.Johnson & K.D.Hill	V
Eucalyptus broviniensis A.R.Bean	E
Eucalyptus corynodes A.R.Bean & Brooker	
Eucalyptus decorticans (F.M.Bailey) Maiden	
Eucalyptus fibrosa subsp. (Glen Geddes M.I.Brooker 10230)	
Eucalyptus grisea L.A.S.Johnson & K.D.Hill	
Eucalyptus infera A.R.Bean	V
Eucalyptus mensalis L.A.S.Johnson & K.D.Hill	R
Eucalyptus pachycalyx subsp. waajensis L.A.S.Johnson & K.D.Hill	E
Eucalyptus paedoglauca L.A.S.Johnson & Blaxell	V
Eucalyptus panda S.T.Blake	
Eucalyptus rhombica A.R.Bean & Brooker	
Eucalyptus rubiginosa Brooker	R
Eucalyptus scoparia Maiden	V
Eucalyptus sicilifolia L.A.S.Johnson & K.D.Hill	R
Eucalyptus sideroxylon subsp. (Waaje N.B.Byrnes 3955)	
Eucalyptus sp. (Chinchilla L.Pedley 4022)	
Eucalyptus sp. (Clermont A.R.Bean 508)	
Eucalyptus sp. (Consuelo Tableland M.I.Brooker B4884)	
Eucalyptus sp. (Inglewood P.Grimshaw+ PG846)	
Eucalyptus sp. (Mt Moffatt Homestead D.F.Blaxell+ 1883)	
Eucalyptus sp. (Rewan H.A.Kerswell 1)	
Eucalyptus sp. (Rossmoya N.H.Speck 1757)	
Eucalyptus sp. (Scartwater L.Pedley X6404)	
Eucalyptus sp. (St Lawrence N.H.Speck 1745)	
Eucalyptus sphaerocarpa L.A.S.Johnson & Blaxell	R
Eucalyptus suffulgens L.A.S.Johnson & K.D.Hill	
Eucalyptus tenuipes (Maiden & Blakely) Blakely & C.T.White	
Eucalyptus tereticornis subsp. (Consuelo Tableland M.I.Brooker B4880	
Eucalyptus terrica A.R.Bean	
Eucalyptus tholiformis A.R.Bean & Brooker	
Eucalyptus virens Brooker & A.R.Bean	V
Eucalyptus viridis var. latiuscula Blakely	
Homoranthus coracinus A.R.Bean	
Homoranthus decasetus Byrnes	R
Homoranthus decumbens (Byrnes) Craven & S.R.Jones	V
Homoranthus melanostictus Craven & S.R.Jones	
Homoranthus montanus Craven & S.R.Jones	V
Homoranthus papillatus Byrnes	R

Homoranthus zeteticorum Craven & S.R.Jones	R
Kunzea opposita var. leichhardtii Byrnes	
Leptospermum sericatum Lindl.	
Myrtaceae (continued)	
Leptospermum venustum A.R.Bean	V
Lysicarpus angustifolius (Hook.) Druce	
Micromyrtus albicans A.R.Bean	
Micromyrtus carinata A.R.Bean	E
Micromyrtus leptocalyx (F.Muell.) Benth.	
Micromyrtus patula A.R.Bean	E
Ochrosperma obovatum A.R.Bean	V
Triplarina calophylla A.R.Bean	
Najadaceae	
Najas browniana Rendle	
Nymphaeaceae	
Nymphaea gigantea Hook. var. gigantea cv. Albert De Lestang	
Oleaceae	
Notelaea pungens Guymer	R
Notelaea sp. (Barakula A.R.Bean 7553)	
Orchidaceae	
Caladenia atroclavia D.L.Jones & M.A.Clem.	E
Chiloglottis trullata D.L.Jones	
Dendrobium discolor var. fuscum (Fitzg.) Dockrill	
Dendrobium kingianum subsp. carnarvonense P.B.Adams	
Dendrobium speciosum subsp. capricornicum (Clemesha) D.P.Banks & Clemesha	
Diuris exitela D.L.Jones	
Diuris luteola D.L.Jones & B.Gray	
Gastrodia crebriflora D.L.Jones	R
Genoplesium pedersonii D.L.Jones	R
Genoplesium sp. (Wyberba D.L.Jones+ 2557)	
Genoplesium validum D.L.Jones	R
Prasophyllum campestre R.J.Bates & D.L.Jones	R
Prasophyllum flavum R.Br.	
Prasophyllum incompositum D.L.Jones	R
Pterostylis cobarensis M.A.Clem.	
Pterostylis gibbosa R.Br.	
Pterostylis longicurva Rupp	R
Pterostylis sp. (Mt Moffatt NP R.Crane 2037)	
Pterostylis woollsii Fitzg.	R
Thelymitra angustifolia R.Br.	
Thelymitra longiloba D.L.Jones & M.A.Clem.	
Phormiaceae	
Dianella fruticans R.J.F.Hend.	R
Dianella revoluta var. tenuis R.J.F.Hend.	
Pittosporaceae	
Bursaria reevesii L.W.Cayzer, Crisp & I.Telford	V
Cheiranthera sp. (Inglewood R.W.Johnson 2940)	
Poaceae	
Amphibromus whitei C.E.Hubb.	X
Aristida annua B.K.Simon	V
Aristida forsteri B.K.Simon	R
Aristida granitica B.K.Simon	E
Digitaria lanceolata R.D.Webster	
Entolasia sp. (Miles S.T.Blake 7709)	
Homopholis belsonii C.E.Hubb.	E
Leptochloa southwoodii N.Snow & B.K.Simon	
Mnesithea pilosa B.K.Simon	
Panicum queenslandicum var. acuminatum Vickery	
Paspalum batianoffii B.K.Simon	X
Planichloa sp. (Salvator Rosa M.Cox 183)	
Polygonaceae	
Rumex stenoglottis Rech.f.	
Proteaceae	
Conospermum sphacelatum Hook.	
Grevillea cyranostigma McGill.	R
Grevillea floribunda subsp. tenella Olde & Marriott	
Grevillea hockingsii Molyneux & Olde	V
Grevillea scortechinii F.Muell. subsp. scortechinii	V
Grevillea singuliflora F.Muell.	R
Grevillea whiteana McGill.	
Persoonia subtilis P.H.Weston & L.A.S.Johnson	
Persoonia terminalis subsp. recurva L.A.S.Johnson & P.H.Weston	
Rhamnaceae	
Cryptandra armata C.T.White & W.D.Francis	
Cryptandra lanosiflora F.Muell.	R
Cryptandra sp. (Gurulmundi G.W.Althofer 8418)	R
Cryptandra sp. (Isla Gorge P.Sharpe 627)	
Pomaderris clivicola E.M.Ross	E
Pomaderris coomingalensis N.G.Walsh & Coates	E
Trymalium minutiflorum E.M.Ross	V
Rubiaceae	
Canthium buxifolium forma (Brigooda P.I.Forster PIF5657)	
Canthium sp. (Duaringa N.H.Speck 1819)	
Galium terrae-reginae Ehrend. & McGill.	
Rutaceae	
Boronia amabilis S.T.Blake	R
Boronia duiganiae Duretto	
Boronia eriantha Lindl.	R
Boronia forsteri Duretto	
Boronia obovata C.T.White	
Boronia odorata Duretto	
Boronia palasepala Duretto	
Boronia repanda (F.Muell. ex Maiden & Betche) Maiden & Betche	E
Boronia sp. (Aranbanga Creek P.Grimshaw+ PG2597)	V
Boronia sp. (Nathan Gorge N.H.Speck 1925)	
Boronia splendida Duretto	
Phebalium whitei Paul G.Wilson	V
Philotheca difformis (A.Cunn. ex Endl.) Paul G.Wilson	
Philotheca sporadica (Bayly) Paul G.Wilson	V
Zieria arborescens subsp. glabrifolia J.A.Armstr.	
Zieria aspalathoides subsp. (Springsure L.Cockburn AQ195493)	
Zieria sp. (Amiens L.Pedley 1518)	
Zieria sp. (Binjour P.I.Forster PIF14134)	E
Zieria sp. (Coominglah A.R.Bean+ 8959)	
Zieria sp. (Monogorilby P.I.Forster PIF1004)	V
Sapindaceae	
Atalaya collina S.T.Reynolds	E
Dodonaea biloba J.G.West	R
Dodonaea macrossanii F.Muell. & Scort.	R
Scrophulariaceae	
Lindernia sp. (Tingoora A.R.Bean 10311)	
Microcarpaea agonis A.R.Bean	E
Solanaceae	
Solanum adenophorum F.Muell.	E
Solanum dissectum Symon	P
Solanum elachophyllum F.Muell.	
Solanum sp. (Coominglah A.R.Bean 10389)	P
Solanum sp. (Dalby R.F.Kelsey 56)	V
Solanum sp. (Monto A.R.Bean 8817)	
Stackhousiaceae	
Stackhousia tryonii F.M.Bailey	R
Sterculiaceae	
Brachychiton sp. (Blackwall Range R.J.Fensham 971)	E
Commersonia sp. (Beeron P.I.Forster PIF4658)	V
Commersonia sp. (Cadarga G.P.Guymer 1642)	
Commersonia sp. (Zamia Range R.W.Johnson 1398)	
Rulingia sp. (Westmar L.Pedley 518)	
Stylidiaceae	
Stylidium ecorne (F.L.Erickson & J.H.Willis) P.G.Farrell & S.H.James	
Thymelaeaceae	
Pimelea leptospermoides F.Muell.	R
Pimelea sp. (Hughenden D.A.Halford Q242)	
Tiliaceae	
Corchorus hygrophilus A.Cunn. ex Benth.	R
Corchorus reynoldsiae Halford	
Corchorus thozetii Halford	X
Viscaceae	
Viscum bancroftii Blakely	
Xanthorrhoeaceae	
Lomandra teres T.D.Macfarl.	R
Zamiaceae	
Macrozamia cranei D.L.Jones & P.I.Forst.	E
Macrozamia crassifolia P.I.Forst. & D.L.Jones	V
Macrozamia fearnsidei D.L.Jones	V
Macrozamia machinii P.I.Forst. & D.L.Jones	V
Macrozamia miquelii (F.Muell.) A.DC.	
Macrozamia moorei F.Muell.	
Macrozamia occidua D.L.Jones & P.I.Forst.	V
Macrozamia platyrhachis F.M.Bailey	E
Macrozamia serpentina D.L.Jones & P.I.Forst.	E
Macrozamia viridis D.L.Jones & P.I.Forst.	E

Appendix 5

Age, foraging substrate and breeding strategy of Australian passerines reviewed by Geffen and Yom-Tov (1999)

Genus	Species	Age	Foraging substrate	Co-operative breeder?	Conservation status in NSW woodlands	Conservation status in the Study Area
Pitta	erythrogaster	old	litter	no		
Pitta	iris	old	litter	no		
Pitta	versicolor	old	litter	no		secure
Cormobates	leucophaea	old	bark	no	secure	secure
Climacteris	affinis	old	bark	yes	declining	
Climacteris	erythrops	old	bark	yes		
Climacteris	melanura	old	bark	yes		
Climacteris	picumnus	old	bark	yes	declining	declining
Climacteris	rufa	old	bark	yes		
Atrichornis	clamosus	old	litter	no		
Atrichornis	rufescens	old	litter	no		
Menura	alberti	old	litter	no		
Menura	novaehollandiae	old	litter	no		
Ailuroedus	crassirostris	medium	fruit	no		
Ailuroedus	dentirostris	medium	fruit	no		
Ptilonorhynchus	violaceus	medium	fruit	no		
Chlamydera	cerviventris	new	ground	no		
Chlamydera	maculata	new	ground	no		secure
Chlamydera	nuchalis	new	ground	no		
Amytornis	barbatus	old	ground	yes		
Amytornis	dorotheae	old	ground	yes		
Amytornis	goyderi	old	ground	no		
Amytornis	housei	old	ground	yes		
Amytornis	purnelli	old	ground	no		
Amytornis	striatus	old	ground	no		
Amytornis	textilis	old	ground	no		
Amytornis	woodwardi	old	ground	yes		
Stipiturus	malachurus	old	ground	yes		
Stipiturus	ruficeps	old	ground	yes		
Malurus	coronatus	medium	ground	yes		
Malurus	cyaneus	medium	ground	yes	secure	secure
Malurus	elegans	medium	ground	yes		
Malurus	lamberti	medium	ground	yes	secure	secure
Malurus	leucopterus	medium	ground	yes		secure
Malurus	melanocephalus	medium	ground	yes		secure
Malurus	pulcherrinus	medium	ground	yes		
Malurus	splendens	medium	ground	yes		secure
Certhionyx	niger	old	flowers	no	secure	secure
Certhionyx	pectoralis	old	flowers	no		
Certhionyx	variegatus	old	flowers	no		
Myzomela	erythrocephala	old	flowers	no		
Myzomela	obscura	old	flowers	no		
Myzomela	sanguinolenta	old	flowers	no		secure

Genus	Species	Age	Foraging substrate	Co-operative breeder?	Conservation status in NSW woodlands	Conservation status in the Study Area
Acanthorhynchus	superciliosus	old	flowers	no		
Acanthorhynchus	tenuirostris	old	flowers	no	secure	secure
Conopophila	albogularis	old	flowers	yes		
Conopophila	rufogularis	old	flowers	yes		secure
Conopophila	whitei	old	canopy	yes		
Plectorhyncha	lanceolata	medium	canopy	yes	secure	secure
Ramsayornis	fasciatus	medium	flowers	no		secure
Ramsayornis	modestus	medium	flowers	no		
Ashbyia	lovensis	new	rock	no		
Epthianura	albifrons	new	ground	no	secure	
Epthianura	aurifrons	new	ground	no		secure
Epthianura	crocea	new	ground	no		
Epthianura	tricolor	new	ground	no		
Entomyzon	cyanotis	medium	flowers	yes	secure	secure
Melithreptus	affinis	medium	bark	yes		
Melithreptus	albogularis	medium	flowers	yes		secure
Melithreptus	brevirostris	medium	bark	yes	secure	secure
Melithreptus	gularis	medium	bark	yes	declining	declining
Melithreptus	lunatus	medium	flowers	yes	secure	secure
Melithreptus	validirostris	medium	bark	yes		
Meliphaga	albolineata	medium	flowers	yes		
Meliphaga	gracilis	medium	flowers	no		
Meliphaga	lewinii	medium	fruit	no		secure
Meliphaga	notata	medium	flowers	no		
Lichmera	indistincta	medium	flowers	no		
Phylidonyris	albifrons	new	flowers	no	secure	secure
Phylidonyris	melanops	new	flowers	no		
Phylidonyris	nigra	new	flowers	no		secure
Phylidonyris	novaehollandiae	new	flowers	yes		
Phylidonyris	pyrrhoptera	new	flowers	no		
Anthochaera	carunculata	new	flowers	no	secure	secure
Anthochaera	chrysoptera	new	flowers	yes		
Anthochaera	paradoxa	new	flowers	no		
Pardalotus	punctatus	old	foliage	no	secure	secure
Pardalotus	quadragintus	old	foliage	no		
Pardalotus	rubricatus	old	foliage	no		secure
Pardalotus	striatus	old	foliage	yes	secure	secure
Dasyornis	brachypterus	old	litter	no		
Dasyornis	broadbenti	old	litter	yes		
Dasyornis	longirostris	old	litter	no		
Chthonicola	sagittatus	medium	litter	yes	declining	declining
Sericornis	beccarii	medium	litter	no		
Pyrrholaemus	brunneus	medium	litter	yes		
Hylacola	cauta	medium	litter	no		
Sericornis	citreogularis	medium	litter	no		secure
Sericornis	frontalis	medium	litter	yes	secure	secure
Calamanthus	fuliginosus		litter	no		
Sericornis	keri	medium	litter	no		
Sericornis	magnirostris	medium	litter	yes		secure
Acanthornis	magnus		litter	no		

Genus	Species	Age	Foraging substrate	Co-operative breeder?	Conservation status in NSW woodlands	Conservation status in the Study Area
Hylacola	pyrropygius	medium	litter	no	secure	
Smicronis	brevirostris	medium	foliage	yes	secure	secure
Gerygone	chloronata	medium	foliage	no		
Gerygone	fusca	medium	foliage	no	secure	secure
Gerygone	laevigaster	medium	foliage	no		
Gerygone	magnirostris	medium	foliage	no		
Gerygone	mouki	medium	foliage	yes		secure
Gerygone	olivacea	medium	foliage	no	secure	secure
Gerygone	palpebrosa	medium	foliage	no		
Gerygone	tenebrosa	medium	foliage	yes		
Aphelocephala	leucopsis	medium	ground	yes	declining	secure
Aphelocephala	nigricincta	medium	ground	yes		
Aphelocephala	pectoralis	medium	ground	no		
Acanthiza	apicalis	medium	canopy	no	secure	secure
Acanthiza	chrysorrhoa	medium	ground	yes	secure	secure
Acanthiza	ewingii	medium	canopy	no		
Acanthiza	inornata	medium	canopy	yes		
Acanthiza	iredalei	medium	canopy	no		
Acanthiza	katherina	medium	canopy	no		
Acanthiza	lineata	medium	foliage	yes	secure	secure
Acanthiza	nana	medium	foliage	yes	secure	secure
Acanthiza	pusilla	medium	canopy	no	secure	secure
Acanthiza	reguloides	medium	litter	yes	secure	secure
Acanthiza	robustirostris	medium	canopy	no		
Acanthiza	uropygalis	medium	canopy	yes	declining	secure
Petroica	goodenovii	old	litter	no	declining	secure
Petroica	multicolor	old	litter	no	secure	secure
Petroica	phoenicea	old	litter	no	secure	secure
Petroica	rodinogaster	old	canopy	no		
Petroica	rosea	old	foliage	no		secure
Microeca	flavigaster	old		no		
Microeca	griseoceps	old		no		
Microeca	leucophaea	old	litter	no	declining	secure
Microeca	tormenti	old		no		
Drymodes	brunneopygia	old	litter	no		
Drymodes	superciliaris	old	litter	no		
Eopsaltria	australis	new	litter	yes	declining	secure
Eopsaltria	georgiana	new	litter	yes		
Eopsaltria	griseogularis	new	litter	yes		
Eopsaltria	pulverulenta	new	litter	no		
Orthonyx	spaldingii	old	litter	yes		
Orthonyx	temminckii	old	litter	yes		
Pomatostomus	halli	medium	litter	yes		
Pomatostomus	ruficeps	medium	litter	yes		
Pomatostomus	superciliosus	medium	litter	yes	declining	declining
Pomatostomus	temporalis	medium	litter	yes	declining	declining
Psophodes	cristatus	old	litter	no		
Psophodes	nigrogularis	old	litter	no		
Psophodes	olivaceus	old	litter	no		secure

Genus	Species	Age	Foraging substrate	Co-operative breeder?	Conservation status in NSW woodlands	Conservation status in the Study Area
Corcorax	melanorhamphos	medium	litter	yes	secure	secure
Struthidea	cinerea	medium	litter	yes	secure	secure
Daphoenositta	chrysoptera	old	bark	yes	declining	secure
Falcunculus	frontatus	old	bark	yes	declining	secure
Oreoica	gutturalis	old	ground	no	declining	declining
Colluricincla	boweri	medium	bark	no		
Colluricincla	harmonica	medium	bark	no	secure	secure
Colluricincla	megarhyncha	medium	bark	no		
Colluricincla	woodwardi	medium	bark	no		
Pachycephala	griseiceps	medium		no		
Pachycephala	inornata	medium	canopy	no		
Pachycephala	lanioides	medium		no		
Pachycephala	melanura	medium		no		
Pachycephala	olivacea	medium	canopy	no		
Pachycephala	pectoralis	medium	canopy	no	secure	secure
Pachycephala	rufiventris	medium	canopy	no	declining	secure
Pachycephala	rufogularis	medium		no		
Pachycephala	simplex	medium		no		
Rhipidura	fuliginosa	medium	air	no	secure	secure
Rhipidura	leucophrys	medium	air	no	secure	secure
Rhipidura	rufifrons	medium	air	no		secure
Rhipidura	rufiventris	medium	air	no		
Dicrurus	hottentotus	medium	bark	no		secure
Grallina	cyanoleuca	medium	ground	yes	secure	secure
Myiagra	alecto	new	air	no		
Myiagra	cyanoleuca	new	air	no		secure
Myiagra	inquieta	new	ground	no	declining	secure
Myiagra	rubecula	new	air	no	secure	secure
Myiagra	ruficollis	new		no		
Monarcha	frater	new		no		
Monarcha	leucotis	new	air	no		secure
Monarcha	melanopsis	new	air	no		secure
Monarcha	trivirgatus	new	air	no		secure
Corvus	bennetti	new	ground	no	secure	secure
Corvus	coronoides	new	ground	no	secure	secure
Corvus	mellori	new	ground	no	secure	
Corvus	orru	new	ground	no	secure	secure
Corvus	splendens	new	ground	no		
Corvus	tasmanicus	new	ground	no		
Manucodia	kareudrenii	new		no		
Ptiloris	magnificus	new	bark	no		
Ptiloris	paradiseus	new	bark	no		
Sphecotheres	viridis	medium	fruit	yes		secure
Oriolus	flavicinctus	medium	fruit	no		
Oriolus	sagittatus	medium	fruit	no	secure	secure
Coracina	lineata	new	fruit	no		
Coracina	maxima	new	ground	yes	secure	secure
Coracina	novaehollandiae	new	canopy	no	secure	secure
Coracina	papuensis	new	canopy	no	secure	secure
Coracina	tenuirostris	new	canopy	no		secure

Genus	Species	Age	Foraging substrate	Co-operative breeder?	Conservation status in NSW woodlands	Conservation status in the Study Area
Lalage	leucomela	new	canopy	no		secure
Lalage	sueurii	new	canopy	no	secure	secure
Artamus	cyanopterus	medium	air	yes	declining	secure
Artamus	cinereus	medium	air	yes	secure	secure
Artamus	leucorhynchus	medium	air	yes	secure	secure
Artamus	minor	medium	air	yes		secure
Artamus	personatus	medium	air	no	secure	secure
Artamus	superciliosus	medium	air	no	declining	secure
Strepera	fuliginosa	medium	canopy	no		
Strepera	graculina	medium	canopy	no	secure	secure
Strepera	versicolor	medium	canopy	no	secure	secure
Gymnorhina	tibicen	new	ground	yes	secure	secure
Cracticus	mentalis	new	canopy	no		
Cracticus	nigrogularis	new	canopy	yes	secure	secure
Cracticus	quoyii	new	canopy	no		
Cracticus	torquatus	new	canopy	yes	secure	secure
Zoothera	dauma	medium	litter	no		
Aplonis	metallica	medium	fruit	no		
Hirundo	neoxena	new	air	no	secure	secure
Hirundo	rustica	new	air	no		
Cisticola	exilis			no		
Cisticola	juncidis			no		
Zosterops	citrinella	new		no		
Zosterops	lateralis	new	canopy	no	secure	secure
Zosterops	lutea	new		no		
Acrocephalus	stentoreus			no		
Eremiornis	carteri			no		
Cinclorhamphus	cruralis			no	secure	
Cinclorhamphus	mathewsi			no	secure	
Anthus	novaeseelandiae			no		
Lonchura	castaneothorax			no		secure
Lonchura	flaviprymna			no		
Lonchura	pectoralis		ground	no		
Dicaeum	hirundinaceum	new	fruit	no	secure	secure
Nectarinia	jugularis		flowers	no		secure

Appendix 6

Threatening processes and taxa affected in the Western Hardwoods area.

COMMON_NAM	SCIENTIFIC	STATUS	BBS priority	BBN priority	predation	water	hollows	woody debris	grasses	shrubs	nectar	desiccation	number of processes
Brown Thornbill	Acanthiza pusilla	C								1			1
Common Death Adder	Acanthophis antarcticus	R	1	1	1			1					2
Feathertail Glider	Acrobates pygmaeus	C	1	1			1						1
Tusked Frog	Adelotus brevis	C	1	1		1							1
Rufous Bettong	Aepyprymnus rufescens	C	1		1			1					2
Azure Kingfisher	Alcedo azurea	C	1	1		1				1			2
Australian Brush-turkey	Alectura lathami	C	1	1						1		1	2
Australian King-Parrot	Alisterus scapularis	C					1						1
Jacky Lizard	Amphibolurus muricatus	C	1	1				1					1
Anomalopus brevicollis	Anomalopus brevicollis	R	1	1				1				1	2
Anomalopus leuckartii	Anomalopus leuckartii	C	1	1				1					1
Long-legged Worm Skink	Anomalopus mackayi	V	1					1					1
Eastern Children's Python	Antaresia maculosus	C					1						1
Yellow-footed Antechinus	Antechinus flavipes	C						1					1
Southern Whiteface	Aphelocephala leucopsis	C	1					1					1
Woma	Aspidites ramsayi	R	1					1					1
Bush Stone-curlew	Burhinus grallarius	C	1	1	1			1		1			3
Major Mitchell's Cockatoo	Cacatua leadbeateri	V	1				1						1
Chestnut-rumped Heathwren	Calamanthus pyrrhopygius	C	1					1		1			2
Red-tailed Black-Cockatoo	Calyptorhynchus banksii	C	1	1			1						1
Yellow-tailed Black-Cockatoo	Calyptorhynchus funereus	C	1	1			1			1			2
Glossy Black-Cockatoo (northern)	Calyptorhynchus lathami erebus	V	1	1			1			1			2
Glossy Black-Cockatoo (eastern)	Calyptorhynchus lathami lathami	V	1	1			1			1			2

COMMON_NAM	SCIENTIFIC	STATUS	BBS priority	BBN priority	predation	water	hollows	woody debris	grasses	shrubs	nectar	desiccation	number of processes
Emerald Dove	Chalcophaps indica	C	1									1	1
Hoary Wattled Bat	Chalinolobus nigrogriseus	C	1				1						1
Little Pied Bat	Chalinolobus picatus	R	1	1			1						1
Broad-shelled River Turtle	Chelodina expansa	C	1	1		1							1
Eastern Snake-necked Turtle	Chelodina longicollis	C				1							1
Frilled Lizard	Chlamydosaurus kingii	C	1	1				1		1			2
Little Bronze-Cuckoo	Chrysococcyx minutillus	C	1									1	1
Black-eared Cuckoo	Chrysococcyx osculans	C	1	1				1		1			2
Spotted Quail-thrush	Cinclosoma punctatum	C	1	1				1					1
White-browed Treecreeper (eastern)	Climacteris affinis	C	1				1	1					2
Brown Treecreeper	Climacteris picumnus picumnus	C	1	1			1	1		1			3
Brown Treecreeper (south-eastern)	Climacteris picumnus victoriae	C	1				1	1		1			3
Grey Shrike-thrush	Colluricincla harmonica	C								1			1
Little Shrike-thrush	Colluricincla megarhyncha	C	1									1	1
Ctenotus eurydice	Ctenotus eurydice	C	1					1					1
Pink-tongued Lizard	Cyclodomorphus gerrardii	C	1					1					1
Rough Frog	Cyclorana verrucosa	R	1			1							1
Northern Quoll	Dasyurus hallucatus	C	1	1	1			1					2
Spotted-tailed Quoll (sth subsp.	Dasyurus maculatus maculatus	V	1	1	1			1					2
Delma inornata	Delma inornata	C	1					1					1
Delma plebeia	Delma plebeia	C	1					1					1
Collared Delma	Delma torquata	V	1	1				1					1
Ornamental Snake	Denisonia maculata	V	1	1		1		1					2
Yakka Skink	Egernia rugosa	V	1	1				1		1			2
Tree Skink	Egernia striolata	C					1	1					2
Saw-shelled Turtle	Elseya latisternum	C				1							1
Krefft's River Turtle	Emydura krefftii	C				1							1
Eastern Yellow Robin	Eopsaltria australis	C								1			1

COMMON_NAM	SCIENTIFIC	STATUS	BBS priority	BBN priority	predation	water	hollows	woody debris	grasses	shrubs	nectar	desiccation	number of processes
Eulamprus amplus	Eulamprus amplus	R						1				1	2
Eulamprus luteilateralis	Eulamprus luteilateralis	R						1				1	2
Eastern Water Skink	Eulamprus quoyii	C	1			1							1
Squatter Pigeon (southern subspe	Geophaps scripta scripta	V	1	1	1				1				2
Brown Gerygone	Gerygone mouki	C	1									1	1
Fairy Gerygone	Gerygone palpebrosa	C		1								1	1
Pale-headed Snake	Hoplocephalus bitorquatus	C	1	1			1	1					2
Piceatus Jewel Butterfly	Hypochrysops piceatus	E	1							1			1
Northern Brown Bandicoot	Isoodon macrourus	C	1	1				1		1		1	3
Golden-tipped Bat	Kerivoula papuensis	R	1	1						1		1	2
Spectacled Hare-wallaby	Lagorchestes conspicillatus	C		1				1	1				2
Varied Triller	Lalage leucomela	C	1									1	1
Swift Parrot	Lathamus discolor	E	1								1		1
Allan's Lerista	Lerista allanae	E		1				1					1
Wonga Pigeon	Leucosarcia melanoleuca	C	1	1						1		1	2
Yellow-faced Honeyeater	Lichenostomus chrysops	C								1			1
Eungella Honeyeater	Lichenostomus hindwoodi	R		1							1		1
White-eared Honeyeater	Lichenostomus leucotis	C								1			1
Yellow-tufted Honeyeater	Lichenostomus melanops	C				1				1			2
White-plumed Honeyeater	Lichenostomus penicillatus	C				1							1
Salmon-striped Frog	Limnodynastes salmini	C	1	1		1		1					2
Eastern Sedgefrog	Litoria fallax	C				1							1
Stony-creek Frog	Litoria lesueuri	C				1							1
Black-striped Wallaby	Macropus dorsalis	C	1	1				1	1	1		1	4
Red-necked Wallaby	Macropus rufogriseus	C						1					1
Hooded Robin (south-eastern)	Melanodryas cucullata cucullata	C	1					1		1			2
Hooded Robin (northern inland)	Melanodryas cucullata picata	C						1		1			2
Lewin's Honeyeater	Meliphaga lewinii	C								1			1

COMMON_NAM	SCIENTIFIC	STATUS	BBS priority	BBN priority	predation	water	hollows	woody debris	grasses	shrubs	nectar	desiccation	number of processes
Fawn-footed Melomys	Melomys cervinipes	C	1							1		1	2
Jacky Winter	Microeca fascinans	C						1		1			2
White-eared Monarch	Monarcha leucotis	C	1	1								1	1
Black-faced Monarch	Monarcha melanopsis	C	1	1								1	1
Carpet Python	Morelia spilota	C	1	1			1	1					2
Large-footed Myotis	Myotis macropus	C	1	1		1							1
Queensland Lungfish	Neoceratodus forsteri	C	1	1		1							1
Plum-headed Finch	Neochmia modesta	C	1	1					1				1
Crimson Finch	Neochmia phaeton	V		1					1				1
Star Finch (eastern subsp.)	Neochmia ruficauda ruficauda	E		1					1				1
Red-browed Finch	Neochmia temporalis	C				1							1
Turquoise Parrot	Neophema pulchella	R	1				1	1	1				3
Border Thick-tailed Gecko	Nephrurus sphyrurus	V						1					1
Satin Blue Butterfly	Nesolycaena albosericea	V	1	1						1			1
Barking Owl	Ninox connivens	C	1	1			1			1			2
Rufous Owl (eastern)	Ninox rufa queenslandica	V		1			1						1
Powerful Owl	Ninox strenua	V	1	1			1			1			2
Eastern Tiger Snake	Notechis scutatus	C	1			1							1
Lesser Long-eared Bat	Nyctophilus geoffroyi	C					1						1
Greater Long-eared Bat	Nyctophilus timoriensis	R	1	1			1						1
Robust Velvet Gecko	Oedura robusta	C					1						1
Bridled Nailtail Wallaby	Onychogalea fraenata	E		1					1				1
Crested Bellbird (southern)	Oreoica gutturalis gutturalis	C	1	1				1		1			2
Crested Bellbird (inland)	Oreoica gutturalis pallescens	C	1	1				1		1			2
Platypus	Ornithorhynchus anatinus	CS	1	1		1							1
Brigalow Scaly-foot	Paradelma orientalis	V	1	1				1		1			2
Plains-wanderer	Pedionomus torquatus	V	1	1				1					1
Long-nosed Bandicoot	Perameles nasuta	C	1	1						1		1	2
Greater Glider	Petauroides volans	C	1	1			1						1

COMMON_NAM	SCIENTIFIC	STATUS	BBS priority	BBN priority	predation	water	hollows	woody debris	grasses	shrubs	nectar	desiccation	number of processes
Yellow-bellied Glider (sth subsp)	Petaurus australis australis	C	1	1			1				1		2
Squirrel Glider	Petaurus norfolcensis	C	1	1			1				1		2
Herbert's Rock-wallaby	Petrogale herberti	C	1	1	1				1	1			3
Brush-tailed Rock-wallaby	Petrogale penicillata	V	1		1				1	1			3
Red-capped Robin	Petroica goodenovii	C						1		1			2
Scarlet Robin	Petroica multicolor	C	1					1		1			2
Flame Robin	Petroica phoenicea	C						1					1
Flock Bronzewing	Phaps histrionica	C	1	1					1				1
Brush-tailed Phascogale	Phascogale tapoatafa	C	1	1			1	1					2
Eastern Water Dragon	Physignathus lesueurii	C	1			1				1			2
Noisy Pitta	Pitta versicolor	C	1									1	1
Narrow-nosed Planigale	Planigale tenuirostris	C	1	1				1					1
Black-throated Finch (sth subsp.)	Poephila cincta cincta	V	1	1					1				1
White-browed Babbler	Pomatostomus superciliosus	C	1					1		1			2
Grey-crowned Babbler	Pomatostomus temporalis	C	1	1				1		1			2
Long-nosed Potoroo	Potorous tridactylus	V	1							1			1
Red-bellied Black Snake	Pseudechis porphyriacus	C	1			1							1
Common Ringtail Possum	Pseudocheirus peregrinus	C	1	1			1			1		1	3
Queensland Pebble-mound Mouse	Pseudomys patrius	C	1						1				1
Eastern Whipbird	Psophodes olivaceus	C	1							1		1	2
Grey-headed Flying-fox	Pteropus poliocephalus	C	1	1							1		1
Little Red Flying-fox	Pteropus scapulatus	C	1	1							1	1	2
Speckled Warbler	Pyrrholaemus sagittatus	C	1	1				1		1			2
	Ramphotyphlops proximus	C						1					1
Fitzroy Tortoise	Rheodytes leukops	V	1	1		1							1
Carpentaria Whip Snake	Rhinoplocephalus boschmai	C	1	1				1					1
Eastern Small-eyed Snake	Rhinoplocephalus nigrescens	C						1					1
Rufous Fantail	Rhipidura rufifrons	C	1	1						1		1	2

COMMON_NAM	SCIENTIFIC	STATUS	BBS priority	BBN priority	predation	water	hollows	woody debris	grasses	shrubs	nectar	desiccation	number of processes
Saltuarius wyberba	Saltuarius wyberba	C						1					1
Greater Broad-nosed Bat	Scoteanax rueppellii	C	1	1			1						1
Central-eastern Broad-nosed Bat	Scotorepens sp. (Parnaby)	C	1				1						1
Yellow-throated Scrubwren	Sericornis citreogularis	C	1									1	1
Large-billed Scrubwren	Sericornis magnirostris	C	1									1	1
Regent Bowerbird	Sericulus chrysocephalus	C	1									1	1
Common Dunnart	Sminthopsis murina	C						1					1
Diamond Firetail	Stagonopleura guttata	C	1	1				1	1	1			3
Golden-tailed Gecko	Strophurus taenicauda	R	1	1			1	1					2
Short-beaked Echidna	Tachyglossus aculeatus	CS	1	1				1					1
Eel-tailed Catfish	Tandanus tandanus	C	1			1							1
Shingle-back	Trachydosaurus rugosus	C	1	1				1	1	1			3
Black-breasted Button-quail	Turnix melanogaster	V	1	1				1				1	2
Painted Button-quail	Turnix varia	C	1	1				1					1
Masked Owl	Tyto novaehollandiae	C*	1	1			1						1
Sandy Gungan	Uperoleia fusca	C	1	1		1		1					2
Lace Monitor	Varanus varius	C					1	1					2
Bandy-bandy	Vermicella annulata	C	1					1					1
Southern Forest Bat	Vespadelus regulus	C	1				1						1
Regent Honeyeater	Xanthomyza phrygia	E	1								1		1