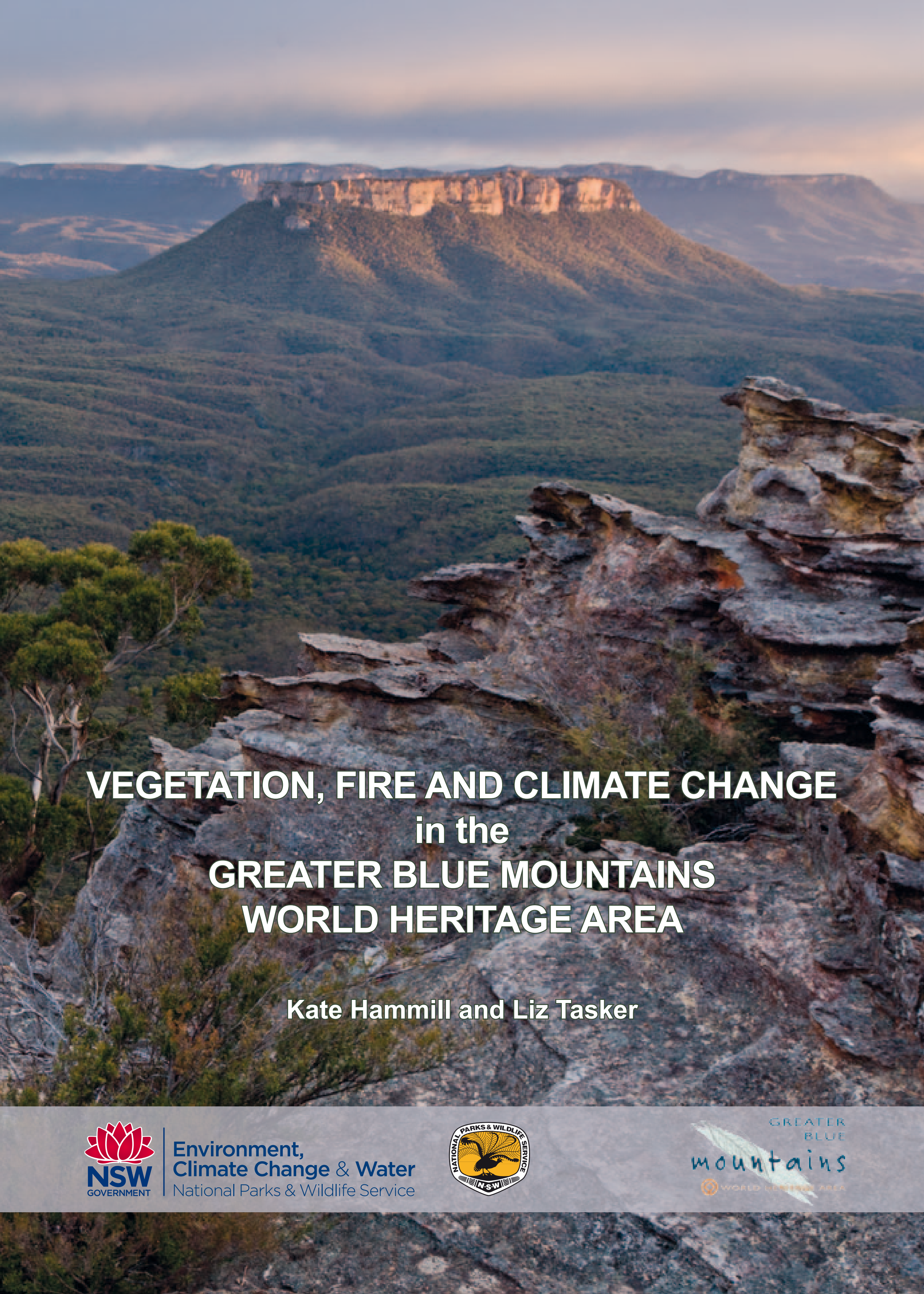


VEGETATION, FIRE AND CLIMATE CHANGE in the GREATER BLUE MOUNTAINS WORLD HERITAGE AREA

Kate Hammill and Liz Tasker

NSW GOVERNMENT
Environment, Climate Change & Water
National Parks & Wildlife Service
NATIONAL PARKS & WILDLIFE SERVICE N.S.W
GREATER BLUE mountains WORLD HERITAGE AREA

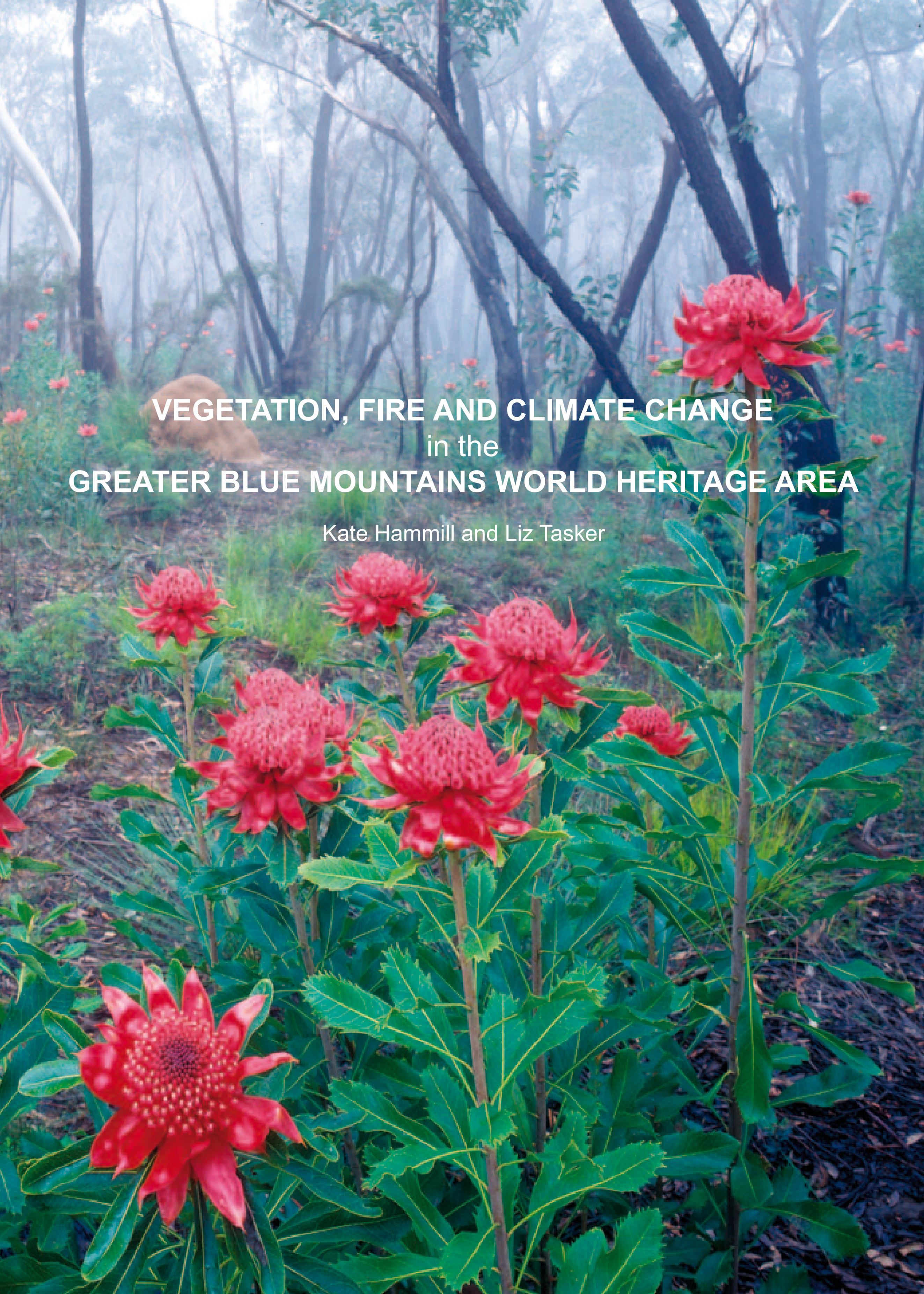
VEGETATION, FIRE AND CLIMATE CHANGE
in the
GREATER BLUE MOUNTAINS WORLD HERITAGE AREA

Kate Hammill and Liz Tasker

An Environmental Trust funded project

VEGETATION, FIRE AND CLIMATE CHANGE
in the
GREATER BLUE MOUNTAINS WORLD HERITAGE AREA

Kate Hammill and Liz Tasker



Acknowledgements
This publication was funded by a dissemination grant from the NSW Environmental Trust. It follows a three-year research project, also funded by the Environmental Trust, *Biodiversity responses to fire regimes under climate change* (2004/RD/0104). The findings from the research project form part of the content of this booklet. Most of the maps in this publication were completed as part of a project funded by the Australian Government Caring for our Country, World Heritage Property Management Program (2008–09), which is summarised in Hammill, Tasker, & Reid (2010) *Monitoring Fire Regimes and Biodiversity in the Greater Blue Mountains World Heritage Area*, an unpublished Department of Environment, Climate Change and Water NSW (DECCW) report to the Australian Government Department of Environment, Water, Heritage and the Arts and Department of Agriculture, Fisheries and Forestry. The fire history maps were compiled from extensive records and digital layers kept by the NSW National Parks & Wildlife Service (now part of DECCW). The vegetation map made use of extensive and detailed local vegetation maps prepared by the Information and Assessment Section, Metropolitan Branch of DECCW (see Further Reading for details). We also acknowledge the prior work of Saskia Hayes in collating some of the vegetation maps for the World Heritage Area. Tony Auld, Doug Benson, Ian Baird, Ross Bradstock and David Keith provided helpful comments on an earlier draft of all or part of the text. We particularly appreciate their time and contribution. Richard Kingswood and Anthony Horwood also provided helpful comments for which we are grateful. Nevertheless any and all errors remain those of the authors. Ian Baird and Fiona Thomson provided information from their unpublished PhD research projects, which is incorporated in the section ‘Forested wetlands’ and in the box ‘Plant dispersal and shifting climate niches’, respectively. Tim Hager and Doug Benson permitted us to use information from their ‘in press’ manuscript on the eucalypts of the Greater Blue Mountains World Heritage Area (GBMWHA). Deyarne Plowman assisted with the preparation of the threatened species list from the NPWS Wildlife Atlas. Jacqueline Reid supported the preparation of this booklet through the Greater Blue Mountain World Heritage Unit of the Parks and Wildlife Division of DECCW. Most of the beautiful photographs of the Blue Mountains in this publication were taken by Ian Brown and Jaime Plaza, and their assistance is much appreciated. Finally we would like to thank Alex Gardiner of the Environmental Trust, who encouraged us to prepare this publication, and provided the support that made it possible.

Publication Details

ISBN 978 1 74293 006 0
DECCW 2010/941
Published by the Department of Environment, Climate Change & Water (NSW) 2010

Written by Kathryn Hammill & Elizabeth Tasker
Design and layout by Elizabeth Tasker
Printed by Focus Press on recycled paper stock.

Cover: Pantoneys Crown, Gardens of Stone National Park. Photo: Jaime Plaza van Roon
Title page: Waratahs (*Telopea speciosissima*), Newnes Plateau, following a bushfire. Photo: Botanic Gardens Trust/Jaime Plaza

Contents

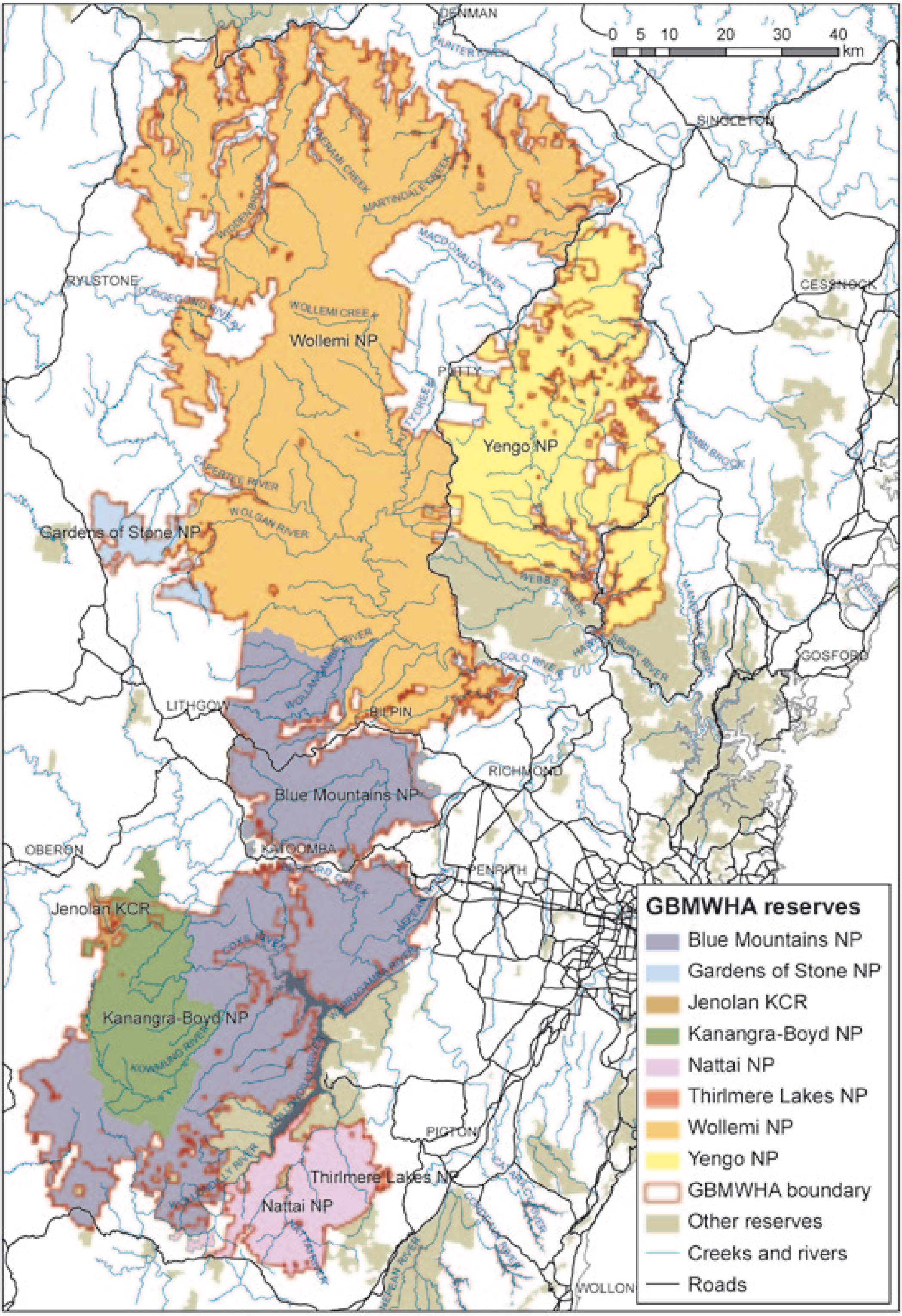


Figure 1. The location of the Greater Blue Mountains World Heritage Area, showing the eight reserves of which it is comprised. At the time of World Heritage listing (in 2000), the eight reserves totalled some 1 032 649 hectares (ha) and numerous private in-holdings existed. Many of these have since been added to the reserves, however they (along with other additions outside the boundary) are yet to be formally recognised by UNESCO as part of the World Heritage Area. Today, the eight reserves total 1 075 452 ha, and this publication deals with this full extent (Wollemi, 501 971 ha; Blue Mountains, 268 128 ha; Yengo, 167 573 ha; Kanangra-Boyd, 69 439 ha; Nattai 49 455 ha, Gardens of Stone 15 130 ha; Jenolan, 3 093 ha; and Thirlmere Lakes, 662 ha).

INTRODUCTION

A World Heritage landscape

The Greater Blue Mountains is a region of more than a million wild hectares, appearing from a distance as a vast landscape clothed in green as far as the eye can see. In some places, ridges and gullies undulate with remarkable regularity, while in others, sculpted sandstone pagodas emerge from low windswept heaths, and sheer orange-gold cliffs drop into expansive valleys of more fertile, erodible and ancient substrates. The landscapes of the Greater Blue Mountains stretch almost 250 km from north to south, from the edge of the Goulburn and Hunter Valleys all the way to the Southern Highlands near Mittagong and the Wombeyan Caves.

An enormous variety of vegetation types occur in this landscape, woven together in a pattern that reflects the soils and geology beneath, as well as different climates and fire regimes. Sheltered, moist, fertile gullies protected from fire provide ideal conditions for verdant rainforests. Adjoining these gullies in areas that burn from time to time are tall wet sclerophyll forests. These forests are also found on the few volcanic areas of the region – the basalt-caps of mountains such as Tomah, Wilson and Irvine, as well as on the cool, moist higher plateaux, as in Kanangra-Boyd, where infrequent fires provide the conditions suited to these forests.

The majority of the Greater Blue Mountains support dry sclerophyll forests. Their muted, grey-green canopy is made up of a variety of eucalypts, and they grow throughout the extensive sandstone country stretching from the Wollemi to the Wollondilly River with relatively low nutrient soils. These forests are remarkable for their diverse understorey of banksias, wattles, peas, and other sclerophyllous shrubs; in spring they are a riot of yellow, pink, red and purple flowers. On slightly more fertile soils, abundant grasses too are found among the understorey.

In areas with soils too shallow or nutrient-poor to support trees, the shrubby heathlands are hardy enough to grow; and in frequently waterlogged areas upland freshwater swamps flourish. In spring the heathlands flower profusely providing important seasonal food resources for many birds and small mammals, while the swamps play a vital role in storing water during wet times, filtering it and gradually releasing it throughout the year.

This impressive diversity is part of what led to the Greater Blue Mountains being formally included on the World Heritage list in 2000[1] in recognition of the global significance of its natural values. The Greater Blue Mountains World Heritage Area (GBMWHA), as it is now known, is made up of eight conservation reserves: Blue Mountains, Gardens of Stone, Kanangra-Boyd, Nattai, Thirlmere Lakes, Wollemi and Yengo national parks and Jenolan Karst Conservation Reserve (Figure 1).

The World Heritage listing recognises the region's globally significant natural values in two particular respects. The first is that it **possesses outstanding examples of ecological and biological processes significant in the evolution of ecosystems and communities of plants and animals.** The second is that it **contains important and significant natural habitats for the conservation of biological diversity, including threatened species of outstanding value.** The juxtaposition of highly diverse eucalypt-dominated communities that have evolved since Australia separated from Gondwana, with relict primitive Gondwanan taxa, such as the Wollemi Pine, that have survived little changed for millions of years exemplify both these values (see box: 'World Heritage values of the Greater Blue Mountains', for more details).

For millions of years both climate change and fire have been major driving forces in the evolution of the distinctive and diverse flora and fauna of the Greater Blue Mountains. However, increasingly significant human influence on the landscape and the possibility of unprecedented conditions in the future, mean that many species and ecosystems may be exposed to conditions beyond those to which they are adapted. This makes it increasingly important that we understand this diversity, the ecological processes at work and the tolerances of these ecosystems to disturbance.

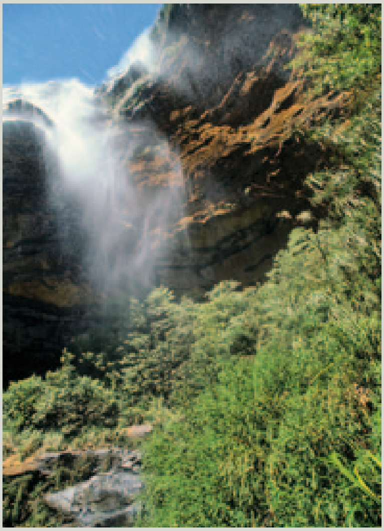
1 The Greater Blue Mountains area was nominated for World Heritage listing in 1998 and officially listed on the 29th November 2000. The required additional official gazettal under the (Australian) Environmental Protection and Biodiversity Conservation Act 1999 took place on 10th January 2001.

World Heritage values of the Greater Blue Mountains

The Greater Blue Mountains region was listed as a World Heritage Area for two major reasons (NPWS & EA 1998). The first is that it possesses outstanding examples of ecological and biological processes significant in the evolution of ecosystems and communities of plants and animals. This is demonstrated by:

- the presence of primitive Gondwanan species of outstanding international significance in the evolution of plant life, including the Wollemi Pine (*Wollemia nobilis*), one of the rarest plants in the world
- the region being a ‘hotspot’ of evolution and diversification of eucalypts that provides an outstanding record of the evolutionary processes associated with the global climatic changes of the late Tertiary period (2 – 65 million years ago: the time during which Gondwana finally split apart, and modern plant families appeared) and Quaternary period (from 2 million years ago to present: a time of repeated, extensive glaciations)
- the highly unusual juxtaposition of a diverse sclerophyllous flora with Gondwanan taxa
- an exceptional representation of the major taxonomic groupings of eucalypts (e.g. genera, subgenera and groups) and aspects of their evolution and radiation
- examples of species divergence occurring in a relatively small area
- representative examples of dynamic processes in eucalypt-dominated ecosystems, including the full range of interactions between eucalypts, understorey, environment and fire, extending from forests with rainforest boundaries to mallee communities with heath boundaries, demonstrating the exceptional ecological tolerance and range of the eucalypts.

The second major reason is that it contains important and significant natural habitats for the conservation of biological diversity, including threatened species of outstanding value. This is demonstrated by:



- outstanding levels of plant diversity at various taxonomic levels (i.e. 152 plant families and 484 genera) and at various spatial scales across the landscape (i.e. local species richness or 'alpha' diversity, species turnover across environmental gradients or 'beta' diversity, and regional species richness or 'gamma' diversity)
- plant taxa with very high levels of species diversity, including the families – Fabaceae (peas and wattles: 149 species), Myrtaceae (eucalypts, tea-trees and bottlebrushes: 150 species), Orchideae (orchids: 77 species), Proteaceae (Banksias, Grevilleas and Hakeas: 77 species), Poaceae (grasses: 57 species), Asteraceae (daisies: 69 species), Cyperaceae (sedges: 43 species), and the genera *Eucalyptus* (101 species) and *Acacia* (64 species)
- an exceptional diversity of habitats including plateau tops, ridges, exposed rocks, cliffs, rocky slopes and sheltered gorges and valleys, which contribute to the World Heritage Area being one of the three most diverse areas on earth for sclerophyllous species and the only one dominated by trees
- an exceptional diversity of Australian fauna, of which more than 40 species are rare or threatened. There are more than 400 species of vertebrates, including 52 mammals, 265 birds (33 per cent of the Australian total), 63 reptiles, more than 30 frogs, and an enormous diversity of invertebrates – for example more than 4000 species of Lepidoptera (moths and butterflies) alone

- ancient, relict Gondwanan species that have survived past climate change within refugia, such as canyons and perpetually moist areas, including the Wollemi Pine (*Wollemia nobilis*) and the primitive gymnosperm *Pherosphaera fitzgeraldii* (previously *Microstrobus fitzgeraldii*)
- an exceptional diversity of eucalypts (close to 100 species) and eucalypt-dominated ecosystems (including tall open forest, open forest, woodland, low open woodland, and mallee shrubland)
- a high diversity of vegetation communities and plant species of conservation significance including 114 endemic species (i.e. found nowhere else) and 127 rare species.

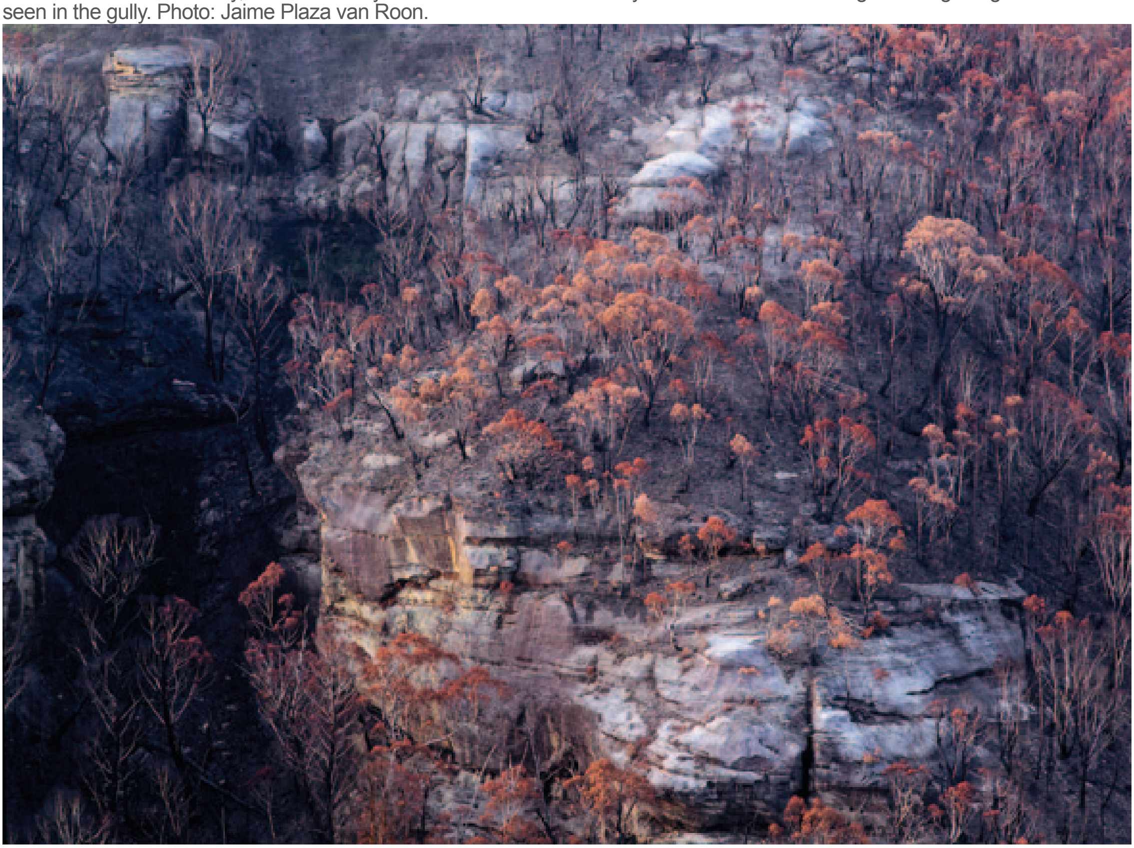
FAR LEFT: Kanangra Walls are one of the most iconic and spectacular places in the World Heritage Area. ABOVE: *Pherosphaera fitzgeraldii*) grows only on a few mist-shrouded cliffs in the upper mountains. LEFT: Wollemi pines are living 'fossils' that exist naturally only in a few deep, protected canyons. Photos: Botanic Gardens Trust/Jaime Plaza.

This publication

Our aim in this publication is to give a brief introduction to some of the biological diversity ('biodiversity') of the Greater Blue Mountains World Heritage Area and the ways in which it responds to fire regimes and climate. We begin by broadly outlining a few of the ways in which plants in general respond to fire, emphasising particular aspects known to play a key role and giving examples from the Greater Blue Mountains. This is followed by a description of patterns of fire in the World Heritage Area, and some of the principles of fire management in conservation reserves. We then outline the major vegetation types of the World Heritage Area, highlighting some important aspects of their ecology and distribution, list any endangered ecological communities that occur in them, and give one or two examples of threatened species that use them as habitat. We stress, though, that there are many more threatened species found in the World Heritage Area, and a current list of these is included at the end of the booklet. The second half of the booklet starts with an overview of the climate change projections relevant to the Greater Blue Mountains region and how fire regimes may change as a consequence. Based on these projections, we discuss how the vegetation of the World Heritage Area may respond, and suggest some ways in which these changes may be detected, managed and (perhaps) mitigated.

The information summarised in this booklet is based on a variety of sources, including vegetation survey and mapping studies, fire management plans and reports, fire mapping data, ecological research, and studies that modelled possible changes in climate, fire regimes and ecological responses. Much of this work has been carried out by scientists in the NSW Department of Environment, Climate Change and Water (DECCW). Wherever possible, we provide the reference for information cited in the text; we also provide a list of suggested further reading at the end of this booklet for those who would like to know more about the topics covered.

This scene shows how the rocky, steep terrain has influenced the severity of this bushfire: the gully has acted like a funnel and burnt much more intensely, while the rocky cliff has reduced the severity of the burn above it. Regenerating sedges can also be seen in the gully. Photo: Jaime Plaza van Roon.



FIRE IN THE GREATER BLUE MOUNTAINS

The Ecological Impacts of Fires on Plants

The Greater Blue Mountains World Heritage Area forms part of the Sydney Basin bioregion, and its terrain, vegetation and climate make it among the most fire-prone regions in the world. Fire plays an important positive role in many Australian ecosystems: many native plants in sclerophyll vegetation depend on fire to break dormancy in soil seedbanks or release seeds from woody cones, to stimulate flowering, and to create the conditions necessary for them to flourish. Fire releases nutrients into the soil and removes competitively dominant plants, allowing more light and rain to reach the soil surface.

Plants have three main ways in which they recover or respond after a fire: they may resprout from underground roots called lignotubers, from regenerative tissue in their stems or from suckers; they may germinate from seeds stored either in a soil seedbank or held in woody cones in the canopy; or they may rely on dispersal from outside the burnt area. The first two strategies (or 'functional types' as they are known – see box: 'Plant Functional Response Groups') are by far the most common, and most plants (including most rainforest plants) of the Greater Blue Mountains fall into one of these two groups.

However, the impacts of fire are complex, and effects depend on the intensity, timing and scale of the fire, as well as the context in which it occurs. For fire, this suite of factors has been formalised in the concept of the fire 'regime' (Gill 1981), which consists of the **intensity**, **season** and **type** of each fire, and the **frequency** at which fires re-occur. The biological effects of a fire also depend on the size (i.e. extent) of the fire, the type of vegetation in which it occurs, and the climatic conditions that follow. Different fires can have very different effects, and while a single fire may have a significant impact on individual plants and animals, the long-term survival of populations is determined by the interactions between fire intensity, season, type and frequency. It should be noted that fire regimes are comprised of all the fires that occur in an area, including prescribed (i.e. planned) fires. Fuel-reduction/hazard-reduction burns are a particular kind of prescribed fire.

Fire **intensity** is one of the most obvious ways in which fires differ, and is a measure of the energy released during a fire (Keeley 2009). (Note: Fire intensity is closely related to, but not the same as, fire severity, which is the amount of loss or change in organic matter above- and below-ground). The stark, blackened landscapes visible in the days after a big bushfire are striking. There may be no remaining leaves, litter or vegetation other than charred tree trunks and black 'skeletons' of larger shrubs over extensive areas. This contrasts very obviously with low intensity fires, including many prescribed burns, which may leave much vegetation remaining, either as scorched leaves or unburnt patches, or a tree canopy still green and largely unchanged.

High intensity fire in heath and dry sclerophyll forest near Pulpit Rock, Grose Valley. Photo: Kate Hammill.

The intuitive reaction is that intense fires must be bad for plants and animals and that low intensity fires are less harmful. While intense fires most certainly are destructive for human life and property, and can be for biodiversity if they burn species or vegetation types that are sensitive to them, the science shows that the reality for much of our native vegetation is quite different.

More intense, hotter fires actually have lots of biodiversity benefits, particularly for the fire-prone dry sclerophyll vegetation types. In south-eastern Australia, some 250 plant species (roughly 15% of the sclerophyll flora) are believed to have dormancy broken by heat (Auld & Denham 2006). Many of these species, particularly the pea-flowers and wattles, have seeds that rarely germinate unless they are exposed to intense heat. For example, for a range of pea-flowers including *Pultenaea daphnoides*, *Pultenaea linophylla* and *Dillwynia floribunda*, much higher seed germination occurs at 80–100°C than at 40 or 60°C (Auld & O'Connell 1991), and low intensity fires will not produce enough heat to stimulate seed germination in many of these species. Eventually, ungerminated seeds in the soil seedbank will senesce and die.

For many other species, such as *Dampiera*, *Scaevola*, *Eriostemon*, *Hibbertia* and *Conospermum*, smoke or charcoal is more important than heat (Howell & Benson 2000). Some species depend on both heat and smoke cues: up to 900 species in south-eastern Australia (just under half the fire-prone flora), including the red spider flower (*Grevillea speciosa*) and grey spider flower (*Grevillea buxifolia*) have seed dormancy broken by the interaction of heat and smoke (Auld & Denham 2006).

Importantly, even the biggest fires show a great deal of variation in intensity (Figure 4): while some areas within a large fire burn at high intensities, other areas burn at much lower intensities. Studies have shown that fire intensity can alter the floristic composition at a site (Morrison 2002). The biggest determinant of fire intensity in the Blue Mountains is weather, but fuel and terrain also play a role (e.g. Hammill & Bradstock 2006; Bradstock *et al.* 2009; 2010), the latter more so in rugged and topographically diverse landscapes such as the Greater Blue Mountains. As a consequence, the patterns of regeneration of fire-cued species also vary across the landscape, as well as from one fire to another. Intense and variable fires are essential for the persistence of many sclerophyllous shrubs: their diversity one of the great assets of the Greater Blue Mountains.


The Grose Valley, apparently devastated following intense fire, will soon be transformed with new growth. Photo: Ian Brown.


Many wattles regenerate *en masse* following a bushfire, their soil seedbank stimulated to germinate by the heat of the fire. Photo: Ian Brown.

Fire **season** can also lead to quite different impacts between fires. Some plant species with seed dormancy broken by fires are much more susceptible to these cues in particular seasons. For example, a study of germination in beard-heath (*Leucopogon*) found that while germination was possible in any season, it was far greater after late autumn or winter fires (Ooi *et al.* 2004). In contrast, for other plant species germination and recruitment may be greater after spring fires, since many seeds will germinate quickly in the warm temperatures (given adequate rainfall). After autumn fires, many seeds remain dormant until temperatures warm the following spring, and this can leave them exposed to seed-eating animals, such as ants and rodents, for much longer (Knox & Clarke 2006). The seasonal timing of fire relative to life-cycle processes in fauna may also lead to greater impacts from fires that occur during the breeding season than from those that occur when post-breeding dispersal has already occurred.

The **type** of fire refers to whether it is an above-ground fire or a below-ground (peat) fire. While below-ground fires are rare in most parts of Australia, elsewhere in the world where there are extensive peat bogs or deep organic soils, such as in parts of Russia, North America and South-east Asia, below-ground fires are common. They do occur, however, in areas of Australia where the humus layer is deep enough to sustain a fire, such as regions of Tasmania where the cold temperatures result in much slower decomposition rates, and occasionally in swamps and heaths in south-eastern mainland Australia (Keith *et al.* 2002). Under most conditions, the substrate in these areas is too wet to catch alight, and a fire will burn through the elevated vegetation without burning below ground, but during drought conditions the substrate may catch fire. Below-ground fires typically burn slowly, smouldering rather than flaming, and burn for a long time. They are also particularly destructive, since they consume the below-ground parts of resprouting plants and much of the soil organic matter, and result in soil collapse, erosion and exposure of the mineral substrate (Keith *et al.* 2002).

The **frequency** at which fires reoccur seems to be one of the major determinants of their long-term impacts in the landscape. For example, if fires repeatedly occur within the juvenile period of plants that are still recovering from the previous fire, then decline or local extinction of these species can occur. The minimum time between fires needed for populations of plants to survive is broadly known for many species of the Sydney Basin; the region has been the subject of much research by DECCW scientists and others, and much of these data are summarised in a Flora Fire Response Database (see Kenny *et al.* 2004 for details).

Flannel flowers (*Actinotus helianthi*) often bloom *en masse* after fire. Photo: Ian Brown.

Two groups of plants are particularly sensitive to the length of the interval between fires (Noble and Slatyer 1980). These are plant species that depend on seed to recover after the adult plants have been killed by a fire and that have a seedbank that is completely exhausted by a single fire, and species which rarely establish in the absence of the disturbance provided by fire (see box: 'Plant Functional Response Groups'). In the former case, the plants need sufficient time to grow to maturity, flower and accumulate a seedbank before they will be able to survive a subsequent fire. Heath banksia (*Banksia ericifolia*) and dagger hakea (*Hakea teretifolia*) are familiar examples of this functional type (needing a minimum of 4–8 and 6–8 years between fires, respectively, in order to survive at a site), as are many other woody shrubs. For species that depend on fire to create suitable conditions for their seedlings to establish in any numbers, such as many wattles and pea-flowers, very long absences of fire from a site may lead to population declines. Since many of the species in this second group have soil seedbanks that last very much longer than the adult plants live, this can be much longer than expected. For example flannel flowers (*Actinotus* species) may only live a few years, but have seeds that can persist for decades. For most species with long-lived soil seedbanks it still is not known just how long these seedbanks can last.

Frequent fires lead to the loss of many woody shrubs, and as a consequence can result in major changes in vegetation structure, with the loss of mid-storey layers. These layers and the dense cover that they provide are an important habitat for many species of animals, including threatened species: providing food, shelter, nesting sites and protection from predators. This loss of habitat is one of the reasons for *high frequency fire* being listed as a key threatening process under the *Threatened Species Conservation Act 1995* in NSW (NSW Scientific Committee 1998).

In summary, there are a number of keys to understanding the impacts of fire on plants. The first is that many native plant species need fire for some aspect of their life cycle or ecology, and that fires thus can have positive as well as negative impacts. The second is that the ecological impacts of fire are determined by fire regimes, that is the intensity, season, type and frequency of the fires. The third key is that species are not 'adapted to fire' *per se*, but to a particular spectrum of fire regimes. Fire intensities or frequencies above or below what they can tolerate, or in a season that is inappropriate, can lead to local extinctions of species, even for species that are dependent on fire in other ways.

Plant Functional Response Groups

Different plants respond to fire in different ways. How they respond is generally consistent across space and time for a given species, and results from the particular combination of life-history attributes that it possesses, such as an ability to resprout, storing its seeds in cones, how long it takes to mature and so on. The consistency of these patterns and their sensitivity to the different components of the fire regime make them a very useful tool with which to group whole suites of species that respond in a similar way, thus distilling an overwhelming species diversity of plants into a relatively small number of 'functional' groups. In fact this approach has proved so effective that it is now used in the majority of Australian studies on vegetation responses to fire and for many studies on the impacts of climate change. Functional groups are also widely used as a tool by conservation land-managers. Most of the discussion that follows is based on a key paper that formulated the currently used approach, that of Noble & Slatyer (1980). Although their scheme is actually applicable to any recurring disturbance, it is most commonly applied to the study of fire regimes.

In the Noble & Slatyer approach there are three key determinants of how plants respond to fire: (1) **their method of persistence** at a site following a disturbance, (2) **how tolerant they are to competition**, that is, whether their seedlings can establish and grow in the absence of disturbance, and (3) **the time they need to reach certain critical life stages**.

Method of persistence

There are three main ways that plants can persist or arrive at a site: by seeds, by resprouting, or by dispersing in from surrounding areas. This last method is relatively common, and consists of species whose seeds are so widely and commonly dispersed that they are available any time a disturbance occurs. Generally these species are wind- or bird-dispersed. Many native daisies (Asteraceae) are in this group, particularly *Ozothamnus* and *Senecio*, as are mistletoes in the genus *Amyema*. This group is insensitive to fire.

In contrast, species that depend on seeds to survive in situ following a disturbance, known as '**obligate seeders**', are sensitive to fire. These are plants in which the adults are killed by fire and the species survives in a burnt area only by virtue of its seeds. These seeds can exist in a long-lived soil seedbank, as is the case for many wattles and peas. For some of these species stimulation from a fire will cause the entire seedbank to germinate (and

BELOW: Lilly pilly (*Acmena smithii*; left), has fleshy fruits that are eaten by animals, *Isopogon anethifolius* (centre) stores its seeds in cones from whch they are released after fire and broad-leaf geebung (*Persoonia levis*; right) resprouts after fire. Photos: Botanic Gardens Trust/Jaime Plaza (left & centre), Ian Brown (right). ABOVE RIGHT: Waratahs (*Telopea speciosissima*) flower profusely two or three years after fire. The old burnt stems are still visible. Photo: Pavel German.

hence be ‘exhausted’), while for others only a proportion of the seedbank will respond to any given fire. This is often a result of the depths at which the seeds are buried – and hence their degree of exposure to heat, smoke or charcoal, all of which stimulate germination. A third major kind of seeder are species that have a relatively transient or short-lived seedbank. Often these seeds are stored in woody cones in the canopy, as in many banksias, cone-sticks (*Petrophile*), drumsticks (*Isopogon*) and casuarinas, with the seedbank only lasting as long as the adult plants remain alive. Other species in this group have transient soil seedbanks; these include daisies in the genera *Cassinia* and *Olearia*, and some eucalypts (including *Eucalyptus oreades*) and grasses, including species of *Deyeuxia* and *Eragrostis*.

The third group, known as ‘**resprouters**’, are also extremely common, both in the sclerophyll flora and in rainforests and wetlands. How tolerant resprouters are to repeated fires depends greatly on how they resprout. Many species revert to a juvenile stage and effectively have to start all over again. Species in this group include the sedges and rushes, bottlebrushes (*Callistemon*), tea-trees (*Leptospermum*) and paperbarks (*Melaleuca*). Other resprouters recover rapidly from a fire and are reproductively mature almost straight away – in fact fire may result in a flush of post-fire flowering as in grass-trees (*Xanthorrhoea*) and Christmas bells (*Blandfordia*). Most grasses and orchids also fall into this group. The third group of resprouters have adult plants that can resprout but juveniles that are killed by fire. Many eucalypts and other species in which adults have thick protective bark but juveniles have little protection fall into this group.

Tolerance to competition

Many native plants that grow in fire-prone vegetation such as dry sclerophyll forest or heathland are intolerant of competition and establish only after disturbance (which does not necessarily have to be fire). For many of these species the establishment of their seedlings is effectively cued to fire, and few plants can establish unless there is a fire. Many eucalypts and wattles fall into this category, such as messmate stringybark (*Eucalyptus obliqua*) and Sydney golden wattle (*Acacia longifolia*). Species in this group are often seen regenerating en masse after fire, but will also make use of other disturbances such as along freshly graded roadsides. The second group in this category consists of species that are tolerant of a wide range of conditions and establish both after and in-between disturbances. Examples of species using this strategy are *Pittosporum* and many *Pomaderris*. The final group in this category consists of species that can only establish in mature, undisturbed communities. Most rainforest species fall into this category. Plants in the first and third groups are sensitive to fire regimes – in the first case needing its disturbance to establish, and in the latter only being able to establish in its absence.

Time to reach critical life stages

Finally, how long a species takes to reach certain key stages in its life-cycle determines where it will occur in the successional sequence that follows a fire event as well, therefore, as how sensitive it will be to fire frequency. There are three vital life stages: (a) the time to reach reproductive maturity after a disturbance, (b) the lifespan of the adults of the species, and (c) the lifespan of the longest-lived seeds of the species.

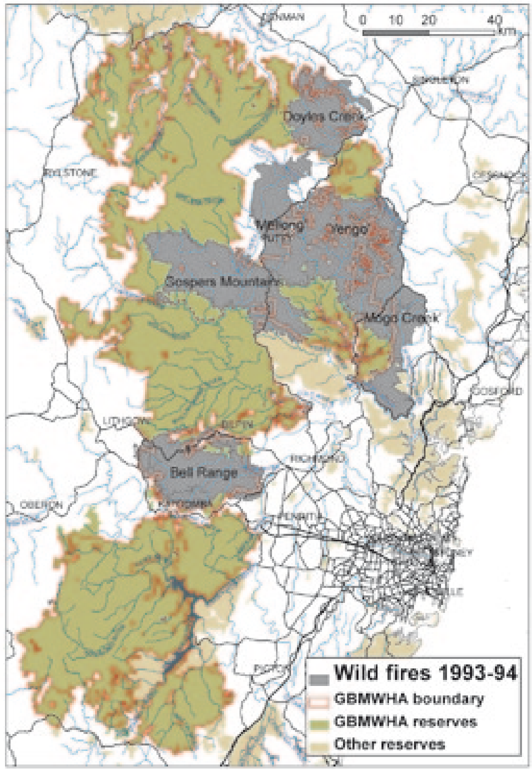
Patterns of fire in the Greater Blue Mountains

The four key drivers of bushfires are: (1) the rate at which fuel accumulates, (2) the rate at which fuel dries, (3) the occurrence of weather suitable for fires to spread, and (4) the presence of ignitions (Bradstock 2010). All four have to be present, and 'switched on' in order for landscape fires to occur. This 'four-switch' conceptual model can be used to consider likely impacts of climate change, as different switches are likely to be differentially sensitive

Major bushfires in the Greater Blue Mountains can burn day and night and for weeks on end, developing fire fronts many kilometres long and affecting many thousands of hectares. Photo: Ian Brown.

to climate change. By identifying which is the 'limiting' switch in any particular landscape, the sensitivity of that landscape to climate change may be able to be predicted.

In south-eastern Australia, the limiting switches are the occurrence of suitable fire weather[1] and ignitions[2]. Fuel quantity and its



availability to burn, that is its dryness, are generally not limiting since the sclerophyll forests and heathlands consist of abundant and largely continuous fuel, both as dead leaf litter and living vegetation, and both accumulate rapidly. The weather conditions that are associated with severe bushfire seasons in south-eastern Australia occur during El Niño-induced droughts. These allow the surface leaf litter, grasses and shrubs to dry to the point where they will readily burn (Cunningham 1984; NSW NPWS 2004). There are typically a couple of El Ninõ episodes in each decade and, consequently, there are often major fire seasons once or twice per decade (Cunningham 1984, Gill & Moore 1996, Bradstock & Gill 2001), although subsequent fires within a decade rarely burn through the same area (Figure 2).

In the Greater Blue Mountains, the link between weather and major fires is particularly apparent. While fuel and terrain do influence the behaviour and spread of fires, the weather on the day as well and in the preceding months or years is the overwhelming influence (Brad-

1 'Fire weather' is encapsulated in the Forest Fire Danger Index (FFDI; Noble et al, 1980). This index is used by fire-fighting agencies to monitor fire risk, schedule prescribed burning and declare Total Fire Ban days. It includes variables of daily temperature, rainfall, relative humidity and wind-speed. The FFDI categories are low (less than 5), moderate (5–12), high (12–24), very high (24–50), extreme (50–100) and – since 2010 - catastrophic (over 100). Very high, extreme, and catastrophic are the categories of most concern to fire-fighters, as this is when fires are more likely to become intense and uncontrollable.

2 The most common sources of ignitions in Blue Mountains National Park for the period from 1957–2003 were arson (35% of fires) and lightning (32% of fires). Dry lightning storms are common in the Blue Mountains in late spring and summer, and these can result in multiple ignitions in remote areas. Escaped campfires and burning-off account for a further 9% each of fire ignitions (NSW NPWS 2004).

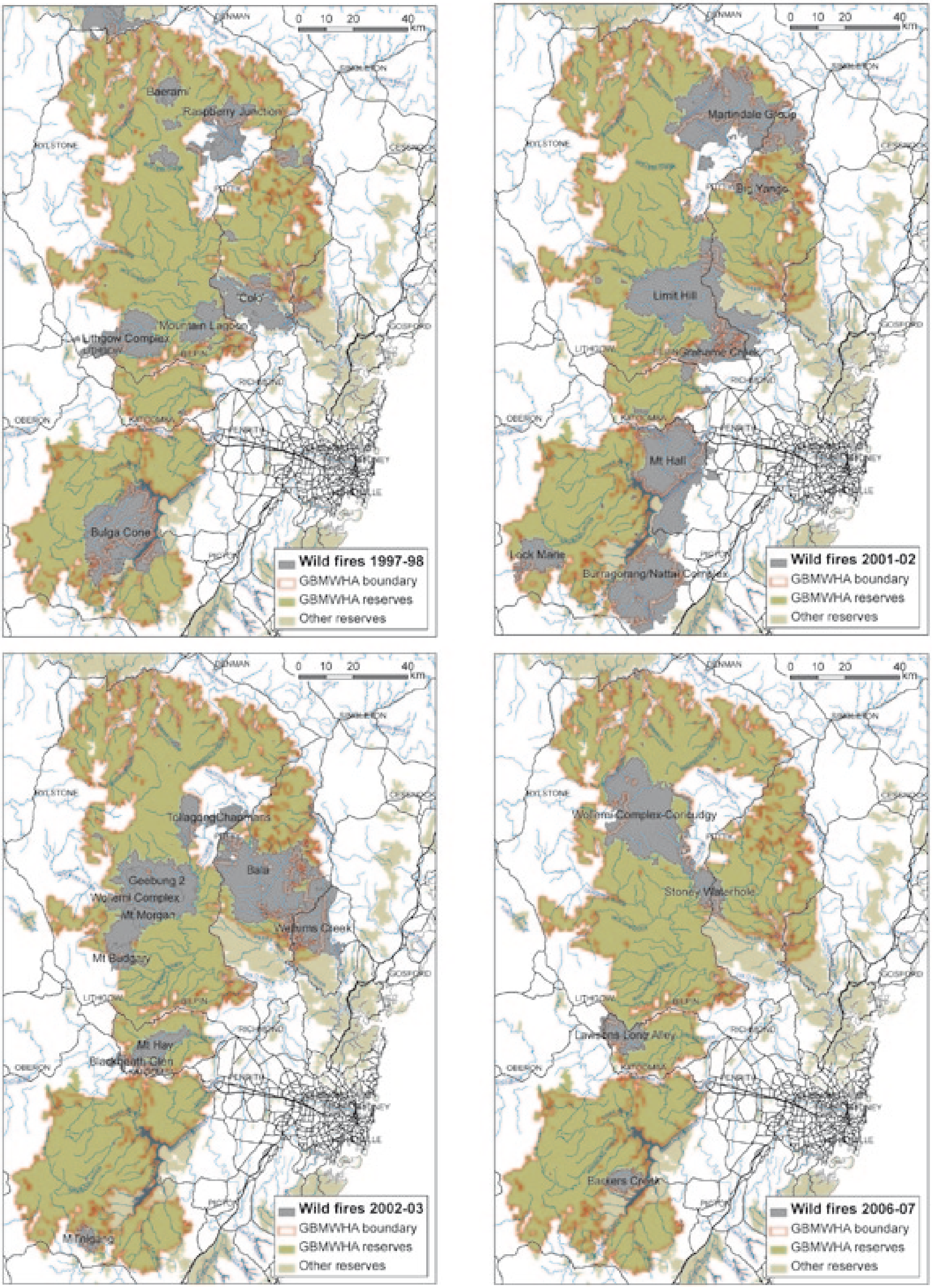


Figure 2. Extent of the major bushfires affecting the Greater Blue Mountains over the last two decades. These occurred during the summers of 1993-94, 1997-98, 2001-02, 2002-03 and 2006-07 and affected approximately 25%, 13%, 25%, 19% and 10% of the GBMWHA reserves, respectively. Notice that the fires in successive years did not burn the same areas; in fact, no more than two of these fires overlapped during this period, and then only in limited locations (in the Grose Valley, Yengo and central Wollemi). Many of these fires burnt not just for a few days, but for many weeks on end, and all were the subject of major fire response operations.

stock *et al.* 2009; 2010). In general, most fires occur from October to December, when conditions are driest and lightning storms most common. Many lightning ignitions occur in remote areas and during average or wet seasons, and most quickly self-extinguish or are put out by fire-fighters. In El Niño years, however, when rainfall is below average and the season has been preceded by drought, ignitions are more likely to continue to burn and, if hot, dry, windy conditions occur, spread rapidly. Severe fire-weather days in the Blue Mountains are associated with strong north-westerly to south-westerly winds, high temperatures and low humidity, and under these conditions fires are difficult to control (NSW NPWS 2004).

Differences in local weather and vegetation types associated with the significant altitudinal gradient within the Greater Blue Mountains – from close to sea level to approximately 1300 metres – also influence the occurrence of fire. Below about 600 metres, the average rainfall is less than 800 mm per year, average temperatures are relatively high and humidity often relatively low. Areas that fall into this category include the lower Blue Mountains, eastern and northern Wollemi, and Nattai and Yengo. In contrast, at elevations above 600 metres, the average rainfall is 1200–1400 mm, average temperatures are lower and humidity often higher. Areas in this category include the upper Blue Mountains, Kanangra-Boyd and western Wollemi. As a result of these differences, in the lower areas ignitions tend to develop into bushfires more often, the bushfire season is longer, and there are more days on which prescribed burns can be carried out (NSW NPWS 2004). This difference is reflected in the number and size of fires that have occurred over the years, which collectively have led to quite different patterns of fire frequencies across the region (Figure 3), with fire frequency generally decreasing with increasing altitude.

Fires in eucalypt forests are fuelled primarily by accumulated surface litter, however under adverse weather conditions the flames can burn into elevated shrub fuels, climb tree bark and, under extreme conditions, become a 'crown fire'. Photo: Ian Brown.

While weather is the overriding influence on fires in the Greater Blue Mountains, fuel and terrain also play a role. Large fires predominantly burn in the widespread eucalypt communities, and these accumulate significant quantities of fine litter and shrubs within 4–10 years of being burnt (Van Loon 1977; Birk & Bridges 1989). The shrubby structure of many of these vegetation communities provides vertical connections that can increase fire intensity under suitable weather conditions and allow flames to 'climb' into the tree canopy. Under extreme weather conditions, however, bushfires do burn through areas with very low fuel loads, even areas burnt just one or two years previously, albeit at lower intensities.

Terrain also affects fire behaviour. Rocky outcrops and escarpments may have very little fuel and can slow or impede the spread of fire. They themselves may often escape being burnt, with the fire passing around them. Fires travel faster, and are more intense and difficult to control when they are burning up a slope: the steeper the slope the more pronounced this pattern (all other factors being equal, i.e. provided the fuel is of a similar quantity and continuity). The steep terrain and closely spaced ridges of the Blue Mountains also create complex wind patterns that can facilitate spotting (burning strips of bark and leaves blown ahead of the fire front, sometimes many kilometres; NSW NPWS 2004).

In response to these many influences, fire behaviour during any one fire 'event' is highly variable, changing from place to place and from day to day. In turn, this creates complex patterns of fire severity across the landscape: no fire burns uniformly. A recent study (Hammill *et al.* 2010) which analysed satellite imagery captured after some of the major fires in the Greater Blue Mountains revealed how complex these patterns are (Figure 4).

When considered in combination with patterns of fire frequency and time since fire (Figure 5), it becomes apparent that there is a complex mosaic of different fire regimes across the landscape. This diversity of fire regimes is a major driver of the diversity of species and ecological communities in the Greater Blue Mountains World Heritage Area.

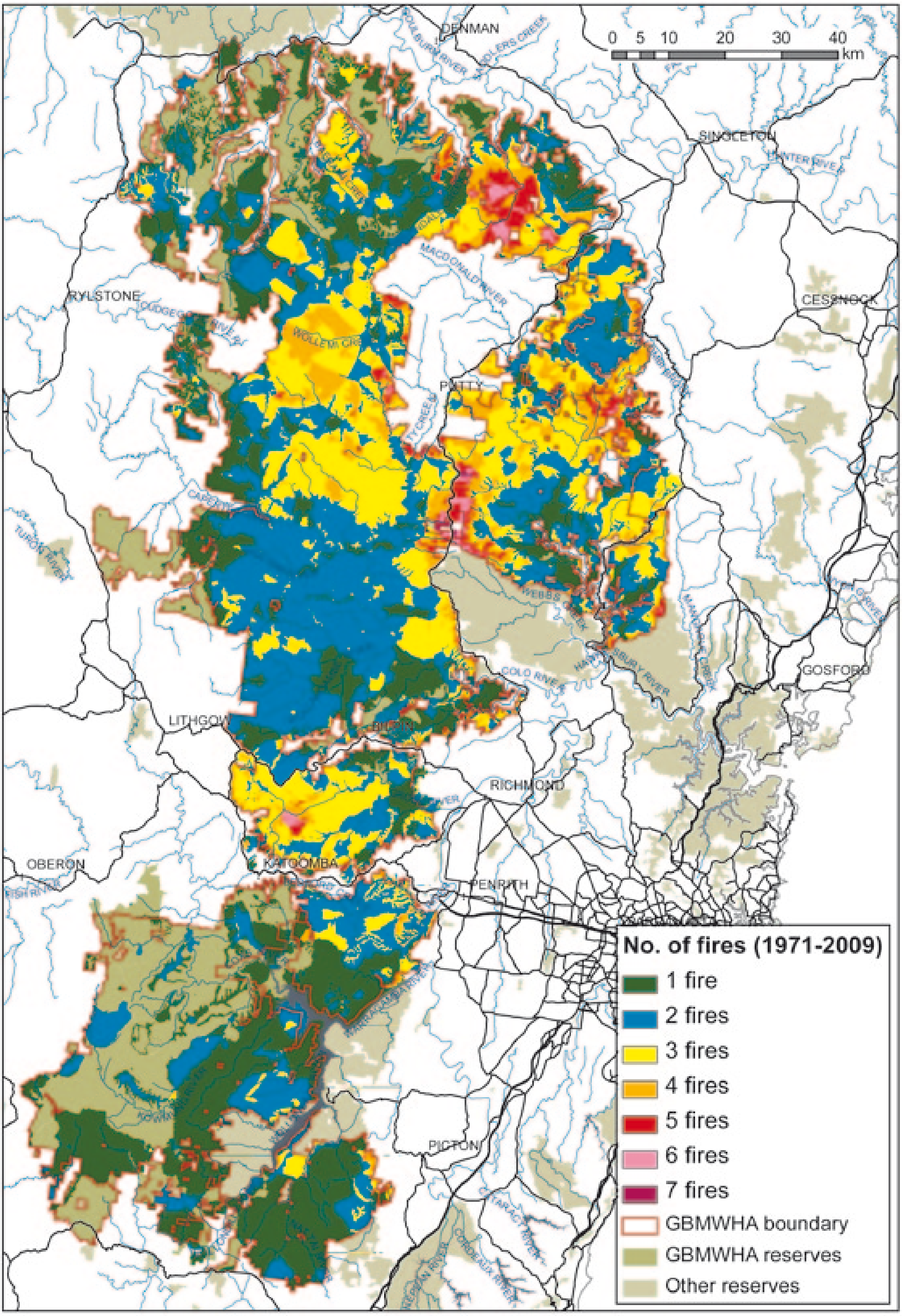


Figure 3. Number of fires affecting different parts of the Greater Blue Mountains during the last four decades. The number of fires from 1971 to 2009 varied from zero to seven, with few areas being affected by more than four fires. The highest fire frequencies occurred in parts of the upper Blue Mountains, eastern Wollemi and Yengo. Large areas in north-west Wollemi and the cool far south-west experienced no fires during this period.

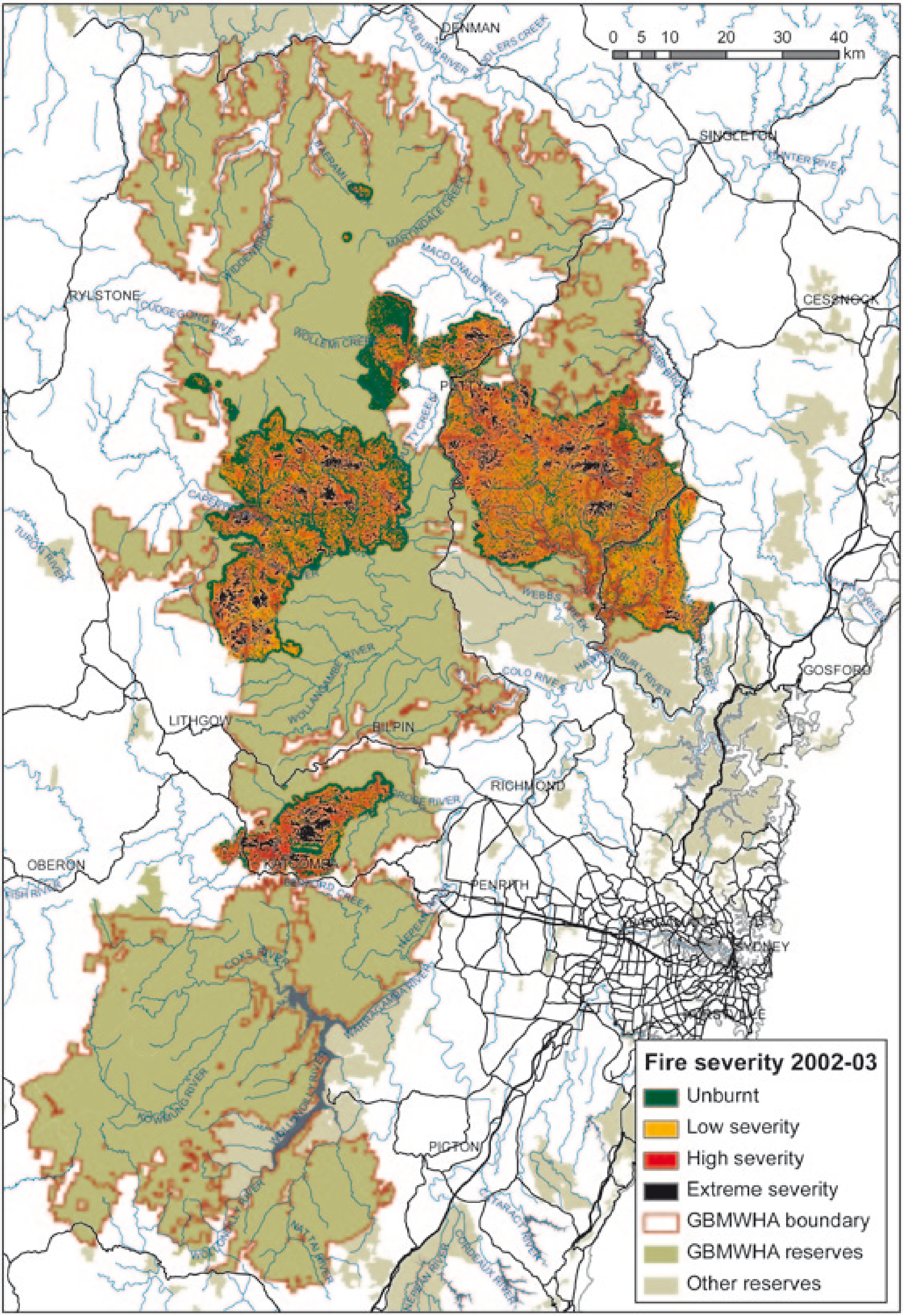


Figure 4. Severity patterns of the 2002-03 bushfires in the Greater Blue Mountains. This map is derived from an analysis of satellite imagery (Hammill *et al*. 2010) and reveals distinct patterns of different fire intensities, ranging from high intensity, crown-consuming fire ('extreme' severity), high intensity, crown-scorching fire ('high' severity) and lower intensity, understorey fire ('low' severity). These different levels of severity correspond mainly to changes in weather from day-to-day and variations in terrain from place-to-place, both of which strongly affect fire behaviour.

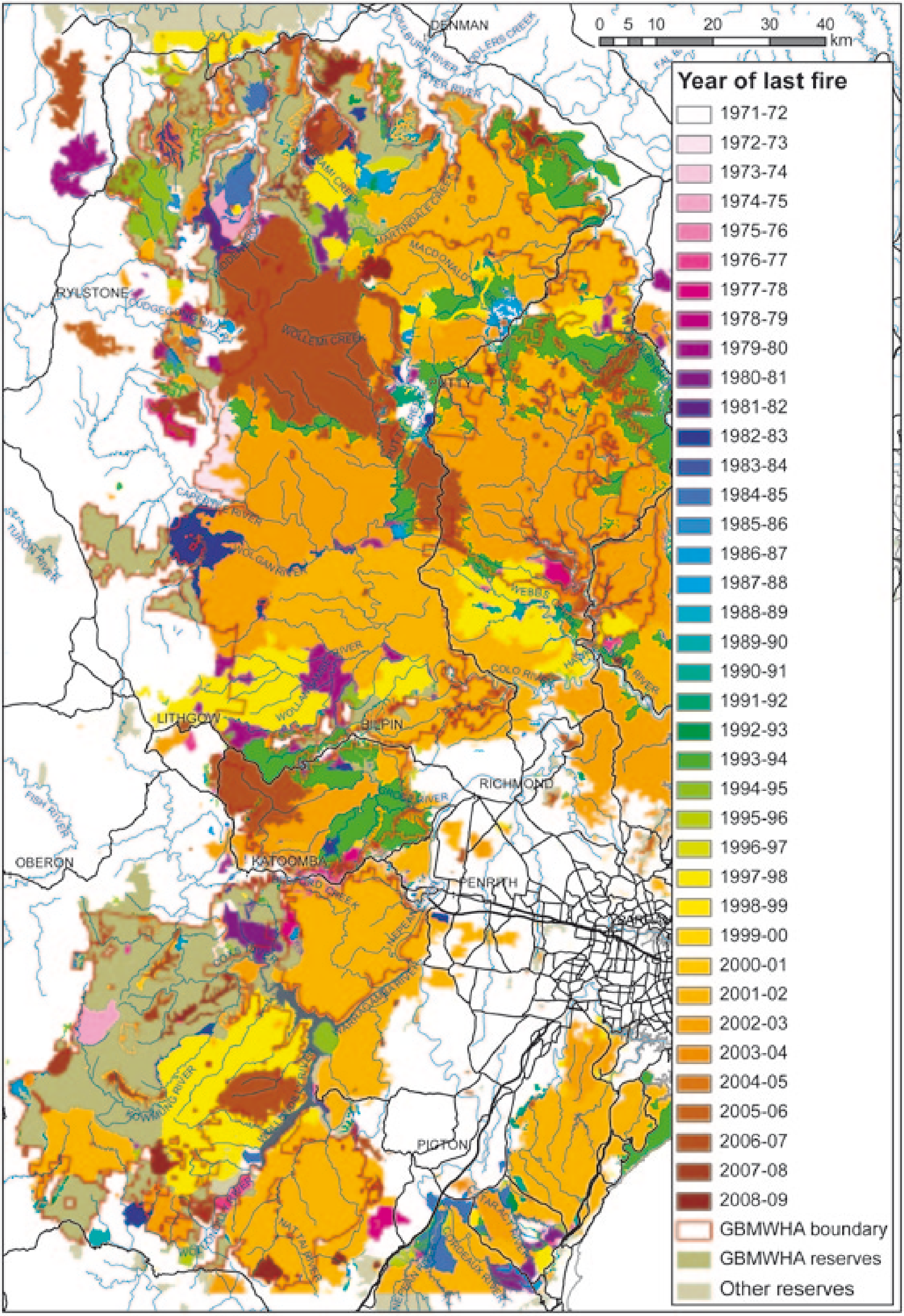


Figure 5. Year of the most recent fire affecting different parts of the Greater Blue Mountains region. A great proportion of the World Heritage Area has burnt within the last decade (yellow to dark red colours), while far smaller proportions were last burnt in the early 1990s (green), 1980s (blue) and 1970s (pink and purple). Note that some areas remain unburnt since 1971 (in the south-west and north-west).

Management of fire

Current fire management for biodiversity in the conservation reserves of NSW is based on a number of principles. The first is that **DECCW has multiple management responsibilities.** These are to: (a) protect life, property and community assets from the adverse impacts of fire; (b) develop and implement cooperative and coordinated fire management arrangements with other fire authorities, reserve neighbours and the community; (c) manage fire regimes within reserves to maintain and enhance biodiversity; (d) protect Aboriginal sites and places, historic places and culturally significant features known to exist within NSW from damage by fire; and (e) assist other fire agencies, land management authorities and landholders in developing fire management practices to conserve biodiversity and cultural heritage across the landscape. Since these different goals often require quite different fire regimes, the landscape is divided into management zones, in which different goals have priority.

Adjacent to human settlements and property, *Asset Protection Zones* are fuel-reduced areas, which may be highly modified, with much or most of the vegetation thinned or removed in order to reduce radiant heat during a fire, and to provide a defendable space that allows residents and fire-fighters to operate during and after the passage of the fire front (NSW RFS 2006; DECCW 2010a). The width of this zone varies depending on the asset to be protected, but it is usually no more than a few hundred metres. *Strategic Fire Advantage Zones* are larger areas intended to complement Asset Protection Zones, and to provide strategically located fuel-reduced areas that may allow fires to be more readily controlled. *Land Management Zones* usually cover the largest area, and are those parts of reserves that are not Asset Protection or Strategic Fire Advantage Zones. The primary aim in Land Management Zones is the maintenance of biodiversity. Nevertheless, fires in these areas are actively managed, and any ignitions that are thought likely to become a threat to either human life or property are extinguished. The fire regimes and fuel loads in these zones are highly variable. Full details of DECCW's fire management and planning approaches can be found in the *Fire Management Manual 2010* (DECCW 2010a). The remainder of this section focuses solely on the biodiversity aspects of fire management in conservation reserves, since a broader discussion is beyond the scope of this publication.

A low intensity prescribed burn. Photo: Pavel German.

Specially-trained NPWS fire fighters can rapidly respond to remote ignitions that are inaccessible by ground-based vehicles.. Photo: Michael Sharp/DECCW.

The second key principle is that **biodiversity conservation outcomes are determined by fire regimes, not single fire events**. In order to be able to 'see' fire regimes – and observe the ecological responses of plants and animals – they have to be mapped. While the post-fire age (i.e. the time since last fire) of a given patch of vegetation can often be estimated by visiting a site, the fire regimes are an 'invisible mosaic' (Bradstock et al. 2005, Gill et al. 2003) that can only be understood through compilation of spatial records of fires over time. By overlaying the maps of fire frequency, severity and time since fire, shown in Figures 3, 4 and 5, the complexity of the mosaic of different fire regimes across the World Heritage Area can begin to be grasped. Fire history maps are compiled and maintained for all national parks in NSW, and are used to provide baseline fire history data against which the response of plants

Table 1: Ecologically sustainable fire frequency guidelines for the major vegetation formations of New South Wales, from Kenny et al. (2004) *Guidelines for ecologically sustainable fire management*. See Table 2 at the end of this booklet for more details of the extent of each vegetation formation in the World Heritage Area.

Vegetation formation	Minimum interval	Maximum interval	Notes
Rainforest	n/a	n/a	Fire should be avoided
Alpine complex	n/a	n/a	Fire should be avoided
Saline wetland	n/a	n/a	Fire should be avoided
Wet sclerophyll forest (shrubby subformation)	25	60	Crown fires should be avoided in the lower end of the interval range
Wet sclerophyll forest (grassy subformation)	10	50	Crown fires should be avoided in the lower end of the interval range
Forested wetlands	7	35	
Grassy woodland	5	40	Minimum interval of 10 years should apply in the Southern Tablelands region
Dry sclerophyll forest (shrub/grass subformation)	5	50	
Dry sclerophyll forest (shrubby subformation)	7	30	
Semi-arid woodland	6	40	Insufficient data to give definite intervals. Available data indicates minimum intervals should be at least 5-10 years, and maximum intervals approximately 40 years
Arid & semi-arid shrubland	6	40	Insufficient data to give definite intervals. Available data indicates minimum intervals should be at least 5-6 years, and maximum intervals approximately 40 years. A minimum of 10-15 years should apply to communities containing Callitris. Fire should be avoided in Chenopod shrublands
Heathland	7	30	
Grassland	2	10	Some intervals greater than 7 years should be included in coastal areas. There was insufficient data to give a definite maximum interval; available evidence indicates maximum intervals should be approximately 10 years.
Freshwater wetland	6	35	

and animals can be measured and understood, to better understand where and how fires occur, and to improve the capacity of managers to be prepared, plan for and respond to fires.

The third key principle is that **species have limits of tolerance to different components of the fire regime**, and these can be identified and managed for. In NSW, state-wide guidelines have been developed which suggest appropriate upper and lower fire frequency thresholds for each of the twelve broad vegetation formations (see Table 1; Kenny *et al.* 2004). The thresholds are used in fire planning and management of native vegetation both in conservation reserves and on other land tenures where a Bush Fire Risk Management Plan is in place (see www.rfs.nsw.gov.au for more information). They are based on an analysis of significant life-cycle and fire response traits of plant species that typically occur in each of the vegetation formations, and in particular groups of plants that are most sensitive to very short or long fire intervals. This information is contained in a database of the fire responses of more than 2500 species.

The shortest inter-fire interval (highest fire frequency) suggested for a vegetation formation is based on estimates of the longest primary juvenile period (number of years to first flowering) for those species most sensitive to high-frequency fire. These are species in which the adult plants are killed by fire and which depend on seed reserves that are entirely depleted by a fire (see box 'Plant Functional Response Groups'). This group of plants are particularly vulnerable to being burnt before

Heath regenerating shortly after fire on Mt Banks, showing post-fire flowering of flannel flowers. Photo: Ian Brown.

they have had time to mature. Thus, if the shortest inter-fire interval is long enough to allow the survival of the species that are slowest to grow and flower, then other faster growing species should also be protected.

The longest inter-fire interval (lowest fire frequency) suggested for a vegetation formation is based on estimates of the life-span of those species most sensitive to low-frequency fire. These are species in which the establishment of seedlings is essentially dependent on fire (i.e. establishment is inhibited in unburnt conditions). Many species in this group have long-lived seedbanks, and for these species the life-span is that of the adults plus the seedbank. Local extinction of plants in this group may occur when the interval between fires exceeds the life-span of established plants and/or their seedbanks.

Further research is needed to identify thresholds of potential concern for the other components of fire regimes, such as season or intensity, and to refine the fire frequency thresholds for particular local species assemblages or environments. For example, in cooler areas and/or higher altitudes plant growth after fires may consistently take longer. Where better knowledge of actual responses is available, for example from monitoring, the generic thresholds can be modified to better suit the local conditions. A recent example of this is a study which suggests more comprehensive fire regime thresholds for several endangered ecological communities in the Blue Mountains Local Government Area (Keith 2010).

Broad-scale fire thresholds are also supplemented with targeted management for threatened species for which fire is of concern. The locations of these species are mapped in Reserve Fire Management Strategies (a fire-planning document prepared for all fire-prone conservation reserves in NSW), and are taken into account when fuel reduction or fire-fighting activities are being planned or implemented. However, it must be noted that the level of knowledge varies greatly between species, and for many little is known of their response to fire. Threatened species locations come from the NSW Wildlife Atlas (www.wildlifeatlas.nationalparks.nsw.gov.au), which in turn are sourced from scientific surveys, and records from amateur and public observations.

Levels of Vegetation Classification (adapted from Keith 2004)

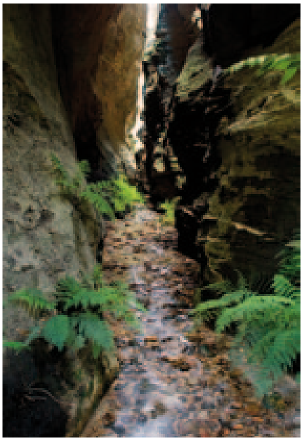
Plant communities are the most detailed and homogeneous units in the vegetation hierarchy. They are locally consistent assemblages of plant species that live together, generally at the same time. Countless plant communities occur across NSW, and are defined in many regional and local mapping studies. There are some 500 plant communities described to date in the Greater Blue Mountains World Heritage Area, a testament to the incredible diversity of vegetation.

Vegetation classes are groupings of related plant communities, defined mainly by overall floristic similarities (i.e. shared plant species), although they may also share structural and habitat characteristics. There are 99 vegetation classes recognised in NSW; some 28 of these can be found in the Greater Blue Mountains World Heritage Area. Each is assigned to a particular vegetation formation according to its most common structural form.

Vegetation formations are the uppermost level of the hierarchy of classification. They are broad groups distinguished by structural (e.g. height, total cover and vertical arrangement of plants) and physiognomic (e.g. growth form of the dominant taxa) features. There are 12 vegetation formations currently recognised in NSW: rainforests, wet sclerophyll forests, grassy woodlands, dry sclerophyll forests, heathlands, freshwater wetlands, forested wetlands, grasslands, alpine complex, saline wetlands, semi-arid woodlands and arid shrublands. Seven of these (all but the last five) occur in the Greater Blue Mountains World Heritage Area.

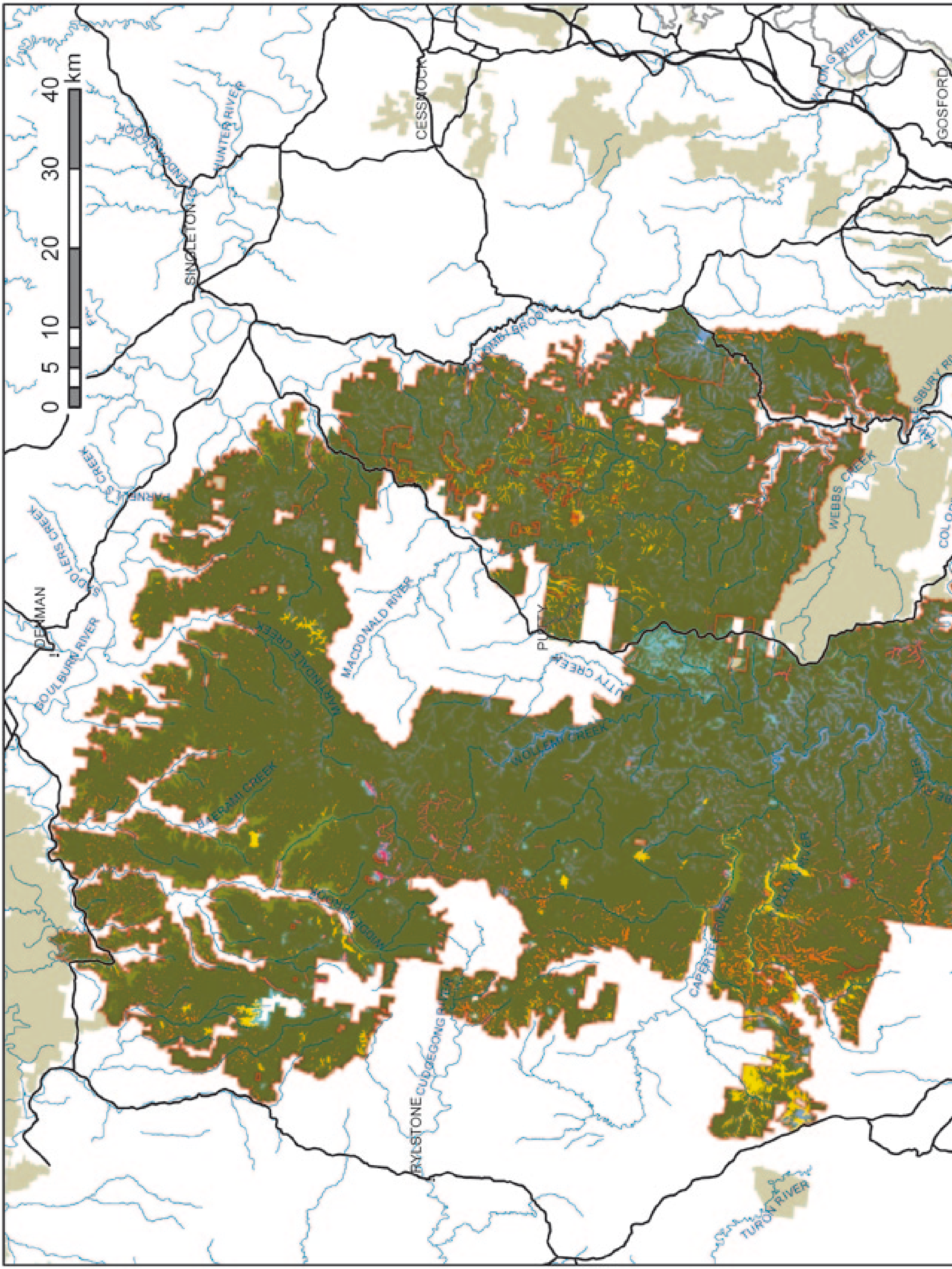
VEGETATION OF THE GREATER BLUE MOUNTAINS

The remote and rugged topography of much of the Greater Blue Mountains, together with its enormous biodiversity, has meant that despite its proximity to Sydney it is only now that we are getting to know the full diversity of its vegetation. DECCW has an ongoing vegetation mapping program for the World Heritage Area which, when complete will result in a complete coverage of detailed vegetation maps for the whole region. These maps describe the vegetation patterns at the level of 'plant communities': a term used in vegetation science to refer to locally consistent assemblages of plant species that can be defined, recognised and mapped (see box: 'Levels of vegetation classification'). When taken all together, regional maps may have many hundreds of mapped communities between them, reflecting subtle variations in their species composition across the landscape.



For a regional overview of vegetation patterns, it is more useful to group these communities into a coarser level of classification that also includes structural information, and has fewer categories. The state-wide classification system of Keith (2004), which identifies 99 vegetation 'classes' and 12 broad structural vegetation 'formations' into which the classes fit, provides a scheme that is used for many land management planning purposes in NSW, including fire management (described above). We have used the Keith (2004) scheme to group similar plant communities from the numerous local vegetation maps covering the Greater Blue Mountains region, and to compile an overall vegetation map for the entire World Heritage Area (Figure 6; Table 2). The following summaries of vegetation classes are based on those in *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT* (Keith 2004).

ABOVE: Deep canyons and gorges add to the diversity of habitats in the Blue Mountains: they also are home to species of plants and animals found nowhere else. Photo: Jaime Plaza van Roon. BELOW: Dissected plateaux showing the characteristic mosaics of different vegetation types, such as the transition from dry forest to heath to tall gully forests around Deanes Creek, south-western Wollemi. The Wolgan Valley and distant peaks of the Hunter Range appear beyond. Photo: Neil Stone/DECCW.


0
5
10
20
30
40
km
CESSNOCK
GOSFORD
SINGLETON
HUNTER RIVER
DENMAN
GOULBURN RIVER
MACDONALD RIVER
MARTINDALE CREEK
PUTTY CREEK
WOLLEMI CREEK
BAERAMI CREEK
WEBBS CREEK
CUDGEGONG RIVER
RYLSTONE
TURON RIVER

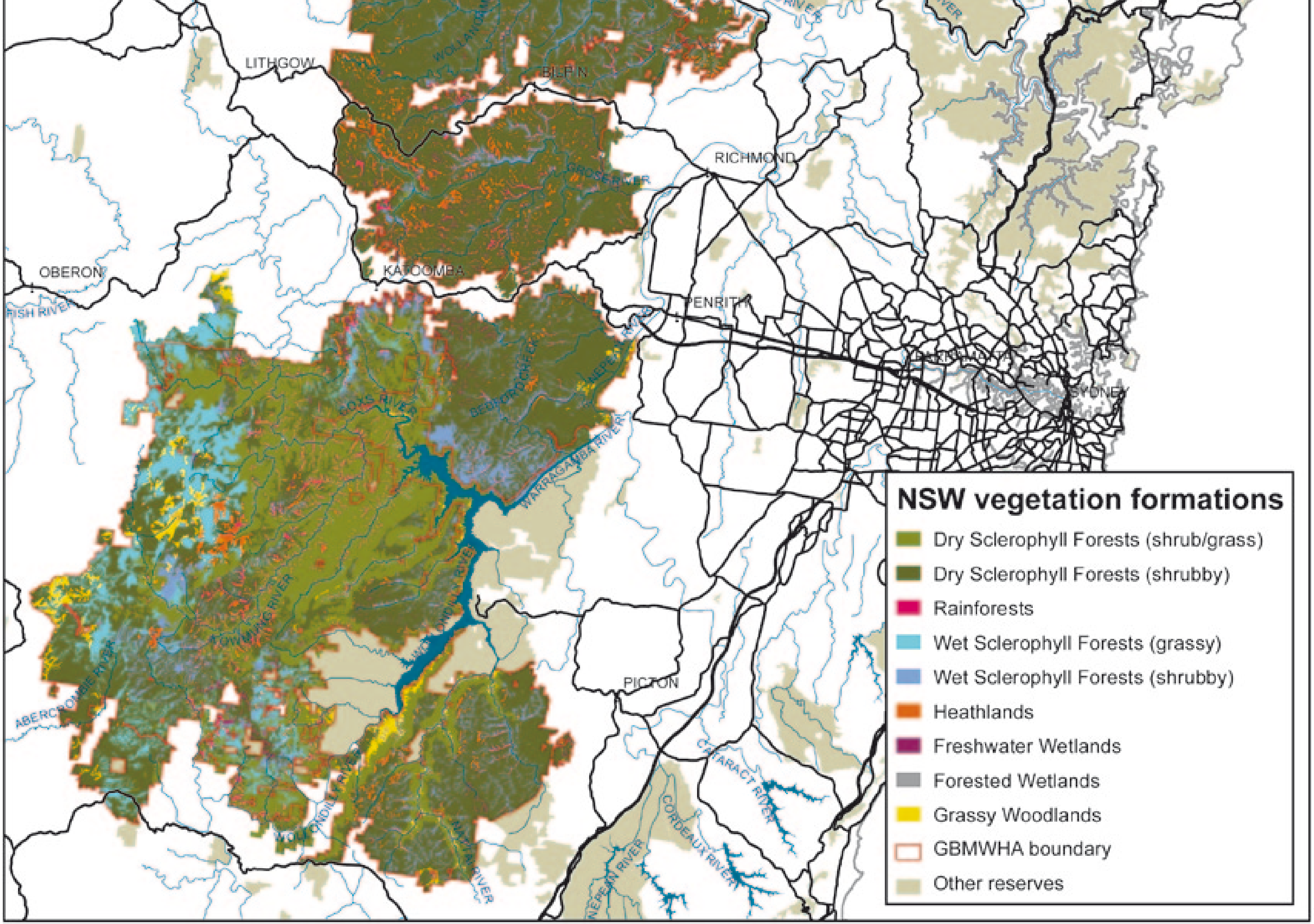


Figure 6. The distribution of NSW vegetation formations in the Greater Blue Mountains World Heritage Area. This map is derived from a compilation of a number of regional, local and individual reserve maps as listed in the further reading section at the end of the publication (see also Hammill et al. 2010). The proportional distribution of each formation in the GBMWHA are listed in Table 2 at the end of this book.

Dry Sclerophyll Forests

The dry sclerophyll forests of the Greater Blue Mountains are the most widespread of the ecosystems and contain much of its eucalypt diversity. These forests are the flammable matrix that carries fire across the landscape.

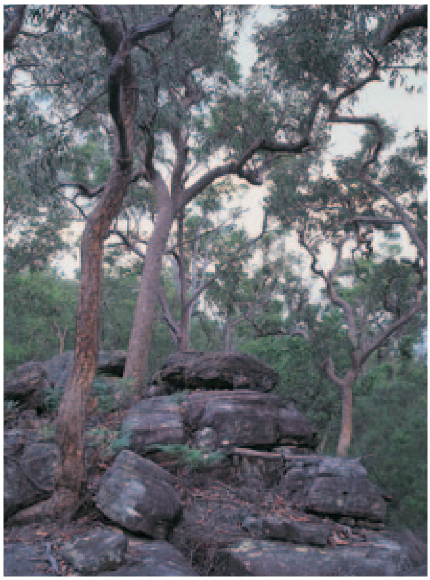
Dry sclerophyll forests occur across almost 85% of the Greater Blue Mountains. They dominate the exposed, low-nutrient soils of the vast sandstone plateaux and the valley slopes of the softer Permian geological deposits. Nine classes of dry sclerophyll forest occur in the Greater Blue Mountains; they vary greatly in composition, including in their canopy eucalypts, reflecting differences in the topography, soil and climate in the areas in which they are found. The seven classes with predominantly shrubby understoreys are found on silica-rich sandstone-derived soils, while a further two classes with a conspicuous presence of grasses and herbs in the understorey, in addition to shrubs, are found on marginally better soils.

Of the classes with predominantly shrubby understoreys, by far the most widespread are the **Sydney Hinterland Dry Sclerophyll Forests**. These forests dominate the sandstone slopes and ridges at low- to mid-elevations in the Greater Blue Mountains, in the coastal rainshadow (which generally receives less than 1000 mm per year) from northern Wollemi and Yengo through to Nattai National Park. Tree species that are particularly distinctive in these forests are yellow bloodwood (*Corymbia eximia*), scaly bark (*Eucalyptus squamosa*) and narrow-leaved apple (*Angophora bakeri*), which occur alongside numerous other common sandstone eucalypts.

Sydney Coastal Dry Sclerophyll Forests and **Sydney Montane Dry Sclerophyll Forests** also occur on the quartz-rich sandstone soils, replacing these hinterland forests in areas of higher rainfall (more than 1000 mm per year). The coastal forests are uncommon in the Greater Blue Mountains, being found only on the eastern fringe of Yengo National Park:

Grass trees and flowering shrubs of peas, tea-trees and wattles form a diverse understorey in many kinds of shrubby dry sclerophyll forests, including this rather sheltered spot in south-eastern Wollemi. Photo: Ian Brown.

they are more extensive nearer the coast. They are characterised by smooth-barked apple (*Angophora costata*), red bloodwood (*Corymbia gummifera*) and broad-leaved scribbly gum (*Eucalyptus haemastoma*), among other eucalypts, over a diverse understorey of sclerophyllous shrubs that are often taller and denser than in other dry sclerophyll forests in the region. The montane class is more extensive in the Greater Blue Mountains, occurring across large areas of the higher plateaux, generally between 750 and 1200 m above sea level, including around the towns of the upper Blue Mountains and on the Newnes Plateau. The striking forests dominated by Blue Mountains ash (*Eucalyptus oreades*), which occur in sheltered locations and on the precipices of the escarpment, are included in this montane class. Other characteristic species in these forests are the peppermints (*Eucalyptus piperita*, *E. dives* and *E. radiata*), silvertop ash (*Eucalyptus sieberi*) and stringybarks (including *Eucalyptus blaxlandii*).



Yellow bloodwood and rough-barked apples on rocky sandstone typify the Sydney Hinterland Dry Sclerophyll Forests. Photo: Rob Jung.

Sydney Sand Flats Dry Sclerophyll Forests also occur on nutrient poor, sandy soils, but are highly restricted within the Greater Blue Mountains where they are found in only one location – the alluvial white sand deposits at Mellong in the upper reaches of the Macdonald River.

In the rainshadow of the Great Dividing Range, three more classes of shrubby dry sclerophyll forests are found, all of which have their main distributions well beyond the Greater Blue Mountains to the south, west, and north of the state. In the high-altitude, south-western parts of the World Heritage Area, the **South East Dry Sclerophyll Forests** and **Southern Tableland Dry Sclerophyll Forests** are the predominant vegetation classes. Silvertop ash (*Eucalyptus sieberi*), broad-leaved peppermint (*Eucalyptus dives*) and Blaxland's stringybark (*Eucalyptus blaxlandii*) often dominate the former, while red stringybark (*Eucalyptus macrorhyncha*), scribbly gum (*Eucalyptus rossii*) and mountain gum (*Eucalyptus dalrympleana* subsp. *dalrympleana*) may dominate the latter. In the northern parts the **Western Slopes Dry Sclerophyll Forests** are restricted to small areas on the dry, lower slopes of the ranges in western Wollemi and Gardens of Stone national parks: they can be distinguished by the presence of ironbarks (*Eucalyptus sideroxylon*) and native pine (*Callitris*). Their main occurrence is further north-west.

Of the classes of dry sclerophyll forest with a mixed shrub/grass understorey in the Greater Blue Mountains, the **Central Gorge Dry Sclerophyll Forests** are the most widespread, occurring extensively on the steep slopes of the Cox's, Kowmung, and Wollondilly river valleys of the southern Blue Mountains, Kanangra and Nattai national parks. They are often characterised by forest red gum (*Eucalyptus tereticornis*), yellow box (*Eucalyptus melliodora*) and narrow-leaved ironbark (*Eucalyptus crebra*).

The **Hunter-Macleay Dry Sclerophyll Forests** are highly restricted, occurring in rain shadow areas on the footslopes of the ranges bordering the Hunter Valley in north-east Wollemi and Yengo. Typical trees are spotted gum (*Corymbia maculata*), narrow-leaved ironbark (*Eucalyptus crebra*) and turpentine (*Syncarpia glomulifera*).

WHY ARE THEY IMPORTANT?

The widespread flammable 'matrix' that drives fire regimes. Their widespread distribution and flammable plants make the dry sclerophyll forests a fire-prone, almost-continuous matrix that allows the spread of the major, landscape-scale fires so characteristic of the region. Other more restricted ecosystems, such as rainforests, heaths and swamps, occur as 'islands' embedded in this

ABOVE: This montane dry sclerophyll forest near Blackheath on a cool, misty day, shows the understorey of sclerophyll-leaved shrubs so typical of these forests. BELOW: The grassy understorey beneath the scribbly gums and grey gums in this dry sclerophyll forest near Capertee illustrates the diversity of this class. Photos: Ian Brown.

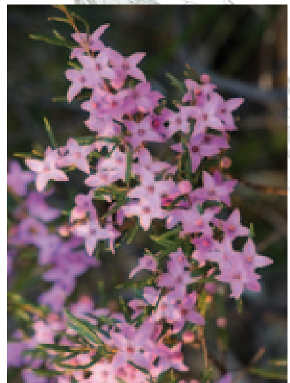
matrix. The fire regimes of the Greater Blue Mountains are largely determined by the characteristics of these forests in combination with weather and terrain. Surface fuel of leaves, bark, sticks and logs, and elevated fuel of shrubs and suspended litter, accumulate over time, and the vertical and horizontal arrangement and quantity of this fuel influences both the spread and intensity of the next fire (Whelan 1995). The regime of multiple fires over time influence the vegetation structure and composition of these forests, which in turn feeds back to influence subsequent fuel accumulation.

High sclerophyllous plant diversity. The dry sclerophyll forests of the Greater Blue Mountains represent some of the most diverse and intact sclerophyll forests in the world's temperate zone. Their high taxonomic and functional diversity are major reasons for the area being inscribed on the World Heritage Register. These forests are the stronghold of many iconic Australian wildflowers, including waratahs, banksias and grevilleas (family Proteaceae); wattles and peas (family Fabaceae); native fuschias (family Ericaceae); and boronias and wax flowers (family Rutaceae). This diversity is not uniform across the Greater Blue Mountains, but is correlated with climate and influenced by fire (Hammill & Bradstock 2008).

Major concentration of eucalypt diversity. Of the nearly one hundred different species of eucalypts in the Greater Blue Mountains World Heritage Area, most are found in the dry sclerophyll forests (see Table 3). These include most of the scribbly gums, stringybarks, grey gums, ashes, bloodwoods, peppermints and angophoras.

Important habitat for animals. These forests provide habitat for a diversity of fauna





LEFT: The beautiful Kowmung wattle (*Acacia clunies-rossii*) is a threatened species of the Central Gorge forests. Photo: Pavel German. MIDDLE: Waratah (*Telopea speciosissima*) and mountain ash (*Eucalyptus oreades*) in the Sydney Montane Dry Sclerophyll Forests. Photo: Jaime Plaza van Roon. RIGHT: Boronia are a delightful component of the understorey of many of the shrubby sandstone forests. Photo: Ian Brown. BELOW: Ironbark and native pine on the western side of the Great Dividing Range signal the influence of inland dry sclerophyll forest flora. Photo: Botanic Gardens Trust / Jaime Plaza.

including insects and other invertebrates, birds, bats and possums. Nectar-rich flowers from both eucalypts and the abundant shrubby understorey provide food for many fauna; large trees provide nesting sites for hollow-utilising species; and rocky outcrops embedded throughout these forests provide habitat for many reptiles including the rare broad-headed snake. These forests are also important habitat for many animals associated primarily with heaths, including the eastern pygmy possum, Rosenberg's goanna and the rock warbler, and most of the animals endemic to the Blue Mountains are found in the dry forests or heaths. Importantly, too, these vast forests are a major habitat connection to reserves to the north, south, east and west outside the Greater Blue Mountains, and are a significant part of the Great Eastern Ranges corridor.

Threatened species. With only a few exceptions, most of the threatened plants and animals of the World Heritage Area can be found in the dry sclerophyll forests, at least some of the time or in certain places (see Table 4). For some species, these forests are their main habitat, while for others, they provide seasonal foraging opportunities or secondary habitat of some kind. Of the many threatened species in the Greater Blue Mountains, only a relatively small number do not make use of the dry sclerophyll forests in some way.

Endangered ecological communities. Most types of dry sclerophyll forest in the Greater Blue Mountains are relatively widespread. However, one endangered ecological community that may occur on the northern fringes of Wollemi National Park is the *Hunter Valley Footslopes Slaty Gum Woodland*, a type of Western Slopes Dry Sclerophyll Forest.

Wet Sclerophyll Forests

The wet sclerophyll forests of the Greater Blue Mountains contain majestic stands of straight-trunked eucalypts towering above a lush, green understorey. These forests are restricted to sheltered slopes and gullies where deep soils provide the moisture and nutrients they need.

Wet sclerophyll forests occupy just over 6% of the Greater Blue Mountains landscape. They occur in areas of moderately fertile soil on sheltered slopes, in gullies and on alluvial flats, and may have either a mesic shrubby or grassy understorey. There are four classes of wet sclerophyll forests in the Greater Blue Mountains; they differ in canopy eucalypt and understorey composition and structure depending on the altitude, climate and soil. With increasing shelter, moisture or soil fertility these forests grade into rainforest and with decreasing shelter or moisture they grade into dry sclerophyll forests.

Majestic mountain blue gum (*Eucalyptus deanei*) tower well over forty metres in the iconic shrubby wet sclerophyll forests of the Grose Valley. Photo: Botanic Gardens Trust/Jaime Plaza.

The impressive blue gum (*Eucalyptus deanei*) forests of the Grose Valley, lower Blue Mountains diatremes (vents of ancient volcanoes now filled with weathered, volcanic rock), and alluvial flats (sometimes with Sydney blue gum, *Eucalyptus saligna*) along the eastern side of the Greater Blue Mountains fall within the shrubby **North Coast Wet Sclerophyll Forests** class. Large turpentine (*Syncarpia glomulifera*) trees feature in these forests, as do mesophyllous shrubs and small trees, which form a multi-layered understorey characteristic of the shrubby subformation. In the Greater Blue Mountains these forests are close to their southern limit; they occur more extensively along the central and north coasts of NSW.

Another shrubby class, the **Southern Escarpment Wet Sclerophyll Forests**, occurs on the higher ranges in the south-western part of the Greater Blue Mountains. These forests are found on moderately fertile soils derived from granite or basalt at altitudes where orographic rainfall and a cool climate provide the moist conditions they require. The canopy includes tall mountain gum (*Eucalyptus cypellocarpa*), brown barrel (*Eucalyptus fastigata*) and ribbon gum (*Eucalyptus viminalis*), which occur in mixed or pure stands, while the understorey includes mesic shrubs and ferns. These forests are found in Kanangra-Boyd National Park, but often lack large, old trees as much of this vegetation was heavily logged prior to reservation.

The **Northern Hinterland Wet Sclerophyll Forests**, one of the classes in the grassy subformations in the Greater Blue Mountains, are tall, semi-mesic forests dominated by grey gum (*Eucalyptus punctata*), ironbarks and turpentine. They are restricted to moderately fertile soils on the northern and eastern foothills of the ranges in Yengo National Park and on the top of the Lapstone monocline on shale-capped ridges. Due to their somewhat drier habitats, these forests do not support a fully developed mesic, shrubby understorey; instead they have a prominent ground cover of grasses with a mix of sclerophyllous and mesophyllous shrubs. They intergrade with the shrub/grass dry sclerophyll forests of the coastal valleys.

The **Southern Tableland Wet Sclerophyll Forests** are found at higher altitudes and are also characterised by a grassy, herbaceous understorey. These forests occur in high rainfall areas on moderate to high fertility soils of the tablelands, including areas in the south-western part of the Greater Blue Mountains. Small patches occur on the limestone around Jenolan. The majority of these forests that once occurred in the Oberon area have been cleared for pasture or pine plantations.

WHY ARE THEY IMPORTANT?

Refuge from fire. Wet sclerophyll forests, particularly the upper canopy, can remain unburnt during major fires, and this may provide a refuge for animals that have a low tolerance of fire, such as greater gliders (*Petauroides volans*). For classes in the shrubby subformation, their occurrence in protected situations and characteristic mesophyllous understorey makes them less flammable than the dry sclerophyll forests. The exception to this is during extreme droughts when high fuel loads, which may have accumulated over some decades without fire, pose a risk of high intensity fires. In contrast, classes in the grassy subformation tend to burn more frequently but at lower intensity – usually as surface fires in the grassy understorey – leaving the high eucalypt canopy and its fauna largely unaffected.

Vulnerable to intense and frequent fire. While the moist conditions in wet sclerophyll forests reduce the frequency of fires, the impact of fires when they do occur – particularly high intensity fire – can be far greater than in the dry sclerophyll forests. A number of the eucalypt species in these forests are 'weak' resprouters (e.g. mountain blue gum, *Eucalyptus deanei*; ribbon gum, *Eucalyptus viminalis*) or are killed by high intensity fire (Blue Mountains ash, *Eucalyptus oreades*; Hager and Benson, in press). When this occurs, the structure of these forests may take a considerable period to return to the pre-fire state. The structure of the understorey of these forests is also relatively sensitive, as although many mesophyllous shrub species can resprout after fire, they generally have thin bark (relative to the resprouting shrubs in the dry sclerophyll forests) and rely on basal tissues for regeneration. This sensitivity is reflected in the relatively long (25-year) minimum inter-fire interval suggested for the shrubby wet sclerophyll forests in the NSW fire frequency thresholds – which is longer than for any other vegetation formation in the Greater Blue Mountains (Table 1).

Concentration of iconic, large forest fauna. These tall forests are the primary habitat for the greater glider (*Petauroides volans*) and yellow-bellied glider (*Petaurus australis*), and Australia's largest forest owl, the powerful owl (*Ninox strenua*). The latter two species are listed as vulnerable species under the Threatened Species Conservation Act. The moist litter layer and dense cover of herbs, ferns, grasses and shrubs provide productive habitat for many ground-dwelling animals, including wombats (*Vombatus ursinus*), swamp wallabies (*Wallabia bicolor*) and the iconic superb lyrebird (*Menura novaehollandiae*).

Endangered ecological communities. The endangered *Blue Mountains Shale Cap Forest* is known to occur within the GBMWHA. Some other endangered communities may also occur in the WHA, but further work is needed to establish this. The *Sun Valley Cabbage Gum Forest* occurs in a single diatreme in the lower Blue Mountains; however it is outside the GBMWHA reserves.

ABOVE: Greater gliders (*Petauroides volans*) occur in both black and grey forms. Photo: Pavel German. BELOW: This gully protected by neighbouring cliffs on Newnes Plateau provides a sheltered site for this grassy forest. Photo: Ian Brown.

Rainforests

Rainforests of the Greater Blue Mountains contain the descendants of the lush forests that once covered the ancient super-continent of Gondwana. Today they occur only in isolated pockets, where moisture and steep terrain have ensured their protection through the ages from the extremes of drought and fire.

Rainforests occupy just over 1% of the Greater Blue Mountains landscape, and are confined to locations that are reliably moist, have moderate to high levels of soil nutrients and minimal exposure to fire. They can be identified by their closed canopy of relatively soft (i.e. non-sclerophyllous, or mesophyllous), horizontally held leaves and shade-tolerant, moist understorey characterised by ferns, herbs and vines. Rainforests usually merge with wet sclerophyll forests around their margin, as the frequency of exposure to fire increases and the reliability of soil moisture decreases. Three classes of rainforest occur in the Greater Blue Mountains.

The most extensive class is **Northern Warm Temperate Rainforests**, a verdant mix of coachwood (*Ceratopetalum apetalum*), lilly pilly (*Acmena smithii*), sassafras (*Doryphora sassafras*) and cedar wattle (*Acacia elata*) trees; tangled vines weaving up to the light; soft-leaved shrubs; and scattered ground ferns and herbs. Mosses, liverworts and lichens occur on tree trunks and the forest floor. These forests occur in small disjunct patches scattered across the protected lower slopes and creek lines of deep sandstone valleys – unique places that have long been protected from fire by escarpments, gorges and moist conditions. They are most common in relatively high rainfall areas (of Blue Mountains, Wollemi, and Kanangra-Boyd national parks) and less common in rain-shadow areas (Yengo and Nattai). Some sub-tropical elements can be found in this class, most notably in the rainforests around Mountain Lagoon where cabbage tree palm (*Livistona australis*), a species more commonly found closer to the

A deep gully sheltered by sandstone cliffs in Wollemi National Park is typical of places where Northern Warm Temperate Rainforests occur. From above, rainforest canopies appear a much brighter green and are denser, contrasting with the more open canopy of the surrounding eucalypt forests. Photo: Botanic Gardens Trust/Jaime Plaza.

ABOVE: The dimly-lit understorey of this warm temperate rainforest in a slot canyon in Wollemi National Park provides ideal conditions for ferns and treeferns. Photo: Jaime Plaza van Roon. BELOW: Rusty fig (*Ficus rubiginosa*) is an indicator of Dry Rainforests. Kanangra-Boyd National Park. Photo: Ian Brown.

coast, are prominent.

An intermediate form between Cool Temperate Rainforests and Northern Warm Temperate Rainforests is also prominent, occurring on highly localised, fertile, upper slopes of basalt-capped mountains, including Mounts Tomah and Wilson, and in the upper gorges of western Kanangra-Boyd National Park and Jenolan Karst Conservation Reserve. These places are characteristically cool and moist as a consequence of their high rainfall and often misty conditions. As with warm temperate rainforests, the canopy consists of coachwood (*Ceratopetalum apetalum*) and sassafras (*Doryphora sassafras*); however, it is the lush tree ferns and abundant mosses cloaking rocks and fallen logs that distinguish this intermediate form from other rainforests in the Blue Mountains. Adjoining wet sclerophyll forests are often dominated by imposing eucalypt giants such as brown-barrel (*Eucalyptus fastigata*) and mountain gum (*Eucalyptus cypellocarpa*).

Coachwood (*Ceratopetalum apetalum*; front) are common in the rainforests of the Greater Blue Mountains. Koombanda Creek, Blue Mountains National Park. Photo: Ian Brown.

The lesser-known **Dry Rainforests** occur where creek lines, rock outcrops or scree slopes provide localised protection and moderate soil nutrients in otherwise depauperate, rough terrain dominated by dry forests. Usually, there is a dense canopy of grey myrtle (*Backhousia myrtifolia*) interspersed with rusty fig (*Ficus rubiginosa*), mutton wood (*Rapanea variabilis*), native quince (*Alectryon subcinereus*) and species of *Pittosporum*. Emergents such as forest red gum (*Eucalyptus tereticornis*), grey gum (*Eucalyptus punctata*) and blue gum (*Eucalyptus deanei*) may also be present. It is the least diverse form of rainforest in the Blue Mountains, characterised by an often sparse shrub layer and ground cover of ferns, vines and herbs. Prominent areas of occurrence include the gorges of the Kowmung and Shoalhaven rivers, around the tributaries of the Hawkesbury River, and in protected rocky limestone pockets in Wollemi and Yengo. A rare form dominated by stinging tree (*Dendrocnide excelsa*) occurs on the steep basalt scree slopes of Mount Wareng and Mount Yengo. Another unusual, intermediate form occurs in a small number of deep

ABOVE: An intermediate form of Warm Temperate and Cool Temperate Rainforest grows at Mount Tomah. BOTTOM: The 'fossil' tree, wollemi pine (*Wollemia nobilis*), known only from a few isolated canyons in Wollemi National Park. Photos: Botanic Gardens Trust/Jaime Plaza.

sandstone gorges in north-west Wollemi, particularly around the headwaters of Widden Brook, where soils have been enriched by the basalts of Nullo Mountain: it contains sassafras (*Doryphora sassafras*), a species typical of Northern Warm Temperate Rainforests, and red cedar (*Toona ciliata*) and stinging tree (*Dendrocnide excelsa*), species that are more typical of Dry Rainforests in the Greater Blue Mountains.

WHY ARE THEY IMPORTANT?

Relics of ancient Gondwanan forests. Rainforests of the Greater Blue Mountains are possibly the best example world-wide of the juxtaposition of lush forests with ancestral links to Gondwana and the modern-day sclerophyll forests that have evolved since then under the influence of increasing climatic variability, drought and fire. This intriguing juxtaposition is one of the main reasons for the listing of the Greater Blue Mountains on the World Heritage Register. Rainforests once covered most of Australia, as well as much of South America, New Zealand, Antarctica and Africa, when all of these land masses were joined as the super-continent Gondwana. As these lands split apart and Australia drifted north, becoming increasingly warm, arid and fire-prone, the rainforests retreated into parts of the landscape that were buffered against these changes, and remain today, some 100 million years later.

Stronghold of moisture-dependent, primitive plants. The protected gullies in which rainforests occur provide a refuge for unique and primitive plants, such as crepe fern (*Leptopteris fraseri*), the rare Wollemi pine (*Wollemia nobilis*), and representatives from primitive angiosperm families including the Winteraceae (mountain pepper, *Tasmannia lanceolata*) and Lauraceae (*Cinnamomum, Cryptocarya, Endiandra, Litsea*). These spe-

Tangles of giant vines such as mountain silkpod (*Parsonia brownii*) characterise many types of rainforests, and often give them a mystical aura. Photo: Ian Brown.

cies cannot survive in the wider drought- and fire-prone landscape. The Wollemi pine is one of the rarest plants in the world, known from fewer than 100 individuals in the wild, it was known only from 120 million-year-old fossils prior to its discovery in a remote canyon of Wollemi National Park in 1994. It has since been the subject of an intensive conservation and propagation program, and is now widely available as a garden plant.

Disturbance-gap ecosystem dynamics. Rainforests differ from the other ecosystems in the Greater Blue Mountains in their reliance on 'disturbance-gap dynamics' for regeneration. Gaps in the canopy created when trees fall, allow light to reach the otherwise shaded forest floor and provide opportunities for seed germination and growth of new plants. Most other ecosystems in the Blue Mountains largely rely on periodic, major disturbance events, such as fire or above-average rainfall, to trigger the recruitment of new individuals into a population.

Refuges for fauna from drought and fire. Rainforests provide important habitat for various species: the fleshy rainforest fruits are eaten by flying-foxes, birds, mountain brushtail possums and satin bowerbirds, the thick and damp leaf litter and rotting logs are favoured by dusky antechinus, lyrebirds and primitive invertebrates. These rainforests also rarely burn, and it is likely that this would make them refuges during bushfires for species from the neighbouring dry sclerophyll forests. These rainforest refuges are relatively small in area, averaging around 2 hectares, although many patches are significantly larger (up to 200 hectares).

Threatened species. Small patches of dry rainforest in perched rocky areas and amongst limestone boulders in the Wolgan and Capertee valleys (among other places) are used by the endangered brush-tailed rock wallaby (*Petrogale penicillata*), a species whose range and numbers have been dramatically reduced by hunting and fox predation. These locations are characterised by rusty fig (*Ficus rubiginosa*), bird's-nest fern (*Asplenium australasicum*), tangled vines and many other mesic shrubs and trees, providing habitat attributes that contrast markedly with the surrounding dry sclerophyll, talus-slope forests. Warm temperate rainforests are the main habitat for the endangered plants, magenta lilly pilly (*Syzygium paniculatum*) and white-flowered wax plant (*Cynanchum elegans*).

Endangered ecological communities. *Western Sydney Dry Rainforest*, which occurs in the Hawkesbury area, including Grose Vale, is likely to occur in various places in the lower Blue Mountains within the GBMWHA reserves.

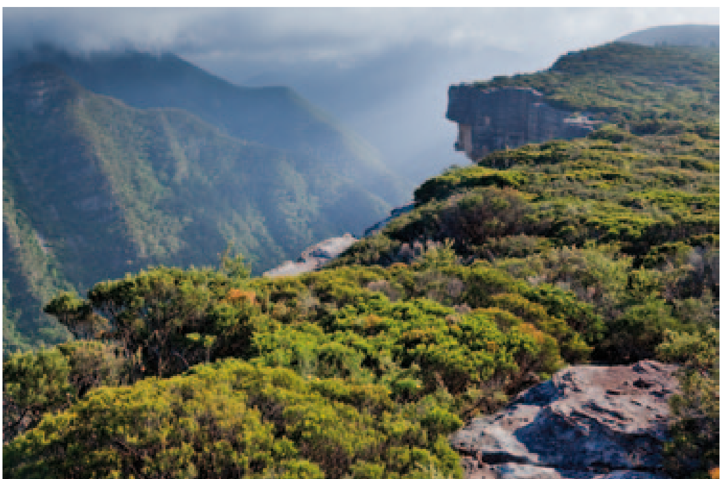
Satin bowerbirds (*Ptilonorhynchus violaceus*) are often found in rainforests, where they feed on soft fruits such as lilly pilly (*Acmena*) and native grape (*Cissus*). Only adult males are blue-black in colour. Photo: Pavel German.

Heathlands

The heathlands of the Greater Blue Mountains are tough-leaved, shrubby plant communities that survive on exposed ridge tops in shallow, nutrient-poor soils. Complex ecological relationships between the heathland plants, fauna and fire, and their scattered distribution in the landscape, have led to high biodiversity.

Heathlands are shrubby, largely treeless communities that occur in just under 2% of the Greater Blue Mountains. They are restricted to shallow, nutrient-poor, sandy soils on rock benches in exposed situations, usually ridge tops. They merge into dry sclerophyll forests in less exposed situations with deeper soil and into upland swamps where moisture is greater. Two classes of heathlands occur in the Greater Blue Mountains, with altitude being the determining factor for which occurs where.

Sydney Coastal Heaths occur on the lower sandstone plateaux in the eastern part of the Greater Blue Mountains (as well as nearer the coast around Sydney), where they occupy shallow, moderately damp soils, mainly on ridge tops. They contain a rich array of sclerophyllous shrubs and an equally rich complement of sedges and herbs. Many patches are relatively small (on average, 4 hectares), and occur on and around rock platforms on exposed sandstone ridge tops jutting above the forests. They occur mainly in Blue Mountains, Nattai and southern Wollemi national parks, and less commonly in Yengo National Park, probably due to conditions there being drier.



Exposed Sydney Montane Heaths atop the spectacular Kanangra Walls, Boyd Plateau with abundant *Boronia* and *Isopogon,* showing just how tolerant heaths are of marginal conditions. Photo: Jaime Plaza van Roon

Sydney Montane Heaths replace the coastal heaths above altitudes of about 600 m. In the Greater Blue Mountains, they are far more extensive, occurring in scattered locations across the high plateaux from western Wollemi through to the tablelands of Kanangra-Boyd National Park. They are prominent on the panoramic ridges of the upper mountains as well as on the spectacular pagodas of Gardens of Stone and western Wollemi. Patches of these heathlands are often small, averaging 3 hectares, although there is considerable variation above and below this size.

WHY ARE THEY IMPORTANT?

Heathlands epitomise the sclerophyllous flora of the region. Their plants have small, tough, pointed leaves with thick cuticles and a high fibre (lignin) content. As with the dry sclerophyll forests, the heathlands are a stronghold for the iconic flowering plant families, particularly the Proteaceae, Fabaceae, Myrtaceae, Ericaceae and Rutaceae. However, they also have a significant number of species from the Restionaceae (rushes) and Cyperaceae (sedges) families, which are not so common in the dry sclerophyll forests.

Fire-dependent communities. Heathlands are highly fire-prone, and many of their plant species are dependent on fire. Consequently, the composition and structure of heathland communities are dynamic in response to fire, both over time and from place to place. In particular, older or less frequently burnt heaths often have dense thickets of the dominant woody shrubs, while younger or frequently burnt heaths are more open and floristically diverse (due to post-fire germination of many species that lie dormant as seeds in the soil for long periods between fires). These differences in the composition and structure of heaths of different post-fire age in turn provide important habitat variation for many heath-dwelling animals, which may need both dense thickets for nesting and diverse nectar resources for foraging.

Stronghold of the mallee eucalypts. Other than a rare emergent tree, the only eucalypts that occur in heathland communities are mallees. These curious, multi-stemmed eucalypts are typically only three or four metres tall at the most; they resprout after fire from a basal lignotuber and, unlike the taller eucalypts, are able to survive the harsh heathland environment. The scattered distribution of the heath patches across the mountains and their long isolation from each other has contributed to the evolution of the numerous mallee species, many of which do not overlap in their distribution (see box: Eucalypt Diversity in the Blue Mountains).

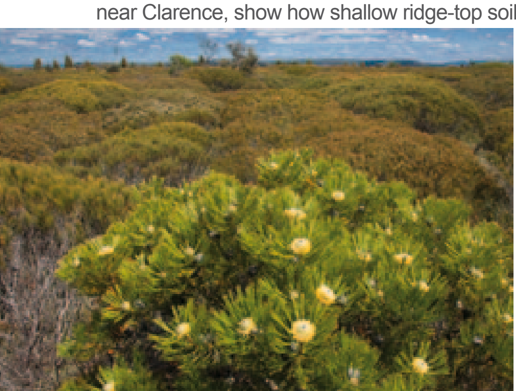
The low, open stature of this heath with dagger hakea, *Actinotus minor*, and an abundance of sedges indicate a fairly recent fire. The Grose Valley and Mount Banks are in the background. Photo: Ian Brown.

Rich habitat for nectivores. Heathlands grow in conditions where nutrients are scarce but sunshine is not, and this has led to most plants economising on leaf production (which requires nutrients including nitrogen and phosphorus) while being prolific nectar producers (which uses sugars produced by photosynthesis). This attracts a diversity of nectivorous (nectar-feeding) birds – particularly honeyeaters – as well as insects and small mammals such as blossom bats and the eastern pygmy possum. Dense thickets of nectar-producing heathland shrubs that flower in winter, such as the heath banksia (*Banksia ericifolia*) and hair-pin banksia (*Banksia spinulosa*) provide critical food resources for nectivorous animals at a time when little else is flowering. This makes heathlands a linchpin in the regional ecology of many nectar-feeding animals.

Threatened species. Some examples of the threatened species that are often found in heath vegetation (but are not necessarily restricted to it) include, *Kunzea camagei*, an endangered shrub from the family Myrtaceae, which is found in montane areas; the southern brown bandicoot (eastern) (*Isoodon obesulus obesulus*), which prefers dense, shrubby vegetation; and the eastern pygmy-possum (*Cercartetus nanus*), which has a close dependency on banksias.

Endangered ecological communities. There are no endangered heathlands within the GBMWHA; however, the endangered *Genowlan Point Allocasuarina nana Heathland* occurs on crown land in the Capertee Valley (Genowlan Mountain) just outside the Greater Blue Mountains reserves.

BELOW LEFT: This heath at Genowlan Point dominated by dwarf she-oak (*Allocasuarina nana*), interspersed with other shrubs, including broad-leaf drumsticks (*Isopogon anemonifolius*) and *Callitris muelleri*, is an endangered ecological community. Photo: Ian Brown. MIDDLE: Eastern pygmy possums (*Cercartetus nanus*) are dependent on flowering shrubs in the family Proteaceae. Photo: Pavel German. BELOW RIGHT: Montane heaths in the spectacular pagoda country of Newnes Plateau near Clarence, show how shallow ridge-top soils support heaths while the deeper soils below have forests. Photo: Ian Brown.



Freshwater Wetlands

The freshwater wetlands of the Greater Blue Mountains include the upland swamps on waterlogged soils in the higher rainfall parts of the sandstone plateaux, and occasional reedlands in more permanent standing water at lower altitudes.

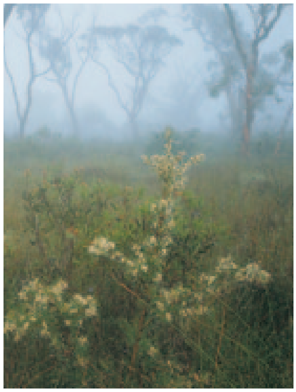
Freshwater wetlands are diverse, usually treeless habitats that occur in areas that are either permanently or temporarily inundated by water, or permanently or temporarily waterlogged. They occupy less than 0.5% of the Greater Blue Mountains World Heritage Area and include sedge- and shrub-swamps on poorly drained, sandy peat soils of the plateaux, and the reedlands and aquatic herbfields along the major waterways. Intricate mosaics of different plant communities often occur within these wetlands in response to slight differences in water levels and soil moisture, and in response to varying fire regimes.

The eucalypts of the surrounding woodlands cannot cope with the waterlogged soils, but sedges thrive in the upland swamps. Kanagra-Boyd National Park. Photo: Ian Brown.

Coastal Heath Swamps are generally restricted to altitudes below 600 m in the Sydney region; however, in the Blue Mountains higher altitude examples of this swamp type are found in the headwaters of creeks on the sandstone plateaux (with most occurring above 500 m in altitude) in areas of relatively high rainfall (~1000 mm or more per year). They are visually prominent, often lush, patches of bright green vegetation scattered amongst the surrounding dry sclerophyll forests. Their often spongy, sandy-peat, low-nutrient soils support dense swards of grass-like plants such as button grass (*Gymnoschoenus sphaerocephalus*) and sword-sedge (various species of *Lepidosperma*), herbs such as sundew (*Drosera*) and coral fern (*Gleichenia*), and a variable layer of small and large sclerophyllous shrubs such as *Callistemon citrinus*, coral heath (*Epacris microphylla*), hairpin banksia (*Banksia ericifolia*), dagger hakea (*Hakea teretifolia*) and various tea trees (*Leptospermum* species). Many of these swamps occur on steeper valley sides in association with groundwater seepage and are known as hanging swamps. Examples of this vegetation can be seen along Bells Line of Road, on the Kings Tableland and in the Mount Hay area. These swamps frequently occur around the edges of townships scattered along the Great Western Highway in the upper Blue Mountains. The prominent swamps on the Newnes Plateau (many of which are outside the World Heritage Area) are often considered to be an intermediate form between this coastal class and the Montane Bogs and Fens.

Similar poorly drained locations at the highest altitudes in the Greater Blue Mountains, up to about 1300 m above sea level, support **Montane Bogs and Fens**. The cool climate, low evaporation rates and impeded run-off in these habitats allow the development of deep, low-nutrient, peaty soils, some of which contain Sphagnum moss. They also feature dense swards of sedges and grasses, with various low growing herbs, and there may be scattered, or occasionally dense, groves of emergent sclerophyllous shrubs such as grey tea tree (*Leptospermum myrtifolium*), alpine bottlebrush (*Callistemon piyoides*), mountain baeckea (*Baeckea utilis*) and *Boronia deanei*. Occasionally, snow gums and other trees may occur within these bogs. The most extensive examples can be seen on the Boyd Plateau in Kanangra Boyd National Park and around Mt Werong to the south.

Coastal Freshwater Lagoons are complexes of aquatic plants that occur in or adjacent to standing water in floodplain lagoons and lakes. They generally have higher nutrient conditions than the upland wetlands described above, and contain dynamic mosaics of sedges and aquatic and floating herbs that vary with the rise and fall of the water level; these include *Eleocharis sphacelata*, twig-rushes (*Baumea* species), duckweed (*Lemna disperma*) and frogmouth (*Phylidrum lanuginosum*). In some situations, low forests of paperbarks (which fall within the Forested Wetlands formation) occur in conjunction with these wetlands. They are uncommon in the Greater Blue Mountains and are largely restricted to the lakes at Thirlmere. Small, unmapped occurrences are also likely to occur along major waterways on the eastern side of the ranges, such as in Glenbrook Creek and the lower reaches of the Macdonald River.



WHY ARE THEY IMPORTANT?

Unique, moisture-dependent habitats. The upland swamps and reedlands of the Greater Blue Mountains are unique assemblages of moisture-dependent plants and animals that occur in a landscape otherwise dominated by dry sclerophyll forests. The swamps, in particular, have a high floristic diversity and are important, moist habitat 'islands' within the broader dry sclerophyll forest landscape.

Disjunct habitat 'islands'. These swamps occur naturally in small, disjunct patches which are only about two hectares in size on average. Species that live in the swamps are therefore also isolated and must be able to survive major disturbance events such as fire. Disturbances like fire can render these species highly vulnerable, especially those with limited ability to disperse or tolerate periodically dry conditions. These wetlands provide habitat for specialised swamp animals such as burrowing crayfish, frogs, giant dragonflies and swamp rats.

Regulate water flows in the landscape. Swamps play a vital role in maintaining water flows in the creeks and canyons below them by absorbing peak flows, storing water in their deep, sandy-peat soils and gradually releasing it during dry periods.

Threatened species. A number of threatened fauna species depend on these swamps, including the giant dragonfly (*Petalura gigantea*), whose underground burrowing larval stage is dependent on adequate groundwater levels, and the Blue Mountains water skink (*Eulamprus leuraensis*). Many other animals such as swamp wallabies and wombats visit from the surrounding forests to take advantage of the food resources and perennial water. The endangered Blue Mountains pine (*Pherosphaera* (previously *Microstrobos*) *fitzgeraldii*) is found in very restricted locations on some wet cliffs in the upper Blue Mountains (around Wentworth Falls and Katoomba).

Endangered ecological communities. Both the Coastal Heath Swamps and the Montane Bogs and Fens of the Greater Blue Mountains include three ecological communities listed under the NSW Threatened Species Conservation Act. These are the *Blue Mountains Swamps*, the *Montane Peatlands and Swamps* and the *Newnes Plateau Shrub Swamp*. The Coastal Heath Swamps on sandstone are also recognised under the federal Environment Protection and Biodiversity Conservation Act 1999 as the endangered ecological community, *Temperate Highland Peat Swamps on Sandstone* (see Table 2). In addition, the wetlands at Thirlmere may fall within the endangered communities *Sydney Freshwater Wetlands* and/or *Freshwater Wetlands on Coastal Floodplains*.

ABOVE: Many swamps are small patches embedded in dry sclerophyll forests. BELOW: Aquatic habitats are rare in the World Heritage Area, and include the serene Lake Couridjah, Thirlmere Lakes National Park. Photos: Ian Brown..

Forested Wetlands

The forested wetlands of the Blue Mountains occur mostly as narrow strips of river oak along larger rivers and creeks. Some areas of coastal floodplain forest remain at lower elevations in the east, where the fertile alluvial soils support small remnants of apple-gum woodlands.

Forested wetlands, also known as swamp sclerophyll forests, are freshwater wetlands dominated by trees. They occur across just 0.5% of the Greater Blue Mountains on the fertile alluvial clays and sandy loams of the larger river valleys. These habitats are structurally similar to other forests in that they are dominated by sclerophyllous trees; however, their understorey is distinctive, being comprised of plants that are able to survive periodic inundation. Two classes of forested wetlands are found in the Greater Blue Mountains. Both occur as very narrow, linear strips along watercourses and their ecology is driven by flooding events.

Coastal Floodplain Wetlands occur on rich, alluvial soils in the eastern parts of the Greater Blue Mountains, where creeks and rivers reach low lying terrain on the edge of the coastal plain. Alluvial flats and elevated terraces along these creeks and rivers support forests of rough-barked apple (*Angophora floribunda*), cabbage gum (*Eucalyptus amplifolia*), and forest red gum (*Eucalyptus tereticornis*), with an understorey of sedges, grasses, herbs and scattered mesophyllous shrubs. Where they extend further upstream, these wetland forests include the narrow strips of prickly-leaved tea tree (*Melaleuca styphelioides*) growing in the alluvial soils in places such as the upper Grose River.

Eastern Riverine Forests occur along major, fast-flowing rivers where they can be easily recognised by the presence of a single dominant tree species, river oak (*Casuarina cunninghamiana*), which can grow to a grand

Stately river oak (*Casuarina cunninghamiana*) are found in narrow belts along the major watercourses of the Greater Blue Mountains, and coast and ranges of NSW, and are the sole dominant tree species in this vegetation class. Photo: Ian Brown.

The larger watercourses of the World Heritage Area, such as Kanangra Creek, provide welcome relief for bush walkers with their cool, flowing waters as well as opportunities to spot platypus (*Ornithorhynchus anatinus*). Photo: Jaime Plaza.

size. The typical habitat of these forests is the sandy, cobble-stone river margins, which are subject to periodic flooding. In the Greater Blue Mountains, these forests occur most prominently in the western parts of the region, along the Cox, Kowmung, Wolgan and Capertee rivers.

WHY ARE THEY IMPORTANT?

Maintain river bank stability. Many of these forests support large, old trees that play a vital role in stabilising the sediments along the margins of the rivers and creeks on which they occur. This is particularly so for the Eastern Riverine Forests, where the roots of massive river oaks can be seen tangled amongst the stones, often holding them in place.

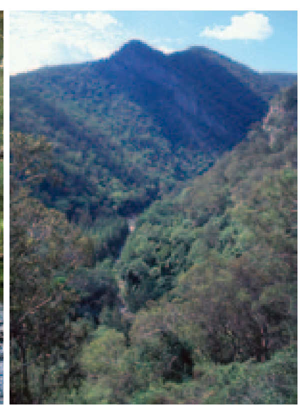
Rich riverine habitats. The floodplain forests are particularly fertile, occurring on the nutrient-rich, fine, alluvial soils. In the wider landscape outside the Greater Blue Mountains reserves, many of these habitats have been cleared for agriculture, especially the Coastal Floodplain Wetlands. Where they remain intact, however, they are characterised by particularly large, hollow-bearing trees which supply important shelter, nesting sites and seasonal food resources for animals, particularly the rough-barked apple (*Angophora floribunda*), which flowers profusely.

Important wildlife corridors. The intact nature of these riverine forests in the Greater Blue Mountains means that they provide important wildlife corridors, spanning the ranges and linking the coastal, hinterland, tableland and western-slopes landscapes from east to west and north to south. Their continuity along the major rivers and abundant resources mean that they are likely to be important routes used by wildlife to move around the landscape.

Threatened species. Two threatened eucalypts occur in forested wetland communities on alluvial soils in the GBMWHA: *Eucalyptus benthamii*, which is restricted to the lower Hawkesbury-Nepean catchment (Blue Mountains and Nattai national parks), and *Eucalyptus aggregata*, which is restricted to water-logged soils in the western Blue Mountains.

Endangered ecological communities. *River-flat Eucalypt Forest on Coastal Floodplains* is like to occur in a number of places at low elevation along the major rivers in the eastern part of Blue Mountains National Park.

BELOW LEFT: The eucalypt-dominated coastal floodplain forests have been extensively cleared throughout their range, and many of the remnants are highly disturbed and often grazed by livestock, as a consequence of their fertile alluvial soils and abundant grassy understorey. They are listed as an endangered ecological community. Photo: DECCW. MIDDLE: River-oaks cope with periodic, rushing flood waters and their roots serve to help stabilise the banks. Photo: Botanic Gardens Trust/Jaime Plaza. RIGHT: The Eastern Riverine Forests, such as this one along the Cox's River, provide important wildlife corridors through the rugged landscapes of the World Heritage Area. Photo: Ian Brown.



Grassy Woodlands

Grassy woodlands occupy only a small part of the Greater Blue Mountains World Heritage Area, but their preference for rich fertile soils and their decimation through clearing elsewhere in the state makes them particularly important for the conservation of threatened ecological communities and species.

Relative to the widespread shrubby forests on sandstone, the grassy woodlands are fringe communities in the Greater Blue Mountains. They occupy just over 2% of the landscape, occurring at both low and high altitudes on deeper soils of moderate to high fertility derived from shales and granites. They occupy the rain shadows of both the coast and ranges. They have a diverse understorey of grasses and herbs, few shrubs, and their trees are often well-spaced. Canopy species include various box, red gum and ironbark eucalypts and, at high altitudes, species from the ash group of eucalypts. There are five classes of grassy woodland in the Greater Blue Mountains, each with quite limited occurrence.

The **Coastal Valley Grassy Woodlands** in the Greater Blue Mountains occur at low altitudes in the valleys of the Wollondilly and Nattai Rivers and on the fringes of the Hunter Valley and Cumberland Plain. These locations are in the coastal rain shadow. Tall trees of forest red gum (*Eucalyptus tereticornis*) are characteristic of these woodlands, as are rough-barked apple (*Angophora floribunda*) and narrow-leaved ironbark (*Eucalyptus crebra*).


Subalpine woodlands occur in cool, high-altitude parts of the World Heritage Area, and have a canopy of snow gums (*Eucalyptus pauciflora*) and mountain gums (*E. dalrympleana*) over a grassy understorey. Photo: Jaime Plaza van Roon.

Subalpine Woodlands are found at the other end of the altitudinal spectrum, in the coldest parts of the Greater Blue Mountains, including on the Boyd Plateau and near Mount Werong in the southern part of Blue Mountains National Park. These woodlands are somewhat shorter than the coastal valley grassy woodlands. The main canopy species are snow gum (*Eucalyptus pauciflora*) and mountain gum (*Eucalyptus dalrympleana*). The ground cover is dominated by the large tussock grass *Poa sieberiana*.

Tableland Clay Grassy Woodlands also occur at high altitudes; however, they are restricted to the richer soils derived from basalt. These woodlands support tall trees of mountain gum (*Eucalyptus dalrympleana*), ribbon gum (*Eucalyptus viminalis*), yellow box (*Eucalyptus melliodora*) and blackwood (*Acacia melanoxylon*). In the Greater Blue Mountains, these woodlands are highly restricted, but they are more widespread elsewhere in NSW, occurring extensively on the Northern and Southern Tablelands. Examples can be found in the vicinity of Mount Werong and Wombeyan Caves.

At lower altitudes, these subalpine and high-tableland woodlands are replaced by **Southern Tableland Grassy Woodlands** and **Western Slopes Grassy Woodlands**. The former grow on loamy soils in the rain shadow of the escarpment in the south-western part of the Greater Blue Mountains, south of Oberon. In the Greater Blue Mountains, the most prominent examples are the upper reaches of the Abercrombie River where the canopy species are mainly broad-leaved peppermint (*Eucalyptus dives*) and apple box (*Eucalyptus bridgesiana*). The latter occur in similar rain shadows north of Lithgow, including in the valleys of the Wolgan and Capertee Rivers and across northern Wollemi, where white box (*Eucalyptus albens*) and yellow box (*Euca-*

lyptus melliodora) become prominent. Both these classes of grassy woodland are at the eastern-most limit of their range in the Greater Blue Mountains, and are more common west of the ranges.

WHY ARE THEY IMPORTANT?

A contrasting ecosystem. Grassy woodlands are unusual in the Greater Blue Mountains as a consequence of their markedly open, grassy understorey and fertile, loamy soils. These attributes, which differ markedly from the surrounding wet and dry sclerophyll forests of the ranges and plateaux, provide habitat for a range of fauna that rarely venture into the shrubby sandstone forests. Prominent among these are seed-eating birds that forage in the grassy ground layer, large grazing mammals, including the grey kangaroo (*Macropus giganteus*) and red-necked wallaby (*Macropus rufogriseus*); and large carnivorous birds, including the nocturnal barn owl (*Tyto alba*) and the diurnal raptors brown falcon (*Falco berigora*) and Australian kestrel (*Falco cenchroides*), which prefer open country. Nectar-feeding birds, such as honeyeaters, and mammals, such as flying foxes (*Pteropus* species), the squirrel glider (*Petaurus norfolcensis*) and feather-tailed glider (*Acrobates pygmaeus*) also make use of the superabundant seasonal flowering of the box eucalypts in these woodlands.

Links with the western ecosystems. The grassy woodlands on the western side of the Greater Blue Mountains represent the meeting of eastern and western ecosystems. Components of the grassy woodland flora and fauna that occur more widely across the tablelands and western slopes of NSW intersect with the sandstone ecosystems of the Sydney Basin along river valleys on the western side of the Greater Blue Mountains.

Threatened species. The grassy woodlands of the Blue Mountains are critically important habitat for the endangered regent honeyeater (*Xanthomyza phrygia*). This species is mostly found in the dry box ironbark open-forest and woodland on the western slopes of the Great Dividing Range, a vegetation type that has been largely cleared for agriculture, leading to the perilous decline of this species. It is associated with forests with copious and reliable nectar-producing trees such as mugga ironbark (*Eucalyptus sideroxylon*), white box (*Eucalyptus albens*), yellow box (*Eucalyptus melliodora*), and Blakely's red gum (*Eucalyptus blakelyi*; Higgins *et al*. 2001). The woodlands of the Capertee Valley are the most important breeding site in Australia for the regent honeyeater.

Endangered ecological communities. Due to their fertile soils and easily accessible terrain, much of the vast original extent of the grassy woodlands was long ago cleared for agriculture, including areas throughout the Sydney Basin, on the tablelands and western slopes. Consequently, grassy woodlands are amongst the least conserved of any native vegetation in NSW and most of the remaining types are recognised as endangered ecological communities. In the Greater Blue Mountains these include *Shale/Sandstone Transition Forest* in the lower mountains and *White Box Yellow Box Blakely's Red Gum Woodland* in the southern and western valleys.

ABOVE: Grassy woodlands are critical habitat for the endangered regent honeyeater. Photo: Chris Tzaros. BELOW: An understorey of grasses and herbs, and a canopy of box eucalypts characterise the grassy woodlands. Photo: Ian Brown.

CLIMATE CHANGE

Climate Change and Fire Regimes

Recent climate change modelling for NSW for temperature and rainfall (DECCW 2010b) downscales the widely used global models from their 300 x 300 km resolution (i.e. the smallest area of land the models can recognise, and which they treat as a homogenous unit) to a 50 x 50 km resolution. This scale is more appropriate for considering regional rather than global changes; however, for the east coast and ranges of NSW (including the Greater Blue Mountains) where there are large variations in elevation, topography and local weather within a 2 500 km^2 area, projections from these models are best treated with caution. The models project that average temperatures for the Sydney region will increase by 1.5 ºC to 3 ºC (for both average minimum and maximum temperatures in all seasons) by 2050 (DECCW 2010b). They are less confident, however, in their projections of rainfall. For Katoomba, the current projections indicate that average summer rainfall may increase (by 20–50%), while average winter rainfall may decrease (by 10–20%). Due to the warmer temperatures, evaporation rates are expected to increase in spring and summer by 10–20%.

The global-scale climate models have also been used to predict how the frequency of dangerous fire weather may change in the future in Australia (Hennessy *et al.* 2006). Using the projected changes in temperature and rainfall, the modelling suggests that by 2020 there may be 2–3 extra days per year in the very high to extreme forest fire danger index categories (region-wide), and by 2050 there may be 3–6 extra days in these categories for Sydney and 6–8 days for Richmond (Hennessy *et al.* 2006). The current average (for the period 1974–2003) is 8.7 days per year in Sydney and 11.5 per year in Richmond, hence these predicted changes equate to a 20–40% increase in very high to extreme weather days by 2020 and a 35–70% increase by 2050. These models also project that high-risk fire weather will, on average, start earlier in the year, in September (rather than October, as currently), extending the fire season.

Changes in the seasonal distribution of rainfall, humidity, wind speed and direction could all significantly alter these projected outcomes, but the models are not yet able to simulate such complex situations.

Indirect effects of climate change on fire regimes are also possible as a result of climate-related changes to vegetation (i.e. fuel loads, their rates of accumulation and their distribution); however, these effects are likely to be complex and in some instances counteractive (Williams *et al.* 2009). Increased CO_2 may enhance plant growth through an effect known as 'CO_2–fertilisation', while reduced rainfall may have the opposite effect on plant growth. Drier conditions may make the fuel more available to burn. This has led some researchers (Bradstock *et al.* 2008; Bradstock 2010) to suggest that there may be an initial increase in fire incidence in the future, as warmer and drier conditions lead to more fires, but that this will be followed by an overall decrease as vegetation biomass (fuel) accumulates more slowly as a result of conditions leading to reduced plant growth.

Determining how all of these effects and interactions may play out over the next few decades presents a considerable challenge, and any modelling research that seeks to do this must deal with many uncertainties and assumptions. A relevant recent study (Bradstock et al 2008) used the results of the fire-weather modelling of Hennessy *et al.* (2006) to explore how certain aspects of fire regimes in the Greater Sydney region may be affected by the changes in temperature and humidity. Process-based computer simulations were used to translate projected changes in fire weather into changes in the total area burnt and frequency of fires in the region. The results of the study indicate that, by 2050, the average area burnt annually by bushfires in the Sydney region could increase by up to 35%, the average interval between fires could decrease by up to 25%, and the probability of high intensity crown fire could increase by 20–25%. However, these projections did not take into account changes to other factors that influence fire activity, particularly rate and patterns of ignitions or fuel. A sensitivity analysis done as part of the same study indicated that if a 10% decline in fuel accumulation occurred this would reduce the annual area burned by 20%, which would cancel out most of the increase in area burnt due to the modelled changes in weather.

The levels of uncertainty and complexity, including the potential for both positive and negative feedback, mean that these kinds of models are not able to make explicit forecasts (Bradstock *et al.* 2008). Nevertheless, any major changes in climate are likely to have a significant impact on regions such as the Greater Blue Mountains, where fire regimes are largely climate/weather-driven.

In the following section, we explore some of the possible consequences of climate change and fire regimes for the biodiversity of the Greater Blue Mountains. The process of identifying particular sensitivities of the biota, can be useful to suggest where management, monitoring and research efforts might be most productive.

Broad-scale Responses of Vegetation

Differences in the composition of the widespread sandstone sclerophyll vegetation communities along current-day climate gradients in the Greater Sydney region provide some clues as to how these communities may be affected by climate change (Hammill & Bradstock 2008). In general, obligate seeder species (i.e. those in which adults are killed by fire and the species relies on seeds for regeneration) are more prominent in the heaths and dry sclerophyll forests in warmer, higher rainfall parts of the Sydney region, such as Brisbane Water National Park (immediately adjacent to the Greater Blue Mountains). Such conditions appear to provide fast-growing seeder species, such as *Banksia ericifolia*, with a competitive advantage and more reliable germination conditions. This suggests that increasing temperatures could favour dominant seeder shrubs in general, particularly if rainfall does not decrease.

LEFT: NPWS fire-fighters light a back-burn (i.e. a fire started intentionally along the inner edge of a fire line to consume the fuel in the path of a bushfire) to reinforce the fire-break provided by the road. Photo: Chris Banffy. BELOW: Large bushfires in the Greater Blue Mountains region are strongly weather-driven, but fuel and topography also play a role. Photo: Chris Banffy.

However, these seeder species are more sensitive to short intervals between fires, compared to species that can resprout. Since projected fire regime changes indicate that fire intervals, on average, could become up to 25% shorter (Bradstock *et al.* 2008), this could have a negative effect on these species. Obligate seeder species with seedbanks that are completely exhausted by a fire have a critical requirement for a minimum interval between fires (see box: 'Plant Functional Response Groups' and Table 1). While intervals shorter than this are currently quite rare in the Greater Blue Mountains World Heritage Area, they may become more common in the future. Thus for these seeder species, the relative strength of these two opposing responses; a positive effect on their growth due to warmer temperatures and a negative effect on populations due to increasing fire frequencies, will both affect the outcome.

Recent studies focussing on the Greater Sydney region have sought to explore these kinds of effects on the overall risk to vegetation in general (Bradstock *et al.* 2008) and on the composition of the dry sclerophyll forests in particular (Hammill & Bradstock 2008). In the first study, the risk of extinction/loss of fire interval-sensitive biodiversity resulting from predicted changes to fire regimes was investigated. Based on the modelling approach used, it found that fire frequencies are unlikely to become adverse for the sclerophyll communities at the landscape-scale (i.e. greater than 50% of the landscape remained within the recommended range of fire intervals for sclerophyll communities). However, the study did not take into account the potential for locally adverse effects on threatened species and vegetation communities that require longer inter-fire-intervals (including the wet sclerophyll forests). The second study was a field-based research project which collected detailed floristic data at sites affected by different fire frequencies over the preceding four decades. Although there was considerable variability in the results depending on location, there was some evidence that higher fire frequencies (in this case, four fires in 37 years) were associated with the presence of more resprouters in the understorey. Resprouting shrubs and herbs, including grasses

The kangaroo grass in this lower Blue Mountains woodland is a summer growing ('C-4') grass, and could be favoured by increased CO_2. Photo: Liz Tasker.

and sedges, are more likely to be tolerant to high fire frequencies and could become more abundant in place of the seeders if fire frequencies increase.

One group of plants for which the role of climatic niches, and hence potential vulnerability to climate change, are better studied are the eucalypts. The incredible diversity of eucalypts in the Greater Blue Mountains is partially a consequence of their adaptation and specialisation to different climate and habitat niches (Hager and Benson, in press). The niche specificity of eucalypts has been demonstrated most recently in an Australia-wide study of 819 *Eucalyptus* species (Hughes *et al.* 1996), which showed that 41% of species occupy a mean annual temperature range of less than 2 ºC. A further 25% occupy a range of less than 1 ºC. While actual climate tolerances of eucalypts may be greater than the range they currently occupy (which would allow them to adapt *in situ*), some shifts in their distributions may be expected as temperatures change. In general, species that are widely distributed, both in elevation and topographically, are likely to be most resilient. A good example is silvertop ash (*Eucalyptus sieberi*), which can occur as a tall forest tree on protected slopes or a short multi-stemmed tree on exposed ridges, and grows from sea level to more than 1000 m (Boland *et al.* 1994). In contrast, eucalypts that are likely to be more vulnerable are those with highly restricted distributions or that are more sensitive to fire: for example, the Faulconbridge mallee ash (*Eucalyptus burgessiana*), which is found on only a few rocky ridges in the lower Blue Mountains; the mountain swamp gum (*Euca-*

lyptus camphora), which is restricted to waterlogged soil; the Blue Mountains ash (*Eucalyptus oreades*), which is killed by intense fire; and the mountain blue gum (*Eucalyptus deanei*), which resprouts only weakly if burnt by an intense fire. Another sensitive group are eucalypts that are under stresses from other causes, such as bell-miner associated dieback or nutrient pollution (e.g. *Eucalyptus benthamii*).

Climate change may lead to other broad-scale changes in vegetation. For example, higher levels of CO_2 in the atmosphere can increase plant biomass production and favour resprouters (Hoffmann *et al.* 2000), although the effects of CO_2 enrichment are limited by soil nutrients, which are notoriously low in the sandstone-derived soils widespread in much of the Greater Blue Mountains. Nevertheless in habitats that have higher-nutrient soils, such as the alluvial flats, basalt caps and shale ridges, if rainfall also increases, then faster rates of fuel accumulation could occur. Higher CO_2, warmer temperatures and sunshine favour tropical, summer growing (or 'C-4') grasses, such as kangaroo grass (*Themeda*) over temperate, winter-growing (or 'C-3') grasses such as *Poa* and wallaby grass (*Austrodanthonia*) (Keith 2004), and this could potentially affect fuel loads as well as species composition, particularly in the grassy woodlands.

These mallee eucalypts, ferns and grasses are vigorously resprouting immediately after a bushfire. Photo: Ian Brown.

While weather is the biggest influence on fire regimes (Hammill & Bradstock 2006; Bradstock *et al.* 2009; 2010), vegetation (i.e. fuel) also plays an important role. The kinds of changes to plant composition described above may influence the flammability of some vegetation types in the Greater Blue Mountains and thus provide feedback effects on fire regimes. Fuel loads in sclerophyll forests generally increase over time after fire up to a certain point (about 20 years in the Blue Mountains; Van Loon 1977), after which they may gradually decline as understorey shrubs senesce and die if left unburnt for long enough (Zylstra 2009). More frequent burning can lead to an increase in the proportion of grasses in the understorey of sclerophyll forests which can, in turn, further increase the frequency at which these forests burn. This is because a dense grassy understorey may have a greater continuity of low fuel than a shrubby one, allowing it to carry fire under a wider range of weather conditions. Under extreme fire weather conditions, however, fires in shrubby understoreys reach higher intensities than grassy ones. Another pathway of vegetation feedback on fire behaviour is through the effects of fire intensity on fuel accumulation. High intensity, crown fires are generally followed by relatively slow fuel accumulation in the early post-fire years. This is because most of the fine fuel has been consumed by the fire and more severely burnt vegetation may take longer to recover. This contrasts with low intensity fires that leave a considerable amount of fine fuel, including the tree canopy, *in situ*.

Dry sclerophyll forests

Intense fires could have more serious impacts on montane dry sclerophyll forest communities. Stands of fire-sensitive Blue Mountains ash (*Eucalyptus oreades*) in the Sydney Montane Dry Sclerophyll Forests are killed by crown fires and recover only by seed. They dominate the dry forests in sheltered

Eucalypt diversity in the Greater Blue Mountains

The Australian continent is unique in being dominated by a single group of trees, the eucalypts. These form the canopy of forests and woodlands in all but the very wettest and driest of habitats (Hill 2002). When used as a common name, the term ‘eucalypt’ refers to three closely related genera: the largest genus, *Eucalyptus*, with approximately 800 species; *Corymbia* (bloodwoods) with 115 species; and *Angophora* (native ‘apples’) with 13 species (Hill 2010). In fact *Eucalyptus* is the second most diverse genus of plants in the world – only *Ficus* (the figs) has more, with over 1000 species (Keith 2004). Almost all eucalypts are endemic to Australia, with just 16 species native elsewhere: in New Guinea, Indonesia and the Phillipines.

The enormous diversity of eucalypts is related to their site sensitivity (Florence 2004). The Greater Blue Mountains with its rugged topography and varied elevation, geology and climate provides a complex mosaic of niches that vary subtly in their average temperatures, rainfall, soil moisture, nutrients and fire regimes. Over tens of millions of years this has given rise to a correspondingly diverse range of eucalypts. The Greater Blue Mountains in fact has the most outstanding concentration of eucalypt diversity in Australia – a major reason for its status as a World Heritage Area. Approximately 13% of all eucalypts (close to 100 species) are found here, far more than in any other major conservation area. For example only 5% of eucalypts grow in the Australian Alps, 6% in the far south-east forests, 1.5% in Tasmania and 3.5% in Kakadu (James 1994).

Within the Greater Blue Mountains, this diversity of eucalypts is reflected in a number of ways. One of these is their taxonomic diversity (taxonomy is the science of distinguishing and classifying organisms on the basis of differences in their morphology, genetics and degree of relatedness). As well as all three genera of eucalypts being present, within the genus Eucalyptus there are a further ten species ‘groups’ present in the GBMWHA (Hill 2002; Hager & Benson, in press). These are the Adnataria (ironbarks and boxes), Bisectaria (with just Eucalyptus squamosa in the region), Exsertaria (red gums), Maidenaria (mountain gums), Transversaria (blue gums), blue-leaved ashes (which includes the scribbly gums), black sallies, green-leaved ashes, peppermints, and stringybarks. Closely related eucalypts also commonly hybridise, producing intermediate forms, which creates a further level of taxonomic diversity. A consequence of this diversity and complexity is that eucalypt taxonomy in the region, and more generally, is still the subject of much debate and ongoing research, both to correctly recognise all the species and to better describe the relationships between them.

The diversity of the eucalypts in the Greater Blue Mountains is also reflected in the diversity of their ecological niches. Of the 96 species formally recognised in the Greater Blue Mountains (Hager and Benson, in press), just over forty have highly restricted distributions, and many of these species are also rare. For example, Nepean River gum (*Eucalyptus benthamii*) is a vulnerable species under both NSW and Australian endangered species legislation and is found only on alluvial soils in the lower Hawkesbury-Nepean catchment. In fact, the mallee eucalypts of the Greater Blue Mountains heaths are remarkable as a classic example of 'vicariant' biogeography (Keith 2004): the phenomenon where closely related species replace one another at different locations. This is a result not only of their site specificity, but also of the poor dispersal ability of their pollen and seeds, and the isolated nature of many of the heath patches in which they occur.

The eucalypts of the Greater Blue Mountains also have a diverse range of growth forms and habitats: from tall forest trees 40 m or more high, such as mountain blue gum (*Eucalyptus deanei*) and ribbon gum (*Eucalyptus viminalis*), which grow on deep, moist, fertile soils in river valleys and on basalt caps, to short, multi-stemmed mallees just 3–5 m high, such as Faulconbridge mallee ash (*Eucalyptus burgessiana*) and cliff mallee ash (*Eucalyptus cunninghamii*), which grow on shallow, nutrient-poor soils on the sandstone ridge tops of the Blue Mountains. There are yet other more subtle expressions of diversity within the eucalypts, including their varied tolerances to disturbances such as flooding and fire, and their different seasons of flowering and fruiting, an important characteristic for nectar-feeding animals, which are thus able to find food year-round.

Given the rugged and remote nature of the Greater Blue Mountains World Heritage Area it may come as no surprise that new eucalypts can still be discovered: recent surveys in the Wollemi and Yengo (Bell 2008) have revealed two undescribed species – now in the process of being formally named.

LEFT: Mountain blue gum (*Eucalyptus deanei*) are the giants of the World Heritage Area; they reach heights of 40 metres or more. Photo: Ian Brown. ABOVE: Blue Mountains Mallee Ash (*Eucalyptus stricta*). Photo: Jaime Plaza. BELOW: Bark type is a useful identification feature in eucalypts. Photos 1-3: Jaime Plaza, 4; Liz Tasker, 5; Ian Brown.

locations adjoining rocky sandstone escarpments and higher gullies in the upper Blue Mountains, locations that are often protected from fire by the surrounding cliffs. However, these forests may be at greater risk if high intensity fires occur more often and encroach into such areas. One such event occurred during the summer of 2006–07, when fires burnt into upper creek canyons of the Grose Valley, killing significant stands of adults of this species. The Blue Mountains ash in these areas currently exist only as regenerating saplings: if another fire burns through before these saplings have matured and produced seed, then the species could be lost from some of these locations. In such an event, the return of the species to these locations would then depend on the dispersal of seeds in from outside the affected area.

Rainforests

Rainforest pockets may shrink and diminish in number if the frequency or intensity of fires burning into them increases. In contrast to the more extensive coastal and tropical rainforests, the Greater Blue Mountains' rainforests occur in small, isolated pockets within the widely distributed sclerophyll forests. These pockets are at risk of being gradually replaced by sclerophyllous vegetation if fires reach and burn into them more frequently. While many rainforest plants can resprout and survive infrequent or low intensity fires (Williams 2000), regeneration may be limited after frequent or high intensity fires. The greater disturbance and light penetration after higher intensity fires also greatly favours the recruitment and growth of eucalypt seedlings over rainforest species. If droughts become more severe in the future, fires may encroach on rainforest pockets more often as the soil, leaf litter and vegetation dry out, even in moist gullies which at other times are a barrier to fire. Dry Rainforests may be most at risk because they occur in less sheltered locations and directly adjoin the dry sclerophyll forests. The Northern Warm Temperate and Warm-Cool Temperate Rainforests are embedded within wet sclerophyll forests, which, because of their tendency to burn less often may afford these rainforests greater protection.

Rainforest communities have some inherent resilience because of high in situ regenerative capacity and long distance dispersal of seeds. Resprouting and the ability for seedlings to establish in mature

Blue Mountains ash (*Eucalyptus oreades*) often occur as even-aged stands, a consequence of a life-cycle in which adult trees are periodically killed by intense fires and replaced by a new cohort of seedlings. Photo: Botanic Gardens Trust/Jaime Plaza.

communities are common functional strategies in rainforest plants, meaning that rainforests have a high capacity to maintain a stable species composition as long as the environmental conditions remain suitable. In addition, many rainforest plants have seeds that are dispersed long distances by birds and by mammals such as flying-foxes. These animals ingest the nutritious fruits (such as lilly pilly, *Acmena smithii*; pepper bush, *Tasmannia lanceolata*; and cheese tree, *Glochidion ferdinandi*) and later deposit the seeds at new locations. The high mobility and migratory tendencies of many of these rainforest animals enable them to visit isolated patches and move between low and high elevations and between northerly and southerly latitudes to take advantage of fruiting and flowering events, depositing seeds at various locations along the way. Thus rainforest communities, although occurring as 'islands' within the flammable sclerophyll forest matrix, do have some strategies that afford them resilience to climate change pressures.


The grey-headed flying-fox is a migratory species that eats native fruits and disperses the seeds long distances. Photo: Pavel German.

Wet sclerophyll forests

Increasing fire frequencies may lead to a decline of understorey shrubs and a shift in the wet sclerophyll forest-rainforest boundary. Mesophyllous, woody shrubs in the understorey of wet sclerophyll forests (including many rainforest species) typically have relatively thin bark, and while most can resprout, their ability to do so after intense or repeated fires is likely to be limited. Examples of species that may be disadvantaged by increased fire frequency are blueberry ash (*Elaeocarpus reticulatus*) and muttonwood (*Rapanea variabilis*). In contrast, many grasses, herbs and ferns in the ground layer are tolerant and rapidly-growing resprouters that mature quickly after fire, and hence an increase in fire frequency may favour these species over the mesophyllous shrubs. In addition, the role of fire in determining the location of wet sclerophyll forest-rainforest boundaries is well documented, and an increase in fire frequency would be likely to result in the advance of wet sclerophyll forests into the margins of neighbouring rainforests.

Intense fires that damage the crown of tall canopy eucalypts can have significant impacts on arboreal fauna. Wet sclerophyll forest trees are often well over 30 metres tall; the canopy of these trees often escapes damage from fire, particularly from fires burning under less extreme weather conditions, because of their sheer height and the sheltered locations in which these forests occur. However, intense fires can cause substantial crown damage. An example of this occurred in the summer of 2006 when fire burnt through the tall blue gum forests in the Grose Valley, scorching most of the canopy. Such fires may expose arboreal mammals like possums and gliders to lethal temperatures, and for those that survive, temporarily remove their food resources and expose them to predators. The ability of these animals to persist in forests affected in this way is not well-known, but it appears that local extinction occurs and that animals disperse back into the site from adjacent habitat. The extensive network of wet sclerophyll forests in the Greater Blue Mountains World Heritage Area is thus likely to be essential in the persistence of such arboreal species in the region following intense bushfires.

Heathlands

An increase in fire frequency would result in changes in species composition. Higher fire frequencies in heathland communities will most affect populations of seeder species, particularly those with longer maturation periods following their establishment from seeds. These include prominent overstorey shrubs such as *Banksia ericifolia* (heath banksia) and species of *Petrophile*, *Boronia*, *Darwinia* and *Pultenaea*. In turn, this could affect fauna that depend on thicket-forming shrubs for nesting or protection from predators. Resprouting herbs, sedges, smaller shrubs and fire ephemerals will probably be less affected and may become more abundant.

Short dispersal distances of seeds and the isolation of heathland patches could affect the survival of heathlands affected by adverse fire regimes. Most heathland plants have seeds that are dispersed relatively short distances, including obligate seeder species of *Banksia* and *Hakea*. In these species seeds may move only a few tens of metres from the parent plant after a fire (Hammill *et al.* 1998; box: 'Plant dispersal and shifting climate niches'). Local extinctions of species in heathland patches as a result of adverse fire regimes may not readily be reversed by recolonisation from other areas because of this highly localised seed dispersal and the scattered and isolated distribution of many heathland patches.

Freshwater wetlands

Droughts may reduce the capacity of swamps to recover from fire. Upland swamps are often the first ecosystem to appear green in a burnt and blackened landscape. This rapid recovery after fire is due to the dominance of resprouting sedges, other grass-like plants, and ferns (although these communities do also contain some seeder species) and the abundant soil moisture which facilitates rapid regrowth. An increase in the severity of droughts could dry these soils more than usual, leading to increased oxidisation, and in the event of a fire, slow their recovery. Over time, plants that are specialists of permanently waterlogged soil may be disadvantaged relative to those that occupy the drier swamp margins. Species from the neighbouring eucalypt forests may encroach into the swamps.

Climate change and altered fire regimes may result in a greater incidence of peat fires. The resilience of upland swamps to fire is largely due to their deep, peaty soils which, if intact, retain moisture and support the characteristic, dense swamp vegetation. However, an increase in the prevalence of severe droughts and more intense fires could result in the organic peat layers in these swamps becoming dry enough to burn. Underground peat fires are, apparently, currently rare in the Greater Blue Mountains, even though the surface organic matter in these swamp soils is frequently burnt when fires occur during dry conditions. If peat fires became more common, they could lead to major and potentially devastating impacts on areas that are burnt, including erosion, loss of soil moisture-holding capacity and an overall decline of the habitat.

Many swamp plants regrow rapidly after fire, but too frequent fire can deplete their starch reserves and cause them to decline. Fires that occur when the substrate has dried out can also be particularly damaging. Photo: Ian Brown.

The survival and breeding success of specialised swamp fauna may be adversely affected if fires increase in frequency or severity. The peak in activity for two well-known threatened fauna species of the swamps – the giant dragonfly and Blue Mountains water skink – occurs in the warmer months of the year, coinciding with the fire season. Adult giant dragonflies may begin to emerge from their burrowing larval stage from late October and are then active throughout summer. Water skinks are most active from September to late April, and the females give birth to live young in late December. The effects of any increase in the frequency and intensity of spring and summer fires for these species are unknown, but could be adverse. These effects are likely to be more pronounced during drier periods when groundwater levels are lower. Other animals that are equally restricted to swamps may be at risk in a similar way.

Forested wetlands

If high intensity fires reach the major river corridors, stands of large river oak may be killed. It is uncommon for fires to burn intensely down into the major river corridors where stands of large river oak (*Casuarina cunninghamiana*) occur, and these impressive trees do not resprout if their canopy is burnt by fire. Under severe drought conditions, fires are more likely to burn intensely and reach these river corridors, as happened in the 2003 fires in the Cotter catchment near Canberra, where many of these trees were killed.

Grassy woodlands

Higher temperatures or droughts may be the greatest threat to some species. An increase in average temperatures has the potential to affect the subalpine woodlands, and place greater stress on species that are only found in these higher altitude woodlands. For example, white sally (*Eucalyptus pauciflora*) is only found in this vegetation class in the Greater Blue Mountains. If temperatures rise beyond the climatic niche of these species, then some replacement by lower altitude species may occur. In the grassy woodlands many grasses and herbs predominantly regenerate after heavy rains from seeds or bulbs lying dormant in the soil, completing their life-cycle within a year or two. Many species also have increased regeneration after fire. In the event of longer or more frequent droughts, the viability of some of these seeds and bulbs could potentially be affected.

Ash contributes mineral nutrients to the soil, but fires that reoccur very frequently can deplete them. Behind the scribbly gums in this photo, rapid regrowth of sedges in a swamp can be seen. Photo: Ian Brown.

Mitigating the Impacts of Climate Change and Fire

Projected climate change impacts on the fire regimes of the Greater Blue Mountains have two very important facets which park managers, and society at large, need to address. The first, and most critical, is managing the potential increase in risk to human settlements. How to most effectively do this is the subject of much research and management effort, both nationally (www.bushfirecrc.com) and specifically in the Greater Sydney region (e.g. Bradstock *et al.* 2008). Reducing the risks will come from implementing a range of strategies, including increased fuel reduction in strategic areas (focussing on where this can be maintained over time and will be most effective in reducing fire impacts on assets); improved construction standards, building materials and urban planning; community education; rapid response to ignitions on high-fire-risk days; and reducing the incidence of arson. All of these strategies require considerable (and sustained) resources, and the optimal mix is a decision for both the community and government.

The second is to manage the potential risks to the natural values of the Greater Blue Mountains World Heritage Area through a range of monitoring, research and management approaches. Dealing effectively with the projected impacts on biodiversity from altered fire regimes and climate change depends on having a combination of strategies. Below, we suggest some practical ways in which this might be achieved.

It is important to continue to map patterns of fires and fire regimes, and to further refine analysis of these. These are the data that allow us to detect change. The systematic mapping of fires in national parks

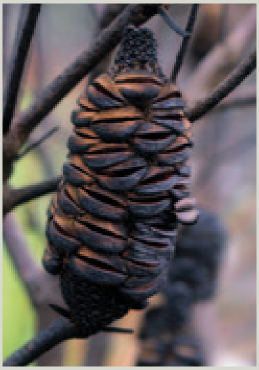
Plant dispersal and shifting climate niches

Climate niches occupied by different plant species are expected to shift under climate change, moving towards both higher elevations and latitudes (i.e. further south in Australia) if temperatures continue to warm as projected (Australian Academy of Science 2010). To survive, plants will need to either adapt in situ or move with their climatic envelope. The ability of plants to adapt will depend on the plasticity in their growth and physiology, and their ability to move will depend on their capacity to disperse, which for most species is a consequence of their seed dispersal.

Seed dispersal is a key ecological process that may affect the success and persistence of many plant species in response to climate change: it is influenced by the many shapes and forms that adapt seeds to being dispersed in different ways: some have thin, light appendages that enable the wind to disperse them, while others readily float and are dispersed by water. Some have nutritious fleshy coatings or oil-rich attachments that are eaten by animals that subsequently drop the seeds elsewhere, while others have barbs and hooks that attach to fur or feathers. Some are flung away from the parent plant by explosive seed pods, yet others have no obvious dispersal mechanism at all. A consequence of this variety of seed dispersal mechanisms is that different plant species have very different dispersal distances, ranging from less than a few metres (e.g. those with no dispersal mechanism such as many Myrtaceae, or with explosive seed pods such as some peas) to many kilometres (e.g. those with animal dispersal, such as grasses or fleshy-fruited species, or those with long-distance wind dispersal, such as daisies).

Australian heathland plants are notable for having highly localised seed dispersal (Keith 2004). We know that this is the case because of studies such as that by Hammill *et al.* (1998) on heath banksia (*Banksia ericifolia*). Heath banksias are killed by fire and depend on seed for regeneration, a strategy known as being an 'obligate seeder'. Heath banksia seeds are quite large and have a papery wing that causes them to spiral as they fall. This wing slows the vertical drop of the seeds and increases the horizontal distance that they can travel in windy conditions. Most seeds of this species disperse and successfully germinate less than 10 metres away from the parent plant, although occasionally they end up as much as 40 metres away. A consequence for populations of this common plant – as well as for other similar species in the family Proteaceae, where the opportunity to 'move' in the landscape is essentially limited to the time immediately following fire when seeds are released and seedlings can establish – is that the rate at which they can move is very slow. For example, if we assume a maximum dispersal distance of 40 metres (see above), and a fire return interval ranging from about every 6 to 40 years (equivalent to one to six fires every 4 decades, which is the range of fire frequencies that has occurred across the GBMWHA since 1971; see Figure 3), this species could probably only move about 100 to 600 metres per century if its climate niche were to shift in the future (given other conditions along the way are suitable).

Australia's sclerophyll vegetation is also remarkable for having proportionally more species whose seeds are dispersed by ants than anywhere else in the world (Berg 1975), with more than 1500 species dispersed in this way. A recent study (Thomson, cited in Ramp & Chapple 2010) has identified more than 200 ant-dispersed species in the Greater Blue

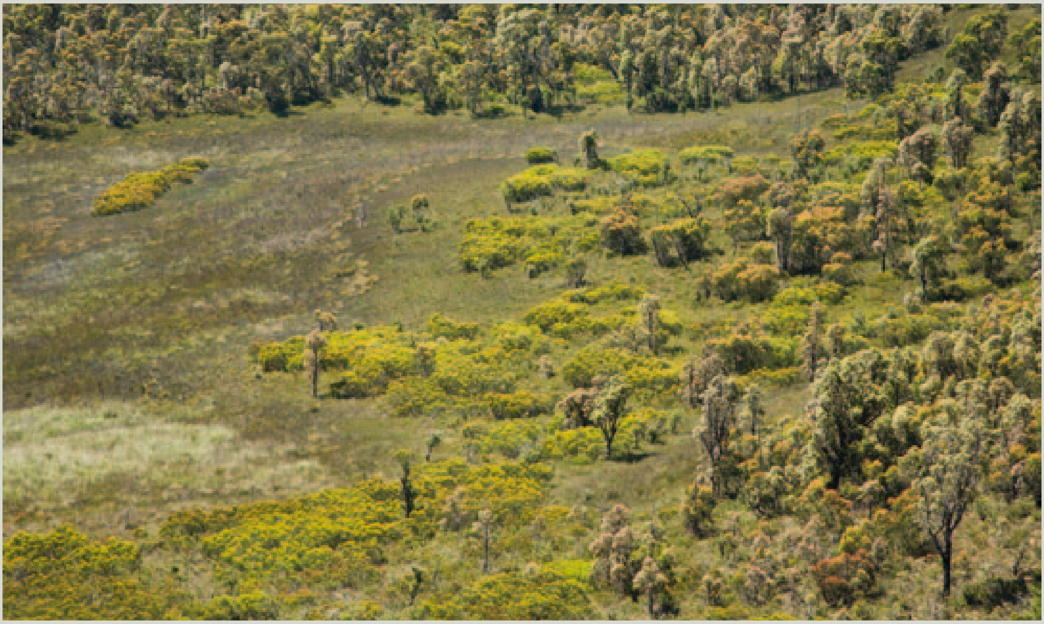


Mountains. Most belong to the family Fabaceae, and many are wattles (Acacia). Ants are attracted to an oil-rich attachment, called an 'elaiosome', that is attached to each seed. They drag the seed back to their nest, consume the elaiosome and discard the seed, often leaving it buried in their nest. This study has revealed that ants moving sunshine wattle (*Acacia terminalis*) seeds disperse them only very short distances, up to 4.2 metres. Such distances are unlikely to keep pace with a shifting climate niche, which may move many kilometres over a decade or two. However, the research also found that ants moved the seeds greater distances at warmer sites in the lower Blue Mountains than at cooler sites in the upper Blue Mountains. Thus, as the climate warms, ants may disperse seeds further, increasing the likelihood that plants will be able to move to new locations.

The ability of plants to move also depends on how specialised their habitat requirements are. Many seeds that disperse far and wide will not land in suitable locations: the more specialised the habitat niche required by a species, the less likely it will be that the seed lands in a location where it can germinate or establish. For species that grow in vegetation types that occur as isolated patches in the landscape, such as swamps and heaths, the chance of finding another patch is also likely to be lower than for species that occur in widespread vegetation types.

As a consequence, many plants may not be able to simply 'follow' their climate niche if it moves (i.e. up in elevation or further south). Whether they are able to do so, and how quickly this happens, will depend on a combination of factors including the dispersal capacity of their seeds and their habitat requirements, as well as their ability to adjust physiologically to the changing conditions and to compete with other species that already exist in the places they disperse to.

LEFT: Fire creates ideal conditions for seedlings such as this *Hakea* to establish. Photo: Kate Hammill. ABOVE: Banksia seeds are released from woody cones after fire; they disperse only relatively short distances. Photo: Jaime Plaza. BELOW: Boundaries between upland swamps and dry eucalypt forests are dynamic over time in response to subtle changes in the local water table and fire regimes – both of which depend on climate. Photo: Ian Brown.



first started in NSW in the 1950s in several parks close to Sydney. Since then, it has become routine agency practice, and has been expanded to all parks in NSW. Systematic fire records have been kept for the Blue Mountains National Park since the early 1970s, and for other newer national parks since their date of declaration. The practice of fire mapping has transformed fire management and fire ecology in Australia, and is a powerful tool that allows us to document fire regimes, the responses of biodiversity, and to detect change when and where it happens.

Fire history maps allow DECCW to annually update the fire history analyses for each park, including area burnt, time since last fire and fire frequency. The results of this are then used to assess the status of the different vegetation formations relative to the recommended fire frequency thresholds (Kenny *et al.* 2004). It is also becoming more common for fire severity maps to be prepared after major fires, and recent work by DECCW (Hammill *et al.* 2010) completed fire severity maps for the Greater Blue Mountains World Heritage Area for all of the major fire seasons of the past decade (2001–02, 2003–04 and 2006–07), making the fire history records for the Greater Blue Mountains the most comprehensive in NSW.

Monitoring the responses of flora and fauna to changes in fire regimes and climate is also critical if we are to detect and manage impacts. Under a recent Environmental Trust project (Hammill & Bradstock 2008), permanent vegetation plots have been established in dry sclerophyll forests across the major climate gradients in the Greater Blue Mountains region. These plots are located according to a scientifically robust survey design, with replication across three levels of (current-day average) annual temperature and annual rainfall, as well as across four levels of past fire frequency. The floristic data collected from these plots in 2006–2007 provide a baseline against which future changes in the composition can be assessed and related to both fire and climate change. Sites from other vegetation types in the Blue Mountains could readily be added, with baseline floristic compositional data available from an extensive vegetation survey database managed by DECCW.

Further research is needed to **verify and improve the adequacy of the state-wide fire frequency thresholds and to identify critical thresholds of fire intensity and season.** The current fire frequency thresholds are derived from a database of the fire responses of plant species from across NSW, and do not yet take account of differences in altitude or climate (and hence the length of the growing season) or local species composition. In addition, frequency guidelines are currently available for only a small number of fauna species and more research is needed to determine if thresholds can be developed for others. While fire intensity and season are known to have ecological effects, for most species the state of knowledge is too poor to identify thresholds of these factors beyond which species declines are likely to occur. If the projections for increased fire intensity under climate change hold true, then knowledge of the critical intensity thresholds for species and ecological communities will become much more important. Identifying these thresholds will allow land managers to better mitigate the impacts of increased fire intensities on biodiversity.

Ensuring that a substantial proportion of each vegetation formation is well above the recommended minimum inter-fire interval threshold (Kenny *et al.* 2004) would also be prudent. Keeping vegetation well within the thresholds at the high frequency fire end of the scale is likely to be more critical, since fire frequency is projected to increase under climate change. It is also the case because the specified minimum interval between fires is derived from the number of years species need before they can start producing seeds, rather than the length of time they need to build up substantial seedbanks. Most seeder species that have recruitment cued to fire produce relatively small crops of seeds for the first few years after they mature, and then continue to produce seeds year after year, increasing the size of their seedbanks over time. Repeated fires at the shortest recommended interval may consequently lead to a decline in their populations.

Maintaining inherent variation in fire regimes is also likely to be important. There is good scientific evidence from the sclerophyll vegetation types of the Sydney sandstone basin that repeating the same interval between fires over and over will cause a decline in plant diversity, even if the interval is above the minimum needed by the most fire-interval sensitive species (Morrison *et al.* 1995). Having ecosystems in a healthy state that will best enable them to cope with the increased stress of climate change or inappropriate fire regimes is likely to be maximised by maintaining inherent variation. By implementing variable frequencies within the specified thresholds, and maintaining a proportion of ecosystems outside the specified fire frequency thresholds, the floristic, faunal and structural diversity of these systems will be enhanced, and this may give them more latitude to respond to change.

More **research on the mechanisms of species responses to fire intensity, season and other critical factors such as fire size and interactions between fire response and climate** is needed. Targeted studies on threatened species and endangered ecological communities that are thought to be particularly sensitive could have immediate benefits.

Support for management of other threats to biodiversity should not be reduced. Climate change and altered fire regimes may exacerbate the impacts of other existing significant threats to biodiversity, such as feral animal predation and competition from introduced weeds. For example, an increase in high frequency fires would diminish the abundance of logs, leaf litter and shrubby understorey in sclerophyll forests and expose small and medium-sized mammals, as well as other ground-dwelling fauna, to much higher predation rates from introduced predators (which are already responsible for the extinction and critical decline of many native animals). A warmer climate would enable some weeds, such as lantana, to expand their distribution to higher altitudes. Thus continuing to aggressively manage these other threats would be an effective way for land-managers to mitigate some of the impacts of climate change on biodiversity.

In conclusion, responding to the potential threats from climate change and altered fire regimes in the Greater Blue Mountains will require a suite of approaches. The diverse native vegetation and biodiversity of the World Heritage Area are of global significance. It is only by better understanding them, being in tune with how they are changing, and understanding which management actions are needed, that we will be able to effectively conserve them.

View from Deane's Lookout over the Wollemi wilderness. Photo: Jaime Plaza van Roon.

Further reading

Bradstock, RA, Williams, JE and Gill, AM 2002, Flammable Australia: *The Fire Regimes and Biodiversity of a Continent*, Cambridge University Press, Cambridge

DEC 2004, *The Native Vegetation of the Nattai and Bargo Reserves*, Department of Environment and Conservation NSW, Sydney

DEC 2006a, *The Vegetation of the Western Blue Mountains*, Report funded by the Hawkesbury–Nepean Catchment Management Authority, Department of Environment and Conservation NSW, Sydney

DEC 2006b, *The Native Vegetation of the Woodford and Erskine Ranges, Kings Tableland and Narrowneck Peninsula in the Blue Mountains National Park*, Department of Environment and Conservation NSW, Sydney

DECC 2008, *The Native Vegetation of Yengo and Parr Reserves and Surrounds*, Department of Environment and Climate Change NSW, Sydney

DECCW 2010c, *The Native Vegetation of Southeastern Wollemi National Park and Surrounds*, Department of Environment, Climate Change and Water NSW, Sydney

Keith, D 2004, *Ocean Shores to Desert Dunes: the Native Vegetation of New South Wales and the ACT*, Department of Environment and Conservation (NSW), Sydney

NPWS 2003, *The Native Vegetation of the Warragamba Special Area*, NSW National Parks and Wildlife Service, Sydney

Whelan, RJ 1995, *The Ecology of Fire*, Cambridge University Press, Cambridge

More information about threatened species, populations and ecological communities as listed under the NSW Threatened Species Act can be found at www.threatenedspecies.environment.nsw.gov.au

References

Auld, TD and Denham, A 2006, 'How much seed remains in the soil after a fire?', *Plant Ecology*, 187, pp.15–24

Auld, TD and O'Connell, MA 1991, 'Predicting patterns of post-fire germination in 35 eastern Australian Fabaceae', *Australian Journal of Ecology*, 16, pp.53–70

Australian Academy of Science 2010, *The Science of Climate Change*, Australian Academy of Science, Canberra

Bell, SAJ 2008, 'Rare or threatened vascular plant species of Wollemi National Park, central eastern New South Wales', *Cunninghamia*, 10 (3), pp.331–371

Berg RY 1975, 'Myrmecochorous plants in Australia and their dispersal by ants', *Australian Journal of Botany*, 23, pp.475–508

Birk, EM and Bridges, RG 1989, 'Recurrent fires and fuel accumulation in even-aged blackbutt (Eucalyptus pilularis) forests', *Forest Ecology and Management*, 29, pp.59–80

Boland, DJ, Brooker, MIH, Chippendale, GM, Hall, N, Hyland, BPM, Johnston, RD, Kleinig, DA and Turner, JD 1994, *Forest Trees of Australia*, CSIRO, Melbourne

Bradstock, RA 2010, 'A biogeographic model of fire regimes in Australia: current and future implications', *Global Ecology and Biogeography*, 19, pp.145–158

Bradstock, RA, Bedward, M, Gill, AM and Cohn, J 2005, 'Which mosaic? A landscape ecological approach for evaluating interactions between fire regimes, habitat and animals', *Wildlife Research*, 32, pp.409–423

Bradstock, RA, Cohn, JS, Gill, AM, Bedward, M and Lucas, C 2009, 'Prediction of the probability of large fires in the Sydney region of south-eastern Australia using fire weather', *International Journal of Wildland Fire*, 18, pp.932–943

Bradstock R, Davies I, Price O and Cary G 2008, *Effects of Climate Change on Bushfire Threats to Biodiversity, Ecosystem Processes and People in the Sydney Region*. Final report to the NSW Department of Environment and Climate Change: Climate Change Impacts and Adaptation Research Project 050831, Australian National University, Canberra

Bradstock, RA and Gill, AM 2001, 'Living with fire and biodiversity at the urban edge: in search of a sustainable solution to the human protection problem in southern Australia', *Journal of Mediterranean Ecology*, 2, pp.179–195

Bradstock RA, Hammill KA, Collins L and Price O 2010, 'Effects of weather, fuel and terrain on fire severity in topographically diverse landscapes of south-eastern Australia,' *Landscape Ecology*, 25, pp.607–619

Cunningham, CJ 1984, 'Recurring fire hazards: a case study of the Blue Mountains, NSW, Australia', *Applied Geography*, 4, pp.5–27

DECCW 2010a, *Fire Management Manual 2010*, Department of Environment, Climate Change and Water (NSW), Sydney. Also available online at http://www.environment.nsw.gov.au/fire/TheNPWSfiremanagementmanual.htm

DECCW 2010b, *NSW Climate Impact Profile: The Impacts of Climate Change on the Biophysical Environment of New South Wales*, Department of Environment, Climate Change and Water (NSW), Sydney

Florence, R 2004, *Ecology and Silviculture of Eucalypt Forests*, CSIRO Publishing, Melbourne

Gill, AM 1981, 'Adaptive responses of Australian vascular plant species to fires', in AM Gill, RH Groves and IR Noble (eds), *Fire and the Australian biota*, Australian Academy of Science, Canberra, pp.243–272

Gill, AM and Moore, PHR 1996, Regional and historical fire weather patterns pertinent to the January 1994 Sydney bushfires, *Proceedings of the Linnean Society of New South Wales*, 116, pp.27–36

Gill, AM, Allan, G and Yates, CJ 2003, 'Fire-created patchiness in Australian savannas', *International Journal of Wildland Fire*, 12, pp.323–331

Hager, T and Benson, D (in press), 'The eucalypts of Greater Blue Mountains World Heritage Area: distribution, classification and habitats of the species of Eucalyptus, Angophora and Corymbia (family Myrtaceae) recorded in its eight conservation reserves', *Cunninghamia*, Royal Botanic Gardens, Sydney

Hammill, KA, Bradstock, RA and Allaway, W 1998, 'Post-fire seed dispersal and species re-establishment in proteaceous heath', *Australian Journal of Botany*, 46, pp.407–419

Hammill, KA and Bradstock, RA 2006, 'Remote sensing of fire severity in the Blue Mountains: influence of vegetation type and inferring fire intensity', *International Journal of Wildland Fire*, 15, pp.213–226

Hammill, KA and Bradstock, RA 2008, *Biodiversity Responses to Fire Regimes under Climate Change*. Final Project Report RD/0104 to the NSW Environmental Trust. Department of Environment Climate Change & Centre for Environmental Risk Management of Bushfires, Sydney

Hammill, KA, Tasker, EM and Reid, J 2010, *Monitoring Fire Regimes and Biodiversity in the Greater Blue Mountains World Heritage Area*. Final Report on Caring for our Country (TAFA) Project 5, Department of Environment, Climate Change and Water, Sydney

Hennessy, KJ, Lucas, C, Nicholls, N, Bathols, J, Suppiah, R and Ricketts, J 2006, *Climate Change Impacts on Fire-weather in South-east Australia*. Consultancy report to the New South Wales Greenhouse Office, Victorian Department of Sustainability and Environment, ACT Government, Tasmanian Department of Primary Industries, Water and Environment, and the Australian Greenhouse Office. CSIRO Atmospheric Research and Australian Government Bureau of Meteorology, Melbourne

Higgins, PJ, Peter, JM and Steele, WK (eds)2001, *Handbook of Australian, New Zealand & Antarctic Birds. Volume 5: Tyrant-flycatchers to Chats*, Birds Australia/Oxford University Press, Melbourne

Hill, KD 2002, 'Angophora and eucalyptus', pp. 73–142 in Harden, GJ (ed). *Flora of New South Wales: Volume 2*. University of NSW Press, Sydney

Hill, KD 2010, 'Genus Eucalyptus', in *New South Wales flora online*, Royal Botanic Gardens & Domain Trust, Sydney: http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=gn&name=Eucalyptus, accessed 14 October 2010

Hoffmann, W, Bazzaz, F, Chatterton, N, Harrison, P and Jackson, R 2000, 'Elevated CO_2 enhances resprouting of a tropical savanna tree', *Oecologia* 123, pp.312–317

Howell, J and Benson, D 2000. *Sydney's Bushland: More Than Meets the Eye*. Royal Botanic Gardens, Sydney

Hughes, L, Westoby, M and Cawsey, EM 1996, 'Climatic range sizes of Eucalyptus species in relation to future climate change', *Global Ecology and Biogeography Letters* 5, pp.23–9

James, T 1994, *An assessment of the World Heritage Values of the Blue Mountains and Surrounding Plateaux*, Final Report. Royal Botanic Gardens, Sydney

Keeley, JE 2009, 'Fire intensity, fire severity and burn severity: a brief review and suggested usage', *International Journal of Wildland Fire,* 18, pp.116–126

Keith, D 2004, *Ocean Shores to Desert Dunes: the Native Vegetation of New South Wales and the ACT*, Department of Environment and Conservation (NSW), Sydney

Keith, D 2010, *Fire Management Thresholds for Threatened Ecological Communities in the Blue Mountains City Local Government Area*. Unpublished report to the Blue Mountains City Council by the Department of Environment, Climate Change and Water NSW, Sydney

Keith DA, McCaw WL and Whelan RJ 2002, Fire regimes in Australian heathlands and their effects on plants and animals, pp.199–237 in Bradstock, RA, Williams JE & Gill AM (eds) *Flammable Australia: the Fire Regimes and Biodiversity of a Continent*, Cambridge University Press, Cambridge

Kenny, B, Sutherland, E, Tasker, E & Bradstock, R 2004, *Guidelines for ecologically sustainable fire management*. Unpublished report prepared under the NSW Biodiversity Strategy, NSW National Parks and Wildlife Service, Sydney

Klaphake, V 2009, *Eucalypts of the Sydney Region*, Van Klaphake, 470 Bulli Creek Rd, Byabarra NSW 2446

Knox, KJE and Clarke, PJ 2006, 'Fire season and intensity affect shrub recruitment in temperate sclerophyllous woodlands', *Oecologia*, 149, pp.730-739

Morrison, DA, Cary, GJ, Pengelly, SM, Ross, DG, Mullins, BJ, Thomas, CR and Anderson, TS 1995, 'Effects of fire frequency on plant species composition of sandstone communities in the Sydney region: inter-fire interval and time-since-fire', *Australian Journal of Ecology*, 20, pp.239–247

Morrison, DA 2002, 'Effects of fire intensity on plant species composition of sandstone communities in the Sydney region', *Austral Ecology*, 27, pp.433–441

Noble, IR and Slatyer, RO 1980, 'The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances', *Vegetatio*, 43, pp.2–21

NPWS and EA 1998, *The Greater Blue Mountains Area World Heritage Nomination*, Report for the Nomination of the Greater Blue Mountains Area for inscription on the World Heritage List by the NSW National Parks and Wildlife Service and Environment Australia, Australian Government Publishing Service, Canberra

NSW Rural Fire Service 2006, *Bushfire Environmental Assessment Code for NSW*, NSW RFS, Sydney

NSW Scientific Committee 1998, *High frequency fire resulting in the disruption of life cycle processes in plants and animals and loss of vegetation structure and composition Threatened Species Conservation Act 1995: Final Determination on High Frequency Fire*, NSW National Parks & Wildlife Service, Sydney. Also available online at http://www.environment.nsw.gov.au/biodiversity

NSW NPWS 2004, *Fire Management Strategy: Blue Mountains National Park*. NSW National Parks & Wildlife Service, Katoomba

Ooi, MKJ, Auld, TD and Whelan, RJ 2004, 'Delayed post-fire seedling emergence linked to season: a case study with *Leucopogon* species (Epacridaceae)', *Plant Ecology*, 174, pp.183–196

Ramp ,D and Chapple, R 2010, *Managing for Ecosystem Change in the GBMWHA*, Final Report number AWRC01/2010, University of NSW, Sydney

Van Loon, AP 1977, *Bushland Fuel Quantities in the Blue Mountains: Litter and Understorey*. Forestry Commission of New South Wales Research Note No.33, Forestry Commission of NSW, Sydney

Whelan, RJ 1995, *The Ecology of Fire*, Cambridge University Press, Cambridge

Williams, PR 2000, 'Fire-stimulated rainforest seedling recruitment and vegetative regeneration in a densely grassed wet sclerophyll forest of north-eastern Australia', *Australian Journal of Botany*, 48, pp.651–658

Williams, R, Bradstock, R, Cary, G, Enright, N, Gill, AM, Whelan, R, Bowman, D, Clarke, P, Hennessy, K, Liedloff, A, Lucas, C and York, A 2009, *Implications of Climate Change for Management of Fire in Areas Managed for Biodiversity Conservation–a Preliminary Assessment*, unpublished CSIRO Report to Australian Department of Climate Change and Department of Environment, Water, Heritage and the Arts, Canberra

Zylstra, P 2009. *Forest Flammability: How Fire Works and What it Means for Fuel Control*. Fire Note 49 (December 2009). Bushfire Cooperative Research Centre, Melbourne. Also available at http://www.bushfirecrc.com/publications/downloads/0912_firenote49_lowres.pdf.

Additional Tables

TABLE 2. Vegetation formations, classes and endangered ecological communities of the Greater Blue Mountains World Heritage Area

TABLE 3. The eucalypts of the Greater Blue Mountains World Heritage Area

TABLE 4. Threatened flora and fauna of the Greater Blue Mountains World Heritage Area.

TABLE 2. Vegetation formations, classes and endangered ecological communities of the Greater Blue Mountains World Heritage Area. The estimated total coverage in the GBMWHA of each vegetation formation and class (based on Keith 2004) is given in hectares (ha) and as a percent (%). The coverages are based on the latest vegetation mapping (see Figure 6). Endangered ecological communities in the GBMWHA (under the NSW Threatened Species Conservation (TSC) Act or the Australian Environmental Protection and Biodiversity Conservation (EPBC) Act) are listed against the vegetation class they fall within. Descriptions of the endangered communities can be found on the DECCW website at (www.environment.nsw.gov.au/threatenedspecies).

Vegetation formation and class	Coverage in GBMWHA		Endangered Ecological Communities
	(ha)	(%)	
Dry Sclerophyll Forests (all)	861513	83.8%	
Sydney Coastal Dry Sclerophyll Forests	3882	0.4%	
Sydney Montane Dry Sclerophyll Forests	123823	12.0%	
Sydney Hinterland Dry Sclerophyll Forests	535152	51.9%	
South East Dry Sclerophyll Forests	14310	1.4%	
Southern Tableland Dry Sclerophyll Forests	61299	5.9%	
Western Slopes Dry Sclerophyll Forests	4712	0.5%	Hunter Valley Footslopes Slaty Gum Woodland (Vulnerable, TSC Act)
Sydney Sand Flats Dry Sclerophyll Forests	5069	0.5%	
Central Gorge Dry Sclerophyll Forests	110546	10.7%	
Hunter-Macleay Dry Sclerophyll Forests	2720	0.3%	
Wet Sclerophyll Forests (all)	100860	9.8%	
North Coast Wet Sclerophyll Forests	55681	5.2%	
Southern Escarpment Wet Sclerophyll Forests	9424	0.9%	
Northern Hinterland Wet Sclerophyll Forests	3901	0.4%	Blue Mountains Shale Cap Forest (Endangered, TSC Act)
Southern Tableland Wet Sclerophyll Forests	31767	3.0%	Blue Mountains Shale Cap Forest (Endangered, TSC Act)
Rainforests (all)	15300	1.4%	
Dry Rainforests	6733	0.6%	Western Sydney Dry Rainforest (Endangered, TSC Act)
Northern Warm Temperate Rainforests (includes the intermediate Cool Temperate Rainforests)	8505	0.8%	
Heathlands (all)	19349	1.8%	
Sydney Coastal Heaths	2308	0.2%	
Sydney Montane Heaths	16789	1.6%	
Freshwater Wetlands (all)	4234	0.4%	
Coastal Heath Swamps	1664	0.2%	Blue Mountains Swamps (Vulnerable, TSC Act)

Newnes Plateau Shrub Swamps (Endangered, TSC Act)			
Temperate Highland Peat Swamps on Sandstone (Endangered, EPBC Act)			
Montane Bogs and Fens	2505	0.2%	Newnes Plateau Shrub Swamps (Endangered, TSC Act)
Montane Peatlands and Swamps (Endangered, TSC Act)			
Coastal Freshwater Lagoons	39	<0.1%	Sydney Freshwater Wetlands (Endangered, TSC Act)
Forested Wetlands (all)	5316	0.5%	
Coastal Floodplain Wetlands	2056	0.2%	River-flat Eucalypt Forest on Coastal Floodplains (Endangered, TSC Act)
Sydney Freshwater Wetlands (Endangered, TSC Act)			
Eastern Riverine Forests	3229	0.3%	
Grassy Woodlands (all)	24419	2.3%	
Coastal Valley Grassy Woodlands	9990	0.9%	Shale / Sandstone Transition Forest (Endangered, TSC Act & EPBC Act)
White Box Yellow Box Blakely's Red Gum Woodland (Endangered, EPBC Act)			
Subalpine Woodlands	3738	0.4%	
Tableland Clay Grassy Woodlands	607	<0.1%	
Southern Tableland Grassy Woodlands	984	<0.1%	White Box Yellow Box Blakely's Red Gum Woodland (Endangered, EPBC Act)
Western Slopes Grassy Woodlands	8972	<0.1%	White Box Yellow Box Blakely's Red Gum Woodland (Endangered, EPBC Act)

TABLE 3. The eucalypts of the Greater Blue Mountains World Heritage Area.
This list is based on a recent assessment of records held at the National Herbarium of NSW and in DECCW surveys by Hager and Benson (in press), and field observations and classification work by Klaphake (2009). It includes 96 species of eucalypts that have been formally documented in the eight reserves of the World Heritage Area, as well as a further 11 that may occur, but require further work to confirm. The species are listed with their common name, species group, growth form, relative distribution and the vegetation formations in which they usually occur: dry sclerophyll forests (DSF); wet sclerophyll forests (WSF); rainforests, (RF); heathlands (H); freshwater wetlands (FW); forested wetlands (ForW) and/or grassy woodlands (GW). Species groups within the genus *Eucalyptus* belong to one of two subgenera, either *Symphyomyrtus* (Adnataria, Bisectaria, Exsertaria, Maidenaria, Transversaria) or *Eucalyptus* (blue-leaved ashes, black sallies, green-leaved ashes, peppermints and stringybarks). Species recognised as either endangered (E) or vulnerable (V) under the *NSW Threatened Species Conservation Act 1995* are indicated.

Genus	Species	Common name	Group	Growth form	Distribution	DSF	WSF	RF	H	FW	ForW	GW
Angophora	*bakeri*	Narrow-leaved apple		small	widespread	y						
Angophora	*costata*	Smooth-barked apple		medium-tall	widespread	y	y					
Angophora	*euryphylla*	Large-fruited apple		medium	restricted	y						
Angophora	*floribunda*	Rough-barked apple		medium-tall	widespread	y	y	y			y	y
Angophora	*hispida*	Dwarf apple		small	restricted				y			
Corymbia	*eximia*	Yellow bloodwood		medium	widespread	y						
Corymbia	*gummifera*	Red bloodwood		medium-tall	widespread	y						
Corymbia	*maculata*	Spotted gum		tall	restricted		y					y
Corymbia	*trachyphloia subsp. amphistomatica*	White bloodwood		medium	restricted	y						
Eucalyptus	*aenea*	Narrow-leaved mallee box	Adnataria	mallee	restricted	y						
Eucalyptus	*agglomerata*	Blue-leaved stringybark	Stringybarks	tall	widespread	y	y					
Eucalyptus	*aggregata (V)*	Small-leaved gum	Maidenaria	small	restricted					y		y
Eucalyptus	*albens*	White box	Adnataria	medium	widespread							y
Eucalyptus	*amplifolia subsp. amplifolia*	Cabbage gum	Exsertaria	tall	widespread		y				y	y
Eucalyptus	*apiculata*	Wollondilly mallee ash	Green-leaved ashes	mallee	restricted				y			
Eucalyptus	*baeuerlenii*	Baeuerlen's gum	Maidenaria	mallee	restricted	y						
Eucalyptus	*baueriana*	Blue box	Adnataria	small-medium	restricted						y	y
Eucalyptus	*bensonii*	Benson's stringybark	Stringybarks	mallee	restricted				y			
Eucalyptus	*benthamii (V)*	Nepean River gum	Maidenaria	tall	restricted						y	
Eucalyptus	*beyeriana*	Beyer's ironbark	Adnataria	medium-tall	restricted	y						y
Eucalyptus	*bicostata*	Eurabbie	Maidenaria	tall	widespread		y					
Eucalyptus	*blakelyi*	Blakely's red gum	Exsertaria	small-medium	widespread							y

Eucalyptus	*blaxlandii*	Blaxland’s stringybark	Stringybarks	tall	widespread	y	y					
Eucalyptus	*bosistoana*	Bosisto’s box	Adnataria	tall	widespread		y					y
Eucalyptus	*bridgesiana*	Apple gum	Maidenaria	small-medium	widespread	y	y			y		y
Eucalyptus	*burgessiana*	Burgess’s mallee ash	Green-leaved ashes	mallee	restricted	y			y			
Eucalyptus	*caleyi subsp. caleyi*	Caley’s ironbark	Adnataria	medium	restricted	y						
Eucalyptus	*camphora subsp. camphora*	Variable-leaved swamp gum	Maidenaria	mallee	restricted					y	y	
Eucalyptus	*cannonii (V)*	Capertee stringybark	Stringybarks	small tree	restricted	y						y
Eucalyptus	*capitellata*	Brown stringybark	Stringybarks	small	localised	y						
Eucalyptus	*conica*	Fuzzy box	Adnataria	small-medium	restricted	y						y
Eucalyptus	*consideniana*	Yertchuk	Blue-leaved ashes	medium	widespread	y						
Eucalyptus	*corticosa (V)*	Olinda gum	Maidenaria	small	restricted	y						
Eucalyptus	*crebra*	Narrow-leaved ironbark	Adnataria	tall	widespread	y	y					y
Eucalyptus	*cunninghamii*	Cliff mallee ash	Green-leaved ashes	mallee	restricted				y			
Eucalyptus	*cypellocarpa*	Monkey gum	Maidenaria	tall	widespread	y	y	y				
Eucalyptus	*dalrympleana subsp. dalrympleana*	Mountain gum	Maidenaria	tall	widespread	y	y					
Eucalyptus	*dawsonii*	Slaty gum	Adnataria	tall	restricted	y						y
Eucalyptus	*deanei*	Broad-leaved blue gum	Transversaria	tall	widespread		y	y			y	
Eucalyptus	*dendromorpha*	Southern Highlands ash	Green-leaved ashes	small	restricted		y					
Eucalyptus	*dives*	Broad-leaved peppermint	Peppermints	medium	widespread	y						
Eucalyptus	*dwyeri*	Dwyer’s red gum	Exsertaria	mallee-small	restricted	y						
Eucalyptus	*elata*	River peppermint	Peppermints	tall	widespread		y				y	
Eucalyptus	*eugenioides*	Thin-leaved stringybark	Stringybarks	tall	widespread	y	y					
Eucalyptus	*fastigata*	Brown barrel	Green-leaved ashes	tall	widespread		y	y				
Eucalyptus	*fergusonii subsp. dor-siventralis*	Winged ironbark	Adnataria	tall	restricted	y	y					

Eucalyptus	*fibrosa*	Flaky-barked ironbark	Adnataria	tall	widespread	y		y				y
Eucalyptus	*fracta (V)*	Small-leaved ironbark	Adnataria	small	restricted	y						
Eucalyptus	*globoidea*	White stringybark	Stringybarks	tall	widespread	y						y
Eucalyptus	*hypostomatica*	Southern forest box	Adnataria	tall	restricted		y					
Eucalyptus	*laevopinea*	Silvertop stringybark	Stringybarks	tall	restricted		y					
Eucalyptus	*laophila*	Newnes mallee ash	Green-leaved ashes	mallee	restricted	y			y			
Eucalyptus	*ligustrina*	Privet-leaved stringybark	Stringybarks	mallee	restricted	y			y			
Eucalyptus	*macarthurii (V)*	Paddy's river gum	Maidenaria	tall	restricted						y	y
Eucalyptus	*macrorhyncha*	Red Stringybark	Stringybarks	medium-tall	widespread	y						
Eucalyptus	*mannifera subsp. gul-lickii*	Western brittle gum	Maidenaria	small-medium	widespread	y						
Eucalyptus	*mannifera subsp. man-nifera*	Blue Mountain brittle gum	Maidenaria	small-medium	widespread	y						
Eucalyptus	*melliodora*	Yellow box	Adnataria	tall	widespread	y						y
Eucalyptus	*michaeliana*	Michael's gum	Exsertaria	medium-tall	restricted	y						
Eucalyptus	*moluccana*	Grey box	Adnataria	medium	widespread	y						y
Eucalyptus	*moorei*	Narrow-leaved sally	Black sallies	mallee	restricted				y	y		
Eucalyptus	*muelleriana*	Yellow stringybark	Stringybarks	tall	restricted	y	y					
Eucalyptus	*multicaulis*	Whipstick ash	Blue-leaved ashes	mallee	widespread				y			
Eucalyptus	*notabilis*	Mountain mahogany	Transversaria	tall	widespread	y						y
Eucalyptus	*nubila*	Blue-leaved ironbark	Adnataria	tall	restricted	y						y
Eucalyptus	*obliqua*	Messmate	Green-leaved ashes	tall	widespread		y					
Eucalyptus	*oreades*	Blue Mountains ash	Blue-leaved ashes	tall	widespread	y	y	y				
Eucalyptus	*ovata*	Swamp gum	Maidenaria	medium-tall	widespread					y		y
Eucalyptus	*paniculata subsp. paniculata*	Grey ironbark	Adnataria	tall	widespread		y					y
Eucalyptus	*parramattensis subsp. parramattensis*	Parramatta red gum	Exsertaria	small	widespread	y					y	

Eucalyptus	*pauciflora*	Snow gum	Blue-leaved ashes	medium	widespread							y
Eucalyptus	*pilularis*	Blackbutt	Peppermints	tall	widespread		y				y	
Eucalyptus	*piperita*	Sydney peppermint	Blue-leaved ashes	medium-tall	widespread	y	y					
Eucalyptus	*polyanthemos subsp. polyanthemos*	Red box	Adnataria	small-medium	widespread							y
Eucalyptus	*praecox*	Round-leaved brittle gum	Maidenaria	small-medium	widespread	y						?
Eucalyptus	*prominula*	Wollombi stringybark	Stringybarks	medium-tall	restricted	y						
Eucalyptus	*punctata*	Grey gum	Transversaria	medium-tall	widespread	y	y	y				y
Eucalyptus	*quadrangulata*	Serrated-leaved gum	Maidenaria	tall	restricted		y					
Eucalyptus	*radiata subsp. radiata*	Small-leaved pepermint	Peppermints	tall	widespread	y	y					
Eucalyptus	*ralla*	Nattai stringybark	Stringybarks	small	restricted	y						
Eucalyptus	*resinifera subsp. res-inifera*	Red mahogany	Transversaria	tall	widespread	y	y					
Eucalyptus	*rossii*	Inland scribbly gum	Blue-leaved ashes	medium	widespread	y						
Eucalyptus	*rubida subsp. rubida*	Candlebark	Maidenaria	tall	restricted							y
Eucalyptus	*saligna*	Sydney blue gum	Transversaria	tall	widespread		y				y	
Eucalyptus	*scias subsp. scias*	Large-fruited red mahogany	Transversaria	small	restricted	y						
Eucalyptus	*sclerophylla*	Hard-leaved scribby gum	Blue-leaved ashes	small-medium	widespread	y				y		
Eucalyptus	*sideroxylon*	Mugga ironbark	Adnataria	tall	widespread	y						y
Eucalyptus	*sieberi*	Silvertop ash	Blue-leaved ashes	small-tall	widespread	y	y					
Eucalyptus	*smithii*	Gully gum	Maidenaria	tall	widespread		y					
Eucalyptus	*sparsifolia*	Narrow-leaved stringybark	Stringybarks	small-medium	widespread	y						
Eucalyptus	*squamosa*	Scalybark	Bisectaria	small	restricted	y						
Eucalyptus	*stellulata*	Black sally	Black sallies	small	restricted	y				y		y
Eucalyptus	*stricta*	Blue Mountains mallee ash	Green-leaved ashes	mallee	widespread	y			y			
Eucalyptus	*tenella*	Small-leaved stringybark	Stringybarks	small	widespread	y						y

Eucalyptus	*tereticornis*	Forest red gum	Exsertaria	medium-tall	widespread	y	y	y			y	y
Eucalyptus	*viminalis*	Ribbon gum	Maidenaria	tall	widespread		y	y			y	y
Potential additional species, for which either the species name, identity or occurrence in the GBMWHA is still to be confirmed												
Eucalyptus	*copulans (E)*	Wentworth Falls sally	Known from just outside the GBMWHA at Wentworth Falls									
Eucalyptus	*dealbata*	Tumbledown red gum	Species listed in the original nomination, but is unconfirmed in northern Wollemi									
Eucalyptus	*expressa*		New species (also known as Eucalyptus sp. aff. eugenioides (Bees Nest Ridge) currently being named									
Eucalyptus	*gregsoniana*	Wolgan snow gum	Possibly occurs in western Wollemi NP, yet to be confirmed									
Eucalyptus	*nobilis*	Northern ribbon gum	Reported from Wollemi NP, near Mount Coricudgy, yet to be confirmed									
Eucalyptus	*siderophloia*	Grey-leaved ironbark	Species in the original nomination, recorded near Yengo National Park, but not confirmed in the park									
Eucalyptus	*sp. Blackheath*	Giant mallee ash	Included to date under E. dendromorpha, possible new species, occurs in wet heath (Klaphake 2009)									
Eucalyptus	*sp. 'Howes Swamp Creek' (E)*		Also known as Eucalyptus wollemiensis, occurs in Wollemi NP, species name yet to be confirmed									
Eucalyptus	*sp. Yarrawarra*	Yarrawarra ironbark	Possible new species on sandstone soils in northern-most Wollemi (Klaphake 2009)									
Eucalyptus	*sp. Yengo*	Crown-fruited stringybark	Possible new species, occurs in Wollemi and Yengo NPs (Klaphake 2009)									
Eucalyptus	*umbra*	Thick-leaved mahogany	Species in the original nomination, recorded east of Yengo NP, but not confirmed in the park									

TABLE 4. Threatened flora and fauna of the Greater Blue Mountains World Heritage Area.
This list has been compiled from records held in the NSW NPWS Wildlife Atlas (search date: October 2010) and the Royal Botantic Gardens PlantNet (www.plantnet.rbgsyd.nsw.gov.au). A total of 97 flora species and 54 fauna species (6 amphibians, 25 birds, 1 insect, 3 reptiles, 19 mammals) are included. Their status under the NSW *Threatened Species Conservation Act 1995* is indicated as either endangered (E; likely to become extinct or in immediate danger of extinction) or vulnerable (V; likely to become endangered unless the circumstances and factors threatening its survival or evolutionary development cease to operate). There may be other threatened species not listed here that also occur in the GBMWHA.

Broad group	Family	Scientific name	Common name	TSC Act
Flora	Anthericaceae	*Caesia parviflora var. minor*	Small Pale Grass-lily	E
Flora	Apiaceae	*Trachymene scapigera*		E
Flora	Apiaceae	*Xanthosia scopulicola*		V
Flora	Apocynaceae	*Cynanchum elegans*	White-flowered Wax Plant	E
Flora	Araliaceae	*Astrotricha crassifolia*	Thick-leaf Star-hair	V
Flora	Asteraceae	*Olearia cordata*		V
Flora	Asteraceae	*Stemmacantha australis*		E
Flora	Casuarinaceae	*Allocasuarina glareicola*		E
Flora	Cunoniaceae	*Acrophyllum australe*		V
Flora	Cyperaceae	*Carex klaphakei*	Klaphake's Sedge	E
Flora	Cyperaceae	*Lepidosperma evansianum*	Evans Sedge	V
Flora	Dilleniaceae	*Hibbertia procumbens*	Spreading Guinea Flower	E
Flora	Dilleniaceae	*Hibbertia puberula*		E
Flora	Dryopteridaceae	*Lastreopsis hispida*	Bristly Shield Fern	E
Flora	Elaeocarpaceae	*Tetratheca glandulosa*		V
Flora	Ericaceae	*Epacris hamiltonii*		E
Flora	Ericaceae	*Epacris sparsa*	Sparse Heath	V
Flora	Ericaceae	*Leucopogon fletcheri subsp. fletcheri*		E
Flora	Fabaceae (Faboideae)	*Bossiaea oligosperma*	Few-seeded Bossiaea	V
Flora	Fabaceae (Faboideae)	*Dillwynia tenuifolia*		V
Flora	Fabaceae (Faboideae)	*Kennedia retrorsa*		V
Flora	Fabaceae (Faboideae)	*Phyllota humifusa*	Dwarf Phyllota	V
Flora	Fabaceae (Faboideae)	*Pultenaea glabra*	Smooth Bush-Pea	V
Flora	Fabaceae (Faboideae)	*Pultenaea sp. Olinda*		E
Flora	Fabaceae (Faboideae)	*Pultenaea villifera var. villifera*	Pultenaea villifera Sieber ex DC. popu	E
Flora	Fabaceae (Mimosoideae)	*Acacia bakeri*	Marblewood	V
Flora	Fabaceae (Mimosoideae)	*Acacia baueri subsp. aspera*		V
Flora	Fabaceae (Mimosoideae)	*Acacia bynoeana*	Bynoe's Wattle	E
Flora	Fabaceae (Mimosoideae)	*Acacia clunies-rossiae*	Kanangra Wattle	V
Flora	Fabaceae (Mimosoideae)	*Acacia flocktoniae*	Flockton Wattle	V
Flora	Fabaceae (Mimosoideae)	*Acacia gordonii*		E
Flora	Fabaceae (Mimosoideae)	*Acacia pubescens*	Downy Wattle	V
Flora	Goodeniaceae	*Velleia perfoliata*		V
Flora	Grammitidaceae	*Grammitis stenophylla*	Narrow-leaf Finger Fern	E
Flora	Gyrostemonaceae	*Gyrostemon thesioides*		E
Flora	Haloragaceae	*Haloragodendron lucasii*		E
Flora	Lamiaceae	*Prostanthera cineolifera*	Singleton Mint Bush	V

Flora	Lamiaceae	*Prostanthera cryptandroides subsp. cryptandroides*	Wollemi Mint-bush	V
Flora	Lamiaceae	*Prostanthera discolor*		V
Flora	Lamiaceae	*Prostanthera stricta*	Mount Vincent Mint-bush	V
Flora	Myrtaceae	*Baeckea kandos*		E
Flora	Myrtaceae	*Callistemon linearifolius*	Netted Bottle Brush	V
Flora	Myrtaceae	*Darwinia biflora*		V
Flora	Myrtaceae	*Darwinia peduncularis*		V
Flora	Myrtaceae	*Eucalyptus aggregata*	Black Gum	V
Flora	Myrtaceae	*Eucalyptus benthamii*	Camden White Gum	V
Flora	Myrtaceae	*Eucalyptus cannonii*	Capertee Stringybark	V
Flora	Myrtaceae	*Eucalyptus corticosa*	Creswick Apple Box	V
Flora	Myrtaceae	*Eucalyptus fracta*		E
Flora	Myrtaceae	*Eucalyptus macarthurii*	Camden Woollybutt	V
Flora	Myrtaceae	*Eucalyptus sp. 'Howes Swamp Creek'*		E
Flora	Myrtaceae	*Homoranthus darwinioides*		V
Flora	Myrtaceae	*Kunzea cambagei*	Cambage Kunzea	V
Flora	Myrtaceae	*Melaleuca biconvexa*	Biconvex Paperbark	V
Flora	Myrtaceae	*Melaleuca deanei*	Deane's Paperbark	V
Flora	Myrtaceae	*Melaleuca groveana*	Grove's Paperbark	V
Flora	Myrtaceae	*Syzygium paniculatum*	Magenta Lilly Pilly	E
Flora	Orchidaceae	*Diuris aequalis*	Buttercup Doubletail	E
Flora	Orchidaceae	*Diuris pedunculata*	Small Snake Orchid	E
Flora	Orchidaceae	*Prasophyllum fuscum*	Slaty Leek Orchid	E
Flora	Orchidaceae	*Prasophyllum pallens*	Musty Leek Orchid	V
Flora	Orchidaceae	*Pterostylis nigricans*	Dark Greenhood	V
Flora	Orchidaceae	*Pterostylis saxicola*	Sydney Plains Greenhood	E
Flora	Poaceae	*Ancistrachne maidenii*		V
Flora	Podocarpaceae	*Pherosphaera fitzgeraldii*	Blue Mountains Pine	E
Flora	Proteaceae	*Grevillea evansiana*	Evans Grevillea	V
Flora	Proteaceae	*Grevillea juniperina subsp. juniperina*	Juniper-leaved Grevillea	V
Flora	Proteaceae	*Grevillea obtusiflora subsp. fecunda*		E
Flora	Proteaceae	*Grevillea parviflora subsp. parviflora*		V
Flora	Proteaceae	*Grevillea parviflora subsp. supplicans*		E
Flora	Proteaceae	*Hakea dohertyi*	Kowmung Hakea	E
Flora	Proteaceae	*Isopogon fletcheri*	Fletcher's Drumstricks	V
Flora	Proteaceae	*Persoonia acerosa*	Needle Geebung	V
Flora	Proteaceae	*Persoonia bargoensis*	Bargo Geebung	E
Flora	Proteaceae	*Persoonia glaucescens*	Mittagong Geebung	E
Flora	Proteaceae	*Persoonia hirsuta*	Hairy Geebung	E
Flora	Proteaceae	*Persoonia marginata*	Clandulla Geebung	V

Flora	Restionaceae	*Baloskion longipes*	Dense Cord-rush	V
Flora	Rhamnaceae	*Pomaderris bodalla*	Bodalla Pomaderris	V
Flora	Rhamnaceae	*Pomaderris brunnea*	Brown Pomaderris	V
Flora	Rhamnaceae	*Pomaderris cotoneaster*	Cotoneaster Pomaderris	E
Flora	Rhamnaceae	*Pomaderris sericea*	Silky Pomaderris	E
Flora	Rutaceae	*Asterolasia buxifolia*		E
Flora	Rutaceae	*Boronia deanei*	Deane's Boronia	V
Flora	Rutaceae	*Leionema lachnaeoides*		E
Flora	Rutaceae	*Leionema sympetalum*	Rylstone Bell	V
Flora	Rutaceae	*Zieria covenyi*	Coveny's Zieria	E
Flora	Rutaceae	*Zieria involucrata*		E
Flora	Rutaceae	*Zieria murphyi*	Velvet Zieria	V
Flora	Scrophulariaceae	*Euphrasia bowdeniae*		V
Flora	Scrophulariaceae	*Euphrasia scabra*	Rough Eyebright	E
Flora	Solanaceae	*Solanum amourense*		E
Flora	Sterculiaceae	*Keraudrenia corollata var. denticulat*	Keraudrenia corollata var. denticulata	E
Flora	Sterculiaceae	*Lasiopetalum joyceae*		V
Flora	Sterculiaceae	*Rulingia prostrata*	Dwarf Kerrawang	E
Flora	Thymelaeaceae	*Pimelea curviflora var. curviflora*		V
Flora	Rhamnaceae	*Pomaderris queenslandica*	Scant Pommaderris	E
Amphibia	Hylidae	*Litoria booroolongensis*	Booroolong Frog	E
Amphibia	Hylidae	*Litoria littlejohni*	Littlejohn's Tree Frog	V
Amphibia	Myobatrachidae	*Heleioporus australiacus*	Giant Burrowing Frog	V
Amphibia	Myobatrachidae	*Mixophyes balbus*	Stuttering Frog	E
Amphibia	Myobatrachidae	*Mixophyes iteratus*	Giant Barred Frog	E
Amphibia	Myobatrachidae	*Pseudophryne australis*	Red-crowned Toadlet	V
Aves	Acanthizidae	*Pyrrholaemus saggitatus*	Speckled Warbler	V
Aves	Accipitridae	*Hamirostra melanosternon*	Black-breasted Buzzard	V
Aves	Accipitridae	*Hieraaetus morphnoides*	Little Eagle	V
Aves	Accipitridae	*Lophoictinia isura*	Square-tailed Kite	V
Aves	Ardeidae	*Ixobrychus flavicollis*	Black Bittern	V
Aves	Cacatuidae	*Callocephalon fimbriatum*	Gang-gang cockatoo	V
Aves	Cacatuidae	*Calyptorhynchus lathami*	Glossy-Black Cockatoo	V
Aves	Climacteridae	*Climacteris picumnus*	Brown Treecreeper	V
Aves	Climacteridae	*Climacteris picumnus victoriae*	Brown Treecreeper (eastern subspecies)	V
Aves	Estrildidae	*Stagonopleura guttata*	Diamond Firetail	V
Aves	Meliphagidae	*Grantiella picta*	Painted Honeyeater	V
Aves	Meliphagidae	*Melithreptus gularis gularis*	Black-chinned Honeyeater (eastern subspecies)	V
Aves	Meliphagidae	*Xanthomyza phrygia*	Regent Honeyeater	E
Aves	Neosittidae	*Daphoenositta chrysoptera*	Varied Sittella	V
Aves	Petroicidae	*Melanodryas cucullata cucullata*	Hooded Robin (south-eastern form)	V

Aves	Petroicidae	*Petroica boodang*	Scarlet Robin	V
Aves	Petroicidae	*Petroica phoenicea*	Flame Robin	V
Aves	Pomatostomidae	*Pomatostomus temporalis temporalis*	Grey-crowned Babbler (eastern subspecies)	V
Aves	Psittacidae	*Glossopsitta pusilla*	Little Lorkeet	V
Aves	Psittacidae	*Lathamus discolor*	Swift Parrot	V
Aves	Psittacidae	*Neophema pulchella*	Turquoise Parrot	V
Aves	Strigidae	*Ninox connivens*	Barking Owl	V
Aves	Strigidae	*Ninox strenua*	Powerful Owl	V
Aves	Tytonidae	*Tyto novaehollandiae*	Masked Owl	V
Aves	Tytonidae	*Tyto tenebricosa*	Sooty Owl	V
Insecta	Petaluridae	*Petalura gigantea*	Giant Dragonfly	E
Mammalia	Burramyidae	*Cercartetus nanus*	Eastern Pygmy-possum	V
Mammalia	Dasyuridae	*Dasyurus maculatus*	Spotted-tailed Quoll	V
Mammalia	Emballonuridae	*Saccolaimus flaviventris*	Yellow-bellied Sheathtail-bat	V
Mammalia	Macropodidae	*Macropus parma*	Parma Wallaby	V
Mammalia	Macropodidae	*Petrogale penicillata*	Brush-tailed Rock-wallaby	E
Mammalia	Molossidae	*Mormopterus norfolkensis*	Eastern Freetail-bat	V
Mammalia	Peramelidae	*Isoodon obesulus obesulus*	Southern Brown Bandicoot (eastern)	E
Mammalia	Petauridae	*Petaurus australis*	Yellow-bellied Glider	V
Mammalia	Petauridae	*Petaurus norfolcensis*	Squirrel Glider	V
Mammalia	Phascolarctidae	*Phascolarctos cinereus*	Koala	V
Mammalia	Pteropodidae	*Pteropus poliocephalus*	Grey-headed Flying-fox	V
Mammalia	Vespertilionidae	*Chalinolobus dwyeri*	Large-eared Pied Bat	V
Mammalia	Vespertilionidae	*Falsistrellus tasmaniensis*	Eastern False Pipistrelle	V
Mammalia	Vespertilionidae	*Miniopterus australis*	Little Bentwing-bat	V
Mammalia	Vespertilionidae	*Miniopterus schreibersii oceanensis*	Eastern Bentwing-bat	V
Mammalia	Vespertilionidae	*Myotis macropus*	Large-footed Myotis	V
Mammalia	Vespertilionidae	*Nyctophilus timoriensis (south-eastern form)*	Greater Long-eared Bat	V
Mammalia	Vespertilionidae	*Scoteanax rueppellii*	Greater Broad-nosed Bat	V
Mammalia	Vespertilionidae	*Vespadelus troughtoni*	Eastern Cave Bat	V
Reptilia	Elapidae	*Hoplocephalus bungaroides*	Broad-headed Snake	E
Reptilia	Scincidae	*Eulamprus leuraensis*	Blue Mountains Water skink	E
Reptilia	Varanidae	*Varanus rosenbergi*	Rosenberg’s Goanna	V