The implications of climate change for biodiversity conservation and the National Reserve System: sclerophyll forests of south-eastern Australia

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Executive summary

The open eucalypt and tall open eucalypt forests of south-eastern Australia occupy a special place in the psyche of many Australians. As the 'back yard' for millions of people, they represent the quintessential Australian forest environment, and contain the world's tallest angiosperms. They are also at the forefront of public perception because of conflicts over conservation versus timber extraction, and the bushfire threat, never more clearly demonstrated than in Victoria in February 2009. And yet this status, and that of many other eucalypt-dominated forest ecosystems in the south-east, is precarious, and the challenges facing conservation management of sclerophyll forests are especially acute in south-eastern Australia.

A combination of literature review, expert workshop and modelling was used to assess the likely impacts of climate change on the biodiversity of the sclerophyll forests and associated communities of south-eastern Australia, and the implications for conservation and the National Reserve System. The biodiversity in the forest biome is likely to experience high levels of biotically significant environmental stress by 2070, with noticeably higher stress under a higher emissions scenario. Substantial proportions of the biome are likely to experience levels of environmental change in the future that are consistent with contemporary differences in vegetation structure (e.g. between Major Vegetation Group classes) and considerable differences in species composition (e.g. about 80% turnover for plants). These environmental changes do not directly imply species extinctions, although considerable changes in species and ecosystems are highly likely, with losses where species are dispersal-limited or local environmental buffering is inadequate.

Changes in moisture regimes (and total moisture availability) are likely to be responsible for most change, probably through direct effects on plant growth; changes in fire regimes in much of the biome are likely to interact with and add to changes in moisture regimes. The biome is in a topographically and environmentally complex region of Australia; as a result forest ecosystems may be somewhat more resilient than others as they have the prospect of shifts in distribution both horizontally (i.e. east–west, north–south) and vertically (elevation), and at local and regional scales.

Past clearing (mainly for agriculture) has rendered forests in some parts of the biome (i.e. the north) more vulnerable to change. Measures to mitigate climate change impacts will need to be varied and flexible, and based on existing conservation approaches, including the continued reservation of large tracts of forest, incorporating elevational gradients, and reducing other non-climate related threatening processes, such as invasive species and clearing.

1 Introduction

The open eucalypt and tall open eucalypt forests of south-eastern Australia occupy a special place in the psyche of many Australians. As the 'back yard' for millions of people, they represent the quintessential Australian forest environment, and contain the world's tallest angiosperms. They are also at the forefront of public perception because of conflicts over conservation versus timber extraction, and the bushfire threat, never more clearly demonstrated than in Victoria in February 2009. And yet this status, and that of many other eucalypt-dominated forest ecosystems, is precarious, and the challenges facing conservation management of sclerophyll forests are especially acute in south-eastern Australia.

1.1 Aims, background and context

This report describes and illustrates potential impacts of climate change on the sclerophyll forests of south-eastern Australia. It focuses on broadscale impacts on forest environments and forest biota using two modelling approaches, and draws on the results of a prior literature review and expert workshop. It explores the direction and magnitude of change in the distributions of major vegetation types within the biome, and discusses the general consequences for ecological processes, conservation measures and vegetation management. The report does not attempt to explain, either at a site level or in terms of detailed aspects of forest ecology, all the likely changes to forest structure and composition.

This report is one of nine on the impacts of climate change on the National Reserve System (NRS). The others are three biome reports: hummock grasslands (Smyth et al. 2012), tropical savanna woodlands and grasslands (Liedloff et al. 2012), temperate grasslands and grassy woodlands (Prober et al. 2012); four modelling reports: climate downscaling (Harwood et al. 2012); generalised dissimilarity modelling (Ferrier et al. 2012); artificial neural network modelling (Hilbert and Fletcher 2012); Bayesian belief network modelling (Martin et al. 2012); and an overall synthesis report (Dunlop et al. 2012). The work in this report has been undertaken by CSIRO in consultation with State and Federal environmental agencies, universities, private consultants and the Climate Change in Agriculture and Natural Resources Working Group (CLAN). It builds on an earlier report on the implications of climate change for the NRS (Dunlop and Brown 2008), which had a national-scale focus; in contrast, this phase of the project has drawn on regional-scale ecological knowledge and analysis.

There is mounting scientific evidence for recent biodiversity impacts of climate change in Australia (C_4 grasses, Johnson et al. 1999; CO_2 effects on vegetation, Berry and Roderick 2002; overall impacts, Hughes 2003; birds, Chambers et al. 2005, Gibbs 2007; predator-prey interactions, Madsen et al. 2006; plant physiological changes, Cullen et al. 2008; trends in vegetation cover, Donohue et al. 2009; vulnerability, Steffen et al. 2009). Of particular concern is the forecast that the effects of climate change will continue for the next century even if near-term emission reduction efforts are successful (Fischlin and Midgley 2007). Biodiversity security into the future is important, as human health depends on it (see evidence in Chivian and Berstein 2008), and there is an urgency to develop on-ground climate adaptation policies for biodiversity (Westoby and Burgman 2006). The first phase of the project highlighted that while the strategic regional framework of Australia's NRS was well suited to addressing the impacts of climate change, it is likely to present considerable challenges to conservation and for the NRS, especially given the history of the development of the NRS over the last 100 years. In particular, the details of regional-scale impacts are likely to be critical.

Climate change impacts on the sclerophyll forests of south-eastern Australia are a national concern as the biome extends over six jurisdictions (Queensland, New South Wales, Victoria, ACT, Tasmania and South Australia); has significant economic, ecological and cultural importance; and is subject to a range of non-climate related threatening processes that compromise its biodiversity and conservation values.

Dunlop and Brown's (2008) hierarchical framework for understanding environmental change envisioned a cascade of impacts as a series of flow-on and feedback effects on the biology and ecology of individuals, species populations, ecosystems and eventually people (Figure 1). Many types of change affect biological and societal phenomena, with considerable uncertainty. It is clear that the responses of individual organisms to climate change will be manifested through changes in the phenology, relative abundances and range of many species (Hughes 2003; Dunlop and Brown 2008; Steffen et al. 2009), community structure (Hilbert and Fletcher 2012) and composition (Ferrier et al. 2012), species interactions (Schweiger et al. 2008) and ecosystem processes (Brown et al. 1997). However, other forceful environmental stressors will interactively affect biological phenomena, the outcomes of which are uncertain. It is certain that changes will occur in all parts of the cascade and conservation management needs to focus on minimising losses of biodiversity values (Dunlop and Brown 2008). There is an urgent need to identify what changes to biodiversity management and the NRS are necessary to manage this process.

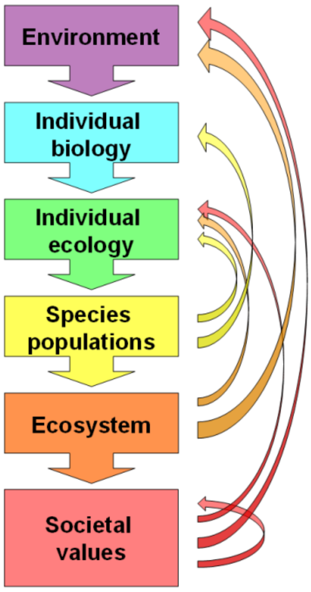

Figure 1 Schematic representation of cascading impacts on biological phenomena and societal values resulting from environmental changes. The direct flow of impacts is represented by large arrows. Important indirect flow is shown as feedback. Changes in the environment trigger many biological and societal changes which feed back to the environment

Source: Dunlop and Brown 2008

In this report, we (i) define the sclerophyll forest biome, (ii) describe the ecological and land use characteristics of the biome, (iii) identify environmental changes that are likely to occur by 2070 using climate modelling, (iv) postulate on how biodiversity will respond to the environmental changes, and close with (v) a discussion of the implications for climate adaptation in conservation and NRS planning. This report draws on a wide range of biome-specific information including literature review, expert workshop, ecological reasoning, and results of several modelling exercises. The modelling aims to quantify projected environmental change in ways that are ecologically more meaningful than direct temperature and rainfall projection. While the modelling itself is robust, it by necessity omits many of the factors and complexities that will determine ecological outcomes, including the direct effects of increases in CO_2 concentrations, changes in disturbances (such as fire), altered species interactions, and other pressures. These issues are addressed as much as possible drawing on the literature and expert knowledge. As such we use the modelling as a guide to help frame biological responses to future environmental change.

The complexity of the climate change-environment-biodiversity system and the extraordinary levels of unknown uncertainty restrict the ecological factors we can make definitive comments about. In particular, we can make few, if any, statements for most species about threshold changes in species phenological, physiological and population responses to changes in CO_2, temperature, rainfall regimes and extreme events. Similarly, as critical as they are, we know very little about how the dynamics of species-specific interactions will change and what effects that will have on ecological processes.

1.2 A note on the modelling used in this report

The modelling uses relationships between the contemporary patterns of biodiversity (ecosystem classes and species composition) and various environmental parameters to describe future changes in the environment (driven by climate change) in ways that are biologically meaningful. We use the term 'biotically scaled environmental stress' (or 'environmental stress') to describe these measures of future environmental change. One version of environmental stress relates to how climate and other environmental variables influence vegetation or ecosystem structure (from the ANN models, Hilbert and Fletcher 2012); the other correlates with contemporary changes in species composition in various groups (from the GDM models, Ferrier et al. 2012). Thus they are much more biologically meaningful than direct measures of change in rainfall or temperature. And while not as simple to conceptualise as projected changes in species distributions, we believe these environmental stress measures are actually much more robust as they are based on community- or ecosystem-level patterns (hence they eliminate many idiosyncrasies of species-level patterns and patchy data) and they make no assumptions about future biodiversity responses.

When applied to current environmental data, the GDM models predict *differences in species composition* at the community level between locations. In this report we have used the same GDM models to quantify predicted *change in the environment* at each location *A* that might result from climate change. The GDM quantifies the change in terms of the contemporary difference in composition that would occur, on average, between two locations *A* and *B* whose environments differ (now) by the same amount that the environment is expected to change at location *A*. Thus, it is a measure of *future environmental change* expressed in terms of *current patterns of species compositions*. Future environmental change is very likely to result in much compositional change, but such changes will be affected by many unquantified factors, including the population dynamics of each species, and interactions between species and other environmental factors we have not considered; hence our choice to describe the GDM outputs as relating to the *environment* rather than presenting them as assumption-laden predictions of changes in *biodiversity*.

1.3 The sclerophyll forest biome

The sclerophyll forests of south-east Australia, distributed in an arc from Gladstone in Queensland to Quorn in South Australia on the mainland, and including the whole of Tasmania, comprise a complex of biodiverse ecosystems of critical importance for conservation, recreation, water supply and rural economies. Intermixed with forests dominated by eucalypts (including *Eucalyptus* and *Corymbia* spp.) is a range of other forest types, notably rainforest (cool temperate, warm temperate and sub-tropical) and open eucalypt grassy woodlands and heathlands.

The biome includes a number of iconic protected areas, such as Blue Mountains, Wollemi and Kosciuszko National Parks in NSW; Namadgi National Park in the ACT; Snowy Mountains and Errinundra National Parks in Victoria; Fraser Island, Border Ranges and Conondale National Parks in Queensland; and the Southwest National Park (and broader Tasmanian Wilderness World Heritage Site) in Tasmania, as well as numerous smaller parks and reserves in all five States and Territories. At the northern extent of the biome as defined for this project (see below), eucalypt forests and associated rainforests form an important part of the Border Ranges national biodiversity hotspot. In addition, the importance of forest environments is recognised in their inclusion in three World Heritage sites: Gondwana Rainforests of Australia, Greater Blue Mountains and the Tasmanian Wilderness.

Regions identified by IPCC in 2001 (Basher et al. 2001) as being particularly vulnerable in Australia do not include sclerophyll forests of south-eastern Australia. However, with the temperature and mean annual rainfall ranges of many eucalypts within 1°C and 20% respectively, substantial shifts in species distributions might be expected. Given the important social and economic assets of national significance – including timber and other forest products, water (from forested catchments), recreation and tourism, aesthetic appeal, and Indigenous and cultural values – this could have serious environmental and socio-economic consequences.

1.3.1 GEOGRAPHIC SCOPE

This report covers (1) sclerophyll forests in the National Vegetation Information System (NVIS) Major Vegetation Groups (MVG) 2 (Eucalypt tall open forest), 3 (Eucalypt open forest), and 4 (Eucalypt low open forest) (DEWR 2007); and (2) closed forests (MVG 1 – Rainforests and vine thickets), which are found in close association with MVG 2 especially. Species of *Eucalyptus* and *Corymbia* dominate MVGs 2, 3 and 4, with a range of species dominant in the cool temperate and sub-tropical rainforests of MVG 1. Ecotonal communities, where understoreys of rainforest species are found beneath canopies of mature tall open-forest (typical 'wet sclerophyll' forest), are common as mosaics.

Eucalypt tall open forests are restricted in their distribution to Tasmania, the highlands of Victoria and the eastern seaboard (Figure 2), and in Western Australia. Eucalypt open forests are distributed in a discontinuous arc from south of Quorn in South Australia along the southern and eastern seaboards to northern Queensland, with large areas also in the Northern Territory and south-west Western Australia. Eucalypt low open forests have a restricted distribution in northern New South Wales, Tasmania and south-west Western Australia.

In a broad sense this biome is defined (in south-eastern Australia) by being largely bounded by the 600 mm long-term average isohyet (Gill and Catling 2002), and is consistent with agroclimatic zones D5, E1, F3 and F4 (Hutchinson et al. 2005). For the purposes of this project we set the geographic limits of the biome to Quorn in South Australia (western boundary) and Gladstone in Queensland (northern boundary).

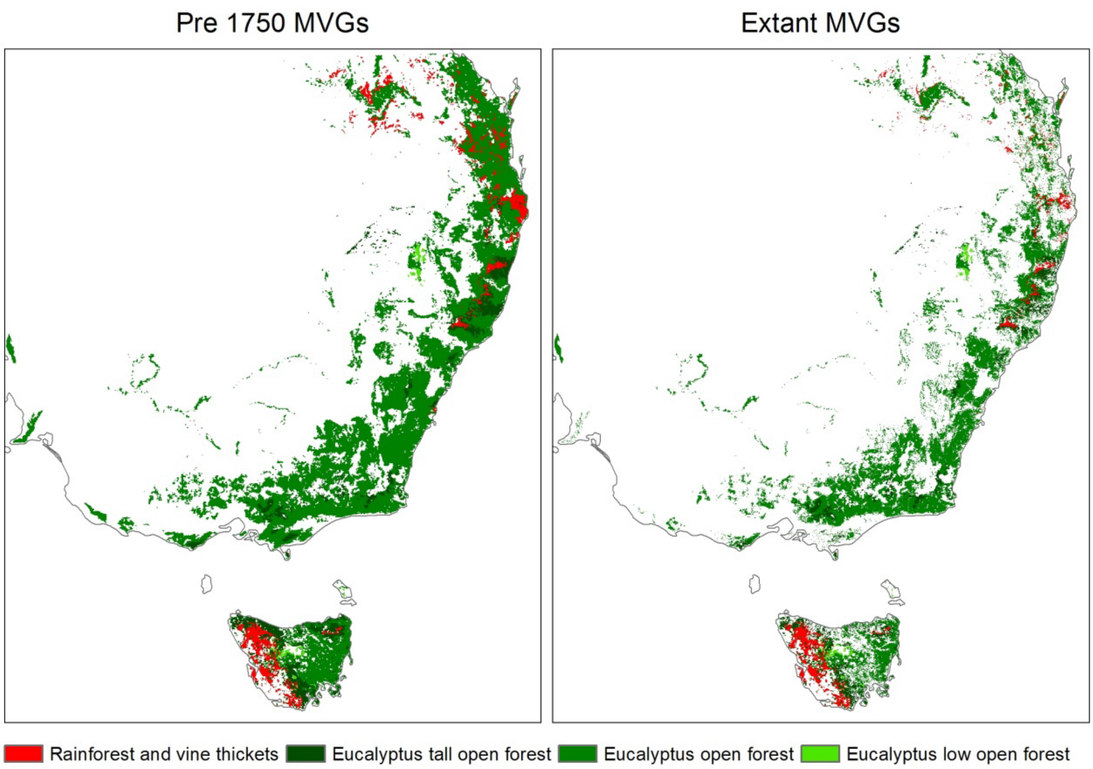

Figure 2 Modelled Pre-1750 and current distributions of major vegetation groups within the biome

Source: DEWR 2007

1.3.2 WHAT ARE THE STRUCTURING ECOLOGICAL PATTERNS AND PROCESSES IN THE TARGET ECOSYSTEMS?

The major drivers of forest ecosystems are terrain (elevation/slope/aspect), soils, fire and climate. These interact with anthropogenic processes in complex ways, summarised in Figure 3.

Terrain plays a critical role in structuring sclerophyll forest systems, which are associated with complex coastal and upland environments. The intimate arrangement of aspect, slope, elevation and the consequent controls on soils, microclimates and moisture create opportunities for fine-scale patterning in communities. This is exemplified in the arrangements of rainforests, tall open forests and open forests on short elevational gradients in dissected topographies along much of the eastern seaboard of the mainland and in Tasmania.

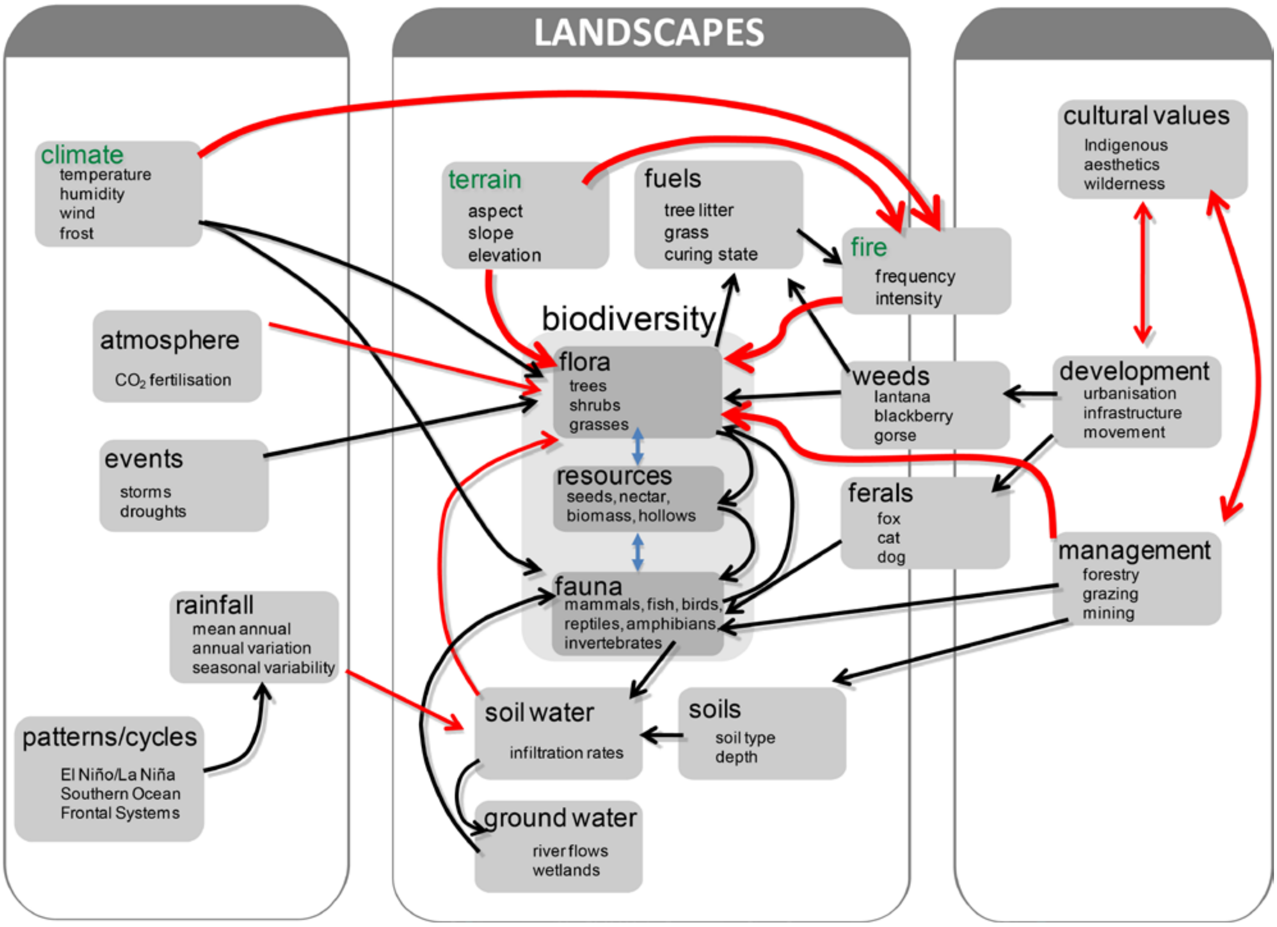

Figure 3 System diagram summarising relationships between key ecosystem drivers. Those in green are recognised as being especially important in sclerophyll forests. Red arrows are dominant regulatory processes; heavy lines indicate relative importance

Fire, as a dominant endogenous disturbance, driving patterns of forest composition and structure, is a complex ecological force for both stability and change. Sclerophyll vegetation throughout much of Australia has evolved with, and in response to, fire. As the Australian climate became drier during the Cainozoic period, charcoal and pollen of species of the family Myrtaceae become more abundant as fire became more frequent (Kershaw et al. 2002). A peak in fire activity around 40,000 yr BP has been attributed to the increased application of fire by Aboriginal people. Strategic fire management, primarily for asset protection, has largely supplanted pre-European fire regimes, although combinations of extreme events can still lead to catastrophic consequences. Within the biome there is a range of susceptibility and dependence on fires for the maintenance of forest dynamics, from fire-sensitive rainforests and coniferous forests, through tall open forests requiring stand-replacing fire events, to mixed forests in which lignotuberous species are tolerant of repeated, relatively frequent fires.

Climate contributes to the structuring of sclerophyll forests and associated forest types through (1) significant shifts in rainfall seasonality from south to north, and (2) local temperature and rainfall gradients along elevational gradients. Climate exerts control over forest distributions and dynamics through interactions with fire and terrain, and more directly through temperature (at high elevations) and rainfall (limiting forest environments to > 600 mm yr^{-1}). The paleo-ecological record suggests that the major driving force behind the development of sclerophylly in Australian vegetation has been climate (i.e. increasing aridity), with increased fire activity a result of this, rather than fire itself being a major force in the evolution of the Australian flora.

From a forest ecological dynamics perspective, changes in temperature, rainfall and evapotranspiration will have important implications for plant growth, disturbance patterns (especially fire, Cary 2002), and changes to the distribution of fundamental and realised niches (Austin et al. 1990); wet sclerophyll forests and associated rainforests are especially at risk (Dunlop and Brown 2008).

1.3.3 THREATS AND CHANGES SINCE EUROPEAN SETTLEMENT

Clearing for agriculture and urban development has affected forests along the eastern seaboard of Australia, and has led to fragmentation especially in the northern part of the biome. As eucalypt open forests and tall open forests occur in relatively high rainfall zones, those in accessible parts of the topography have been subject to clearance for agriculture, particularly in northern New South Wales and southern Queensland. In the higher altitude regions of southern New South Wales, Victoria and Tasmania, the steepness of the topography and severity of winters render forest country largely inappropriate for agriculture. However, these environments have been affected by management for timber, resulting in 'internal' fragmentation (i.e. although there are still large contiguous areas of forests in south-eastern Australia, these have been broken up by roads, logging coupes, fire management) that impacts adversely on species and ecosystems (Norton 1996). Forest environments in south-eastern Australia have undergone landscape fragmentation through clearing for agriculture, exotic tree plantations, transport and human settlement, affecting fire patterns and, consequently, floristic diversity (Gill and Williams 1996).

Fire is a natural and necessary factor in the dynamics of sclerophyll forests. Changes to fire regimes (as a result of climate change) or the application of inappropriate regimes through management can impair important forest processes such as regeneration, nutrient cycling and the development of structural complexity. There is considerable variation in fire susceptibility and dependence in forests across south-eastern Australia. In the south (including parts of Tasmania), and especially at higher altitudes, the dynamics of regeneration of the major forest dominants is stand replacement after catastrophic fire; in the north, fires tend to be less damaging and forests are composed (at least in part) of species that resprout after fire (through lignotubers). However, across much of this region sclerophyll forests are made up of complex mixtures of these fire-response types – for instance, in northern New South Wales and southern Queensland, topography and microclimate have led to stands of mixed age, lignotuberous species in exposed, upper slope and ridge environments, with even-aged, non-resprouting species in protected gullies and lower slopes (wet sclerophyll), with pyrophobic rainforest the ultimate expression of this pattern in lower parts of the landscape that are protected for long periods from damaging fires. Alterations, in terms of both increasing and decreasing fire frequency, will have significant impacts on the structure and composition of tall open forests. A relaxation of fire frequency is likely to lead to increased shrubbiness in open forests with naturally grassy understoreys, and invasion and establishment of pyrophobic closed canopy rainforests in tall open forests, within edaphic limits. These processes already occur locally and follow cycles of fire frequency. Increased incidence of fire in shrubby open forests can also lead to structural simplification and increased grass cover at the expense of understorey shrubs. Again, this occurs under current regimes, especially where frequent fires are lit to promote grass growth for grazing animals. Changes in fire management policies, for example increased application of prescribed burning practices for improved asset protection, will also lead to shifts in forest structures and compositions.

Timber harvesting has been practised extensively in eucalypt forests since the arrival of Europeans in the late eighteenth century and can be both a threat and an asset in forested environments. Harvesting operations have been the basis of a substantial industry and have led to the development of a number of regional settlements. Timber harvesting and silvicultural practices have, to a large extent, been based on the natural structures and regeneration patterns of the forests. In the tall open forests, where natural stand dynamics are driven by periodic catastrophic fire, harvesting has generally followed a coupe/clearfall model and can mimic natural-stand replacement processes; in mixed-age open forests this is replaced by selective harvesting, except where harvesting for woodchips is practised (Florence 1996). However, some practices such as slash burning (Neyland 2004) and the impact of heavy machinery on soils (Pennington et al. 2004) may threaten structural and compositional diversity.

Pests and diseases and *exotic plants and animals* pose a threat in all Australian biomes. In south-eastern Australian forests these threats include feral animals such as foxes (Saunders et al. 1995), cats and wild dogs (Johnson 2006), pigs (Choquenot et al. 1996), goats (Pisanu et al. 2005) and horses (Nimmo et al. 2007). There are many weeds in the biome, but among the most serious are blackberry (Thorp and Lynch 2000), lantana (Gooden et al. 2009), cat's claw creeper (Batianoff and Butler 2002), camphor laurel (Neilan et al. 2006), bridal creeper (Morin et al. 2006), and broad-leaved privet (Swarbrick et al. 1999). The pathogen *Phytophthora cinnamomi* has been present in south-eastern forests for many decades and is predicted to change in host specificity and distribution with climate change (Cahill et al. 2008); there is no published modelling for Australia, but in Europe, increased winter temperatures are predicted to allow the spread of *P. cinnamomi* into areas in eastern Europe that are currently free of the pathogen (Bergot et al*.* 2004). In general, model predictions of the rates of geographic shift in regional climates indicate that they will outstrip the rates at which many species can move: the lag period between the change in climate and the establishment of 'new' arrangements of species and ecosystems is a time in which the original vegetation might be susceptible to dieback (Loehle and LeBlanc 1996). It is unknown how significant examples of dieback in south-eastern Australian forests (e.g. bell-miner mediated dieback: Wardell-Johnson et al*.* 2005; Stone and Haywood 2006) will be affected by climate change, but increased physiological stress caused by higher temperatures and lower rainfall could place a larger proportion of the forest estate under threat.

Cattle grazing occurs in open forests with grassy ground layers and can have severe local impacts. The attendant fire management to promote grassiness can also lead to nutrient run-down and compromised regeneration. Direct impacts of grazing include changes to fine fuel loads and hence fire behaviour; increased fire frequencies due to grazing burns to promote grass growth over shrub and tree regeneration (Tasker and Bradstock 2006); localised degradation of stream banks and water quality (Jansen and Robertson 2001; Lunt et al*.* 2007); and loss of understorey richness and structural complexity (Tasker and Bradstock 2006).

Recreational use is high, as forests form the backdrop for much of the most densely populated parts of Australia along the eastern and southern seaboards, and as such represent a vital asset for recreation opportunities and outdoors experiences. Many people equate wet sclerophyll forests and rainforests with areas of high biodiversity (McAlpine et al*.* 2005), and these environments are popular foci for recreational activities across south-eastern Australia – this is in part due to a bias towards protection of these forest assets in the formal reserve system (McAlpine et al*.* 2007). Alterations in the position of the sclerophyll-rainforest ecotone, mediated by climate-induced changes to fire regimes, may render these areas less attractive to recreational users, but there are also inherent risks to these areas posed by recreational activities in addition to climate change such as unplanned fires, weeds, harvesting of wild plants, introduction of domestic pets and trampling (Sun and Walsh 1998).

1.3.4 CLIMATE CHANGE IMPACTS ON KEY ECOSYSTEM PROCESSES

Fire

Many alterations in ecological processes, species distributions, and community compositions in forests caused by climate change will be mediated by change to fire regimes. Fire has been a major moulding force in Australian vegetation over the last 40,000 years, and especially in the last 11,000 (Kershaw et al. 2002). Indications are that fire frequency will increase in south-eastern Australian forests with progressive climate change (Cary 2002), placing additional stresses on biota, particularly those that depend on longer inter-fire periods and a mosaic of post-fire recovery stages (e.g. Leadbeater's possum) and those that require the supply of hollow-bearing trees for nesting (Koch et al. 2008). The likely major influence of climate change on fire in sclerophyll forests will be on frequency; fire intensity is also important and is predicted to increase, but anticipated changes are less than for frequency (Cary 2002). Increasing public pressure to conduct more frequent fuel reduction burning to protect human life and assets will be compounded by a climate-induced increase in fire frequency, leading to changes in forest structure and composition over time, especially in forest understoreys. The impacts on individual species will be many and varied, both to single fire events and to changed fire regimes (Whelan et al. 2002). A significant impact of increased fire frequencies will be on the development and persistence of tree hollows (Mackey et al. 2002).

Regeneration dynamics

The CO_2 fertilisation effect will be more evident in regenerating forests as older plants respond less (Steffen and Canadell 2005) and could lead to greater rates of reestablishment after disturbance, for example fires and logging, with consequent impacts on water yields in supply catchments. The observed effect of higher temperatures on increased germination of plants in alpine environments (Hughes 2000) may also occur at lower elevations. There will also be ecological impacts on regeneration through competition with species colonising novel environments, and through compounding effects of multiple stresses (e.g. lower rainfall → increased fire frequency → increased grassiness → increased grazing pressure) (Calder and Kirkpatrick 2008).

Tree growth

Early estimates of the likely response of plants to elevated CO_2 (from experiments and modelling) are now considered to be over-estimates that will not eventuate in field conditions. There are, as yet, no FACE (free air carbon dioxide enrichment) experiments in south-eastern Australian forests or with sclerophyll forests species that can inform us about actual plant growth responses (Raison et al. 2007). General predicted trends, however, are for increased growth with higher temperatures where rainfall is not limiting, and increased water use efficiency (partially offsetting reductions in rainfall). Some of this increased growth will be limited by soil nutrient conditions (Kirschbaum 2000)

Plant–animal interactions

There is some evidence that eucalypt leaf chemistry, particularly C:N ratios, can be altered by elevated CO_2 concentrations. This can lead to reduced protein content and increased total phenolics and condensed tannins, with possible implications for plant–insect and plant–microbe interactions (e.g. herbivory, decomposition rates) (Gleadow et al. 1998), although changes in leaf thickness and C:N ratios in *Lantana* leaves due to increased CO_2 levels did not affect the feeding rates of two introduced biocontrol beetles (Johns et al. 2003). Changes in plant phenology can be both matched by shifts in animal cycles, or they can be asynchronous (Bezemer and Jones 1998; Cleland et al. 2007). This type of asynchrony could be serious in ecosystems, such as eucalypt forests, where plant reproduction and population genetic structures are supported by insect pollinators (Cleland et al. 2007).

Critical biodiversity assets

Impacts on wildlife are likely to come about through two major mechanisms: changed forest structure due to alterations in fire frequencies, and direct impacts through direct environmental stress. For the former, models of species' responses to habitat complexity after fire have been developed for south-eastern Australia (e.g. Catling et al. 2001). In a long-term study of the impacts of fire on small mammals, Recher et al. (2009) found that species' responses varied considerably and were attributed to differences in diet, nesting preferences, quality of the ground habitat, and overstorey structural diversity. Their conclusions were that factors other than fire, such as long-term rainfall patterns and drought, were responsible for controlling populations. An increased frequency of extreme fire weather conditions over recent decades is over and above that observed over a longer time period, and may be due to climate change (Lucas et al. 2007).

For birds, more able to shift location in unfavourable climatic conditions, there is circumstantial evidence of increases in abundance of invasive, adaptable native species relative to non-invasive, less adaptable species (Olsen 2008), but it is thought that because of the altitudinal range over which forests are distributed in the south-east, climate impacts are likely to be moderate (Brereton et al. 1995; Chambers et al. 2005). This does not necessarily apply to montane species, however, such as the gang gang cockatoo (Chambers et al. 2005) or species at the limits of their distribution, for example alpine frogs (Brereton et al. 1995; Pouliquen-Young and Newman 1999). Brereton et al. (1995) used BIOCLIM to explore expected changes in ranges of a number of species in south-eastern Australia: of the 11 forest species examined, the bioclimatic ranges of 7 were expected to decline by 0–50%, and of 3 by 51–89% under the most modest climate change scenario applied (a 1°C rise in temperature, 5% rise in summer rainfall and 5% decrease in winter rainfall). Only 2 species (helmeted honeyeater, giant Gippsland earthworm) would not persist under the most extreme scenario (3°C rise in temperature, 10% increase in summer rainfall, 10% decrease in winter rainfall), although 7 others would suffer contractions in bioclimatic ranges of 51–89%. They conclude that forest species are less prone to the effects of climate change than those in other biomes in south-eastern Australia (e.g. heathland, coastal, grasslands, woodlands, mallee, alpine and wetlands) because of the chance for altitudinal migration, and the main effects are on those species with very restricted current ranges. However, this work only predicts changes in fundamental niche distribution, and not realised niches, which may be affected by other, direct (e.g. nutrition/physiology/metabolism) and indirect impacts (e.g. rates of predation).

Soil organic carbon

Soil organic carbon (SOC) is essential for maintenance of key ecosystem processes such as soil fertility, water retention and plant productivity, and forests are thought of as carbon capture and storage solutions to an elevated atmospheric CO_2 world (e.g. Lal 2005). Recent modelling in Australia predicts that soils will be a sink for carbon, except under high emissions regimes, where there will be a net loss that is only partially offset by an increase in net primary productivity (NPP) (Grace et al*.* 2006). Only modest changes in SOC are predicted for low emissions scenarios by 2100 (some minor increases, some minor decreases, depending on biogeographic area), but more significant declines of between 4.4% and 8.7% are predicted under a higher emissions regime due to climate-induced changes in decomposition rates, making these regions net emitters of carbon (Grace et al. 2006).

Invasive plants and animals

One of the key threats to conservation of climate change is changed distribution of invasive species. Climate change will affect the climate envelopes of invasive species as much as it will native species: some will increase in range, others will decrease. The fundamental process that will govern how forest environments respond to these changes will be how susceptibility to invasion changes. Forests are, to a degree, buffered against major and sudden changes in invasion susceptibility by being comprised of long-lived biological and structural elements, but associated changes in fire frequency and intensity will render invasion opportunities for some species, although there are few published case studies on which to base predictions of future invasions due to climate change (Ward and Masters 2007; Brook 2008).

There is little published work relating directly to climate change impacts of invasive species in south-eastern Australian forests. What we do know is that invasive plants can and do change structural and compositional aspects of these environments (Duggin and Gentle 1998; Gooden et al. 2009), and that increasing urbanisation and patterns of settlement as a result of climate change will provide habitats that some invasive species will take advantage of (White et al. 2008). In addition, some natives, and exotics that are not currently considered threats, will become invasive; similarly, there will be species that are considered problems now that will contract in range as a result of predicted climate change (e.g. groundsel bush *Baccharis halmifolia*; Sims-Chilton et al. 2010).

1.3.5 CURRENT CONSERVATION APPROACHES

Currently, about 19% of eucalypt forests are in formal conservation reserves (Figure 4). Forests have enjoyed greater protection than other widespread ecosystems by virtue of their commercial value and considerable community support for their protection, recognised in the various regional forest agreements. Traditional forestry management regimes have not necessarily always been compatible with conservation objectives (Lindenmayer and Ough 2006). Clearing patterns, based on exploitation of suitable soils for agriculture, have resulted in significant losses of rainforests and other wet forest types from the biome, especially in northern New South Wales and southern Queensland, and concomitant losses of eucalypt open forests have occurred due to urban expansion.

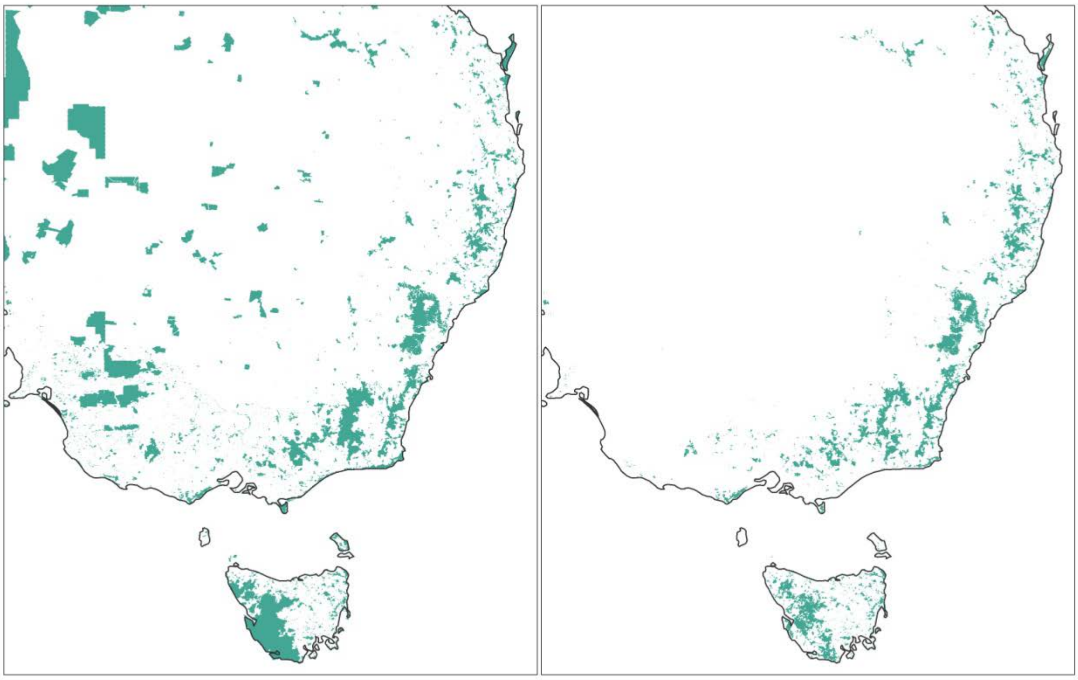

Figure 4 Protected areas within the region (left) and within the biome area (right)

2 Methods

We used a combination of literature review, expert opinion (via a workshop) and two spatial modelling approaches to inform projections for the likely impacts of climate change on forest ecosystems and the NRS.

2.1 Climate change scenarios

Two 1 km^2 scenarios were considered, outputs from the CSIRO Mk3.5 GCM downloaded from OzClim (CSIRO 2012): a *medium* impact scenario, using the A1B emissions scenario, and a *high* impact scenario using the A1FI emissions scenario (IPCC 2000). The main future date considered was 2070, although an intermediate 2030 scenario was also developed.

The first step was to download monthly climate change grids at 0.25° resolution for maximum temperature, minimum temperature, rainfall and evaporation, by specifying the above scenarios in OzClim. Spatial downscaling was carried out using the ANUCLIM software (Houlder et al. 2000), which incorporates three submodels: ESOCLIM, which outputs raw climate variable grids; BIOCLIM (Busby 1986), which outputs grids of bioclimatic parameters; and GROCLIM, which can output gridded indices from simple growth models. The beta release of ANUCLIM version 6.0 was used, which allows climate change grids to be applied over the historical 1990-centred climate surfaces. Software (Harwood and Williams 2009) was written to interpolate the raw 0.25° CSIRO grids to cover the whole Australian land mass, and relate evaporation change to the date range used in ANUCLIM 6. Following this interpolation, monthly maximum temperature, minimum temperature, rainfall, and evaporation change grids were input into ANUCLIM 6 with a 0.01° digital elevation model. The result was a suite of monthly 0.01° (≈1 km^2) resolution future climate surfaces for maximum temperature, minimum temperature, rainfall, evaporation and radiation, with 35 BIOCLIM variables and four plant growth indices for each scenario.

Specific climate change predictions for 2070 under medium and high emissions scenarios are given in Suppiah et al. 2007.

2.2 Classification of environments using artificial neural networks (ANN)

Our approach uses maps of vegetation classes at various scales along with detailed, spatial estimates of climate, topographic and edaphic variables to objectively classify environments that are characteristic of these vegetation classes. The goal is to transform a high dimensional, physical environment space (many climate variables and, in the case of the MVGs, a number of terrain and soil variables as well) into a lower dimensional, ecologically meaningful space. This enables various analyses of future environments, including comparisons with the current environment and identifying changes in spatial distribution of environment classes. The transformation is accomplished through supervised classification. Then, given any spatial scenario of change in the climate we can map these *ecological environments* in geographic space. Most importantly, we can compare this new spatial map of environments with what we estimate it is today and also with the spatial distribution and extent of the actual ecological classes. In this way, we can quantify how the extent and distribution of the environmental classes may change in the future and infer how climate change may affect vegetation classes and, consequently, biodiversity and function.

We used artificial neural networks (ANN) for the supervised classification of environments based on mapped vegetation classes. This methodology builds on the successes of a similar approach that was used in the Wet Tropics Bioregion of north-east Queensland where an ANN was used to classify 15 structural/physiognomic forest environments based on a range of climatic, edaphic and topographic variables (Hilbert and Van Den Muyzenburg 1999, Hilbert et al. 2001). For all of Australia, we classified environments at two vegetation scales, seven terrestrial ecoregions (global biomes) and 23 MVGs. The ecoregions are derived from Thackway and Cresswell's (1995) biogeographic regionalisation for Australia. The MVG data consist of a digital map of their pre-clearing distributions at a one hectare resolution for the entire continent (Thackway et al. 2007).

We used FANN (Fast Artificial Neural Network Library) to classify environments of both the ecoregions and the MVGs. This software is an open source neural network library available from http://leenissen.dk/fann/, which implements multilayer artificial neural networks in C. For the ecoregions, the network structure consisted of 23 bioclimatic inputs, 150 hidden nodes and seven output nodes, corresponding to the ecoregions. We used the largest output node value to map ecoregions in the current and climate change scenarios. For the MVGs we used a single, multiple-output neural network to classify the available environmental variables by MVG class with 35 input nodes (23 bioclimatic variables, three soil variables and nine topographic variables), 150 hidden nodes and 23 output nodes representing the MVGs. We used the largest output node value to map MVGs in the current and climate change scenarios.

We also trained individual classifications for each of the ecoregions and each of the MVGs using the Tiberius software (Brierley unpublished) to rank variable importance using the Gini Coefficient (Breiman et al. 1984). Here, we used 35 bioclimatic variables for the ecoregions and 35 bioclimatic variables plus the additional 12 soil and topographic variables for the MVGs.

The ANNs provide much more information than is apparent in a classification, where the output node with the largest value is chosen as a pattern's (location's) classification. By using the values of all the output nodes we calculated the dissimilarity of this vector to the vector with the value of 1.0 for the class that is mapped at that location and all other values of 0.0. The dissimilarity is the vector angle between the two, normalised to the range [0,1] (Hilbert and Van Den Muyzenburg 1999). For example, a location that is mapped as Rainforest and vine thickets with a dissimilarity of 0.1 has an environment that is more typical of this class than another location, also mapped as this class, with a dissimilarity of 0.4. Hilbert and colleagues (Hilbert et al. 2001, Hilbert & Ostendorf 2001) interpret dissimilarity as an index of relative environmental stress. It could also be thought of as a propensity to change. Dissimilarities greater than 0.5 indicate environments that are more like that of some other class than the one that is mapped.

A detailed description of the methods used in this project is provided in the accompanying report, Hilbert and Fletcher (2012).

2.3 Generalised dissimilarity modelling (GDM)

Generalised dissimilarity modelling (GDM) is a statistical technique for modelling the compositional dissimilarity between pairs of geographical locations, for a given biological group (e.g. reptiles), as a function of environmental differences between these locations (Ferrier 2002; Ferrier et al. 2002, 2007). The measure of compositional dissimilarity (d) employed in this project is the Sorenson, or Bray–Curtis, index:

$$d_{ij} = 1 - \frac{2A}{2A + B + C}$$

where *A* is the number of species common to both locations *i* and *j*

B is the number of species present only at location *i*

C is the number of species present only at location *j*

In other words, based on this measure, the compositional dissimilarity between a given pair of locations is the proportion of species occurring at one location that do not occur at the other location (averaged across the two locations) – ranging from 0 if the two locations have exactly the same species through to 1 if they have no species in common.

GDM uses data on species recorded at a sample of locations across the region of interest to fit a model predicting the compositional dissimilarity between pairs of locations as a non-linear multivariate function of the environmental attributes of these locations. Another way of viewing this is that GDM effectively weights and transforms the environmental variables of interest such that distances between locations in this transformed multidimensional environmental space now correlate, as closely as possible, with observed compositional dissimilarities between these same locations (see Ferrier et al. 2007 for full explanation).

This project employed a set of GDM models already derived for the Australian continent by a separate (then) DEWHA-funded Caring for Our Country Open Grants project performed by CSIRO in collaboration with DEWHA and the ANU Fenner School of Environment and Society (Williams et al. 2009). These models were derived using continent-wide biological data collated within DEWHA's Australian Natural Heritage Assessment Tool (ANHAT) database – a compilation of species-location records from a large number of herbaria, museums, State and Commonwealth departments, and private individuals. The models were fitted at 1 km^2 grid resolution[1] across the entire continent using best-available environmental layers for 76 climate, terrain and substrate variables (Williams et al. 2010). Models were derived for 12 different biological groups, six of which were employed in the work described in this current report:

- vascular plants (model based on data for 12,881 species at 374,640 locations – i.e. 1 km^2 grid cells)
- land snails (model based on 2,774 species at 19,118 locations)
- frogs (model based on 218 species at 100,143 locations)
- reptiles (model based on 819 species at 83,661 locations)
- birds (model based on 690 species at 242,814 locations)
- mammals (model based on 298 species at 100,369 locations).

The current project used the above models to infer potential changes in biological composition as a function of projected changes in climate across the continent. This is based on the assumption that the amount of change in species composition expected for location *A* as a result of climate change will be equivalent to the compositional dissimilarity currently observed between location *A* and another location *B* with a current climate matching that projected for location *A* (Ferrier and Guisan 2006; Ferrier et al. 2007). It is likely that the actual change in biological composition resulting from climate change will be shaped by many factors, and associated sources of uncertainty, beyond those considered in this modelling, such as biotic interactions, indirect effects of changed fire regimes, dispersal ability, lag effects, adaptation capacity and plasticity. The level of compositional change predicted by the GDM approach is therefore best interpreted as no more than a relative indicator of potential 'environmental stress' expected to be experienced by species in a given biological group under a given climate scenario.

The GDM-based analyses performed in this project resulted in maps depicting the following:

- The predicted dissimilarity between the *current composition of each grid cell and its composition under a given climate scenario*, as a general indicator of potential environmental stress on a cell-by-cell basis. This was estimated and mapped separately for each of the six biological groups (listed above). A weighted average of these six maps was also derived, in which each biological group was weighted according to the total amount of spatial turnover exhibited by the group under current climate conditions (see Williams et al. 2010 for further explanation of this weighting). All of the remaining analyses below were performed for vascular plants only
- The minimum predicted dissimilarity between the *current composition of each cell and the future composition of all cells on the continent under a given climate scenario*, as an indicator of 'disappearing [biotically scaled] environments' (as per Williams et al. 2007)

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[1] The models were fitted to data based on 0.01° by 0.01° grids, which are approximately 1 km by 1 km, but their exact dimensions vary with latitude.

- The minimum predicted dissimilarity between the *future composition of each cell under a given scenario and the current composition of all cells on the continent*, as an indicator of 'novel or no-analogue [biotically scaled] environments' (as per Williams et al. 2007)
- Two measures of the potential contribution that environmental heterogeneity around each cell may make to ameliorating, or buffering, the effects of a given climate scenario:
  a. the proportional change in effective habitat area within a surrounding radius varying from 750 m up to 100 km, where 'effective habitat area' is the summed area of all cells within this radius, with each cell weighted according to the predicted similarity (1-d_{ij}) between the composition of this cell (current versus future) and the current composition of the focal cell (see Ferrier et al. 2004, and Allnutt et al. 2008 for a more detailed explanation of this concept)
  b. the predicted dissimilarity between the current and future composition of each cell (from the first dot point above), minus the minimum predicted dissimilarity between the current composition of this cell and the future composition of any other cell within a radius varying from 750 m to 100 km.
- An extension of the analysis of 'proportional change in effective habitat area' described above to consider the added effect of habitat loss and fragmentation. In this case only cells mapped as extant vegetation (based on the NVIS) are allowed to contribute to the calculation of effective habitat area.

A detailed description of the above methods is provided in the accompanying report by Ferrier et al. (2012).

2.4 Bayesian Belief Network modelling of buffel grass

Using Bayesian Belief Networks (BBN; Marcot et al. 2006) we modelled the susceptibility and suitability of the Australian landscape to buffel grass (*Pennisetum ciliare* [syn.] *Cenchrus ciliaris*) colonisation building on a framework developed by Smith et al*.* (2012).The framework is based on three invasion requirements: the introduction of plant propagules to a site; the establishment of new plants at a site; and the persistence of established, reproducing (seed-producing) populations at a site. The establishment and persistence nodes of the BBN combine to influence the suitability to invasion, and the introduction and suitability combine to influence a site's susceptibility to invasion. Introduction, establishment and persistence are influenced by key environmental variables such as landscape properties (e.g. soil type, tree cover, fire frequency), climate properties (rainfall, temperature, soil moisture), and dispersal properties (distance to nearest infestation). The relationship between these key environmental variables and the invasion requirements are defined by experts and empirical data and are illustrated through an influence diagram, which forms the basis of the BBN.

To illustrate the predictions of the model spatially, we used GIS layers to represent the key environmental variables directly or to be proxies for the key environmental variables. For example, the current known distribution of buffel grass as mapped by the Australian Virtual Herbarium can be used to estimate the distance to an infestation.

2.4.1 ELICITING EXPERT KNOWLEDGE

We captured the current understanding of buffel grass ecology, management and invasion through a review of the literature, expert workshop and follow up discussions with small groups and individual experts. After an initial review of existing empirical information, a two-day expert workshop was convened with 13 experts in buffel grass ecology and management. During this workshop experts identified the key environmental variables that influence buffel grass introduction, establishment and persistence and the relationship between these variables. The GIS layers available for mapping the key environmental variables directly or indirectly were also identified. We used a combination of facilitated group discussion and small breakout groups and feedback to develop a set of feasible key environmental variables for consideration in the BBN.

During the workshop an influence diagram was developed live using Netica (4.08), allowing experts to visualise the relationships they were expressing and facilitating easy updating and modifications as the workshop progressed. Over two days, the structure of the BBN and initial states of the nodes were developed. Conditional probability tables were developed afterwards in consultation with small groups of experts. Elicited probability tables (EPTs) were sought via consensus, whereby experts expressed their responses within small groups (3–4 experts) and, through discussion of their respective reasoning, negotiated a common group response. For large Conditional Probability Tables (CPTs), Cain's (2001) CPT calculator was used to generate the full CPT table from the EPT where the experts provided the key anchoring points. For example, the first set of probabilities elicited was such that the parents (any other variable that directly influences the state of that variable) were all in positive states and the second set such that the parents were all in negative states. For all other sets, each parent was switched from its positive to negative state. The full CPT was then interpolated from the EPT using the CPT calculator.

2.4.2 CLIMATE SCENARIOS

We examined three climate scenarios. Firstly, we mapped the predicted landscape susceptibility and landscape suitability of buffel grass across Australia based on BIOCLIM data (Harwood and Williams 2009) representing current climate. Secondly, we examined future landscape suitability of buffel grass using the BIOCLIM data for 2070 mid and high scenarios.

BIOCLIM layers were generated for high (high sensitivity A1F1) and medium (medium sensitivity A1B) sensitivity scenarios for 2070 using OZCLIM data for CSIRO Mk3.5, downscaling via ANUCLIM6 (beta) (IPCC 2000; Harwood and Williams 2009). Refer to Harwood and Williams (2009) for further details on generation of current climate and 2070 BIOCLIM grids.

2.4.2.1 Connecting the BBN to GIS

We converted each GIS layer into a 25 km^2 national grid, generating a 146 row x 179 column matrix of grid cells totalling 26,134 cells. This spatial scale of modelling was deemed appropriate given the precision of data we had from the experts on buffel grass ecology and current distribution. To read the GIS data into the BBN, we developed our own software which took as input a text file containing the GIS layers as a string of 26,134 values and fed it into Netica. Output from Netica was then converted back into a text file and converted into a raster for projection using ArcGIS. Spatial analyst and R (version 2.9.2; http://www.r-project.org/) were then used to calculate the difference between the current and 2070 medium and 2070 high predictions.

2.4.3 MODEL SENSITIVITY

The sensitivity of each of the three invasion requirements (introduction, establishment and persistence) to the environmental variables included in the BBN were tested using entropy reduction. The degree of entropy reduction *I*, is the expected difference in information *H* between variable *Q* with *q* states and findings variable *F* with *f* states (Smith et al. 2012).

$$I = H(Q) - H(Q \mid F) = \sum_q \sum_f \frac{P(q,f)\log_2[P(q,f)]}{P(q)P(f)}$$

A full description of the results of the Bayesian modelling component of this project is available in the accompanying report by Martin et al. (2012).

2.5 Review

The literature review identified and discussed the major ecological drivers of forest ecosystems, and highlighted some of the threatening processes that may affect forests under climate change. In sections 1.3.3. and 1.3.4, this report incorporates relevant content from the review.

2.6 Workshop

Understanding complex natural systems, their internal dynamics and relationships to exogenous factors and their likely response to significant environmental change, requires an integrated approach. This must include existing knowledge, expert opinion and modelling.

To determine the current knowledge of south-eastern sclerophyll forests ecosystems and explore expected change, a workshop of invited experts covering forest ecology, fauna ecology, fire ecology and fuel dynamics, forest modelling, forest conservation and management planning, forest policy, NRS policy and practice was convened, facilitated by Michael Dunlop (CSIRO). The workshop aim was to arrive at a consensus on the characteristics that make the biome special, and:

1. share understanding of the types of changes likely to affect the biome, its biota and socio-economic characteristics
2. discuss options for modelling and detecting proposed changes, with information on what's needed to do it and how best to progress it
3. share understanding of the implications of different kinds of changes for biodiversity, habitat protection and NRS
4. share knowledge of what can be done and what new information is required.

The workshop was held in Canberra on 6–7 May 2009. Experts in forest ecology, climate change policy and conservation planning were invited from federal and state environment authorities (including New South Wales, Victoria, Tasmania, Queensland), CSIRO and the university sector.

The workshop comprised a number of short presentations that addressed key issues for discussion:

- Climate change policy and the CSIRO NRS projects
- Climate change and conservation
- NRS1 project
- Key ecosystem drivers and responses to climate change
- Modelling approaches for NRS2
- Fire and biodiversity in sclerophyll forests.

Discussions were then focused on range of related topics:

- Key ecosystem drivers
  - terrain
  - forest dynamics
  - fire
- Role of modelling
- Potential impacts of climate change
  - extreme events (drought)
  - fire
  - ecosystem processes
  - invasive specie
  - disease
  - niche availability
- Adaptation options
  - connectivity
  - translocation
  - management to maintain processes
- Adaptive management, risk and climate change

- Social and economic issues

The full summary of this workshop is in Appendix A.

3 Results

3.1 How is the environment changing in the forest biome?

3.1.1 HOW MUCH IS IT CHANGING?

Area changes based on ANN modelled distributions of MVG environments are substantial under both medium and high emissions scenarios (Table 1). Proportionally, the environment of MVG 1 undergoes the greatest reduction in area (43% and 68% reduction of pre-1750[2] coverage for medium and high scenarios respectively), and the environment of MVG 2 the least (35% and 27% reduction).

Mean ANN dissimilarity (stress) values were high for all MVGs within this biome under both medium and high emissions scenarios for 2070 (Table 2, Figure 5); stress > 0.5 indicates a future environment that is more similar to the environment of a different MVG. There are similar patterns in changes in stress across the whole biome and in environments within the NRS. Analysis restricted to areas of uncleared vegetation showed similar levels of stress and area reductions, except for MVG 4 environments that had a reduction of 80%.

Future environmental stress modelled with the GDM, correlated with compositional dissimilarity, is also > 0.5 for plants, reptiles and snails under the 2070 medium scenario; under the high scenario, stress for mammals (in MVG 1), and frogs (MVG 2 & 3) also exceeds 0.5 (Figure 6). These patterns of environmental stress are similar within the NRS, although there is some suggestion that those areas within the NRS have slightly lower levels of stress compared with the whole biome area. In contrast to the ANN stress (which is more correlated with vegetation structure), the GDM stress tended to be slightly but consistently lowest in MVG 4.

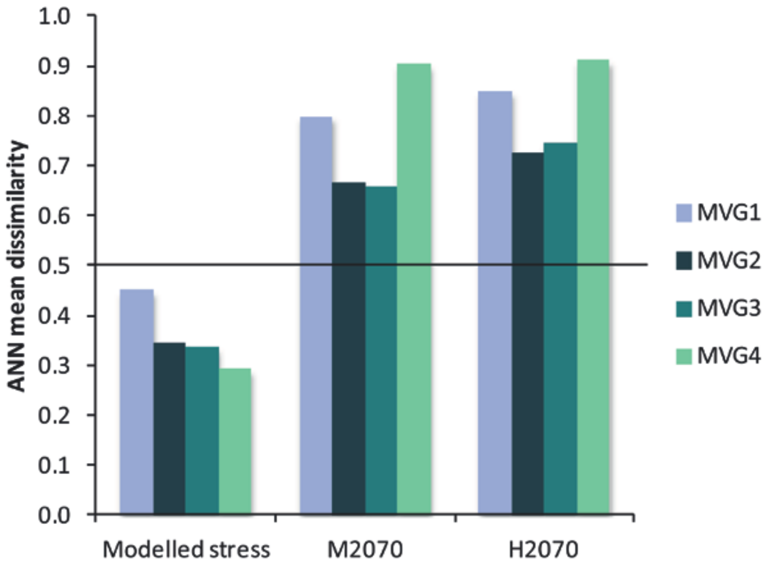
Table 1 Areas (km^2) of MVGs 1–4 mapped (NVIS) and modelled (ANN), and under climate change scenarios

	NVIS MAPPED	ANN MODELLED	2070 MEDIUM ANN MODELLED	2070 HIGH ANN MODELLED
pre-1750				
MVG1	29 481	30 154	17 074	9 617
MVG2	36 822	48 416	31 452	35 152
MVG3	286 166	226 535	175 278	125 219
MVG4	3 029	5 276	3 936	2 838
extant				
MVG1	16 854	18 606	8 826	3 957
MVG2	26 727	35 324	23 874	26 351
MVG3	167 351	135 115	112 916	82 635
MVG4	2 586	4 339	2 128	858

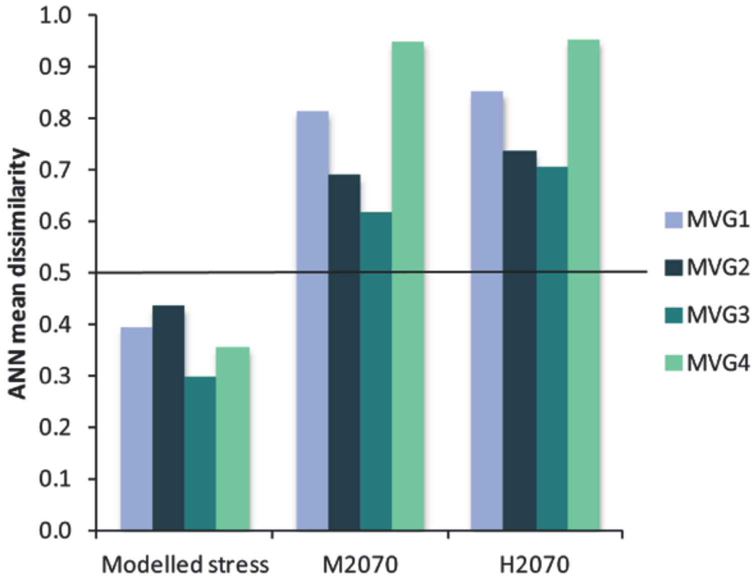
[2] Pre-1750 vegetation cover is used as a baseline so that the impacts of clearing on modelled outcomes of climate change can be assessed.

Table 2 Mean environmental stress (ANN dissimilarity) and standard errors for current environments and environments in 2070 medium and high climate change scenarios, using both modelled pre-1750 forest cover and extant (i.e. vegetation remaining after clearing)

	CURRENT MEAN	SE	2070 MED MEAN	SE	2070 HIGH MEAN	SE
pre-1750						
MVG1	0.450	0.002	0.80	0.001	0.85	0.001
MVG2	0.350	0.002	0.67	0.001	0.73	0.001
MVG3	0.340	0.001	0.66	0.001	0.75	0.000
MVG4	0.290	0.005	0.90	0.003	0.91	0.003
extant						
MVG1	0.428	0.002	0.798	0.002	0.839	0.002
MVG2	0.361	0.002	0.658	0.002	0.713	0.001
MVG3	0.328	0.001	0.639	0.001	0.730	0.001
MVG4	0.304	0.005	0.915	0.003	0.922	0.003



(a)



(b)

Figure 5 ANN dissimilarity (stress) for each MVG and 2070 medium and 2070 high climate scenarios: (a) extant vegetation, whole biome; (b) extant vegetation, NRS only

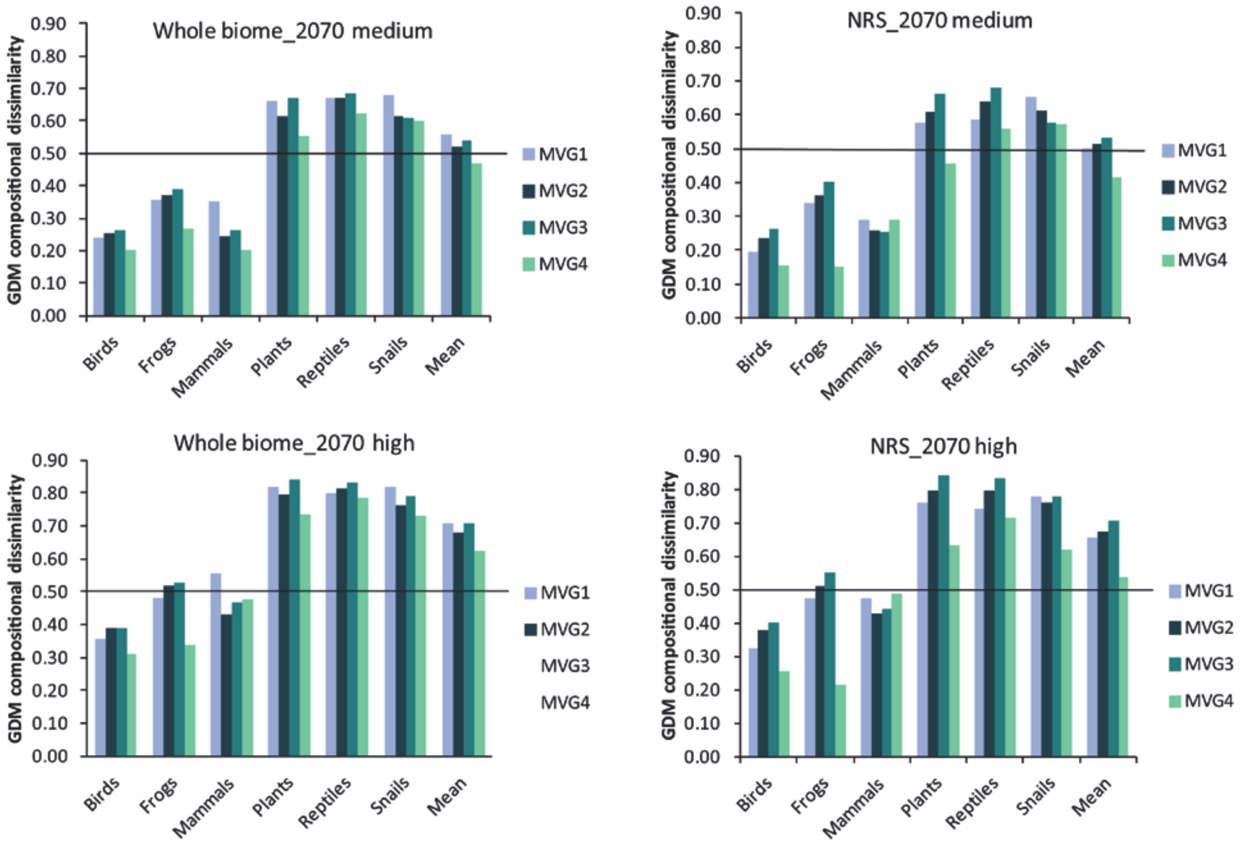


Figure 6 Mean GDM dissimilarity between current and projected compositions of selected taxonomic groups within the south-eastern Australian forest MVGs, for whole biome and NRS areas

3.1.2 WHERE IS THE BIOME CHANGING?

3.1.2.1 Ecoregions

Based on modelled distributions of ecoregion-level environments, a significant proportion of forested areas will have environments more like those typical of temperate grasslands and Mediterranean forests, with a small proportion becoming suitable for xeric deserts and tropical savannas (Figure 7). Under the high climate change scenario, around half of the area now suitable for temperate forests will become more suitable for other ecosystems. Local adaptation of existing plant and animal communities may offset some of these changes.

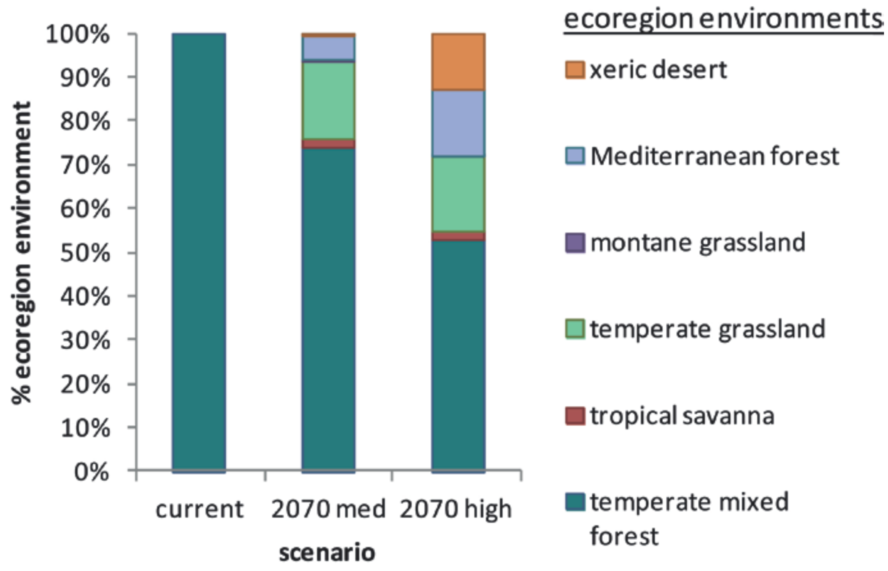


Figure 7 Proportional changes in temperate forest ecoregion environments under climate change

3.1.2.2 Major Vegetation Groups

At MVG level there are clear shifts in the balance between open eucalypt woodland and eucalypt forest environments in both climate change scenarios (Figure 8). The following list summarises where various changes in environment are predicted. Actual change in species and ecosystems will depend on many factors and may be quite different.

In the 2070 medium emissions scenario:

- expansion of open forest environments in western Victoria
- replacement of open forest environments by those of open woodlands in southern East Gippsland
- loss of open forest environments and replacement by those of grasslands/herblands/sedgelands in the Kosciusko National Park region
- replacement of rainforest environments with open forest environments in the Illawarra region
- expansion of open woodland environments at the expense of open forest environments in the Wollemi National Park area
- loss of low eucalypt forest environments from the New England Tableland and replacement by open woodlands environments
- loss of rainforest environments and replacement by open forest environments from northern New South Wales coast, partly offset by
- expansion of rainforest environments in southern Queensland at the expense of open forest environments
- loss of tall open forest environments and replacement by open forest environments from almost all of Victoria, southern New South Wales and north-east Tasmania; north-west and southern central Tasmania and northern New South Wales are little changed
- erosion of rainforest environments in central western Tasmania and replacement by environments more suitable for grasslands (possibly including button-grass moorlands).

In the 2070 high emissions scenario:

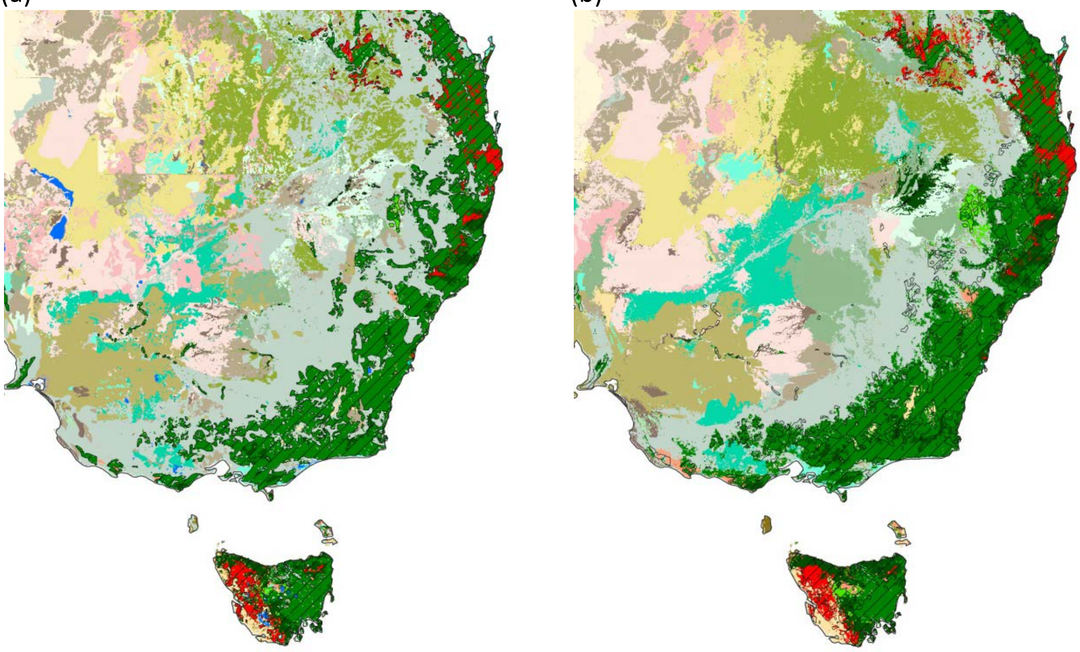
- loss of low eucalypt forest environments and replacement by chenopod shrubland environments in south-east Tasmania; given the current coastal distribution of chenopods in Tasmania, this is more likely to be replacement by open woodlands and/or low forests and scrubs dominated by *Acacia mearnsii* and/or *Allocasuarina* species, with some loss to grasslands of *Poa*, *Austrodanthonia*, *Austrostipa* and/or *Themeda*

- further movement east of the environment of *Callitris* forests and woodlands (MVG 7) along the western boundary of the biome
- further expansion of open woodlands environments along the New South Wales coast and in western parts of the biome in southern Queensland
- loss of open forest environments from South Australia and replacement by mallee woodland environments
- loss of rainforest environments in southern Queensland, including most of those predicted under the medium scenario, and Tasmania
- expansion of 'other forests and woodlands' (MVG 10) environments north of Newcastle and in northern New South Wales and southern Queensland.

3.1.2.3 ANN modelled environmental stress

In the 2070 medium climate change scenario (Figure 9b), ANN modelled environmental stress increases in most regions of the biome, especially along the western edge, central Victoria, East Gippsland, north of Sydney (Wollemi National Park) and southern Queensland. The high emission scenario (Figure 9c) leads to increased areas of high stress in most regions, especially the eastern (coastal) part of the biome, with the exception of forests on the north-western slopes of the Great Dividing Range in Victoria and southern New South Wales.

(a) (b)



(c) (d)

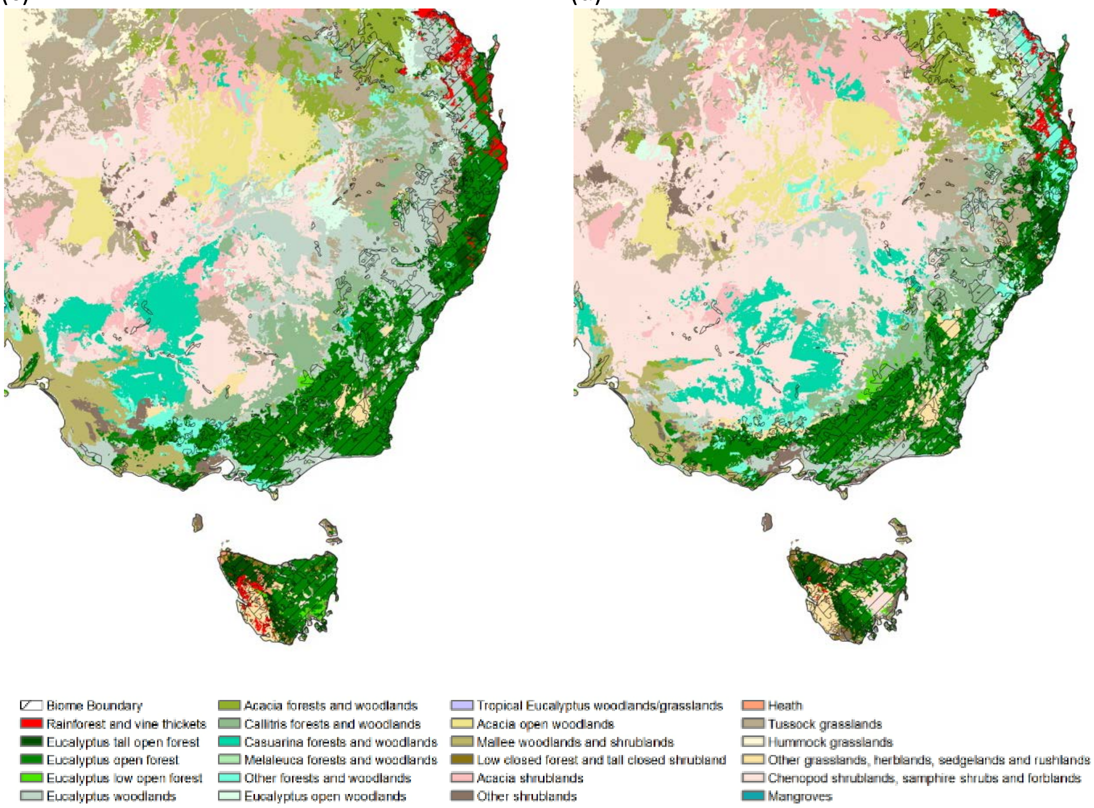
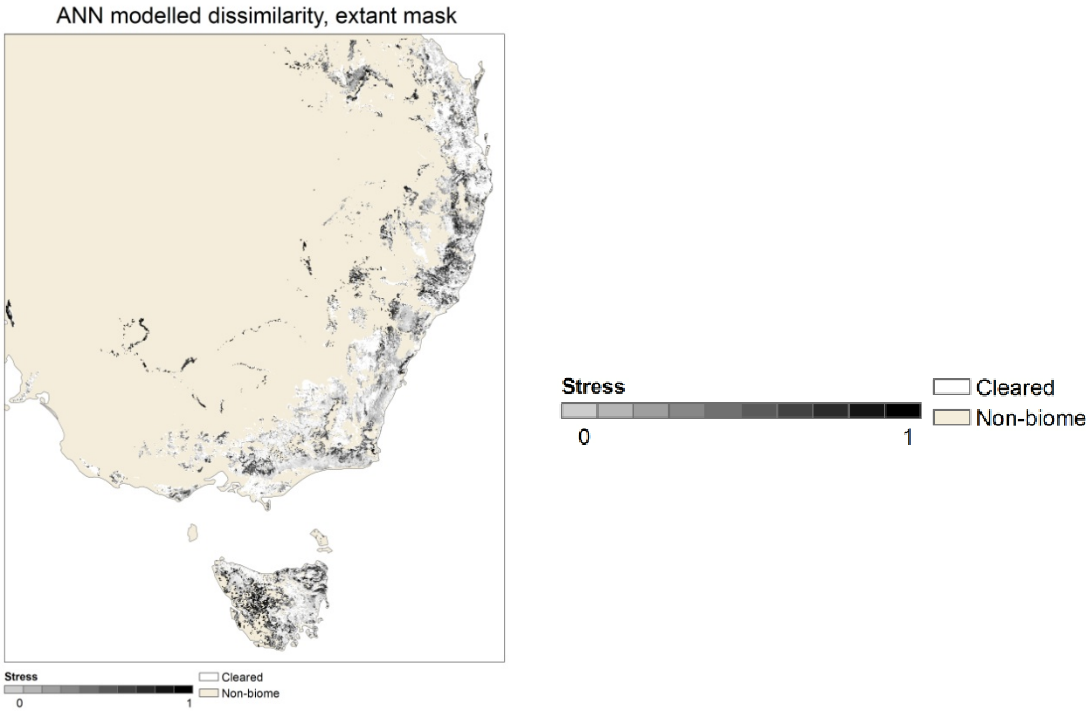


Figure 8 Distribution of MVG environments: (a) pre-1750 mapped distributions; (b) ANN modelled pre-1750 distributions; (c) ANN modelled distributions, 2070 medium scenario; (d) ANN modelled distributions, 2070 high scenario. Hatched area represents forest biome area

(a)



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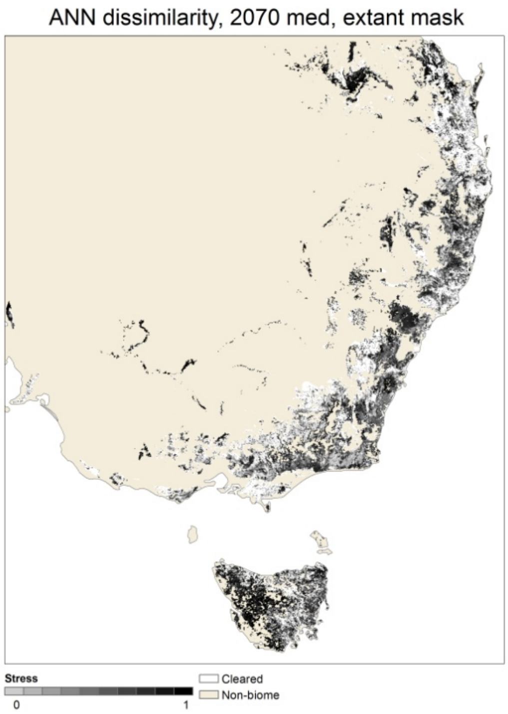

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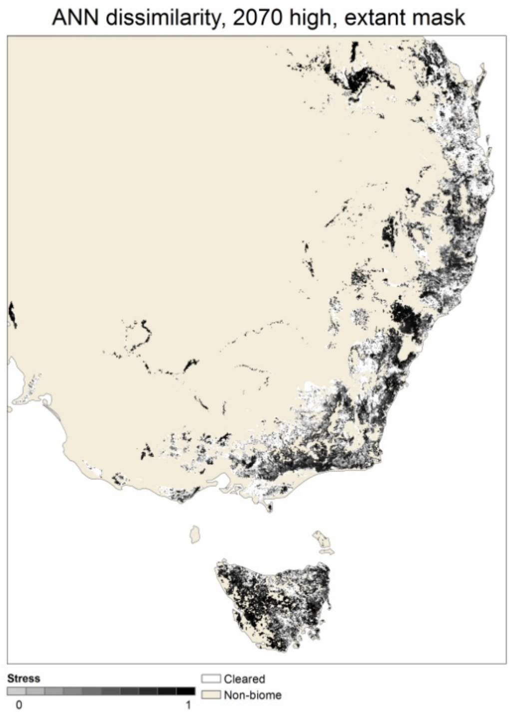

Figure 9 ANN dissimilarity (= stress) maps using extant (current) vegetation: (a) NVIS mapped and ANN modelled; (b) current ANN modelled and 2070 medium ANN modelled; (c) current ANN modelled and 2070 high ANN modelled

3.1.2.4 GDM modelled environmental stress for selected species groups

Using both 2030 and 2070 medium and high climate change scenarios, the impacts on individual taxonomic groups is variable (Figure 10a–d). Predicted environmental stress in birds, mammals and frogs is reasonably low in the biome under both 2030 scenarios, but for plants, reptiles and snails there is already high predicted environmental stress along parts of the eastern seaboard. These patterns are accentuated by 2070 under both medium and high scenarios; exceptions are lesser environmental stress in mammals in southern NSW, Victoria, inland parts of northern NSW and Tasmania, and low environmental stress for frog communities in the Australian Alps and Tasmania, even under the high scenario (Figure 9d). It should be noted that these groups have been analysed independently; the predicted major environmental stress for plant species communities will result in more severe environmental and ecological changes for other taxa through feedback mechanisms (e.g. changes in critical habitat resources).

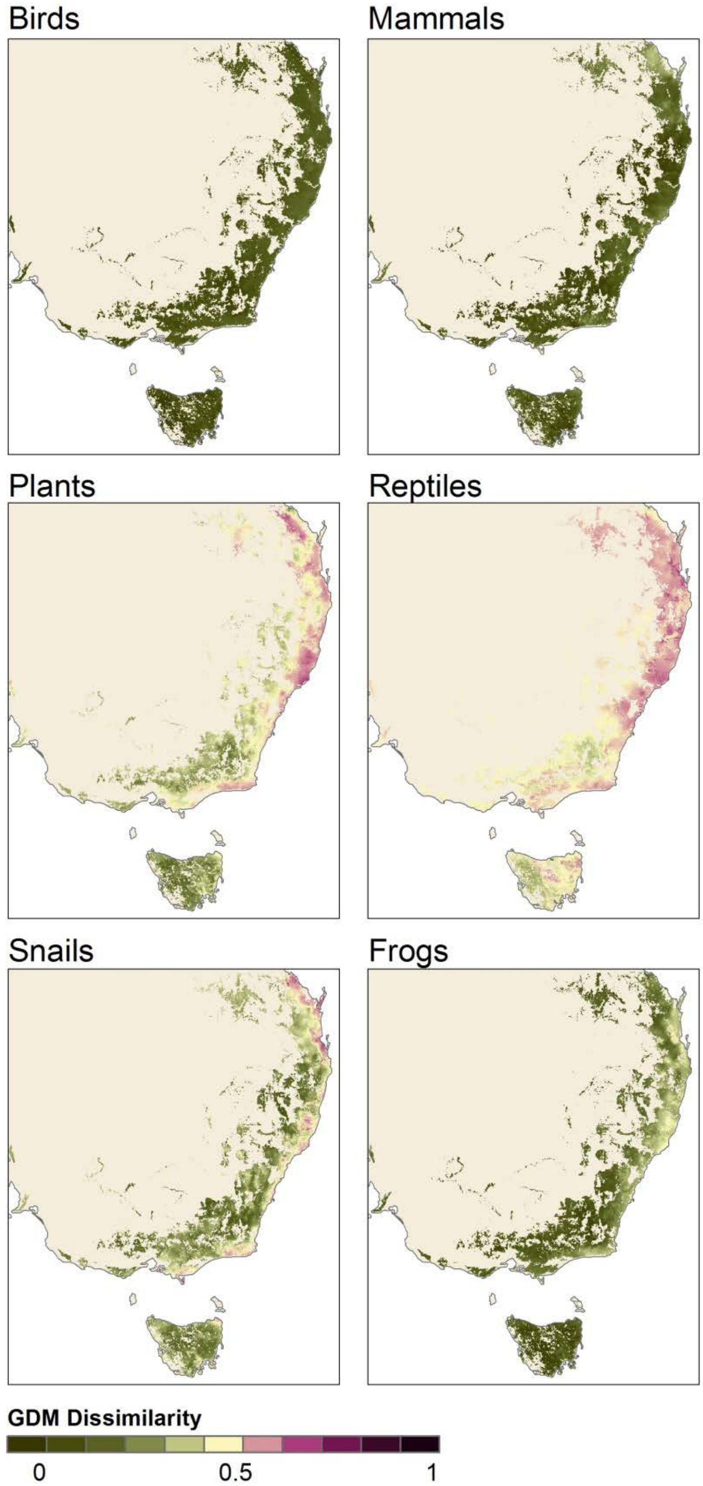

Figure 10a GDM dissimilarity for 2030 medium scenario. High dissimilarity (dark pink) indicates a high level of stress and low dissimilarity (dark green) indicates low stress

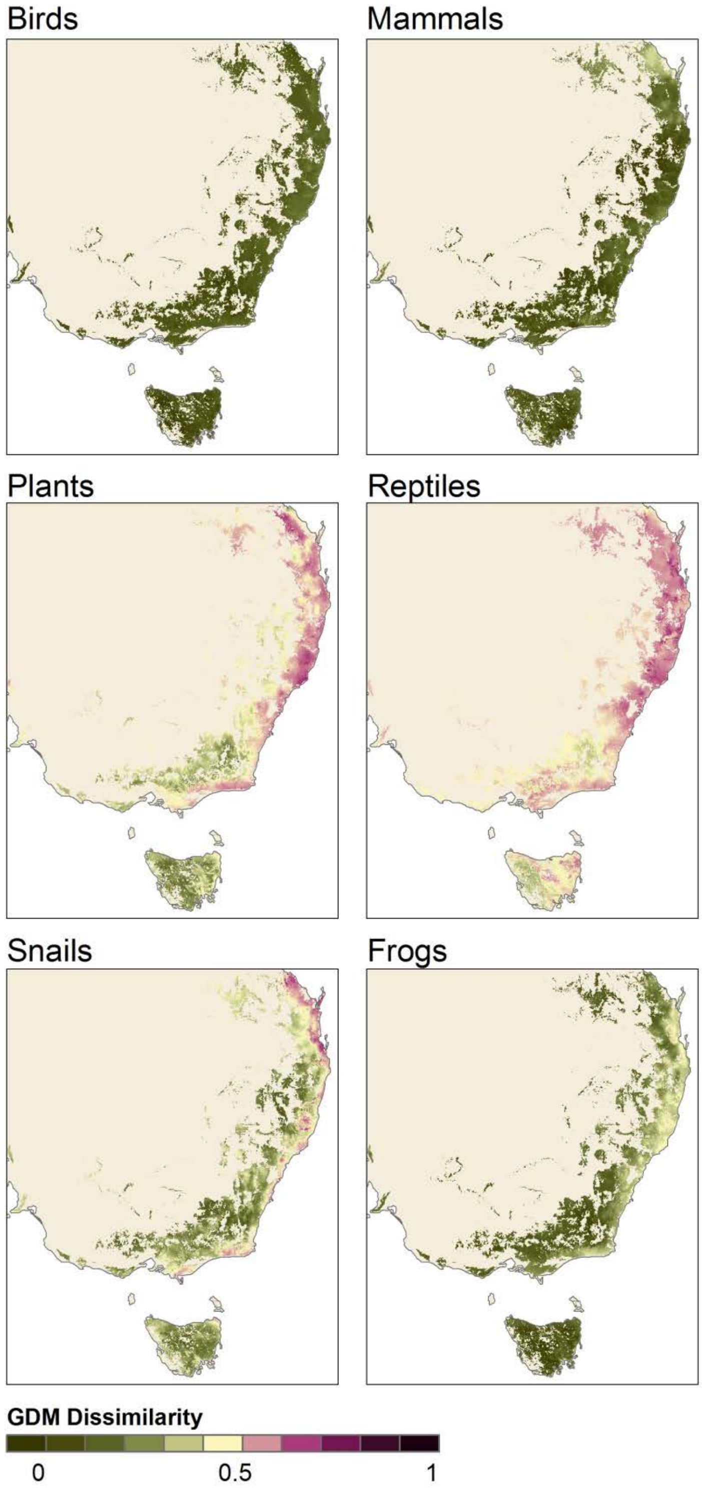

Figure 10b GDM dissimilarity for 2030 high scenario. High dissimilarity (dark pink) indicates a high level of stress and low dissimilarity (dark green) indicates low stress

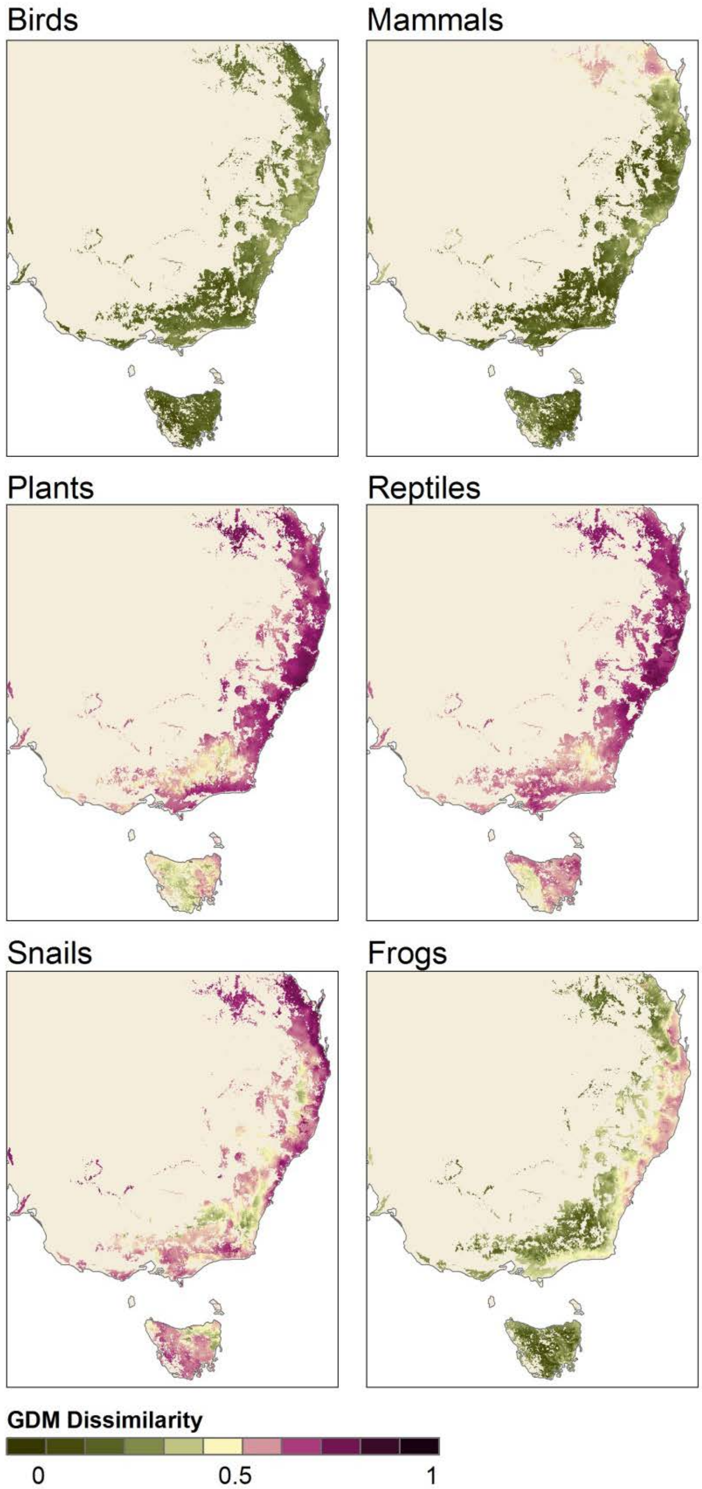

Figure 10c GDM dissimilarity for 2070 medium scenario. High dissimilarity (dark pink) indicates a high level of stress and low dissimilarity (dark green) indicates low stress

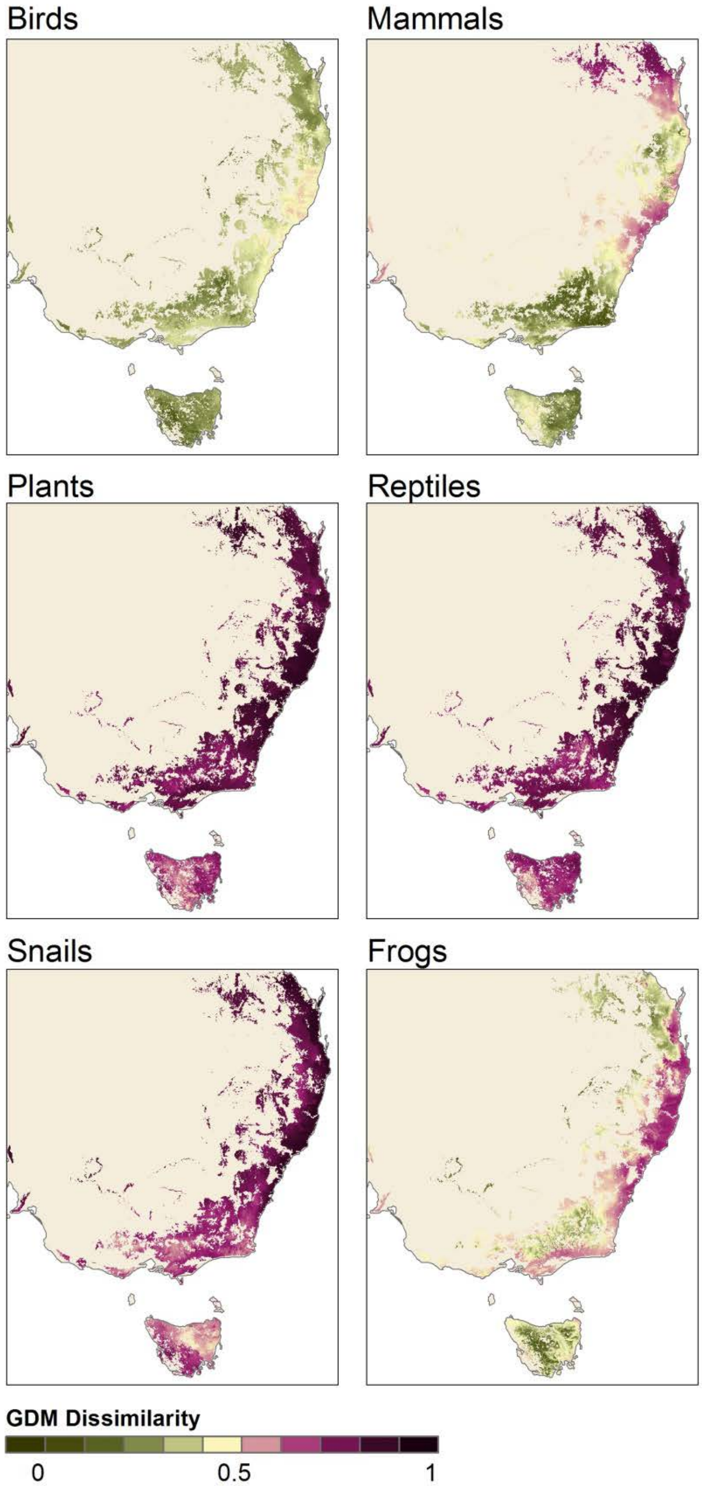

Figure 10d GDM dissimilarity for 2070 high scenario. High dissimilarity (dark pink) indicates a high level of stress and low dissimilarity (dark green) indicates low stress

Overall, the environmental stress for all groups is notably higher in the high emissions scenario than the medium emissions scenario (Figures 10c, 10d; Figure 11). Northern (especially coastal) and Gippsland portions of the biome tend to be affected sooner than other areas (Figures 10b, 10d; Figure 11). Different taxa are affected at different rates (Figure 10), but overall, under the high 2070 scenario most parts of the biome are predicted to have environments that would typically be associated with communities that are more different than they are similar to current communities. This does not mean that species in these groups will not persist in the areas; rather, it is likely that the combinations of taxa we witness there today will be different.

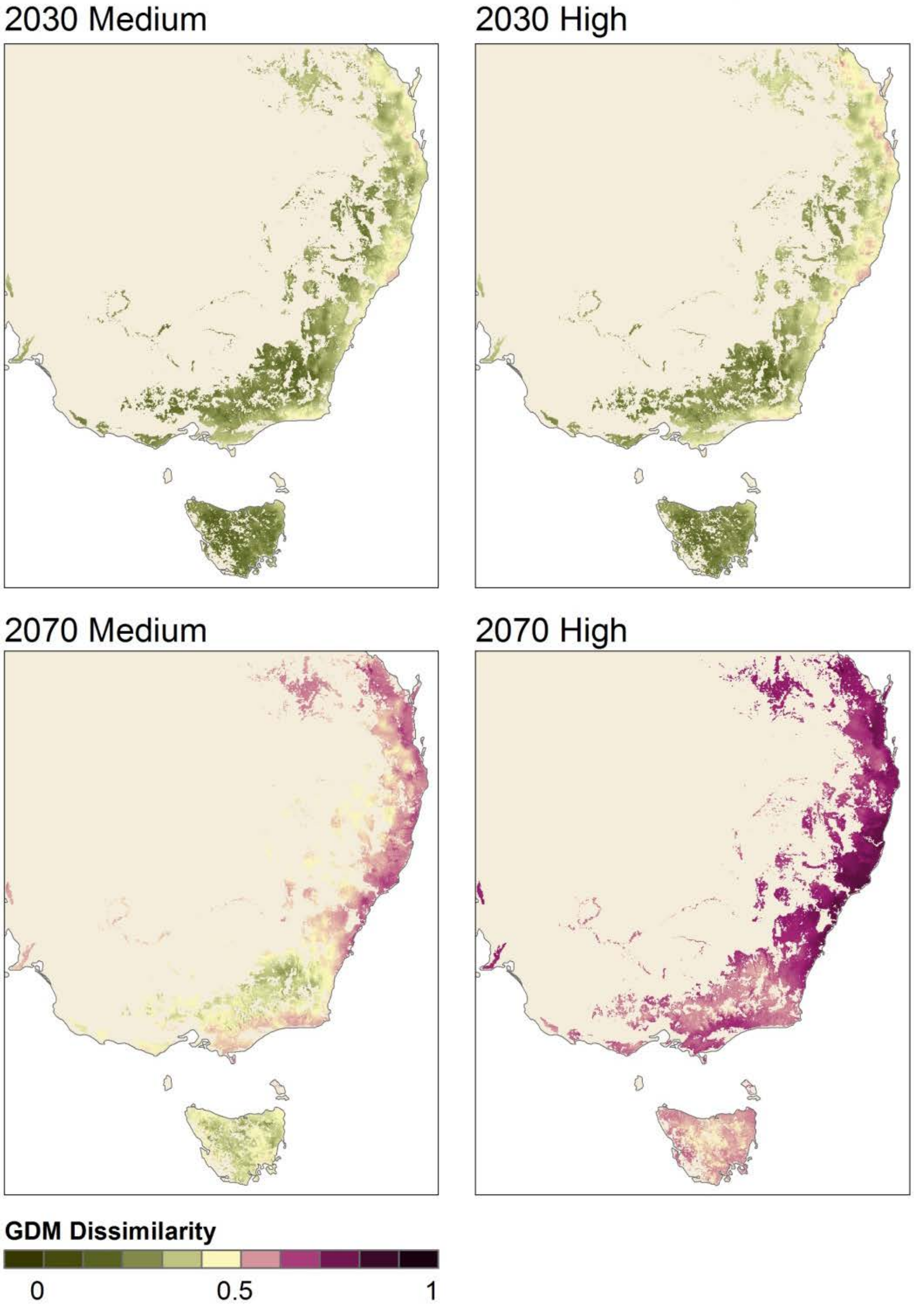

Figure 11 Weighted average dissimilarities for six taxonomic groups for 2030 and 2070 medium and high emissions scenarios. High dissimilarity (dark pink) indicates a high level of stress and low dissimilarity (dark green) indicates low stress

3.1.2.5 Invasive species – buffel grass

The majority of the south-eastern forests biome covers areas of low buffel suitability both currently (73%) and under future scenarios (52% 2070 medium, 72% 2070 high) (Figure 12). The 2070 medium scenario results in some increase in habitat suitability, particularly in the proportion of the biome shifting to medium suitability from currently low suitability; however, the 2070 high scenario results in only minor changes among the suitability classes compared to the current distribution (Martin et al. 2012).

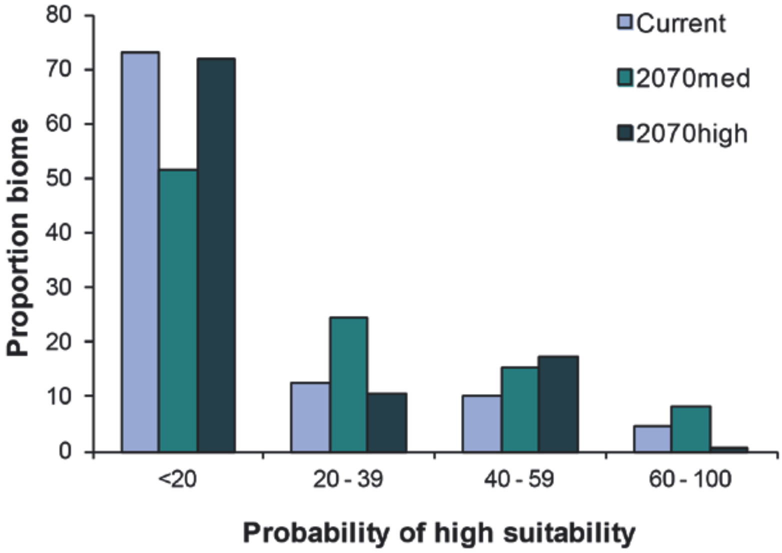

Figure 12 Proportion of whole south-eastern forest biome predicted to be highly suitable to buffel grass colonisation under current, 2070 medium and 2070 high emissions scenarios

These patterns are also reflected in the distribution of the NRS in the buffel suitability classes, that is, only minor changes between the current distribution and the 2070 high scenario distribution, and an increase in the proportion of the NRS system in the medium suitability class in the 2070 medium scenario (Figure 13) (Martin et al. 2012).

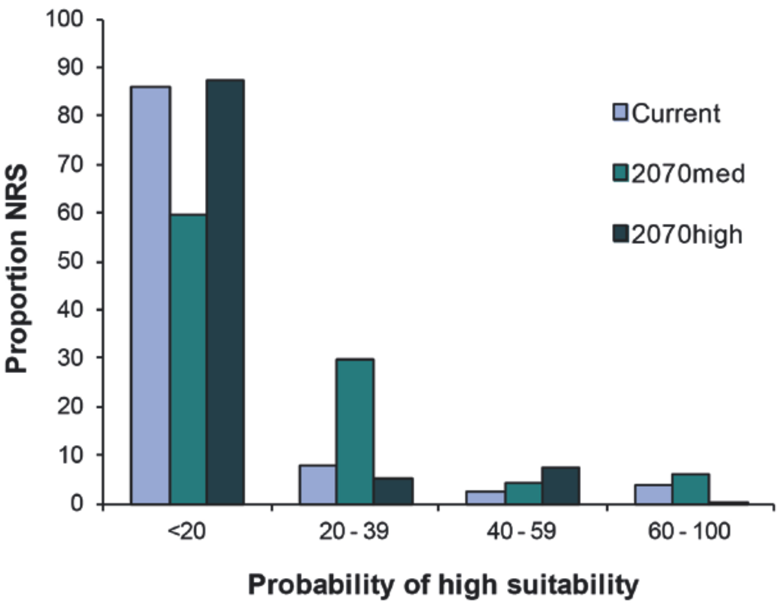

Figure 13 Proportion of NRS within south-eastern forest biome predicted to be highly suitable to buffel grass colonisation under current, 2070 medium and 2070 high emissions scenarios

Suitability for buffel grass invasion is highest along the western and northern boundary of the biome (Figure 14), as drier, more open environments replace those currently supporting open forest ecosystems.

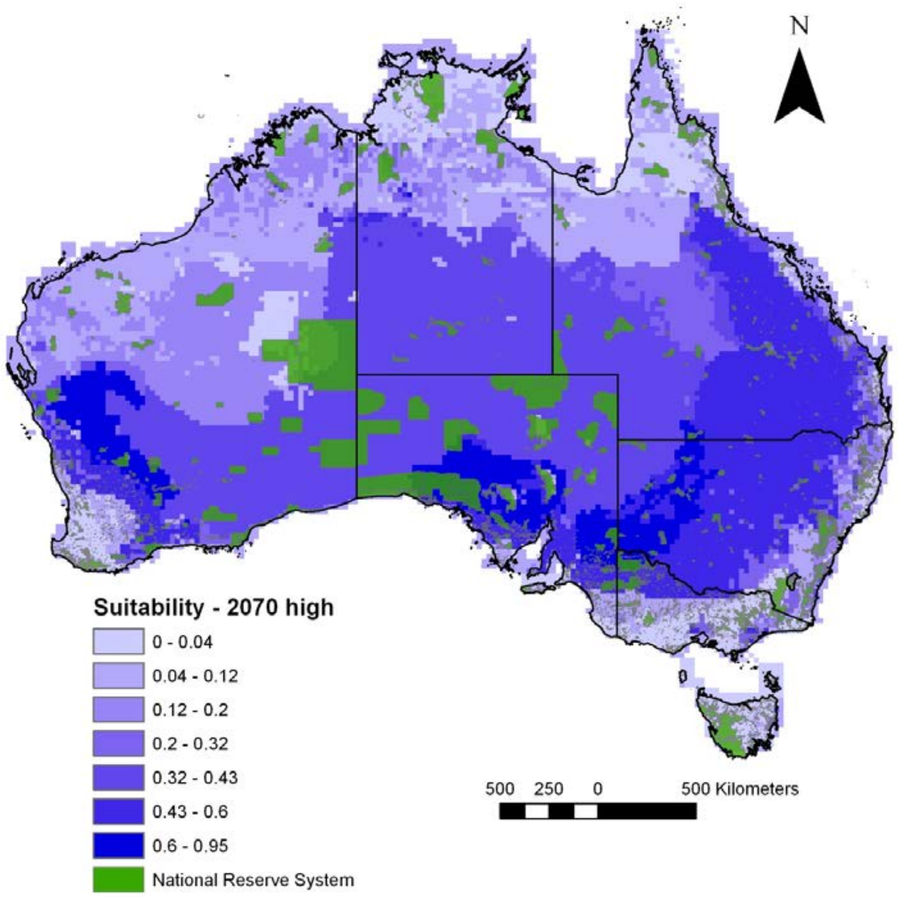

Figure 14 Probability of high suitability for buffel grass colonisation under 2070 high climate scenario

3.1.3 WHICH CLIMATE VARIABLES ARE MOST DRIVING PREDICTED CHANGES IN THE BIOME?

Moisture-based variables account for most of those contributing to modelled distributions of forest MVG environments (Table 3). For rainforest (MVG 1) environments, soil moisture in both the warmest and wettest quarters are important; for tall open forests temperature, rainfall seasonality and soil hydraulic conductivity, rather than moisture, determine distribution, indicating a soil texture response.

Table 3 Top three bioclimatic variables contributing to modelled distributions of MVG environments

MVG	BIOCLIMATIC VARIABLES
1	mean moisture index of warmest quarter
	moisture index seasonality
	mean moisture index of highest quarter
2	mean temperature of wettest quarter
	weighted average of median A horizon hydraulic conductivity
	precipitation seasonality
3	annual mean moisture index
	mean moisture index of coldest quarter
	highest period moisture index
4	mean moisture index of warmest quarter
	mean moisture index of coldest quarter
	annual mean moisture index

See Fenner School of Environment and Society 2012 for full definitions of these variables.

3.2 To what extent might impacts on biodiversity of the environmental changes be buffered by environmental variability at continental, regional and local scales?

3.2.1 DO THE ENVIRONMENTS CURRENTLY IN THE BIOME OCCUR ELSEWHERE IN THE FUTURE?

There are likely to be significant shifts in some MVG environments (see discussion in section 3.1.2, and Figure 6). Environments that currently support forests in MVGs 1–4 generally contract with climate change within the existing boundaries of the biome. There are few areas where 'new' forest environments appear. This is consistent with the overall eastwards movement of drier environments suitable for ecosystems currently occupying central and western parts of south-eastern Australia.

3.2.2 DO ANY ENVIRONMENT TYPES DISAPPEAR FROM THE BIOME OR CONTINENTALLY?

ANN modelling indicates that no MVG environments will disappear from the biome, although significant reductions in area are likely, as discussed in 3.1.1. The GDM modelling shows that, under a medium scenario, by 2070 most current environments in the biome will still occur *somewhere* on the continent (Figure 15). However, under the high emissions scenario, any future environments in the biome would likely be considerably different from any current environments (Figure 15). The exceptions to this are environments in central Victoria and Tasmania, where there is a greater chance of them occurring elsewhere on the continent.

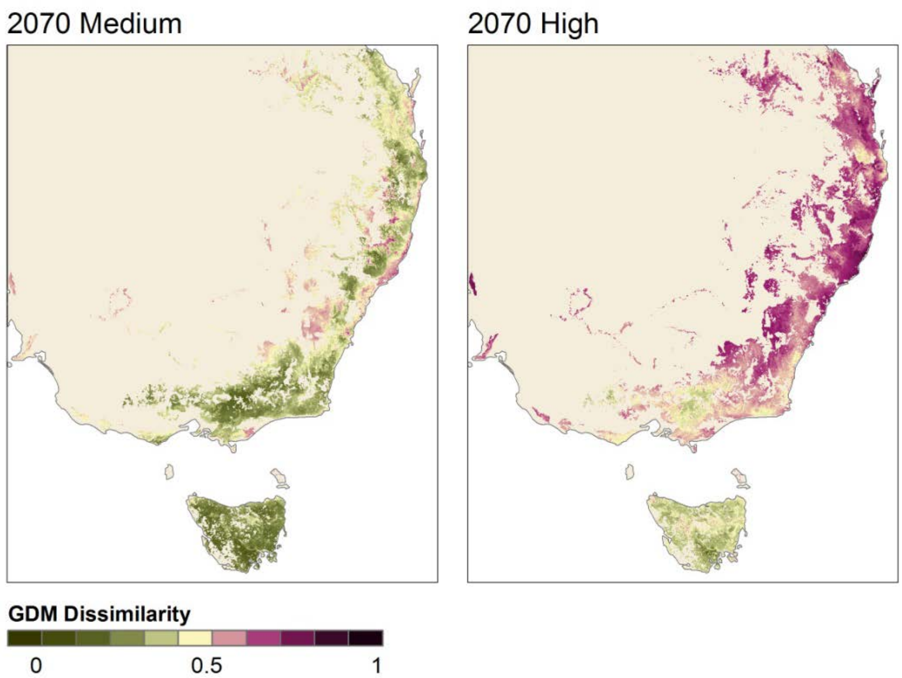

Figure 15 Minimum dissimilarity based on plant composition for each cell compared with all cells within a 50 km radius and a sample (1 in 1000) of the rest of the continent. Dark pinks indicate that the current environment is likely to disappear

3.2.3 ARE THERE ANY NOVEL ENVIRONMENT TYPES?

Under the medium emissions scenario there are predicted to be novel environments within the biome, especially along the coastal fringe and in South Australia (Figure 16). Current upland environments are still represented on the continent. However, this picture changes dramatically under the high emissions scenario, with most of the biome having future environments that are somewhat different from current environments found anywhere on the continent.

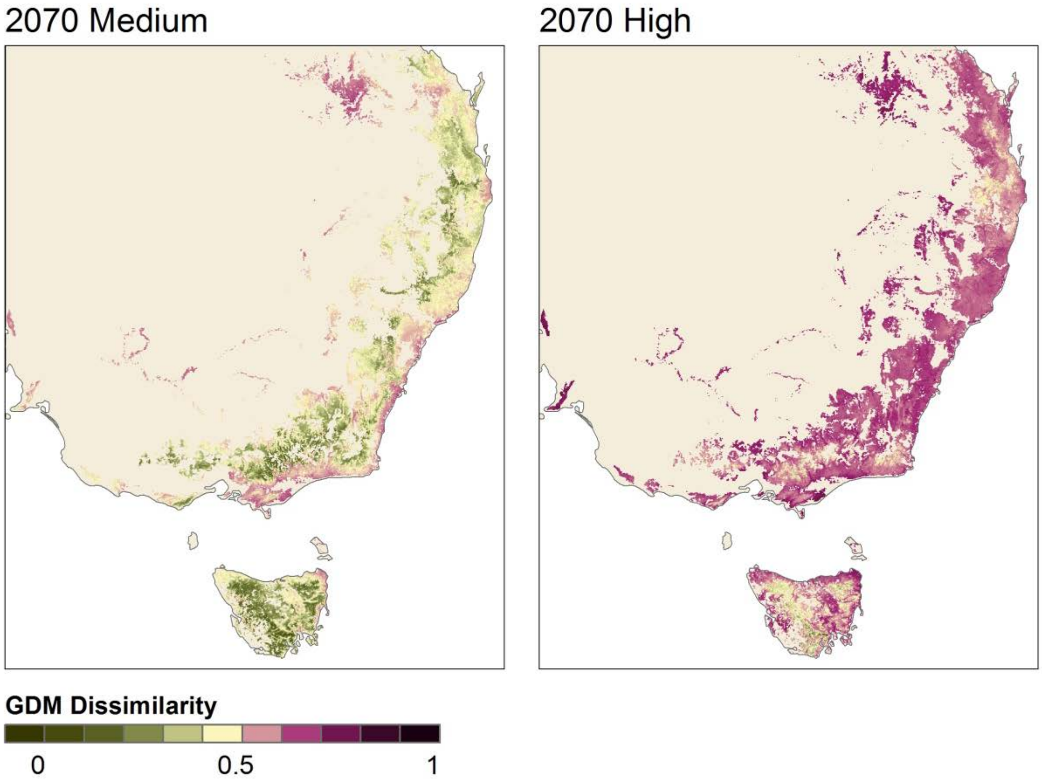

Figure 16 Minimum dissimilarity based on plant composition for each cell in the future (2070) compared with all cells within a 50 km radius and a sample (1 in 1000) of the rest of the continent in the present. Dark pinks indicate that the future environment is not currently represented in the biome

3.2.4 HOW MUCH BUFFERING IS PROVIDED BY LOCAL-SCALE LANDSCAPE HETEROGENEITY?

Forest environments in south-eastern Australia are characterised by a high level of local landscape heterogeneity, imparted by complex topographies, variable soil conditions and steep, local climate gradients. The modelling showed good levels of buffering at 25 km and 100 km scales in many parts of the biome, but little effective buffering at 750 m (Figure 17). However, the data used in the modelling were of insufficient resolution to detect much of the local environmental variability typical of the biome and discussed in the workshop. For more mobile taxa such as birds and mammals there may be scope for species to move locally (dispersal constraints and connectivity allowing). The greater buffering capacity of, for example, slopes compared with ridge and mountain tops at local (3 km radius) scales is demonstrated in Figure 18. These results show that while buffering is available at regional scales, local-scale buffering is also important, highly variable, and needs further investigation.

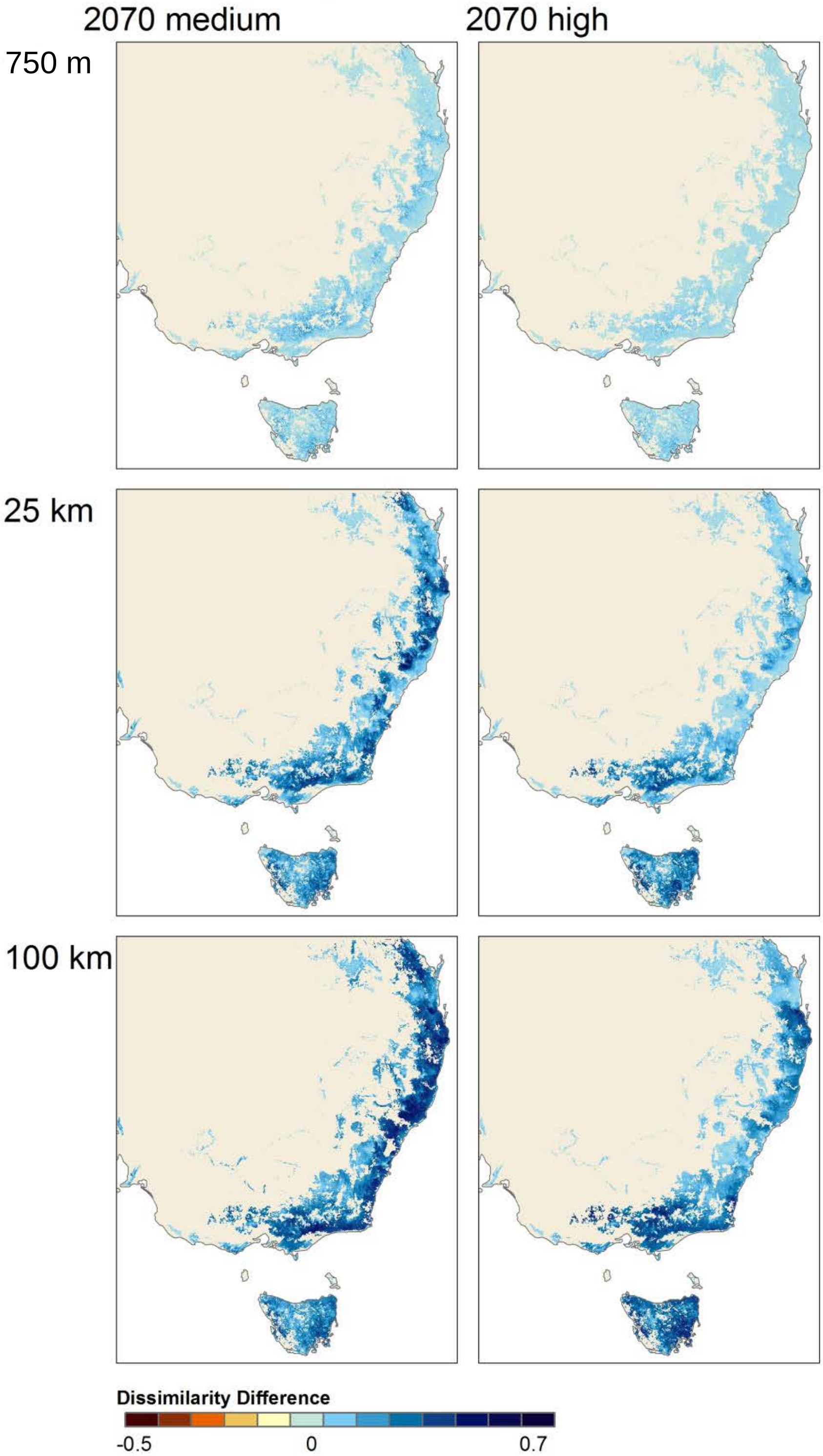

Figure 17 Difference in dissimilarity between that of the central cell and the minimum dissimilarity within 750 m, 25 km and 100 km radii. Dark blues indicate good buffering (more similar environments within the radius than in the central cell)

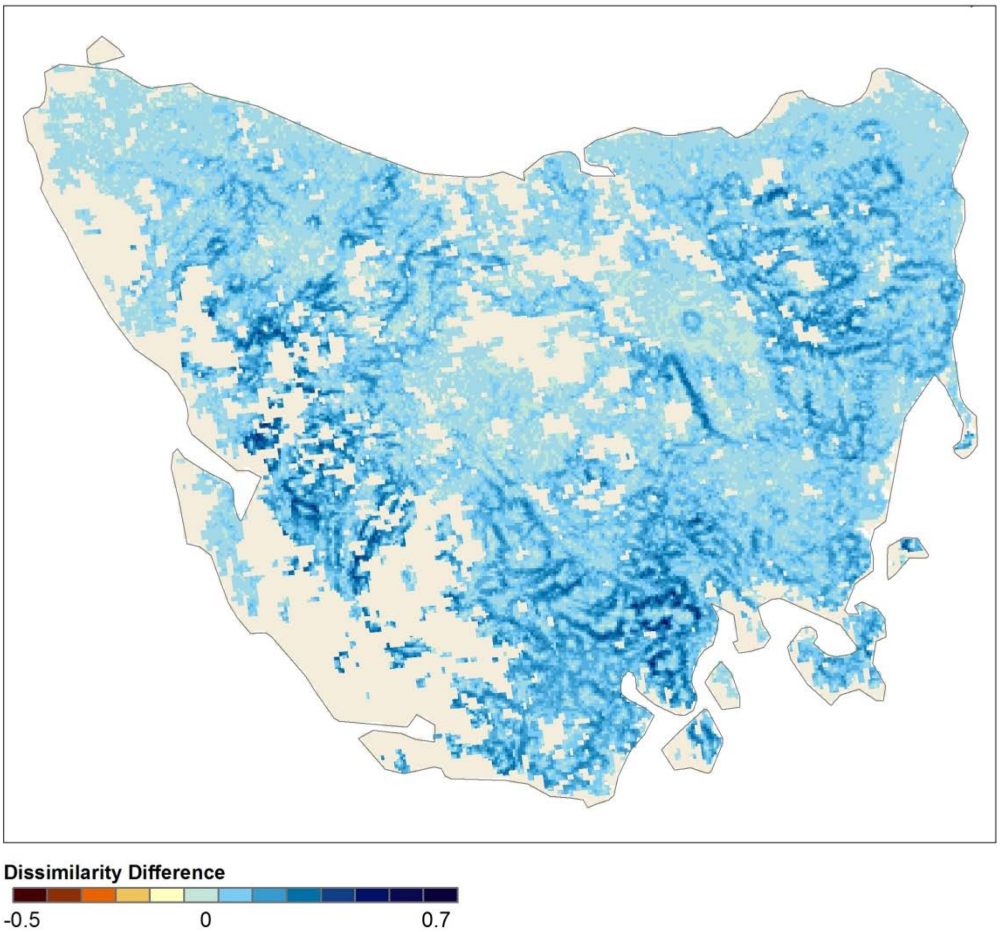

Figure 18 Difference in dissimilarity between that of the central cell and the minimum dissimilarity within 3 km radius, showing the influence of complex topography in Tasmania. Dark blues indicate good buffering (more similar environments within the radius than in the central cell)

The 'effective habitat area' analysis (section 2.3) shows similar trends of higher buffering in the ranges (especially in the south) and in Tasmania, with much more effective buffering under the medium than the high emissions scenario (Figure 19). Buffering is only likely to be of benefit if species can disperse; this will be possible for mobile taxa such as birds and some plants dispersed by wind, but there are likely to be significant lags in the development of ecosystems that we recognise as forests today.

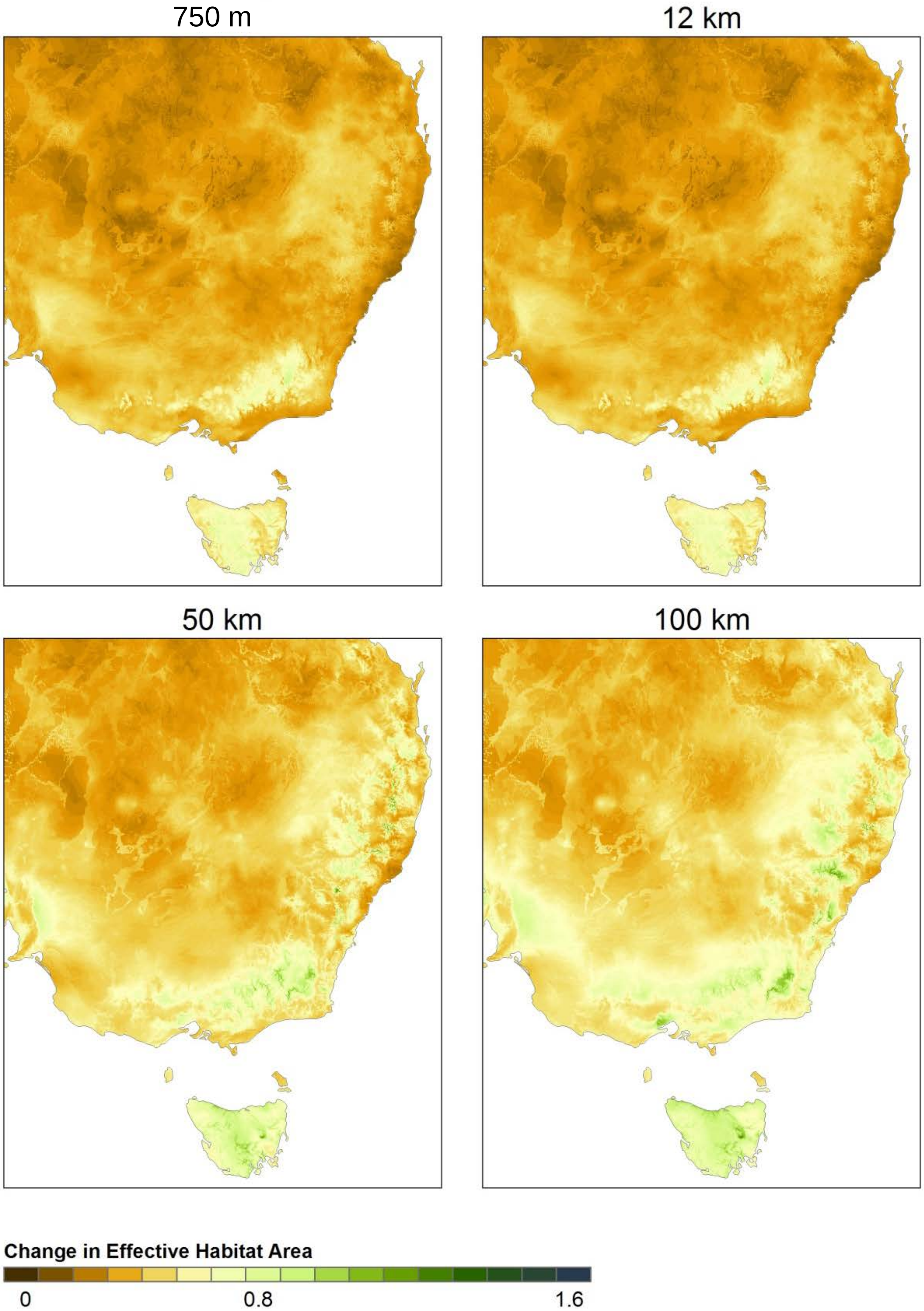

Figure 19a 2070 medium emissions scenario: the proportional change in effective habitat area within various radii, where 'effective habitat area' is the summed area of all cells within the radius, with each cell weighted according to the predicted similarity (1-d_{ij}) between the composition of this cell (current versus future) and the current composition of the focal cell. Dark browns indicate increased stress within habitat; dark greens (> 1) indicate increase in total suitable environment in the area

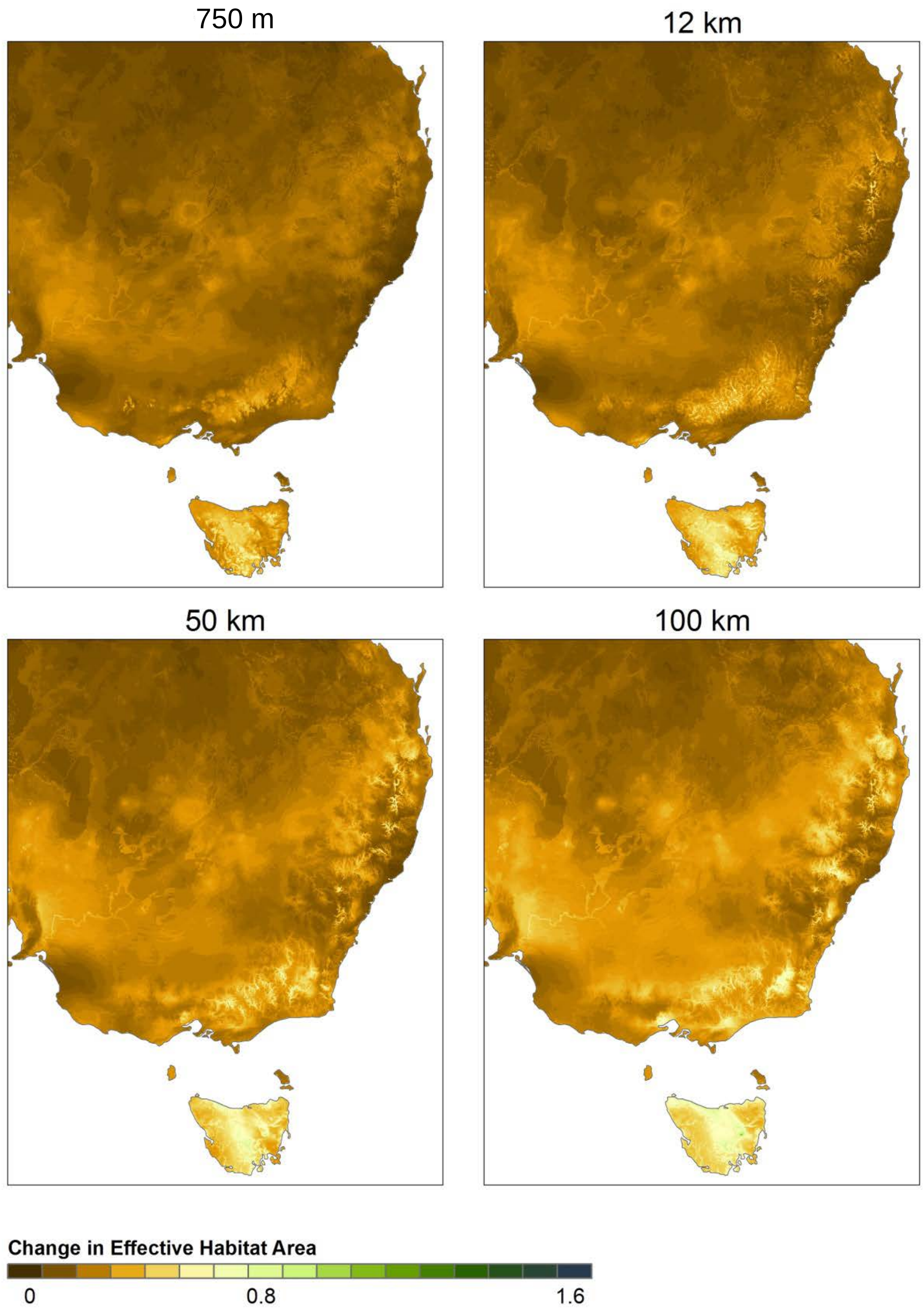

Figure 19b 2070 high emissions scenario: the proportional change in effective habitat area within various radii, where 'effective habitat area' is the summed area of all cells within the radius, with each cell weighted according to the predicted similarity (1-d_{ij}) between the composition of this cell (current versus future) and the current composition of the focal cell. Dark browns indicate increased stress within habitat; dark greens (> 1) indicate increase in total suitable environment in the area

3.3 To what extent does habitat loss magnify the changes in environment or reduce the buffering due to environmental heterogeneity?

Environmental stress due to climate change is generally similar in the extant and cleared areas of the biome, except that the loss of MVG 4 environment is much greater when only considering remaining vegetation (Table 1). Habitat loss generally exacerbates the likely reduction in buffering capacity through removal of potential new effective habitat areas (Figure 20). This is especially acute in the western parts of the biome (western Victoria, South Australia), along the northern New South Wales coast and southern Queensland, and along the western edge of the biome in northern Victoria and western New South Wales. Western Tasmania is least affected, but in the 2070 high emissions scenario all parts of the biome are predicted to show declines in EHA and become vulnerable to change.

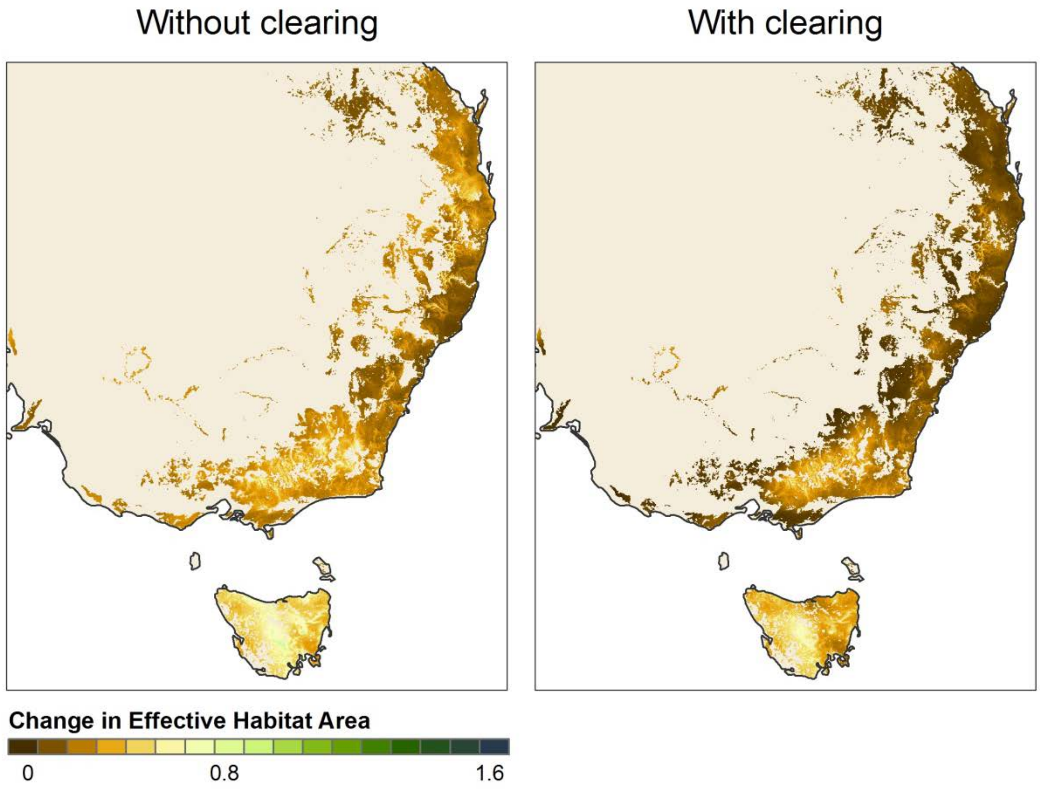

Figure 20 The proportional change in effective habitat area for pre-1750 vegetation (left) and masked for clearing (right), all cells within a 50 km radius, plants only, 2070 high emissions scenario. Dark browns indicate increased stress within habitat; dark greens (>1) indicate increase in total suitable environment in the area

3.4 Interactions between climate change and land use

The level of habitat loss and degradation in this biome is highly variable. In the southern parts (including Tasmania), broadscale clearing has not affected forest cover or connectivity as much as in other parts of the biome (especially south-east Queensland). However, forest management practices and urban encroachment have rendered forest ecosystems vulnerable to a range of potentially adverse influences, including inappropriate fire regimes and introductions of exotic plants and animals. This is demonstrated in the reduction in effective habitat areas (Figure 20).

4 Discussion

4.1 What major ecological changes are likely?

Climate change will affect forest ecosystems through impacts on the major drivers that determine forest ecological processes. These changes will have compositional and structural consequences, especially at the vulnerable margins of the biome and where in the future, environments more suitable for other, non-forest ecosystems are likely to occur.

4.1.1 STRUCTURAL CHANGE

The predicted reduction of tall open forests in much of the southern mainland by 2070 under the high emissions scenario will result in substantial changes in forest structure. This opening may be further exacerbated by increased frequency or severity of drought. As environments become drier (and more fire-prone, see below) there may be a loss of rainforest understoreys, and this in itself will allow more frequent fires to occur. Replacement of tall open forest species with open forest species will result in (on average) a reduction in canopy height, and replacement of shrubby understoreys with grassy ones – with substantial implications for a range of fauna, especially those dependent on special habitat resource (e.g. tree hollows) for reproduction (Kavanagh and Stanton 2005; Mackey et al. 2002).

4.1.2 COMPOSITIONAL CHANGE

Accompanying structural change will be some degree of compositional change. The GDM modelling used here suggests a degree of environmental change is expected that is consistent with dramatic changes in plant species composition, and along with it some vertebrate (reptiles) and invertebrate (snails) groups. Birds, being highly mobile, are not predicted to be so sensitive to changed environments in that they should be able to find suitable environments elsewhere within the biome. But note that the modelling of bird communities was done independently of plant communities, changes in which could readily drive bird community changes. There is evidence that narrow endemics are likely to be most sensitive to climate change (Malcolm et al. 2006) unless they can disperse to alternative, suitable environments. Vulnerable regions in this biome include the Border Ranges national biodiversity hotspot, the alpine areas of Kosciusko National Park and parts of Tasmania.

4.1.3 ALTERED FIRE REGIMES

There are uncertain and conflicting futures for fire regimes in temperate forests (Bradstock 2010), but they will play a dominant role in influencing change. The general prediction that a drier continent will experience reduced fire frequencies (through reduction in fuel accumulation) is not met in forests, where fuels are litter and shrub-based and fires are limited by fuel moisture content – adequate growth of fuels and quicker curing times may therefore result in increased fire frequencies. In tall open forests, adapted to catastrophic fires on the frequency of 100+ years, a greater frequency may result in replacement of the overstorey with species tolerant of more fire (i.e. lignotuberous species). However, the major driving mechanism behind climate-induced changes to fire regimes in forests generally is likely to be the incidence of severe drought, leading to elevated fire danger (Lucas et al*.* 2007). In open forests, the increase in fuel growth due to CO_2 fertilisation may be offset by a reduction in growth due to less favourable (drier) climates (e.g. Booth et al*.* 2010), but ignition frequencies may be higher due to increased lightning strikes, and the southward spread of C_4 grasses will allow greater fire spread due to higher fuel loads. Impacts of changed fire regimes on fauna are complex, and are manifest through changes in forest structure and, to a lesser extent, composition.

4.1.4 EFFECTIVENESS OF REFUGIA

In the dissected topographies of the Great Dividing Range, a core area for open and tall open forests, species richness is high partly because of the heterogeneity in edaphic and climatic environments at small scales (Ashton and Attiwill 1994; Florence 1996; Bale et al. 1998). The extreme example of this is the occurrence of rainforest environments within a matrix of open forest, usually in fire-protected gullies. There is also a range of other restricted environments that have led to the development of forest communities of limited distribution. In some cases (especially rainforests), more widespread and frequent fire would be a serious threat to their persistence – unless fire frequency is so high that fuels do not accumulate to levels necessary for fire encroachment into mesic forest environments. Extreme fire weather conditions, however, may allow this to occur irrespective of fuel loads, and it could be exacerbated by increased establishment of flammable understory species (see below).

4.1.5 INVASIVE PLANTS

Perturbation of ecological processes through rapid climate change is likely to lead to opportunities for invasive plants to spread, possibly over large distances (Scott et al. 2008). It may also allow 'sleeper' species to expand their ranges (and/or become locally abundant), with a general trend of species moving from north to south, thereby placing additional stress on the western and northern boundaries of the forest biome. In addition, changed climate conditions may lead to increased reproductive success in pollen-limited invasive plants through spread of exotic pollinators (Stokes et al. 2006), and a general increase in the abundance of exotic species (as communities undergo ecological filtering) will be expected.

Shifts in C_4 grasses further south in Australia may also pose a threat. In particular the threat from buffel grass (*Pennisetum ciliare*) increases with climate change, with a shift southwards of its existing distribution into what are now temperate open grassy woodlands (Martin et al. 2012). This in turn will alter fire regimes, as explained above. Other invasive species such as lantana (*Lantana camara*) will also affect fire regimes through altering fuel availability and flammability, and place rainforest environments under greater threat (Batianoff and Butler 2002).

4.1.5 PESTS AND DISEASES

There is some evidence that forest growth may be impacted by an increase in diseases that affect leaf area (e.g. Pinkard et al. 2010), and that this might offset some of the potential gains in growth due to elevated CO_2. Similarly, increased climate extremes (especially drought) that place forests under physiological stress can lead to severe decline due to insect attack (Allen et al. 2010). As the incidence of extreme drought is predicted to increase under climate change scenarios for Australia, this poses a serious risk to forest ecology.

4.2 What conservation management options are available?

Current conservation goals and processes will continue to be appropriate under climate change, and a range of species-to-landscape approaches will be needed. Moderating the rate of conversion to alternative land uses (especially conversion to agriculture and urban), using established methods for restoring forest communities (using native species), and promoting sympathetic off-reserve management will all contribute to improving forest resilience to climate change. In addition, we canvas the following specific options for conservation management.

4.2.1 RESERVE CONTINUOUS ELEVATION SEQUENCE FROM COAST TO MOUNTAINS

There is widespread acknowledgement that conservation planning, even without the imperative of rapid environmental change, is best done at regional scales (e.g. Rouget et al. 2006). Given (1) the impact of fragmentation on the resilience of forest ecosystems to climate change, (2) the importance of topographic complexity in retaining a range of forest environments, and (3) the likely elevational shifts in boundaries between MVGs, reservation of a continuous transect of land from the coast to the eastern slopes of the Great Dividing Range might allow for re-sorting of species and communities along environmental gradients without the added constraint of habitat fragmentation. Ideally this would be done in several places from western Victoria to southern Queensland. The relatively small 'outliers' of the biome in South Australia are far more vulnerable and will be difficult to conserve.

4.2.2 RESTRICT FRAGMENTATION/IMPROVE CONNECTIVITY

Forests have typically been relatively resilient to past major climate change events (Noss 2001), but fragmented forest landscapes are more vulnerable. Further fragmentation will increase this vulnerability, and reduce the effectiveness of adaptation through genetic processes (Jump and Penuelas 2005). This emphasises the importance of both reducing fragmentation and encouraging greater connectivity in landscapes already fragmented by land clearing. Clearly, past clearing has increased the likelihood of distributional and compositional change in forest ecosystems; strategic restoration may alleviate some of the additional threats imposed on forests by climate change.

4.2.3 PROTECT REFUGIA

Multiple types of refugia are likely to remain important for the maintenance of many species of the biome. These include refuges from fire, pests and diseases, drought and human activities, as well as past climatic refuges. Climate change places refugia, as we currently know them, under threat; nonetheless they are likely to remain 'special' places in the environment where unique arrangements of species are found. Whether they will continue to support ecosystems similar to those at present is uncertain, but they are likely to provide critical resources for species of limited environmental tolerance. Many species that appear to have restricted ecological limits may have substantial genetic variability (e.g. *Eucalyptus regnans*; Nevill et al. 2010), and also may undergo significant fluctuations in range during rapid global change without losing genetic variation (Hamrick 2004). Identification and protection of genetically distinct populations will be a key response.

4.2.4 FAVOUR LARGE REMNANTS

Large remnants, encompassing a greater diversity of environments, will protect a greater number of communities and species than small remnants. Larger size will allow for more buffering against changed fire regimes at the margins and invasion by exotic species (Pickett and Thompson 1978). Current large reserves within the biome will play a critical role in allowing for adaptation to new climates.

4.2.5 ADAPT FIRE POLICIES

Australian sclerophyll forests are characterised by their relationship with fire for promotion of regeneration. Altered fire regimes due to changes in fuel accumulation and drying rates, and the increased incidence of severe fire weather conditions (Bradstock 2010) will require systematic planning and research to devise fire management actions that maintain fire regimes appropriate for conservation, while also allowing for changes in fuel dynamics. Additional resources may need to be devoted to fire detection and suppression in conservation areas to mitigate undesirable outcomes.

4.2.6 MODIFY FORESTRY MANAGEMENT

Much reliance will be placed on the contribution of currently unreserved forests to overall forest conservation under climate change. Forestry management practices that maintain natural ecological processes will afford the best protection against climate change. This would require a reduced rate of conversion to plantations (minimal now anyway) and other land uses, and modification of some existing silvicultural regimes (e.g. clear-cutting in multiple-aged stands) (Noss 2001). In general, management to promote high structural and compositional diversity, mitigation of increased fire risk, and incorporation of climate change into planning decisions will help reduce the impact of climate change on biodiversity in managed forests.

5 Conclusions

Sclerophyll forests in south-eastern Australia, while perhaps somewhat more resilient to the impacts of climate change than other biomes, are likely to undergo substantial change by 2070, with much more significant changes under a higher emissions scenario. The relatively intact nature of the biome (especially in the south, including Tasmania) and the complex nature of the terrain that forests occupy afford some additional robustness, but in the north of the biome past clearing has rendered forests more vulnerable.

Wetter forest habitats in the central and southern parts of the biome are at risk due to reductions in available moisture and synergistic relationships with increased risk of fire. In addition, structural and compositional change (resulting in habitat change) is likely to be substantial across the whole biome, although this does not necessarily imply loss of species or other values.

Adaptation to climate change will require a range of management interventions, most of which are already being applied for conservation outcomes, but some (e.g. new fire management strategies, species translocations, reservation of genetically distinct populations) will require additional effort and support. In particular, forest management practices by both public and private sectors will need to take potential climate impacts into account to reduce the magnitude of climate change–induced stress on forests in south-eastern Australia.

Most importantly, the protection of refugia and maintenance of connectivity (both within and outside the NRS) will be critical in conserving biodiversity at local and regional scales.

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Appendix A Workshop summary

Workshop participants (department names correct as at time of workshop)

PARTICIPANT	AGENCY NAME (AT TIME OF WORKSHOP)
Dr Mike Austin	CSIRO Sustainable Ecosystems
Mr Justin Billing	Department of Environment, Water, Heritage and Arts
Dr Ross Bradstock	University of Wollongong
Dr Geoff Cary	Australian National University
Mr Michael Doherty	CSIRO Sustainable Ecosystems
Ms Liz Dovey	Department of Climate Change
Mr Fred Duncan	Forest Practices Authority, Tasmania
Dr Mike Dunlop (facilitator)	CSIRO Sustainable Ecosystems
Dr Teresa Eyre	Department of Environment and Resource Management, Queensland
Ms Helen Federoff	Department of Sustainability and Environment, Victoria
Dr Simon Ferrier	CSIRO Entomology
Dr Louise Gilfedder	Department Primary Industries, Water and Environment, Tasmania
Dr Dave Hilbert (project leader)	CSIRO Sustainable Ecosystems
Dr Alan House (organiser)	CSIRO Sustainable Ecosystems
Mr Gary Howell	Department of Sustainability and Environment, Victoria
Dr David Keith	Department of Environment and Climate Change, NSW
Dr Graeme Newell	Department of Sustainability and Environment, Victoria
Ms Elizabeth Oliver	Department of Environment, Water, Heritage and Arts
Dr Ross Peacock	Department of Environment and Climate Change, NSW
Dr Kristen Williams	CSIRO Sustainable Ecosystems
Dr Alan York	University of Melbourne

Workshop schedule

Time	Wednesday 6 May
10:00	Tea and coffee
10:15-10:30	Welcome and Introduction (Alan, Mike)
10:30-10:45	Introductions
10:45-12:00	Round table report back on homework (Participants)
12:00-1:00	Lunch
1:00-1:45	Presentation on environmental and biodiversity change (Mike)
1:45-2:30	Presentation on key ecosystem drivers of biome (Alan)
	Discussion of sclerophyll forests as a system (Alan/Mike)
2:30-3:30	Presentation on what's likely to change (report on draft lit. review) (Alan) Discussion: changing sclerophyll forest systems (Alan/Mike)
3:30-4:00	Afternoon tea
4:00-5:30	Presentation and Discussion: Modelling and detection of big changes (Dave)
5:00	Close
	Thursday 7 May
8:15	Tea and coffee
8:30 - 8:45	Update on changing biome (Mike)
8:45-10:00	Presentation and Discussion: Typology of big change phenomena, "working scenarios" (Mike/Alan)
10:00-10:30	Morning tea
10:30-11:30	Discussion: Implications for conservation, agencies and NRS (Mike)

11:30-12:30	Presentation, discussion: Adaptation options (Mike)
12:30-1:30	Lunch
1:30-2:15	Discussion: Information needs following on from adaptation options What info is actually needed, how to get it? (Simon)
2:15-3:15	Round table on emerging issues, challenges, lessons (Mike)
3:15-3:30	What's next
3:30	Afternoon tea / Close

Homework

Prior to the workshop, invitees were asked to provide:

1. A SHORT biography and summary of your interest/experience in this biome and how this might relate to climate change
2. A summary of your organisation's/State's response to climate change and reserve design/management
3. A few lines on what you think the big issues are with respect to south-eastern Australian forests and climate change.

These responses were collated and used to provide background for the facilitator to use in directing discussion. Participants were also asked to speak briefly to these points at the start of the workshop.

Presentations

A number of short presentations were given over the two days to set the scene and stimulate discussion. The major points are summarised below.

DCC climate change policy and relationship between NRS1 and NRS2 *(Dovey)*

- Three pillars to DCC approach:
  - Shaping a global solution to climate change
  - Reducing CO_2 emissions
  - Adapting to change (primary focus)
- Knowledge required to improve ability to adapt; identify vulnerabilities
- Biodiversity/natural ecosystems most vulnerable to change in temp of 1.5–2°C
- Priority themes for COAG include terrestrial biodiversity (led by Steve Williams, JCU). Purpose is to identify key gaps and enhance capacity to do research
- Also National Adaptation Research Plan (NARP – to be announced)
- DCC activities include:
  - National impact assessments include forests (commercial and conservation), coastal, aquatic ecosystems; reports not finalised
  - NRS1 report (Dunlop & Brown)
  - Fire and biodiversity report.

Climate change – current position *(Dovey)*

- Climate now outside the envelope of known geological history
- CO_2 now leading shifts in temperature
- Emissions data is outside the range of current predictions – if all greenhouse gases are converted to CO_2 equivalents, concentration in the atmosphere is approximately 425 ppm (target for stabilisation is 450 ppm)
- Chances of reversing current trends are minimal, and there is an inevitable change in temperature

- Still uncertainties over changes in rainfall and seasonal variability
- Trends in increasing rainfall in NW and decreasing in SE and SW Australia confirmed
- Future run-off projections are dire: up to 20% reduction in SE Queensland, neutral–5% reduction across much of the rest of the biome except eastern Tasmania, where runoff modelled to increase by 0.1–2%
- Extreme rainfall events are predicted to increase in NSW
- Much complexity in changes in relative humidity, wind strength, frost incidence, water availability.

Climate change and conservation *(Billing)*

- >9000 areas in NRS (including IPAs): 9.4% in formal reserves, 1.9% in IPAs, 0.3% private
- Focus on identifying areas <10% reserved by IBRA sub-regions
- $38M available now for reserve acquisition under Caring for Country
- Targeting sub-regions with <10% reservation by bioregion and 0% by sub-region
- NRS encouraging a regional approach to purchase of private land for reservation to avoid too many small blocks
- Aims for managing for climate change: minimise genetic loss and maximise resilience; avoiding impacts of major threatening processes
- Travelling stock routes not in NRS scope even though they are a very valuable resource – other state and federal initiatives may pick them up.

NRS1 summary *(Dunlop)*

- Cascade of impacts and many types of change
- Species interactions will be critical, species will respond individually
- Changes hard to predict, large degree of uncertainty
- Climate change will affect all aspects of biodiversity
- Three mental models of possible change:
  - Change in relative abundance *in situ*
  - Rapid/long-distance dispersal and flow on impacts
  - Gradual distributional changes
- Some evidence for all of these; need to expect and plan for each
- Need to manage the change to minimise the loss
- CAR principles are robust under climate change
- Maintain habitat diversity for species survival/persistence
- Diversity of environment as a surrogate for habitat diversity can work
- Four 'wicked' threats identified:
  - Fire regimes
  - Species churn
  - Water security
  - Land use change (agricultural adaptation might amplify impacts of climate change, e.g. Intensification of pastures, etc)
- Issues (connectivity, translocation, refugia, resilience) often ill-defined
- Key messages:
  - Assess objectives carefully
  - Protect habitat adequately
  - Manage threats.

SE Australian sclerophyll forests: key ecosystem drivers and how the biome might respond to climate change *(House)*

See 1.3.4 in main body of report for summary.

Modeling approaches for NRS2 *(Hilbert)*

Three major components:

- Modelling potential changes in distribution of environmental types / ecosystem classes using artificial neural nets (ANN)
- Modelling potential changes in community composition using generalised dissimilarity modelling (GDM)
- Modelling potential invasion by buffel grass using Bayesian belief networks (BBN)

Classification of environments using artificial neural networks

- Objective classification of environments based on mapped vegetation or ecosystem types
- Assess how these environments may change in extent and location with climate change
- Assess stress to the vegetation as it occurs now due to dissimilar environments in the future
- Identify possible major shifts in biome distributions
- Identify novel environments where no existing vegetation types are likely to survive in the long-run
- Identify 'refugia'

Issues – some big questions

- Is there really any value in attempting to model impacts of climate change on biodiversity?
- Relative emphasis on direct *versus* indirect impacts? How might we consider other indirect impacts – changed fire regimes, land use, etc?
- Relative emphasis on top-down *versus* bottom-up modelling? Are there some key species that need to be modelled individually?

Issues – biological data

- For GDM approach the fallback is to use models derived from ANHAT data. But for which groups: plants, birds, mammals, reptiles, termites, etc? Are there any better survey datasets available from other sources?
- For ANN approach the fallback is to use mapped NVIS classes. But at which classification level? Are there any better vegetation (or ecosystem) mapping datasets available from other sources?

Issues – environmental data

- Planning to use best-available continental datasets for climate (35 ANUCLIM variables at 250 m resolution – temperature, precipitation, radiation, moisture indices, growth indices), terrain (10 variables at 250 m resolution), soil/bedrock (8 variables at 1 km resolution)
- But what are likely to be the key variables for this biome, and what are we missing? Inter-annual variability in, and episodic nature of rainfall?

Issues – climate scenarios

- Planning to use three broad emission scenarios suggested by National Biodiversity Climate Change and Vulnerability Assessment – 'recovery', 'stabilisation' and 'run-away' – combined with three types of regional change
- Projected climate surfaces will be derived by linking extended ANUCLIM software with downscaled CSIRO GCM outputs.

Fire and biodiversity project update and relevance to sclerophyll forest ecosystems *(Bradstock)*

Summarised in Impacts of climate change – Fire (see below).

Subsequent discussion was centred on a number of issues emerging from these presentations and the literature review. These are summarised below.

Key ecosystem drivers – current

Terrain and forest dynamics

Patterning in sclerophyll forests is controlled by a number of factors, including major environmental gradients (rainfall, temperature, soil fertility, aspect) and their interaction with disturbance, mainly fire.

In this biome, species and community distributions are also determined by terrain – the rugged nature of much of the biome results in very complex landscapes wherein refugia (sheltered gullies, wet sites, fertile soils, etc.) are an important feature. Using climate as the sole basis of predicting species' distributions or predictions of change under climate change is likely to be misleading if the concept of terrain is ignored.

Dynamic processes in forests are often impulse-driven – an example was given of a single, major rainfall event causing a major regeneration event in forest understoreys, something that had a long-lasting effect. Drought (discussed below) is also likely to induce these sorts of legacy changes in structure and composition in forests.

Policy changes over the past 20 years have led to unforeseen problems in forests. In NSW, private forests are now subject to harvesting to meet RFA supply commitments as supplies of timber from State-managed forests become unavailable – return period is currently 10 years, and this will impact on forest structure and possibly composition. Grazing in forests previously used for timber production has become less common; this will lead to altered regeneration dynamics, structure and fire behaviour.

Fire

Fire was recognised as having a special and significant role in determining how the biome looks and works.

In addition to the presentation and subsequent discussion below (under Impacts of climate change), the following points were raised.

- Pre- and post-fire weather critical for vegetation recovery (e.g. for germination and/or repsrouting), and largely determine forest structural outcomes, irrespective of climate change
- Impacts of last major fire are more important than longer-term fire regime in determining ecosystem responses. Past and present forest management activities also affect responses to fire
- Fire-induced mosaics are important for a range of biota, especially small mammals, which depend on access to a range of post-fire recovery stages for different parts of their life cycle
- Large regional variability in responses to fire across the biome: e.g. Tasmanian coniferous forests are special case, and are being lost to fire and replaced (in places) by eucalypt-dominated forests; fires lit by shepherds in 1960s–80s very extensive and caused widespread change
- Also in Tasmania, there have been major changes in relative abundances and spatial distribution of, for example, button grass due to fire at expense of heathlands
- Use of fire to promote grazing in decline in north: management and regulation costs are too high for financial returns.

Role of modelling

In addition to the modelling approaches outlined above for the NRS2 project, specific modelling applications were seen to be relevant to this biome.

Species distribution models (SDM) were considered an appropriate method to use to explore possible changes in species' ranges and extinction risk due to climate change. However, there are many constraints in its application. A key unknown is the extent to which fundamental and realised species' niches coincide; difference between them will be critical in determining outcomes under climate change. SDMs could be linked to stochastic population models to reduce disparities in model outcomes, and they could be linked to forest gap models (stand-based) such as BRIND to explore changes to both forest distribution and dynamics. Some new research would be necessary to find out how best to accomplish this.

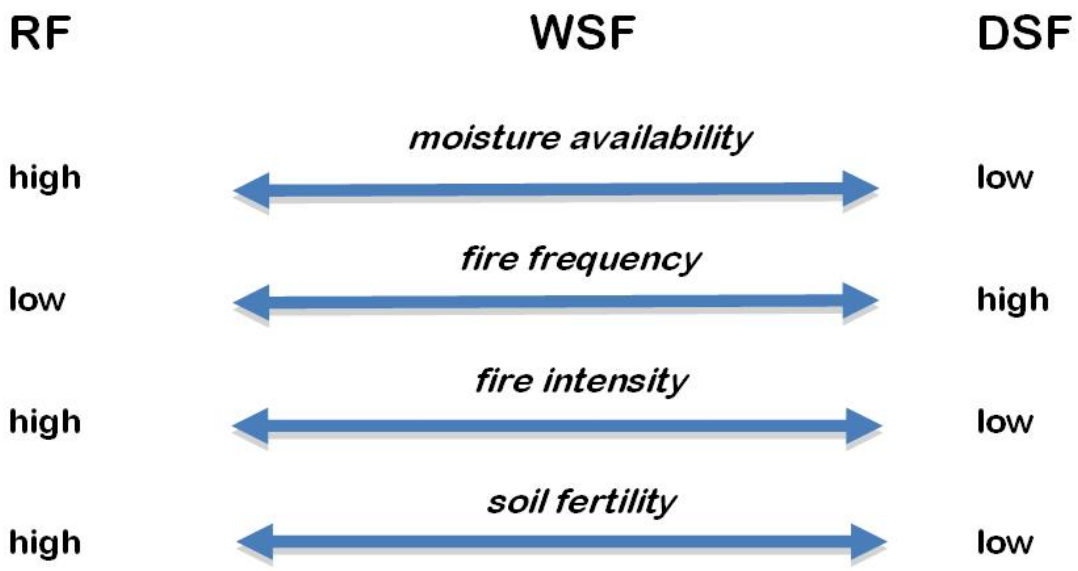
Process models could also be linked with correlative models to allow exploration of a range of forest dynamics issues (e.g. density dependence, competition, establishment and early growth etc.), as well as examination of alternative management scenarios by applying sensitivity analyses – this is likely to achieve better outcomes than simple correlative models alone.

Population modelling can play a role in determining the probability of establishment and early growth after disturbance (e.g. fire) under climate change, and varying the coefficients of variation of these parameters could serve as a sensitivity analysis to different climate change scenarios.

A general *caveat* is warranted, however – caution must be applied in extrapolating model results based on case study approaches, as the domain of application might be quite limited. In this biome, with such a broad climatic and biogeographic range, this is likely to be the case. Also, model projections should be expressed in terms of risk (i.e. probabilities of events) rather than deterministic predictions.

Impacts of climate change on sclerophyll forests

A simple, generalised model of the biome was suggested as a way to generate scenarios of change due to climate.



In this model the major forest types corresponding to MVG 1–3 are recognised as distinct, mappable entities, but in reality are part of a continuum of vegetation along the gradients of temperature, moisture, soil fertility and disturbance by fire, and the interactions between them. It was agreed that this was too simplistic to allow specific impact statements to be made about the three vegetation types.

Impacts on *composition* are likely to be manifest through competition, establishment processes, habitat 'quality' (i.e. soil, terrain, etc.) and availability (of habitats and propagules). Impacts on structure will be partly dependent on compositional change, and partly on shifts in, for example, the grass/shrub balance in the understorey.

Drought

Given the recent (and in some parts of the biome still current) severe drought, there was much discussion on how an increase in severe drought might affect forest ecosystems. This debate differentiated between drought and the drying (through lower rainfall, higher temperatures and increased evapotranspiration) predicted in most climate change scenarios, although the separate impacts of these processes are hard to define.

Evidence for drought effects included crown dieback in Tasmanian coniferous forests (*Athrotaxis selaginoides*) [Gilfedder/Duncan] and increased distress in arboreal mammals (especially koalas) in Queensland [Eyre].

In some parts of the biome, however, ecosystems have been seen to be remarkably resilient to major change: an example was given of recovery from fire and severe drought in the Brindabella Range. In contrast, prolonged drought in Queensland led recently to dieback in brigalow (*Acacia harpophylla* – outside this biome) vegetation, normally considered to be extremely robust.

Drought can have highly variable impacts within and between genera at a common site, for example, within *Banksia, Eucalyptus*, some species were affected and others not even within local areas – possibly a soil effect?

Fire

Fire was a central topic in much of the discussion about possible change in this biome. Fire is a key driver of past and current ecological dynamics, and will continue to be so in a climate-changed world. There was general consensus, however, that fire, despite decades of research in forest ecosystems, is still a complex and poorly understood environmental factor, especially in terms of its relationships with species, communities and vegetation dynamics.

The following points summarise the main points of Ross Bradstock's presentation and the associated discussion:

- Climate change will affect fire regimes, and thereby forest composition and structure
- Interactions between direct effects of fire (mortality, structural change, etc) and indirect (e.g. changed composition, invasive species)
- Can more or less deal with some management issues, e.g. fuel management, but optimal solutions are not known, even without climate change
- Increasing economic considerations, e.g. protection of property, might conflict with conservation objectives
- Research is turning towards cost–benefit analyses of different fire management approaches
- Much complexity in unravelling the drivers of fire and where they may go in the future
- Already evidence of increased fire frequency, e.g. western USA, linked to climate change
- Impacts are most obvious in areas where fuel management had been least effective
- Paleo-ecological record indicates that charcoal frequency closely tracks changing climates
- Fire is complex – fire regimes, species and functional types, society and management all intersect
- Climate change acts on fire weather and through this fire danger and risk, and on fire regimes
- Recent trend of increasing forest fire danger index – not known if this is climate change or natural variation
- Simultaneous increase in incidence of extreme fire weather
- Fires dependent on 4 'switches':
  - Biomass (amount of fuel)
  - Availability (fuel condition – moisture content), affected by drought
  - Spread (fire weather conditions, wind, temperature, relative humidity)
  - Ignition (lightning, arson)
- All switches need to be ON for fire to occur, but are turned on at different rates in different ecosystems – there is always a characteristic limiting switch: in forests these are typically availability and spread
- open sclerophyll forest (= dry sclerophyll) fire frequencies measured in years (5–10), tall open forests (= wet sclerophyll) in decades to centuries (10–100)
- Potential for frequency to increase in open forests, but there are antagonistic effects, cf. drying (may result in less fuel through slower growth rates and accumulation) vs. CO_2 fertilisation (promoting increased growth) – will these cancel each other out?

- Some evidence that forest fire frequencies will be 'squeezed' (i.e. shortened), but there is a need for fire-free intervals to be long enough for regeneration/stand replacement because of reduced moisture slowing recovery. May lead to compromised resilience on many plant species
- Modelling suggests that a very large increase in prescribed burning will be necessary to achieve an even modest reduction in risk under climate change
- Some increases in fire frequency may be tolerable and pose no threat to biodiversity, but this rule cannot be applied generally across the biome
- Priority actions include:
  - Assessing potential impact of climate change
  - Negative impact of elevated fire danger, increased CO_2 and moisture availability as determinants of future fire regimes
  - Effects of variation in fires, fire regimes on fauna
  - Assess current adaptive management strategy
  - Approaches to domain and thresholds of concern
  - Benefit–cost analyses of potential management responses

- Consensus that only safe bet is that fire frequencies will increase under climate change – spatial configuration of fuels in litterfall-based systems (WSF) means mosaic burns may not work well, and uncertainty about climate change impacts on wind strength and direction make prediction difficult
- Socio-economic issues, e.g. human expansion has increased incidence of arson: major population centres close correlation with increased fire frequency, plus more high fire danger days = more fires.
- Modelling can be used to estimate the direction and amount that fire frequency might be affected by changes in each of these limiting processes (switches)
- Alterations in fire frequency can have significant impacts on regeneration and subsequent composition and structure – e.g. *E. delegatensis* forest burnt twice with short interval leading to lack of regeneration of dominant species
- Fire is also a social issue: management can do something about mitigating ignition risk at times of high fire danger – monitoring known arsonists, closing parks, etc.

Processes

Changed gene flow might be one process change to have conservation consequences. An example was given of hybridisation in eucalypts in Tasmania, which has always occurred, but one adverse outcome could be reductions in nectar quality/quantity, with subsequent implications for nectar-feeding species such as the swift parrot. Also in Tasmania, woodland and open forest dieback has been linked to a reduction in autumn rainfall (i.e. change in seasonality).

There are no classical successional processes in sclerophyll forests; changes in overstoreys happen over long time-scales, for example, in *E. delegatensis, E. regnans, E. oreades*, where fire drives the availability of gaps and recruitment. However, some changes are happening over quite short time-scales. Timber harvesting can favour more fecund species over, for example, original dominants, such as *E. sieberana* replacing blue gums in southern NSW – is this a differential climate change impact on reproductive success?

Forests have complex structures, and competition is a significant ecological filter. Climate change will have impacts on future composition and structure through effects on competition; species have specific temporal 'windows' for regeneration and establishment – climate change might cause these to close, or open for other species.

There is evidence of vegetation thickening in both understorey and overstorey in forests in Queensland: it is not known if this is due to increased growth promoted by CO_2 enrichment or lag effects from prior management activities, such as logging and fire management. We have no experimental evidence of what structural changes might be expected due to increased CO_2 alone.

We also lack frameworks for how invertebrates, fungi and microbes might respond to climate change. As these organisms mediate many ecological processes, it may not be cost-effective to use funds for conservation of iconic species if fundamental ecological interactions are not maintained.

Invasives

There are likely to be different issues in respect of invasive species between the northern, largely summer rainfall part of the biome, and the temperate southern part. In the north, species such as *Lantana camara* have already altered forest ecology, especially fire behaviour. There is no southern analogue to this, except where forests have been severely disturbed and/or cleared (e.g. gorse, blackberry, etc). However, the southern spread of C_4 grasses may have significant implications for ecological processes as discussed earlier. Establishing where C_4 grasses might spread to under various climate change scenarios is an important modelling exercise. In the north, they may spread to more fertile sites, and in the south their spread might be limited by soil conditions. Their impacts on ecological processes are likely to be through superior competitive ability and speed of recovery after disturbance, and greater drought tolerance. Their potentially greater biomass would also influence fire regimes.

There is also some evidence of invasive native animals moving into areas previously not occupied by them, for example, noisy miners expanding their range into forests made more open by drought, grazing and fire – these impacts can be quite rapid, especially for highly mobile species such as birds.

Niche availability

For some vegetation types within this biome, current and future trends in temperature will further restrict what are already limited distributions. Examples were given of *Nothofagus micropetalum* rainforest at 1000 m in NSW, where there has already been an increase of >1°C since 1960; a further rise would place stress on these montane systems and possibly render them uncompetitive against more temperature- and fire-tolerant eucalypt forests.

Similar concerns were raised over species at their latitudinal limits of their distributions; for example, a predicted 3°C warming would result in the loss of part of the realised niche of *Eucalyptus delegatensis* in the northern part of its distribution in NSW.

Disease

Phytophthora cinnamomi is predicted to become more widespread in eastern Australia as a result of climate change, and to infect a wider range of host species. Recent dieback episodes, for example in Tasmania, are possibly partly due to *P. cinnamomi*, but this has occurred during a prolonged drought and in periods of extreme temperatures; separating these impacts is difficult.

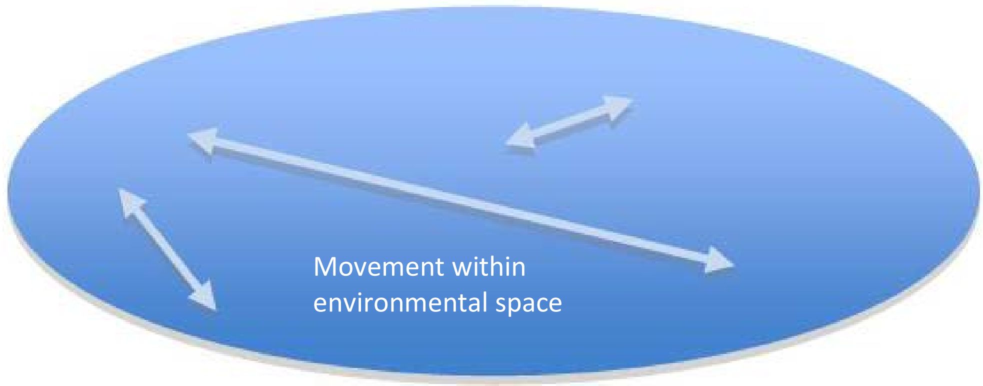
Adaptation options

Many of the comments made about the general policy and legislative approaches that might be relevant to climate change and reserve establishment and management were general in nature, and could equally be applied to other biomes.

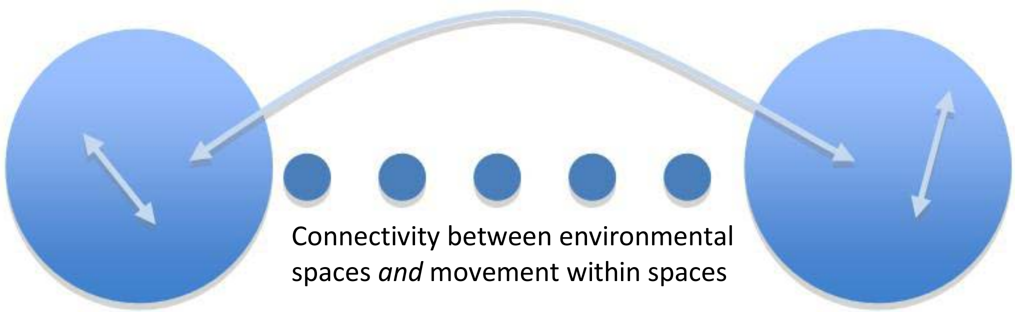
Arising from the first phase of this project, NRS1, it was suggested that there are four fundamental targets for conservation: species, ecosystems, landscapes and diversity. Many of the current federal and state-based activities, policies and legislation focus on species (e.g. EPBC Act) and ecosystems (state land clearing legislation, among others), and not explicitly on landscapes or 'diversity'. The NRS is limited in this respect, and at state level the asset-based approach to identification of priority acquisitions for conservation purposes will not be sufficient to accommodate the landscape and diversity dimensions necessary to build resilient Australian forest environments.

A simple model was suggested to examine the issues around adaptation, based on a crude distinction between the north of the biome, where forest cover is more fragmented, and the south, where there is greater contiguous cover. This is an artificial division with a notional boundary suggested in the Hunter Valley. In reality, both situations pertain to the whole biome:

- South of biome – species movements are mainly within climatic/environmental space (forests ± contiguous), so primary management goal is to reduce threats, including new native species and invasive exotics adding to competition. There have to be suitable environments for species to move to, so maintenance of habitat diversity and environmental gradients is critical.



- North of biome – forests are more fragmented, and major limiting factor is dispersal (so need to improve connectivity) OR establishment conditions OR availability of niche/environmental type OR ongoing threatening processes/competition. Ideally management would address all of these.



It is informative to consider what parameters of habitat patches might be useful when assessing their conservation value, and the weightings given to different parameters may vary depending on which model of change was dominant:

- habitat quality
- threatened species
- proximity (isolation, connectivity) to other patches
- diversity (within patch and between this and other patches)
- ease of management
- landscape context (matrix type and management).

Connectivity

Participants recognised that this biome, at least in its southern regions, is still reasonably intact. In the north of NSW and in southern Queensland forests are more fragmented by agricultural and urban development.

As a general principle, it was agreed that connectivity was important for conservation, especially in relation to climate change where species may need to move though the landscape, and to improve representation of under-conserved ecosystems. From an NRS perspective, maintaining or improving connectivity in the landscape is an important issue if it allows disjunct blocks of conserved biome to function better at a landscape scale. Initiatives such as the Great Eastern Ranges project (NSW) are crucial to achieve changes in management outside the current NRS. However, acquisitions to improve connectivity should be assessed against the need to manage other threatening processes.

Not all lack of connectivity is expressed as fragmentation into forest patches – 'internal' fragmentation of forest blocks can occur as a result of management (e.g. logging, roads, powerlines) and concomitant changes in structure and floristics (e.g. lantana in north, native shrubs in south).

In some instances, where particularly vulnerable biodiversity assets are concerned, preventing access to threatened habitats by highly mobile exotic species may mean managing for isolation rather than connectedness, either within or between reserved patches. The relative permeability of ecosystems to species movements through them also needs to be known, as some ecosystems may present a barrier to species that prevents them from attaining new, climate change–induced, realised niches.

Translocation

Translocation was considered a useful tool for overcoming barriers to species movements caused by lack of habitat contiguity or poor dispersal ability. However, since the likelihood of translocations being successful is very low, the participants agreed that facilitating natural movements was a better biological solution wherever possible, as translocations avoid the natural ecological processes that filter species and genotypes, possibly with adverse outcomes (e.g. lack of competitive ability in new habitat). This suggests that translocations will need to be performed a number of times, and to a range of possible target locations, to ensure a higher probability of success.

There was a general acceptance also that biota may not need to be moved about the landscape and may be able to persist *in situ*; species should adapt and move between current realised niches to other parts of their fundamental niche if the biome does not change materially. However, if significant changes occur (as a result of, for example, altered fire regimes leading to more open, grassy structures, or increased woody growth), then relying on species' ability to shift within their fundamental niche space may be insufficient to ensure survival, especially where the twin constraints of lack of dispersal and narrow fundamental niche breath coincide: in this case, *ex situ* measures might be appropriate. The use of SDMs could possibly assist in planning these efforts.

For some species, our ability to influence outcomes might be limited. An example of *Eucalyptus delegatensis* at its northern distributional limit was given – a 3°C rise in mean annual temperature would leave it with nowhere to go, effectively meaning a loss of part of its realised niche. In these cases, participants felt it was important to manage to minimise loss of fundamental niche space. In time, as greenhouse gas mitigation efforts start to take effect, niches might reappear, so *ex situ* conservation can play a part in providing genetic material for reintroductions (if natural movement is not feasible).

Manage to maintain processes

The species-based approach to conservation will not be sufficient to retain all the current arrangements of species and communities in forest landscapes. If forest ecosystems contain a level of redundancy in terms of individual species' roles in ecological processes, then we might accept a level of loss if management can be directed at maintaining those processes. Here it is important to distinguish between the conflicting objectives of trying to conserve everything, and the likely outcomes irrespective of efforts to do this – careful judgement based on the best available information will be critical. Again, managing for minimal loss is likely to be the most effective solution, recognising that some degree of species-level management and research will be necessary to understand how to go about it.

Managing for species and processes will therefore require different objectives and policy settings, especially as societal expectations are that species will be conserved *in situ* and that there is no level of acceptable loss. *Ex situ* conservation of iconic species will continue to be important, both to meet these expectations and to actually conserve species, but these will be constrained by lack of funding and science knowledge. In essence, we may be moving to a situation where it is not the task of the NRS to conserve individual species – they will be passengers in the attempts to conserve habitats.

Adaptive management, risk, and climate change

The principle of adaptive management was discussed in respect of risk. It was claimed that, generally, there is already sufficient information to apply adaptive management, but rarely is there the commitment to implement it or the monitoring to assess its effectiveness.

Acknowledging that there is always uncertainty in applying adaptive management is important – climate change adds to this uncertainty, so conservation plans need to allow for this and be based on concepts of robustness. Long-lived major structural elements in forests (i.e. trees) confer some degree of robustness on the biome, but the speed with which climate change is happening may mean that we cannot assume that forests will not also change rapidly.

In this respect, the natural inertia in the research–policy–management chain has meant lags in applying science to outcomes on the ground. As current policy is set, and decisions are being made now using those policy settings, the scope for new information to make a difference is likely to be at lower levels, for example in reserve acquisition and on-ground management. As land in this biome is expensive (compared with other biomes), acquisitions need to be made using the best available scientific knowledge.

Social and economic issues

The workshop agreed that socio-economic issues would significantly influence climate change–driven conservation aspirations in this biome.

The significant social and economic importance of sclerophyll forests was recognised as both a potential benefit when considering conservation planning or climate change, and a barrier.

The biome has the greatest human population density, with high community expectations for it to deliver a range of socio-economic services such as recreation, timber, clean water and aesthetic/spiritual appeal. Specific examples include the community desire to retain mountain ash forests close to Melbourne in what is effectively a late post-fire stage of development, despite the obvious risks associated with wildfire. There are also Indigenous stakeholders whose rights to access have been compromised, with a number of land rights claims affecting parts of the biome.

Conflicts over land use will also have an impact on the ultimate success of the NRS in conserving forest biodiversity. In Tasmania, conversion of non-threatened forest areas to plantations has had perverse biodiversity outcomes: off-reserve management is important to contribute to ameliorating effects of climate change.

Similarly, increased pressure is being placed on the forest estate through other state policies, for example, agriculture (‘food bowl of Australia’) and water management (‘drought-proofing’).

There are opportunities in this biome for economic and community-driven initiatives, especially in the arena of carbon stores and revegetation. Carbon is a new value in forests, and is not necessarily thought of in the same way as biodiversity – water is similar – and there is an implicit assumption that carbon management equates to biodiversity management: there is an urgent need to test this hypothesis. Depending on how management for carbon is done, there could be serious adverse consequences for biodiversity. Against this is the prospect of improving conservation outcomes through restoration of cleared areas and rehabilitation of disturbed forest habitats. If the wetter and more productive parts of the landscape are included in this, they may become valuable refuges and sources for re-population.

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