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Review

Native forests and climate change: Lessons from eucalypts

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ABSTRACT

The purpose of this paper is to review studies relevant to potential climate change impacts on natural stands of eucalypts, with a view to identifying not only specific lessons for the management of native forests in Australia but also some general lessons relevant to native forests anywhere. More than 800 species of *Eucalyptus* are found naturally across Australia, as well as species such as *E. deglupta* and *E. urophylla* in countries north of Australia. Eucalypts provide a particularly interesting opportunity to examine the likely impacts of climate change, as many species have been widely evaluated in trials within and outside Australia, often under conditions that are warmer and sometimes drier than those found within their natural distributions. Results from these trials indicate the intrinsic ability of particular eucalypt species and provenances to tolerate conditions that are somewhat different from those experienced within their natural distributions. Eucalypts have particularly poor dispersal capabilities, so natural stands will be generally unable to track changing climatic conditions. Therefore, in the period to the end of the present century a key issue for each eucalypt species under climate change is whether its intrinsic adaptability will be sufficient to allow it to survive where it is currently located. Their ability to survive will be affected not only by climatic, but also atmospheric changes, which will affect important processes such as photosynthesis and water exchange. Again eucalypts provide a useful group for climate change studies as their commercial significance has led to various enhanced carbon dioxide experiments being carried out, as well as detailed genomic studies. This review considers eucalypts in relation to four main areas; (i) resources and characteristics (natural distributions and introduced distributions including their adaptability/plasticity), (ii) analysis tools (species distribution models and growth models), (iii) physiological factors (including temperature, drought and enhanced CO_2) and (iv) interactions with other species (including pests and diseases). Priorities for future research are identified. It is concluded that analyses that do not allow for the intrinsic climatic adaptability of tree species, as well as their particular dispersal capabilities, are unlikely to provide reliable predictions of climate change impacts.

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1. Introduction

Hundreds of eucalypt species dominate the native vegetation in landscapes over much of Australia (Department of the Environment and Water Resources, 2007). Many of these ecosystems, particularly in higher rainfall areas (>300 mm annual rainfall), have been extensively cleared for agriculture since European settlement. For instance, more than 47 million hectares of eucalypt woodlands have been cleared since 1770, particularly in eastern Australia and the south-west of Western Australia. Considering just one vegetation type as an example, more than 92% (over five million hectares) of the White Box–Yellow Box–Blakely's Red Gum (*Eucalyptus albens–Eucalyptus melliodora–Eucalyptus blakelyi*) grassy woodlands, that once occurred extensively in south-eastern Australia, have been lost. (*Note:* authorities for all species cited are as given in the Atlas of Living Australia (ALA), www.ala.org.au.)

Effectively conserving natural eucalypt stands is complex enough given the high species diversity and history of extensive clearing. However, climate change makes the problem considerably more complex. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) has provided strong evidence that the Earth's climate is warming. Australia's mean surface air temperature has warmed by 0.9 °C since 1910 and there has been a 17% decline in average winter rainfall in the southwest of Western Australia since 1970 (CSIRO and BoM, 2014). Australian temperatures are expected to continue to warm. Warming by 2090, compared to 1986–2005, is projected to be 2.8–5.1 °C if global emissions continue on a high emissions pathway (see climatechangeinAustralia.gov.au for projections updated in 2015 and derived from more than 40 global climate models).

The purpose of this paper is to review studies relevant to potential climate change impacts on natural stands of eucalypts and to identify some important issues for their management and conservation, as well as for native forests stands in general. While the focus is on natural eucalypt stands, primarily analyses of single species, inferences are also drawn from relevant research related to commercial and experimental eucalypt stands both in Australia and overseas. More specific issues related to climate change and commercial eucalypt plantations around the world have been reviewed separately (Booth, 2013).

Eucalypts are particularly interesting for climate change studies. Any plant (or animal), which experiences climatic conditions outside those of its current natural distribution as a result of climate change can respond in one of four ways: tolerate, evolve, move (disperse) or die (Aitken et al., 2008; Allendorf et al., 2013). Individuals may simply tolerate new conditions and persist. While there is evidence that some animals, such as fruit flies, can rapidly evolve to cope with climate changes (Parmesan, 2006), generation times in trees are generally so long that such changes will be insignificant over the decades to the end of this century. Eucalypts also have particularly poor dispersal capabilities, with seed dispersal distances usually similar to tree height (Cremer, 1977; Griffin, 1980). For instance, records of invasiveness of non-local eucalypts in Australia suggest that successful colonisation rates are equivalent to only about one metre per year (Ruthrof et al., 2003). Moreover, adaptability via widespread gene-flow (in this context, gene-flow to a population from places with significantly different climates) is also limited in eucalypts, as these are predominantly insect pollinated. So, in terms of climate change to the end of the present century, most native eucalypt stands can neither be expected to evolve to cope with changing conditions nor to disperse to more favourable locations. Assisted migration/colonisation is being considered in Australia, but involves considerable expense and significant risks (Burbidge et al., 2011). So, a key question for most natural eucalypt stands is whether they can they survive where they are presently located or will they become locally extinct?

To review this question we consider four main areas; (i) resources and characteristics (natural distributions and introduced distributions including their adaptability/plasticity), (ii) analysis tools (species distribution models and tree growth models), (iii) physiological factors (including temperature, drought, enhanced CO_2) and (iv) interactions with other species (including pests and diseases). Fig. 1 shows the key processes through which climate influences species growth and distribution, as well as the sections within which particular topics are considered in the main text. The discussion section considers the implications of this review including research uptake and key research needs.

To illustrate one of the key points of the paper, that is the need to consider not only natural distributions but also results from trials in climate change studies, we provide figures related to *Eucalyptus dunnii*. We use data from the Atlas of Living Australia to examine its natural distribution and also consider its climatic adaptability as described by Jovanovic et al. (2000). We assess how climate change may affect the natural distribution. To keep the example simple we consider climate change in relation to just one variable, annual mean temperature, and use just simple ranges of suitable conditions.

2. Resources and characteristics

2.1. Natural distributions

Eucalypts are shrubs and trees that take a wide range of physical forms and occupy a broad range of climatic and ecological niches. They are primarily distributed across Australia with a small number of species found to the north of Australia in Papua New Guinea, Indonesia and the Philippines. According to the Australian Plant Census, some 839 species exist within genus *Eucalyptus*, as well as 100 species within the closely related *Corymbia* (bloodwoods, ghost and spotted gums) and 10 species in the *Angophora* genera (B. Lepschi, pers. comm.). A long and

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