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Estimating potential range and hence climatic adaptability in selected tree species

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ABSTRACT

Estimating climatic conditions within the potential range of different species is important, as it can assist evaluating their ability to tolerate climate change. Potential range was analysed using a BIOCLIM analysis in relation to three climatic variables: a growth index, the mean minimum temperature of the coldest period (week) and a moisture index. Three eucalypt species were analysed to demonstrate some of the strengths and weaknesses of the method. These included a well-known commercially important species (*Eucalyptus globulus*), a lesser-known species (*E. botryoides*) and a rare species (*E. kruseana*). To provide a simple assessment of climatic adaptability the highest values of mean annual temperature were determined from within the potential ranges of the three species. It is concluded that, if they are available, analysing conditions at eucalypt plantings outside their natural distributions may be most useful for determining how species may cope with changing climates. However, if such data are not available, for example for lesser-known or rare species, then the analysis of the potential range may provide some tentative indication of species likely climatic adaptability.

1. Introduction

There has been an enormous increase in the use of the closely related areas of species distribution modelling (SDM) and ecological niche modelling (ENM) in recent years (see, for example, the books by Franklin, 2009 and Peterson et al., 2011). Despite advances in understanding species climatic adaptability described below, most plant and animal climate change studies have been based only on analyses of natural distributions (see, for example, the highly cited work of Thomas et al., 2004). For instance, three major climate change studies of eucalypts have all based their research solely on conventional SDM analyses, which were based on closely describing climatic conditions within the species natural distributions (Hughes et al., 1996; Butt et al., 2013; Hamer et al., 2015). They respectively predicted "substantial changes", "potentially large distributional shifts" and "six inland species predicted to lose 95% of their suitable habitat in a moderate change scenario". However, they all acknowledged that their results would be affected if the species studied could tolerate conditions somewhat different from those of their natural distributions. They did not analyse this climatic adaptability because results from trials outside the natural distribution were not available for many of the species they were analysing. A simple analysis method that provided some tentative indication of tree species climatic adaptability would be extremely useful, particularly for lesser-known species.

Svenning and Skov (2004) pioneered the analysis of potential range of tree species on the basis of analysis of just three variables related to winter cold, growing season heat and drought. This paper has become a key paper in the forestry and climate change research area, being cited several hundred times. With the aim of further informing future climate change impact studies, Nogués-Bravo et al. (2014) used SDM/ENM methods to estimate species potential range size for 48 European tree species. Potential range may be defined as the range that would be achieved should all dispersal constraints be overcome (Gaston, 2003). Following Svenning and Skov (2004), Nogués-Bravo et al. (2014) hypothesized that potential range relates to species climatic tolerance and that the degree of range filling is influenced by species dispersal. They consider that historical constraints, including past major effects, such as glaciation, as well as on-going effects, such as competition with other species, produce realized ranges that are less than potential ranges.

Conventional SDM analyses use either many variables to analyse realized ranges associated with current natural distributions and/or sophisticated packages which closely fit conditions within natural distributions. For example, most analyses carried out with MaxEnt (Phillips et al., 2006), which is now the leading SDM

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package, use 19 BIOCLIM variables provided by the WorldClim database (Hijmans et al., 2005; Booth et al., 2014). In contrast, unconventional studies such as the studies of Svenning and Skov (2004) and Nogués-Bravo et al. (2014), use just three variables to describe potential range. These less tightly defined descriptions include locations which have a greater range for key variables often used in climate change studies, such as mean annual temperature, than are included in conventional SDM analyses.

Peterson et al. (2011) noted that definitions of ‘potential distributional area’ (which is equivalent to ‘potential range’) vary. Taking the view of Nogués-Bravo et al. (2014), it is the union of what Peterson et al. (2011) describe as the occupied (G_O) and ‘invadable’ areas (G_I) (see Fig. 1). That is, if present distributional constraints are overcome, but negatively and/or positively interacting species are present (for further details see Peterson et al. (2011) particularly chapters 3 and 8). However, Peterson et al. (2011) point out that some of the literature uses the term to mean the abiotically suitable area (i.e. G_A). This is also an area where dispersal constraints are unlimited, but where other interacting species are absent. The results presented here are discussed in terms of both views of potential range. If just the phrase ‘potential range’ is used this means the sum of the occupied and invadable area (i.e. G_O and G_I). If the phrase ‘abiotically potential range’ is used this means the abiotically suitable area (i.e. G_A). Both Svenning and Skov (2004) and Nogués-Bravo et al. (2014) have provided useful overviews of previous research related to ‘potential range’ in their introductions, so here we concentrate mainly on previous research relevant to ‘abiotically potential range’.

Nogués-Bravo et al. (2014) focussed on the use of climatic variables, so their findings would assist future analyses of the likely impacts of climate change on species distributions. They applied two methods, one based on the BIOCLIM model (Nix, 1986; Booth et al., 2014) and the other on Mahalanobis distance (Farber and Kadman, 2003). These involved fairly complex data processing in terms of extracting distributional data, applying SDM methods and then mapping their results. In contrast, the present paper shows how an analysis largely similar to the Nogués-Bravo et al. (2014) BIOCLIM-based method can be carried out relatively easily for Australian species using the freely accessible Atlas of Living Australia (ALA) (www.ala.org.au).

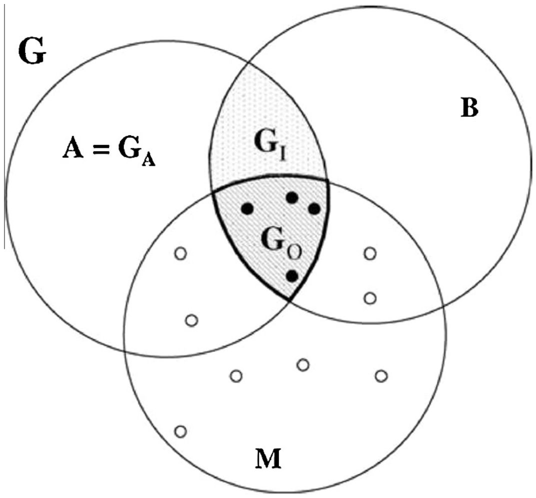

Fig. 1. A BAM diagram (from Barve et al., 2011, modified from Soberón and Peterson, 2005) illustrating the three major interacting factors that determine species geographic (**G**) distributions: **B**iotic, **A**biotic and **M**ovement. The small closed circles indicate presences, while the small open circles indicate absences. G_A is the abiotically suitable area, G_O is the occupied distributional area and G_I is the invadable distributional area. ‘Potential range’ is the occupied plus invadable areas (i.e. $G_O + G_I$). See Peterson et al. (2011) for more information.

The ALA represents a major advance in biodiversity databases and ecological modelling. It provides ready access to more than 55 million locational points for the distributions of more than 110 000 plant and animal species and over 400 layers representing climate, substrate, topographic, vegetation, social and boundary conditions (Belbin and Williams, 2015). It provides integrated access to simple plotting facilities, as well as sophisticated SDM methods such as MaxEnt (Phillips et al., 2006) and Generalised Dissimilarity Modelling (Ferrier, 2002). The Global Biodiversity Information Facility (GBIF) is supporting the development of systems based on the ALA for other countries. Similar systems, using ALA program code, but with somewhat different interfaces, have recently become available for Spain and France. Though many plant species could be potentially analysed using the method described, here the focus is on tree species to facilitate comparison with the Nogués-Bravo et al. (2014) research. The present study examined three contrasting eucalypts, including a well-known and commercially important species *Eucalyptus globulus* Labill. (considered by some taxonomists and the ALA as a subspecies *E. globulus* Labill. subsp. *globulus*), a lesser-known species (*E. botryoides* Smith) and a rare species (*E. kruseana* F. Muell.). Eucalypts are particularly suitable for climate change studies as they include hundreds of species, many of which have been widely tested for commercial purposes in many countries (Booth et al., 2015). For example, *E. globulus* is a major plantation species in Australia as well as globally, and there are several descriptions of its climatic adaptability (Jacobs, 1981; Webb et al., 1984; Booth and Pryor, 1991; CAB International, 2005).

One of the earliest SDM studies was carried out for a eucalypt species and it was soon realized that many eucalypt species can grow successfully under climatic conditions somewhat different from those within their natural distributions (Booth et al., 1988). Therefore to understand the abilities of trees to cope with climate change there is a need to analyse data from both natural distributions and, if possible, from plantings outside their natural distributions (Booth, 1991).

Two of the earliest climate change studies included analyses of tree species. In what has become the most commonly used approach for SDM climate change studies, Busby (1988) analysed the natural distribution of *Nothofagus cunninghamii* Hook. (now known as *Lophozonia cunninghamii* (Hook. f.) Heenan & Smissen) to determine its realized niche (sensu Hutchinson, 1957). This is similar to the occupied distributional area (G_O) shown in Fig. 1. He then applied a simple climate change scenario and showed how its distribution might change. In contrast, Booth and McMurtrie (1988) used BIOCLIM to analyse climatic conditions at 71 sites representing over 90% of the plantation area of *Pinus radiata* in Australia. This provided an analysis of climatically suitable areas in terms of parts of the Hutchinson (1957) fundamental niche (i.e. the abiotically suitable area, G_A). It is relevant here as commercial forestry trials have no natural dispersal constraints and managers do everything possible to reduce negative interactions with other species. Though it has a very limited natural distribution of only about 7000 ha in California (along with about 150 trees on two Mexican islands off the Baja Peninsula) and is classified as ‘endangered’, *P. radiata* has proved to be highly climatically adaptable, becoming the most widely planted softwood plantation species in the southern hemisphere (Lavery and Mead, 2000). No climate change analysis of its natural distribution could hope to be successful without taking this adaptability into account.

Just as *P. radiata* has been widely evaluated in trials and extensively grown commercially in the southern hemisphere, so also about 400 eucalypt species have been widely assessed around