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CONSERVING PHYLOGENETIC DIVERSITY, WITH REFERENCE TO VICTORIAN EUCALYPTS

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ABSTRACT: Preserving the tree of life (i.e. phylogenetic diversity) is increasingly recognised as important in conservation. Australia is a key area for retaining the tree of life because it holds a disproportionately large amount of phylogenetic diversity. We examine the degree to which the phylogenetic diversity of Victorian eucalypts is reserved within conservation areas. Based on modelled distributions of 101 eucalypt species and a phylogeny constructed from four molecular markers, we show that Victoria's conservation reserve system contains approximately a quarter of the eucalypt phylogenetic diversity. Some species do not exist at all within the reserve system. Large increases in reserved phylogenetic diversity could be achieved with small increases in the area set aside for conservation. Further, we show that any developments within Victoria's national parks should consider impacts on the reservation of eucalypt phylogenetic diversity.

Keywords: biological conservation, phylogeny, reserve design, spatial conservation planning, Zonation

INTRODUCTION

Conservation of biodiversity relies on a variety of management strategies to help prevent decline and ultimately loss of genetic, species and ecosystem diversity. With habitat loss being a major driver of species extinctions (Diamond 1989), and causing ongoing loss of biodiversity (Brook et al. 2008), setting aside areas for conservation is a cornerstone of applied conservation (Margules & Pressey 2000). However, many such conservation reserves are located in areas that are unwanted for human use, rather than because they encompass a broad representation of biodiversity. Indeed, conservation reserves are usually located in infertile regions or mountainous regions of the world (Margules & Pressey 2000).

To help conserve biodiversity better, modern planning tools aim to establish conservation reserve systems that efficiently encompass the broad suite of biodiversity, and at levels that are deemed adequate to allow them to persist (Margules & Pressey 2000; Moilanen et al. 2009). These conservation planning tools can set targets for representation of species, land (or sea) forms, vegetation types, or any set of features that we might wish to reserve.

Australia's eucalypts are iconic, and clearly capture the imagination of the public. They feature in art, music and literature (Wrigley & Fagg 2010), such as works by Albert Namatjira (Kleinert 2000), Banjo Paterson (Terry 2014), and contemporary literature such as Murray Bail's *Eucalyptus* (Bail 1998). Even Australia's prime minister (at least, prime minister at the time of writing) is willing to share his opinion about his favourite eucalypt (*Eucalyptus tereticornis*), and enter the debate about the proper taxonomy of the eucalypt group. As an aside, he clearly believes that *Eucalyptus* should be synonymous with eucalypt, although he might not fully appreciate the implications of that position (http://tinyurl.com/faveuc).

When conserving species, reserving a representative set is often a goal while minimising the opportunity costs of foregone land use (the so-called minimum-set problem — Wilson et al. 2009). Alternatively, within some constraint on the area set aside for reserves, we might aim to maximise the representation of reserved species (the so-called maximum-coverage problem — Wilson et al. 2009). Minimum-set and maximum-coverage problems are duals of the same issue. And regardless of the scheme used, different species could be weighted in different ways, such as by economic values, threat status, or any of a myriad of features.

The phylogenetic diversity of a set of species is an important feature to consider in conservation planning because the phylogeny represents the evolutionary history of the taxa. Evolutionary history will reflect biogeographic origins and patterns, the potential for future evolutionary change, and to some extent the functional diversity of the taxa. The phylogeny of a set of taxa can be represented by a tree, with branches on the tree reflecting separate evolutionary lineages (see Bayly 2016, this volume). More closely related species will be separated by shorter branches in the phylogeny (Figure 1).

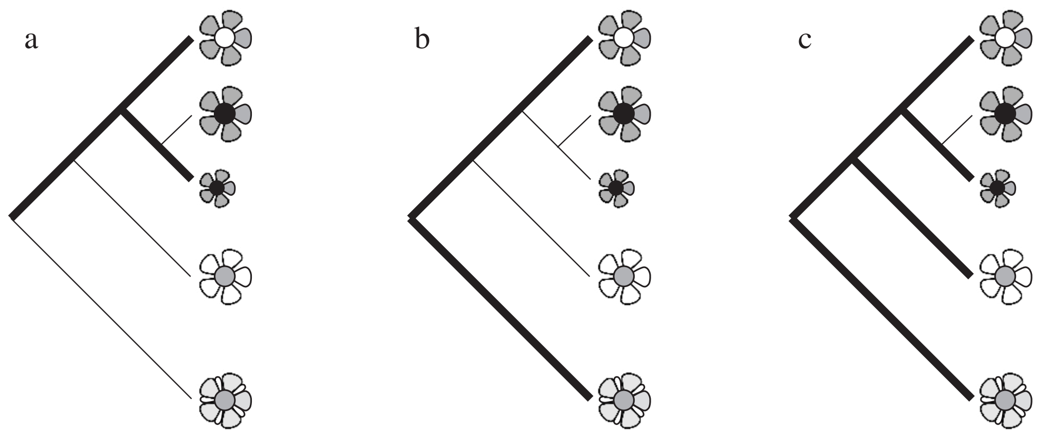

Figure 1: Five different species, each represented by a different floral symbol, are arranged according to their phylogeny, with the points of divergence of the branches representing the evolutionary divergence of the species. If we were to select two species (thick branches), the selected set would have the least phylogenetic diversity, as measured by the total phylogenetic branch length, if the bottom species were excluded (a) compared with when it is included, which maximises the phylogenetic diversity encompassed by two species (b). If we were to select four species, the selected set would have the greatest phylogenetic diversity when excluding one of the black-centred species (c).

In conservation planning, species that are more evolutionarily distinct would be weighted more heavily. The exact weighting would depend on how phylogenetic diversity is measured, but a logical choice is to measure phylogenetic diversity by the total phylogenetic branch length of the taxa (Faith 1992). Thus, different subsets of species will represent different amounts of phylogenetic diversity even if the number of species is the same (Figure 1).

Here we investigate the reservation of eucalypt phylogenetic diversity in Victoria, Australia. We examine the current reservation status of eucalypts, identify potential to increase reservation of eucalypt phylogenetic diversity, and examine threats to reserved phylogenetic diversity through development within national parks. Despite eucalypt taxa being a very high-profile group of species, we show that some in Victoria are very poorly represented in the reserve system.

METHODS

To illustrate how phylogeny can be incorporated in conservation planning for eucalypts, we report on results presented in Pollock et al. (2015). Our analysis evaluates representation of phylogenetic diversity of eucalypts within Victoria's existing reserve system, and investigates effects of either increasing or decreasing the area of Victoria's conservation estate. Expansion of the conservation estate is couched in terms of adding extra conservation reserves, and reductions are couched in terms of opening up conservation reserves to development.

The distribution of 101 eucalypt species (one *Angophora*, two species of *Corymbia*, and 98 species of *Eucalyptus*) were predicted with species distribution models that were tailored to the different species depending on data availability. Most species were modelled with boosted regression trees (Elith et al. 2008) or MAXENT (Phillips et al. 2006). The distributions of three species with very restricted ranges (*E. eugenioides*, *E. verrucata* and *E. victoriana*) were defined by delineating their ranges manually. Each cell (squares of 225 m on each edge) across Victoria was assigned a probability of presence for each species based on its predicted range (see Pollock et al. 2015 for details).

The phylogeny of the species was assembled for the species (and outgroup taxa) using molecular data (ITS, ETS, matK and the psbA-trnH intergenic spacer) from a larger phylogeny (Thornhill et al. in prep.). Five species with missing molecular data were inserted into the phylogeny with a branch length of zero at the stem node shared with the species with which it was assumed to be most closely related (see method in Rosauer et al. 2009).

The predicted probability of occurrence of each species in each cell was then able to predict the probability that a branch of the eucalypt phylogeny was present in each cell. This was achieved by calculating the probability that all species sharing that branch were absent from the cell; the probability of the branch being present was simply the complement of the probability of the branch being absent.

Spatial priorities for conservation within Victoria were then analysed with Zonation (Moilanen et al. 2012), which aimed to maximise reservation of phylogenetic diversity within Victoria, subject to constraints such as total land area and suitability of cells for reservation. Suitability of cells for reservation will, for instance, depend on tenure; areas

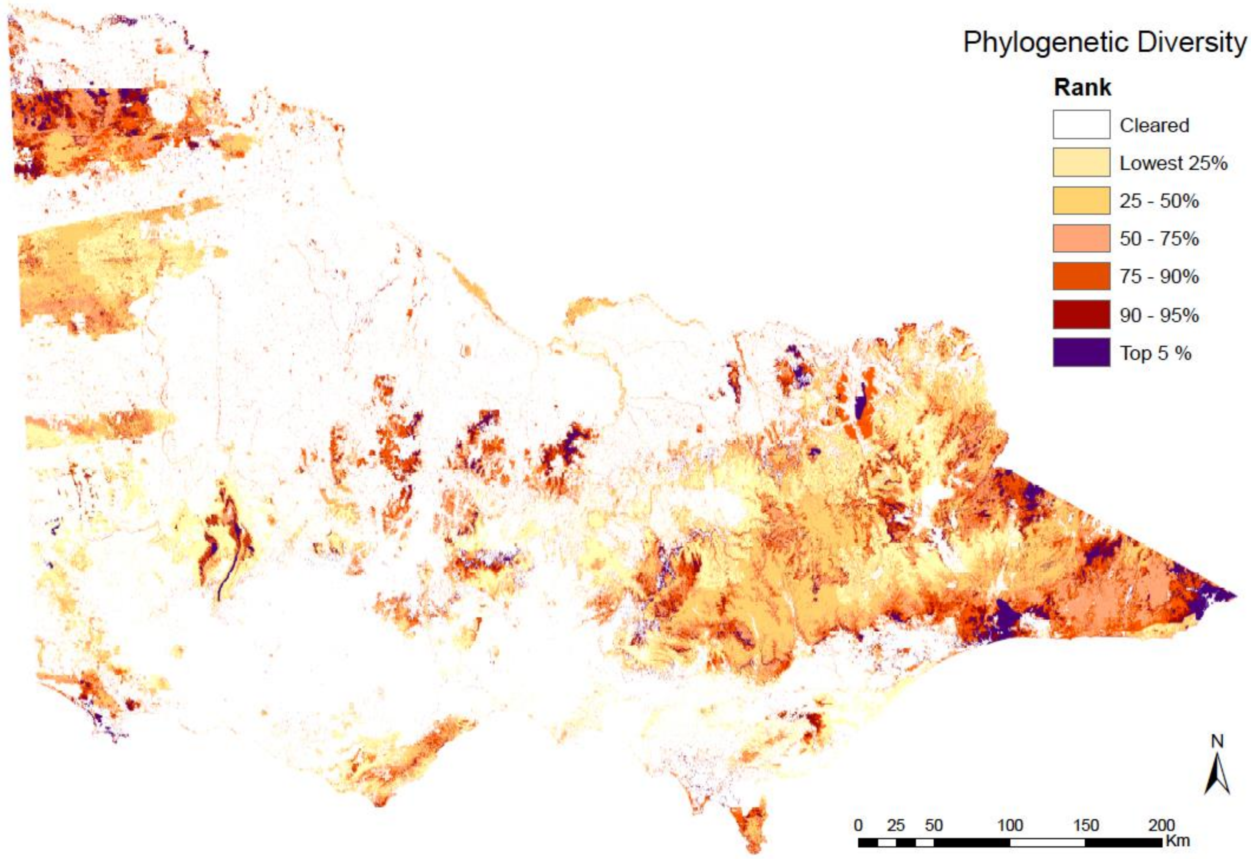

Figure 2: Priorities for conservation of eucalypt phylogenetic diversity within Victoria's current areas with woody vegetation (independent of land tenure), using the spatial conservation prioritisation software Zonation. Darker areas contribute disproportionately more to phylogenetic diversity than paler areas (reproduced from Pollock et al. 2015).

currently in conservation reserves might be assumed to be the first areas selected for reservation. Zonation solutions typically express the level of reservation of features (in this case, the features are branches of the phylogeny) by the proportion of their full distribution that is within the selected areas.

Zonation was used to evaluate reservation priorities by ignoring current land tenure, and then examining how well the current conservation reserve system protects eucalypt phylogenetic diversity. The metric of phylogenetic diversity that has been typically used in conservation assessments is Faith's phylogenetic diversity, in which branches are considered protected when a single occurrence is in the reserve network (1992). This presents a problem in spatial planning with many planning units, particularly for planning relying on species distribution models. Thus, instead of aiming to represent every branch at least once within the reserve network (i.e. as suggested in Figure 1), we aimed to optimise the proportion of the spatial distribution of each branch that was in the reserve network.

Benefits from further expanding the conservation reserve system and threats from allowing development within current conservation reserves were examined by setting constraints on where areas could be added to or subtracted from the reserve network. Additions were limited to areas of Victoria currently with woody vegetation, and also assuming that land had not been cleared. Subtractions were examined for areas within national parks that the Victorian Government had designated as potential development zones for boosting tourism. These development zones identify areas within Victorian national parks where infrastructure might be built in collaboration between the public and private sectors, and thus represent areas where vegetation might be cleared in the future.

RESULTS AND DISCUSSION

Eucalypt phylogenetic diversity varies across the state, often at very fine scales. Some notable regions with high phylogenetic diversity that is not found elsewhere include Murray-Sunset National Park in the north-west (mallee eucalypts), the Grampians National Park in the west, central Victoria (box-ironbark forests), and various parts of Gippsland in the east (Figure 2).

The current Victorian conservation estate reserves approximately a quarter of the state's eucalypt phylogenetic diversity (Figure 3). If the same total land area had been located within conservation reserves prior to any clearing (and the land had not been cleared), then almost a half of the eucalypt diversity could have been reserved (Figure 3,

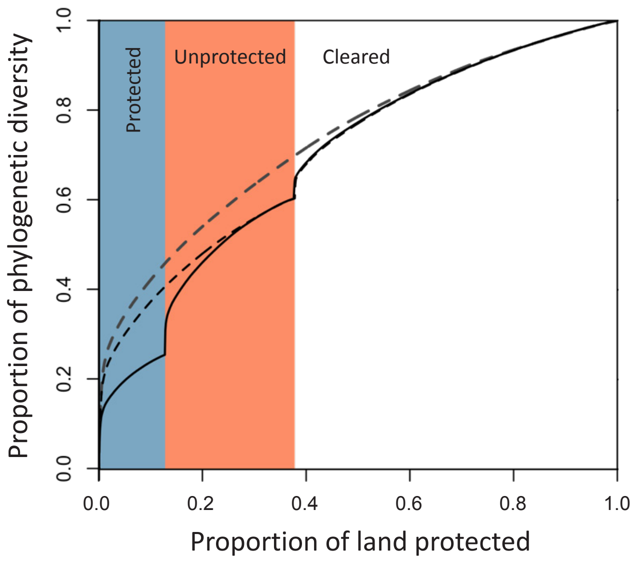

Figure 3: Proportion of total eucalypt phylogenetic diversity in Victoria protected areas versus total land area protected (proportion of Victoria) assuming optimal allocation of areas. Results are shown assuming land had not been cleared (grey dashed line), when initially focusing conservation areas on land currently not cleared (black dashed line), and when initially focusing on those areas currently in the conservation estate (black solid line). Figure modified from Pollock et al. (2015).

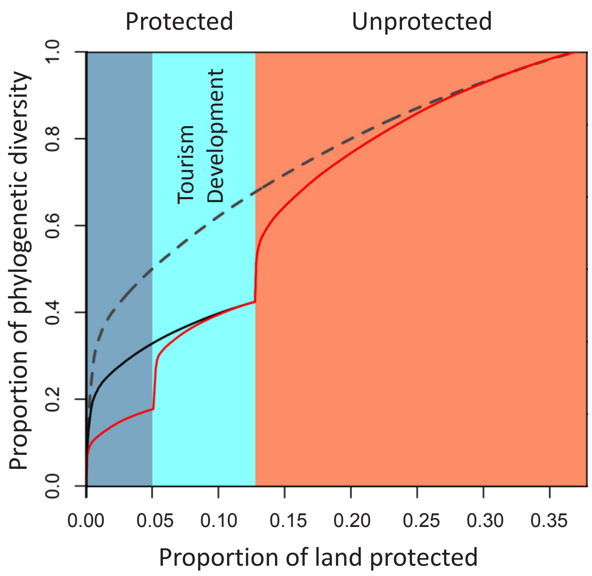

Figure 4: Proportion of total eucalypt phylogenetic diversity in Victoria protected areas versus total land area protected (proportion of Victoria) assuming optimal allocation of areas. Results are shown when focusing conservation areas initially on land currently not cleared (dashed line), on areas that are currently in the conservation estate (black solid line), and on current areas outside development zones (red line). Figure modified from Pollock et al. (2015).

grey dashed line). Even restricting reserves to the areas currently with woody native vegetation, approximately 40% of the diversity could be captured with the same total area as the existing reserve system (Figure 3, black dashed line). Thus, the current reserve system inefficiently reserves eucalypt phylogenetic diversity, a result that is consistent for many other conservation reserve systems worldwide; conservation reserves are biased towards areas that are unwanted for other human uses, such as unwanted for agriculture, mining or urban development, and usually reserve a biased subset of biodiversity (Margules & Pressey 2000).

However, the inefficiency of Victoria's conservation reserve system generates potential large benefits with modest investments. The steep rise in the solid black line when moving from areas that are protected to areas that are unprotected (Figure 3) indicates that large increases in phylogenetic diversity can be achieved by reserving relatively small fractions of Victoria's land.

Conversely, if land were to be removed from Victoria's conservation estate (modelled as losses from areas in national parks that are open to development), then large losses in eucalypt phylogenetic diversity would accrue (Figure 4). In the extreme (and unrealistic) scenario of all areas in development zones being cleared, then the reserved eucalypt diversity would decline to little over 10% of its total potential (Figure 4). This is approximately half the level that could be achieved if the same total area of land were reserved within the current conservation estate, and only a third of what would be achieved if reserves were allocated most efficiently to all woody vegetation within Victoria. While there is no prospect that all areas in development zones of Victorian national parks would be cleared, this analysis emphasises the importance of these development zones for conserving eucalypt phylogenetic diversity, and that any developments should consider impacts on the reservation status of these (and other) species.

These results are based on nature reserves as the means of conservation. It should be noted that reserves do not guarantee conservation of the species that they encompass, and other mechanisms for conservation exist that can aid conservation without changes in land tenure (e.g. management agreements with landholders). Nevertheless, these results emphasise that representation of eucalypt phylogenetic diversity within Victoria's protected area network is relatively low, and that opportunities for improvement exist (Figure 3). Indeed, some species with small isolated populations (e.g. *E. strzeleckii*) are not known to exist in any of Victoria's conservation reserves, and numerous undescribed eucalypt species might have similar restricted distributions outside Victoria's conservation reserves. The low level of reservation of species in a group as iconic as eucalypts suggests that other taxa are also likely to be poorly represented within Victoria's protected area network. Opportunities exist to systematically examine the benefits of further reservation, or to examine the benefits of conservation actions more generally.

References

Bail, M., 1998. *Eucalyptus*. Text Publishing, Melbourne, Victoria.

Bayly, M., 2016. Phylogenetic studies of eucalypts: fossils, morphology and genomes. *Proceedings of the Royal Society of Victoria* 128(1): 12–24.

Brook, B.W., Sodhi, N.A. & Bradshaw, C.J.A., 2008. Synergies among extinction drivers under global change. *Trends in Ecology & Evolution* 23: 453–460.

Diamond, J.M., 1989. Overview of recent extinctions. In *Conservation for the Twenty-First Century*, D. Western, M.C. Pearl, eds:. Oxford University Press, London, UK, pp. 37–41.

Elith, J., Leathwick, J.R. & Hastie, T., 2008. A working guide to boosted regression trees. *Journal of Animal Ecology* 77: 802–813.

Faith, D.P., 1992. Conservation evaluation and phylogenetic diversity. *Biological Conservation* 61: 1–10.

Kleinert, S., 2000. Namatjira, Albert (Elea) (1902–1959). Australian Dictionary of Biography. National Centre of Biography, Australian National University.

Margules, C.R. & Pressey, R.L., 2000. Systematic conservation planning. *Nature* 405: 243–253.

Moilanen, A., Wilson, K.A. & Possingham, H.P. 2009. *Spatial Conservation Prioritization: Quantitative Methods and Computational Tools*. Oxford University Press, Oxford.

Moilanen, A., Meller, L., Leppänen, J., Montesino Pouzols, F., Arponen, A. & Kujala, H., 2012. Zonation spatial conservation planning framework and software v. 3.1.

Phillips, S.J., Anderson, R.P. & Schapire, R.E., 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling* 190: 231–259.

Pollock, L.J., Rosauer, D.F., Thornhill, A.H., Kujala, H., Crisp, M.D., Miller J.T. & McCarthy, M.A., 2015. Phylogenetic diversity meets conservation policy: small areas are key to preserving eucalypt lineages. *Philosophical Transactions of the Royal Society B: Biological Sciences.* 370: 20140007.

Rosauer, D., Laffan, S.W., Crisp, M.D., Donnellan, S.C. & Cook, L.G., 2009. Phylogenetic endemism: a new approach for identifying geographical concentrations of evolutionary history. *Molecular Ecol*ogy 18: 4061–4072.

Terry, P., 2014. *Banjo*. Allen & Unwin, Sydney, NSW.

Thornhill, A.H., Crisp, M.D., Cook, L.G., Nelson, L.A., Yeates, D.K., Knerr, N., Lam, K.E., Külheim C. & Miller, J.T., in preparation. Lineages through time and biome mapping: a comparison of Australian *Acacia* (Fabaceae) and the eucalypts (Myrtaceae).

Wilson, K.A., Cabeza, M. & and Kelin, C.J., 2009. Fundamental concepts of spatial conservation prioritization. In *Spatial Conservation Prioritization: Quantitative Methods and Computational Tools*. Oxford University Press, Oxford, pp. 16–27.

Wrigley, J.W. & Fagg, M., 2010. *Eucalypts: A Celebration*. Allen & Unwin, Crows Nest, NSW.