HOTSPOTS, DISTRIBUTION, AND TRAITS - THE UNIQUENESS OF AUSTRALIAN ENDEMIC PLANTS

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New Phytologist

UNSW | z5367160

Hotspots, Distribution, and Traits - The Uniqueness of Australian Endemic Plants

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Abstract

Rationale: With anthropogenic change rapidly causing ecosystems globally to spiral out of control, conservation efforts and practices need to be perfected and refined before it is too late. Conservation science is constantly restricted by a lack of comprehensive foundational knowledge in which to base policy and legislation. In this new digital age the formation of global and regional biodiversity databases has enabled the sharing and expansion of knowledge. Use of a multitude of biodiversity databases may become a critical approach in the future to effectively fill in the gaps of knowledge restricting the effective global management of the worlds flora.

Methods: We created as first of its kind Australian endemic genera database through the compilation of seven global or country specific plant databases. Trait data and vulnerability data taken from AusTraits and IUCN Redlist were adjoined. Using information from both IUCN and AusTraits with our endemic genera dataset we analysed patterns of dispersal, morphology, distribution, and threatened status.

Key Results: Endemic genera were found to be extensively clustered around southern parts of the continent, following a latitudinal gradient from north to south. Seed sizes of endemic genera were smaller, assisting anemochory dispersal, while non-endemic plants were hypothesised to be more likely hydrochorous, due to a larger size.

Main Conclusion: The results and outputs of this study provide a methodological backbone for further use of inter-country biodiversity databases, while also highlighting the importance of understanding characteristic traits of under threatened flora in conservation practice.

Key Words: Bioregion, Endemic, Dispersal, Threatened

Introduction

Anthropogenic change has fundamentally altered global ecosystems, creating an international crisis emphasised by wildlife decline (Kraus et al., 2023). Extinction rates are now 1000 times greater than historical levels, with future rates expected to further increase (May & Lawton, 1995; De Vos *et al.,* 2015). Globally, the number of species assessed as threatened is increasing at a steady rate (IUCN, 2023), with close to one million individual species at risk of extinction by 2050 (Tollefson, 2019).

Endemism in its most simple definition is defined as taxa that only inhabits a specific area or region (Anderson, 1994; Burlakova et al., 2011). Endemic species are found to have the greatest impact on global extinction rates (Kraus et al., 2023; Gallagher et al., 2023). This is explained by their unique limiting characteristics that differentiate them from ubiquitous species. Common attributes such as narrow geographical range, small populations, and limited physiological tolerance (Shaffer, 1981) leave endemic species vulnerable to anthropogenic threats, climate change, and stochastic events (Cahill *et al.,* 2013; Kraus *et al.,* 2023), oftentimes resulting in extinction. Endemics are believed to be more specialised, requiring resources only obtainable in unobstructed environments, causing them to be competitively excluded from disrupted and/or fragmented ecosystems (Wijesinghe & Brooke, 2004). Endemism is distinguished by limited trait variability and environmental tolerance, due to adaptation to hyper-specific environmental regimes. Alteration of abiotic and biotic conditions will often leave endemic plants incredibly vulnerable to population decline (Behroozian *et al.,* 2020). The vulnerability of endemics to disturbances leaves them often the first group under threat, evidenced by <90% of extinct species listed on the IUCN Redlist considered endemic (IUCN, 2023).

Endemism is a foundational component often considered in conservation practice due to its positive relationship with biodiversity, ecosystem functioning, genetic diversity, and rare species (Skarbeck, 2008). Its relative importance to conservation biology is a result of the unique association endemic species have with their inhabited ecosystem. Often endemic species are crucial as environmental indicators for measuring relative health or disturbance of a region or landscape (Hobohm and Tucker, 2013). Endemicity is an important source of functional diversity with significant decreases in endemic abundance associated with ecosystem degradation; caused by increased vulnerability and deterioration of functional redundancy (Chua *et al.,* 2019). Endemic species drive vital ecosystem services; loss of such species will create a snowball effect resulting in the associated decline of these services (Jefferies, 2006). In a world with limited funding for conservation biology utilising endemism is an effective method to identify global priorities and critical regions, allowing application of conservation to yield the greatest payoffs for biodiversity (Lamoreux et al., 2006).

Plant biodiversity is crucial for life and is an incredibly vital element in ecosystems. Diversity of flora positively influence provisioning services, regulating services and cultural services (Quijas *et al.,* 2021). Protecting and conserving species of endemic nature is not only good conservation and ecological practice, but also beneficial socially and economically (Kraus *et al.,* 2023; Crisp *et al.,* 2001). Endemic plants present themselves as ideal modern conservation focal points due to their highly impactful role in ecosystem services, making endemic hotspots critical conservation focuses. Australia's unique biogeography and characteristics makes it an incredibly diverse biogeographic region, with high proportions of endemicity across the plantae kingdom. It is estimated that approximately 90% of vascular plants are endemic to Australia (Chapman, 2009). Of 310,129 global plant species, Australia accounts for 24,716 of those, or 7.9% (Chapman, 2009). Within tracheophytes, Australia contains >18,000 or 7% of the worlds flowering plants, 120 or 11.7% of the world's gymnosperms, and 498 or 4.2% of the worlds Ferns and Allies (Chapman, 2009). Of all native Gymnosperms and Magnoliophyta, 93%, and 96% of species are endemic to Australia, highlighting Australia's biodiversity and importance to global conservation and management. In terms of endemic richness Australia ranks second, behind only Brazil, and is one if five countries with >10,000 endemic plant species (Gallagher *et al.,* 2023). Despite Australia's high endemicity rate, the proportion of plant species successfully assessed for threatened status evaluations is only 0.39 (Gallagher *et al.,* 2023), a considerably low rate compared to other countries of similar endemic occurrence and economic status. Plant conservation in Australia is constantly grappling with methods to mitigate major threatening processes such as habitat loss, invasives, climate change, altered fire regimes, and habitat fragmentation (Yates *et al.,* 2019; Broadhurst & Coates, 2017), while also feebly educating cultural and economic benefits (Broadhurst & Coates, 2017). Despite these efforts, indicators highlight an ongoing decline of biodiversity (Cresswell and Murphy, 2017). Conservation management of Australian endemic flora will continue to be insufficient until a comprehensive understanding of basic taxonomy and functional biology can be achieved.

Incomplete taxonomic knowledge and the restricted ability to instantaneously identify taxa is one of the most common complications to achieving successful plant conservation (Coates & Atkins, 2001, Wege *et al.,* 2015). This new digital era which we currently inhabit has enabled the compilation of comprehensive large-scale global or local biodiversity databases. These databases present themselves as a revolutionary aid for conservation science, providing the vital backbone of biological knowledge needed to implement efficient and successful policy and legislation. Global plant databases such The World Checklist of Vascular Plants (Govaerts *et al.,* 2021), and World Flora Online along with regional databases such as AusTraits (Falster *et al.,* 2021) feature foundational information regarding taxonomic identification, distribution, functional traits, and endemic status. All collected from wide ranges of peer-reviewed literature, authoritative scientific databases, and herbariums before being scrutinized and quality checked by experts (Govaerts *et al.,* 2021; Falster *et al.,* 2021; Borsch *et al.,* 2020). These databases seemingly fill a large gap in biological knowledge for conservationists while also providing standardised collections of information, allowing for the application of more complicated and complete academic research (Andrew *et al.,* 2021; Murguía-Romero *et al.,* 2023; Standish *et al.,* 2021). As plant conservation is often inhibited by scarce funding (Havens et al., 2014), and the value of plant biodiversity is often underestimated (Esperon-Rodriguez et al., 2022), standardised databases such as the ones previously mentioned are incredibly important for education and driving research into a more intuitive and efficient direction. However, a natural downfall of databases created from multiple assembled global-based sources is a lack of consistency and completeness between variables, often requiring intense manipulation for smaller scale, regional based projects.

As stated by Cogoni *et al.,* (2021) it is necessary for the formation of ‘priority lists’ of plants requiring conservation management to locate target species (i.e., endemics) that enhance biodiversity. In this study we utilise a collection of global and country-specific floral databases to compile a checklist of endemic genera for Australia, to optimise endemic species conservation efforts in the future. Conservation practice at a species level can often be inefficient and unnecessarily troubling, especially when the combining of individual databases is involved. Variation in taxa ID is common and supporting information such as geographical distribution is often inconsistent across databases. Identical information is only present in 60% of plants across the four major global vascular plant checklists (Schellenberger Costa et al. 2023). Species level diversity analyses are often subject to the mercy of several restraining factors: time exhaustive, expensive and requires specialised/expert knowledge (Kallimanis *et al.,* 2012). Often these databases are reliant upon citizen science and non-expert observations, often resulting in incomplete taxonomic identification or elementary observations. This combined with the lack of synchronous data entry methods, leave taxonomic analyses at the species level unappealing and sometimes dubious. Biodiversity monitoring and analyses completed at the genus level present as a more efficient and effective method, with changes in genera richness shown to accurately represent changes in species richness (Kallimanis *et al.,* 2012).

We intended to achieve several objectives that will enable future research to identify patterns, distributions, functions, forms and locations of importance of native plant conservation. This study aims to compile a checklist on endemic vascular plant genera in Australia, for the use of further publications, research, and conservation efforts. From this dataset we examine and assess vulnerability, distribution, and functional traits of endemic plants. The goal being to further improve foundational knowledge for conservation practice by expanding knowledge on similarities and differences of evolutionary attributes, habitat characteristics and distribution range between the two groups, encouraging more applied plant conservation.

Objectives are separated into three separate components: 1) assemble a comprehensive list of Australian endemic plant flora using a wide collection of scientifically supported databases 2) Map distribution and habitat of Australian endemic plants 3) Identify endemic plants of greater risk and assess overall threatened status of Australian endemics 4) Compare and contrast functional similarities and differences between endemics and non-endemics. It is hypothesised that endemic plants will have a higher likelihood of threatened status classification, and that non-endemic genera traits (i.e seed size, plant height) will align with an increased dispersal range.

Methods

Study Region and Defining Endemism

The region of interest for this study consisted entirely of mainland Australia and Tasmania. Any associated external island territories like Norfolk Island, Christmas Island etc were not considered as part of Australia due their minimal weighting in national conservation policy and considerable geographic and environmental differences. Islands not officially classified as distinct territories were included as part of Australia for this study, as removal of all or selected islands would be logistically difficult. The majority of such islands are islets or are of such small distances from the coast that environmental and biological conditions would not be distinct enough to consciously from plant occurrence searches.

Endemicity as previously mentioned is when a taxon only inhabits a specific area or region. Issues arise with the simplicity of this definition when accounting for introduced species.For this study we considered the impact of introducing species to a non-native range on that genus' endemicity. Due to evidence that phenotypic change in exotic plants can lead to rapid evolution, and subsequent speciation (Flores-Moreno *et al.* 2015) we concluded that successfully introduced species to regions outside Australia removes endemicity.

Dataset Collation

Data was collected from 7 individual global (Govearts *at al.,* 2021) or country-specific (Belbin *et al.,* 2021; Cámara-Leret *et al.,* 2020; Schoenberger *et al.,* 2020; Joyce *et al.,* 2020; Munzinger *et* al., 2020; Fought et al., 2022; Figure 1) vascular plant databases. Collation of datasets together was performed using R (R Core Team, 2023) and R Studio (R Studio Team, 2020). Fought et al., (2020) previous study centred on endemic species within Australia formed the foundation of our dataset. The Australian Endemic Species dataset contained all genera with at least one naturally occurring species, providing a list of native Australian genera. This data was used as a skeleton frame in which the rest of relevant information was added to. From there genera names from New Zealand (Schoenberger *et al.,* 2020), New Caledonia (Cámara-Leret *et al.,* 2020), Indonesia (Joyce *et al.,* 2020), and New Guinea (Munzinger *et al.,* 2020) data were crosschecked with native Australian genera names using the tideyverse package within R (Wickham *et al.,* 2019). Before cross-checking, data cleaning was applied on the non-Australian datasets to remove data errors, blank values, and NA's using *tidyverse*. Singapore records within the Indonesian dataset were discovered to contain errors and was subsequently filtered out of all analysis. Boolean values were applied for each non-Australian dataset, TRUE values indicating that the Australian and non-Australian datasets both contained records of the same genus, while FALSE values revealing that an Australian genus did not occur in the non-Australian dataset, and is possibly endemic according to that database. Each genus within the Australian natives contained multiple TRUE or FALSE values, one for each dataset crosschecked with. For global data the World Checklist of Vascular Plants (WCVP) was used (Govearts *at al.,* 2021). WCVP Records of Australian occurrences were filtered out before the same methodology was applied.

All plant observational data from Atlas of the Living Australia (ALA) (Belbin *et al.,* 2021) was collected and filtered to only include Australian wide observations. The previous methods were again applied with each genus allotted a TRUE/FALSE value depending on whether it occurred in both datasets – Australian native genera and ALA. The Australian native genera were crosschecked against 6 total datasets: ALA, WCVP, New Zealand, Indonesia, New Caledonia, and New Guinea. TRUE occurrences were given a value of 1 while FALSE occurrences a value of 0. These values were than summed, with a maximum value a genus was able to achieve being six, and a minimum being zero. If a genus incurred a value of 2 or greater, this meant that at least 2 individual databases had occurrences of the genus outside Australia and was subsequently classified as non-endemic. All genera allocated a value of zero were immediately considered endemic, since no databases had any records of genus incidences outside Australia. Genera with a count of one, were classified as unclear as an intermediatory step since it was unclear whether those incidences were reliable or purely a data error of a single database. Endemicity of unclears was manually checked using the database with the TRUE occurrence, against other global databases such as The Plant List and The Global Biodiversity Information Facility (GBIF). These sources were cross analysed for taxonomic synonyms, data errors, or ornamental/introduced species recordings. For an unclear classification to be changed to endemic, evidence would have to be found of data input errors or ornamental species occurrence. If an unclear genus had <10 relatively close occurrences in a single region outside Australia, strong conclusions could be made those incidences were merely ornamental/introduced individuals. For an unclear classification to be altered to non-endemic evidence of taxonomic synonyms or a sustaining population outside Australia would have to be present. Occurrences were considered a self-sustaining population if of a size >20 in a region outside Australia, and in close geographical and temporal distance. Taxonomic synonyms are scientific names of a genus which is now known by a different name. It was the most common reason for an unclear genus to be classed as non-endemic. An example is *Niemeyera*, which was classified by Joyce *et al.,* (2020) as native to Indonesia. Upon examination of The Plant List and World Flora Online it was discovered that *Niemeyera* is also called *Apostasia,* which is commonly located throughout Southeast Asia.

IUCN Threatened Status and AusTrait Data

To test our hypotheses, we combined IUCN Redlist (IUCN, 2023) and AusTraits (Falster *et al.,* 2021) data with our endemic species dataset using the *tidyverse* in R. IUCN Redlist data was retrieved from completing a filtered search for Australian plants, with all external island territories excluded. Redlist categories of no interest such as “lower risk/near threatened”, “lower risk”, and “data deficient” were removed. Leaving five categories of importance, ranging from low extinction risk (Least Concern) to high extinction risk (Critically Endangered). To understand functional and evolutionary differences as well as potentially explain the distributions of endemic and non-endemic species, traits of dispersal were extracted from AusTraits and combined to our Australian endemic dataset. These traits include plant height, seed dry mass, dispersal syndrome, and plant growth form. Each trait was specifically chosen in accordance with their predicted relationship they contain with endemicity. For categorical variables such as plant growth form and dispersal syndrome the most observed value for each genus was applied. For example, if 55% of all Grevillea observations within AusTraits were of the growth form: Tree, Grevillia within the Australian endemic genera data would be valued as a tree. Categories of plant growth form were also collapsed into simplified versions for ease of graphical presentation and simplicity. Each orginal AusTrait category was organized into one of the following: tussock, tree, shrub, herb, fern, and limber. Growth forms such as palmoid, lycophyte, and graminoid were manually removed as they only contained one or very few species. For numerical values such as seed dry mass and plant height the mean value of all AusTrait observations of a genus was calculated and applied to the Australian endemic genera data.

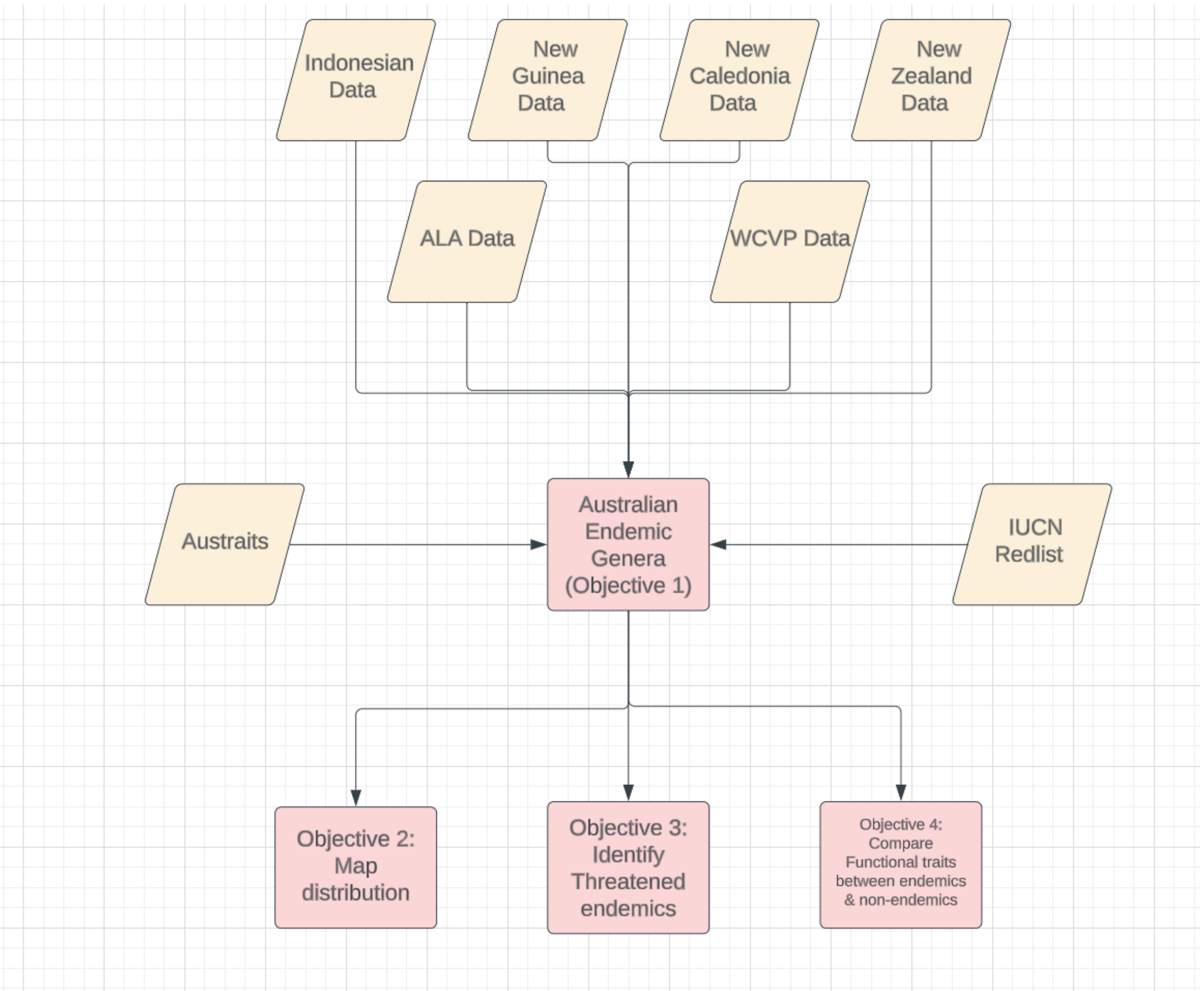

Figure 1: Flowchart of study methodology. Yellow indicates external datasets, red indicates objectives of study

Mapping Distribution

Distribution mapping of endemic species were conducted using the *sp* (Pebesma & Bivand, 2005), *here* (Muller *et al.* 2020), *ggplot2* (Wickham, 2016), *sf* (Pebesma & Bivanad, 2023), *maps* (Becker *et al.,* 2022) and *maptools* (Bivand & Lewin-Koh, 2023) packages. Distribution was mapped by calculating density of endemic species with Australian bioregions (Environment Australia, 2000). Species richness was used to calculate density as occurrence data biases more populated areas. Richness of each bioregion was divided by area of inhabited bioregion to provide a standardised measure of density across all Australian bioregions.

Statistical Tests

Testing for relationships between plant height/seed mass and endemicity was completed using a non-parametric Wilcoxon Ranked test. Assumptions of normality were tested on plant height and see mass; however, normality was not able to be achieved through transformation, hence the application of a non-parametric test. Chi squared contingency tables were utilised for testing for relationships present between endemicity and dispersal type/threatened status/major Vegetation group.

Results

In total we found 2139 native plant genera within Australia. Of those 2139 genera, 704 were classified as endemic to mainland Australia, and 149 classified as non-endemic genera. Meaning that 33% of all genera with at least one native species occurring within Australia are entirely endemic. The most species rich genera include Acacia (sp. 1056), *Eucalyptus* (sp.717), *Grevillia* (sp. 367), *Caladenia* (sp. 278), and *Stylidium* (sp. 278), all classified as non-endemic. The most species rich endemic genera however include Daviesia (sp. 131), *Gastrolobium* (sp. 110), *Persoonia* (sp. 101), *Prostanthera* (sp. 101), and *Verticodia* (sp. 101).

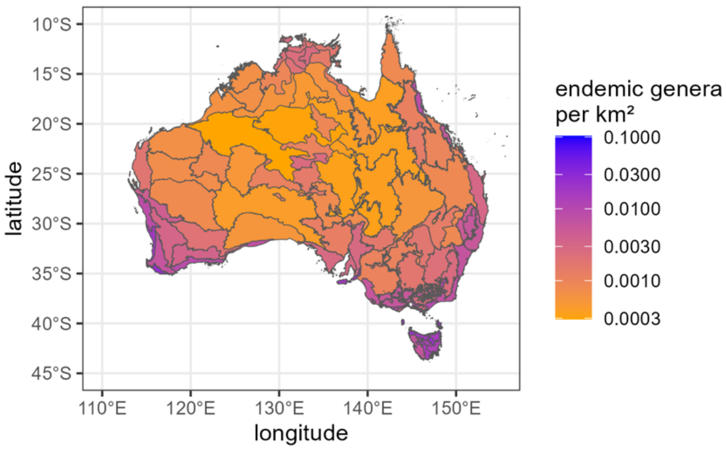

Figure 2: Map of Australian endemic plant genera density per bioregion. Bioregions collected from Interim Biogeographic Realisation for Australia (IBRA)

Distribution of Endemic genera is shown in (Figure 2). Endemic genera become noticeably more abundant further south. Endemicity is highest in South-West Australia, a global biodiversity hotspot. Southern Tasmania and the Eastern coast also feature high endemicity per km^2. Areas of low endemicity include inland arid Australia, and northern tropical Australia.

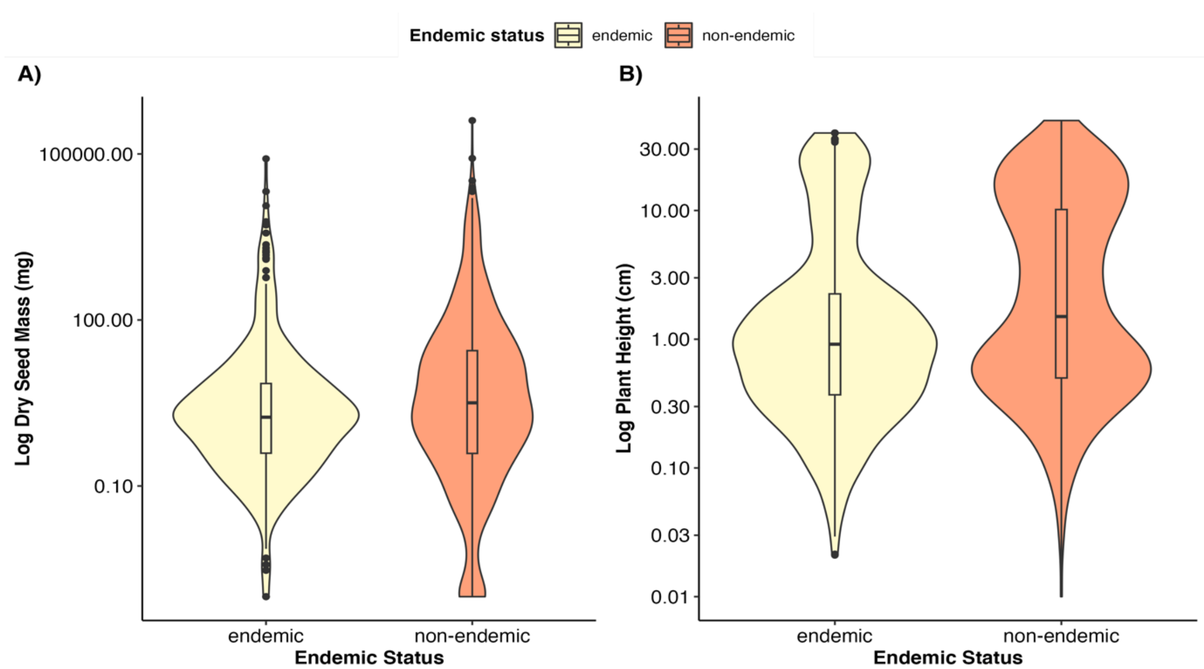

Figure 3: A) Violin plot of dry seed mass between Endenic and non-Endemic genera of Australia. Data submitted to a log scale. B) Violin plot of plant height between Endenic and non-Endemic genera of Australia. Data submitted to a log scale.

Dry Seed mass was significantly higher in non-endemics than endemics (Wilcoxon-Rank Test: Z = 199830, P <0.001; Figure 3**a**). plant height mirrored these results with non-endemics significantly taller than endemics (Wilcoxon-Rank test: Z = 296893, P = <0.001; Figure 3**b**). Dispersal type significantly differed between endemic and non-endemic plants (Table 1). Both endemic and non-endemic plants were dominated by animal-dispersal (zoochory), almost having the exact same proportion of genera dispersing diaspores through animals (Figure 4). However, endemic plants have a greater proportion of genera utilising anemochory (wind dispersal), while non-endemics have larger number of genera dispersing diaspores through hydrochory.

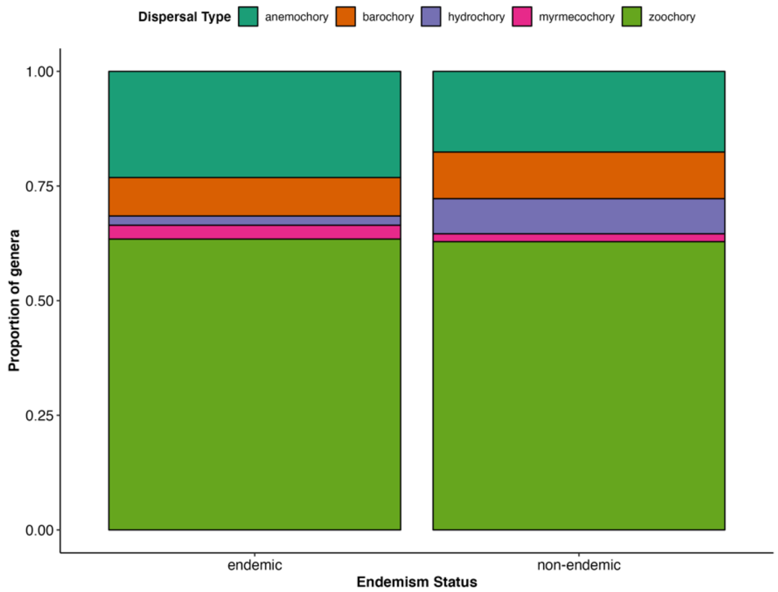

Figure 4: Proportion of Seed dispersal traits between endemic and non-endemic plants.

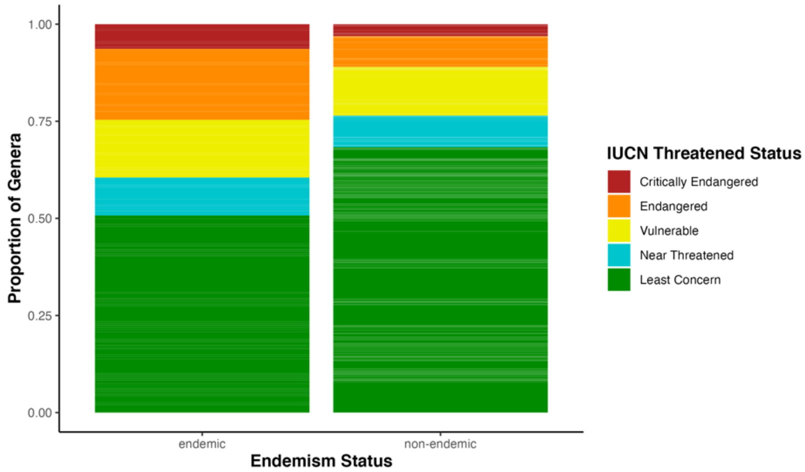

Figure 5: Threatened status of Australian endemic genera. Categories limited to critically endangered, vulnerable, near threatened and least concern. Extinct, data deficient and lower rick classifications removed due to lack of data or lack of relevancy to figure.

There was a significant association between the threatened status and the endemicity in Australian native plant genera (Table 1). Endemic genera were more likely to be classified as Near Threatened, Critically Endangered, Endangered, and Vulnerable. While non-endemic plants were more likely to of least concern than expected. Proportion of non-endemic genera classified as least concern is substantially larger than endemic plants, however the proportion of critically endangered and endangered endemic plants are markedly greater than non-endemics (Figure 5). Endemic genera at greatest risk include *Persoonia*, *Synaphea* and *Adenathos* (Supplementary Information: https://roconnell0.github.io/Trial/treemap.html).

Table 1: Chi Squared Test values.

~ ENDEMICITY	DEGREES OF FREEDOM	X^2	P VALUES
THREATENED STATUS	4	78.85	<0.01
DISPERSAL TYPE	4	17.75	0.02

Discussion

Australian endemic plants follow a latitudinal gradient in Australia, becoming more densely populated the further south. This phenomenon is both unexpected and surprising considering that one of the least endemic genera rich areas is northern tropical Australia. The tropics are generally believed to have substantially greater levels of endemism than cooler, more temperate regions (de Gouvenain & Silander, 2017), with subtropical regions often having higher than expected endemism per area size. The Australian wet tropics bioregion, one of the country's most diverse systems, contains very high levels of restricted endemism (Williams *et al.* 2003). However, the evidence in which these findings are based on are species focused, with endemism measured at species level and not genus levels. From this we can conclude that this study has uncovered a noticeable disparity in endemic prevalence across taxonomic levels, and that richness is not constant but can vary between levels. Higher species endemicity combined with lower genera endemicity indicates that speciation and evolutionary divergences of plant species occurred relatively recently. The dispersal of many plants in northern Australia is predicted to have possibly occurred before the last glacial period, when sea levels dramatically rose, separating New Guinea and Australia (Cook *et al.,* 2019). Northern Australia's proximity to south-east Asia is also an influential factor in the limited number of endemic genera, with wide ranged diaspores dispersal a factor in plant genera homogeneity between southeast Asia and tropical Australia. South Western Australia is a globally recognised biodiversity hotspot. Its high diversity is further supported in this study, with extremely high instances of endemicity – the highest within Australia. The charestically old weathered, flat landscape, with a lack of major rover networks while also containing largely nutrient-deficient hotspots has created a unique environment allowing genera to specialise and diverge (Hopper *et al.* 1996). Exact reasons as to why this hotspot is so biodiverse when compared to other regions within Australia are unclear, Charles Darwin personally noted that the great species richness could be attributed to the fact that the region was a somewhat wet pocket isolated by ocean and desert (Myers *et al.* 2000). Using data collated from this study we hypothesise that the high biodiversity of this region may possibly be due to unique dispersal methods, due to the combination of the hotspots isolated location and Australian endemic plants affinity for animal zoochory. Hooper & Gioia echo this belief (2004) believing that bird pollination may be a leading factor in the region's high biodiversity and endemicity. However, further region-specific research is required into dispersal traits of endemic plants before appropriate conclusions can be made.

Interestingly, dry seed mass within endemic plants was greater than seed mas than non-endemics. Non-endemics are assumed often to be greater seed dispersers, and it was originally hypothesised that non-endemics seed mass would be lower, due to lighter mass allowing for more effective anemochory. Anemochory and zoochory are assumed to be the leading dispersal methods for the movement of flora from Southeast Asia to northern Australia, this is because of the large distances required to be travelled by diaspores (van Rheede *et al.,* 2000*)*. However, seed mass being lighter in endemics than non-endemics show that dispersal across country may not be believed to be driven by wind. Heavier seed mass, as seen in non-endemic plants, can oftentimes be associated with hydrochory (Chambert & James, 2009). The greater seed mass combined with a higher incidence of hydrochory indicate that non-endemics may have colonised northern Australia in the past through the dispersal of seeds via water currents. On the other hand, Thompson *et al.* (2011) showed that distance of seed dispersal is more strongly correlated with the height of a plant. Plant height is also considerably greater in non-endemics than endemics, emphasising the importance of dispersal methods of plants in relation to distribution and range.

As expected, endemic species are at a considerably greater threat than non-endemics due to their limited range. Endemic genera at greatest risk such as *persoonia* and *synaphea* are considerably affected by habitat fragmentation and removal. The IUCN classifies any taxa under threat if they fall under either Vulnerable, endasngered, or critically endangered categories. The tendency for endemic plants to be classified under any of these three categories indicate the increased chance of endemic plants to face severe anthropogenic impact and habitat degradation. Areas of high biodiversity such as South-Western Perth and coastal NSW are characterised as unique, nutrient poor environments. Environemtns like these are often the most vulnerable to disturbance (McIntyre, S., & Lavorel, 1994), emphasising the care required to be taken in the future in conservation management of endemics and their threatened habitat. Evaluating groups of organisms to identify potential threats is a crucial process that enables the eventual inclusion of specific species on legally mandated lists of endangered species. This inclusion serves as a trigger for developing plans to restore these species and creating strategies for their management and monitoring. These efforts aim to prevent extinction, promote recovery, and ensure the protection of threatened species.

The efforts undertaken in this study ideally should serve as a framework for future likewise projects and conservation management. In the face of a 6th mass extinction event, efficient and effective methods are becoming more and more necessary in conservation science. The results uncovered and dataset created from this research will hopefully encourage expanded research into endemic plant genera in Australia, with more thorough research into endemic plants and how their specific traits and characteristics make them unique required,

Acknowledgments

Special thank you to Adele Gemmell, Andreas Bartnitzky, Serena Zhang, and James Weppner for their continued hard and invaluable work in this project. Thank you as well to Will Cornwell for the formation of this study and irreplaceable advice and knowledge.

Data Availability Statement

The data that supports the findings of this study and supporting information is available at Gitbub: https://github.com/roconnell0/Trial

References

Anderson, S. (1994). Area and endemism. *The quarterly review of biology*, **69**(4), 451-471.

Andrew, S.C., Mokany, K., Falster, D.S., Wenk, E., Wright, I.J., Merow, C., Adams, V. and Gallagher, R.V. 2021. Functional diversity of the Australian flora: strong links to species richness and climate. *Journal of Vegetation Science*, **32**(2), e13018.

B Borsch, T., Berendsohn, W., Dalcin, E., Delmas, M., Demissew, S., Elliott, A., Fritsch, P., Fuchs, A., Geltman, D., Güner, A. et al. 2020. World Flora Online: Placing taxonomists at the heart of a definitive and comprehensive global resource on the world's plants. *Taxon*, **69**(6), 1311-1341.

Becker, O., Minka, A., Deckmyn. A. 2022. _maps: Draw Geographical Maps_. R package version 3.4.1, <https://CRAN.R-project.org/package=maps>.

Behroozian, M., Ejtehadi, H., Memariani, F., Pierce, S., & Mesdaghi, M. 2020. Are endemic species necessarily ecological specialists? Functional variability and niche differentiation of two threatened Dianthus species in the montane steppes of northeastern Iran. *Scientific reports*, *10*(1), 11774.

Belbin L, Wallis E, Hobern D, Zerger A 2021 The Atlas of Living Australia: History, current state and future directions. Biodiversity Data Journal, **9**: e65023. https://doi.org/10.3897/BDJ.9.e65023.

Bivand R, Lewin-Koh N. 2023. _maptools: Tools for Handling Spatial Objects_. R package version 1.1-7, <https://CRAN.R-project.org/package=maptools>.

Broadhurst, L., & Coates, D. 2017. Plant conservation in Australia: current directions and future challenges. *Plant diversity*, **39**(6), 348-356.

Burlakova, L. E., Karatayev, A. Y., Karatayev, V. A., May, M. E., Bennett, D. L., & Cook, M. J. 2011. Endemic species: contribution to community uniqueness, effect of habitat alteration, and conservation priorities. *Biological Conservation*, **144**(1), 155-165.

Cahill, A.E., Aiello-Lammens, M.E., Fisher-Reid, M.C., Hua, X., Karanewsky, C.J., Yeong Ryu, H., Sbeglia, G.C., Spagnolo, F., Waldron, J.B., Warsi, O. et al. 2013. How does climate change cause extinction?. *Proceedings of the Royal Society B: Biological Sciences*, **280**(1750), 20121890.

Cámara-Leret, R., Frodin, D.G., Adema, F., Anderson, C., Appelhans, M.S., Argent, G., Arias Guerrero, S., Ashton, P., Baker, W.J., Barfod, A.S. et al., 2020. New Guinea has the world's richest island flora. *Nature*, **584**(7822), pp.579-583.

Chambert, S., & James, C. S. 2009. Sorting of seeds by hydrochory. *River Research and Applications*, **25**(1), 48-61.

Chapman, A. D. 2009. Number of Living Species in Australia and the World, Second Edition. *Department of the Environment, Water, Heritage and the Arts*, Australian Government, Canberra.

Chua, K. W., Tan, H. H., & Yeo, D. C. 2019. Loss of endemic fish species drives impacts on functional richness, redundancy and vulnerability in freshwater ecoregions of Sundaland. *Biological Conservation*, **234**, 72-81.

Coates, D. J., & Atkins, K. A. 2001. Priority setting and the conservation of Western Australia's diverse and highly endemic flora. *Biological Conservation*, **97**(2), 251-263.

Cogoni, D., Fenu, G., Dessì, C., Deidda, A., Giotta, C., Piccitto, M., & Bacchetta, G. 2021. Importance of Plants with Extremely Small Populations (PSESPs) in Endemic-Rich Areas, Elements Often Forgotten in Conservation Strategies. *Plants*, **10**(8), 1504.

Cook, G. D., Bond, W. J., February, E. C., & Williams, R. J. 2019. Savannas of Australia and New Guinea. *Savanna Woody Plants and Large Herbivores*, 51.

Cresswell, I. D., & Murphy, H. T. 2017. Australia state of the environment 2016: biodiversity, independent report to the Australian Government Minister for the Environment and Energy. *Australian Government Department of the Environment and Energy, Canberra*.

Crisp, M. D., Laffan, S., Linder, H. P., & Monro, A. N. N. A. 2001. Endemism in the Australian flora. Journal of Biogeography, **28**(2), 183-198.

de Gouvenain, R. C., & Silander, J. A. 2017. Temperate forests. *Reference module in life sciences*.

De Vos, J. M., Joppa, L. N., Gittleman, J. L., Stephens, P. R., & Pimm, S. L. (2015). Estimating the normal background rate of species extinction. *Conservation biology*, **29**(2), 452-462.

Environment Australia. 2000. Revision of the interim biogeographic regionalisation of Australia (IBRA) and the development of version 5.1.–summary report. *Environment Australia, Canberra*.

Esperon-Rodriguez, M., Tjoelker, M.G., Lenoir, J., Baumgartner, J.B., Beaumont, L.J., Nipperess, D.A., Power, S.A., Richard, B., Rymer, P.D. and Gallagher, R.V., 2022. Climate change increases global risk to urban forests. *Nature climate change*, **12**(10), 950-955.

Falster, D., Gallagher, R., Wenk, E.H., Wright, I.J., Indiarto, D., Andrew, S.C., Baxter, C., Lawson, J., Allen, S., Fuchs, A . et al. 2021. AusTraits, a curated plant trait database for the Australian flora. *Scientific Data*, **8**(1), 254.

Flores-Moreno, H., García-Treviño, E. S., Letten, A. D., & Moles, A. T. 2015. In the beginning: phenotypic change in three invasive species through their first two centuries since introduction. *Biological invasions*, **17**, 1215-1225.

Fought, E., Woolley, S., Alam Shufol, B., Cornwell, W., 2022. BEES3041 Australian Endemic Species, [Dataset] UNSW

Gallagher, R.V., Allen, S.P., Govaerts, R., Rivers, M.C., Allen, A.P., Keith, D.A., Merow, C., Maitner, B., Butt, N., Auld, et al. 2023. Global shortfalls in threat assessments for endemic flora by country. *Plants, People, Planet*.

Govaerts, R., Nic Lughadha, E., Black, N., Turner, R., & Paton, A. 2021. The World Checklist of Vascular Plants, a continuously updated resource for exploring global plant diversity. *Scientific Data*, **8**(1), 215.

H. Wickham. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

Havens, K., Kramer, A. T., & Guerrant Jr, E. O. 2014. Getting plant conservation right (or not): the case of the United States. *International Journal of Plant Sciences*, **175**(1), 3-10.

Hobohm, C., & Tucker, C. M. (2013). The increasing importance of endemism: responsibility, the media and education. In: *Endemism in vascular plants* (pp. 3-9). Dordrecht: Springer Netherlands.

Hopper, S. D., & Gioia, P. (\2004. The southwest Australian floristic region: evolution and conservation of a global hot spot of biodiversity. *Annu. Rev. Ecol. Evol. Syst.*, **35**, 623-650.
Hopper, S. D., Harvey, M. S., Chappill, J., Main, A. R., & Main, B. Y. 1996. The Western Australian biota as Gondwanan heritage? a review. In *Gondwanan heritage* (pp. 1-46). Surrey Beatty & Sons.

IUCN. 2023. IUCN red list of threatened species. IUCN. https://www.iucnredlist.org/

Jeffries, M. J. 2006. *Biodiversity and conservation*. Routledge.

Joyce, E.M., Thiele, K.R., Slik, F.J. and Crayn, D.M., 2020. Checklist of the vascular flora of the Sunda-Sahul Convergence Zone. *Biodiversity Data Journal*, **8**.

Kallimanis, A. S., Mazaris, A. D., Tsakanikas, D., Dimopoulos, P., Pantis, J. D., & Sgardelis, S. P. 2012. Efficient biodiversity monitoring: Which taxonomic level to study?. *Ecological Indicators*, **15**(1), 100-104.

Kraus, D., Enns, A., Hebb, A., Murphy, S., Drake, D. A. R., & Bennett, B. 2023. Prioritizing nationally endemic species for conservation. *Conservation Science and Practice*, **5**(1), e12845.

Lamoreux, J. F., Morrison, J. C., Ricketts, T. H., Olson, D. M., Dinerstein, E., McKnight, M. W., & Shugart, H. H. 2006. Global tests of biodiversity concordance and the importance of endemism. *Nature*, **440**(7081), 212-214.

McIntyre, S., & Lavorel, S. 1994. How environmental and disturbance factors influence species composition in temperate Australian grasslands. *Journal of Vegetation Science*, *5*(3), 373-384.
Müller K. 2020. _here: A Simpler Way to Find Your Files_. R package version 1.0.1, <https://CRAN.R-project.org/package=here>.

Munzinger, J., Morat, P., Jaffré, T., Gâteblé, G., Pillon, Y., Rouhan, G., Bruy, D., Veillon, J.M. and Chalopin, M., 2020. FLORICAL: Checklist of the vascular indigenous flora of New Caledonia. http://publish.plantnet-project.org/project/florical

Murguía-Romero, M., Ortiz, E., Serrano-Estrada, B., & Villaseñor, J. L. 2023. The Kew's" World Checklist of Vascular Plants" and its relevance to the knowledge of the flora of Mexico. *Botanical Sciences*, **101**(2), 632-653.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature*, **403**(6772), 853-858.
Pebesma E, Bivand R. 2005. "Classes and methods for spatial data in R." _R News_, *5*(2), 9-13. <https://CRAN.R-project.org/doc/Rnews/>.
Pebesma, E., & Bivand, R. 2023. Spatial Data Science: With Applications in R (1st ed.). Chapman and Hall/CRC. https://doi.org/10.1201/9780429459016

Quijas, S., Jackson, L. E., Maass, M., Schmid, B., Raffaelli, D., & Balvanera, P. 2012. Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assessment. *Journal of Applied Ecology*, **49**(4), 929-940.

R Core Team. 2023. R: A language and environment for statistical computing. R Foundation For Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Raup, D. M. 1995. *Extinction rates* (Vol. 11). J. H. Lawton, & R. M. May (Eds.). Oxford: Oxford University Press.

RStudio Team 2020. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

Schellenberger Costa, D., Boehnisch, G., Freiberg, M., Govaerts, R., Grenié, M., Hassler, M., Kattge, J., Muellner-Riehl, A.N., Rojas Andrés, B.M., Winter, et al. 2023. The big four of plant taxonomy–a comparison of global checklists of vascular plant names. *New Phytologist*.

Schoenberger, I., Wilton, A., Boardman, K., Breitwieser, I., de Lange, P., de Pauw, B., Ford, K., Gibb, S., Glenny, Da., Greer, et al. 2020 Checklist of the New Zealand flora - seed plants, Landcare Research NZ Ltd, DOI: https://doi.org/10.26065/tjd1-rf61

Skarbek, C. (2008). A review of endemic species in the Eastern Arc Afromontane Region: Importance, inferences, and conservation. *Macalester Reviews in Biogeography*, **1**(1), 3.

Standish, R. J., Gove, A. D., Grigg, A. H., & Daws, M. I. 2021. Beyond species richness and community composition: Using plant functional diversity to measure restoration success in jarrah forest. *Applied Vegetation Science*, **24**(3), e12607.

Tollefson, J. 2019. One million species face extinction. *Nature*, **569**(7755), 171.

van Rheede, van Oudtshoorn, K., van Rooyen, M. W., van Rheede van Oudtshoorn, K., & van Rooyen, M. W. 1999. Anemochory. *Dispersal Biology of Desert Plants*, 33-68.

Wege, J. A., Thiele, K. R., Shepherd, K. A., Butcher, R., Macfarlane, T. D., & Coates, D. J. 2015. Strategic taxonomy in a biodiverse landscape: a novel approach to maximizing conservation outcomes for rare and poorly known flora. *Biodiversity and Conservation*, **24**, 17-32.

Wickham H, Averick M, Bryan J, Chang W, McGowan LD, François R, Grolemund G, Hayes A,Henry L, Hester J, et al. 2019. “Welcome to the tidyverse.” _Journal of Open Source Software_, *4*(43), 1686. doi:10.21105/joss.01686 <https://doi.org/10.21105/joss.01686>.

Wijesinghe, M. R., & Brooke, M. D. L. (2004). What causes the vulnerability of endemic animals? A case study from Sri Lanka. *Journal of Zoology*, **263**(2), 135-140.

Williams, S. E., Bolitho, E. E., & Fox, S. 2003. Climate change in Australian tropical rainforests: an impending environmental catastrophe. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, **270**(1527), 1887-1892.

Yates, C. J., McNeill, A., Elith, J., & Midgley, G. F. 2010. Assessing the impacts of climate change and land transformation on Banksia in the South West Australian Floristic Region. *Diversity and Distributions*, **16**(1), 187-201.