Using evidence of decline and extinction risk to identify priority regions, habitats and threats for plant conservation in Australia

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Abstract

Threatened species lists are used at global, national and regional scales to identify species at risk of extinction. Many species are listed due to restricted population size or geographic distribution, and decline is often inferred rather than quantified. Vascular plants comprise over 70% of nationally listed threatened species, but there is an incomplete picture of which species are most at risk of extinction, where these occur and the factors behind their declines. We compiled published information and the best available field knowledge including 125 expert interviews to identify declining and at risk species. The candidate list comprised 1135 taxa, which were mostly listed as Critically Endangered or Endangered under Federal and/or State legislation but included 80 that are currently unlisted but considered to be highly threatened. 418 taxa were assessed as having a documented, suspected or projected continuing decline. These were ranked based on extinction risk and magnitude of continuing decline, which suggest that 296 are at risk of extinction under current management regimes, including 55 at high risk of extinction. Declining and imperilled taxa are concentrated in a relatively small number of regions and habitats, and six threatening processes are driving the majority of declines. Field surveys and robust, repeatable monitoring are required to better inform population trends and extinction risk, as well as inform the status of almost 200 taxa that are potentially imperilled but poorly

known. Identification of declining taxa can identify key issues for flora conservation across a continent, and allow for targeted and efficient recovery efforts.

Introduction

Prevention of species extinction is a key goal of conservation biology, and central to this agenda are threatened species lists (Lamoreux *et al.* 2003). These lists formally identify species that are at risk of extinction, and identify threats and recovery actions. Since the first global classification of extinction risk under the World Conservation Union (IUCN) Red List in the 1970s, nations and jurisdictions have pursued independent listing processes guided by the Red List criteria. These define threat categories based on quantitative thresholds relating to geographic range, population size, rate of decline and extinction risk (IUCN Standards and Petitions Subcommittee 2017).

Regional and taxonomic group analyses have shown that many species are listed based on IUCN criterion D (total population size very small), with D2 (which includes restricted area of occupancy or number of locations) susceptible to being misapplied (Landsberg and Clarkson 2004; Mace *et al.* 2008; Partel *et al.* 2005; Silcock *et al.* 2014). Species rarely qualify for listing based on quantified reduction in population size (criterion A) or extinction risk (criterion E). This is especially so for plant species, where conservation assessments are typically made using herbarium collections interpreted by botanists, rather than quantitative demographic data (Burgman *et al.* 1995). Identifying population declines is difficult, due to the paucity of repeatable time-series monitoring data for the vast majority of the world's species and the long time frames necessary to identify trends (Brummitt *et al.* 2015; Clark and Bjornstad 2004; Jenkins *et al.* 2003; Lindenmayer and Likens 2010). There is seldom quantified evidence of species declines (Rayner *et al.* 2014) and threatened species lists tend to be dominated by narrow-range endemics with small distributions and/or population sizes (Burgman 2002; McIntyre 1992; Silcock *et al.* 2014).

However, given that extinction is the end-point of unhalted population declines, and because intrinsically rare species may have ecological syndromes and breeding systems that are adapted to survival in small populations (Coates and Atkins 2001; Flather and Sieg 2007; Gaston 1994; Mace and Kershaw 1997; Yates *et al.* 2007), declining species should be of the highest conservation concern. Regional studies have shown that concentrations of narrow-range endemics and species of high conservation concern often do not overlap (Lavergne *et al.* 2005; Partel *et al.* 2005), as well as poor correlations between listing status and scope and urgency of management actions (Ocock 2008; Williams 2006). A collation of species suffering continuing declines should provide a mechanism for identifying regions and habitats where flora conservation is most serious and where recovery effort should be concentrated.

Australia's parlous record of species extinctions and declines since European settlement is well-documented for mammals (Burbidge *et al.* 2008; McKenzie *et al.* 2007; Woinarski *et al.* 2015) and birds (Garnett *et al.* 2011; Szabo *et al.* 2012), but the most recent assessment of the status of Australia's threatened flora was undertaken more than two decades ago (Briggs and Leigh 1996). Plants comprise 72% of Australia's national threatened species list, with 1308 listed species (Department of Environment and Energy 2017). A further 370 species are listed as Critically Endangered or Endangered at a State level but not listed federally, with more than ten times that number considered Vulnerable, Rare, Near Threatened or Priority Flora on State and Territory lists (J. Silcock, unpublished data).

We collated the best available information on current population trends and threats for all plants listed as Endangered and Critically Endangered at State and/or Federal level in Australia. We used this information to consider: (1) What proportion of listed taxa have continuing declines and are threatened with extinction? (2) Where do declining taxa, including the taxa most at risk of extinction, occur? (3) In what habitats are they concentrated?, and (4) What processes are causing continuing declines? Our results provide for clear conservation actions, and can guide future investment, policy, community engagement and regional conservation efforts.

Materials and methods

All taxa listed as Critically Endangered and Endangered under the EPBC Act and/or State legislation were assessed using Australian Virtual Herbarium records and recovery plans, conservation and listing advice, species profiles, reports and peer-reviewed literature. Seven species listed as Extinct that had been recently 'rediscovered' were also included. Taxa that were not likely to meet Endangered criteria on a national level (i.e. are listed based on their distribution in one state, as is the case for numerous species in Victoria and New South Wales) or are considered by relevant experts to be taxonomically suspect were excluded, as were hybrids and varieties. Subspecies were included, as many are taxonomically and morphologically distinctive and highly restricted. This process aimed to identify the Australian plants at most risk of extinction, so taxa assessed as the lower conservation status of Vulnerable were not included, unless expert opinion identified that they warranted a higher listing (see below).

For most of the 1055 listed taxa that met these criteria, the available information was insufficient to make reliable assessments, particularly in relation to current population trends and threats. Semi-structured interviews with 125 botanists, ecologists, land managers and threatened species officers with expertise in particular geographic regions, vegetation communities or taxonomic groups were conducted between February 2016 and November 2017 to gather the most up-to-date information for each species. The interview process also uncovered 81 taxa that meet Critically Endangered or Endangered criteria (IUCN Standards and Petitions Subcommittee 2017) but are not currently listed.

The final candidate list comprised 1135 taxa (including 85 subspecies, 50 from Western Australia), for which the following information was collated: family, conservation status (EPBC and State or Territory), bioregion occurrence (Thackway and Cresswell 1995), broad habitat preference, estimated number of populations (defined as geographically isolated occurrences with infrequent dispersal between them (Keith 2000), total population estimate (where available; often accurate estimates were not available, so IUCN cut-offs were used, i.e. <50, <250, <1000, <2,500, <10,000 or >10,000; IUCN Standards and Petitions Subcommittee 2017), threats (divided into past, documented/current and potential/ suspected), evidence of decline (past and continuing), whether the taxa had been thoroughly searched for in suitable habitat (i.e. the likelihood that its current known distribution and abundance reflects its actual distribution and abundance), and references and/or experts consulted (Table 1).

Expert opinion was particularly critical in assessing population trends, as time-series data (see Brummitt *et al.* 2015) that spanned sufficient time to detect trends and were comparable between years were available for fewer than 20 taxa. Even where monitoring data were available (accessed for 252 taxa), it proved difficult to interpret. Expert opinion often differed from apparent trends in the data, typically due to inconsistencies in monitoring techniques or comprehensiveness between years, discovery of new plants, or age structure data and observations not available from simple population counts. Expert observations and perceptions when not supported by quantitative data, are also subject to inaccuracies and biases. We attempted to minimise subjectivity by using targeted and consistently-phrased questions where experts were asked to justify or qualify their assessments of population trends and threats.

Given the paucity of time-series data, continuing declines were rarely quantified or documented, so could also be suspected or projected (based on decline in quality of habitat or observed lack of recruitment). Taxa with evidence of continuing decline were then scored according to whether all populations were declining, abundance of the taxon and extinction risk (Table 1). These categories are based on IUCN parameters, but formulated to best utilise the information that was available and able to be collected for all taxa, and the judgements of experts about continuing decline and concerns for their persistence. We have used existing IUCN parameters concerning number of mature individuals for assigning our extinction risk categories. Categories 4 and 5 are the 'imperilled' species with moderate and high extinction risk, respectively. Recovery options were also recorded for all declining species. Even after expert interviews, many taxa remained poorly-known. These were placed in a list of poorly known species and actions required to elucidate their status identified.

The habitats and regions of critical importance for botanical conservation in Australia were categorised according to concentrations of declining plant species (categories 3, 4 and 5; Table 1). The threats to species are less amenable to categorisation because many operate in interaction. These threatening processes and interactions are presented.

Results

Overview of trends and extinction risk

Of the 1135 candidate taxa assessed, 418 (37%) have continuing declines, which are documented for 128 taxa (11%) based on repeat field observations occasionally supported by quantitative data, and suspected or projected due to declining habitat quality and/or known threats for a further 297 (26%). There was insufficient information to infer population trends for a further 265 (23%). The remaining 40% of candidate taxa are mostly narrow-range endemics that meet IUCN criteria for listing as Critically Endangered or Endangered due to small population size, extent of occurrence and/or area of occupancy, combined with fragmented or restricted number of populations and fluctuations in population parameters (IUCN Standards and Petitions Subcommittee 2017) but are not considered by experts to be declining. Although some of these low abundance taxa are at risk of extinction due to stochastic and genetic effects (Frankham et al. 2014), some do not meet criteria for listing, often due to the findings of targeted surveys in the period since they were listed. More than half the declining taxa are known from ≤5 populations, including 69 that are restricted to a single population, while 20% of declining taxa have total known population sizes of <100 individuals.

Of the 418 declining taxa, 97 are ranked as risk category 1 (Table 1), with no imminent extinction risk under current management regimes and usually at least some large, healthy populations. Recovery actions have been implemented and declines arrested for a further 26 taxa (risk category 2), although their long-term survival is still considered tenuous and management-dependent due to low numbers and ongoing threats. One-quarter of declining taxa (107) are ranked as risk category 3, with continuing declines documented, suspected or projected across all populations. If current trajectories and management regimes continue, extinction may occur in the future, but the taxon remains relatively abundant (>5000 plants). The remaining 187 taxa have documented continuing declines across all populations, and are considered to be imperilled. Fifty-five of these are ranked as category 5 with high risk of extinction over the next decade due to the taxon being extremely rare (typically <250 individuals and/or a single populations) (see Supplementary Material). Only 12 high-risk taxa are currently listed as Critically Endangered nationally, and 13 are not listed. Six regions and four habitats have the highest concentrations of imperilled plant species, while six threatening processes are responsible for the majority of continuing declines (Table 2).

Regions of high extinction risk

Species predicted to be at most risk of extinction are concentrated where centres of endemism (Crisp *et al.* 2001) correspond with highly-modified agricultural and urban landscapes (Figure 1b). Three heavily-cleared bioregions in the high-endemism south-west Australian floristic region (Hopper and Gioia 2004) – the Avon Wheatbelt, Swan Coastal Plain and Jarrah Forest – together have 52 imperilled taxa, including 15 at high risk of extinction (Table 2; Appendix 1). Many narrow-range endemics and habitat specialists are now confined to small roadside remnants, town commons or nature reserves, which are susceptible to ongoing habitat degradation and human disturbance, agricultural edge effects, weed invasion, high densities of herbivores, *Phytophtora* dieback and, in the greater Perth area, ongoing habitat loss and impacts from urban expansion (Coates and Atkins 2001). South-eastern South Australia and adjacent areas of Victoria, encompassing the Eyre York Block, Kanmantoo, Flinders Lofty Block and Naracoorte Coastal Plain bioregions, have also been heavily cleared for agriculture, and many plants are now restricted to roadsides and rail reserves. The peat swamps of the Fleurieu Peninsula are particularly heavily modified through clearing, weeds and altered hydrology (Bickford *et al.* 2008), and four high risk species inhabit these swamps.

Shrubs and orchids comprise the majority of at risk species in southern Australian remnants. Recent taxonomic work on ground orchids has described many new and highly restricted species, many of which now occur in small fragmented populations sometimes numbering only a few plants (Swarts and Dixon 2009). Most remnant shrub populations are dominated by mature individuals with limited recruitment due to lack of fire or other disturbance to stimulate regeneration, representing an extinction debt that will play out in the absence of active disturbance management as older plants senesce (Kuussaari *et al.* 2009). The Stirling Range contains a major concentration of imperilled shrubs, but the major cause of declines here is *Phytophthora cinnamomi* dieback, as discussed below, rather than habitat loss and modification.

Other regions with high concentrations of imperilled taxa are South Eastern Queensland (20 imperilled species/6 high risk) and the Sydney Basin (19/3). Both have suffered major historic habitat loss that continues due to urban development, while weeds, human disturbance and changed disturbance regimes affect surviving remnants (Auld and Tozer 2004; Bradshaw 2012; Lynch and Drury 2006). Australia's offshore islands have relatively high numbers of imperilled species for their size, concentrated on Norfolk, Lord Howe and sub-Antarctic Islands including Macquarie. These islands have endemic and restricted species whose populations have been decimated by historical land clearing and/or introduced herbivores, although in some cases are beginning to recover with concerted conservation efforts over the past two decades (Auld *et al.* 2010; Sykes and Atkinson 1988; Whinam *et al.* 2014).

There are large numbers of candidate but relatively few declining taxa in high-endemism but less modified bioregions, such as the Wet Tropics and New England Tablelands (Figure 1). Queensland's Brigalow Belt is highly modified but has relatively few endemic species and thus fewer threatened with extinction (Fensham *et al.* 2018). There are very few listed or declining species across arid and semi-arid Australia: excluding the drier parts of south-western WA and south-eastern SA, only 35 candidate and 10 declining threatened taxa occur in the 70% of Australia that receives <500 mm rainfall per annum (Figure 1a). The drier parts of Australia have been far less heavily modified than more arable and populous regions, and adaptations of the flora to drought has conferred some resilience to introduced herbivores (Silcock *et al.* 2014). There are, however, numerous dryland shrubs and trees with limited or no recruitment and some of the more restricted species are at risk of extinction as older plants senesce (Auld *et al.* 2015; Denham and Auld 2004). Fifty-eight of Australia's 89 bioregions have three or fewer declining threatened taxa (Figure 1b), while 48 have no imperilled (category 4 and 5) species (Figure 1c). Conversely, only seven bioregions have >10 imperilled taxa, and high risk species (category 5) come from 21 bioregions.

Habitats with concentrations of declining and high-risk taxa

Four habitat types spanning multiple regions harbour high numbers of imperilled taxa. Mountain ranges, particularly rock outcrops, are recognised worldwide as centres of endemism for plant species (e.g. Baskin and Baskin 1988; Keppel *et al.* 2017; Porembski and

Barthlott 2000). Mountainous habitats tend to be relatively intact and less heavily impacted by land clearing and fragmentation, meaning that many species are not declining despite being highly restricted. Of the 153 candidate taxa assessed from Australia's mountain ranges and outcrops, only 31 (20.3%) have continuing declines. Of these, however, 10 were assessed as having high risk of extinction, accounting for 18.2% of all high-risk taxa. The restricted distributions of most species, sometimes confined to one or two peaks, renders them extremely vulnerable to local impacts (Burgman *et al.* 2007). Feral herbivores, mostly goats but also deer, horses and rabbits in some areas, are the most common threat. Other threats are species- and site-specific, including infrastructure maintenance, native herbivores, insect borers, mites, pathogens including *Phytopthora* species, and proposed mining or urban expansion. Declines of rare mountain-top species tend to be better documented than for other habitats, but causes of decline are not always well-understood. Most taxa are characterised by low recruitment and poor understanding of their seed bank ecology. The impacts of future climate change are typically poorly understood, but often predicted to be severe and may exacerbate other threats (Auld and Leishman 2015; Petitpierre *et al.* 2016).

Wetlands bear the brunt of changes in agricultural and urban landscapes, and have been extensively cleared, sown to pasture species, had their hydrology altered and been subject to concentrated grazing pressure and weed invasion (Burgin *et al.* 2016; Casanova and Powling 2014; Fairfax and Fensham 2002; Kingsford 2000). Where modified wetlands support endemic or restricted species, these are at risk of extinction (Table 2). Wetlands are also vulnerable to further hydrological changes and drying under future climate change scenarios, but impacts on threatened flora remain mostly undocumented.

The temperate and sub-tropical fertile grasslands and grassy woodlands of eastern and southern Australia have been extensively cleared for agriculture since European settlement (Fensham 1998; Kirkpatrick *et al.* 1995). Small, fragmented remnants now comprise Critically Endangered and Endangered ecological communities Victoria, Tasmania, New South Wales and Queensland. These remnants are mostly on roadsides, rail lines and in tiny reserves, and are subject to grazing, weed invasion, human disturbance and ongoing habitat loss. Lack of fire to create recruitment spaces between introduced and native perennial grasses is causing declines in populations of many threatened inter-tussock forbs and orchids, particularly in temperate grasslands (Morgan 1997; Williams *et al.* 2006). Most threatened grassland taxa, including all bar one ranked as imperilled, are from Victoria and Tasmania (Table 2; Appendix 1).

Lowland sub-tropical rainforests of Queensland and New South Wales have been heavily cleared for agriculture and urban settlement (Webb 1982). There is huge pressure on fragmented remnants from ongoing habitat loss for urban expansion, weeds, hydrological changes, recreation and myrtle rust (see below). These cumulative impacts are leading to incremental declines of populations of threatened species. In particular, many species that occurred sparsely throughout large areas of lowland rainforest are now restricted to precariously small populations in weedy paddocks or remnants with little recruitment (David Jinks, pers.comm., April 2017). Species that occur on rainforest margins are especially vulnerable as they need disturbance and light to germinate, but vigorous introduced weeds and native vines are taking over this niche.

Threats

The vast majority of Australia's imperilled plants have suffered historical declines due to habitat destruction and now survive as small, fragmented populations in small remnants that are inherently vulnerable to further loss and degradation (Burgman *et al.* 2007). At least 111 declining taxa mostly occur on narrow roadside remnants, and a further 200 in remnants of vastly reduced size that are typically subject to numerous threatening processes. Over 65% of imperilled taxa, including 36 high-risk taxa, occur only in small remnants. It seems likely that some populations of long-lived species are continuing to persist but have fallen below a minimum viable population size (Bulman *et al.* 2007; Traill *et al.* 2010) and/or are restricted to tiny remnants that are inherently vulnerable to degradation and within which ecological processes, particularly those driving recruitment, no longer operate. The period over which Australia's flora extinction debt will be realised may take many decades, depending on the life histories of the plants involved and the size and condition of remnant patches (Guardiola *et al.* 2013; Hylander and Ehrlen 2013; Koyanagi *et al.* 2017). Identifying the species most at risk of extinction is the first step towards understanding and attempting to mitigate this risk.

When species are restricted to small remnants, myriad threats operate in concert. Over 120 taxa, including 70 of the 187 imperilled taxa, have limited or no recruitment, often due to lack of appropriate disturbance (usually fire) to stimulate recruitment and reduce competition, and/or high total grazing pressure. Lack of fire is also implicated in declines for threatened species in less modified ecosystems, where rainforest and shrubland is encroaching on formerly open habitats, notably coastal lowlands and wet sclerophyll forests in north Queensland and heathlands in northern New South Wales. Too-frequent fire, often interacting with invasion of weedy grasses, is a suspected threat for many species, but there is little quantitative data to show this threat driving species to extinction. Grazing, browsing and/or trampling by herbivores is a documented threat to 95 declining taxa, including feral herbivores (rabbits, hares, pigs, goats and deer) for 46 taxa, native herbivores (mostly macropods) for 22, and domestic livestock for 15. Threats from herbivores interact with other threatening processes, and grazing is the primary cause of declines for only six imperilled taxa.

While the legacy of past land use is severe, other threats intensify and emerge frequently. Urban expansion around capital cities continues apace, and is a major threat to 39 imperilled taxa including 8 with high extinction risk (Table 2). These taxa are concentrated in the greater Perth, Melbourne, Sydney and Brisbane areas and south of Darwin, where centres of high endemism and diversity coincide with urban development and proposed expansion. Threats are myriad and unrelenting, including ongoing habitat loss as well as degradation through direct human impacts (e.g. recreation, pollution, infrastructure maintenance and arson) and edge effects such as weed incursion and nutrient run-off. It is very difficult to implement burning due to their proximity to urban centres.

Two plant diseases are at the forefront of conservation concerns in Australia. The threat from *Phytophthora cinnamomi*, a soil-borne water mould pathogen that destroys the roots of affected plants, is well-documented (Cahill *et al.* 2008; Shearer *et al.* 2007), particularly in the Eastern Stirling Range Montane Heath Community where numerous endemic taxa are threatened with extinction (Barrett and Yates 2015). Phytophthora has also been documented in forests of Victoria (Reiter *et al.* 2004; Weste 2003), New South Wales

(McDougall *et al.* 2003) and Tasmania, and is responsible for continuing declines in 10 imperilled species, often in conjunction with other threats. More than 80 other Endangered species are known or suspected to be susceptible, but *Phytopthora* has not yet been recorded in their populations.

The myrtle rust fungus (*Puccinia psidii*) was first detected in New South Wales in 2010 and is now affecting rainforest flora along much of the east coast (Carnegie *et al.* 2016; Pegg *et al.* 2014). More than 70 Myrtaceous species are known to be susceptible, although impacts vary from leaf spots to reduced fecundity to death of entire plants. Restricted and already threatened species are being impacted, including high-risk *Gossia gonoclada*, while more widespread and abundant species are severely impacted across their range to the point where they may be threatened with extinction.

Climate change is considered a potential threat to 67, or 13% of, declining taxa, mostly due to decreasing winter rainfall trends in southern Australia, increased temperatures and drying in alpine areas. However, there are few documented ongoing declines, and no taxa are currently considered at high extinction risk due solely to climate change.

Recovery options

Of the 418 declining taxa, 73 (17%) have relatively low recovery potential and few management options. Some are naturally rare and restricted with gradual declines that are considered at least partly 'natural' with few apparent anthropogenic causes. Others have become restricted to a tiny number of plants at one or two degraded sites, while some have already had so much recovery effort directed towards them that further options are limited.

The remainder of the species have medium to high recovery potential and targeted recovery actions were identified by experts. The most common recovery actions to stem declines were habitat protection, management and restoration, encompassing weed control (194 taxa), planned burns or other active disturbance to stimulate recruitment into populations (190 taxa), and protection from grazing and trampling (90 taxa). Land acquisition was only deemed an important management priority for five taxa, reflecting the fact that most already occur in reserves or on public land such as road reserves. Disease management, particularly phosphite spraying and preventing the spread of *Phytophthora* is needed for 33 species. Translocation has been attempted for 108 species, and is planned, proposed or recommended for a further 64. While monitoring is recommended for all species, further field surveys are a high priority for 88 and targeted research for 90 (mostly involving better understanding of germination cues, seedbank ecology, disturbance responses and, for a small number, taxonomic work).

192 taxa were identified as poorly known and potentially imperilled, and actions to elucidate their status are outlined. South Eastern Queensland has the most such taxa (29), followed by the Wet Tropics (18), Avon Wheatbelt (16), and the Brigalow Belt South, New England Tablelands and Sydney Basin (all with 13 species).

Discussion

We have collated the most up-to-date information on Australia's most imperilled plant species, identified omissions from current threatened species lists, and highlighted taxa that need urgent conservation intervention. This exercise, whilst daunting in the face of the number of listed species, was streamlined by sourcing expert knowledge about population trends and documented threats. Only 37% of plants listed as CR or EN have continuing declines, even using a precautionary approach that includes suspected and projected declines, although population trends for a further 23% are unknown. Of the declining taxa, 55 are known from <250 plants and/or a single population and are considered at high extinction risk.

While we have not attempted to critique existing threatened species lists here, it is clear that some species that would meet the criteria for Critically Endangered are not listed as such, while others were regarded by experts as not being at high risk of extinction and should probably be downgraded. For example, just 12 of the 55 taxa identified as at high risk of extinction are currently listed as Critically Endangered nationally, and the remainder need to be nominated as a matter of urgency. Conversely, 56 taxa that were assessed as having no documented declines, or even to be stable or increasing, are currently listed as Critically Endangered nationally. This points to a clear need for re-evaluation and standardisation of current lists, and consistent application of IUCN listing guidelines. There is also a need to collect systematic, repeatable field data for the vast majority of species, to back up suspected and projected declines and provide a stronger basis for investment in recovery actions (Rayner *et al.* 2014).

There is no 'magic bullet' for the conservation of Australia's imperilled flora. Most declining species require ongoing site-based management, including fencing, weeding, fire management, disease control and monitoring. Our results highlight the importance of small remnants for conservation (Tulloch *et al.* 2016), despite the exaggerated problems of managing these areas. Far more imperilled species occur on narrow roadsides than in National Parks or other large remnants, and these require greater protection from ongoing clearing and disturbance, as well as ongoing habitat restoration. Many populations are persisting but have limited regeneration. Better understanding of reproductive biology, especially in relation to fire regimes, seedbanks and the role of disturbance, is required to inform management of many imperilled species.

The size of the poorly known list, encompassing more than 15% of all candidate species, highlights the need for further targeted surveys and monitoring. Field surveys and monitoring are critical to inform population parameters and trends. Critically, data must be collected systematically and in a manner that is repeatable over time, with detailed notes on methodology, definition of an individual, accurate GPS and GIS mapping of populations and sampled areas, and robust management and storage of data (Keith 2000). Measurements for at least three points in time are necessary to assess trends (Lughadha *et al.* 2005), and are not available for the vast majority of Australia's threatened plants. Australia is not unique in this regard, with a lack of basic biological data being responsible for most failures of targeted recovery attempts globally (Heywood and Iriondo 2003). Our list of poorly known Endangered and Critically Endangered species is likely to under-estimate the true number of potentially imperilled species. For example, there are 750 Queensland plants known from <10 collections (Keith McDonald, unpublished data) and 1947 species considered Priority Flora in Western Australia (Department of Biodiversity, Conservation and Attractions 2017); there is scant knowledge of threats, biology and status for nearly all these species.

Sixty-three listed taxa were not assessed due to experts flagging considerable taxonomic uncertainty, including 33 with <10 populations. Resolution of these taxa is a priority. 30% of the 2614 species considered Data Deficient or poorly known at State and/or National levels are yet to be formally described (Beth Crase, unpublished data), while an average of 230 new species have been described each year in the past decade (Australian Virtual Herbarium 2017; Chapman 2009). Many of these are geographically restricted, known from few records and potentially imperilled.

In stark contrast to mammals and birds, and despite major habitat loss and degradation, Australia's record of plant extinction and endangerment is not catastrophic. A much smaller proportion of plant taxa have become extinct (0.18% of vascular plants, as compared to 2.66% of birds and 7.14% of mammals), imperilled species are concentrated in a relatively small number of regions and habitats, and with long-term investment and research there are good prospects of recovery for the majority taxa. Evidence of continuing decline through substantiated threats paves the way for concerted, targeted and efficient recovery efforts, and provides a snapshot of plant conservation across a vast continent.

Conclusion

Identifying the plant species that are both rare and have continuing population declines has allowed for continental botanical conservation assessment. This assessment shifts the focus away from rarity *per se* towards evidence of continuing decline and high extinction risk. The collation of these species provides an objective analysis of the regions, habitats and threatening processes where the flora of Australia is imperilled, and could be applied in other locations where there is sufficient expert knowledge.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Table 1. Key information compiled for assessing extinction risk in the Australian flora.

Fields A-C were compiled for all 1135 candidate taxa; fields D-F were compiled only for the 418 taxa assessed as having continuing declines. Taxa with unknown population trends were placed in a separate list and actions required to elucidate their status identified.

Field	Explanation
A. Past decline	Either **documented** (typically by Herbarium specimens or other reliable records from now-extinct populations); **inferred** (based on loss of habitat); or **not documented**.
B. Continuing decline	Either **increasing** or **stable** (based on time-series monitoring data and/or repeated site recordings); **not documented** (no robust time-series monitoring data, but expert opinion that species is not declining); **documented** (based on time-series monitoring data and/or repeated detailed site recordings); **suspected** (not clear from monitoring data, or no monitoring data exists, but suspected from repeat observations; often taxa that experience major fluctuations and/or are disturbance-dependent); **projected** (based on declining quality of habitat, lack of recruitment and/or identified threats); or **unknown**. The dates of available time-series monitoring were also recorded.
C. Threats (=causes of past, current or future decline, e.g. habitat loss, weeds, lack of fire)	Divided into **past** (no longer affecting taxa); **documented and current** (known to be causing decline of, or direct and immediate threat to, at least some populations); and **potential or suspected** (identified as potentially having a detrimental impact on populations, but with no data to indicate its current impact, or threats postulated to affect populations in the future).
D. Continuing decline/ extinction risk	**1** = documented, suspected or projected decline in some populations, but typically with some large healthy populations and no concern for taxon's persistence under current management regimes; **2** = declines halted (in some cases reversed) and extinction risk lowered with recovery efforts, but taxon's long-term survival remains tenuous and management-dependent due to low numbers (<2500 individuals and/or single population) and ongoing threats; **3** = continuing declines in all populations documented, suspected or projected; if current trajectories continue, extinction is possible in the long-term (>100 years), but remains relatively abundant (>5000 plants); **4** = continuing declines documented, suspected or projected across all populations AND low numbers (typically <2500 plants), extinction possible in medium-term (10-100 years); **5** = continuing declines documented AND species extremely rare (known from <250 individuals and/or a single population); high extinction risk within the next 10 years.
E. Recovery options	Management actions required to address extinction risk.

Table 2. Regions, habitats and threatening processes that account for high numbers of at risk and imperilled plants, sorted by number of imperilled taxa.

Imperilled taxa are categories 4 and 5; high-risk category 5 (see Table 1). Groups are not mutually exclusive.

Group	Candidate taxa (declining)	No. imperilled (high risk)	% candidate taxa imperilled (high risk)
Regions			
R1. South-west WA remnants	189 (103)	52 (15)	27.5 (7.9)
R2. South-East Australia remnants (SA, VIC)	93 (49)	19 (9)	20.4 (10.7)
R3. South Eastern Queensland bioregion	116 (55)	20 (6)	17.2 (5.2)
R4. Sydney Basin	103 (42)	19 (3)	18.4 (2.9)
R5. Stirling Range, WA	58 (32)	18 (1)	31.0 (1.7)
R6. Islands	42 (11)	3 (1)	7.1 (2.4)
Habitats			
H1. Mountain-top endemics	153 (31)	18 (10)	11.8 (6.5)
H2. Wetlands in modified environments	53 (27)	11 (5)	20.6 (9.4)
H3. Fertile grasslands and open grassy woodlands	99 (46)	19 (4)	24.2 (4.0)
H4. Subtropical rainforest	54 (28)	11 (3)	20.4 (5.6)
Threats			
T1. Inappropriate fire/disturbance regimes (documented impact) [A]	170 (98)	44 (10)	25.9 (5.9)
T2. Herbivore grazing and trampling [A]	205 (95)	43 (13)	21.0 (6.3)
T3. Urbanisation	106 (75)	39 (8)	36.8 (7.5)
T4. Phytophthora	41 (31)	22 (7)	53.6 (17.1)
T5. Climate change [B]	100 (53 [B])	21 (13)	21.0 (13.0)
T6. Myrtle rust, QLD/NSW	9 (9)	4 (1)	44.4 (11.1)

[A] Many species are declining from a complex suite of threats and causes, with grazing/trampling (including domestic livestock, feral herbivores and/or native herbivores) or inappropriate disturbance regimes only one factor in their demise, or any affecting some sites.

[B] Potential threat for many species, but few species at risk solely due to climate change

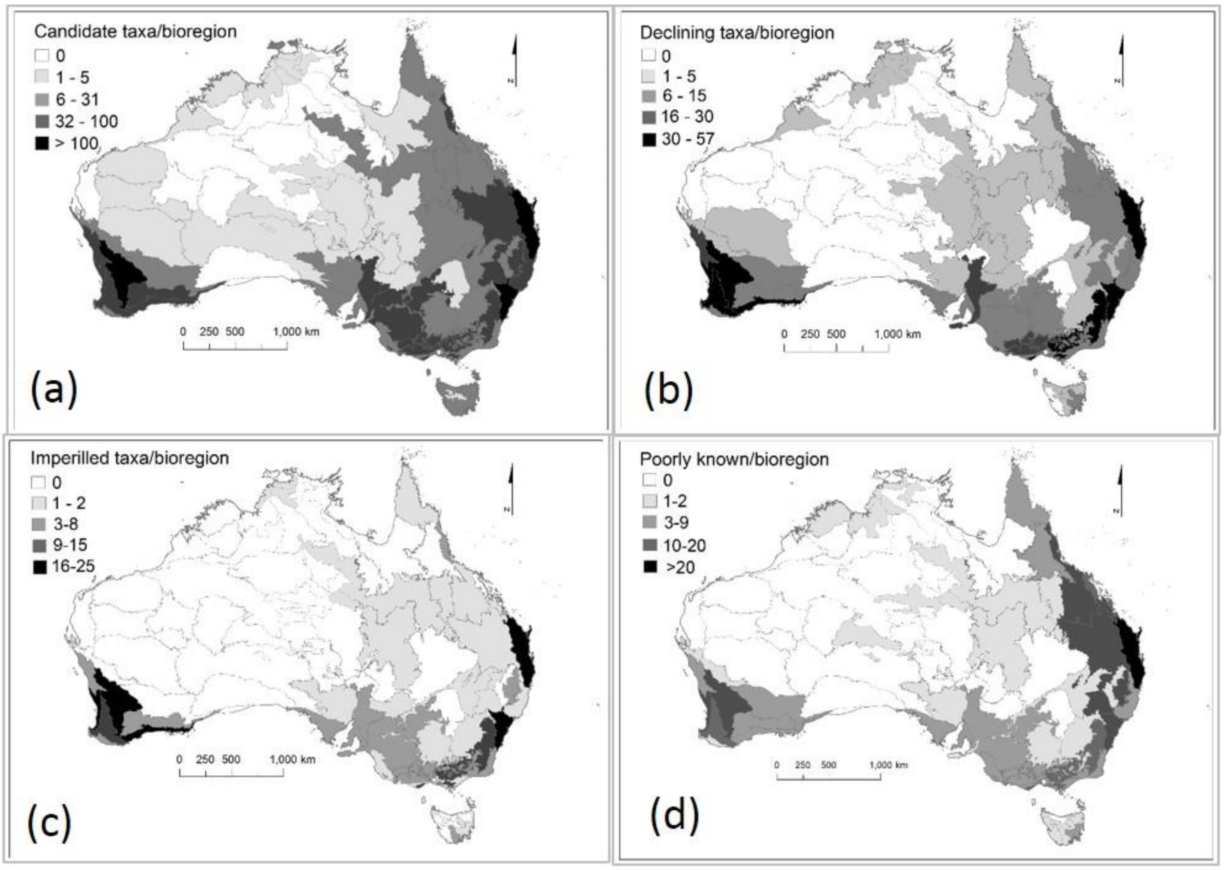

Figure 1. Numbers of (a) candidate, (b) declining, (c) imperilled (extinction risk categories 4 and 5, see Table 1), and (d) poorly known taxa per bioregion. Two island bioregions (Subtropical Islands, encompassing Lord Howe and Norfolk, and Subantarctic Islands including Macquarie) have numerous candidate taxa, including 3 and 1 imperilled respectively, but are not visible on the map due to their small size.