Title

The threats to Australia's imperilled species and implications for a national conservation response

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Abstract

Since European occupation of Australia, human activities have caused the dramatic decline and sometimes global extinction of many of the continent's unique species. Here we provide a comprehensive review of threats to species listed as threatened under Australia's *Environment Protection and Biodiversity Conservation Act* 1999. Following accepted global categories of threat, we find that invasive species affect the largest number of listed threatened species (1,257 species, or 82% of all threatened species); system modifications (e.g. fire) (74% of listed species) and agricultural activity (57%) are also important. The ranking of threats was largely consistent across taxonomic groups and the degree of species' endangerment. These results were significantly different ($P < 0.01$) from recent analysis of threats to threatened species globally, which highlighted overexploitation, agriculture and urban development as the major drivers of decline. Australia is distinct not only in the biodiversity it contains but also in the extent and mixture of processes that threaten the survival of these species. Notably, the IUCN threat classification scheme separates the numerous threats (e.g. urban development, agriculture, mining) that cause habitat loss, fragmentation and degradation, hence further research is required to quantify the net impact of these threats. We provide feasible suggestions for a more coordinated national approach to threatened species conservation, which could empower decision makers and managers at all levels with improved resources and information on threats and management. Adequate policy, legislative support and funding are critical for ensuring on-ground management is successful in halting the decline of Australia's threatened species.

Introduction

Australia accounts for five percent of the world's landmass, 12.5% of chordate species, and almost 8% of all described plant, animal and fungi species (Chapman 2009). The majority of these species occur nowhere else on earth, with >85% of Australia's plants, mammals, reptiles and amphibians being endemic (Chapman 2009). Australia is one of 17 'megadiverse' nations (Mittermeier et al. 1997), and one of only two of these nations that is wealthy in economic terms (the other being the United States; World Bank 2017). Human population density is comparatively low and geographically biased to the country's southeast coastal areas (ABS 2016). Additionally, while deforestation and intensive land-uses have

impacted much of south-western and eastern Australia (Bradshaw 2012, ABARES 2016), vast areas of the continent have experienced low human impact and are considered largely intact (Watson et al. 2016). These factors indicate that Australia has the potential to conserve all its remaining species.

However, this would contrast with Australia's extremely poor record for species' extinctions globally (IUCN 2015a, IUCN 2015b). Since European occupation, 90 extinctions of Australian taxa have been recognised under the EPBC Act (36 plants, 27 mammals, 22 birds, four frogs and one invertebrate; Commonwealth of Australia 2015a). The actual number of extinctions is likely higher, as a number of known extinctions are yet to be listed under national legislation (e.g. *Tornelasmias capricorni* (Ponder 1996); *Fluvidona dulvertonensis* (Mollusc Specialist Group 1996)), and there is likely to have been many extinctions that have gone unrecorded (Tedesco et al. 2014). While many of Australia's best known extinctions (e.g. thylacine (*Thylacinus cynocephalus*), pig-footed bandicoot (*Chaeropus ecaudatus*), paradise parrot (*Psephotellus pulcherrimus*)) occurred decades ago, the extinction rate remains unabated for some taxonomic groups (Woinarski et al. 2015). At least three extinctions have occurred since 2009 (Christmas Island pipistrelle (*Pipistrellus murrayi*), Christmas Island forest skink (*Emoia nativitatis*) and Bramble Cay melomys (*Melomys rubicola*)), and many Critically Endangered species are declining (Garnett et al. 2011; Woinarski et al. 2014), showing that Australia's biodiversity crisis is ongoing (Woinarski et al. 2017a). Without significant improvements in our efforts, it is estimated that a further 17 threatened birds and mammals are likely to be lost from Australia over the next 20 years (Geyle et al. 2018). As a signatory of the Convention on Biological Diversity, Australia has international obligations to prevent these and any other further extinctions. Specifically, Aichi Target 12 of the United Nation's Strategic Plan for Biodiversity 2011-2020 calls for the prevention of the extinction of known threatened species (CBD 2010). If Australia is to meet these targets, ongoing loss of species must be halted.

A recent review of the threats to imperilled species globally highlighted that overexploitation (e.g. hunting, logging), agriculture and urban development are currently the leading drivers of species decline (Maxwell et al. 2016). Given Australia's unusual biophysical circumstances of geographic isolation combined with a long history of fire (Crisp et al. 2011), it is likely that the dominant threat drivers interact with Australian biodiversity in unique ways. Following the release of Australia's first Threatened Species Strategy in 2015

(Commonwealth of Australia 2015b), it is timely to provide a comprehensive review of the threats that imperil threatened species across Australia, as this information is critical to successful, long-term conservation action.

This review complements previous assessments of threat incidence among particular taxonomic groups (Burgman et al. 2007; Garnett et al. 2011; Woinarski et al. 2015; Allek et al. 2018). We focus on the 1,533 freshwater and terrestrial invertebrate, vertebrate and plant species and subspecies (hereafter, taxa) listed as threatened (Vulnerable, Endangered and Critically Endangered) under Australia's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The threats to the listed taxa are formally documented in the Australian Government's Species Profiles and Threats Database (SPRAT Database; Commonwealth of Australia 2015a), although in many cases this documentation is conjectural or based on limited evidence, and often does not discriminate between primary causal factors and factors that may have contributed in a minor way to decline. This is not necessarily a failing of the database, but reflects the lack of knowledge of the threats affecting some Australian taxa. For many taxa, such as the birds, the SPRAT database draws on the same data used for the IUCN assessments, so that the two sets of threat data should be broadly comparable. Threats are categorised using the IUCN Red List classification, which describe the proximate threats to species (Salafsky et al. 2008; IUCN 2017). Table 1 provides a description of the threat categories used.

A primary objective of our analyses is to compare the relative frequency with which threatening processes are listed under Australia's threatened species legislation. In doing so, we provide a national level understanding of which drivers are thought to be affecting Australia's threatened taxa. We then consider current efforts to address the threats to Australian biodiversity, including the national Threatened Species Strategy. We conclude by providing recommendations for enhancing the planning and governance environment of threat management to improve the conservation of Australian biodiversity. The methods for data compilation and analysis are detailed in the Supplementary Material.

Prevalence of threats to Australian threatened taxa

Invasive species, ecosystem modifications and agriculture are the threats listed as affecting the largest numbers of Australian threatened taxa (Fig. 1). This pattern is consistent across each broad taxonomic group (plants, invertebrates and vertebrates; Fig. 2), category of endangerment (Vulnerable, Endangered and Critically Endangered; Fig. 2), and across all vertebrate classes other than fish (for which invasive species, ecosystem modifications and pollution are the most common threats; Fig. 2). We found no statistically significant difference among groups in the relative rankings of threats (broad taxonomic groups ($H=0.028$, $p=0.98$), vertebrate groups ($H=2.59$, $p=0.63$) and category of endangerment ($H=0.24$, $p=0.88$).

Invasive species is the most common threat, listed as affecting 82% (n = 1257) threatened taxa in Australia (Fig. 2). In total, 267 invasive species (207 plants, 57 animals, 3 pathogens) are listed as affecting Australian threatened taxa. The European rabbit (*Oryctolagus cuniculus*), threatens 21% (n=322) of EPBC Act listed taxa (Fig. 3). The impacts of rabbits on Australian taxa are numerous and include: grazing plants, particularly seedlings and saplings (Denham and Auld 2004); competition for food resources (Bird et al. 2012); land degradation (Eldridge et al. 2006); and facilitating hyper-predation (Smith and Quin 1996). One species that has experienced considerable impacts from rabbits is the purple wood wattle (*Acacia carneorum*; Vulnerable), which occurs in the southeast of central Australia (DEWHA 2008). Rabbit grazing is particularly pronounced on the young of this species, which has caused a serious lack of recruitment, impacting the species regeneration (Auld 1993).

Four other invasive species (feral goat (*Capra hircus*), feral cat (*Felis catus)*, feral pig (*Sus scrofa*) and root rot fungus (*Phytophthora cinnamomi*)) are listed as threatening over 100 threatened taxa each (Fig. 3). The purple copper butterfly (*Paralucia spinifera*; Vulnerable), for example, is threatened by feral pigs, feral goats and a number of invasive plant species (e.g. blackberry (*Rubus fruticosus*) and scotch broom (*Cytisus scoparius*)), all of which contribute to the degradation of the species habitat (TSSC 2016a). 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 in Western Australia, 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 (Podger et al. 1990).

Feral cats and the European red fox (*Vulpes vulpes*) are two invasive species that have had and continue to have a devastating impact on Australian species, particularly critical weight range mammals (Woinarski et al. 2015). The feral cat and the European red fox threaten 123 and 95 EPBC Act listed species, respectively. One of these species is the greater stick-nest rat (*Leporilus conditor*; Vulnerable). Feral cats and foxes have had a catastrophic impact on the greater stick-nest rat over much of its range and the species is now only persists in fenced reserves and cat and fox free islands (Woinarski et al. 2014). The other species in the genus *Leporilus*, the lesser stick-nest rat (*Leporilus apicalis*; Extinct) is believed to have gone extinct due to predation pressure from feral cats and foxes across the entirety of range (Woinarski et al. 2014).

Problematic native species are listed as threats for one-fifth of threatened taxa. The most prevalent is grazing pressure from macropods, which is listed as a threat to 152 threatened plant and five threatened animal taxa. Increased macropod abundance in some regions (e.g. Barker and Caughley 1991; Silcock et al. 2012) is partly due to lethal control and exclusion of dingoes (*Canis dingo*; Letnic et al. 2012), the proliferation of reliable water points (Fensham and Fairfax 2008) and greater extent and reliability of palatable feed grasses (Newsome 1975).

Ecosystem modification, which includes the impacts of changed fire and hydrological regimes, is listed as a threat for almost three quarters of threatened taxa (74%, n = 1136). Fire has had a considerable influence on species and ecosystems across much of the continent and many species have evolved to cope with or rely on fire (Woinarski and Recher 1997; Bowman et al. 2012). Since European occupation, many areas have experienced dramatic changes in fire regime, ranging from too little fire, to regimes of fire too often or too intense (Russell-Smith 2001; Ward et al. 2001). Numerous plants require fire to germinate, or to open up inter-tussock spaces for recruitment, and are declining due to lack of regular fire (Stuwe and Parsons 1977; Morgan 1997; Williams et al. 2006). For example, the orange dryandra (*Banksia aurantia*; Critically Endangered), known only to occur within Wandoo National Park in Western Australia, is threatened by a lack of fire (DEWHA 2008b). The species requires a specific fire regime for it to regenerate successfully and one population of the species is likely to have already gone extinct due to lack of fire (TSSC 2013).

Across much of Australia, hydrological regimes have changed substantially since the 1800s, through water impoundment (Kingsford 2000), drawdown of aquifers (Powell et al. 2015),

drainage of swamps (Casanova and Powling 2014; Bickford et al. 2008) and salinity (National Land and Water Resources Audit 2001). There are over 500 large dams (volume >1 GL) and many thousands of smaller dams across Australia (ABS 2010), which together have had a significant impact on biodiversity, particularly on freshwater species and those that occur in agricultural landscapes (Kingsford et al. 2017). The silver perch (*Bidyanus bidyanus*; Critically Endangered), for example, is heavily impacted by water management and use, in addition to a multitude of other threats (e.g. invasive species, invasive pathogens; DoE 2013). The species is endemic to the Murray-Darling Basin, which has an estimated 4,000 barriers to fish movement (Lintermans 2007). These dams, weirs and other structures are severely impacting this highly migratory freshwater species (DoE 2013).

Agricultural activity (e.g. cropping, livestock grazing and wood plantations) is the third most commonly listed threat, affecting 57% of taxa (n = 873; Fig. 1). The Margaret River burrowing crayfish (*Engaewa pseudoreducta*, Critically Endangered), for example, is threatened by a number of activities associated with agriculture, such as land clearing and cattle grazing which have degraded and destroyed much of the species habitat (DEWHA 2009). Livestock grazing is the dominant land use in Australia, occupying 54% of the continent (ABARES 2016) and threatens 621 taxa.

Human disturbance, originating from recreational, military, and other outdoor activities is listed as a threat to 588 taxa. Human disturbance is one of the key threats to the eastern subspecies of the hooded plover (*Thinornis rubricollis rubricollis*, Vulnerable). Recreational activities such as beach driving and dog-walking both contribute to crushing or disturbance of eggs, chicks and nesting birds (Dowling and Weston 1999; Garnett et al. 2011).

The impacts of climate change and severe weather, particularly the alteration of species' habitat due to changes in temperature and rainfall, drought, temperature extremes, and storms and flooding, are listed as threatening 533 Australian taxa. The impacts of climate change are anticipated as major future threats (e.g. habitat shifting in response to changed precipitation and temperature regimes: Garnett et al. 2013; Reside et al. 2013), but numerous species are already being affected. Carnaby's black-cockatoo (*Calyptorhynchus latirostris*; Endangered) and the grey-heading flying-fox (*Pteropus poliocephalus*; Vulnerable), for example, suffer high rates of mortality in periods of extreme heat (Welbergen et al. 2008; Saunders et al. 2011). Additionally, it is likely that the number of taxa that will or are already being impacted by climate change is greater than reported here, as it is only included as a threat when there is

existing evidence of a direct impact (TSSC 2015). Additionally, the interaction between climate change and other threats is not likely to be captured in the SPRAT database, downplaying this threat to Australian species. It is expected that the impacts of climate change will be highly interactive, altering the severity and extent of other threats such as fire (Hughes 2003), water use (Nielsen and Brock 2009) and agriculture (Hannah et al. 2013).

Numerous forms of transport corridors and lineal infrastructure, such as roads, railroads, and utility and service corridors, threaten 465 taxa. Roads predominantly cause direct mortality from vehicle collisions and inhibit dispersal, which can severely affect population genetics (Taylor and Goldingay 2010). Plant species, such as the Scott River boronia (*Boronia exilis*; Endangered), are particularly susceptible to road construction and maintenance (Trombulak and Frissell 2000). This small flowering plant endemic to Western Australia is threatened by road maintenance activities, which include the construction of drainage channels, mowing, other related disturbances (TSSC 2016b).

Overexploitation – including the harvesting (e.g. hunting, fishing, collection, logging) of species from the wild – is affecting 420 taxa. The giant barred frog (*Mixophyes iterates*; Endangered) is one species threatened by overexploitation, specifically logging, as the species is particularly sensitive to its impacts (Lemckert 1999). However, it is important to note that chytrid fungus likely played a major role in the decline of the species in the past few decades (Mahony 1993), as with many Australian amphibians (DSEWPC 2013). The impacts of threats such as logging are now having an increased impact on species that are already under pressure (Lemckert and Brassil 2000).

Urban development, including housing, commercial, industrial, tourism and recreational development, is listed as a threat to 341 taxa. Caley's grevillea (*Grevillea caleyi*; Endangered) is one such species and has lost 85 percent of its habitat due to clearing for urban growth around Sydney, New South Wales (Auld and Scott 1997). Although one population of the species is protected within a national park, other populations are considered highly disturbed (Auld and Scott 1997) and are at risk from further fragmentation (DEC 2004).

Energy production, which includes the exploration, development and production of fossil fuels, renewable energy and minerals, threatens 289 Australian threatened taxa. Abbott's booby (*Papasula abbotti*; Endangered) and Christmas Island frigatebird (*Fregata andrewsi*;

Endangered) have both experienced a substantial reduction in habitat due to mining operations on Christmas Island (TSSC 2015b, TSSC 2016c). The clearance of forest for phosphate mining on Christmas Island has substantially reduced nesting habitat, causing population declines of both species (TSSC 2015b, TSSC 2016c).

Pollution, from urban wastewater, industrial and agricultural effluents and solid waste, is threatening 225 Australian taxa. The threat from pollution is particularly high for freshwater species (Dudgeon 2006). The habitat of the Blue Mountains water skink (*Eulamprus leuraensis*; Endangered), a lizard species endemic to New South Wales, is currently under threat from numerous forms of pollution (TSSC 2016d). Runoff from roads and industrial sites, inappropriate dumping of industrial and domestic waste, and pesticide, herbicide and fertiliser runoff from forestry and agriculture are all believed to be impacting the species (TSSC 2016d).

Comparison of threats between Australian and globally threatened species

In the recent threat assessments of IUCN Red List Threatened and Near Threatened terrestrial, freshwater and marine species (n = 8,688), Maxwell et al. (2016) showed that overexploitation (71.8%), agriculture (62.2%) and urban development (34.7%; Fig. 4) are the dominant threats to species globally. We used this same data to compare threats to global species with those threatening species in Australia (we removed Near Threatened species and species groups comprised of marine and mostly marine species to enable direct comparison with the threats to the EPBC Act listed taxa used in our analysis). Of the 5,296 IUCN Red Listed species examined, agriculture (74.0%), overexploitation (71.1%) and urban development (34.3%) are the most commonly listed threats to these species. Here, we found that invasive species, system modifications and agriculture are the most prevalent threats to threatened taxa in Australia. The relative proportional incidence of the threats to Australian species differs significantly from those affecting species globally ($\chi 2=97.86$, df=9, p=<0.0001; Fig. 4).

The predominant difference between the threats to Australian species and to species globally is that invasive species and system modifications are more prevalent in Australia and overexploitation more prevalent globally. Australia's long separation from other continents and its fauna and flora's subsequent evolution in isolation has likely had a considerable influence on these species' susceptibility to the impact of invasive species (Blumstein 2002;

Cox and Lima 2006). Additional to this is the interaction between invasive species and the boom-bust ecological cycles driven by climate that predominates much of the continent. Climate phenomena such as the El Niño Southern Oscillation have been found to have a considerable influence on interactions between introduced predators and native mammals, in many cases increasing predation pressure on species already under stress (Letnic et al. 2005; Letnic and Dickman 2006).

Ecosystem modifications, particularly changed fire regimes, is also more prevalent in Australia compared to globally. Since European occupation, the changes to fire regimes in Australia has been complex (Bowman 2003). These changes vary considerably: from ecosystems evolved with no fire experiencing devastating fires (e.g. Tasmanian high-altitude relict forest, Marris 2016), ecosystems evolved with fire experiencing very little fire (e.g. Cape York grassy woodlands, Crowley and Garnett 1998), through to areas evolved to a particular fire regimes experiencing a new regime that does not meet the ecological needs of the species (e.g. Sydney bushland, Auld and Scott 1997).

Finally, overexploitation is more prevalent of a threat globally than it is in Australia. The impact of overexploitation is particularly pronounced in the tropics (Bradshaw et al. 2009), with logging (Barlow et al. 2006), bushmeat hunting (Ripple et al. 2016), overfishing (Dudgeon, 2006) and the pet trade (Harris et al. 2017) all having a considerable impact on species globally. However, it is important to note that overexploitation has had and continues to have a devastating impact on Australian taxa. Numerous species have been driven to extinction from hunting (e.g. Lord Howe swamphen (*Porphyrio albus*), Tasmanian Emu (*Dromaius novaehollandiae diemenensis*), Lord Howe parakeet (*Cyanoramphus subflavescens*; Garnett et al. 2011); Thylacine (Woinarski et al. 2014)), and logging continues to push species such as Leadbeater's possum (*Gymnobelideus leadbeateri*; Woinarski et al. 2014) and swift parrot (*Lathamus discolour*; Garnett et al. 2011) towards extinction.

Australia's responses to threats affecting its threatened taxa

There has been an on-going response to addressing the threats to Australia's threatened taxa for decades (Stephens and Maxwell 1996). Many government departments, non-government organisations, communities and individuals make significant efforts at local, regional and national scales towards reducing the threats that are causing the decline of these taxa (NRMMC 2010). These efforts include but are not limited to: establishing and managing the

national protected area estate, including Indigenous Protected Areas and private protected areas (NRMMC 2009); active management of threats (e.g. rabbits; Pedler et al. 2016) and threatened species (Kangaroo Island glossy black-cockatoo (*Calyptorhynchus lathami halmaturinus*); Berris et al. 2018); establishment and maintenance of captive breeding programs (e.g. Orange-bellied parrot (*Neophema chrysogaster*); Smales et al. 2000); advocating for threatened species protection (e.g. Leadbeater's possum; Lindenmayer and Possingham 2013); collecting data and information to understand species' persistence needs (e.g. Palm cockatoos (*Probosciger aterrimus*); Murphy et al. 2003); and improving approaches to help guide decision making for improving species survival (e.g. McCarthy et al. 2008).

The nation's protected area network forms the cornerstone of these efforts by protecting species habitat (NRMMC 2009), as protected areas are the most effective means of mitigating many of the threats that cause habitat loss (Geldmann et al. 2013). In Australia, protected areas are vital to counter the numerous and cumulative impact of such threats (e.g. urban development, agriculture, transportation and mining). However, despite recent pronounced expansion, many threatened species are afforded little to no protection within Australia's protected area network (Watson et al. 2011), much of which is biased towards the continent's arid and infertile interior (Venter et al. 2017). Additionally, the key threats to Australian threatened species, such as invasive species and fire, often operate irrespective of land tenure (Woinarski et al. 2011; Woinarski et al. 2013; Legge et al. 2017) and have contributed to the decline in many populations of threatened species in protected areas across the continent (Wayne et al. 2017). Threats such as these, when unmanaged, can transform ecosystems and degrade otherwise intact habitat (Russell-Smith 2007; Preece et al. 2010). To be effective, protected areas need active management – which requires committed funding – if they are to achieve their goal of protecting threatened species (Kearney et al. 2018).

Taxa listed as threatened under the EPBC Act are also afforded legal protection through this primary piece of environmental legislation. The EPBC Act provides a legal framework to protect matters of national environmental significance, which includes threatened taxa, threatened ecological communities, and heritage places (Commonwealth of Australia 2017a). The EPBC Act plays a major role in the response to many of the threats affecting Australian threatened taxa, with two main pathways of doing so. First, the EPBC Act's taxon-focussed response is through the preparation of conservation advices, and in some cases, of more

extensive recovery plans. These recovery plans, which are binding on the Commonwealth Minister for the Environment (EPBC Act Section 34D(1)(c)), and conservation advices, which the Minister needs to 'have regard to' (Section 34D(1)(ca)) aim to inform the action needed to recover each taxon. As of November 2017, the Australian Government provided details on recovery plans made or adopted under the EPBC Act for 735 threatened taxa and lists 124 taxa for which recovery plans are required to be prepared (Commonwealth of Australia 2013; Commonwealth of Australia 2017b). Second, key threatening processes can also be listed under the EPBC Act, and such listing is a first step towards supporting and coordinating efforts to ameliorate its impacts (Hawke 2009). Listing may be followed by the development of a threat abatement plan or threat abatement advice, which provide information on the research and management actions needed to reduce the impact of threatening processes on listed taxa (Commonwealth of Australia 2016).

Despite the protected area estate, on-ground management and legislative protection, Australia has been unable to reverse or prevent further decline in all but a small minority of threatened species (Garnett et al. 2011; Woinarski et al. 2014; Garnett et al. 2018), and the general trend for threatened taxa is for ongoing decline. Key to this trend is the fact that the impacts of many threats continue to increase. The recent Australian State of the Environment Biodiversity report highlights an increase in the impact of a number of key threats to Australian biodiversity with a particularly pronounced increase in the effect of climate change, clearing and fragmentation, livestock grazing, invasive species and pathogens, altered fire and hydrological regimes (Cresswell and Murphy 2017). Cresswell and Murphy (2017) also identify that while progress is being made in management of some threats; resources for the management of many threats are currently insufficient and, in many cases, have declined in recent years. These resource inadequacies have also been identified in both national and international studies of funding for the conservation of Australian biodiversity (McCarthy et al. 2008; Waldron et al. 2013).

Additional to increasing impact of threats and decreasing resources to manage them, a number of other impediments to achieving positive outcomes for threatened species have been identified. These include: the ineffectiveness of many threatened species recovery plans, either because they are not funded, or not successfully implemented (Bottrill et al. 2011); loose or unspecified relationship between monitoring results and triggers for emergency conservation actions (Lindenmayer et al. 2013); a lack of national, coordinated monitoring

on how well management is working for threatened species recovery (Legge et al. 2018); the absence of a comprehensive national plan to recover Australian threatened species (McDonald et al. 2015); and the lack of commitment for species recovery (Woinarski et al. 2017a).

In an attempt to redress some of these impediments, the Australian Government recently adopted a national Threatened Species Strategy (Commonwealth of Australia 2015b). The strategy aims to use science, action and partnerships to promote the recovery of Australian threatened species. The strategy's main initiatives centre around bringing focus to its priority species, enhancing management attention to particular key threats (notably predation by feral cats) and targets for improving recovery practices (Commonwealth of Australia 2015b). The Threatened Species Strategy is an important step towards a nation-wide, strategic approach. However, to date, the strategy focuses principally on 20 mammal, 20 bird and 30 threatened plant species and one key threat, feral cats (Commonwealth of Australia 2015b) and there is no detailed understanding or articulation of what is needed to ensure the persistence of all Australian threatened species. What is missing is a national level picture on how best to coordinate efforts and resources for managing threats across all of Australia's threatened species. To turn around the trend of ongoing species decline, Australia needs to move beyond enumerating the threats known to impact threatened taxa, to understanding the extent and severity of each threat, the interactions between them and, importantly, identifying and implementing effective threat management.

What is needed to redress Australian threatened species declines?

At present, although significant efforts are in place, the *status quo* is insufficient to conserve Australia's threatened taxa. A more comprehensive, adequately funded, coordinated national response would enable a clearer definition of the total set of responses required to redress Australia's threatened species declines. This would include understanding where threatened species occur, where the threats affecting them operate and which location-based actions and legislative support are required to effectively abate key threats to ensure species recovery. Importantly, some of this information is already available for species that have existing recovery plans and national action plans (e.g. for birds and mammals). However, for the majority of threatened species, such plans are absent or include critical knowledge gaps in species occurrences, threats and effective recovery strategies. Some of this knowledge is

likely held by local land managers, but has not been brought together to enable a clear national pathway to threatened species recovery success.

Below we expand upon five ways to meet this challenge. These are focussed around two broad themes: (1) ensuring financial and legislative support for implementing known urgent actions to recover threatened species, including (1a) adequate resources for the implementation of recovery actions, and (1b) effective policy support for response mechanisms and management; and (2) developing, funding and implementing a co-ordinated national threatened species response, which involves (2a) identifying and filling knowledge gaps in understanding the distributions of species and threats, the severity and interactions of their impacts on species (2b) understand the impacts (e.g. clearing, pollutants) of drivers that lead to threatening process, so that effective response mechanisms can be designed, (2c) co-ordinating information and resources to help policy makers and local land managers guide and implement the actions required for species recovery, including the ongoing collection and sharing of information to guide effective management.

First and foremost, the actions known to be essential and urgent for threatened species survival require funding commitments. Recovery plans, conservation advices and action plans provide information on the actions needed to prevent the extinction, and in many cases to enable the recovery, of many species but come with no resourcing for the implementation of these actions. For example, two of the three recently extinct Australian species had recovery plans in place (Christmas Island pipistrelle and Bramble Cay melomys) and the actions needed to prevent their extinctions had been identified; however, no funding was made available in time to prevent these extinctions (Martin et al. 2012; Woinarski et al. 2017b). If recovery plans are to be effective, just as if Australia's response to the extinction crisis is to be effective, the commitment of adequate funding to support these plans is urgently needed.

Additional to the urgent need for increased funding, management responses to threatened species declines require the support of policy and legislation for implementation. The on-ground threatening processes that cause species decline are increasingly impacted by governance factors (Woinarski et al. 2017a). For example, protected area downgrading, downsizing and degazettement events have affected one-third of Australia's protected area network since 1977 (Cook et al. 2017), with many protected areas also opened up to uses incompatible with biodiversity conservation (Ritchie et al. 2013). The loss and degradation of

threatened species habitat has occurred despite current land-clearing laws (Reside et al. 2017; Rhodes et al. 2017). Additionally, state governments have allowed logging in critical species habitat, including old growth forests and protected areas (e.g. Lindenmayer and Possingham 2013; Stojanovic et al. 2017). Without governance and legislative support, many efforts to conserve Australia's threatened taxa will be undermined.

Beyond these urgent implementation priorities, the development of a more co-ordinated national response for threatened species recovery would create clearer pathways to achieving longer-term success. This would include identifying and filling some critical information gaps, especially for the many species without complete recovery plans or actions plans. Much of this information is dispersed amongst numerous government and non-government agencies, land managers and other experts working across a region, and could be brought together through a coordinated national approach. Additional essential information can be obtained over time through surveys, experimental management and monitoring of species responses.

First, we need targeted information on the extent (over how much of the species range the threat impacts) and severity (rate of decline caused) of the individual and interactive impacts of each threat to each species. At present we are limited in our understanding of where and how threats operate across landscapes (Evans et al. 2011), although we do know that impacts vary considerably across different ecosystems (Price et al. 2008) and taxa (Clavero et al. 2009). Threats operate in a complex environment interacting with their surrounds and often with other threats (Doherty et al. 2015). Some threats have an antagonistic effect on one another (Côté et al. 2016), while others have additive and even synergistic effects (Brook et al 2008). Currently, there is extensive knowledge on some threats (e.g. cats; Legge et al. 2017; Woinarski et al. 2017b), some interactions (e.g. fire and climate change (Bradstock et al. 2014), fire and introduced predators (McGregor et al. 2014)), and their impacts on some threatened species (e.g. birds; Garnett et al. 2011; mammals; Woinarski et al. 2014). However, a unified understanding of the threats, their interactions and the severity of their impacts on all EPBC Act listed species is lacking.

Second, we need to better understand the actual drivers of the threats causing declines to enable the development of response actions. The IUCN threat classification scheme used here includes many threats that are entangled and key processes of interest are dispersed across a number of categories. In particular, habitat loss, fragmentation and degradation are

disaggregated into the IUCN threat categories of urban development, human disturbance, energy production, transportation, some components of system modifications and agriculture. These threats together constitute a leading cause of species decline and extinction in Australia (State of the Environment Committee 2011; Cresswell and Murphy 2017). An understanding of which drivers result in particular species declines in which places is needed to enable the development of suitable response mechanisms, whether these are related to policy, planning or on-ground management actions. Estimating the costs and likely benefits of these actions will enable an understanding of the resources required to implement various actions as part of a national response.

Finally, we need to combine existing and new information and resources to build, support, implement, and learn from, a co-ordinated national response for threatened species recovery. A range of governments, non-government organisations, Indigenous rangers and organisations, private industries and philanthropists provide resources and efforts to support threatened species conservation. These efforts span all types of land tenure in Australia. A national level understanding of current conservation actions across the different land tenures would provide a much-improved understanding of progress (and current shortfalls) around achieving outcomes for threatened and declining species (as well as other aspects of biodiversity), and where more support is needed. This could involve collating locally held information on the management needs of species, the strategies that are already being implemented, their costs and effectiveness, to help identify gaps. Future management decisions at the ground level, and policy or funding decisions at higher levels, could then be based on the best available information on how to complement existing efforts and progress towards meeting international, national and local goals for species conservation.

Conclusion

To provide an understanding of the drivers imperilling Australian species, we have reviewed the threats affecting Australia's listed threatened taxa. We found that invasive species, system modifications (particularly changed fire regimes) and agriculture are the most prevalent threats to Australian threatened taxa. While we note that some progress has been made in response to many of these threats, the on-going decline of many of these species indicates these efforts have not been enough. We emphasise that while essential, protected areas alone will not effectively combat the impacts of many of these threats, highlighting the need for comprehensive management across the continent and more effective threat management

within reserves. We highlight that if Australia is to conserve its globally significant biodiversity, a better-planned response supported by adequate funding and effective policy and legislation is urgently needed.

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Conflicts of interest

The authors declare no conflicts of interest.

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Figures

Figure 1

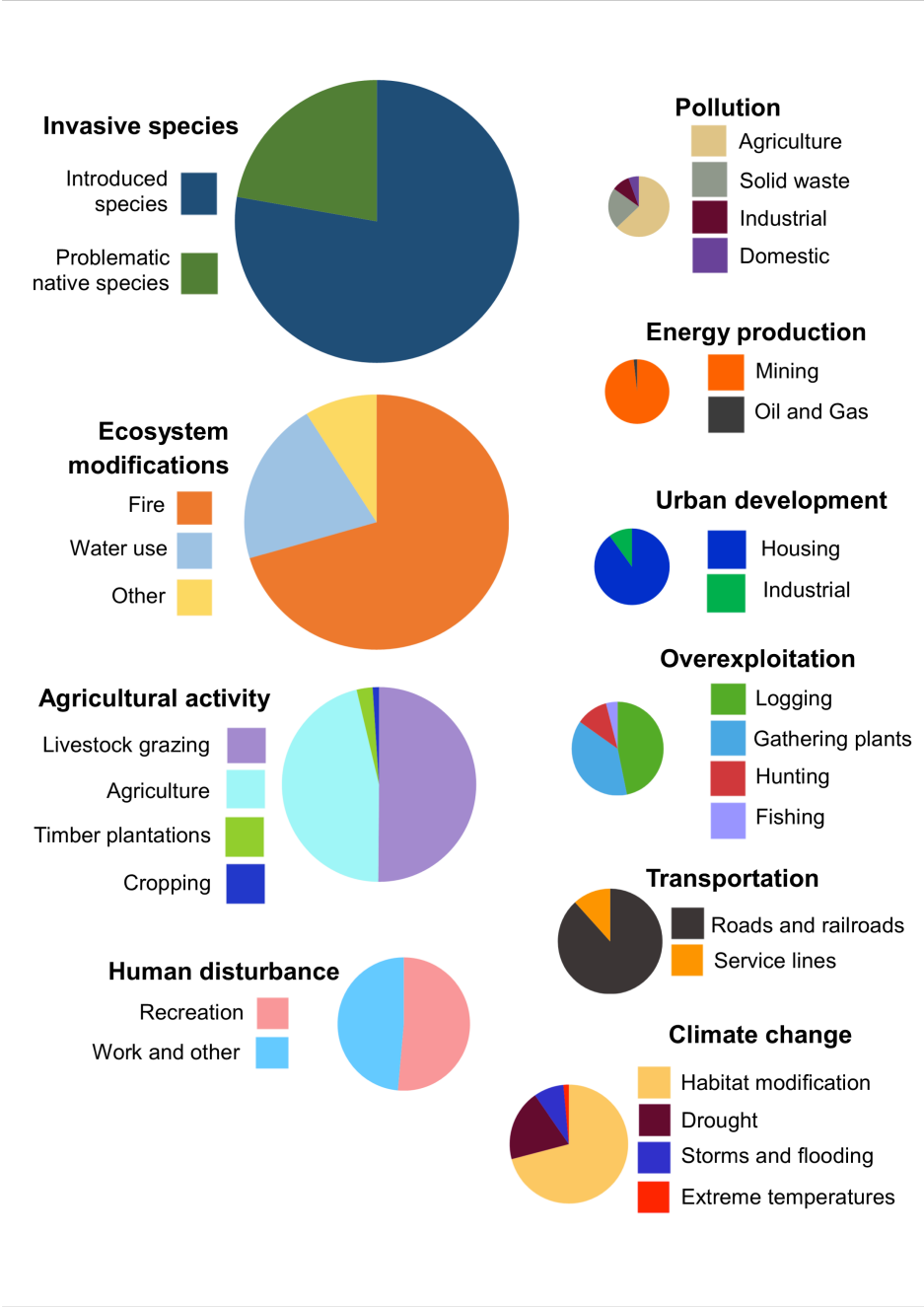

Figure 1: The prevalence of threats to Australian threatened taxa (n=1533). Each chart is scaled according to the number of EPBC Act listed taxa listed as being affected by each threat category (e.g. Urban development). Each pie chart segment represents a sub-class threat (e.g. Housing). We removed threats categories that impacted <20 taxa (e.g. Geological events) and sub-class threats that impact <5 taxa (e.g. Renewable energy) as they were too small to be displayed effectively. See Appendix 1 for further details.

Figure 2

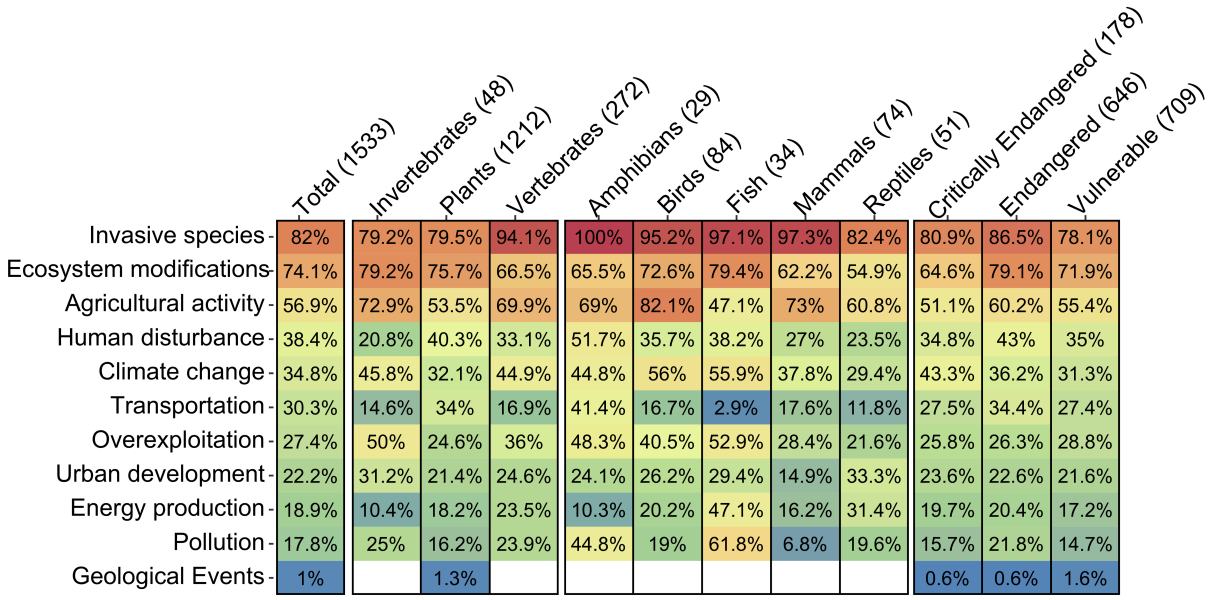

Figure 2: The prevalence of threats to Australian threatened taxa across broad taxonomic groups, vertebrate taxonomic groups and extinction risk categories. The colour of each cell is scaled to correspond with the percentage of the species group listed as being affected by each threat category. For example, cells that represent species groups for which 100% are affected by a particular threat category (e.g. amphibians by invasive species) are shaded red. Cells that represent groups for which only a small percentage are threatened (e.g. plants by geological events), the cell is shaded blue. Cells representing groups which have no species listed as being affected by a particular threat are left blank (e.g. vertebrates by geological events).

Figure 3

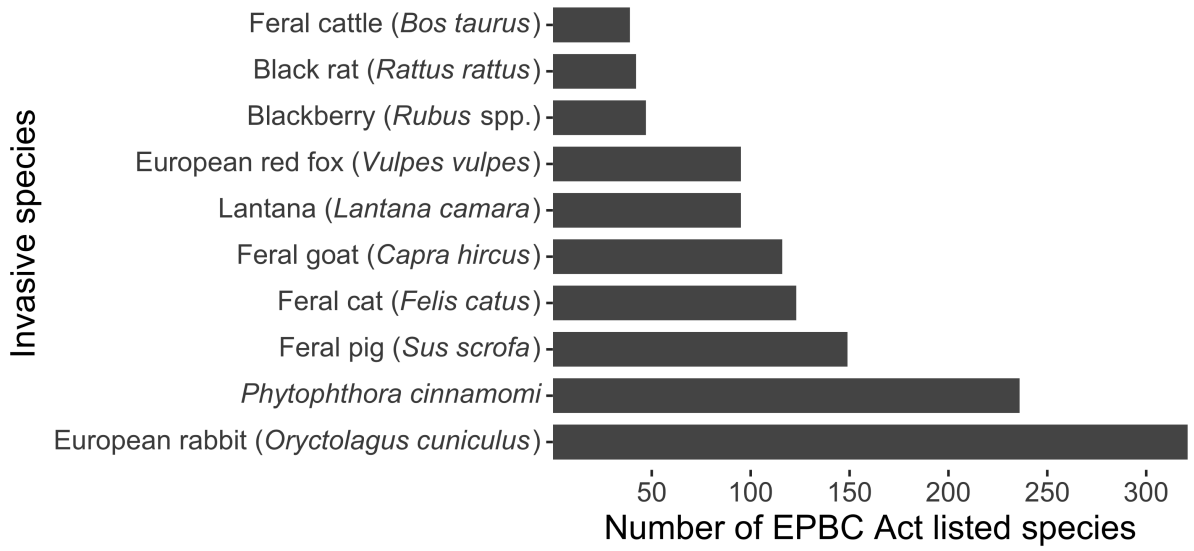

Figure 3: The 10 invasive species listed as impacting the greatest number of EPBC Listed threatened taxa (n=1533). In total, 267 invasive species are listed as impacting EPBC listed species. In total, the SPRAT database lists 207 plants, 57 animals, three pathogens as threatening EPBC Act listed taxa. This includes 230 non-native species (187 plants, 41 animals and two pathogens) and 37 problematic native species (20 animals, 16 plants and one pathogen).

Figure 4

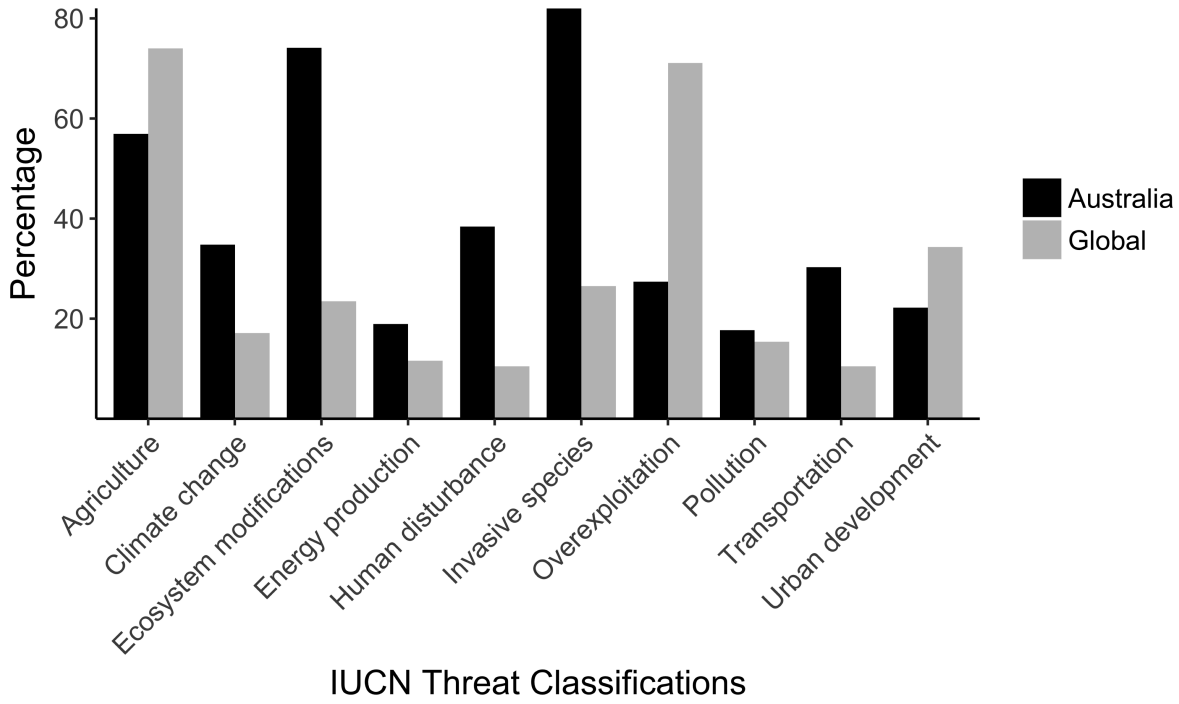

Figure 4: The percentage of Australian (n = 1533) and global threatened species (n = 5,296) threatened by each threat category. Information on the threats to global species taken from data used by Maxwell et al. (2016), who evaluated the threats to 8,688 terrestrial, freshwater and marine species listed as Near Threatened, Vulnerable, Endangered or Critically Endangered on the IUCN Red List of Threatened Species. To enable a direct comparison with the threats to EPBC Act listed taxa, we removed Near Threatened species and species groups comprised of marine and mostly marine species from the Maxwell et al. (2016) database.

Tables

Table 1: The threat categories used in this analysis and their description

IUCN Red List threat category	Abbreviated threat category	Description
Residential & Commercial Development	**Urban development**	Threats from human settlements or other non-agricultural land uses with a substantial footprint
Agriculture & Aquaculture	**Agriculture**	Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture and aquaculture
Energy Production & Mining	**Energy production**	Threats from production of non-biological resources
Transportation & Service Corridors	**Transportation**	Threats from long narrow transport corridors and the vehicles that use them
Biological Resource Use	**Overharvesting**	Threats from consumptive use of 'wild' biological resources including both deliberate and unintentional harvesting effects; also persecution or control of specific species
Human Intrusion & Disturbance	**Human disturbance**	Threats from human activities that alter, destroy and disturb habitats and species associated with non-consumptive uses of biological resources
Natural System Modifications	**Ecosystem modifications**	Threats from actions that convert or degrade habitat in service of 'managing' natural or semi-natural systems, often to improve human welfare. For example, fire and fire suppression; dams and water use.
Invasive & Other Problematic Species, Genes and Diseases	**Invasive species**	Threats from non-native and native plants, animals, pathogens/microbes, or genetic material that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance
Pollution	**Pollution**	Threats from introduction of exotic and/or excess materials or energy from point and non-point sources
Geological Events	**Geological events**	Threats from catastrophic geological events
Climate Change & Severe Weather	**Climate change**	Threats from long-term climatic changes which may be linked to global warming and other severe climatic/weather events that are outside of the natural range of variation or potentially can wipe out vulnerable species habitat