A novel threat-abatement framework confirms an urgent need to limit habitat loss and improve management of invasive species and inappropriate fire regimes for Australia's threatened species

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Keywords:

Biodiversity; Conservation; Extinction; Threat management; Habitat retention; Protected Areas.

Abstract

Earth's extinction crisis is escalating, and threat classification schemes are increasingly important for assessing which human activities are the most prominent drivers of species declines. However, a quantitative understanding of the conservation responses needed to abate threatening processes, and avoid species extinctions, is often lacking. Here, we provide a threat abatement framework which groups threats based on the shared conservation goal of the actions needed to abate their impact. We apply this framework to Australia's threatened species to quantify the relative importance of achieving different conservation response goals. Our analysis shows the most important conservation responses across Australia are habitat retention and restoration, due to the combined impact of threatening processes causing habitat destruction and degradation (e.g. logging, mining, urbanisation and agriculture), which affects the majority (86%) of Australia's threatened species and the effective control of invasive species (82%). Most species also require conservation responses focussed on improved fire management (66%). We show that implementing responses in isolation will be inadequate for abating species extinctions as almost all species (89%) require multiple, integrated management responses to redress their threats. We also acknowledge that already small and potentially genetically compromised taxa may require more direct interventions (e.g. captive insurance populations or genetic rescue). Our analysis highlights the necessity of addressing multiple threats at appropriate geographic scales across Australia. Our threat abatement framework ensures that core conservation actions can be identified and aid recovery of threatened species, and can be applied to other geographic regions and conservation contexts.

1. Introduction

The global biodiversity crisis is accelerating, driven by a multitude of human activities and threatening processes that affect species directly or indirectly (Maxwell et al. 2016; IPBES 2019). Actions required to overcome these threats operate at international, regional, national, and local scales, through policy, planning, legislation and on-ground management (Rands et al. 2010). While there have been some successes for particular species or locations, current efforts to implement these actions are insufficient overall, resulting in the ongoing decline of biodiversity (Butchart et al. 2010; Tittensor et al. 2014).

The International Union for Conservation of Nature and Conservation Measures Partnership threat classification (IUCN-CMP 2018) contains important information on the types of threats affecting species' persistence and the prevalence of each threat's impact. At the global scale, its use demonstrates that overexploitation (e.g. logging, hunting) and agriculture are the most frequent threats to Threatened and Near Threatened species worldwide, affecting 72% and 62% of species, respectively (Maxwell et al. 2016). However, regional and country-level analyses using the IUCN-CMP (or similar classification schemes (e.g. Balmford et al. 2009)) indicate variation between regions in terms of the dominant threats to species persistence. For example, in Australia, invasive species, agriculture, and altered fire regimes are the most common listed threats to species (Kearney et al. 2019), while in China, logging, agriculture and species harvesting are the most prevalent (Yiming & Wilcove 2005).

Describing and ranking threats using classifications such as the IUCN-CMP scheme highlights the dominant threats to threatened species but does not directly inform the broader conservation management and policy responses required to abate threats and improve species persistence and recovery. To inform responses, threat classification schemes must be translated to define and quantify the importance of reciprocal conservation response goals. Most imperilled species do not rely on the management of a single threat but rather suffer from 'threat syndromes' where multiple

threats interact (Maxwell et al. 2016; Geary et al. 2019). Hence, a threat abatement framework is important for identifying management responses that can address multiple threats simultaneously.

Many threatening processes affect species via similar mechanisms and as a consequence, the reciprocal management responses may share a common conservation goal. For instance, human activities listed under the IUCN-CMP threat classification scheme such as urban development, transport infrastructure and agriculture cause species endangerment through the removal, fragmentation, and degradation of habitat and therefore require a conservation response that ensures the extent and quality of threatened species habitat is retained and restored where necessary (Foin et al. 1998). Depending on the region and circumstances, this will require different landscape and site based actions, ranging from improved strategic planning, legislation and enforcement to halt land-clearing, land-stewardship incentives and, in cases where regulation is unable to reduce habitat destruction or degradation effectively, protected area establishment (Rands et al. 2010; Evans 2016) but the common goal of these actions is halting habitat destruction, degradation and/or fragmentation.

To assess the mixture of responses required to abate threats, we developed a threat abatement framework that groups IUCN-CMP threat categories based on the shared conservation goal of the actions needed to ameliorate their impacts. We apply this framework to Australia's threatened species, to quantify the importance of the different conservation responses needed to redress Australia's extinction crisis. The Australian continent's threatened species have experienced devastating impacts of multiple threats, including widespread and ongoing land clearing (Bradshaw 2012, Ward et al. 2019); invasive species and disease (Woinarski et al. 2015; Scheele et al. 2019) and altered fire regimes (Bradstock et al. 2012). Australia, despite being regarded as one of only 17 megadiverse nations (Mittermeier et al. 1997), holds one of the world's worst contemporary extinction records and continues to grapple with how to effectively respond to ongoing threatening

processes (McDonald et al. 2015). Our framework is aimed to assist in overcoming this shortfall in Australia and can be extended to biodiversity conservation elsewhere.

2. Methods

2.1 Species data

We focused on Australian listed threatened species and subspecies (hereafter, threatened taxa), which are those assessed as being at risk of extinction (Vulnerable, Endangered or Critically Endangered) under the national environmental legislation, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). As of October 2020, 1797 taxa were listed in one of these three categories of extinction risk. In this analysis, we focus on 1532 terrestrial and freshwater taxa listed as threatened in the EPBC Act for which threat data are currently available.

Threat data on listed threatened taxa in Australia are available through the Australian Government's Species Profile and Threats (SPRAT) database (Commonwealth of Australia 2015). We acknowledge that the data we use is limited by incomplete knowledge of biodiversity (Hortal et al. 2015) and threats to species persistence. However, the SPRAT database is the only comprehensive threat database for EPBC Act listed threatened taxa and is compiled from numerous sources including species listing advices, species recovery plans, published literature and individual experts (Commonwealth of Australia 2015). These data have been used in a number of studies assessing the threats and pressures affecting Australian taxa (e.g. Evans et al. 2011; Kearney et al. 2018). The data used in this analysis were derived from the latest complete database available (2016 release).

2.2 Threat abatement framework

This framework builds upon the IUCN-CMP Threat classification scheme, which was originally defined in Salafsky et al. (2008) and has since been used in numerous regional and global conservation analyses (e.g. Maxwell et al. 2016; Kearney et al. 2019). This classification is used in IUCN Red List species' assessments (IUCN 2016) to describe the proximate activities or processes

that have, are, or may impact the persistence of species of which all but geological events are linked to human activities (IUCN-CMP 2018).

We coupled each IUCN-CMP threat category with the broad conservation response needed, based on the shared conservation goal of overcoming each threat. We identified six key conservation responses needed to overcome the ten IUCN-CMP threat categories relevant to Australian threatened taxa (Table 1). We do not aim to be prescriptive about the specific actions or costs of responding to each threat at the site and landscape scale, as these will be diverse, dependant on local knowledge and social, economic, and political factors, and are likely to vary across space and time.

The conservation response that aims to retain and/or restore the habitat quality and extent (which we label '**Retain and restore habitat'**) is needed to ameliorate the impacts of eight IUCN-CMP Threat categories: *1. Residential & commercial development, 2. Agriculture & aquaculture, 3. Energy production & mining, 4. Transportation & service corridors, 5.3 Logging & wood harvesting, 6. Human intrusion & disturbance, 7.2 Dams & water management/use and 7.3 Other ecosystem modifications.* This response covers both retention and restoration of habitat to acknowledge that for many species, historic habitat destruction has left them with inadequate habitat within which to recover (Foin et al. 1998) and to shift in response to a changing climate (Maxwell et al. 2019). To achieve the effective retention and restoration of habitat, a mixture of site and non-site actions are needed. These efforts include halting the clearing of species' habitat via mechanisms such as land-clearing legislation, strategic planning that includes the protection and restoration of sensitive and key areas and improved public and private sector operations complemented by public education and awareness campaigns.

Effective management of species overexploitation (labelled '**Prevent species overexploitation**') aims to mitigate the impacts of three IUCN-CMP Threat categories: *5.1 Hunting terrestrial animals, 5.2 Gathering terrestrial plants, 5.4 Fishing & harvesting aquatic species*. Actions to

ameliorate these threats include effective and enforced legislation to ensure sustainable species harvesting, enforcement to prevent illegal harvest, protected area establishment and management, and the development of harvest alternatives (Hutton and Leader-Williams 2003). Education and awareness programs would also be valuable actions to prevent species overexploitation.

The conservation response of reinstating or managing appropriate fire regimes ('**Manage fire**') has the goal of mitigating the impacts of IUCN-CMP Threat category *7.1 Fire & fire suppression*. This includes on-ground management supported by policy (Government of South Australia 2014) and strategic planning to ameliorate its impacts (Legge et al. 2011; Russell-Smith et al. 2015). We recognize that treating fire and fire suppression as a threat requiring a separate response is a particularly Australian perspective. In some regions of the world, particularly tropical rainforests, fire is often used to pave the way for agriculture (Bowman et al. 2011) and in these circumstances should be treated as habitat destruction and therefore would be included in the response 'retain and restore habitat'.

Effectively managing invasive species, diseases and pathogens ('**Manage invasive species**') aims to address the impacts of IUCN-CMP Threat category *8. Invasive & other problematic species and diseases*. These efforts include on-ground management supported by legislation (Tollington et al. 2017), biosecurity policy and practice (Shine et al. 2005), strategic planning (Braysher 2017), and education and awareness programs. In circumstances where an invasive species is not readily managed, additional efforts that enable threatened species to persist, such as translocation or predator-free exclusion fencing (Hayward et al. 2014) will be a critical component of the response to manage invasive species.

The IUCN-CMP Threat category *9. Pollution* requires a response that removes or reduces the impacts of pollution ('**Manage pollution**'). Proactive actions include policy and legislation along with compliance and enforcement as well as private sector standards and codes (de Vries and

Hanley 2016) and public awareness programs. Reactive actions will also need to include on-ground efforts to restore natural areas post-pollution impacts (Philp et al. 2005).

Finally, the goal of a response to IUCN-CMP Threat category *11. Climate change and severe weather* is to mitigate and reduce the impacts of anthropogenic climate change on threatened species (labelled '**Mitigate climate change**'). This includes actions around effective and enforced legislation, public awareness programs and industry policy and standards to limit net greenhouse gas emissions and increase natural CO2 sequestration (Miles & Kapos 2008). These will need to be complemented with on-ground actions to build species resilience and adaptation potential, such as retaining and restoring species' habitat to ensure species can move as their suitable climate envelope shifts and changes (Maxwell et al. 2019) and translocations to establish new populations for species for which current populations will be severely compromised by changing climate. Fire management is also a vital component of climate change adaptation and mitigation, at least in Australia (Bradstock et al. 2012).

Taxa with already small and genetically compromised populations that are affected by processes such as inbreeding, genetic drift and Allee effects, will require direct intervention to ameliorate these processes (e.g. captive insurance populations, genetic rescue; Caughley 1994). These efforts may need to occur additional to or irrespective of other threat management actions (Caughley 1994). As these threats are not dealt with by the IUCN Threats Classification scheme or the SPRAT database, they are not considered in this analysis. However, such actions are critical to the persistence of a number of Australian threatened taxa (e.g. orange-bellied parrot (*Neophema chrysogaster*); Garnett et al. 2010; mountain pygmy possum (*Burramys parvus*); Woinarski et al. 2014), and their inclusion in broadscale conservation planning exercises is vital.

2.3 Analyses

We collated the response or combination of responses that must be undertaken for the effective conservation of each Australian threatened taxon. Specifically, we quantified how many threatened taxa would benefit from achieving the goals of each individual response and how many would benefit from each combination of responses. We also present these results for each taxonomic group.

3. Results

3.1 Threatening processes and management responses

Australian threatened taxa collectively require all six conservation responses, but three dominate, with 86% (n=1323) of taxa listed as benefiting from actions to retain and restore habitat, 82% (n=1257) requiring invasive species management, and 66% (n=1008) needing effective fire management (Fig. 1). Currently, 35% (n=533) of taxa require efforts to mitigate and build resilience to climate change, 18% (n=273) need amelioration of pollution impacts, and 17% (n=257) require protection from overexploitation (Fig. 1).

3.2 Across taxonomic groups

The proportion of species dependent upon each conservation response varied considerably across taxonomic groups (Table 2). The response with the greatest variation among dependent taxa was pollution management, with between 7% (mammals) and 65% (fish) of taxa listed as requiring, or at least benefitting from, this response. The conservation response aimed at retaining and restoring habitat showed the least variation, with between 84% (reptiles) and 100% (frogs) requiring these actions (Table 2). Similarly, between 78% (invertebrates) and 100% (frogs) of species within each taxonomic group need the management of invasive species. There was moderate variation between taxonomic groups for the management of overexploitation (3–44%), fire management (15–69%) and climate change mitigation and resilience (29–56%; Table 2).

3.3 Multiple conservation responses

The vast majority of threatened taxa (89%) have many listed threats and hence are likely to require multiple conservation responses (Fig. 2), with two-thirds of taxa included in this study needing three or more conservation response goals to be achieved in order to address their threats (Fig 2). Of the 11% of taxa (n=171) requiring a single conservation response, 69 taxa (5%) require the retention and restoration of habitat, 53 (3%) require invasive species management and 27 (2%) require fire management (Table 2; final column).

A small proportion (2%; n=26) threatened taxa across Australia need the achievement of every conservation response goal considered in our framework, to address all of their corresponding threats. The dominant three responses required showed the highest amount of pairwise overlap amongst affected species: over 70% of taxa (n=1105) included in this analysis require (among other management actions) the combination of actions to retain and restore habitat and manage invasive species; 58% (n= 893) require the combination of fire management and retain and restore habitat; and 56% (n=858) require the combination of fire management and invasive species management (Fig. 3).

4. Discussion

Our threat abatement framework links threatening processes to broad conservation responses, revealing the relative importance of achieving each response goal for averting species' extinctions. Our framework shifts the emphasis from what is causing biodiversity decline (problem focused) to what needs to be done to reverse this decline (solution focused) – a key tenet of global conservation agreements such as the Convention on Biological Diversity's (CBD) Strategic Plan for Biodiversity 2011-2020 (CBD 2011). In applying this framework to Australia's listed threatened species, we find that 86% are subject to multiple threats that amount to habitat destruction and degradation, including logging, mining, urbanisation and agriculture, for which the key conservation response is habitat retention and restoration. The two additional priority responses highlighted in this study are the management of invasive species and fire regimes (benefitting 82% and 66% of species,

respectively). Furthermore, we find that only one in ten species require a single conservation response: almost all require multiple responses to address their listed threats. The breadth and extent of responses required emphasises the importance of a comprehensive national policy agenda for mitigating threats, including integration between local land management, regional, state and national efforts, if Australia is to reverse its extinction crisis.

Our analysis builds on previous studies showing that abating the extinction crisis in Australia requires overcoming its past and current vegetation clearing rates (Burgman et al. 2007; Evans 2016), susceptibility to invasive species as a large island nation (Woinarski et al. 2015; Kearney et al. 2019), and myriad shifts in fire regimes (Evans et al. 2011; Bradstock et al. 2012) caused by many factors, including habitat fragmentation, urbanisation (Gill and Williams 1996), and the loss of traditional Indigenous fire management practices in many areas (Bliege Bird & Nimmo 2018). By focussing on the necessary responses, rather than the underlying threats, our analysis reveals just how crucial retention and restoration of habitat is for ensuring the persistence of Australia's threatened species. As nations such as Australia increase the area within formal protected areas (Maxwell et al. 2020), there is less support for new protected area establishment in the areas needed for long-term biodiversity outcomes (Lindenmayer et al. 2018; Visconti et al. 2019), hence these actions must be innovative, diverse and numerous. Many species exist on land that is unlikely to ever be designated as a protected area (Watson et al. 2011; Maron et al. 2018). Conservation covenants and effective land stewardship (Burns et al. 2016), other forms of private protected areas (Fitzsimons 2015), effective land-clearing legislation (Evans 2016), and improved industry (e.g. agriculture, mining, urban development) practice complemented by strategic planning (Bekessy et al. 2012) are vital to retain threatened species' habitat on the remaining 80% of land currently not in the protected area estate (Commonwealth of Australia 2017). In Australia the majority of threatened species have distributions that overlap with Indigenous tenures (Renwick et al. 2017; O'Bryan et al. 2020), and enhanced support for conservation management in these areas will benefit biodiversity and provide social returns on investment (SVA 2016). In addition, 30% of threatened taxa overlap

with urban areas (Ives et al. 2016), with 39 species occurring only in urban areas (Soanes & Lentini 2019), places where traditional protected areas are generally less feasible. These urban and other highly modified landscapes now support novel ecosystems that are becoming increasingly important for supporting some threatened species' habitats (Maclagan et al. 2018).

Our analysis shows that for Australia at least, while designated protected areas are necessary (or at least beneficial) for most threatened species to support their existing populations and prevent further habitat destruction, threatened species' recovery require more than expansion of the protected area estate (Kearney et al. 2018): additional management of threats will also need to occur (e.g. introduced predators and changed fire regimes: Woinarski et al. 2011; invasive plants: Driscoll et al. 2014). For example, multiple Australian threatened mammal species are declining within protected areas across Australia due to insufficient management of fire regimes and introduced predators (Wayne et al. 2017). Similarly, two of Australia's most recent vertebrate extinctions, the Christmas Island pipistrelle (*Pipistrellus murrayi*) and Christmas Island forest skink (*Emoia nativitatis*) occurred within substantial protected areas; where the management of introduced species and timing of developing captive insurance populations were inadequate (Woinarski et al. 2017).

The small set (1 in 10) of Australian threatened species that are being driven toward extinction due to a single threatening process offer opportunities for a swift, single conservation response to avert extinctions. For example, the primary threat to Clarence galaxias (*Galaxias johnstoni*), a fish species endemic to Tasmania, is predation by (and competition with) introduced brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) (TSS 2006). The effective management of these introduced species (including translocating the species to trout-free areas) is the sole response needed to conserve the Clarence galaxias (TSS 2006). Likewise, the habitat of red silky oak (*Alloxylon flammeum*), a rainforest tree species endemic to north-east Queensland, has been almost completely cleared for agriculture (Weston & Crisp 1991). Preventing any further clearing of this

species' habitat is now critical, as is enhancing existing populations and establishing new ones (i.e. restoration; TSSC 2008).

Our framework allows for an examination of the degree to which species require multiple actions to halt and reverse declines. Almost all threatened species in Australia and globally (Maxwell et al. 2016) face multiple threats and therefore require multiple actions. Across countries, the dominant threats are diverse (e.g. Australia: Kearney et al. 2019; Canada: Venter et al. 2006; China and the US: Yiming & Wilcove 2005), hence the requisite actions to abate the impact of these threats need to be similarly diverse, targeted and integrated. In our framework, we avoided focussing on specific conservation actions, which vary in their feasibility and appropriateness across space and time, and need to be determined at local scales. Furthermore, this information is highly dependent on the scale and severity of each threat, data that are currently not available for all threatened species across the continent. A far more detailed analysis of threats and conservation actions is required to achieve this. However, in areas where data on the geographic scale and impact severity of threats, and information on the appropriateness, feasibility, costs and effectiveness of actions are available, this framework could be used to translate information on threats into actions for rapid identification of priority threat management responses (Carwardine et al. 2012, 2019).

The threat abatement framework we have outlined here is generic, applicable globally and of use to governments and conservation planners working at various scales. It provides a high-level understanding of the diversity and relative importance of achieving key conservation response goals. This framework quickly quantifies the relative roles of different efforts to minimise harmful human activity and promote on-ground management, thus helping shape local conservation strategies. Further efforts are required to translate these high-level responses into specific resourced actions and to guide management of a diverse suite of actions, ensuring investments maximise on-ground opportunities to achieve sustained outcomes for threatened species.

Literature cited

Balmford A, Carey P, Kapos V, Manica A, Rodrigues ASL, Scharlemann JPW, and Green RE. 2009. "Capturing the Many Dimensions of Threat: Comment on Salafsky et al." *Conservation Biology* 23 (2): 482–87. https://doi.org/10.1111/j.1523-17392009.01196.x.

Bekessy, SA, White M, Gordon A, Moilanen A, Mccarthy MA, and Wintle BA. 2012. "Transparent Planning for Biodiversity and Development in the Urban Fringe." Landscape and Urban Planning 108 (2–4): 140–49. https://doi.org/10.1016/J.LANDURBPLAN.2012.09.001.

Bellard C, Genovesi P, Jeschke JM. 2016. "Global Patterns in Threats to Vertebrates by Biological Invasions." Proceedings of the Royal Society of London B: Biological Sciences 283 (1823). https://doi.org/10.1098/rspb.2015.2454.

Bliege Bird R, Nimmo D. 2018. "Restore the Lost Ecological Functions of People." Nature Ecology & Evolution 2 (7): 1050–52. https://doi.org/10.1038/s41559-018-0576-5.

Bowman DMJS, Balch J, Artaxo P, Bond WJ, Cochrane MA, D'Antonio CM, DeFries R, et al. 2011. "The Human Dimension of Fire Regimes on Earth." Journal of Biogeography 38 (12): 2223–36. https://doi.org/10.1111/j.1365-2699.2011.02595.x.

Bradshaw, C.J., 2012. Little left to lose: deforestation and forest degradation in Australia since European colonization. *Journal of Plant Ecology*, *5*(1), pp.109-120. https://doi.org/10.1093/jpe/rtr038

Bradstock, RA, Williams RJ, Gill AM (eds.). 2012. Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World. CSIRO Publishing. https://doi.org/10.2989/10220119.2012.715728.

Braysher M. 2017. Managing Australia's Pest Animals: A Guide to Strategic Planning and Effective Management. CSIRO Publishing. https://doi.org/10.1080/14486563.2017.1374464.

Burgman MA, Keith D, Hopper SD, Widyatmoko D, Drill C. 2007. "Threat Syndromes and Conservation of the Australian Flora." Biological Conservation 134 (1): 73–82. https://doi.org/10.1016/j.biocon.2006.08.005.

Burns E, Zammit C, Attwood S, Lindenmayer D. 2016. "The Environmental Stewardship Program: Lessons on Creating Long-Term Agri-Environment Schemes." In Learning from Agri-Environment Schemes in Australia, 33–52. Canberra, Australia: ANU Press. https://www.jstor.org/stable/j.ctt1d10hdp.10

Butchart SHM, Walpole M, Collen B, van Strien A, Scharlemann JPW, Almond REA, Baillie JEM, et al. 2010. "Global Biodiversity: Indicators of Recent Declines." Science 328 (5982): 1164–68. https://doi.org/10.1126/science.1187512.

Carwardine J, Martin TG, Firn J, Ponce Reyes R, Nicol S, Reeson A, Grantham HS, Stratford D, Kehoe L, and Chadès I. 2019. "Priority Threat Management for Biodiversity Conservation: A Handbook." *Journal of Applied Ecology* 56 (2): 481–90. https://doi.org/10.1111/1365-2664.13268.

Carwardine J, O'Connor T, Legge S, Mackey B, Possingham HP and Martin TG. 2012. Prioritizing threat management for biodiversity conservation. Conservation Letters, 5(3), pp.196-204. http://dx.doi.org/10.1111/j.1755-263X.2012.00228.x

Caughley, G., 1994. Directions in conservation biology. *Journal of animal ecology*, pp.215-244. https://www.jstor.org/stable/5542

CBD. 2011. “COP 10 Decision X/2: Strategic Plan for Biodiversity 2011-2020.” 2011. https://www.cbd.int/decision/cop/?id=12268.

Commonwealth of Australia. 2015. “Species Profile and Threats Database (SPRAT).” Canberra, Australia: Department of the Environment and Energy, Australian Government. 2015. https://doi.org/http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl.

Commonwealth of Australia. 2017. “The National Reserve System (NRS) - Protected Area Information (CAPAD).” Canberra, Australia: Department of the Environment and Energy, Australian Government. 2017. https://www.environment.gov.au/land/nrs/science/capad.

Driscoll DA, Catford JA, Barney JN, Hulme PE, Inderjit, Martin TG, Pauchard A, et al. 2014. “New Pasture Plants Intensify Invasive Species Risk.” PNAS 111 (46): 16622–27. https://doi.org/10.1073/pnas.1409347111.

Evans MC. 2016. “Deforestation in Australia: Drivers, Trends and Policy Responses.” Pacific Conservation Biology 22 (2): 130–50. https://doi.org/http://dx.doi.org/10.1071/PC15052.

Evans MC, Watson JEM, Fuller RA, Venter O, Bennett SC, Marsack PR, Possingham HP. 2011. “The Spatial Distribution of Threats to Species in Australia.” BioScience 61 (4): 281–89. https://doi.org/10.1525/bio.2011.61.4.8.

Fitzsimons JA. 2015. “Private Protected Areas in Australia: Current Status and Future Directions.” Nature Conservation 10: 1–23. https://doi.org/10.3897/natureconservation.10.8739.

Foin TC, Riley SPD, Pawley AL, Ayres DR, Carlsen TM, Hodum PJ, Switzer PV. 1998. "Improving Recovery Planning for Threatened and Endangered Species." Source: BioScience. Vol. 48.

Garnett, S., Szabo, J. and Dutson, G., 2011. *The action plan for Australian birds 2010*. CSIRO publishing.

Geary WL, Nimmo DG, Doherty TS, Ritchie EG, Tulloch AIT. 2019. "Threat Webs: Reframing the Co-occurrence and Interactions of Threats to Biodiversity." Journal of Applied Ecology, June, 1365-2664.13427. https://doi.org/10.1111/1365-2664.13427.

Gill AM and Williams JE. 1996. Fire regimes and biodiversity: the effects of fragmentation of southeastern Australian eucalypt forests by urbanisation, agriculture and pine plantations. *Forest Ecology and Management*, *85*(1-3), pp.261-278.

Government of South Australia. 2014. "Fire Management: Environmental Assessment and Management Procedure. Policy Prepared for Strategic Assessment under the EPBC Act." Adelaide, SA. https://www.environment.sa.gov.au/files/sharedassets/public/fire_management/fire-management-environmental-assessment-policy-and-procedure-gen.pdf.

Hayward, M.W., Moseby, K. and Read, J.L., 2014. The role of predator exclosures in the conservation of Australian fauna. In Glen A, Dickman C (eds) *Carnivores of Australia: Past, present and future*, pp.353-371.

Hortal J, de Bello F, Diniz-Filho JAF, Lewinsohn TM, Lobo JM, and Ladle RJ. 2015. "Seven Shortfalls That Beset Large-Scale Knowledge of Biodiversity." Annual Review of Ecology,

Evolution, and Systematics 46 (1): 523–49. https://doi.org/10.1146/annurev-ecolsys-112414-054400.

Hutton JM, Leader-Williams N. 2003. “Sustainable Use and Incentive-Driven Conservation: Realigning Human and Conservation Interests.” Oryx 37 (2): 215–26. https://doi.org/10.1017/S0030605303000395.

IPBES. 2019. “Global Assessment Report on Biodiversity and Ecosystem Services.” https://www.ipbes.net/news/Media-Release-Global-Assessment.

IUCN-CMP. 2018. “Threats Classification Scheme (Version 3.2).” International Union for Conservation of Nature - IUCN.

IUCN. 2016. Rules of Procedure for IUCN Red List Assessments 2017–2020. Version 3.0. Approved by the IUCN SSC Steering Committee in September 2016.

Ives CD, Lentini PE, Threlfall CG, Ikin K, Shanahan DF, Garrard GE, Bekessy SA, et al. 2016. “Cities Are Hotspots for Threatened Species.” Global Ecology and Biogeography 25 (1): 117–26. https://doi.org/10.1111/geb.12404.

Kearney SG, Adams VM, Fuller RA, Possingham HP, Watson JEM. 2018. “Estimating the Benefit of Well-Managed Protected Areas for Threatened Species Conservation.” Oryx 54 (2): 276-284. https://doi.org/10.1017/S0030605317001739.

Kearney SG, Carwardine J, Reside AE, Fisher DO, Maron M, Doherty TS, Legge S, et al. 2019. “The Threats to Australia’s Imperilled Species and Implications for a National Conservation Response” Pacific Conservation Biology 25 (3): 328. https://doi.org/10.1071/PC18024.

Legge S, Murphy S, Kingswood R, Maher B, Swan D. 2011. “EcoFire: Restoring the Biodiversity Values of the Kimberley Region by Managing Fire.” Ecological Management & Restoration 12 (2): 84–92. https://doi.org/10.1111/j.1442-8903.2011.00595.x.

Lindenmayer D, Thorn S, Noss R. 2018. “Countering Resistance to Protected-Area Extension.” Conservation Biology 32 (2): 315–21. https://doi.org/10.1111/cobi.12990.

Maclagan SJ, Coates T, Ritchie EG. 2018. “Don’t Judge Habitat on Its Novelty: Assessing the Value of Novel Habitats for an Endangered Mammal in a Peri-Urban Landscape.” Biological Conservation 223 (July): 11–18. https://doi.org/10.1016/j.biocon.2018.04.022.

Maron M, Simmonds JS, Watson JEM. 2018. “Bold Nature Retention Targets Are Essential for the Global Environment Agenda.” Nature Ecology & Evolution 2 (8): 1194–95. https://doi.org/10.1038/s41559-018-0595-2.

Maxwell SL, Fuller RA, Brooks T, and Watson JEM. 2016. “Biodiversity: The Ravages of Guns, Nets and Bulldozers.” Nature 536 (7615): 143. https://doi.org/10.1038/536143a.

Maxwell S, Reside A, Trezise J, McAlpine CA, Watson JEM. 2019. “Retention and Restoration Priorities for Climate Adaptation in a Multi-Use Landscape.” Global Ecology and Conservation, May, e00649. https://doi.org/10.1016/J.GECCO.2019.E00649.

Maxwell SL, Cazalis V, Dudley N, Hoffmann M, Rodrigues ASL, Stolton S, Visconti P, Woodley S, Maron M, Strassburg BBN, Wenger A, Jonas HD, Venter O, Watson JEM. 2020. “Area-Based Conservation in the 21 St Century.” Preprints (January): 1–42. https://doi.org/10.20944/preprints202001.0104.v1.

McDonald JA, Carwardine J, Joseph LN, Klein CJ, Rout TM, Watson JEM, Garnett ST, McCarthy MA, Possingham HP. 2015. “Improving Policy Efficiency and Effectiveness to Save More Species: A Case Study of the Megadiverse Country Australia.” Biological Conservation 182: 102–8. https://doi.org/10.1016/j.biocon.2014.11.030.

Miles L, Kapos V. 2008. “Reducing Greenhouse Gas Emissions from Deforestation and Forest Degradation: Global Land-Use Implications.” Science. https://doi.org/10.1126/science.1155358.

Mittermeier, R. A., Gil, P. R., and Mittermeier, C. G. (1997). ‘Megadiversity: Earth’s Biologically Wealthiest Nations.’ (CEMEX: Mexico City.)

O’Bryan CJ, Garnett ST, Fa JE, Leiper I, Rehbein J, Fernández-Llamazares Á, Jackson MV, Jonas HD, Brondizio ES, Burgess ND, Robinson CJ, Zander KK, Venter O, Watson JEM. 2020. “The Importance of Indigenous Peoples’ Lands for the Conservation of Terrestrial Mammals.” Conservation Biology, August, cobi.13620. https://doi.org/10.1111/cobi.13620.

Olah G, Theuerkauf J, Legault A, Gula R, Stein J, Butchart S, O’Brien M, Heinsohn R. 2018. “Parrots of Oceania-a Comparative Study of Extinction Risk.” Emu-Austral Ornithology 118 (1): 94–112. https://doi.org/10.1080/01584197.2017.1410066.

Philp JC, Bamforth S, Singleton I, Atlas RM. 2005. “Environmental Pollution and Restoration: A Role for Bioremediation.” In Bioremediation, 1–48. https://doi.org/10.1128/9781555817596.ch1.

Rands MR, Adams WM, Bennun L, Butchart SH, Clements A, Coomes D, Entwistle A, et al. 2010. “Biodiversity Conservation: Challenges beyond 2010.” Science 329 (5997): 1298–1303. https://doi.org/10.1126/science.1189138.

Renwick AR, Robinson CJ, Garnett ST, Leiper I, Possingham HP, Carwardine J. 2017. “Mapping Indigenous Land Management for Threatened Species Conservation: An Australian Case-Study.” PLoS One 12 (3). https://doi.org/ARTN e017387610.1371/journal.pone.0173876.

Russell-Smith J, Lindenmayer D, Kubiszewski I, Green P, Costanza R, Campbell A. 2015. “Moving beyond Evidence-Free Environmental Policy.” Frontiers in Ecology and the Environment 13 (8): 441–48. https://doi.org/10.1890/150019.

Salafsky N, Salzer D, Stattersfield AJ, Hilton-Taylor C, Neugarten R, Butchart SHM, Collen B, et al. 2008. “A Standard Lexicon for Biodiversity Conservation: Unified Classifications of Threats and Actions.” Conservation Biology 22 (4): 897–911. https://doi.org/10.1111/j.1523-1739.2008.00937.x.

Scheele BC, Pasmans F, Skerratt LF, Berger L, Martel A, Beukema W, Acevedo AA, et al. 2019. “Amphibian Fungal Panzootic Causes Catastrophic and Ongoing Loss of Biodiversity.” Science 363 (6434): 1459–63. https://doi.org/10.1126/science.aav0379.

Shine C, Williams N, Burhenne-Guilmin F. 2005. “Legal and Institutional Frameworks for Invasive Alien Species.” In Invasive Alien Species: A New Synthesis, edited by Mooney HA, Mack RN, McNeely JA, Neville LE, Schei PJ, Waage JK, 223–84.

Soanes K, Lentini PE. 2019. “When Cities Are the Last Chance for Saving Species.” Frontiers in Ecology and the Environment, April, fee.2032. https://doi.org/10.1002/fee.2032.

SVA. 2016. “Consolidated Report on Indigenous Protected Areas Following Social Return on Investment Analyses.” Canberra.

Tittensor DP, Walpole M, Hill SLL, Boyce DG, Britten GL, Burgess ND, Butchart SHM, et al. 2014. “A Mid-Term Analysis of Progress toward International Biodiversity Targets.” Science 346 (6206): 241–44. https://doi.org/10.1126/science.1257484.

Tollington S, Turbé A, Rabitsch W, Groombridge JJ, Scalera R, Essl F, and Shwartz A. 2017. “Making the EU Legislation on Invasive Species a Conservation Success.” Conservation Letters 10 (1): 112–20. https://doi.org/10.1111/conl.12214.

TSS (Threatened Species Section). 2006. “Recovery Plan: Tasmanian Galaxiidae 2006-2010.” http://www.environment.gov.au/system/files/resources/6fd0ad0c-3a93-4d41-9cb5-116710d7fe12/files/tasmanian-galaxiidae.pdf.

TSSC. 2008. “Approved Conservation Advice for Alloxylon Flammeum (Red Silky Oak).” http://www.environment.gov.au/biodiversity/threatened/species/pubs/56400-conservation-advice.pdf.

Venter O, Brodeur NN, Nemiroff L, Belland B, Dolinsek IJ, and Grant JWA. 2006. “Threats to Endangered Species in Canada.” BioScience 56 (11): 903–10. https://doi.org/Doi 10.1641/0006-3568(2006)56[903:Ttesic]2.0.Co;2.

Visconti P, Butchart SHM, Brooks TM, Langhammer PF, Marnewick D, Vergara S, Yanosky A, Watson JEM. 2019. “Protected Area Targets Post-2020” 364: 6437. https://doi.org/10.1371/journal.

de Vries, FP, Hanley N. 2016. “Incentive-Based Policy Design for Pollution Control and Biodiversity Conservation: A Review.” Environmental and Resource Economics. Springer Netherlands. https://doi.org/10.1007/s10640-015-9996-8.

Ward MS, Simmonds JS, Reside AE, Watson JEM, Rhodes JR, Possingham HP, Trezise J, Fletcher R, File L, Taylor M. 2019. “Lots of Loss with Little Scrutiny: The Attrition of Habitat Critical for Threatened Species in Australia.” Conservation Science and Practice, September. https://doi.org/10.1111/csp2.117.

Watson JEM, Evans MC, Carwardine J, Fuller RA, Joseph LN, Segan DB, Taylor MF, Fensham RJ, Possingham HP. 2011. “The Capacity of Australia’s Protected-Area System to Represent Threatened Species.” Conserv Biol 25 (2): 324–32. https://doi.org/10.1111/j.1523-1739.2010.01587.x.

Wayne AF, Wilson BA. Woinarski JCZ. 2017. “Falling Apart? Insights and Lessons from Three Recent Studies Documenting Rapid and Severe Decline in Terrestrial Mammal Assemblages of Northern, South-Eastern and South-Western Australia.” Wildlife Research 44 (2): 114. https://doi.org/10.1071/WR16178.

Weston PH, Crisp MD. 1991. “Alloxylon (Proteaceae), a New Genus from New Guinea and Eastern Australia.” Telopea.

Woinarski JCZ, Burbidge AA, Harrison PL, 2014. *The action plan for Australian mammals 2012*. CSIRO publishing.

Woinarski JCZ, Burbidge AA, Harrison PL. 2015. “Ongoing Unraveling of a Continental Fauna: Decline and Extinction of Australian Mammals since European Settlement.” PNAS 112 (15): 4531–40. https://doi.org/10.1073/pnas.1417301112.

Woinarski JCZ, Garnett ST, Legge SM, Lindenmayer DB. 2017. “The Contribution of Policy, Law, Management, Research, and Advocacy Failings to the Recent Extinctions of Three Australian Vertebrate Species.” Conserv Biol. https://doi.org/10.1111/cobi.12852.

Woinarski JCZ, Legge S, Fitzsimons JA, Traill BJ, Burbidge AA, Fisher A, Firth RS, Gordon IJ, Griffiths AD, Johnson CN McKenzie NL, Palmer C, Radford I, Rankmore B, Ritchie EG, Ward S, Ziembicki M. 2011. The disappearing mammal fauna of northern Australia: context, cause, and response. Conservation Letters, 4(3), pp.192-201.

Yiming L, Wilcove DS. 2005. “Threats to Vertebrate Species in China and the United States.” BioScience 55 (2): 147–53.

Tables

Table 1

IUCN threat categories	Threat mechanism	Conservation response	Shared conservation goal
1. Residential and commercial development 2. Agriculture and aquaculture 3. Energy production & mining 4. Transportation and service corridors 5.3 Logging and wood harvesting 6. Human intrusions and disturbance 7.2 Dams and water management/use 7.3 Other ecosystem modifications	- Direct death of individuals, reduction in population size - Destruction, fragmentation and/or degradation of habitat - Loss of food and other resources - Disturbing and harassing individuals - Exacerbate other threats (e.g. roads and invasive species)	Retain and restore habitat	Ensure adequate extent of habitat for species, via retention through halting land clearing and habitat destruction, and as a last resort, strategically locating activities to minimise impact on threatened species, and restoration where inadequate habitat is available for species recovery.
5.1 Hunting and collecting terrestrial animals 5.2 Gathering terrestrial plants 5.4 Fishing and harvesting aquatic resources	- Direct death of individuals, reduction in population size - Associated flow on effects (e.g. loss of prey species and other species-to-species interactions and associations).	Prevent species overexploitation	Manage harvesting to levels compatible with threatened species persistence, halting harvest where necessary.
7.1 Fire and fire suppression	- Direct death of individuals, reduction in population size - Destruction and/or degradation of habitat - Amplification of other threats (e.g. invasive predators) - Loss of functional processes	Manage fire regimes	Restore and/or maintain ecologically appropriate fire regimes for species persistence.
8. Invasive and other problematic species, genes and diseases	- Direct death of individuals, reduction in population size - Increased competition for resources - Habitat degradation - Flow on effects (e.g. loss of species-to-species interactions)	Manage invasive species	Eradicate, contain or manage established invasive species and diseases. Prevent new/potential invasive species and diseases from arriving. Translocate affected species to invasive-free areas.
9. Pollution	- Direct death of individuals, reduction in population size - Habitat degradation which when severe is the equivalent of habitat destruction.	Manage pollution	Prevent or reduce the impact of various forms of pollution on threatened species, through changing industrial products and practices, restoring buffers for threatened species and habitats.
11. Climate change and severe weather	- Direct death of individuals - Habitat degradation and/or destruction - Loss of suitable climatic envelope - Increased severity of other threats (e.g. fire, drought)	Mitigate climate change	Limit net GHG emissions and increase natural CO_2 sequestration. Ensure resilient areas of habitat and broader ecosystems that protect this habitat from climate impacts are safeguarded and managed.

Table 1: A summary of each IUCN threat category, the corresponding broad conservation response, shared conservation goal. IUCN threats *10. Geological Events* and *12. Other threats* were excluded from this analysis.

Table 2

		Plants	Birds	Mammals	Reptiles	Invertebrates	Fishes	Frogs	All	The number of taxa requiring single response
Total number of taxa in each group		**1212**	**84**	**74**	**51**	**49**	**34**	**29**	**1532**	**171**
Retain and restore habitat	***% of taxon***	*86%*	*89%*	*86%*	*84%*	*86%*	*91%*	*100%*	***86%***	***69 (5%)***
Prevent direct species exploitation	***% of taxon***	*16%*	*27%*	*11%*	*14%*	*31%*	*44%*	*3%*	***17%***	***10 (<1%)***
Manage fire	***% of taxon***	*69%*	*67%*	*61%*	*43%*	*69%*	*15%*	*41%*	***66%***	***27 (2%)***
Manage invasive species	***% of taxon***	*79%*	*95%*	*97%*	*82%*	*78%*	*97%*	*100%*	***82%***	***53 (3%)***
Manage pollution	***% of taxon***	*16%*	*19%*	*7%*	*18%*	*24%*	*65%*	*45%*	***18%***	***0 (0%)***
Mitigate climate change	***% of taxon***	*32%*	*56%*	*38%*	*29%*	*45%*	*56%*	*45%*	***35%***	***12 (<1%)***

Table 2: The number and percentage of Australian threatened taxa from each taxonomic group ('taxon') that would benefit from each broad conservation response.

Figures

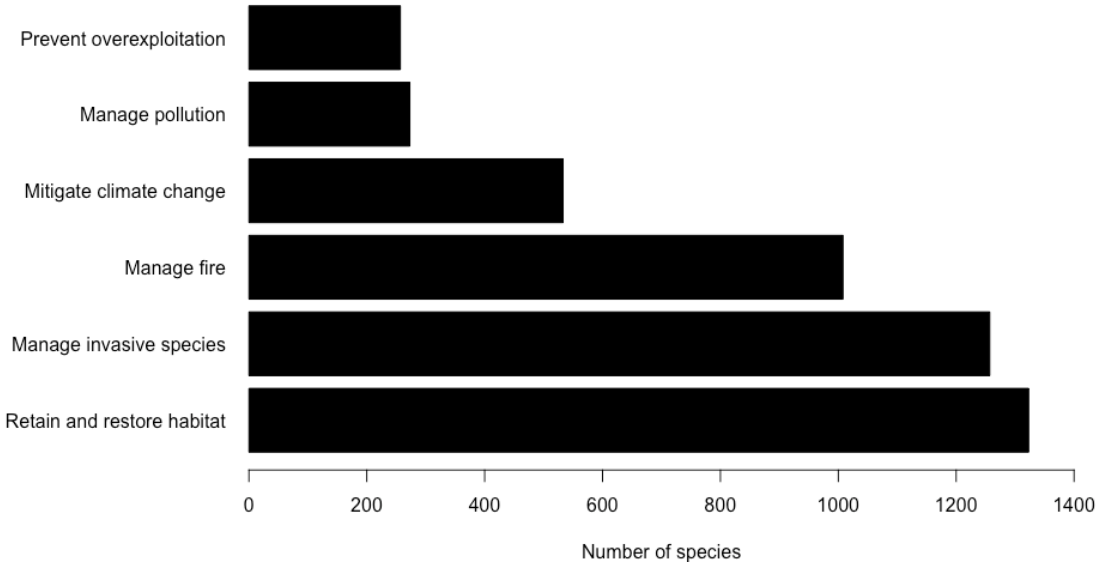

Figure 1: The number of Australian threatened species (n=1,532) that would benefit from different conservation responses based on the threats they face.

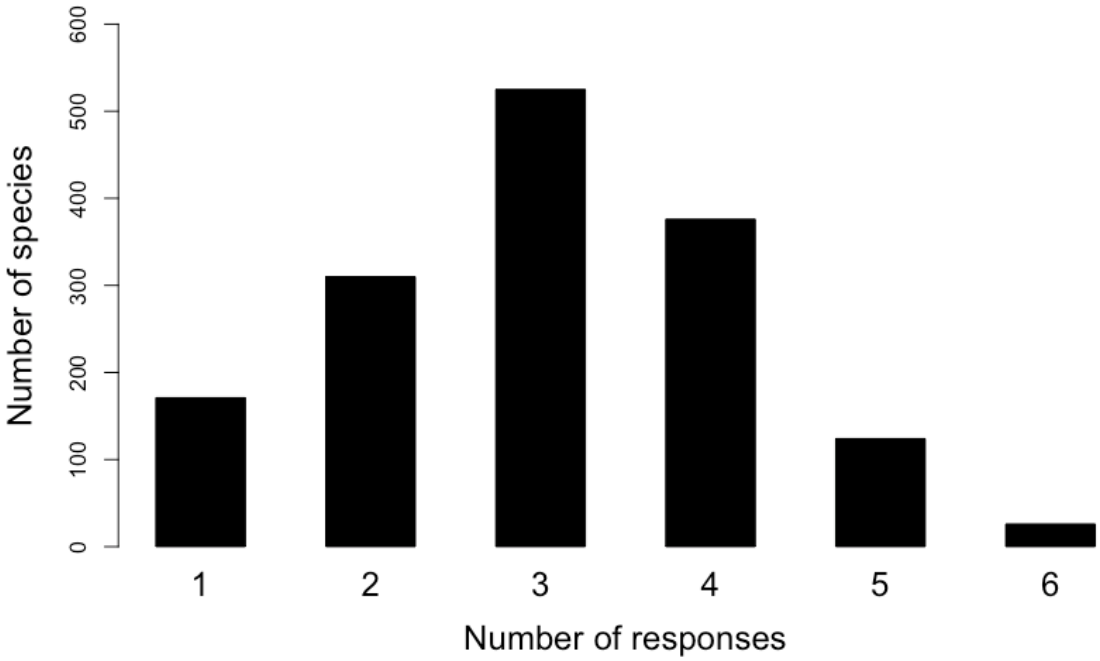

Figure 2: The number of Australian threatened species that would benefit from one or combinations of up to six broad conservation responses.

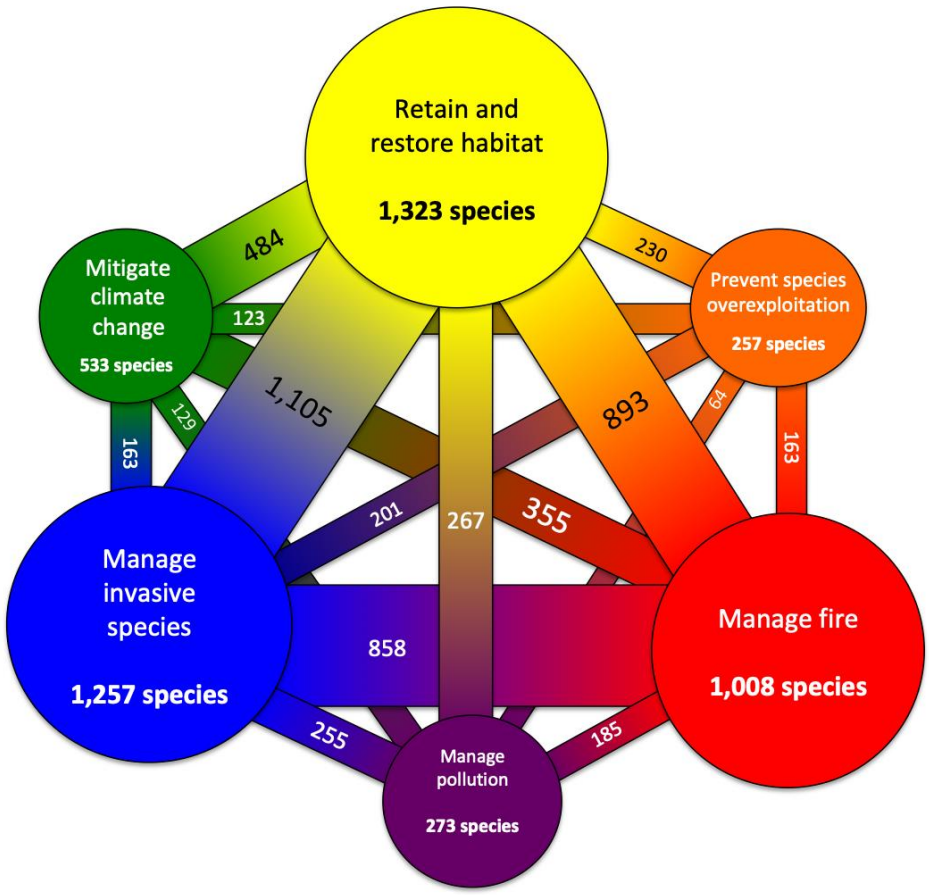

Figure 3: The number of Australian threatened taxa that would benefit from each conservation response (circles) and the number of taxa that would benefit from each pair of conservation responses (lines connecting circles). The number of species needing each conservation response and combination of responses are shown inside circles or lines. The size of circles and the thickness of lines connecting them are scaled to approximate the number of taxa benefited. Note that combinations of three or more required responses are not depicted.