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# No More Extinctions: Recovering Australia's Biodiversity

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## Keywords

climate change, conservation, recovery, threats, threatened species

## Abstract

Most conservation programs and laws aim to prevent extinction. However, there is a gulf between such aspirations and the current reality of escalating biodiversity loss. This review focuses on efforts to prevent extinctions in Australia, but much of this consideration is likely to apply globally. As context, we consider the reasons for trying to prevent extinction, review Australia's extinction record, and note that there are likely to be many more extinctions than formally recognized. We describe recent cases where conservation actions have prevented extinction. We note that extinction is a pathway rather than solely an endpoint, and many decisions made or not made on that pathway can determine the fate of species. We conclude that all looming extinctions can and should be prevented. This will require transformational change in legislation, increased resourcing, more consideration of poorly known species, and increased societal recognition of the need to be responsible for the care of country.

# INTRODUCTION

One fundamental objective of biodiversity conservation is to prevent the extinction of species; indeed "preventing extinction is the central driver of almost all conservation action" (1, p. 390). However, there are many challenges in preventing extinction and many failures: The current global extinction rate is approximately 10 to 500 times greater than the background rate (about 0.05 to 2 extinctions per million species years) and is accelerating (2, 3). Although extinction typically is perceived as the death of the last individual of a species, extinction is the culmination of a pathway of preceding choices. While we describe Australia's extinction record, and note some examples where extinctions have been averted, our principal objective is to describe how to prevent further extinctions in Australia.

## Why Prevent Extinctions?

Human societies and economies are inextricably linked to the natural world; hence, our existence depends upon the well-being of nature (4). Part of this rationale is utilitarian: Many species have instrumental value because they provide, or potentially provide, resources (such as food, pharmaceutical products, ecosystem services) of economic value, so the loss of any species may diminish the resources available to humanity (5). People derive a range of health benefits from connecting with intact nature (6) and are emotionally wounded (solastalgia) by extinctions and other biodiversity degradation (7). Particularly among First Nations people, many species have profound cultural or spiritual importance, and their loss may represent a tear in that cosmology (8). Some argue that our society has ethical responsibilities to protect biodiversity and the natural world in general (9). There may be a religious component of this concern; for example, Pope Francis (10) recognized that "Because of us, thousands of species will no longer give glory to God by their very existence, nor convey their message to us. We have no such right." Intrinsic rationales include the argument that all species have a right to exist, arguably including legal rights (11), particularly for those listed as threatened under legislation (12). There is also a moral obligation for intergenerational equity—to pass to our descendants a world that is as diverse and healthy as the one we have inherited (13).

Conversely, arguments are made that we need not be concerned about extinctions. Over the long course of evolutionary history, extinctions are "natural" and inevitable. Some have disputed that species have any inherent right or that humanity has any duty of care for them (14). Extinctions may also be treated as an inevitable consequence of, and collateral damage to, our society's way of life and demand for resource exploitation, for example, that it may be considered appropriate to preference some actions (e.g., mine development) even if an extinction is a possible or likely consequence (15).

Australians want extinctions to be prevented, are willing to pay (variably, for different species) to prevent extinction (16), and consider that governments should spend whatever it takes to prevent extinctions (17). However, such support is relative and contextual: If forced to make a choice in a hypothetical wildfire scenario between protecting a single human or preventing the extinction of a snail species in that wildfire, Australian respondents overwhelmingly preferred to save the human (18).

## Making Choices: Should We Try to Save All Species?

There is much contention about whether all species can and should be saved from extinction and, if not, what processes should be used for prioritizing the species to save. The rationales and value systems involved in seeking to prevent extinction differ among people, and some species are valued more than others, because of their utility, taxonomic distinctiveness, or significant ecological role, or because they are perceived as beautiful, charismatic, familiar, or iconic (19–21). Such valuations permeate conservation efforts globally (22, 23). Typically, investment in conservation is far higher for iconic vertebrate species than for poorly known invertebrates, and the extinction of the former is mourned more than the latter (24).

The Australian government (25) aims to prevent any further extinctions, to preserve all species. However, some have argued that to try to prevent all extinctions is delusional and impossible (26), especially given escalating threats and risks of biodiversity loss associated with global climate change. A conservation focus on individual imperiled species can help tap into human empathy and may be appropriate when these constitute a manageable number or will bring co-benefits to many other species. However, many Australian ecosystems are in a state of collapse (27), so preventing a few extinctions might come at the expense of managing entire assemblages of interconnected species. Halting or reversing the momentum of decline for a larger number of threatened but currently less imperiled species may be a better use of scarce resources than focusing on a few, especially because the costs of conservation actions may magnify the closer a species is to extinction. However, this form of conservation triage is confronting because it adopts slippery slope ethics—countenancing any extinction subverts the ethical basis for preventing extinctions more generally—and assumes a finite, inadequate pool of conservation funding (28, 29).

One approach is to use structured decision-making to prioritize threat management actions and species for conservation investment, typically with the objectives of optimizing return on investment, maximizing biodiversity benefit, reducing risks of extinction, or minimizing the number of extinctions (30–33). The resources needed to prevent extinction of the species most at risk (34) can then be quarantined and the remaining funding optimized to maximize conservation benefit. Such formal approaches can also highlight knowledge gaps that currently constrain conservation effectiveness, and hence prioritize research to overcome such ignorance. The Saving Our Species program in New South Wales is implementing an explicit strategic prioritization based on estimating what portfolio of actions across all threatened species is most likely to reduce the collective extinction risk over a 100-year period (31). Recently, the Australian government has prioritized threatened species (and places) for conservation investment based on multiple principles and objectives, as well as analyses of parameters representing risk of extinction, shared threats and potential collateral benefits, management feasibility and effectiveness, taxonomic distinctiveness, societal value, and representativeness (of taxonomic groups and geographical spread) (25). This analysis resulted in 110 threatened species (and 20 places) being prioritized for investment. However, any such subsetting will inevitably leave a residue of unselected species, highlighting a need for a portfolio of approaches and funding sources to prevent extinction. The challenge is to spread, or grow the pool of, investments (and to implement other fundamental changes in governance) so that all looming extinctions are prevented by urgent responses; to take proactive actions to control those threats that will drive declines and imperilment for many more species; and to take more strategic actions that ultimately provide long-term fixes (such as habitat restoration). At least for Australia, and probably globally, all recent extinctions could have been prevented (35), and almost any future extinction probably can be prevented given sufficient resourcing, knowledge, and commitment.

## Extinction as a Pathway: Preceding Steps and Recovery Post Prevention

Extinction is often conceived as the death of the endling, the last individual (36). However, although such an event is momentous, extinction is not a single final event in isolation. Rather, it can also be conceived as a pathway leading to that point (37), often involving the cumulative extirpation of subpopulations. A historical series of events form part of this extinction process, and actions taken or not taken along this pathway can change a species' destiny and offer options for

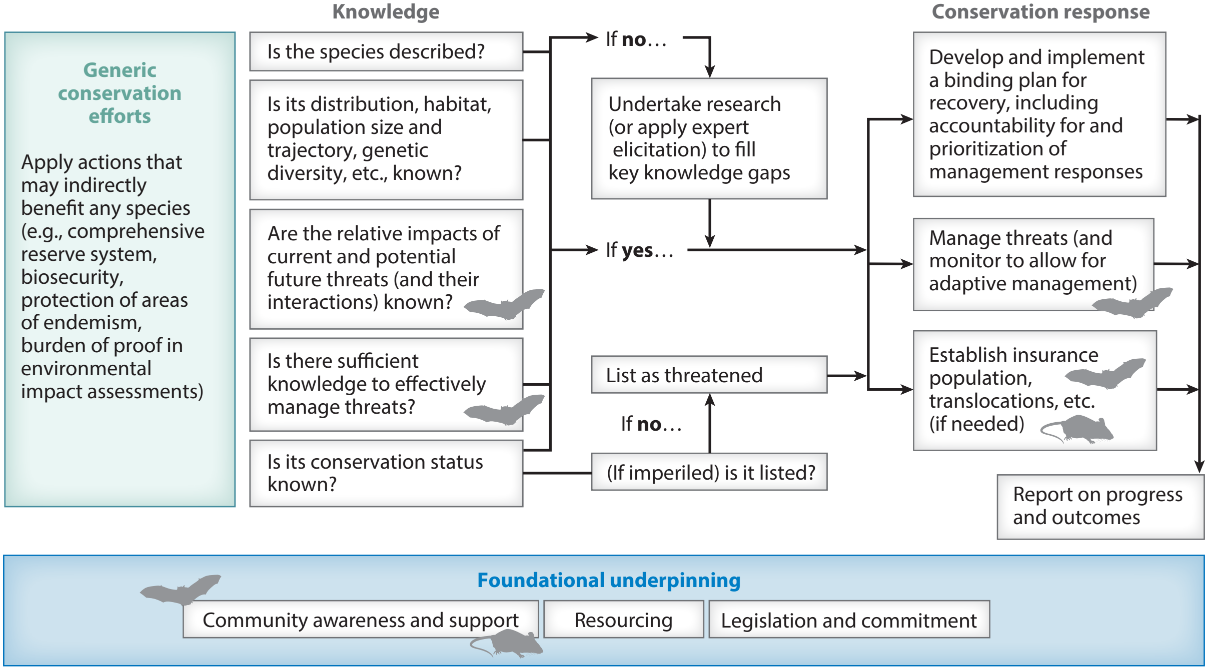


**Figure 1**

Basic pathway for preventing extinctions. Failures in any of the steps on this pathway may result in extinctions. Failings that contributed to extinction of the Christmas Island pipistrelle (*bat icon*) and Bramble Cay melomys (*rodent icon*) are indicated. Note that in some cases, the imminence of loss may mean that it is necessary to fast-track through, or miss, some steps.

avoiding extinction (38). In some cases, the pathway to extinction may involve a sequence of decisions that are individually inconsequential but collectively fatal (39). In other cases, decisions made in the absence of key knowledge have resulted in unexpectedly adverse impacts (40). In such cases, the precautionary principle should be, but often is not, applied. A retrospective assessment of three recent Australian extinctions has helped elucidate the chain of events that decide the fate of species (**Figure 1**). This sequence of events and decision points probably applies generically to other extinctions and the missed opportunities to prevent them.

There may also be a pathway after extinction, whereby the lost species subsequently disappears from human familiarity and memory (societal extinction) (41), leading to a shifting baseline in our perceptions of nature.

Preventing extinction is also not an endpoint. Rather, it contributes toward a broader objective for recovering threatened species (25, 42). These two concepts of extinction prevention and recovery are often paired; for example, the Australian Environment Protection and Biodiversity Conservation Act 1999 seeks to "in particular prevent the extinction, and promote the recovery, of threatened species" [s. 3(2)(e)]. Although the immediate and urgent conservation priority is to prevent extinction, this could mean simply maintaining species in captive breeding populations or seedbanks devoid of any presence in nature (extinct in the wild). However, such protection may buy time to maintain a species, for example, to allow research to develop effective means to control currently unmanageable threats. Ideally, once extinction has been averted, species should be returned to the status they had prior to the onset of decline (43). However, given the major transformations of most Australian environments, such a target is unrealistic for most species saved from extinction. More pragmatic objectives may be required, such as some successful return to the wild, an increasing population size, and extinction risk reduced sufficiently so that the species no longer qualifies for listing as threatened. Management actions have prevented the extinction of many species, but such success may be fragile and reversed rapidly if that support is withdrawn or weakened (44). As is the case globally (45), many Australian threatened species are likely to be conservation dependent (46) and require perpetual investment to bolster gains and stave off the recurring risk of extinction.

### De-Extinction

The concept of extinction as a definitive ending has been challenged recently by proposals for de-extinction, the resurrection of long-lost species through cloning (somatic cell nuclear transfer) or through genetic manipulation of DNA accessed from specimens (47). An iconic Australian species, the thylacine (*Thylacinus cynocephalus*), has been a standard-bearer for this venture (48). The de-extinction concept is tantalizing but controversial. One criticism is that it diverts funding from preventing the extinction of extant but highly imperiled species, although proponents claim their funding sources are different and complementary, that resources spent on de-extinction add to the total pool of conservation investment, and that lessons learned can be applied to the conservation of extant species. Ethical concerns include that any success with de-extinction will weaken the resolve of societies and governments to prevent extinction (on the premise that such a fate may be reversible); that any resurrected individuals are likely to represent only a tiny proportion of the genetic heterogeneity of the population before its extinction; and that individuals of de-extinct species will be simply forlorn curiosities, condemned to captivity because the threats that caused extinction remain (48–50). Beyond these ethical arguments, there is also an enormous practical challenge, and to date progress has been marginal.

## AUSTRALIA'S EXTINCTIONS

### National Context

Due to its long period (30 million years) of isolation, Australia's biota is highly distinctive: Approximately 90% of its biota is endemic (51, 52). First Nations people have managed the country for millennia, but colonization by Europeans from 1788 has led to extensive environmental changes and the introduction of many invasive species.

Australian legislation and policy weave together four main components that make complementary contributions toward preventing extinctions: (*a*) the establishment and management of a national reserve system, (*b*) an environmental assessment and approval process that constrains the biodiversity impacts of proposed developments, (*c*) listing of key threatening processes and development of abatement plans for such threats (an attempt to treat underlying causes of biodiversity decline), and (*d*) listing and management of species and ecological communities threatened with extinction. Listed threatened species are accorded more legislative protection than unlisted species, but the protection is limited. For every listed threatened species, a management framework is laid out in a conservation planning document, but although these indicate priorities for actions, no funding is guaranteed.

Relative to global norms, Australia is wealthy and has low population density, and its land mass is under a single government. Conservation responsibility and effort are shared by the national and state/territory governments, and many semi-government authorities, such as zoos (e.g., Zoos Victoria with its pledge of *Fighting Extinction*) and conservation nongovernmental organizations, provide major contributions toward preventing extinction. These factors should facilitate conservation of its biodiversity, including capability to prevent extinctions.

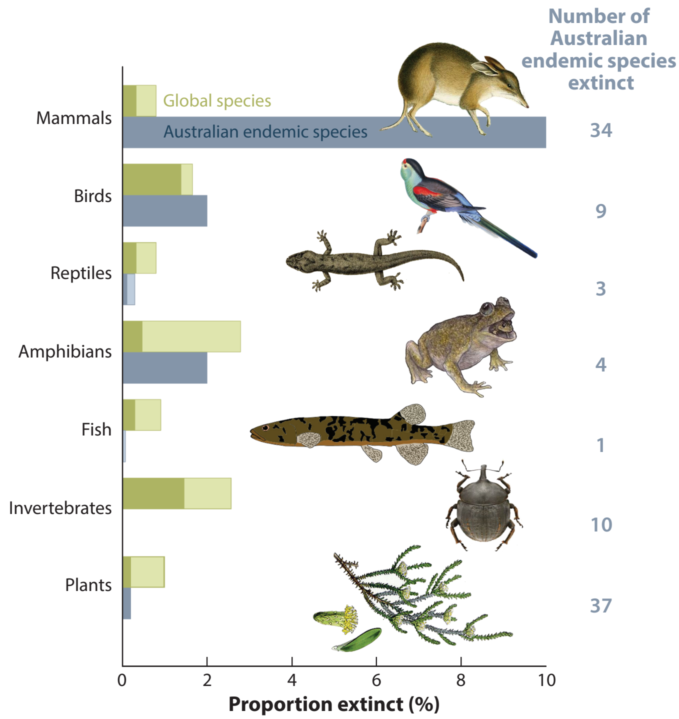


**Figure 2**

Number and proportion of extinctions in Australia since European colonization. The figure shows the numbers (on the right) of extinct (and extinct in the wild) Australian endemic species across taxonomic groups, represented by pig-footed bandicoot (*Chaeropus ecaudatus*), paradise parrot (*Psephotellus pulcherrimus*), Christmas Island forest skink (*Emoia nativitatis*), gastric brooding frog (*Rheobatrachus silus*), Lake Pedder galaxias (*Galaxias pedderensis*), Lord Howe Island ground weevil (*Hybomorphus melanosomus*), and Table Mountain daisy bush (*Ozothamnus selaginoides*). One endemic protist (seaweed *Vanvoorstia bennettiana*) is also extinct but not shown on the graph, and some other taxonomic groups (such as fungi, with no known Australian extinctions) are not shown. The blue bars show the number of extinct species as a proportion of all endemic species in each group. The green bars show global near-equivalents (the number of extinct species as a proportion of all species that have been assessed in each group), as per the International Union for Conservation of Nature database. For both Australian and global proportions, the darker shading within the bar denotes Extinct, and the paler shading denotes Extinct in the Wild plus Critically Endangered (possibly extinct). We thank Hermes Escalona for permission to use the photograph of the Lord Howe Island beetle (*H. melanosomus*).

## Australian Extinctions: Tallies and Characteristics

A 2019 review found that in the 235 years since its European colonization, 97 Australian endemic species have been formally recognized as having become extinct (53) (**Figure 2**). A further 3 species are extinct in the wild. Reflecting some of the many uncertainties about extinctions (54), 2 of the "extinct" Australian plant species have been rediscovered ("Lazarus" species) (55, 56) since that 2019 review, and recent taxonomic revisions have resulted in the lumping of one extinct plant and one extinct mammal with extant species (57, 58), thereby reducing the tally of formally recognized extinctions to 93 species. For mammals, the Australian tally and proportion of extinct species vastly outnumber those of any other continent; for other taxonomic groups, rates of extinction broadly match those elsewhere in the world (**Figure 2**).

As is the case globally (59), there are likely to be many Australian cases of unrecognized extinctions, dwarfing the tally of formally recognized extinctions. This is because little is known of many taxonomic groups. For example, an estimated 69% of Australian invertebrates and 76% of its fungi are undescribed (51). Many of these are likely to have become extinct over the last two centuries—so-called dark extinctions, the loss of a species before it has been discovered and described (60). This poor state of knowledge precludes a reliable estimate of the number of extinctions in these groups, but if Australian invertebrates have become extinct at the same rate as Australian plants and vertebrates, they have probably suffered approximately 6,000 extinctions. If they have become extinct at the same proportion as invertebrates globally, the estimated number of extinctions of Australian invertebrates is approximately 7,400 (i.e., an average rate of approximately 25–30 extinctions per year since 1788). Further evidence of underestimation of extinctions is illustrated in the fate of Christmas Island biodiversity: 51 of its 253 endemic species have not been reported for more than 100 years, yet only two of these are formally recognized as extinct (61). Undoubtedly, many more are extinct. For example, the flea *Xenopsylla nesiotes* and tick *Ixodes nitens* were obligate ectoparasites of the extinct Maclear's rat (*Rattus macleari*), endemic to Christmas Island, and have not been recorded since the host's extinction around 1902 (62, 63). This case also illustrates the phenomenon of coextinction, the consequential loss of associated species (such as obligate pollinators and parasites) that may accompany the extinction of any given species, magnifying the rate of extinctions (62, 64).

Uncertainty about whether a species is extinct or extant is not restricted to poorly known taxonomic groups. For example, there is doubt for some Australian birds [e.g., buff-breasted button-quail (*Turnix olivii*), last definitively recorded in 1924 (65)]. An extreme case is that of the smooth handfish (*Sympterichthys unipennis*): This was one of the first Australian fish species to be described (in 1817, following the collection of a single individual near Hobart in 1802), but there have been no subsequent records. In this case, its status (as either extinct or data deficient) has been contested (66), and the International Union for Conservation of Nature (IUCN) concluded that the survey effort has been insufficient to demonstrate extinction (67). To help try to resolve such uncertainty, recent attempts have been made to provide a consistent numerical approach to estimating the likelihood of extinction for such lost species based on search effort and detectability (68). For example, with only four records since 1900, the probability that the Christmas Island shrew (*Crocidura trichura*) is extinct has been calculated as 96.3% (69). Notwithstanding the near certainty of its loss, it is still not formally recognized as extinct.

Happily, some long-lost species have persisted, although failure to detect them for many years may indicate that their hold on existence is tenuous. For example, notwithstanding many targeted searches, the Victorian grassland earless dragon (*Tympanocryptis pinguicolla*) was not reported for more than 50 years (from 1969) until its rediscovery in 2023 at a single site for which development was proposed. This serendipitous rediscovery has prompted protection of the site and the development of a successful captive breeding program: Its otherwise likely extinction has been averted or forestalled.

In part, the marked incompleteness of the formal listings of extinct Australian species is because listing requires compelling evidence, a barrier for poorly known species. The IUCN defines extinction as cases in which "there is no reasonable doubt that the last individual has died" and "exhaustive surveys have been undertaken in all known or likely habitat throughout its historical range" (70). Part of the rationale for such a high evidentiary bar is that the erroneous listing of species as extinct may result in conservation neglect for species that may actually be extant: "extinction by assumption" or the "Romeo error" (71). This may have been the case for the white-chested white-eye (*Zosterops albogularis*), which was listed as extinct under Australian legislation in 2000 but probably then still extant and desperately needing conservation support (72).

Australian extinctions have included some highly iconic species, most notably the thylacine, which was Australia's largest carnivorous marsupial and the sole recent representative of the family Thylacinidae. However, less spectacular Australian extinctions have also marked the ending of long evolutionary histories. For example, genetic analysis demonstrated that the extinct Christmas Island forest skink (*Emoia nativitatis*) diverged from its closest living relative 13 million years ago (73).

Island endemic species represent a disproportionately large component of Australian extinctions: 17 of the 93 formally recognized extinct species were restricted to islands, whereas such islands comprise only 0.5% of the Australian land mass. The preponderance of island species in the set of Australian extinctions (and in the set of highly imperiled species) is consistent with a global pattern of the susceptibility of island species (74, 75), due largely to their predator naivety, vulnerability to novel disease, small population size, and typically low reproductive output. Likewise consistent with global patterns, most extinct mainland invertebrates, plants, and frogs had very small ranges (53). However, many of the now extinct Australian mammals had vast ranges (76), and some Australian regions now have <50% of the (non-bat) mammal species they had 200 years ago (77), resulting in marked and extensive losses of ecological function (78) and Indigenous cultural integrity.

Although dating many of the extinctions is challenging, because species may have persisted long after the last confirmed record (79), the Australian extinction rate has been reasonably uniform since about the 1830s (53). The most recent formally recognized extinctions have been the Christmas Island pipistrelle (*Pipistrellus murrayi*; last recorded in 2009) (38), Christmas Island forest skink (last recorded in the wild in 2010 and last captive animal died in 2014), and Bramble Cay melomys (*Melomys rubicola*; between 2009 and 2011). Additional species have become extinct since these, but such loss has not yet been formally recognized, for example, the *Banksia montana* mealybug (*Pseudococcus markharveyi*), whose last individuals were extirpated by wildfire in December 2019 (80).

The number of Australian species listed as threatened continues to increase, particularly for species in the most imperiled status (Critically Endangered, from 146 in 2010 to 395 in January 2024). The rate of extinctions of Australian species is predicted to increase five- to tenfold over the next few decades (34, 81–83), under the assumption of status quo management and resourcing. Such dire predicted outcomes highlight the need for more strategic, and increased, conservation investment and a pervasive need for climate change mitigation and adaptation.

## Causality: Primary Threats

Controlling or mitigating the threats causing population loss is the self-evident key to preventing extinction. Although the evidence of causality is meager for some Australian extinctions, the primary causes have been habitat loss and introduced species (53). As an example of the latter, all Australian frog extinctions have been caused by chytrid fungus (*Batrachochytrium dendrobatidis*, resulting in the disease chytridiomycosis) (84). These main causal factors are also the main drivers of decline in Australia's extant threatened species (53, 85, 86), but the direct and indirect impacts of climate change are becoming increasingly potent (87). The extinction of the Bramble Cay melomys as rising sea level and storm surges inundated its small island home has been claimed as a global precedent, the first recent mammal extinction caused by climate change (88). Climate change consequences include the increased incidence of catastrophic drought, wildfire, and climate extremes (89); coral bleaching; and phenological disruptions of codependent species (90). Most at risk are environments and species at climatic termini [such as upland rainforests of the Wet Tropics (91) and alpine areas], because these habitats are likely to disappear with climate change, and disturbance-intolerant species, which include many phylogenetically distinctive species of great antiquity: the vestiges of an earlier age.

A profound climate change–related event was the Black Summer wildfire of 2019–2020, which burned more than 10 million hectares of forests in southern and eastern Australia, including the entire range of at least 520 species (92). Notwithstanding the consequent losses, these wildfires also illustrated what conservation authorities can do to prevent extinction, such as the successful emergency protection of the iconic Wollemi pine (*Wollemia nobilis*) (93). Comparable events are likely to recur more frequently due to climate change, resulting in repeated incidences of catastrophic loss but also marked habitat changes and simplification, as the inter-fire interval declines to a point beyond the threshold needed for the postfire recovery of many species and habitats (94).

Other threats are also increasing or novel. Myrtle rust caused by the fungus *Austropuccinia psidii* was first detected in Australia in 2010 and has since spread extensively, causing the rapid decline of, and threatening extinction for, many endemic plant species in the family Myrtaceae, a major component of many Australian ecosystems (95). A previously unknown nidovirus killed almost the entire adult population of Bellinger River snapping turtle (*Myuchelys georgesi*) in December 2014 and January 2015 (96). With increasing global connectedness (and climate change), the incidence and impacts of such new threats are likely to accelerate.

For some threats, there is no known management solution. One example is the invasive wolf snake *Lycodon capucinus*. Non-curative responses, such as translocations of affected threatened species to areas in which the threat does not occur, may provide a stopgap, and targeted research and technological breakthroughs have provided some hope for control of some other challenging threats, such as myrtle rust (97).

Some threats have easier technical solutions: Habitat loss can be controlled through the conservation reserve system, habitat restoration, and regulation of land clearing. However, the legislation has loopholes and shortcomings (including its failure to consider cumulative impacts) that have allowed the ongoing destruction of habitat for many threatened species (39). At least 7.7 million hectares of habitat for threatened species was cleared between 2000 and 2017 (98). Furthermore, historic clearing has fragmented many habitats, with isolated and nonviable populations of many threatened species twinkling out over time. There is now a momentum of decline, an extinction debt, for such habitats and species. Conservation reserves also provide inadequate safeguards against many threats, such as disease, invasive species, and climate change. Indeed, four of the five most recent Australian extinctions have been of species that occurred entirely or mostly within conservation reserves, and biodiversity in many Australian reserves continues to decline (99).

Attempts to prevent extinction are often complicated by the number of threats, which have complex and compounding interactions. Individual threatened species are affected by an average of 3 threats, with a maximum of 15 (85). For example, threats affecting the koala (*Phascolarctos cinereus*) include habitat loss and fragmentation, disease, wildfire, predation by dogs, and climate change (days of extreme heat). Such threat cocktails can make for formidable management challenges, especially if the manner of interactions among threats (and management responses) is dynamic or poorly known (100).

## Causality: Governance

Threats such as habitat loss are proximal causes of extinction, but underlying all modern extinctions is neglect or failures of governance. The three most recent extinctions of Australian vertebrates (i.e., Bramble Cay melomys, Christmas Island forest skink, and Christmas Island pipistrelle) were predictable and preventable: These species could and should have been saved. The shortcomings that contributed to, or allowed, most recent extinctions include some or all of the following factors (**Figure 1**): inadequate recognition of the imminence of extinction (or the urgent need to intervene), inadequate knowledge of the primary factor(s) driving decline, inadequate knowledge of how threats can be ameliorated, lack of strategic planning to define management priorities, insufficient resourcing, ineffective advocacy, shortcomings in biosecurity (especially for island species), insufficient protection in environmental law, lack of binding obligation by responsible governments to prevent extinctions, and insufficient specification of responsibility and accountability (15). And of course, government actions or inactions are the underlying reasons why some threats, such as climate change, exist. Unless these failings are redressed, many further extinctions are inevitable.

There is a disconnect between societal valuation of biodiversity and the reality of what governments spend on conservation. Relative to other nations, and to the number of its threatened species, funding by Australian governments has been disproportionately small and far less than is required to prevent extinctions (101). The Australian government spends approximately AUS $120 million annually on recovery efforts for threatened species, representing only 15% of the investment needed to prevent further extinctions and achieve recovery (102). In comparison, US spending on a comparable number of threatened species is tenfold higher, resulting in far greater success in recovering threatened species (102, 103).

However, the recent extinction of the *Banksia montana* mealybug reveals that extinctions can occur even when reasonable conservation efforts are made. For this species, there was adequate knowledge of its ecology, threats, and distribution; its imperiled status was formally recognized; it occurred within a well-resourced conservation reserve with comprehensive management plans; and conservation interventions (including translocations) had been attempted. Nonetheless, its status was so parlous that a severe wildfire overwhelmed the last known population in a single day (80). Once a species is reduced to a critically small population size or range, chance events can overcome conservation efforts (104).

## Showcasing Success

As is the case globally, the imminent extinction of some Australian species has been averted by management efforts (105). Such cases give hope and provide templates for conservation efforts more broadly and demonstrate that there are many pathways to recovery (106). The protection associated with more than 30 years of conservation legislation and actions has resulted in reduction in likelihood of extinction for approximately 6% of Australia's threatened animal species (46). This includes 9 threatened mammal species translocated to predator-free islands and large fenced exclosures to escape predation by introduced cats (*Felis catus*) and red foxes (*Vulpes vulpes*) (92, 107). Australian populations of humpback whale (*Megaptera novaeangliae*) recovered as a consequence of advocacy and legislative change prohibiting exploitation (108).

Islands have been particularly important for conservation success in Australia (109). Their isolation means eradication of pests and weeds is more achievable and enduring. Capability, ambition, and community support for island eradications of invasive animals have increased markedly in recent decades, although, as is the case globally, there is some opposition to killing of invasive species even if the objective is to prevent extinctions (110). The eradication of introduced mammals on the 131-$km^2$ Macquarie Island allowed many threatened species to recover (111). The recent eradication of introduced rodents from the 16-$km^2$ Lord Howe Island—notwithstanding complications of human inhabitation, rugged topography, and dense vegetation—will prevent the extinction of many highly imperiled endemic species and allow for the reintroduction of the Lord Howe phasmid (*Dryococelus australis*), one of the few threatened invertebrates to have been included in captive breeding programs (112).

Captive breeding has been important for preventing extinction. Conservation managers on Christmas Island established captive populations of Lister's gecko (*Lepidodactylus listeri*) and blue-tailed skink (*Cryptoblepharus egeriae*) shortly before the last wild individuals were killed by introduced wolf snakes (113). However, the status of both species remains tenuous: Whereas there has been some success with recent translocations of blue-tailed skinks to two islets (each approximately 2 ha) in another Australian territory in the Indian Ocean, the Cocos (Keeling) Islands, Lister's gecko is currently restricted to two captive breeding facilities with no viable wild populations (114). An extreme case of extinction averted is for the Norfolk Island morepork (*Ninox novaeseelandiae undulata*), which declined to one female in 1986. Introductions of additional birds from the most closely related subspecies led to some recovery (72), and there are now several cases of comparable genetic rescue for Australian threatened species with very small and dwindling subpopulations (115).

However, even such successes may be transient, especially if management lapses. For example, the Norfolk Island green parrot (*Cyanoramphus cookii*) has been rescued twice from almost certain extinction (116). In some cases (such as Lister's gecko), conservation efforts may result only in a twilight existence in the palliative care of captive populations. Such a fate may in most cases be preferable to extinction, but such extinct in the wild species do not contribute to the ecological function of their former existence, are likely to become habituated to the artificial conditions of captivity, and may need enduring funding support (117).

## BUILDING A BETTER CONSERVATION FUTURE

There is a vast gap between the ideal—preventing further extinction—espoused in Australian (and global) policy and legislation and the reality that threat loads are increasing and current trajectories of biodiversity loss are dire and mostly worsening. Reducing the risks and rate of extinction of Australian biodiversity is an almost insuperable challenge. However, in the following sections, we build from the successes described above, consolidate from current conservation efforts, and craft a framework to meet such challenges and transform conservation in Australia.

### How Can It Be Achieved? Examples of Imminent Extinctions and How They Can Be Averted

There is no single remedy for avoiding extinctions. Every species has a different constellation of threats and array of responses needed to safeguard it. However, many of the species that are most imperiled and challenging to conserve share some characteristics, and hence some commonalities in the types of conservation responses needed (**Table 1**).

As examples of the diversity of causation and solutions, and the magnitude of the task, we provide brief accounts of what is required for two of the most challenging cases, galaxiid fish (*Galaxias* spp.) and swift parrot (*Lathamus discolor*), representing contrasting examples of the syndromes listed in **Table 1**. These are difficult cases, but success with these should demonstrate we have capability to prevent any further extinctions.

Many of the Australian species at gravest risk of extinction are highly restricted. These include many *Galaxias* species, small freshwater fish that are highly susceptible to predation and competition from introduced trout (*Oncorhynchus mykiss*, *Salmo trutta*). In some cases, a single barrier in a waterway, such as a waterfall, is all that prevents further encroachment of trout into the last havens of these native fish (83). Galaxiid populations can also be destroyed by postfire rainfall events that lead to sediment and ash slugs that catastrophically reduce water quality. To prevent extinction of these fish, community awareness programs and regulatory and on-ground actions are needed to bolster the current barriers to trout, remove trout from some stretches of

**Table 1 A typology of species at heightened extinction risk and the conservation response required to prevent their extinction[a]**

| Predisposing factors causing extinction risk | Context | Examples | Response priorities |
|---|---|---|---|
| Poorly known (including unnamed, undiscovered) | Extinction risks, threats, ecology, management response all insufficiently known | Kangaroo Island assassin spider (*Zephyrarchaea austini*) | Taxonomic research; research aiming to fill other key knowledge gaps (e.g., distribution, threats, monitoring); application of precautionary principle; reservation and management of sites of high endemism |
| Climate terminus | Climate suitability of habitat likely to shrink to nothing | Alpine and upland rainforest species, coral reefs | Insurance populations; tighter constraints on causes of climate change; (in some cases) genetic management; management that reduces overall threat burden |
| Disturbance intolerant | Climate change will lead to increased incidence and reach of major disturbances | Nightcap oak (*Eidothea hardeniana*) | Insurance populations; tighter constraints on causes of climate change; intensive management to minimize disturbance; management that reduces overall threat burden |
| Legacy of poor governance | Decisions made that increase extinction risk and/or are not precautionary | Maugean skate (*Zearaja maugeana*) | Insurance populations; legislative change; management that reduces overall threat burden |
| Highly localized and/or very small population | Tiny remnant population, probably inbred, vulnerable to random accidents | Nightcap oak, Yalmy galaxias (*Galaxias* sp. nov. 'Yalmy') | Insurance populations; reserve establishment and management; enhanced biosecurity; translocations (where appropriate); management that reduces overall threat burden; genetic management |
| Complex ecology; basket-load of threats | Multiple interactive threats in a complex socio-political environment | Swift parrot (*Lathamus discolor*) | Insurance populations; strategic prioritization of management options; management that reduces overall threat burden; policy coordination |
| Threats with no known control | Threatened by predators or disease for which no known remedies exist | Lister's gecko (*Lepidodactylus listeri*); Bellinger River turtle (*Myuchelys georgesi*); Tasmanian devil (*Sarcophilus harrisii*); Baw Baw frog (*Philoria frosti*) | Insurance populations; translocations beyond range of threat; research into threat control; enhanced biosecurity; management that reduces overall threat burden |
| Dependent upon highly exploited habitat or resources | Tension between conservation and economic/social factors very focused in small areas | Victorian grassland earless dragon (*Tympanocryptis pinguicolla*) | Insurance populations; legislative change; habitat protection and restoration |
| Overexploited (or bycatch) | Tension between conservation and economic/social factors can be acute | Hammerhead sharks (*Sphyrna* spp.) | Legislative change; compliance enforcement |
| Transnational migrants | Protective legislation and management must be coordinated across multiple nations | Eastern curlew (*Numenius madagascariensis*) | International cooperation and global agreements |

[a]Some species may fit more than one type. In all cases, required response may also include increased advocacy and investment.

waterway, and protect waterways from sedimentation. In anticipation of wildfire, captive facilities also need to be established that can hold fish until they can be returned safely (118).

A more complex case is the swift parrot, representative of many species with multiple threats. Models predict that it is almost certain to become extinct over the next three decades if management is not improved substantially (119). It breeds only in forests of Tasmania and some offshore islands, but breeding locations vary between years depending upon the (highly variable) flowering pattern of eucalypts. In some years, critical breeding sites will be in lands subject to intensive timber harvesting. It is an obligate hollow-nester, but this essential resource continues to be diminished by clearing, timber harvesting, and wildfire, with current legislation providing inadequate protection against such cumulative impacts (120). Its extinction risk is compounded by predation of eggs, chicks, and brooding females by sugar gliders (*Petaurus notatus*) (121), introduced to Tasmania in the nineteenth century. After breeding, swift parrots migrate to mainland southeastern Australia, where their diminishing flocks disperse widely, seeking to track the complex patterning of flowering eucalypts. Habitat loss and fragmentation jeopardize this dispersive strategy, and compounding this problem, habitat degradation has favored noisy miners (*Manorina melanophrys*), despotic native honeyeaters that compete for resources and exclude other bird species (122). Preventing the extinction of the swift parrot will require a coordinated set of conservation actions implemented over many years. Among the suite of possible conservation priorities that must be implemented urgently (123) are the establishment of an insurance captive breeding population and the closing of legislative loopholes to guarantee habitat protection. Further research is also important to find ways to reduce nest predation. Investments are also needed in actions that pay long-term dividends, particularly restoration to increase habitat connectivity across its range.

## How Can It Be Achieved? Transformational Changes

Beyond the management responses required to prevent the extinction of individual imperiled species, there is a need for broad-scale changes in how biodiversity is valued and protected. Although Australia's environmental legislation has undoubtedly helped to avert some extinctions, a continuing toll of extinctions is evidence of multiple failings and weaknesses in that legislation (124). Legislative changes aimed at more effectively halting extinctions are required (125). Some of the most important and transformative include the following. (*a*) Legal rights and standing should be accorded to biodiversity, such that species are not by default owned, disregarded, or considered subordinate to our interests (126). (*b*) More accountability is needed within the governance system, such as to explicitly assign responsibilities for the implementation of actions required to prevent extinctions and to institute inquests should extinctions occur (125). (*c*) Biodiversity statistics and outcomes (such as the number of extinctions, or number of species for which extinction risk has decreased) should be embedded as part of the core of measures of the nation's state, well-being, and progress. Previous efforts to do so (127) were peripheral and have largely been discontinued, leaving only a thin veneer of biodiversity accounting included in the current national well-being index (128). (*d*) The precautionary principle should be applied routinely, particularly to increase obligations for protection of poorly known but imperiled species. For example, for unlisted species known from only one or few sites, where these sites are under threat of development, the burden of proof should fall on project proponents to demonstrate that any potentially affected species also occur elsewhere (129). (*e*) Greater protection should be provided across a comprehensive set of special areas of biodiversity significance. There should be legal requirements to identify, appropriately manage, and provide inviolate protection for critical habitat, refuges, and havens for every threatened species (107, 130, 131) and for other sites of outstanding biodiversity significance, such as centers of endemism and biodiversity-rich islands (109). (*f*) More robust and effective biosecurity should be regulated and implemented, to reduce the continuing incursions of pests, weeds, and disease to Australia and its islands (109). Finally, (*g*) efforts are needed to mandate the development and implementation of threat abatement and recovery plans and ensure that these plans have more clout.

Fundamental to preventing further extinctions is commitment. There is now such a headline commitment ("towards zero extinctions") in the Australian government's recent Threatened

Species Action Plan (25), with an explicit objective over a 10-year timeframe (2022–2032) that "new extinctions of plants and animals are prevented" and an explicit target that "species at high risk of imminent extinction are identified and supported to persist."

Conservation success or failure often depends upon the extent and continuity of resourcing. Conservation is a long-term proposition, and governments must recognize that short cycles of investment will not secure enduring benefits (132). A significant increase in government investment is needed (102), complemented by other sources, particularly contributions by business, nongovernmental organizations, and the community generally. Recognizing the need to increase the diversity of funding approaches, the Australian government recently established the Nature Repair Act, which aims to establish a biodiversity market that encourages investments by business and land owners in management actions that will benefit threatened species.

It is not only recurrent funding that is important. Increasingly, biodiversity will be buffeted by environmental catastrophes, and rapid emergency responses will be needed to secure affected species. An example of such a response was a AUD $200 million fund rapidly established by the Australian government during the Black Summer wildfires. This provided critical support that helped save and recover affected wildlife (133). Comparable funding should be secured to allow for rapid responses for future emergencies.

Ignorance increases the likelihood of extinction. Knowledge is needed to assess extinction risks, evaluate population size and trajectories, understand (and predict) the magnitude of impacts of threats causing decline, and identify the most effective management responses (**Figure 1**). For many Australian imperiled species, knowledge is inadequate for guiding conservation actions, and yet waiting for research to reveal further information may be fatal (134). Uncertainty must be factored into conservation planning and management, such as through the application of the precautionary principle and use of expert elicitation (135).

Currently, there are explicit and unstated biases in efforts made to prevent extinction, and such biases increase the likelihood of more extinctions of poorly known and less charismatic species. Funding disparity is one manifestation of this bias; for example, governments allocated at least AUD $12 million to koala recovery following the Black Summer wildfires (which burned 17% of koala distribution), far more than the collective investment in recovery for 382 invertebrate species that had all of their known range burned (136). Notwithstanding such inequity, the increasing imperilment of iconic species, such as platypus (*Ornithorhynchus anatinus*) and koala, can serve to raise awareness and galvanize community concern about biodiversity loss more generally.

Undescribed species are largely dealt out of legal protection and community concern. For example, the relevant global conservation target is to "ensure urgent management actions, to halt human induced extinction of *known threatened* species" (emphasis added, Target 4: Kunming-Montreal Global Biodiversity Framework). The commitment excludes trying to prevent the extinction of undescribed species or those not formally listed as threatened. This is a vortex of conservation neglect: There is typically little public concern for invertebrates and fungi, so disproportionately few resources are directed at resolving their taxonomy or status, so they remain unlisted and unprotected. Should they become extinct, such extinction typically is not recognized; therefore, the degree and risk of loss remain largely underappreciated (137, 138). A linked series of actions can help avoid such extinction by ignorance or neglect. A change in mindset to a more egalitarian approach is fundamental, although we recognize that people generally, and hence governments, will value koalas more than native cockroaches or mosquitoes (21, 139). To reduce the likelihood of extinctions, investment in taxonomic research and on the status (distribution, population size and trajectory), threats, and management needs of poorly known species must be prioritized. Recent advances in e-DNA and metabarcoding markedly increase capability for such research (140). However, even as technological advances allow us to better document and understand the natural world, that world is diminishing and becoming ever more unstable.

As is the case globally (141), many described Australian species have not been recorded in recent decades (61). Some of these are formally recognized as threatened; others are not. Such species could be listed as plausibly extinct, and a list of plausibly extinct species may help to provide a more accurate estimate of the actual extent of Australian extinctions and provide a stimulus for the community and researchers to prioritize targeted searches for such species (141).

Monitoring is critical in the fight to prevent extinction, because it can provide warnings of unexpected declines or of the imminence of extinction and hence the need for urgent management response (134), help identify causality and changes in the occurrence and impacts of threats (142, 143), and provide evidence of management effectiveness and recovery (144). However, although existing monitoring is documenting population trajectories of some threatened species (145), many are not monitored, or, if monitored, such monitoring is inadequate (146). One positive recent development is the vast increase in monitoring data contributed by the public (147). Many technological advances, such as machine learning approaches to sift and manage massive data sets from passive image or acoustic data collections, are also helping to increase monitoring efficiency, spread, and resolution (148).

The world is changing. Australia's biodiversity will be exposed to new threats and intensified impacts of existing threats. Preventing extinctions will become an increasingly formidable task, and one increasingly reliant on planning and preparedness for a different future. Approaches can and must be taken to build resilience and adaptation in Australian biodiversity. Such actions should include (*a*) translocating species to anticipate changing climatic conditions and to spread risks under scenarios of more frequent environmental catastrophes; (*b*) establishing insurance populations of imperiled species; (*c*) controlling tractable threats that may be amplified by climate change or that compound climate change impacts; (*d*) building more robust biosecurity systems; and (*e*) developing plans and implementing management to maintain as much as possible of those environments (such as long-unburnt habitat) that may be most diminished by climate change. And of course, fundamental to the conservation outcomes of the future will be striving harder now to take actions that will limit climate change.

Societal support and advocacy are critical to prevent further extinctions. Education, personal experience, narratives about extinct and threatened species, ceremonial mourning, literature, and art can all serve to raise the cultural appreciation and value of threatened species and catalyze society's sense of regret and anguish about extinctions and support for preventing them (149–151).

Extinctions will continue to occur so long as our society ignores them or tolerates them as a collateral consequence of a lifestyle, economy, and ethics that is apart from and can disregard nature. This worldview is diametrically opposed to the First Nations cultural perspective that we are part of the natural world and have responsibility for the caring of country. Australian society would do well to pay more respect for and share such a worldview.

## Global Reprise

Conservation is a global concern. One example is the need for international collaboration for those components of Australian biodiversity that migrate internationally (such as shorebirds), for which conservation failure in any part of the range may subvert efforts elsewhere.

The challenges confronting Australian biodiversity mostly also apply globally, especially as the world is increasingly interconnected and climate change increasingly trumps other threats and threatens to overwhelm local or national conservation responses. There is a daunting risk that extinction rates will escalate catastrophically as global tipping points are breached and ecosystems collapse. This dire future can be averted, but it will require transformational change, based on how much we consider and care for the natural world and for the destiny we wish to bequeath future generations.

## DISCLOSURE STATEMENT

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