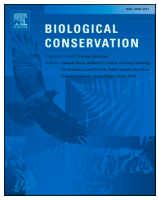
Biological Conservation 279 (2023) 109946

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon



Lights at the end of the tunnel: The incidence and characteristics of recovery for Australian threatened animals

John C.Z. Woinarski [a], Stephen T. Garnett [a], Graeme Gillespie [e], Sarah M. Legge [a,b], Mark Lintermans [c], Libby Rumpff [d,*]

[a] Charles Darwin University, Darwin, Northern Territory 0810, Australia
[b] Fenner School of Environment & Society, The Australian National University, Canberra, Australian Capital Territory, Australia
[c] Centre for Applied Water Science, Institute for Applied Ecology, University of Canberra, ACT 2601, Australia
[d] School of Ecosystem and Forest Sciences, The University of Melbourne, Parkville, Victoria, Australia
[e] Conservation and Restoration Science, Science, Economics and Insights Division, Department of Planning and Environment, Parramatta 2150, New South Wales, Australia

ARTICLE INFO

Keywords:
Conservation
De-listing
Recovery
Threatened species

ABSTRACT

Recovery of threatened species is a widely recognised conservation goal. We assess the incidence and characteristics of recovery for threatened Australian animals from the establishment of Australia's national environmental legislation in 2000 to 2022. Formal de-listings have been few, and mostly not indicative of actual recovery. However, we assessed that 29 taxa (1 fish, 4 frogs, 1 reptile, 8 birds and 15 mammals), representing 6.5 % of the 446 species that we consider were justifiably listed as threatened, have recovered over this period such that they no longer meet the eligibility criteria for listing as threatened.

Most of the recovered species are mammals whose previous decline was due to introduced predators. Their recovery has been enabled by sustained management actions (establishment of predator-free havens, translocations and predator control). The lack of recovery of invertebrates is possibly because these have received little conservation investment. The limited recovery of fish is due to limited capacity for abating the threats of introduced fish predators and of exploitation and degradation of aquatic systems. Species threatened by habitat loss and degradation, fire and climate change are under-represented in recoveries.

De-listing of the taxa that we assess here to have recovered would provide a tangible recognition and indicator of conservation success and help maintain the integrity of the threatened species list. However, most of the recovered species would rapidly become eligible for re-listing should their conservation management be withdrawn. Although there is a prevalent trend for decline of Australia's threatened species, these recoveries merit recognition.

1. Introduction

Much of the world's biodiversity is in decline (Westveer et al., 2022). This trend is evident in increasing numbers of species being listed as threatened (e.g., https://www.iucnredlist.org/resources/summary-statistics). Most such listing processes have an objective relating to improving the conservation status of the listed threatened species, ideally to such an extent that the species has recovered, and no longer meets any eligibility criteria for listing as threatened. Globally, some cases of recovery have been recognised (Hoffmann et al., 2010), for example through the IUCN's Green Status assessments (Akçakaya et al., 2018; Grace et al., 2021).

However, in most cases, threatened species are not recovering, but rather continuing to decline (Butchart et al., 2007; Waldron et al., 2017). Australia is typical of this global trend. For example, Bayraktarov et al. (2021) reported that for 65 threatened Australian bird species with adequate monitoring data, abundance declined on average by 44 % over the period 2000 to 2016. Likewise, for 71 threatened Australian mammals, abundance declined by an average of 35 % between 2000 and 2017 (Tulloch et al., 2023). The tendency for status deterioration for Australian threatened species is also evident in the far larger number of listed animal species whose conservation status has been up-listed (64

* Corresponding author.
E-mail address: lrumpff@unimelb.edu.au (L. Rumpff).

https://doi.org/10.1016/j.biocon.2023.109946
Received 9 November 2022; Received in revised form 18 December 2022; Accepted 30 January 2023
Available online 6 February 2023

species) than down-listed (10 species) over the period since the establishment of Australia's national environmental legislation, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), in 2000. This tendency for lack of recovery or ongoing decline for listed threatened species represents a significant conservation failure. The terminus for such failure is extinction. At least five of the animal species listed as threatened under the EPBC Act have become extinct subsequent to and notwithstanding their listing as threatened: Christmas Island pipistrelle *Pipistrellus murrayi* on 26 August 2009 (Woinarski, 2018), Christmas Island forest skink *Emoia nativitatis* on 31 May 2014 (Woinarski et al., 2017; Woinarski et al., 2019), Bramble Cay melomys *Melomys rubicola* between 2009 and 2011 (Waller et al., 2017), *Banksia montana* mealybug *Pseudococcus markharveyi* in January 2020 (Moir, 2021), and white-chested white-eye *Zosterops albogularis* between 2000 and 2009 (Garnett and Baker, 2021).

To help counterpoint such failures, and to seek conservation lessons that can be applied more broadly, we aim here to describe the alternative terminus, the cases of recovery of Australia's threatened animal species. Documentation of such cases of recovery can provide guidance for the management of other threatened species, and provide hope and a qualified basis for optimism for those involved in threatened species management to demonstrate that successful conservation is possible. Here, we define recovery by two characteristics: (i) the species was formerly (i.e., since 2000) appropriately listed under the EPBC Act as threatened (i.e., it met the eligibility criteria); and (ii) the species now no longer meets any criteria for listing as threatened.

This simple objective belies some interpretational challenges (Table 1). Many cases of de-listing are due to errors in the original listing, made evident with the accrual of more information that, with hindsight, demonstrates that the listed species never actually met the eligibility criteria for listing as threatened (change type 12 in Table 1). This interpretational challenge is magnified by the lack of, or limited, documented information about the eligibility of listed species in the early years of the EPBC Act: for example, at the Act's inception (in 2000), most of the species initially included as threatened (273 animal species, representing 53 % of all 518 animals listed up to October 2022) were simply transferred from listings under a previous Act (which used different eligibility criteria), and very few (14, or 5 %) of these initial listings included any documentation of listing criteria.

A further interpretational constraint is that under the EPBC Act the conservation status of threatened species is not required to be subject to regular review, such that changes in the values of those parameters relevant to categorising conservation status (e.g., population size and trajectory, number of locations, extent of occurrence) are not routinely reported, and do not routinely inform, and are not routinely reflected in, changes in the listed status of species. This lack of formal periodic review for listed Australian threatened species contrasts with the situation in the United States where the *Endangered Species Act* mandates that relevant government departments must review the status and trend of every listed species with a recovery plan every five years to report on progress (Evansen et al., 2021). Likewise, there are comparable regular reviews of the global conservation status for some animal groups (Butchart et al., 2006).

Another complication for documenting recovery in Australia is that the EPBC Act stipulates that species should not be de-listed – even if they no longer meet eligibility criteria for listing – if de-listing them is considered likely to have a detrimental effect on the species' subsequent survival. Hence, some species are retained on the list as threatened, even though they no longer meet the eligibility criteria.

Any assessment of the incidence of recovery in Australia's threatened species is also compromised by the biases and non-comprehensiveness of such listings, most notably with only a very small proportion of Australia's imperilled invertebrates being formally assessed and listed as threatened (Walsh et al., 2013). The non-congruence between formal listing under the EPBC Act and actual imperilment is evident also in a recent review of the status of Australia's freshwater fish: only three of the 22 most imperilled species, many close to extinction, are listed as threatened under the EPBC Act (Lintermans et al., 2020).

To address some of these challenges, we reviewed all of the EPBC Act listings of threatened animal species, using available evidence about conservation status, to assess whether the species still met eligibility criteria for listing as threatened. Our main sources included recent expert assessments for comprehensive sets of Australian biodiversity, including all Australian freshwater fish (Lintermans, 2017; Lintermans et al., 2020; and a series of recent IUCN accounts), frogs (Gillespie et al., 2020; Geyle et al., 2021b), squamate reptiles (Chapple et al., 2019), freshwater turtles (Van Dyke et al., 2018), birds (Garnett and Baker, 2021) and mammals (Woinarski et al., 2014b). There has been no comparable recent conservation status review encompassing Australian threatened invertebrate species, with the exception of butterflies (Geyle et al., 2021a).

Table 1
Interpretation of combinations of threatened species listing across two time periods (Time 0 – in this study 2000; and Time 1 – in this study 2022). Note that eligibility for listing is here considered to be actual fit (i.e., where possible informed by subsequent evidence). Our focus in this paper is particularly on change types numbered 3 and 4, but we note also change types 2, 7 and 8. Note that to simplify this comparison, the Table does not consider changes within threatened categories (e.g., from Vulnerable to Endangered).

Time 0		Time 1		
Fit to criteria	Listed status	Fit to criteria	Listed status	Interpretation (change type)
Meets eligibility criteria for listing	Listed	Extinct		
		Meets eligibility criteria for listing	Listed	Remains validly recognised as threatened (1)
			Not listed	Mistaken de-lists (2)
		Does not meet eligibility criteria for listing	Listed	Recovered, but recovery not recognised in de-listing (3)
			Not listed	Recognised valid recovery (4)
	Not listed	Extinct		
		Meets eligibility criteria for listing	Listed	Belated recognition as threatened (5)
			Not listed	Unrecognised ongoing imperilment (6)
		Does not meet eligibility criteria for listing	Listed	Doubly erroneous: recovery not recognised (7)
			Not listed	Unrecognised recovery (8)
Does not meet eligibility criteria for listing	Listed	Extinct		
		Meets eligibility criteria for listing	Listed	Hidden actual deterioration in status (9)
			Not listed	Unrecognised actual deterioration in status (10)
		Does not meet eligibility criteria for listing	Listed	Spurious ongoing listing (11)
			Not listed	Spurious de-lists (as should not have been listed originally as threatened) (12)
	Not listed	Extinct		
		Meets eligibility criteria for listing	Listed	Recognised deterioration in status (13)
			Not listed	Unrecognised deterioration in status (14)
		Does not meet eligibility criteria for listing	Listed	Spurious assessment of deterioration in status (15)
			Not listed	Recognised ongoing non-threatened (16)

Moreover, recovery is a nuanced concept (Redford et al., 2011). For example, under the IUCN Red List (and EPBC Act) criteria, species that were eligible for listing as threatened in 2000 on the basis that their rate of population reduction was >30 % over the preceding 10 years (or three generations) (criterion A2) may no longer be eligible for listing as threatened in 2022 if their rate of population reduction over the preceding 10 years was 20 %: i.e., they may be considered valid to de-list (at least under that criterion) even though their population continues to decline. Conversely, species may be increasing over the last 10 years, and hence could be considered to have recovered, even if their current population size is only a minute proportion of their population size at the time of European colonisation of Australia (1788).

In this assessment, our objectives are to: (i) identify and enumerate Australian animal taxa that were threatened but have recovered such that they no longer meet the eligibility criteria for listing as threatened; (ii) assess the characteristics of recovered species (e.g., whether they are disproportionately distributed across taxonomic groups, threat types, ecological characteristics (e.g., island endemics) or across the criteria on which they were originally listed as threatened); (iii) describe the management actions that contributed to their improvement in conservation status; and (iv) consider whether such recovered taxa still require ongoing conservation attention. We also compare the number of recovered species with that of the United States, noting that the two countries have broadly similar numbers of threatened species (Wintle et al., 2019).

We recognise that while de-listing may be considered to be the ultimate successful outcome for threatened species management, recovery of some species may be almost impossible (Doremus, 2000). There are other important indicators and modes of conservation success, including preventing extinction, down-listing (i.e., still threatened, but to a status that is less imperilled), and conserving species such that they do not become threatened (Doremus and Pagel, 2001; Pidot, 2020). For the Australian biota, many cases of such partial success have been described recently (Garnett et al., 2018). In focusing this paper on recovery to de-listing standard, we do not intend to derogate such other forms of success: all conservation successes are important.

2. Methods

2.1. Taxa considered

We focus solely on threatened animals, on the grounds that the evidence base underlying the listing as threatened of many Australian plant species is too insubstantial, and the status of most of Australia's listed threatened plant species has not been subject to recent review (Silcock et al., 2021). The EPBC Act allows for listing of subspecies and populations: to simplify descriptions here we refer to all listed taxa as species. Eligibility criteria for listing species as threatened under the EPBC Act largely mirror those of the IUCN Red List, with eligibility thresholds for five criteria: (i) reduction in population size, (ii) small geographic range (and continuing decline), (iii) small population size and decline; (iv) very small or restricted population, and (v) quantitative analysis of population viability (for more details see Threatened Species Scientific Committee (2021)). Following the Act, we consider only the Australian population of any species that also occurs elsewhere. Although we consider all listed animal species, our principal focus is on Australian endemic species (452 of the animal species listed since 2000) and taxa with distinct breeding populations in Australia (35 species, such as the Australian population of southern cassowary *Casuarius casuarius*), rather than species which are non-breeding visitors to Australia (31 species, such as the greater sand-plover *Charadrius leschenaultii*), given that the population trajectory and conservation status of many non-endemic species may be mostly influenced by factors operating beyond Australia.

We considered all taxa that are or have been listed as threatened (i.e., Vulnerable, Endangered and Critically Endangered, Extinct in the Wild, but not including taxa listed initially as Extinct) under the EPBC Act, since its inception in 2000 until December 2022. This comprises 74 invertebrate, 56 fish (40 freshwater, 16 marine), 42 frog, 72 reptile, 152 bird and 122 mammal species. Because we sought to identify actual cases of recovery, we also evaluated, for all listed species, whether they were validly listed (i.e., met eligibility criteria) initially, in order to account for cases of spurious recoveries (i.e., case 11 in Table 1). To examine the proportional rate of recoveries (and its variation among taxonomic groups), we also tally the number of species-years of listings. This comprises the sum across species of the number of years each has been included as threatened on the EPBC Act list, with some tweaks: (i) for the three cases in which listed threatened species have been listed subsequently as Extinct, we exclude years after that formal recognition of extinction; (ii) for species that we consider have recovered, we take the mid-point of years from initial listing to 2022 (given the difficulty of being more precise for the year at which eligibility criteria were no longer met). We tally this metric for all listed species, and also for the subset of species that we consider were validly listed.

We exclude from our consideration a group of eight threatened marine fish species listed as Conservation Dependent, as this category is narrowly targeted under the EPBC Act to marine 'fish' (which is defined to include marine organisms other than reptiles or mammals) regulated under marine fisheries plans and programs.

We also do not evaluate recovery of the set of Australian animal species listed globally by the IUCN, but not under the EPBC Act. Our focus on the listings under the EPBC Act is partly because such listings have legislative clout (unlike the IUCN listings), so there is significant interest in ensuring that the list is robust. Furthermore, conservation actions for Australian animals are likely to be far more influenced by EPBC Act listings than by IUCN listings. Any consideration of IUCN listing of Australian animals adds another challenge because there are many inconsistencies with the lists of Australian animals recognised as threatened by the IUCN and under the EPBC Act (including that the EPBC Act allows for listings of subspecies and populations, and that the IUCN list is based on status across the entire global range). This lack of concordance is particularly marked for invertebrate species: as at June 2022, 67 Australian invertebrate species were listed as threatened under the EPBC Act and 338 by the IUCN, but only 23 occurred on both lists. Although our focus is in assessment of actual recoveries of EPBC Act listed species, rather than on also assessing the number of recoveries of IUCN-listed Australian animals, we note that we use information from changes in IUCN listings (and the accounts therein) to inform our assessments of recovery for EPBC Act listed species (e.g., Table 3).

2.2. Formal de-listings

We compiled all cases of formal de-listings for animal taxa that have been listed as threatened under the EPBC Act (i.e., potentially change types 2, 4, 10 and 12 in Table 1), and evaluate the factors on which those de-listings were based, using the IUCN status change categories: genuine change (i.e., the taxon was validly listed as threatened under a previous assessment, but now no longer meets eligibility criteria due to improvements in population trajectory, increases in population size, number of locations, distributional extent, etc.), new information, taxonomic review, mistake, incorrect data, or 'other' (IUCN Standards and Petitions Subcommittee, 2022).

2.3. Actual recoveries

Using all relevant information sources, we identified those validly listed threatened species that we consider now no longer meet eligibility criteria (i.e., change types 3 and 4 in Table 1). To help identify only those species with valid recoveries, we also identify those listed species that now do not meet eligibility criteria for listing as threatened, but probably never did (i.e., they were not validly threatened when listed: change type 11 and 12 in Table 1).

Conservation actions for Australian threatened animals have often included translocations. We include translocated populations in our assessment of recovery (e.g., where these may lead to increased population size, number of locations or area of occupancy) where these meet IUCN translocation standards (IUCN/SSC, 2013) – i.e., we do not include translocated populations that are essentially captive.

2.4. Characteristics of cases of recovery

We categorise the characteristics of recovered species and contrast these tallies with those for listed threatened species that have not recovered. The categories we consider are: (i) taxonomic group, (ii) listing criteria (although the criteria on which the listing was based were often not stated, especially for early EPBC Act listings), (iii) year of listing, (iv) initially assigned conservation status, (v) principal threats, (vi) whether the species is or was endemic to islands smaller than Tasmania, (vii) and whether the species' conservation management was at least nominally orchestrated by a recovery plan. We also note the type of management (or policy) actions implemented for the recovered species. To compare the principal threats for recovered species with unrecovered species, we use the compilation of threats for Australian threatened species given in Ward et al. (2021), tallying only those threats given there as medium or high impact.

Our interpretation of these characteristics is largely narrative rather than analytical, although for most of these characteristics we compare the frequency distribution across classes (e.g., for initial conservation status: Vulnerable, Endangered, Critically Endangered) between recovered species and validly listed unrecovered species, using chi-squared tests. More complex analysis is constrained given that (i) there are relatively few recoveries, (ii) many of these characteristics are strongly conflated (for example, species with more imperilled conservation statuses and listed soon after the implementation of the EPBC Act are more likely to have had recovery plans (Walsh et al., 2013)), and (iii) some characteristics are highly qualified (e.g., although a species may have nominally been managed through a recovery plan, many recovery plans were not actually implemented).

3. Results

Details of our assessments for individual species are provided in Supplement S1. We note that the eligibility fit for some species is equivocal, and in Supplement S1 we provide some documentation for species that may have recovered but for which the evidence for such status is not yet compelling.

At its inception in 2000, the EPBC Act listed 275 Australian animal taxa as threatened (i.e., excluding Extinct species and Conservation Dependent fish). Subsequently (to October 2022), 237 additional species have been added to this list.

3.1. Formal de-listings of taxa listed as threatened

Over the period 2000 to 2022, 30 species have been de-listed from the EPBC Act. However, for two of these cases (grey nurse shark *Carcharias taurus* and spotted-tailed quoll *Dasyurus maculatus maculatus*), de-listing was accompanied by simultaneous re-listing of the taxon as two separate entities (Supplement S1). Another two taxa were de-listed but re-listed in later years (ghost bat *Macroderma gigas* and western grass-wren *Amytornis textilis myall*). Hence, there are 26 cases of actual de-listings: these comprise three invertebrates, one fish, two frogs, six reptiles, five birds and nine mammals (Supplementary material S1).

Of the de-listings, most were due primarily to taxonomic changes (mostly concluding that the listed taxon was no longer validly recognised) or to new information that indicated that the taxon was never eligible for listing as threatened (Supplement S1). In some cases (e.g., the graceful sun moth *Synemon gratiosa*), the additional evidence was largely due to targeted surveys catalysed by the listing.

We consider that only three of the formal de-listings represent recoveries. The humpback whale *Megaptera novaeangliae* has exhibited major population increases since the cessation of commercial harvesting (Harrison and Woinarski, 2018). The two de-listed frogs – waterfall frog *Litoria nannotis* and common mist-frog *L. rheocola* – are more complex cases. Both exhibited rapid and severe reductions in population size and distribution over the period ca. 1988 to 1994, following the introduction of chytrid fungus, but have persisted in small remnant populations that are now stable or increasing and hence they no longer meet any listing criteria based on decline (Phillott et al., 2013; Threatened Species Scientific Committee, 2020).

3.2. Recovery not yet recognised in de-listing

Our assessment of species that have recovered but have not yet been de-listed is summarised in Tables 2 and 3, detailed in Supplement S1, and described briefly below. We consider that 43 currently listed species (one invertebrate, one frog, 10 reptiles, 23 birds and 8 mammals) did not meet eligibility criteria at the time of listing, and still do not meet them (i.e., change type 11 in Table 1): details are given in Supplement S1. Excluding these species and the de-listed species that did not meet eligibility criteria, we conclude that 447 animal species (70 invertebrates, 55 fish, 41 frogs, 54 reptiles, 124 birds and 103 mammals) have been validly listed since the establishment of the EPBC Act.

3.2.1. Taxonomic group

3.2.1.1. Invertebrates. We assessed that none of the EPBC Act-listed invertebrate species (all Australian endemics) have recovered to the extent that they no longer meet criteria for listing as threatened.

3.2.1.2. Fish. Captive breeding and translocation programs, fish passage improvements and some enhanced regulations on fishing have reduced extinction risk for several listed threatened fish species. However, we assessed that only one of the EPBC Act-listed fish species, Murray cod *Maccullochella peelii*, an endemic freshwater species, has recovered to the extent that it no longer meets criteria for listing as threatened (Tables 2, 3). This represents 1.8 % of the fish taxa that we consider have been validly listed, and a rate of recovery of 0.1 species per 100 species-years.

3.2.1.3. Frogs. In addition to the two validly de-listed frog species noted above, we assessed that two frog species still listed as threatened under the EPBC Act have recovered to the extent that they no longer meet criteria for listing as threatened (Tables 2, 3). This represents 9.8 % of the frog taxa that have been validly listed, and a rate of recovery of 0.67 species per 100 species-years.

3.2.1.4. Reptiles. Only one reptile species validly listed as threatened under the EPBC has recovered to the extent that it no longer meets criteria for listing as threatened (Tables 2, 3).

3.2.1.5. Birds. Based mainly on the review by Garnett and Baker (2021), we assessed that eight bird species that have been validly listed as threatened by the EPBC Act have recovered to the extent that they no longer meet criteria for listing as threatened (Tables 2,3). This represents 6.5 % of the bird taxa that have been validly listed, and a rate of recovery of 0.48 species per 100 species-years.

3.2.1.6. Mammals. We concluded that 15 mammal species listed as threatened under the EPBC Act have recovered to the extent that they no longer meet criteria for listing as threatened (Tables 2, 3). This represents 14.6 % of the mammal taxa that have been validly listed, and a rate of recovery of 0.85 species per 100 species-years.

Table 2
Summary table of numbers of listed and recovered species by taxonomic groups.

Taxonomic group	No. species			% recoveries all (validly listed)	Species-years: all spp. (validly listed spp.)	Recoveries per 100 species-years: all (validly listed)
	listed under the EPBC Act (no. validly listed)	delisted taxa (no. that represent actual recoveries)	No. valid recoveries not yet formally de-listed (total recoveries)			
Invertebrates	74 (70)	3 (0)	0 (0)	0	853 (798)	0 (0)
Fish	56 (55)	1 (0)	1 (1)	1.8 (1.8)	966 (952)	0.10 (0.11)
Frogs	42 (41)	2 (2)	2 (4)	9.5 (9.8)	623 (601)	0.64 (0.67)
Reptiles	72 (54)	7 (0)	1 (1)	1.3 (1.9)	1221 (777)	0.08 (0.13)
Birds	152 (124)	4 (0)	8 (8)	5.3 (6.5)	2530 (1654)	0.32 (0.48)
Mammals	122 (103)	9 (1)	14 (15)	12.3 (14.6)	2086 (1756)	0.71 (0.85)
Total	518 (446)	26 (3)	25 (28)	5.4 (6.3)	8279 (6516)	0.34 (0.43)

3.2.2. Listing criteria

It is challenging to compare between recovered and not recovered species in relation to the criteria under which they were originally listed, given that listing criteria were not documented for many species, and that many species were found eligible under more than one criterion. Table 3 lists the broad eligibility criteria for all 29 species that we consider have recovered: 16 recovered species were originally listed under criterion A (rate of population decline), 15 under criterion B (small geographic range and decline), nine under criterion C (small population size and decline), six under criterion D (very small population size), and none under criterion E (quantitative analysis). This represents a marginal and non-significant over-representation of recovered species under criterion A (55 % of recovered species cf. 28 % for unrecovered validly-listed species for which criteria were given), C (31 % for recovered species cf. 19 % for unrecovered species) and D (21 % for recovered species cf. 8 % of unrecovered species), and under-representation of B (52 % for recovered species cf. 68 % for unrecovered species) ($\chi^2 = 5.6$, df = 3, p = 0.14).

3.2.3. Date of listing

Of the 29 species that we consider to have recovered, 24 were listed under the EPBC Act in 2000; one in 2003; two in 2005 and two in 2016 (greater sand-plover and great knot *Calidris tenuirostris*). The proportion of recovered species that were listed in 2000 (83 %) is appreciably higher than for validly listed unrecovered species (46 %) ($\chi^2 = 14.1$, df = 1, $p < 0.001$).

3.2.4. Initially assigned conservation status

Of the 29 recovered species, 19 (66 %) were initially listed as Vulnerable, nine as Endangered and one as Critically Endangered; a smaller proportion (45 %) of the unrecovered species were originally listed as Vulnerable ($\chi^2 = 5.9$, df = 2, p = 0.06).

3.2.5. Principal threats

By far, the threat that affected the largest number of recovered species was introduced predators (specifically foxes and cats) (Table 4). Comparisons with unrecovered species are complicated because many species are threatened by multiple factors. However, Table 4 indicates that, relative to recovered species, unrecovered species were disproportionately threatened by climate change, habitat loss, fire, 'other', introduced fish predators, forestry and habitat degradation due to livestock and to weeds.

3.2.6. Island endemism

Ten (34 %) of the recovered species had distributions (or breeding populations) at the time of listing that were restricted to islands smaller than Tasmania, a higher proportion than for validly listed unrecovered species (17 %) ($\chi^2 = 5.8$, df = 1, p = 0.02).

3.2.7. Recovery planning

Of the 29 recovered species, 18 (62 %) species had some form of recovery plan, a higher proportion than for validly listed unrecovered species (50 %) ($\chi^2 = 3.1$, df = 1, p = 0.09).

4. Discussion

4.1. Synopsis of main findings

Our study presents – for the first time – an Australian perspective on the challenge of recovery for threatened species. Such assessment is important because, as for threatened species policy and management generally across the globe, a fundamental objective of the EPBC Act is to 'in particular prevent the extinction, and promote the recovery, of threatened species' (s 3.2.e). Hence, tallying the recoveries of threatened species helps to assess the extent to which the Act's objectives are being realised. We found that, over the period 2000 to 2022, 29 threatened Australian animal species have recovered to the extent that, in principle, they could be – or, in three cases, have been – delisted. These are important conservation gains – to some extent, an antidote to the distress of near pervasive conservation failures – and such cases of conservation success merit acknowledgement and celebration. They show that recovery can be achieved: it is not merely an aspirational goal, as has been suggested by some (Doremus, 2000). Some of these recoveries represent remarkable achievements arising from sustained and strategic conservation management.

The extent of recovery that we note here has been largely obscured previously because there has been far more focus on deterioration in the status of Australian biodiversity (Janke et al., 2022) and because the recoveries have not been acknowledged through de-listing. There is little overlap between the species complement in our assessment of recoveries and in the formal de-listings. Most of the species we consider to have recovered have not yet been de-listed, and most of the formal de-listings do not constitute recoveries (but rather consequences of taxonomic revision or newly acquired information).

4.2. Pathways to recovery

The 29 cases demonstrate that there may be many pathways to recovery. The humpback whale has recovered largely because its primary threat (hunting) was removed due to legislative and policy change, at national and global scales (Harrison and Woinarski, 2018). For three of the frog species (Australian lace-lid *Litoria dayi*, waterfall frog, common mistfrog), recovery appears to have been largely a natural equilibration or adaptation to the novel threat of chytrid fungus (Scheele et al., 2014; Brannelly et al., 2021) or because some parts of the frogs' former range have provided some protection from that threat (Puschendorf et al., 2011); this stabilisation or recovery may have also been facilitated by the imposition of some biosecurity measures. After long periods of substantial decline, the range and abundance of the growling grass-frog *Litoria raniformis* has been relatively stable over the last ca. 10–20 years, probably because the species has reached some contracted state within its former realised niche, where threats are reduced or better tolerated. Furthermore, in some parts of its range, population size has increased or at least stabilised in modified managed wetlands (Wassens et al., 2010;

Table 3
List of Australian animal taxa that are or have been listed as threatened, but now no longer meet eligibility criteria for listing as threatened. Note that the fit to eligibility criteria is not always available for some taxa, particularly those listed under the EPBC Act from soon after its establishment. Asterisk indicates non-endemic taxon.

Species	Common name	Current and previously assigned EPBC Act status (date of such listing)	Current and previously assigned IUCN status (date of such listing)	Eligibility criteria as listed under EPBC Act	Basis for considering that it no longer meets these criteria	Principal threats	Recovery plan	Reasons for recovery
Maccullochella peelii	Murray cod	VU (2003)	LC (2019), CR (1996)	A, B, C	Actual recovery over the period 2000–2022, from long period of decline	Habitat degradation due to many factors, fishing	Single species (2010)	Fishing regulations; habitat restoration; captive breeding and translocation program
Litoria dayi	Australian lace-lid	VU (2019); EN (2000)	EN (2004)	B1 + B2 (a, bi,ii)	Populations now stable or increasing, following previous rapid and severe decline	Disease	Multi-species (2001)	Natural process
Litoria nannotis	Waterfall frog	De-listed (2020); VU (2000)	EN (2004)	A2	Populations now stable or increasing, following previous rapid and severe decline	Disease	Multi-species (2001)	Natural process
Litoria raniformis	Growling grass frog, southern bell frog	VU (2000)	EN (2004)	[A2]	Populations now stable	Disease, habitat degradation, predation by introduced fish	Single species (2012)	Natural process; some habitat protection and restoration
Litoria rheocola	Common mistfrog	De-listed (2020); VU (2000)	EN (2004)	A2	Populations now stable or increasing, following previous rapid and severe decline	Disease	Multi-species (2001)	Natural process
Aprasia pseudopulchella	Flinders Ranges worm-lizard	VU (2000)	LC (2018), NT (1996), VU (1994)	B1	Populations now stable	Habitat loss	nil	Previous habitat loss now halted, in part through reservation
Amytornis barbatus barbatus	Bulloo grey grasswren	EN (2014); VU (2005)		B1	Populations now stable	Habitat loss and degradation	nil	Habitat reservation and management
*Calidris tenuirostris***	Great knot	CR (2016)	[EN (2019, 2015), VU (2012, 2010), LC (2009, 2008, 2004)]	A2	Populations now stable or declining at a rate less than threshold	Habitat loss, hunting, climate change	nil	
*Casuarius casuarius johnsonii**	Southern cassowary	EN (2000)		A2	Populations now stable or declining at a rate less than threshold	Habitat loss and fragmentation	Single species (2002, 2007)	Habitat reservation and restoration
*Charadrius leschenaultii***	Greater sand plover	VU (2016)	[LC (2019, 2016, 2012, 2009, 2008, 2004, 2000)]	A2	Populations now stable or declining at a rate less than threshold	Habitat loss, climate change	nil	
Erythrura gouldiae	Gouldian finch	EN (2000)	NT (2016, 2013, 2012), EN (2008, 2006, 2004, 2000, 1996, 1994)	[C2]	Population increasing	Habitat degradation due to livestock, fire	Single species (2006)	Habitat and fire management
*Halobaena caerulea**	Blue petrel	VU (2000)	[LC (2020, 2018, 2016, 2012, 2009, 2008, 2004)]	[A2]	Australian breeding population now increasing	Predation by cats at breeding sites	Multi-species (2005)	eradication of cats, rodents and rabbits on main Australian breeding island (Macquarie)
*Phoebetria fusca***	Sooty albatross	VU (2000)	[EN (2018, 2017, 2016, 2012, 2010, 2008, 2007, 2005, 2004,	[A2, C2]	Populations now stable	By-catch in commercial fisheries	Multi-species (2001, 2011)	Fishing regulation

(*continued on next page*)

Table 3 (*continued*)

Species	Common name	Current and previously assigned EPBC Act status (date of such listing)	Current and previously assigned IUCN status (date of such listing)	Eligibility criteria as listed under EPBC Act	Basis for considering that it no longer meets these criteria	Principal threats	Recovery plan	Reasons for recovery
			2003); VU (2000)]					
*Thalassarche melanophris**	Black-browed albatross	VU (2005)	[LC (2018, 2017); NT (2016, 2014, 2013) EN (2012, 2010, 2008, 2005, 2004, 2003); VU (2002)]	A, B, C	Australian breeding population now stable or increasing	Habitat degradation at main breeding site, by-catch in commercial fisheries	Multi-species (2001, 2011)	Habitat restoration due to eradication of rabbits on main Australian breeding island (Macquarie); fishing regulation
Bettongia lesueur Barrow and Boodie Islands subspecies	Boodie, burrowing bettong (Barrow and Boodie Islands subspecies)	VU (2000); IUCN (EN 1994; VU 1996)	NT (2019, 2008); VU (1996); EN (1994)	[B1, D]	Population now stable or increasing, more locations, larger AOO, EOO	Introduced predators	Multi-species (2012)	Island populations protected through biosecurity; many new populations re-established through translocations to predator-proof havens
Bettongia lesueur lesueur	Boodie, burrowing bettong (Shark Bay subspecies)	VU (2000); IUCN (EN 1994; VU 1996)	NT (2019, 2008); VU (1996); EN (1994)	[B1, D]	Population now stable or increasing, more locations, larger AOO, EOO	Introduced predators	Multi-species (2012)	Island populations protected through biosecurity; many new populations re-established through translocations to predator-proof havens
Dasyurus geoffroii	Chuditch, western quoll	VU (2000)	NT (2019, 2008), VU (1996); EN (1994)	[C1]	Population now stable, more locations, larger AOO, EOO	Introduced predators	Single species (1994, 2012)	Intensive control of a main threat (introduced predators), and successful translocations
Isoodon auratus barrowensis	Golden bandicoot (Barrow Island)	VU (2000)	NE	[B1 + 2]	Population now stable or increasing, more locations, larger AOO, EOO	Introduced predators	nil	Island populations protected through biosecurity; new population established by translocation to predator-proof havens
Lagorchestes hirsutus bernieri	Rufous hare-wallaby (Shark Bay)	VU (2000)	[VU (2016, 2008, 1996); EN (1994)]	[B1 + 2]	Population now stable or increasing, more locations, larger AOO, EOO	Introduced predators	Single species (2012)	Island populations protected through biosecurity; new population established by translocation to predator-proof havens
Lagorchestes hirsutus dorreae	Rufous hare-wallaby (Shark Bay)	VU (2000)	[VU (2016, 2008, 1996); EN (1994)]	[B1 + 2]	Population now stable or increasing, more locations, larger AOO, EOO	Introduced predators	Single species (2012)	Island populations protected through biosecurity; new population established by translocation to predator-proof havens
Lagorchestes hirsutus Central Australian subspecies	Mala	EN (2000)	[VU (2016, 2008, 1996); EN (1994)]	[A2, B1 + 2, C2, D1]	Population now stable or increasing, more locations, larger AOO, EOO	Introduced predators, fire	Single species (2000, 2012)	New populations established by translocation to predator-proof havens
Lagostrophus fasciatus fasciatus	Banded hare-wallaby	VU (2000)	VU (2016); EN (2008); VU (1996); EN (1994)	D	Population now stable or increasing, more locations, larger AOO, EOO	Introduced predators	Multi-species (2007, 2012)	Island populations protected through biosecurity; new populations established by translocation to predator-proof havens
Leporillus conditor	Greater stick-nest rat	VU (2000)	NT (2012); VU (2008); EN (1996)	[B, C, D]	Population now stable or increasing, more locations, larger AOO, EOO	Introduced predators	Single species (1999, 2004)	Island populations protected through biosecurity; new populations established by translocation to predator-proof havens
Macrotis lagotis	Bilby, greater bilby	VU (2000)	VU (2015, 2008, 1996, 1994); EN (1990)	[A2]	Population now stable or increasing, more locations, larger AOO, EOO	Introduced predators; fire	Single species (2006)	New populations established by translocation to predator-proof havens; some remnant populations managed through reservation and

(*continued on next page*)

Table 3 (*continued*)

Species	Common name	Current and previously assigned EPBC Act status (date of such listing)	Current and previously assigned IUCN status (date of such listing)	Eligibility criteria as listed under EPBC Act	Basis for considering that it no longer meets these criteria	Principal threats	Recovery plan	Reasons for recovery
								fire and predator control
*Megaptera novaeangliae***	Humpback whale	De-listed (2022); VU (2000)	LC (2018, 2008)	A2	Australian breeding population now increasing	Commercial hunting [formerly]	Single species (2005)	Legislative protection from hunting
Onychogalea farenata	Bridled nail-tailed wallaby	VU (2000)	VU (2016), 2008, 1996)	A, B, C	Population now increasing, more locations, larger AOO, EOO	Introduced predators, fire, climate change, weeds	Single species (2001, 2005)	Intensive control of introduced predators; new populations established by translocation to predator-proof havens
Perameles bougainville	Western (Shark Bay) barred bandicoot	EN (2000)	VU (2016); EN (2008, 1996, 1994)	[B1 + 2]	Population now increasing, more locations, larger AOO, EOO	Introduced predators	Multi-species (2007, 2012)	Island populations protected through biosecurity; new populations established by translocation to predator-proof havens
Perameles gunnii (Victorian population)	Eastern barred bandicoot	VU (2000)		[A2, B1 + 2, C1 + 2, D]	Population now increasing, more locations, larger AOO, EOO	Introduced predators	Single species (1996, 2010, 2021)	New populations established by translocation to predator-proof havens
Petrogale xanthopus xanthopus	Yellow-footed rock-wallaby (SA and NSW)	VU (2000)	[NT (2016, 2008)]	[A2]	Population now stable or increasing	Introduced predators, habitat degradation due to introduced herbivores	nil	Intensive control of introduced predators and herbivores; habitat restoration

Table 4
Threats affecting nominally de-listable species relative to all EPBC Act threatened species. Tallies of threats across all EPBC Act listed animals are from Ward et al. (2021). Threats are ordered from those affecting the largest number of unrecovered species. 'Other' comprises a large range of threats affecting relatively few species.

Threat type	No. of recovered spp. for which this is a *high or medium impact* threat	Total number of unrecovered spp. for which this type is given as a *high or medium impact* threat
Introduced predators: mammals	16 (55.2 %)	123 (32.1 %)
Fire	4 (13.8 %)	121 (31.6 %)
Climate change	3 (10.3 %)	114 (29.8 %)
Habitat degradation: livestock and introduced mammals	4 (13.8 %)	89 (23.2 %)
Habitat loss	5 (17.2 %)	76 (19.8 %)
Disease	4 (13.8 %)	44 (11.5 %)
'Other' (pollution, genetics, hunting, etc.)	1 (3.4 %)	43 (11.2 %)
Habitat degradation: weeds	1 (3.4 %)	35 (9.1 %)
Aquatic system degradation	2 (6.9 %)	34 (8.9 %)
Introduced predators: fish	1 (3.4 %)	27 (7.0 %)
Forestry	0 (0)	27 (7.0 %)
Native species	0 (0)	24 (6.3 %)
Fishing	3 (10.3 %)	23 (6.0 %)
Introduced invertebrates	0 (0)	19 (5.0 %)
Total no. of species included	29	383

Littlefair et al., 2021). Some habitat protection measures implemented for specific populations may have contributed further to its conservation, but generally only at a local scale. The recent trend for increase in population size of the Gouldian finch *Erythrura gouldiae* may also represent some largely natural process or adaptation, although at least some regional populations have benefited from targeted management of fire and the pressures imposed by livestock grazing (Legge et al., 2015). The two 'recovered' shorebirds are quirks of timing. The (Australian populations of) great knot and greater sand-plover were both listed in 2016 based on precipitous decline associated with an episode of massive loss of habitat (elsewhere in their range) in 2006, but since then (over the three generations period relevant to listing criteria), as a consequence of no further severe and acute habitat loss, the population has declined proportionally far less or been relatively stable.

Most of the recoveries we document are more clearly due to long-term strategic management. The Murray cod has benefited from decades of regulations on fishing, and captive breeding and translocations, undertaken for recreational fishing and conservation purposes (Gilligan et al., 2019). Its gradual recovery is notwithstanding ongoing deterioration in habitat quality across much of its range, and such degradation means that its recovery is reliant on ongoing active management. The recovery of the southern cassowary is largely due to extensive reservation, and legislation that has successfully halted previous rates of habitat loss (Garnett and Baker, 2021). The recovery of the highly range-restricted Bulloo grey grass-wren *Amytornis barbatus barbatus* is broadly comparable: recent reservation and targeted habitat management has protected and restored its habitat, providing some conservation security (Garnett and Baker, 2021). The recovery of the Flinders Ranges worm-lizard *Aprasia pseudopulchella* is due to reservation and curbing the rate of habitat loss within its limited range (Chapple et al., 2019). To some extent, the recoveries for sooty albatross *Phoebetria fusca* and black-browed albatross *Thalassarche melanophris* are due to regulation of commercial fishing, particularly the use of exclusion devices to reduce by-catch (Garnett and Baker, 2021).

All other cases of recovery are due to effective control of invasive animal species, particularly of foxes and cats. Eradication of introduced cats, rabbits and rodents from Macquarie Island (over the period 2006 to 2014) has led to a reversal of the previously declining populations of many breeding seabirds, including blue petrel *Halobaena caerulea* and black-browed albatross (Springer, 2018). Fourteen of the recovered species are mammals that are extremely susceptible to introduced predators (Radford et al., 2018). All have benefited from a sustained and strategic program of intensive control of predators. For most cases, this has been accompanied by translocations to a network of havens (predator-proof exclosures and islands from which predators have been eradicated) (Legge et al., 2018), resulting in increases in the number of locations, population size, area of occupancy and extent of occurrence of many threatened mammal species. These management programs have been undertaken by government agencies and conservation NGOs (Moseby et al., 2009; Kanowski et al., 2018; Algar et al., 2020). At least five additional threatened mammal species have also benefited from these management programs, but despite some improvement in status are probably still eligible for listing as threatened (Supplement S1). Future strategic expansions of this program of translocations and havens for additional predator-susceptible Australian mammals, supported by priority funding from the Australian government (Commonwealth of Australia, 2022), are likely to lead to recovery of additional currently threatened Australian mammals (Ringma et al., 2019).

4.3. Characteristics of recovered species

The recovered species are not a random subset of all Australian threatened animals. Most of the recovered species are birds and mammals. To some extent this may simply be because there are more species of birds and mammals listed as threatened. However, Australia's threatened birds and mammals also have a higher profile than threatened species in other animal groups, and have been the beneficiaries of more conservation investment than is the case for threatened invertebrates, fish, frogs and reptiles (Walsh et al., 2013), even though they are more expensive to conserve (Wintle et al., 2019). For threatened fish, recovery remains a formidable challenge, given the limited capability to abate the threat posed by introduced fish, to redress ongoing habitat degradation and to deal with the competing demands posed by exploitative use of water.

There is a strong tendency for recovered species to have been listed for a long period – indeed, most of the recovered species were listed at the EPBC Act's establishment in 2000 following listing under previous legislation, and many were subject to some conservation actions prior to 2000. This suggests that recovery may be a long-term proposition, as many of the threats that affect Australia's threatened species are deeply etched and cannot readily be moderated over a short time period (Fraser et al., 2022). The need for sustained long-term conservation management actions to recover species has been recognised globally, and noted to be a mis-match to political expectations of a rapid return on conservation investment (Piipponen-Doyle et al., 2021).

Most of the species that we consider to have recovered were initially listed as Vulnerable. Their disproportionate representation in recoveries is probably simply because species in this category are closer to the eligibility threshold for listing: a greater change in population trajectory is required to recover Endangered or Critically Endangered species. The sole case of recovery of a species initially listed as Critically Endangered was for the great knot and, as noted above, this recovery is a quirk of timing.

There was more likelihood of recovery for threatened species that were restricted to islands. This is probably because some threats, such as introduced predators, can be eradicated from islands but not from mainland areas. In the Australian context, many island-endemic species have also benefited from translocations to other islands or mainland havens, increasing the likelihood of recovery. Conversely, island-endemic species are also over-represented in Australia's extinctions (Woinarski et al., 2019). Accordingly, as it is globally (Fernández-Palacios et al., 2021), the management of islands is critical for the conservation of Australia's biodiversity (Woinarski et al., 2014a; Burbidge et al., 2018; Woinarski et al., 2018), as is recognised by the inclusion of six islands among the 20 priority places targeted for threatened species management in Australia's most recent national Threatened Species Action Plan (Commonwealth of Australia, 2022).

There was weak evidence that species with recovery plans were more likely to recover than species without such plans, but it is difficult to provide a robust assessment of this benefit, as many recovery plans are not implemented or implemented in small part; and some recovery plans are now long expired. While analysis of a random sample of recovery plans showed no benefit (Bottrill et al., 2011), some have contributed substantially to recovery (Garnett et al., 2018). A review of the role that recovery plans can play in Australian threatened species conservation is warranted.

Most of the cases we consider to be eligible now for de-listing involve effective control of the principal threat of introduced mammalian predators (cats, foxes) – through local eradications, island biosecurity, translocations and intensive sustained control programs. For many Australian threatened species affected by other invasive species (e.g., introduced fish and invertebrates) effective control methods have not been developed, have unacceptable non-target impacts (e.g., toxins in waterways) or are unfeasible (Jackson et al., 2004; Lintermans et al., 2020), and hence most species threatened by these other introduced species have not recovered and are unlikely to do so in the near future.

Few of the cases of recovery are due primarily to the effective control of broad-scale habitat loss, climate change, inappropriate fire regimes, forestry or natural systems modification (particularly of aquatic systems). These factors continue to affect Australian biodiversity across vast areas. In general, legislation and policy has not been adequate to provide sufficiently for species threatened by these factors – indeed, notwithstanding some controls over vegetation clearing, especially where this may affect threatened species, at least 7.7 million hectares of potential threatened species habitat was removed over the period 2000 to 2017 (Ward et al., 2019). Although Australia has an extensive and moderately comprehensive conservation reserve system, this alone has not provided sufficient security to recover threatened animal species, and many threatened species occur mostly on unreserved lands (Kearney et al., 2022). However, we qualify that assessment to note that reserves encompass, or overlap with, much to all of the range of Australia's most imperilled vertebrates (Garnett et al., 2022), and such reservation may have halted population loss for some highly localised plant and animal species (and especially so from the threat of habitat loss); and that the declining trajectories of many other threatened species may have been even more dire without such reservation. For fire and climate change, management is likely to become increasingly challenging, as evidenced in the major losses in the population size of many threatened species in the Australian mega-fires of 2019–20 (Legge et al., 2022). With continuation of current levels of investment and management, and likely escalation of the impacts and magnitude of these factors, there is only a very small and diminishing likelihood of future recovery of species threatened by these factors.

4.4. Policy implications of recovery

Most of the species that we consider have recovered have not been formally delisted. This is likely to be due to several factors. Whereas the US *Endangered Species Act* imposes an obligation to undertake reviews at 5-year intervals of the status of listed threatened species (Evansen et al., 2021), there is no comparable requirement for regular review of the status of Australian threatened species. Such a review process could provide the mechanism to document cases of recovery more routinely, and hence to de-list those recovered species. Such regular review of species' conservation statuses would also help assess the extent to which the objectives of the EPBC Act are being met, help refine and update

investment priorities (e.g., to species whose status is most rapidly deteriorating), and would allow for the application of a Red List Index (Butchart et al., 2007) to measure broad trends in the status of Australia's threatened species. In the Australian case, status review may be especially useful for those legacy species listed at the onset of the EPBC Act, for which listing documentation is typically sparse and opaque. It is likely that such comprehensive regular review is not mandated or undertaken for species listed under the EPBC Act due to funding constraints: it is an arguable proposition that the finite resources that are committed to the conservation of Australia's threatened species (Wintle et al., 2019) may be better spent on undertaking conservation actions for listed species or for assessing nominations for listing of unlisted species rather than reviewing the status of already listed species. In part, because there is no obligation for regular review of status, there is inadequate monitoring for most threatened species (Scheele et al., 2019) and hence little available documentation of conservation parameters, and change in those parameters, for most listed species. Our assessments of current status were particularly constrained for listed threatened invertebrates, for many of which there is little or no recent documentation relevant to conservation parameters.

The EPBC Act also provides explicit hurdles for de-listings. Firstly, whereas nomination for listing can be made by any member of the public, nominations for de-listing can be made only by the statutory committee tasked with assessments or by the relevant government department. Secondly, the Act provides an insurance against de-listings that may cause conservation detriment: 'The Minister must not delete … a native species from a particular category unless satisfied that: (a) the native species is no longer eligible to be included in that category; or (b) the inclusion of the native species in that category is not contributing, or will not contribute, to the survival of the native species' [s 186(2A)]. On this basis, a species will not be de-listed, even if it no longer meets any eligibility criteria, if the existing listing is believed to contribute to survival of the species.

There is some risk that the legal listing of species as threatened, when they are not eligible for listing, may subvert the authority of the list. For example, Bouchet et al. (1999) claimed that 'the scientific credibility of (relevant) legal instruments will be seriously affected if they maintain protected status to species that do not require it for their survival'. However, de-listing is a complex issue (New and Sands, 2003; Taylor et al., 2005). It can mark success in conservation, and such recognition provides an important demonstration that investment in conservation management or policy can produce tangible benefits. Nonetheless, recovery may be a fragile state (Groom, 2010) and, if de-listed, a species may no longer be a priority for conservation investment, the conservation gains may be lost and the species may rapidly become eligible again for listing as threatened (Doremus and Pagel, 2001). One response to this potential transitoriness of recovery is to require a mandatory period for monitoring . For example, the US *Endangered Species Act* requires a de-listed species to be monitored for five years after de-listing to assess whether recovery is likely to be sustained. Likewise, the IUCN has a requirement that a species will not be de-listed for at least five years after an assessment that it no longer fits eligibility criteria. Another approach is recognition of conservation dependent or conservation reliant categories (Scott et al., 2010) for species that no longer meet eligibility criteria for listing as threatened, but whose non-threatened status depends upon ongoing management actions. The EPBC Act includes a Conservation Dependent (CD) category, but this is narrowly circumscribed to marine species eligible for listing as threatened that are managed under approved commercial fisheries programs, with such threatened species still allowed to be taken in commercial harvest programs. Pidot (2020) suggested a variant on this approach – contingent de-listing – whereby a listing would be considered dormant and could be restored rapidly should the status of a de-listed species regress. The majority of the species that we consider to be eligible for de-listing do indeed require ongoing management, mostly in the form of island biosecurity, ongoing control of introduced predators, captive breeding and maintenance of reserves. If the conservation progress for recovered species is to be formally acknowledged, it may be appropriate to revise the EPBC Act to include a concept of Conservation Dependent status that is not narrowly confined to fish subject to an approved fisheries management plan, and that can be used to acknowledge the need for ongoing management.

Furthermore, recovery is more complex than no longer meeting the IUCN Red List criteria for listing (Redford et al., 2011; Akçakaya et al., 2018). In most of the cases of recovery we recognise – and especially for the predator-susceptible mammals – their current population size and distributional extent is still only a very small proportion of their abundance and range at the onset of European colonisation of Australia (Woinarski et al., 2014b). The baseline has shifted, and recovery does not yet mean a return to the status that existed prior to the onset of decline.

4.5. International comparison

It is challenging to compare the extent of recovery of the Australian threatened fauna with that of other countries, partly because we do not use formal de-listings as our metric. Doremus and Pagel (2001) noted that only five US taxa had been de-listed because of actual recovery over the period 1973 to 2000. However, the US Fish & Wildlife Service (as at October 2022) lists 54 US animal taxa that have been de-listed because of recovery (https://ecos.fws.gov/ecp/report/species-delisted). Given comparable numbers of listed threatened species in the US and Australia, this suggests a higher degree of conservation success for the former, possibly because of greater resourcing for conservation (Wintle et al., 2019).

4.6. Conclusions and context

Notwithstanding the recoveries that we document, these are vastly outweighed by the increases in the numbers of species listed over this period, and the general trend for ongoing or accelerating declines for Australia's listed threatened species (Bayraktarov et al., 2021; Garnett et al., 2022; Janke et al., 2022). Clearly, on balance, the conservation actions applied to date have been insufficient to recover the majority of Australia's threatened species.

We recognise that recovery, even of species primarily threatened by controllable factors, will be a long journey; but we demonstrate here that it can be achieved. We therefore contend that conservation managers should aim to measure success at least in part through documentation of such cases. Indeed, an explicit long-term objective of, and performance criterion for, conservation programs or legislation should be to increase the number of currently listed threatened species that have recovered sufficiently to the point that they are no longer eligible for listing as threatened.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2023.109946.

CRediT authorship contribution statement

John Woinarski Conceptualisation, Methodology, Writing – original draft preparation, Writing – review & editing; Stephen Garnett Writing – original draft preparation, Writing – review & editing; Graeme Gillespie Writing – review & editing; Sarah Legge Writing – original draft preparation, Writing – review & editing; Mark Lintermans Writing – original draft preparation, Writing – review & editing; Libby Rumpff Writing – original draft preparation, Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

Acknowledgements

This work was not directly funded, but was faciltated, by the Australian Government's National Environmental Science Program Threatened Species Recovery Hub. We thank Fiona Fraser for comments on a draft.

References

Akçakaya, H.R., Bennett, E.L., Brooks, T.M., Grace, M.K., Heath, A., Hedges, S., Hilton-Taylor, C., Hoffmann, M., Keith, D.A., Long, B., Mallon, D.P., Meijaard, E., Milner-Gulland, E.J., Rodrigues, A.S.L., Rodriguez, J.P., Stephenson, P.J., Stuart, S.N., Young, R.P., 2018. Quantifying species recovery and conservation success to develop an IUCN green list of species. Conserv. Biol. 32, 1128–1138.

Algar, D., Morris, K., Asher, J., Cowen, S., 2020. Dirk Hartog Island 'return to 1616'project–the first six years (2014 to 2019). Ecol. Manag. Restor. 21, 173–183.

Bayraktarov, E., Ehmke, G., Tulloch, A.I.T., Chauvenet, A.L., Avery-Gomm, S., McRae, L., Wintle, B.A., O'Connor, J., Driessen, J., Watmuff, J., Nguyen, H.A., Garnett, S.T., Woinarski, J., Barnes, M., Morgain, R., Guru, S., Possingham, H.P., 2021. A threatened species index for Australian birds. Conserv. Sci. Pract. 3, e322.

Bottrill, M.C., Walsh, J.C., Watson, J.E.M., Joseph, L.N., Ortega-Argueta, A., Possingham, H.P., 2011. Does recovery planning improve the status of threatened species? Biol. Conserv. 144, 1595–1601.

Bouchet, P., Falkner, G., Seddon, M.B., 1999. Lists of protected land and freshwater molluscs in the Bern convention and european habitats directive: are they relevant to conservation? Biol. Conserv. 90, 21–31.

Brannelly, L.A., Webb, R.J., Jiang, Z., Berger, L., Skerratt, L.F., Grogan, L.F., 2021. Declining amphibians might be evolving increased reproductive effort in the face of devastating disease. Evolution 75, 2555–2567.

Burbidge, A.A., Legge, S.T., Woinarski, J.C.Z., 2018. Australian islands as 'arks' for biodiversity. In: Moro, D., Ball, D., Bryant, S. (Eds.), Australian island arks: conservation, management and opportunities. CSIRO Publishing, Clayton, pp. 99–113.

Butchart, S.H.M., Akcakaya, H.R., Kennedy, E., Hilton-Taylor, C., 2006. Biodiversity indicators based on trends in conservation status: strengths of the IUCN red list index. Conserv. Biol. 579–581.

Butchart, S.H.M., Akçakaya, H.R., Chanson, J., Baillie, J.E.M., Collen, B., Quader, S., Turner, W.R., Amin, R., Stuart, S.N., Hilton-Taylor, C., 2007. Improvements to the red list index. PLoS ONE 2, e140.

Chapple, D.G., Tingley, R., Mitchell, N.J., Macdonald, S.L., Keogh, J.S., Shea, G.M., Bowles, P., Cox, N.A., Woinarski, J.C.Z., 2019. The Action Plan for Australian Lizards and Snakes 2017. CSIRO Publishing, Melbourne.

Commonwealth of Australia, 2022. 2022-2032 Threatened Species Action Plan: Towards Zero Extinctions. Department of Climate Change Energy the Environment and Water, Canberra.

Doremus, H., 2000. Delisting endangered species: an aspirational goal, not a realistic expectation. In: Environmental Law Reporter, 30, pp. 10434–10454.

Doremus, H., Pagel, J.E., 2001. Why listing may be forever: perspectives on delisting under the US endangered species act. Conserv. Biol. 15, 1258–1268.

Evansen, M., Carter, A., Malcom, J., 2021. A monitoring policy framework for the United States endangered species act. Environ. Res. Lett. 16, 031001.

Fernández-Palacios, J.M., Kreft, H., Irl, S.D.H., Norder, S., Ah-Peng, C., Borges, P.A.V., Burns, K.C., de Nascimento, L., Meyer, J.-Y., Montes, E., Drake, D.R., 2021. Scientists' warning–The outstanding biodiversity of islands is in peril. Glob. Ecol. Conserv. 31, e01847.

Fraser, H., Legge, S.M., Garnett, S.T., Geyle, H., Silcock, J., Nou, T., Collingwood, T., Cameron, K.A., Fraser, F., Mulcahy, A., Walker, G., Woinarski, J.C.Z., 2022. Application of expert elicitation to estimate population trajectories for species prioritized in Australia's first threatened species strategy. Biol. Conserv. 274, 109731.

Garnett, S.T., Baker, G.B. (Eds.), 2021. Action Plan for Australian Birds 2020. CSIRO Publishing, Melbourne.

Garnett, S.T., Latch, P., Lindenmayer, D.B., Woinarski, J.C.Z. (Eds.), 2018. Recovering Australian threatened species: a book of hope. CSIRO Publishing, Clayton.

Garnett, S.T., Hayward-Brown, B.K., Kopf, R.K., Woinarski, J.C.Z., Cameron, K.A., Chapple, D.G., Copley, P., Fisher, A., Gillespie, G., Latch, P., Legge, S., Lintermans, M., Moorrees, A., Page, M., Renwick, J., Birrell, J., Kelly, D., Geyle, H. M., 2022. Australia's most imperilled vertebrates. Biol. Conserv. 270, 109561.

Geyle, H.M., Braby, M.F., Andren, M., Beaver, E., Bell, P., Byrne, C., Castles, M., Douglas, F., Glatz, R., Haywood, B., Hendry, P., Kitching, R., Lambkin, T., Meyer, C., Moore, M., Moss, J., Nally, S., New, T., Palmer, C., Petrie, E., Potter-Craven, J., Richards, K., Sanderson, C., Stolarski, A., Taylor, G., Williams, M., Woinarski, J.C.Z., Garnett, S.T., 2021a. Butterflies on the brink: identifying the australian butterflies (Lepidoptera) most at risk of extinction. Aust. Entomol. 60, 98–110.

Geyle, H.M., Hoskin, C.J., Bower, D.S., Catullo, R., Clulow, S., Driessen, M., Daniels, K., Garnett, S.T., Gilbert, D., Heard, G.W., Hero, J.-M., Hines, H.B., Hoffmann, E.P., Hollis, G., Hunter, D.A., Lemckert, F., Mahony, M., Marantelli, G., McDonald, K.R., Mitchell, N.J., Newell, D., Roberts, J.D., Scheele, B.C., Scroggie, M., Vanderduys, E., Wassens, S., West, M., Woinarski, J.C.Z., Gillespie, G.R., 2021b. Red hot frogs: identifying the Australian frogs most at risk of extinction. Pac. Conserv. Biol. 28, 211–223.

Gillespie, G.R., Roberts, J.D., Hunter, D., Hoskin, C.J., Alford, R.A., Heard, G.W., Hines, H., Lemckert, F., Newell, D., Scheele, B.C., 2020. Status and priority conservation actions for australian frog species. Biol. Conserv. 247, 108543.

Gilligan, D., Zampatti, B., Lintermans, M., Koehn, J., Butler, G., Brooks, S., 2019. Maccullochella peelii. https://doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12576A103325360.en.

Grace, M.K., Akçakaya, H.R., Bennett, E.L., Brooks, T.M., Heath, A., Hedges, S., Hilton-Taylor, C., Hoffmann, M., Hochkirch, A., Jenkins, R., 2021. Testing a global standard for quantifying species recovery and assessing conservation impact. Conserv. Biol. 35, 1833–1849.

Groom, C., 2010. Justification for continued conservation efforts following the delisting of a threatened species: a case study of the woylie, Bettongia penicillata ogilbyi (Marsupialia: Potoroidae). Wildl. Res. 37, 183–193.

Harrison, P.L., Woinarski, J.C.Z., 2018. Recovery of Australian subpopulations of Humpback Whale Megaptera novaeangliae. In: Garnett, S., Latch, P., Lindenmayer, D., Woinarski, J. (Eds.), Recovering Australian threatened species: a book of hope. CSIRO Publishing, Clayton, pp. 5–12.

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T.M., SHM, Butchart, Carpenter, K.E., Chanson, J., Collen, B., Cox, N.A., WRT, Darwall, Dulvy, N.K., Harrison, L.R., Katariya, V., Pollock, C.M., Quader, S., Richman, N.I., ASL, Rodrigues, Tognelli, M.F., Vié, J.-C., Aguiar, J.M., Allen, D.J., Allen, G.R., Amori, G., Ananjeva, N., Andreone, F., Andrew, P., Aquino Ortiz, A.L., JEM, Baillie, Baldi, R., Bell, B.D., Biju, S.D., Bird, J.P., Black-Decima, P., Blanc, J.J., Bolaños, F., Burfield, I.J., Burton, J.A., Capper, D.R., Castro, F., Catullo, G., Cavanagh, R.D., Channing, A., Chao, N.L., Chenery, A.M., Chiozza, F., Clausnitzer, V., Collar, N.J., Collett, L.C., Collette, B.B., Cortez Fernandez, C.F., Craig, M.T., Crosby, M.J., Cumberlidge, N., Cuttelod, A., Derocher, A.E., Diesmos, A.C., Donaldson, J.S., Duckworth, J.W., Dutson, G., Dutta, S.K., Emslie, R.H., Bolivar-G, W., Farjon, A., Fowler, S., Freyhof, J., Garshelis, D.L., Gerlach, J., Gower, D.J., Grant, T.D., Hammerson, G.A., Harris, R.B., Heaney, L.R., Hedges, S.B., Hero, J.-M., Hughes, B., Hussain, S.A., Inger, R.F., Ishii, N., Iskandar, D.T., RKB, Jenkins, Kaneko, Y., Kottelat, M., Kovacs, K.M., Kuzmin, S.L., I, J.M., La Marca, E., Lamoreux, J.F., MWN, Lau, Lavilla, E.O., Leus, K., Lewison, R.L., Lichtenstein, G., Livingstone, S.R., Lukoschek, V., Mallon, D.P., PJK, McGowan, McIvor, A., Moehlman, P.D., Molur, S., Muñoz Alonso, A., Musick, J.A., Nowell, K., Nussbaum, R.A., Olech, W., Orlov, N.L., Papenfuss, T.J., Parra-Olea, G., Perrin, W.F., Polidoro, B.A., Pourkazemi, M., Racey, P.A., Ragle, J.S., Ram, M., Rathbun, G., Reynolds, R.P., AGJ, Rhodin, Richards, S.J., Rodríguez, L.O., Ron, S.R., Rondinini, C., Rylands, A.B., Sadovy de Mitcheson, Y., Sanciangco, J.C., Sanders, K.L., Santos-Barrera, G., Schipper, J., Self-Sullivan, C., Shi, Y., Shoemaker, A., Short, F.T., Sillero-Zubiri, C., Silvano, D.L., Smith, K.G., Smith, A.T., Snoeks, J., Stattersfield, A.J., Symes, A.J., Taber, A.B., Talukdar, B.K., Temple, H.J., Timmins, R., Tobias, J.A., Tsytsulina, K., Tweddle, D., Ubeda, C., Valenti, S.V., van Dijk, P.P., Veiga, L.M., Veloso, A., Wege, D.C., Wilkinson, M., Williamson, E.A., Xie, F., Young, B.E., Akçakaya, H.R., Bennun, L., Blackburn, T.M., Boitani, L., Dublin, H.T., da Fonseca, G.A.B., Gascon, C., Lacher Jr., T.E., Mace, G.M., Mainka, S.A., JA, McNeely, Mittermeier, R.A., Rodriguez, J.P., Rosenberg, A.A., McGregor Reid, G., Samways, M.J., Smart, J., Stein, B.A., Stuart, S.N., 2010. The impact of conservation on the status of the world's vertebrates. Science 330, 1503–1509.

IUCN Standards and Petitions Subcommittee, 2022. Guidelines for Using the IUCN Red List Categories and Criteria. Version 15. Gland, Switzerland.

IUCN/SSC, 2013. Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0. Gland, Switzerland.

Jackson, J.E., Raadik, T.A., Lintermans, M., Hammer, M., 2004. Alien salmonids in Australia: impediments to effective impact management, and future directions. N. Z. J. Mar. Freshw. Res. 38, 447–455.

Janke, T., Johnston, E., Cresswell, I., 2022. The State of Australia's Environment: 2021 State of the Environment Report. Australian Government, Canberra.

Kanowski, J., Roshier, D., Smith, M.A., Fleming, A., 2018. Effective conservation of critical weight range mammals: reintroduction projects of the Australian Wildlife Conservancy. In: Garnett, S., Latch, P., Lindenmayer, D., Woinarski, J. (Eds.), Recovering Australian threatened species: a book of hope. CSIRO Publishing, Clayton, pp. 269–280.

Kearney, S.G., Carwardine, J., Reside, A.E., Adams, V.M., Nelson, R., Coggan, A., Spindler, R., Watson, J.E.M., 2022. Saving species beyond the protected area fence: threats must be managed across multiple land tenure types to secure Australia's endangered species. Conserv. Sci. Pract. 4, e617.

Legge, S., Garnett, S., Maute, K., Heathcote, J., Murphy, S., Woinarski, J.C.Z., Astheimer, L., 2015. A landscape-scale, applied fire management experiment promotes recovery of a population of the threatened gouldian finch, Erythrura gouldiae, in Australia's tropical savannas. PLoS ONE 10, e0137997.

Legge, S.M., Woinarski, J.C.Z., Burbidge, A.A., Palmer, A., Ringma, J., Radford, J., Mitchell, N., Bode, M., Wintle, B., Baselar, M., Bentley, J., Copley, P., Dexter, N., Dickman, C.R., Gillespie, G., Hill, B., Johnson, C., Latch, P., Letnic, M., Manning, A., McCreless, E.E., Menkhorst, P., Morris, K., Moseby, K., Page, M., Pannell, D., Tuft, K., 2018. Havens for threatened Australian mammals: the contributions of fenced areas and offshore islands to protecting mammal species that are susceptible to introduced predators. Wildl. Res. 45, 627–644.

Legge, S., Woinarski, J., Scheele, B., Garnett, S.T., Lintermans, M., Nimmo, D., Whiterod, N.S., Southwell, D., Ehmke, G., Buchan, A., Gray, J.E., Rumpff, L., van Leeuwen, S., Williams, D., Ahyong, S.T., Hossain, A., Hunter, D., Kennard, M., Marsh, J., McCormack, R.B., Michael, D., Mitchell, N., Newell, D., Raadik, T.A.,

Tingley, R., 2022. Rapid assessment of the biodiversity impacts of a megafire to guide urgent management intervention and recovery. Divers. Distrib. 28, 571–591.
Lintermans, M., 2017. Conservation status of Australian fishes – 2017. Lateral Lines 47, 173–175.
Lintermans, M., Geyle, H.M., Beatty, S., Brown, C., Ebner, B., Freeman, R., Hammer, M., Humphreys, W.F., Kennard, M.J., Kern, P., Martin, K., Morgan, D., Raadik, T.A., Unmack, P.J., Wager, R., Woinarski, J.C.Z., Garnett, S.T., 2020. Big trouble for little fish: identifying Australian freshwater fishes in imminent risk of extinction. Pac. Conserv. Biol. 26, 365–377.
Littlefair, M.E., Nimmo, D.G., Ocock, J.F., Michael, D.R., Wassens, S., 2021. Amphibian occurrence and abundance patterns across a modified floodplain ecosystem. Aust. Ecol. 46, 1343–1355.
Moir, M.L., 2021. Coextinction of pseudococcus markharveyi (Hemiptera: Pseudococcidae): a case study in the modern insect extinction crisis. Aust. Entomol. 60, 89–97.
Moseby, K.E., Hill, B.M., Read, J.L., 2009. Arid recovery – a comparison of reptile and small mammal populations inside and outside a large rabbit, cat and fox-proof exclosure in arid South Australia. Aust. Ecol. 34, 156–169.
New, T.R., Sands, D.P.A., 2003. The listing and de-listing of invertebrate species for conservation in Australia. J. Insect Conserv. 7, 199–205.
Phillott, A.D., Grogan, L.F., Cashins, S.D., McDonald, K.R., Berger, L., Skerratt, L.F., 2013. Chytridiomycosis and seasonal mortality of tropical stream-associated frogs 15 years after introduction of batrachochytrium dendrobatidis. Conserv. Biol. 27, 1058–1068.
Pidot, J.R., 2020. Contingent delisting. In: University of Colorado Law Review, 91, pp. 649–676.
Piipponen-Doyle, S., Bolam, F.C., Mair, L., 2021. Disparity between ecological and political timeframes for species conservation targets. Biodivers. Conserv. 30, 1899–1912.
Puschendorf, R., Hoskin, C.J., Cashins, S.D., McDonald, K., Skerratt, L.F., Vanderwal, J., Alford, R.A., 2011. Environmental refuge from disease-driven amphibian extinction. Conserv. Biol. 25, 956–964.
Radford, J.Q., Woinarski, J.C.Z., Legge, S., Baseler, M., Bentley, J., Burbidge, A.A., Bode, M., Copley, P., Dexter, N., Dickman, C.R., Gillespie, G., Hill, B., Johnson, C.N., Kanowski, J., Latch, P., Letnic, M., Manning, A., Menkhorst, P.W., Mitchell, N., Morris, K., Moseby, K.E., Page, M., Ringma, J., 2018. Degrees of population-level susceptibility of australian mammal species to predation by the introduced red fox Vulpes vulpes and feral cat Felis catus. Wildl. Res. 45, 645–657.
Redford, K.H., Amato, G., Baillie, J., Beldomenico, P., Bennett, E.L., Clum, N., Cook, R., Fonseca, G., Hedges, S., Launay, F., Lieberman, S., 2011. What does it mean to successfully conserve a (vertebrate) species? Bioscience 6, 39–48.
Ringma, J., Legge, S., Woinarski, J.C.Z., Radford, J.Q., Wintle, B., Bentley, J., Burbidge, A.A., Copley, P., Dexter, N., Dickman, C.R., Gillespie, G.R., Hill, B., Johnson, C.N., Kanowski, J., Letnic, M., Manning, A., Menkhorst, P., Mitchell, N., Morris, K., Moseby, K., Page, M., Palmer, R., Bode, M., 2019. Systematic planning can rapidly close the protection gap in Australian mammal havens. Conserv. Lett. 12, e12611.
Scheele, B.C., Guarino, F., Osborne, W.S., Hunter, D.A., Skerratt, L.F., Driscoll, D.A., 2014. Decline and re-expansion of an amphibian with high prevalence of chytrid fungus. Biol. Conserv. 170, 86–91.
Scheele, B.C., Legge, S., Blanchard, W., Garnett, S.T., Geyle, H.M., Gillespie, G.R., Harrison, P.L., Lindenmayer, D.B., Lintermans, M., Robinson, N.M., Woinarski, J.C.Z., 2019. Continental-scale assessment reveals inadequate monitoring for threatened vertebrates in a megadiverse country. Biol. Conserv. 235, 273–278.
Scott, J.M., Goble, D.D., Haines, A.M., Wiens, J.A., Neel, M.C., 2010. Conservation-reliant species and the future of conservation. Conserv. Lett. 3, 91–97.
Silcock, J.L., Collingwood, T.D., Llorens, T., Fensham, R.J., 2021. Action Plan for Australia's Imperilled Plants. Threatened Species Recovery Hub National Environmental Science Program, Brisbane.
Springer, K., 2018. Eradication of invasive species on Macquarie Island to restore the natural ecosystem. In: Garnett, S., Latch, P., Lindenmayer, D., Woinarski, J. (Eds.), Recovering Australian threatened species: a book of hope. CSIRO Publishing, Clayton, pp. 13–22.
Taylor, M.F., Suckling, K.F., Rachlinski, J.J., 2005. The effectiveness of the endangered species act: a quantitative analysis. Bioscience 55, 360–367.
Threatened Species Scientific Committee, 2020. Listing Advice: Litoria nannotis (Waterfall Frog), Canberra. www.environment.gov.au/biodiversity/threatened/species/pubs/1817-listing-advice-11122020.pdf.
Threatened Species Scientific Committee, 2021. Guidelines for assessing the conservation status of native species according to the Environment Protection and Biodiversity Conservation Act 1999 and Environment Protection and Biodiversity Conservation Regulations 2000, Canberra. https://www.dcceew.gov.au/sites/default/files/env/pages/d72dfd1a-f0d8-4699-8d43-5d95bbb02428/files/tssc-guidelines-assessing-species-2021.pdf.
Tulloch, A.I.T., Jackson, M.V., Bayraktarov, E., Carey, A., Correa-G, D.F., Driessen, M., Gynther, I.C., Hardie, M., Moseby, K., Joseph, L., Preece, H., Suarez-Castro, A.F., Stuart, S., Woinarski, J.C.Z., Possingham, H.P., 2023. Effects of different management strategies on long-term trends of Australian threatened and near-threatened mammals. Conservation Biology in press.
Van Dyke, J.U., Ferronato, B., Spencer, R.-J., 2018. Current conservation status of Australian freshwater turtles. Aust. J. Zool. 66, 1–3.
Waldron, A., Miller, D.C., Redding, D., Mooers, A., Kuhn, T.S., Nibbelink, N., Roberts, J. T., Tobias, J.A., Gittleman, J.L., 2017. Reductions in global biodiversity loss predicted from conservation spending. Nature 551, 364.
Waller, N.L., Gynther, I.C., Freeman, A.B., Lavery, T.H., Leung, L.K.-P., 2017. The bramble cay melomys Melomys rubicola (Rodentia: Muridae): a first mammalian extinction caused by human-induced climate change? Wildl. Res. 44, 9–21.
Walsh, J.C., Watson, J.E.M., Bottrill, M.C., Joseph, L.N., Possingham, H.P., 2013. Trends and biases in the listing and recovery planning for threatened species: an Australian case study. Oryx 47, 134–143.
Ward, M.S., Simmonds, J.S., Reside, A.E., Watson, J.E.M., Rhodes, J.R., Possingham, H. P., 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. Conserv. Sci. Pract. 1, e117.
Ward, M., Carwardine, J., Yong, C.J., Watson, J.E.M., Silcock, J., Taylor, G.S., Lintermans, M., Gillespie, G.R., Garnett, S.T., Woinarski, J., Tingley, R., Fensham, R., Hoskin, C.J., Hines, H.B., Roberts, J.D., Kennard, M.J., Harvey, M.S., Chapple, D.G., Reside, A.E., 2021. A national-scale dataset for threats impacting Australia's imperiled flora and fauna. Ecol. Evol. 11, 11749–11761.
Wassens, S., Hall, A., Osborne, W., Watts, R.J., 2010. Habitat characteristics predict occupancy patterns of the endangered amphibian Litoria raniformis in flow-regulated flood plain wetlands. Aust. Ecol. 35, 944–955.
Westveer, J., Freeman, R., McRae, L., Marconi, V., Almond, R.E.A., Grooten, M., 2022. A Deep Dive into the Living Planet Index: A Technical Report. Gland, Switzerland, WWF.
Wintle, B.A., Cadenhead, N.C.R., Morgain, R.A., Legge, S.M., Bekessy, S.A., Possingham, H.P., Watson, J.E.M., Maron, M., Keith, D.A., Garnett, S.T., Woinarski, J.C.Z., Lindenmayer, D.B., 2019. Spending to save: what will it cost to halt Australia's extinction crisis? Conserv. Lett. 12, e12682.
Woinarski, J., 2018. A bat's end: the Christmas Island pipistrelle and extinction in Australia. Melbourne, CSIRO Publishing.
Woinarski, J., Ball, D., Burbidge, A.A., 2014. Islands. In: Lindenmayer, D., Dovers, S., Morton, S. (Eds.), Ten commitments revisited: securing Australia's future environment. CSIRO Publishing, Collingwood, pp. 117–128.
Woinarski, J.C.Z., Burbidge, A.A., Harrison, P.L., 2014b. The Action Plan for Australian Mammals 2012. Melbourne, CSIRO Publishing.
Woinarski, J.C.Z., Garnett, S.T., Legge, S.M., Lindenmayer, D.B., 2017. The contribution of policy, law, management, research, and advocacy failings to the recent extinctions of three australian vertebrate species. Conserv. Biol. 31, 13–23.
Woinarski, J.C.Z., Burbidge, A.A., Reside, A., 2018. Enhancing island conservation outcomes: the policy and legal context, need, and options. In: Moro, D., Ball, D., Bryant, S. (Eds.), Australian island arks: conservation management and opportunities. CSIRO Publishing, Clayton, pp. 45–59.
Woinarski, J.C.Z., Braby, M.F., Burbidge, A.A., Coates, D., Garnett, S.T., Fensham, R.J., Legge, S.M., McKenzie, N.L., Silcock, J.L., Murphy, B.P., 2019. Reading the black book: the number, timing, distribution and causes of listed extinctions in Australia. Biol. Conserv. 239, 108261.