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Havens for threatened Australian mammals: the contributions of fenced areas and offshore islands to the protection of mammal species susceptible to introduced predators

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Abstract

Context. Many Australian mammal species are highly susceptible to predation by introduced house cats (*Felis catus*) and European red foxes (*Vulpes vulpes*). These predators have caused many extinctions and have driven large distributional and population declines for many more species. The serendipitous occurrence of, and deliberate translocations of mammals to, 'havens' (cat- and/or fox-free offshore islands, and mainland fenced exclosures capable of excluding cats and/or foxes) has helped avoid further extinction.

Aims. The aim of this study was to conduct a stocktake of current island and fenced havens in Australia and assess the extent of their protection for threatened mammal taxa that are most susceptible to cat and fox predation.

Methods. Information was collated from diverse sources to document (1) the locations of havens and (2) the occurrence of populations of predator-susceptible threatened mammals (naturally occurring or translocated) in those havens. The list of predator-susceptible taxa (67 taxa, 52 species) was based on consensus opinion from >25 mammal experts.

Key results. Seventeen fenced and 101 island havens contain 188 populations of 38 predator-susceptible threatened mammal taxa (32 species). Island havens cover a larger cumulative area than fenced havens (2152 km^2 versus 337 km^2), and reach larger sizes (largest island 325 km^2, with another island of 628 km^2 becoming available from 2018; largest fence: 123 km^2). Islands and fenced havens contain similar numbers of taxa (27 each), because fenced havens usually contain more taxa per haven. Populations within fences are mostly translocated (43 of 49; 88%). Islands contain translocated populations (30 of 139; 22%); but also protect *in situ* (109) threatened mammal populations.

Conclusions. Havens are used increasingly to safeguard threatened predator-susceptible mammals. However, 15 such taxa occur in only one or two havens, and 29 such taxa (43%) are not represented in any havens. The taxon at greatest risk of extinction from predation, and in greatest need of a haven, is the central rock-rat (*Zyzomys pedunculatus*).

Implications. Future investment in havens should focus on locations that favour taxa with no (or low) existing haven representation. Although havens can be critical for avoiding extinctions in the short term, they cover a minute proportion of species' former ranges. Improved options for controlling the impacts of cats and foxes at landscape scales must be developed and implemented.

Additional keywords: conservation management, introduced species, islands, pest control, predation, threatened species, wildlife management.

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Introduction

Invasive species are major threats to biodiversity globally. As well as contributing to past extinctions (e.g. Szabo *et al*. 2012; Scheele *et al*. 2017), they continue to exert pressure on extant species: over one-quarter of all IUCN-listed threatened taxa are at risk from invasive species (Bellard *et al*. 2016). Invasive mammalian predators are especially potent influences on other vertebrates and have been linked to over half of the global extinctions of mammals, birds and reptiles (Doherty *et al*. 2016). House cats (*Felis catus*) and rats (*Rattus* spp.) are amongst the most damaging mammalian predators (Medina *et al*. 2011; Bellard *et al*. 2016; Doherty *et al*. 2016), and also the most widespread (e.g. invasive rodents occur on over 80% of oceanic islands; Towns *et al*. 2006). The impact of invasive species depends on where they have colonised, and on the susceptibility of native species to the invader. These factors interact to produce geographical variation in impact. Invasive species have been, and continue to be, especially damaging on small islands (Courchamp *et al*. 2003; Towns *et al*. 2006; Jones *et al*. 2008; Loehle and Eschenbach 2012; Tershy *et al*. 2015; Doherty *et al*. 2016), on some large islands and in some mainland regions of the world, including the Americas, India, Indonesia, New Zealand and Australia (Loehle and Eschenbach 2012; Bellard *et al*. 2016; Doherty *et al*. 2016).

In Australia, introduced mammalian predators have affected native mammals more profoundly than other vertebrate groups. Over 30 mammal species (>13% of all terrestrial Australian mammals, and all endemic) have been driven to extinction in the past 250 years. Cats and European red foxes (*Vulpes vulpes*) have been the main drivers for at least two-thirds of these losses (Short and Smith 1994; Woinarski *et al*. 2015). Many remaining mammalian taxa have declined severely in both distribution and density, again with cats and foxes implicated in most declines (Burbidge and McKenzie 1989; Short and Smith 1994; Dickman 1996; Smith and Quin 1996; Woinarski *et al*. 2015). Cats now occur across the entire Australian mainland and Tasmania, and are present on many larger islands (Abbott 2008; Legge *et al*. 2017). Foxes occupy most of the mainland south of the tropics; they are absent from Tasmania but present on some other large islands off the southern half of the continent (Dickman 1996; Saunders *et al*. 2010). Impacts of predation can be exacerbated by other threats that affect habitat structure, such as changed fire regimes and grazing (McGregor *et al*. 2015), or by the presence of other introduced species that support elevated predator populations (especially rodents and rabbits (*Oryctolagus cuniculus*; Dickman 1996; Pedler *et al*. 2016). However, while these other factors may compound and magnify the impacts of predation, they have contributed less significantly than have introduced predators to the decline and extinction of the Australian mammal fauna (Woinarski *et al*. 2014; Woinarski *et al*. 2015).

Australian mammal species vary in their population-level susceptibility to predation by cats and foxes. Some are unaffected, while others can persist with adequate and sustained predator control; but for a suite of species even very low densities of introduced predators cause decline and local extinction (Christensen and Burrows 1995; Short 2009; Moseby *et al*. 2011; Radford *et al*. 2018). Taxa that are most predator-susceptible tend to be in the preferred prey size range for cats and foxes (35 g–5.5 kg; Burbidge and McKenzie 1989). They also have ecological traits that increase their exposure to these predators: they are mostly ground-dwelling rather than arboreal or volant, and are more likely to occur in arid areas where shelter from predators is scant (Smith and Quin 1996; Burbidge and Morris 2002; Johnson 2006; Short 2009) and cat densities can be higher (Legge *et al*. 2017). Some predator-susceptible taxa persist in natural refuges where cat and/or fox density is naturally low or predation risk is reduced, such as in some of the most rugged rocky areas of their former range that provide indestructible shelter (Burbidge and McKenzie 1989); examples are the golden-backed tree-rat (*Mesembriomys macrurus*; Hohnen *et al*. 2015) and the central rock-rat (*Zyzomys pedunculatus*; McDonald *et al*. 2018). Broad-scale and intensive poison-baiting to reduce predator density can also support the persistence of taxa in some areas, e.g. woylie (*Bettongia penicillata*; Burrows and Christensen 2002; Kinnear *et al*. 2010; Doherty *et al*. 2017), at least in the short-term (Kinnear *et al*. 2017). Finally, taxa susceptible to foxes (but less so to cats) may persist in northern Australia, e.g. spectacled hare-wallaby (*Lagorchestes conspicillatus*), and Tasmania, e.g. eastern bettong (*Bettongia gaimardi*), where foxes are absent (Fisher *et al*. 2014). However, the taxa that are most acutely predator-susceptible, such as the boodie (*Bettongia lesueur*) and western barred bandicoot (*Perameles bougainville*), usually have persisted only where cats and/or foxes are absent, such as on some islands (Short and Smith 1994; Burbidge *et al*. 1997; Burbidge and Manly 2002; Short 2009). Congenerics (*Perameles myosuros*, *P. fasciata*, *P. papillon*, *P. notina*, *Bettongia pusilla* and *B. anhydra*) that had no island populations are extinct.

Offshore islands have been crucial for avoiding extinction for nine Australian mammal taxa whose previous distributions included the mainland (i.e. excluding island endemics) (Burbidge *et al*. 1997; Johnson 2006). An example is the greater stick-nest rat (*Leporillus conditor*). At the time of European colonisation, this species occurred in an band across southern Australia from the west coast into New South Wales. It was extirpated from the mainland by the 1930s and survived only because a small population existed naturally on the Franklin Islands (5.1 km^2) (Copley 1999). As well as acting as serendipitous arks, islands have been used purposefully as sites for conservation translocations (for various reasons) from as early as the 1880s, but accelerating from the 1960s (Burbidge *et al*. 2018). For example, from its relic population on the Franklins, the greater stick-nest rat has since been successfully translocated to three other islands and two fenced (i.e. predator-proof) areas on the mainland. In another example, the mala (*Lagorchestes hirsutus* undescribed subspecies), exists in the wild only because it was translocated to Trimouille Island from a captive colony after the mainland population had collapsed due to predation, possibly worsened by fire (Gibson *et al*. 1994; Langford and Burbidge 2001). Successful eradications of cats and foxes from islands began in the late 1970s, beginning with a program on Hoskyn Island (Burbidge and Morris 2002; Campbell *et al*. 2011). The ability to eradicate cats and foxes from islands broadened options for later mammal translocation programs. The use of 'mainland islands', or fenced areas from which introduced predators (and often other introduced species like rabbits) are removed and then excluded, first emerged as a conservation tool in the 1980s (Long and Robley 2004; Sydee and Beder 2006). As techniques for fence construction improved and their conservation benefit established, the construction of mainland fenced areas in Australia has accelerated (Burns *et al*. 2012; Dickman 2012).

Management of island and fenced areas crosses various levels of government, non-government organisations and private landholders. While this distributed effort results in diverse approaches and funding sources, it may also lead to uncoordinated decisions (Hayward *et al*. 2014; Ringma *et al*. 2018) that have the potential to create substantial legacies of inefficiency, as seen in other conservation actions (e.g. marine and terrestrial reserve networks; Stewart *et al*. 2003; Fuller *et al*. 2010). Further expansion of this network of fenced areas and islands is included in the Commonwealth Government's Threatened Species Strategy (Commonwealth of Australia 2015). The effectiveness of this policy support would be much enhanced by a strategic, nationally coordinated approach to prioritising which taxa are in greatest need of fenced area and island havens, and where these sites should be located (Ringma *et al*. 2017, 2018).

The term 'haven' has not been explicitly defined (at least in the conservation sense used here) in the peer-reviewed literature, and we note that previously it may have been used interchangeably with 'refuge' or 'refugia' (e.g. Commonwealth of Australia 2015), referring to areas in which a principal threat is naturally absent or occurs at a level that does not affect population viability and persistence (Reside *et al*. 2014). Refugia are typically long-established areas that naturally provide a measure of protection allowing persistence of species, whereas havens typically include sites that have been recently established and shaped by human intervention for an explicit purpose of conservation. Havens may encompass a range of management interventions to safeguard species (e.g. Commonwealth of Australia 2015); here we follow Ringma *et al*. (2018), and restrict the term 'haven' to islands and mainland fenced areas, where the principal threat (introduced predators) is either naturally absent or excluded by management. In Australia, these types of havens provide the greatest security for taxa susceptible to predation from cats and foxes (Short 2009; Moseby *et al*. 2011).

We assessed the current extent of representation, within fenced and island havens protected from cats and foxes, of self-sustaining populations of Australian mammal taxa most susceptible to cat and/or fox predation. We collated information from many sources to identify every known island and fenced haven in Australia. We used an assessment of the susceptibility of all Australian terrestrial mammal species to cats and foxes (Radford *et al*. 2018) to identify the taxa most at risk from introduced predators, then collated information on all populations of those susceptible taxa that exist in island and fenced havens (and the number and total area of havens supporting each taxon). This collation allowed us to compare the relative contributions, advantages and disadvantages of island versus fenced havens. Most importantly, the collation highlighted those predator-susceptible taxa most in need of additional representation within havens, and to which future investment in havens should be primarily directed.

Methods

Data collation: threatened mammals susceptible to cat and/or fox predation

Our starting list included all non-volant terrestrial mammalian taxa noted as threatened (i.e. Vulnerable, Endangered, Critically Endangered) or Near Threatened by the Mammal Action Plan using IUCN listing criteria (Woinarski *et al*. 2014), plus any additional taxa listed as threatened by the Australian Government's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). We used the Mammal Action Plan and EPBC Act rather than IUCN listings because we aimed to consider subspecies whenever threat status had been assessed separately at that taxonomic level (IUCN assessments are carried out at the species level). We assume taxa considered Least Concern in the Mammal Action Plan and not listed as threatened require no additional protection from introduced predators, and therefore exclude them from consideration here.

Not all threatened mammals are at risk primarily because of predation by cats and foxes, and in these cases, havens from predators are not likely to be the priority management response or to produce significant conservation benefit. To restrict the list of threatened mammal taxa to those that would most benefit from havens as a priority conservation measure, we used expert opinion to categorise each taxon into one of four levels of susceptibility to introduced predators; the process and results of this exercise are described in (Radford *et al*. 2018). The four categories were:

- *Extreme predator-susceptibility*: taxon will not maintain viable populations unless introduced predators are absent or almost absent.
- *High predator-susceptibility*: taxon likely to persist over at least the medium-term (e.g. 20 years) with introduced predators, but with severe reduction in population size or viability, or likely to persist with introduced predators where the predator abundance has been much reduced.
- *Low predator-susceptibility*: taxon likely to persist with introduced predators, but with some reduction in population size or viability.
- *Not predator-susceptible*: population size and/or viability of taxon unaffected by introduced predators.

Complete or almost complete exclusion from cats and foxes is necessary to prevent extinction for taxa categorised as extremely susceptible to introduced predators; cat and fox exclusion (or almost complete exclusion) will also have considerable benefit to taxa categorised as highly susceptible to introduced predators. Although many mammal species are susceptible to both cats and foxes, some may be less susceptible to one of these two predators, and protection from both predators may therefore not be required. Our analysis does not include this level of differentiation because for most native mammal species, we lack the specific information on cat versus fox susceptibility (but cf. Newsome *et al*. 1997).

To assess the benefits of havens for mammal taxa, we restricted our compilations to the threatened mammals that were categorised as extremely or highly susceptible to predation by introduced predators, hereafter referred to collectively as 'predator-susceptible' taxa. However, our database (Supplementary Information) includes information on the locations of haven populations for all Australian terrestrial threatened mammal taxa, regardless of how susceptible they are to cat and fox predation. Whereas our compilation includes subspecies, Radford *et al*. (2018) reports on predator susceptibility for species only; this leads to some slight discrepancies between the two papers, regarding the numbers of taxa rated as extremely or highly susceptible to cats and foxes.

Data collation: havens for threatened mammals

Mainland fenced areas

We compiled a list of all current mainland fenced areas, from earlier compilations (Dickman 2012), through personal knowledge and, personal communications with site managers, and reference to management plans and reports available online, noting their status (introduced predators present or not), location, size and the native mammal species protected within. Our list excludes fenced areas surrounding captive populations that are supported by supplementary feeding and/or frequent restocking; we note, however, that these colonies represent additional insurance against extinction. Our list also excludes four relatively small fenced exclosures built at Wongalara Sanctuary (two exclosures of 6.25 ha each; Frank *et al*. 2014) and at Kakadu National Park (two exclosures of 64 ha each; Gillespie *et al*. 2015). These fenced areas were constructed for experimental research and are not expected to be maintained in the long-term. Fenced areas were classed as potential havens if their exclusion fence was functional and being maintained, and if cat and foxes were mostly absent (i.e. incursions are being identified and remedied). One site (Arid Recovery) has six separate compartments surrounded by predator-proof fencing. Two compartments deliberately contain cats inside the fence to promote predator-awareness behaviours in the resident populations of predator-susceptible mammal taxa, e.g. boodies (*Bettongia lesueur*) and bilbies (*Macrotis lagotis*), in an effort to 'train' native mammals to co-exist with introduced predators in an open landscape. The cats are neutered, radio-collared, closely monitored and managed to prevent adverse impacts on the native mammal populations; the mammal populations are also closely monitored and expanding in size. Given the intensity of risk management, and the security of the surrounding fence, we included the entire area at Arid Recovery that is surrounded by predator-proof fencing; however, the areas for each compartment are separately listed in Table 1, and the compartments with cats could be subtracted from the area totals should circumstances change.

Table 1. Predator-proof fenced exclosures on the Australian mainland

List of extant fenced exclosures (in decreasing order of size) on the Australian mainland that are constructed to maintain wild, self-sustaining populations of threatened mammals. The exclosures are divided into those currently operating as havens, and those that are currently compromised by the unmanaged presence of feral cats and/or foxes. Some fenced areas are made up of two or more compartments; in these cases, the compartments are listed separately. The year the fence (or fence compartment) was completed, and its size, is shown. If completion dates were unavailable, we used the date of the first translocation to the fenced areas

Site name	Managed by	State	Area (km^2)	Sub-area (km^2)	Year established	Comments
Arid Recovery Reserve	Arid Recovery	SA	123.0			Cats deliberately introduced, and heavily managed, in Red Lake and Dingo compartments, to promote predator awareness behaviours
Main				14.0	1998	
First				8.0	2000	
Second				8.0	2000	
Northern				30.0	2001	
Red Lake				26.0	2004	
Dingo				37.0	2008	
Scotia Sanctuary	Australian Wildlife Conservancy	NSW	78.9			AWC reconstructed original fence (Earth Sanctuaries Ltd) that was not effective
Stage one				42.0	1998; 2004	
Stage two				36.7	1998; 2008	
Mt Gibson Sanctuary	Australian Wildlife Conservancy	WA	78.3		2015	
Matuwa (Lorna Glen)	Western Australian Department of Biodiversity, Conservation and Attractions and Martu traditional owners	WA	11.0		2010	
Yookamurra Sanctuary	Australian Wildlife Conservancy	SA	10.9		1991; 2007	AWC reconstructed original fence (Earth Sanctuaries Ltd) that was not effective
Dryandra Woodland	Western Australian Department of Biodiversity, Conservation and Attractions	WA	10.0		2017	
Wadderin Sanctuary	Community group, Shire of Narembeen	WA	4.3		2008	
Mount Rothwell	Mount Rothwell Conservation and Research Centre; Prudentia Investments	Vic.	4.2		2002	Purchased 2006 Earth Sanctuaries Ltd and renamed from Little River
Perup Sanctuary	Western Australian Department of Biodiversity, Conservation and Attractions	WA	4.2		2010	
Mulligan's Flat Sanctuary	Australian Capital Territory Government	ACT	4.0		2009	
Woodlands Historic Park	Parks Victoria	Vic.	4.0		1987	
Waychinicup National Park	Western Australian Department of Biodiversity, Conservation and Attractions	WA	3.8		2010	
Cranbourne Royal Botanic Gardens	Royal Botanic Gardens Board Victoria	Vic.	3.6		1997	Fence construction began in 1986, then upgraded to predator-proof by 1997
Karakamia Sanctuary	Australian Wildlife Conservancy	WA	2.5		1994	
Julia Creek Aerodome	McKinlay Shire Council and Queensland Department of Environment and Heritage Protection	Qld	2.5		2008	
Whiteman Park Woodland Reserve	Western Australian Department of Planning, Lands and Heritage	WA	2.0		2010	
Richard Underwood Nature Refuge	Queensland Department of Environment and Heritage Protection, Glencore Mining, private landholders	Qld	1.3		2009	Built to protect northern hairy-nosed wombats
Hamilton Community Parklands	Southern Grampians Shire Council, Conservation Volunteers Australia	Vic.	1.0		1990	Fence constructed in 1990; substantial repairs in 2015
Nangeen Hill Nature Reserve	Western Australian Department of Biodiversity, Conservation and Attractions, and WWF	WA	0.5		2011	
Total (km^2)			349.8			

(*continued next page*)

Table 1. (*continued*)

Site name	Managed by	State	Area (km^2)	Sub-area (km^2)	Year established	Comments
Fenced areas not currently secure versus cats and/or foxes						
Peron Peninsula, Shark Bay	Western Australian Department of Biodiversity, Conservation and Attractions	WA	1000		1997	Fenced peninsula. Sheep, cattle eradicated, but not cats, foxes, goats
Currawinya National Park	Queensland Dept, of National Parks, Sport and Racing	Qld	25		2001	Fence damaged in floods; being repaired
Epping Forest National Park	Queensland Dept, of National Parks, Sport and Racing	Qld	25		2002	Excludes dogs and foxes, but not cats
Venus Bay Conservation Park	South Australian Dept. Environment, Water and Natural Resources	SA	14		1996	Cats never removed. Bilbies and woylies 'just' persisting
Heirisson Prong	Useless Loop Community Biosphere Project Group	WA	12		1989	Fence across peninsula first built in 1989, repaired in 1991; never an effective barrier. Cats never eradicated, fox incursions regular
Genaren Hill	Private landholder and Genaren Hill Landcare Group	NSW	3.9		1998	Failed by 2005, following sale of property
Total (km^2)			1080			

Islands

We used the islands database compiled by the Environmental Resources Information Network on all Australian islands outside of the Australian Antarctic Territory to derive a list of all islands over 1 ha in size, with their coordinates and areas (SEWPAC 2012). This list included 5442 islands, covering 32 969 km^2. We excluded islands smaller than 1 ha because they are very unlikely to support viable populations of threatened mammal taxa, or cats and foxes. We then compiled information on the presence of cats, foxes and native mammal taxa on Australian islands smaller than Tasmania from multiple sources (Table S1). Islands confirmed as free of both cats and foxes were classed as potential havens. If cats or foxes could access the island at times (e.g. low tides), these islands were excluded, because such incursions are rarely monitored or responded to. Cat eradication has recently been completed on Dirk Hartog Island, with confirmation of the eradication expected in 2018; this island is included in the tally of potential island havens, but not yet in the tally of havens that contain threatened mammal populations.

Haven statistics

We created a matrix of the occurrence of threatened mammal taxa against all mainland and island havens and used it to calculate a range of comparative metrics for the two haven types. Haven populations were further identified as being *in situ*, or as having been translocated to the site. We noted whether translocations were successful or unsuccessful, or if their outcome was still uncertain because they had been carried out recently (in the last year; see below). Noting the ongoing expansion of the haven network, and of threatened mammal populations introduced to them, our compilation reflects the situation at October 2017.

We needed to make consistent decisions about when to include or exclude populations of mammals from our collation. The IUCN Red List guidelines for inclusion of translocated populations in species status assessments (IUCN Standards and Petitions Subcommittee 2017) provides some relevant guidance. It states that populations translocated to sites within their former distribution can be included in an assessment if they would persist for more than 10 years without ongoing, direct intensive management such as supplementary feeding, continual restocking and veterinary care. Populations that rely on management to counteract anthropogenic threats (including fencing to exclude introduced predators) can be included if they meet the criterion of 10-year persistence. Populations translocated to sites outside the taxon's previous known distribution can also be included in assessments, if the purpose of the translocation was for conservation, the new site is 'geographically close' to the original distribution, the translocation occurred over 5 years ago and the population is breeding. Note that the time needed to elapse after translocation before a population can be included in an assessment is not definitive ('. . .*if they would persist for more than 10 years*. . .'); this verb tense encompasses future expectations as well as past performance. Many of Australia's haven mammal populations have been translocated to their havens within the last 10 years. Translocation success is generally high (see Results), and most translocation failures occur within the first year (Short 2009). We therefore opted to include populations in our collation that have persisted in their haven for 1 year or more, to maximise the currency of the information.

Results

Threatened mammals susceptible to cat and/or fox predation

Of the 124 terrestrial mammal taxa listed as threatened or Near Threatened by the Mammal Action Plan, and/or as threatened by the EPBC Act, 14 taxa (comprising 12 species) were categorised as extremely predator-susceptible, and 53 (comprising 40 species) as highly predator-susceptible (Table S2). The following analyses focus on this subset of extremely and highly susceptible taxa ($n = 67$ taxa, from 52 species).

Potential havens for threatened mammals

Mainland fenced areas

There are currently 19 fenced areas with functional, predator-proof fencing on the Australian mainland, ranging in size from 0.5 km^2 to 123 km^2 (median = 4.0 km^2) and covering a total area of 350 km^2 (see Table 1; Fig. 1). The two largest fenced areas (Arid Recovery, Scotia) contain multiple compartments (six and two respectively); we use the combined area of the compartments in both cases in the collation, but the compartment areas are also shown separately in Table 1. An additional five fenced areas (1080 km^2) are not functional: introduced predator incursions have not been sufficiently managed, leading to extirpations of most or all of the translocated mammal populations (Table S2). In some cases, cats and/or foxes were never eradicated from within (Venus Bay, Peron Peninsula); in one case, the fence was constructed to protect an *in situ* species (northern hairy-nosed wombat; *Lasiorhinus krefftii*) from dogs, and was also fox-proof but not cat-proof (Epping Forest); and in yet other cases, the fence was damaged, and introduced predators became established (Heirisson Prong, Currawinya, Genaren Hill). Table 1 shows the date of initial construction; some of the original fences have since been rebuilt with much-improved designs (reconstruction dates also shown). A further 10 fenced areas were excluded from the collation because they protect populations that depend on regular management supplementation (Eraring Power Station, Harry Waring Marsupial Reserve, Little Desert Nature Lodge, Moonlit Sanctuary, Softfoot Sanctuary, Tidbinbilla Nature Reserve, Uluru-Kata Tjuta National Park, Watarrka National Park, Warrawong Sanctuary, Yelverton Brook Conservation Park). One of these (Watarrka) was decommissioned in 2017. We are aware of eight future fenced areas that are underway or being planned for the next 10 years. If successfully completed, they will cover 918 km^2; their locations are shown in Fig. 1. Three are proposed by private landholders (Wandiyali-Environa, 4 km^2; Mallee Refuge at Secret Rocks, 8 km^2; Tiverton, 10 km^2),

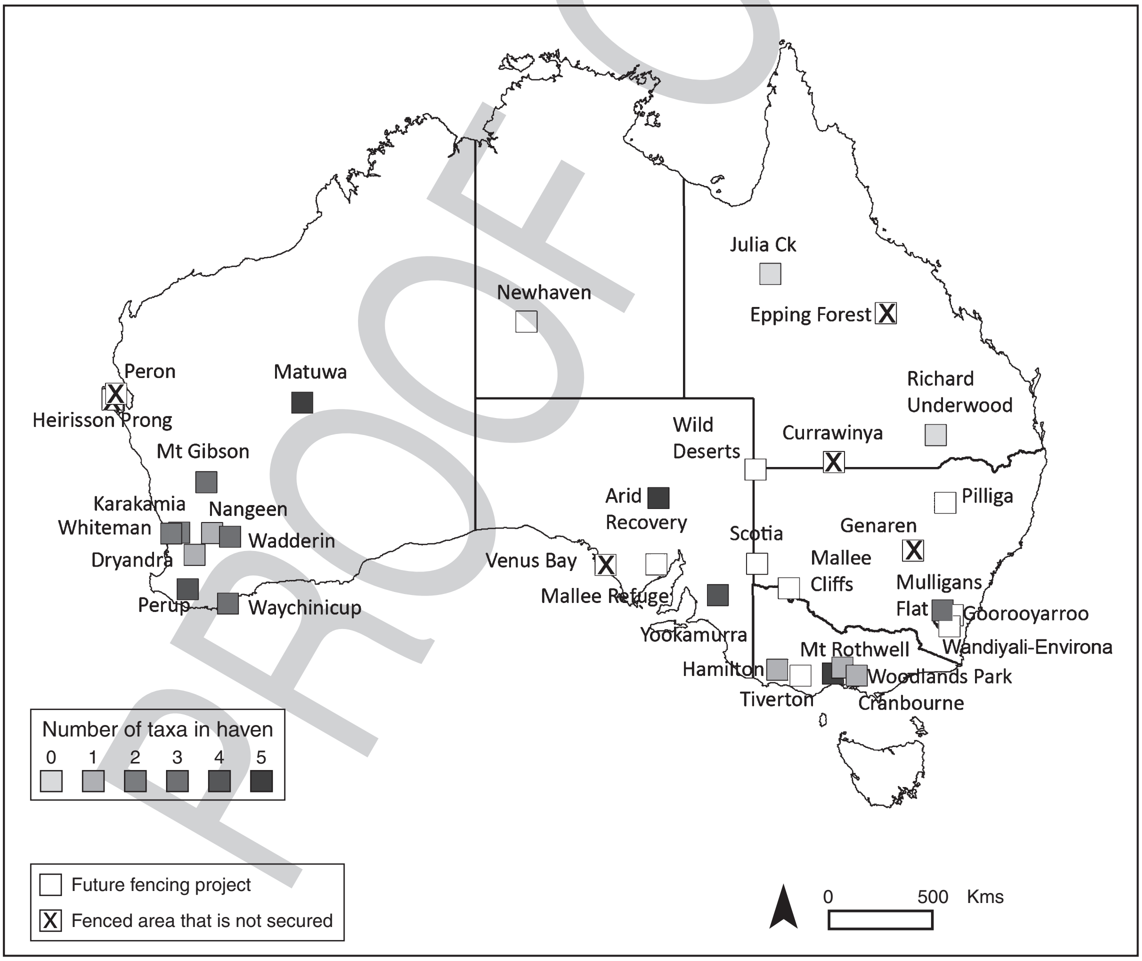

Fig. 1. Locations of fenced havens for threatened terrestrial mammal taxa in Australia. The number of predator-susceptible threatened mammal taxa in each haven is shown by cgreyscale. Fenced areas with damaged fences, and/or unmanaged introduced predators within, are shown in grey. Some of these are likely to become functional havens in the near future (e.g. Currawinya, Venus Bay). Note that the Epping Forest fence was designed primarily to exclude dogs and foxes (but not cats); it fulfils this aim effectively. Future fence projects are shown in pale green. Sizes of fenced havens are given in Table 1.

and five by NGOs partnering with government (Goorooyarroo, ACT, 7 km^2, ACT Government and Woodland and Wetland Trust; Newhaven, 695 km^2, Australian Wildlife Conservancy and Commonwealth Government; Pilliga, NSW, 58 km^2; Mallee Cliffs, 96 km^2, NSW government and Australian Wildlife Conservancy; Wild Deserts, 40 km^2, NSW Government and University of NSW).

Islands

Of the 5442 Australian islands over 1 ha in size, 42% are off the coast of Western Australia, 31% off Queensland, 11% off Northern Territory, 5% off Tasmania, 4% off South Australia, 3% off Victoria, 2% off NSW and 2% occur in Commonwealth waters.

We identified 752 islands where the presence or absence of cats and/or foxes is known. In most cases we could match these islands to a numbered island in the national islands database, but in 43 cases (5.7%), we could not (Table S2). In calculating percentages, we have assumed these unnumbered islands are present in the national database to avoid double counting areas in the denominator. Cats and/or foxes are present on at least 162 islands; these islands include the larger islands, so the cumulative area for islands with cats and/or foxes is 25 297 km^2, or 76.7% of the total island area (Table S2). There are 590 islands confirmed as free of cats and foxes. These 590 potential havens cover 5468 km^2, or 16.6% of the total island area, or 0.06% of Australia's land area (Fig. 2; Table S2). Islands known to be cat- and fox-free range in size from 0.01 to 628 km^2 (Dirk Hartog Island is the largest, with next largest being Barrow Island at 325 km^2). The median size of islands known to be cat- and fox-free is 0.7 km^2, reflecting the fact that most Australian islands are small. The state of Western Australia has the largest number of islands confirmed as cat- and fox-free (160; 7% of WA islands), followed by Tasmania (106; 37% of Tasmanian islands). New South Wales has the

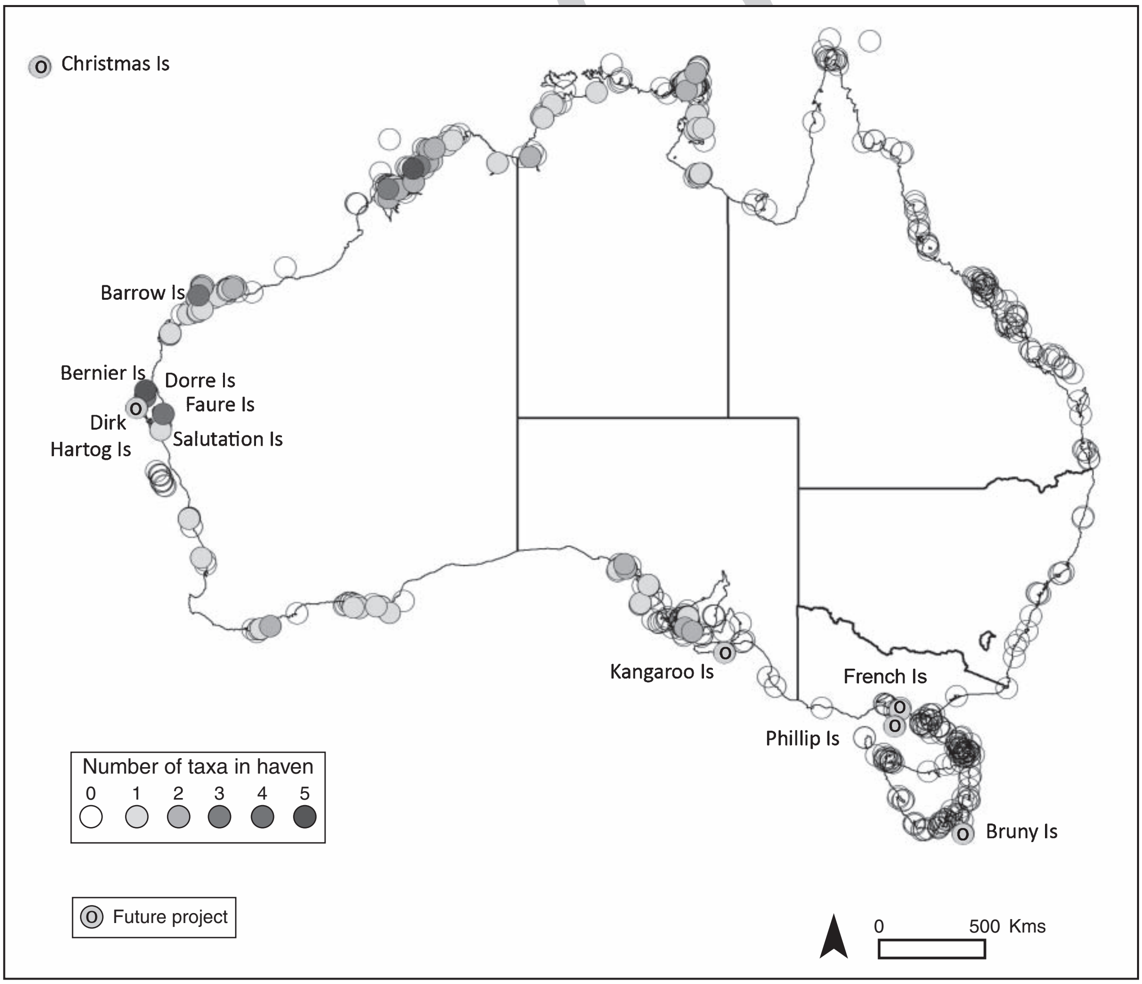

Fig. 2. Locations of 590 Australian islands that are known to be cat- and fox-free. The locations of 101 island havens for predator-susceptible terrestrial mammal taxa are superimposed. The number of predator-susceptible threatened mammal taxa in each haven is shown by colour-coding. Future island projects (all involving cat eradication) are shown in pale yellow and are labelled (Christmas Island is shifted slightly from the west to fit within the map frame). Island sizes are given in Table S1.

fewest cat- and fox-free islands (12; 14% of NSW islands) (Fig. 2; Table S2). Cat and fox status is unknown for most (4690) Australian islands. However, these islands are mostly small, and their cumulative area is just 2205 km^2, or 6.7% of the total island area. These islands are also not known to contain threatened predator-susceptible mammal species. Although we do not include these generally small and poorly known islands as havens in our tallies, we recognise that it is possible that some of these may provide some degree of haven for *in situ* populations of some predator-susceptible species.

We are aware of projects (underway or proposed) to eradicate introduced predators from another five large islands by 2030 (French, 174 km^2; Bruny, 356 km^2; Phillip, 101 km^2; Christmas, 137 km^2; Kangaroo, 4416 km^2; totalling 5184 km^2).

Haven statistics

Of the 19 functional mainland fenced areas, 17 currently contain one or more populations of threatened mammal taxa that are predator-susceptible. Together, these 17 fenced areas hold 49 populations of 27 taxa (25 species) in an area of 337 km^2. The fenced areas are largely in the south of the continent (Fig. 1). Of the 590 islands known to be cat- and fox-free, 101 (covering 2152 km^2) hold 139 populations of 27 threatened mammal taxa (22 species) that are predator-susceptible (Fig. 2). Barrow Island is currently the largest haven containing threatened mammal taxa, but translocations to Dirk Hartog Island are already underway, and this island should join the haven network by the end of 2018. Therefore, across the two haven types there are 118 havens (covering 2490 km^2) protecting 188 populations of 38 predator-susceptible mammal taxa (32 species) (Table 2; Table S2).

Taxa that are predator-susceptible are unevenly represented within havens (Fig. 3). Some taxa occur at five or more sites (11/67 taxa, 16%, occur in five or more havens). The taxa with highest levels of representation in havens are the golden-backed tree-rat (10 havens, all islands), woylie (10 havens), golden bandicoot (*Isoodon auratus*; 13 havens, all islands), northern quoll (*Dasyurus hallucatus*; 23 havens, all islands) and pale field rat (*Rattus tunneyi tunneyi*; 33 havens, all islands). Twenty-nine taxa (43% of all predator-susceptible taxa) are not represented in any havens, and an additional 15 taxa (23%) occur only in one or two havens. Of taxa with representation within havens, 11 taxa occur only in fenced havens, 12 only on island havens and the remaining 15 taxa are represented in both islands and fenced havens.

Most taxa categorised as extremely predator-susceptible exist now only within havens; only 4/14 (29%) have population(s) that are currently present in an open landscape in the presence of introduced predators: eastern quoll (*Dasyurus viverrinus*) and eastern bettong are both present in Tasmania with cats, but no foxes, and extinct on the mainland where foxes are present. Gilbert's potoroo (*Potorous gilbertii*) and central rock-rat are on the mainland in the presence of cats and foxes, but both are precarious (Table S2). Of the 53 taxa categorised as highly predator-susceptible, all except two taxa (96%) have populations that co-exist with cats and/or foxes. The two exceptions, Recherche rock-wallaby (*Petrogale lateralis hacketti*) and Pearson rock-wallaby (*P. l. pearsoni*), are island endemics.

Island havens outnumber fenced havens, cover a greater total area and can reach a much larger size (Fig. 4). They protect a larger number of populations, but a similar number of taxa, as do fenced havens (Table 2; Fig. 4). Fenced havens are more likely than islands to protect multiple threatened mammal taxa within the site (Fig. 5).

Islands and fenced areas both protect translocated populations (30 and 43 respectively), but islands play a much larger role in protecting *in situ* populations (109 on islands versus six in fenced areas; Table 2; Fig. 6). Island translocations have been more common in Western Australia and South Australia, and they have been more common south of the tropics (Fig. 7). The cumulative areas used in mammal translocation programs have expanded at a similar pace for fences and islands since the 1970s, but the addition of Dirk Hartog Island (628 km^2) in 2018 will cause the cumulative island haven area used in translocations to expand substantially (Fig. 8).

Island translocations have been more successful than translocations to fenced areas, in terms of the proportion of translocated populations that have persisted for at least 12 months (islands: 30/35 (86%); fences: 42/60 (70%); Table S2).

Table 2. Summary of the contributions of island and fenced havens to protecting extremely and highly predator-susceptible threatened Australian mammals

Full details are in Table S2. Note that the totals for the number and area of havens are not the sum of the values for extremely and highly susceptible taxa, as some havens contain two or more taxa

	Islands			Fenced areas			All havens
	Extremely susceptible	Highly susceptible	Total	Extremely susceptible	Highly susceptible	Total	
Number of populations	28	111	139	17	32	49	188
Naturally occurring populations	13	96	109	0	6	6	115
Translocated populations	15	15	30	17	26	43	73
Number of taxa	11	16	27	11	16	27	38
Number of species	9	13	22	9	16	25	32
Number of havens	16	90	101	11	15	17	118
Total haven area (km^2)	457	1992	2152	323	341	337	2490

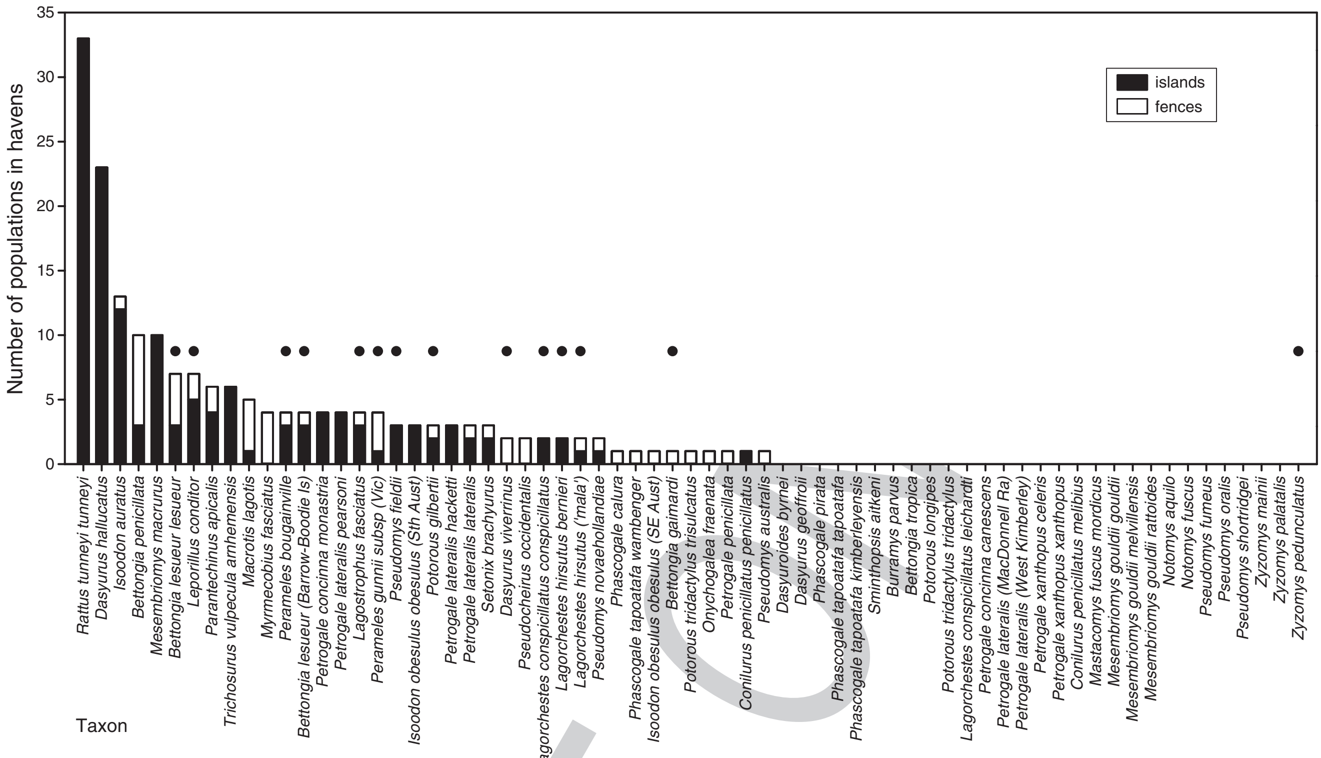

Fig. 3. Frequency histogram of haven populations for predator-susceptible mammal taxa. Fenced and island havens are shown separately. Taxa categorised as extremely susceptible (as opposed to highly susceptible) to introduced predators are identified with a dot above the bar.

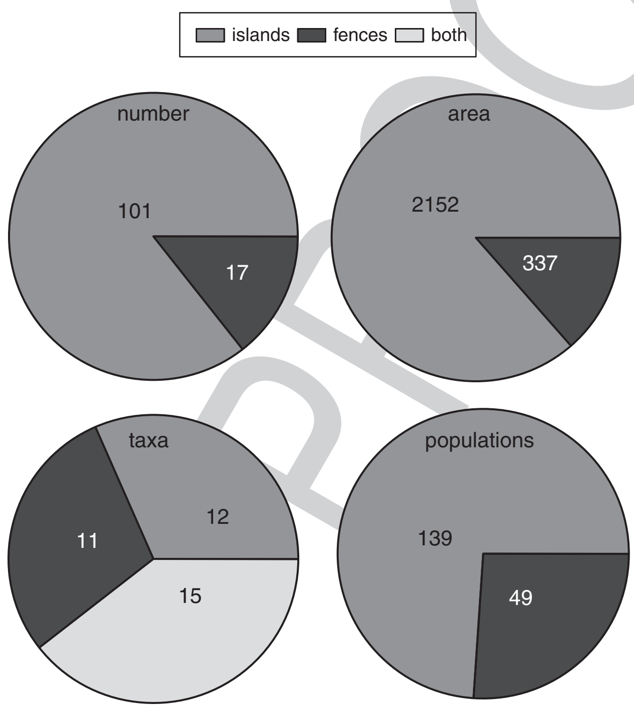

Fig. 4. Number, areas, taxa and species represented within fenced and island havens.

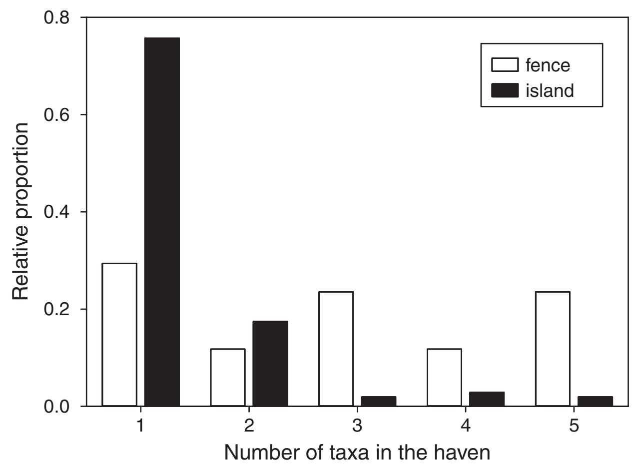

Fig. 5. Relative proportion of havens with varying numbers of threatened mammal taxa within. The proportions are calculated for each haven type separately.

Discussion

In the present paper, we show that island and fenced havens are providing a critical and effective role in the conservation of Australian mammals, and that this contribution is increasing.

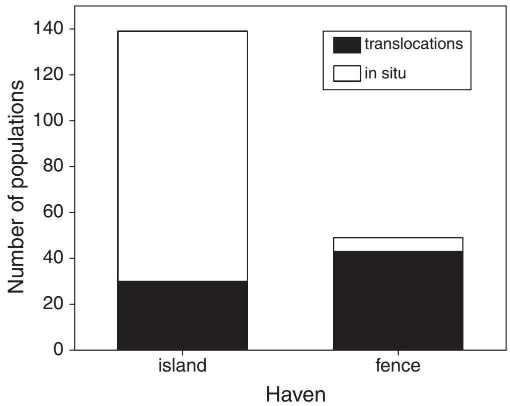

Fig. 6. Representation of translocated versus *in situ* population within fenced and island havens.

Our collation identifies 118 havens with mammal taxa that are extremely or highly susceptible to predation by cats and foxes. These havens currently comprise 17 mainland fenced areas (each 0.5–123 km^2, covering 337 km^2 in total) and 101 continental offshore islands (each 0.03–235 km^2 in size, covering 2152 km^2 in total), and protect a mix of *in situ* and translocated populations, with most of the translocations occurring since the 1980s. Few other countries rely so heavily on sites where introduced species are physically removed or excluded (Keitt *et al*. 2011; DIISE 2015). An exception is New Zealand, where 28 fenced areas (enclosing 84 km^2) were built between 1999 and 2009 (Burns *et al*. 2012), and introduced mammals have been eradicated from over 115 islands covering 460 km^2 (Towns *et al*. 2013; Russell *et al*. 2015). In New Zealand, havens are used primarily to protect native bird species; fence construction and island eradications

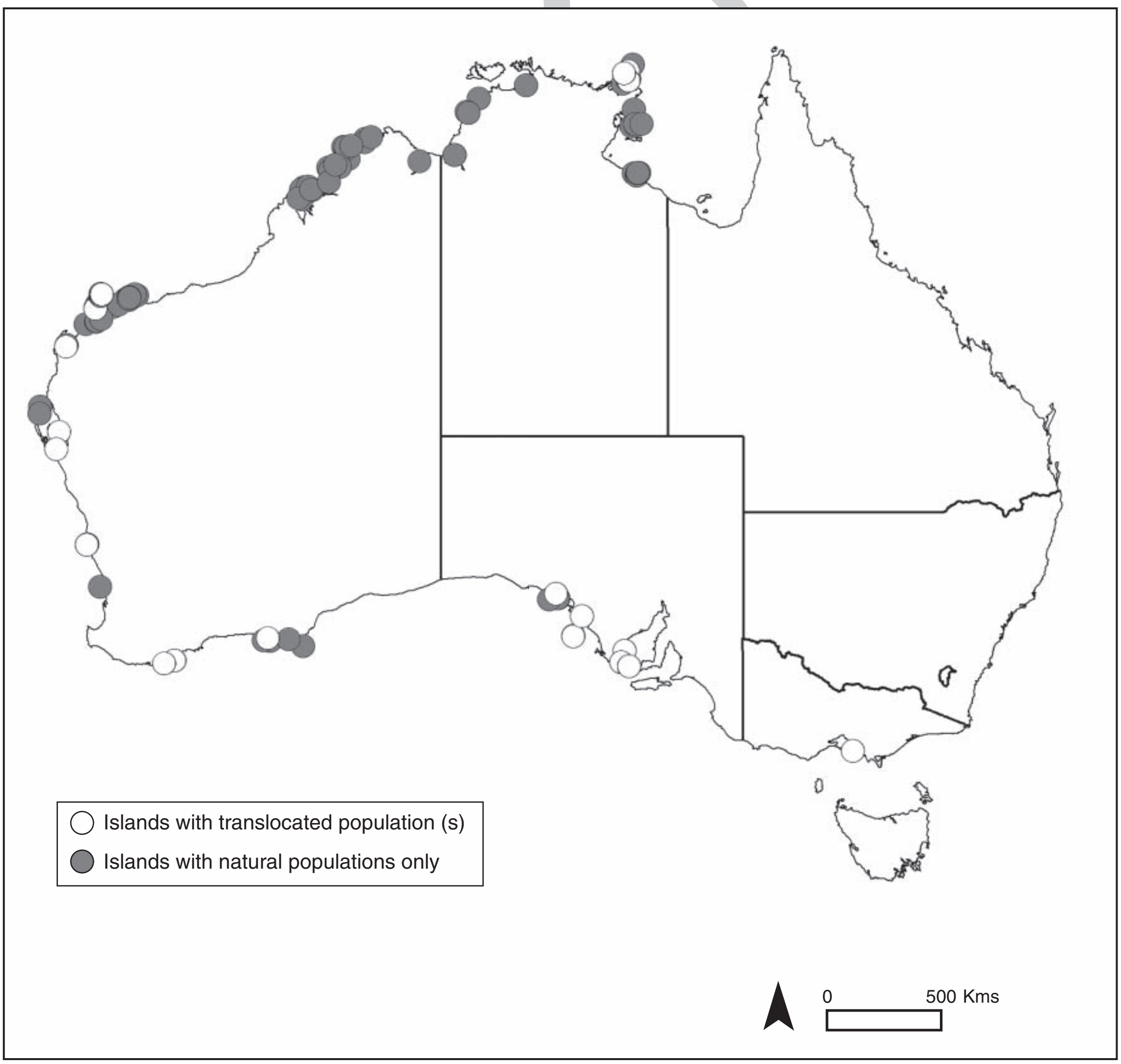

Fig. 7. Locations of populations translocated to Australian islands.

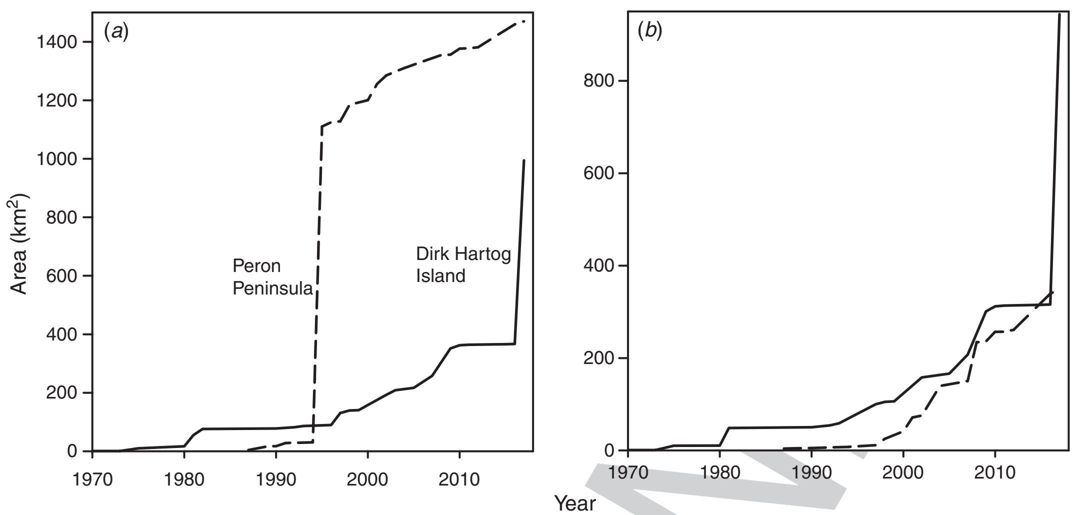

Fig. 8. The expansion of islands and fenced areas used in translocation projects. (*a*) All islands and fenced area projects, regardless of whether the projects were successful or not. This includes a small number of fenced areas that were completed but where cats and foxes were never adequately controlled, plus fenced areas that were effective for a while, but later failed. Note the large increase in area when Peron Peninsula was fenced off; however, cats were never eradicated from within, and fox incursions occur regularly. The large increase in island areas at the end of 2017 is due to the addition of Dirk Hartog Island. (*b*) The expansion of islands and fenced areas that became (and have remained) effective havens for predator-susceptible mammal taxa. Both graphs add islands from the date of the first translocation, and fences from the date of their construction.

are relatively complex because smaller introduced mammals like rodents and mustelids need to be removed along with cats (Burns *et al*. 2012; Norbury *et al*. 2014).

The subset of threatened mammal taxa that is most susceptible to predation by introduced predators was based on a summary of expert opinion (Radford *et al.* 2018)). The expert categorisation largely aligned with the current representation of taxa in open landscapes versus havens. Fourteen taxa were identified as 'extremely susceptible'; for these, having populations that are completely, or almost completely, separated from foxes and cats is considered essential for avoiding extinction. Of these, 10 taxa persist only in havens. Of the four exceptions that persist in open landscapes, two have very small and precarious populations (in refugial areas) that are the subject of very intensive management (Gilbert's potoroo, central rock-rat). For example, the central rock-rat's distribution at the time of European settlement extended from central Australia to the Cape Range in Western Australia, and north to the Granites in the Tanami bioregion. It has been lost from almost all this extensive range (McDonald *et al*. 2018) and its current area of occupancy is amongst the smallest of Australian mammals. The other two exceptions have populations that are separated from the introduced predator to which they are most susceptible (eastern quoll and eastern bettong are particularly susceptible to fox predation; they were extirpated from open landscapes on the mainland, but persist in Tasmania where foxes are absent). A further 53 taxa were categorised as 'highly susceptible' to cats and/or foxes; for these, complete exclusion from introduced predators at least at some sites is considered an important (but not immediately essential) component of their conservation management, because their maintenance in open landscapes may be supported with alternative management actions. Apart from two island endemics, these taxa all have some populations that co-exist, at least currently, with cats and foxes. However, the distributions or population densities of these species are all attenuated, as evidenced by their threatened status (Woinarski *et al*. 2014).

Comparison of islands and fenced areas

Australian island havens outnumber mainland fenced areas by almost 7-fold, cover a much larger total area (2152 versus 337 km^2) and individually, reach much larger sizes. The largest haven for predator-susceptible threatened mammal taxa is Barrow Island (235 km^2). However, feral cats have recently been eradicated from Dirk Hartog Island (628 km^2; foxes were absent) and translocations of threatened mammal species there have begun. In contrast, the largest fenced area with a functional fence is Arid Recovery at 123 km^2, and there are currently only three other functional fenced areas >11 km^2. The disparities between island and fenced havens in their sizes and total area may be accentuated in the next 20–30 years, because projects to eradicate cats and foxes from another five large islands (totalling 5184 km^2) are underway or proposed by a range of communities and groups supported by national policy (Commonwealth of Australia 2015). At least eight new fenced areas are also planned over the next 10 years, totalling 918 km^2, some with support from NSW, ACT and Commonwealth governments. These will include the largest exclosure yet established (Newhaven, at 695 km^2); however, their combined area is still smaller than that of the new island projects.

Islands have played a much greater role than fenced areas in protecting *in situ* populations of predator-susceptible taxa (109 island populations; six fenced populations), because of their capacity to be serendipitous havens, and their larger size.

Of the 101 island havens, only eight have been the subject of cat and/or fox eradication programs (all others had never experienced the introduction of predators), and these islands from which introduced predators have been eradicated now protect eight translocated and four *in situ* populations of predator-susceptible mammals. Fence construction projects are almost always initiated with the explicit intention to reintroduce regionally extinct species into the fenced area, which means they are much less likely to have *in situ* threatened taxa. Fenced havens protect more translocated populations (43) of predator-susceptible taxa than islands (30) (Fig. 4), but the cumulative areas used for successful translocation projects have increased similarly for islands and fenced areas over the past few decades (Fig. 8). In New Zealand's fenced areas, the ratio of translocations to fenced areas versus islands is also broadly similar (63 translocated to fenced areas, 82 to islands during 1999–2009, Burns *et al*. 2012).

Islands protect more populations of threatened mammals than fenced areas, even though the two haven types protect similar numbers of taxa (Fig. 4). Two factors likely contribute to this difference. First, some taxa are naturally represented on multiple islands. This is particularly marked for northern taxa (pale field rat, northern quoll, golden bandicoot, golden-backed tree-rat, nabarlek; *Petrogale concinna monastria*) that have *in situ* populations on numerous Kimberley islands (and Pilbara islands, for some taxa). Second, fenced areas are more likely than islands to protect two or more taxa within a single haven (Fig. 5). Constructing and then maintaining a fenced area requires a substantial upfront and ongoing investment (Hayward *et al*. 2014; Norbury *et al*. 2014); fenced area projects often aim to translocate as many mammal taxa into the fenced haven as possible to maximise the conservation benefit. In contrast, options for island havens that are already predator-free are more numerous, so it is possible there has been less incentive to carry out translocations of multiple taxa to single islands. Moreover, some islands already have *in situ* mammal taxa (or other valuable species that may be affected by a translocation), which can limit options for multiple translocations.

Although most island havens support just one or two predator-susceptible mammal taxa, some Western Australian islands are notable exceptions. Barrow, Bernier and Dorre Islands each protect four or five predator-susceptible threatened taxa, all of which are *in situ* rather than translocated. These islands were protected by the Western Australian government as fauna reserves very early in the 20th century and have been only briefly used for other purposes (e.g. pastoralism, infirmaries, oil and gas extraction; the last with environmental protocols imposed). This probably limited opportunities for introduced species to become established (Ride *et al*. 1962). In contrast, along the same stretch of coast, Faure and Dirk Hartog Islands were used for longer periods as pastoral leases. Exotic species (including cats) were introduced, and the native mammal fauna of both islands was largely extirpated (Baynes 2008). Cats were eradicated from Faure in 2001 (Algar *et al*. 2010), and from Dirk Hartog by 2017–18, and both islands have been (or will be) the subject of translocation programs involving multiple species (Burbidge *et al*. 2018).

Another difference between the haven types is who operates them. Fenced areas have been operated by State and Territory governments (15; of which the Western Australian government operates seven), non-government organisations (six; of which Australian Wildlife Conservancy operates four), local governments (three), community groups and individuals (six), and there is one example of co-management with an Indigenous group (Matuwa) – these figures exceed the total for fenced areas in Table 1 because some fenced areas are partnerships (Table 1). The wide variety of tenures and land use on the mainland has allowed for diverse management models (Innes *et al*. 2015). Fenced areas in New Zealand also have a diverse suite of instigators, including community groups and private individuals (Burns *et al*. 2012). Most Australian predator-free islands have land tenures that are controlled by government (Commonwealth, state or territory) or by Indigenous groups, in this last case especially for northern Australian islands. However, the recent interest in adding human-populated islands (Phillip, Christmas, Bruny, French, Kangaroo Islands) with multiple land tenures and interests to the portfolio of havens (Commonwealth of Australia 2015) will necessitate more complex management models (Glen *et al*. 2013*a*).

Our focus here is on predator-susceptible mammal taxa, because Australian mammals are most at risk from introduced predators. However, we note that islands without introduced predators are also more likely to provide viable havens for predator-susceptible species in other taxonomic groups (e.g. birds, reptiles) than are fenced areas, because the islands are generally larger, and because to date there have been very few successful cases of reintroductions of predator-susceptible bird and reptile species to Australian exclosures (e.g. Read *et al*. 2011; Bennett *et al*. 2012; Kemp and Roshier 2016).

Biases in the data

Our information on the distribution of introduced predators and threatened mammals on islands is imperfect. First, the presence of cats and/or foxes is unknown for most Australian islands (4690 out of 5442) and confirming cat and/or fox absence is more difficult than confirming their presence. Many of these islands, especially in the tropics (outside the distribution of the fox), will be free of introduced predators. Most of these islands are small (their combined area is 2204 km^2, 6.7% of the total island area), and introduced predators are less likely to occur on smaller islands (Legge *et al*. 2017). Thus the real number of cat- and fox-free islands is certainly higher than our estimate of 590 islands. However, small islands may also be less suitable for supporting viable populations of native mammals, so even if cat- and fox-free, small islands may not function as havens for predator-susceptible taxa. Second, many Australian islands have never been surveyed for their native fauna, particularly in the tropics (where most Australian islands are located, SEWPAC 2012). Thus, the number of *in situ* populations of predator-susceptible mammal taxa on cat- and fox-free islands is certainly higher than our estimate. One conclusion from this assessment is that continuing to undertake biological surveys of Australian islands is a priority, particularly those that are relatively poorly known and those that may have significant conservation values.

Potential for expansion of the haven network

Our collation indicates much room for further effective expansion in the haven network. Of 590 known potential island havens, only 101 (17%) support populations of threatened mammal taxa that are predator-susceptible. All states and territories have dozens of islands over 1 ha in size, from 85 for the Commonwealth to 2285 for Western Australia, with 5.5% (Queensland) to 33% (South Australia) of these already confirmed as cat- and fox-free. In addition, the cumulative area of islands with unknown feral predator status is more than four times the area of mainland havens; these islands represent a potentially valuable resource as either places of *in situ* conservation, or as targets for translocation of species currently poorly represented in the haven network. Suitable islands may not be available for all taxa (e.g. most islands are tropical, but many predator-susceptible threatened mammal taxa exist south of the tropics; some mammals require specific habitats or larger areas than are available on islands). Some islands will be unsuitable for translocations, because of small size, or because they support endemic plant and animal taxa or have other values (e.g. seabird rookeries) that could be at risk from a mammal translocation. In spite of these constraints, there are many potential options for further island translocations, without even considering preparatory programs to eradicate introduced species. In contrast to islands, most extant fenced havens (17/19) already protect predator-susceptible threatened mammal taxa, and often several taxa, so substantial expansion of the number of threatened mammal populations in exclosures will mostly entail establishment of new sites.

If the primary objective of creating havens is species conservation, then future investment should be preferentially taxa not currently represented, or for those under-represented in the existing haven portfolio (Fig. 3); this is likely to include islands and/or fences in northern Australia (Fig. 1). Although five taxa occur in 10 or more havens, 15 taxa (22.7% of all predator-susceptible threatened taxa) occur only in one or two havens, and 29 taxa (43%) are not represented in any haven. Of the latter, the taxon at greatest risk of imminent extinction from predation from introduced predators is likely the central rock-rat (*Zyzomys pedunculatus*); this assessment is corroborated by a recent independent analysis (Geyle *et al.* 2018) This species persists at a handful of sites on the tops of the West MacDonnell Ranges, with distribution and population size continuing to decline (McDonald *et al.* 2015). It is the only taxon categorised as 'extremely susceptible' to predation by introduced predators that is not represented within a haven, and should therefore be the highest priority for inclusion in future havens, in addition to ongoing intensive management in open landscapes to protect extant populations (McDonald *et al.* 2017*a*). The species had a previous distribution that stretched from central Australia to the Cape Range of coastal Western Australia; translocation options to havens could include many sites within this former mainland distribution, as well as islands off the Western Australian coast, as long as these sites contained suitable habitat and food resources (McDonald *et al.* 2017*b*; McDonald *et al.* 2018).

Advantages and disadvantages of fenced areas versus islands

Islands and fenced areas offer different constraints and possibilities for predator-susceptible species. Establishing (with or without prior eradication programs) and then maintaining the biosecurity of island populations of threatened taxa can be cheaper than for fenced areas (Scofield *et al.* 2011; Hayward *et al.* 2014; Innes *et al.* 2015). The perimeters of islands do not need to be continually repaired and eventually replaced. Islands are not constantly challenged by introduced species at their boundary in the way that fences are, as long as the sea distance that separates them from a potential invasion source exceeds the swimming capacity of the potential invaders, and human visitation to islands is regulated by appropriate biosecurity protocols. Neither of these factors is guaranteed, particularly for islands that currently or previously supported introduced species – indicating that invasion vectors exist, or did exist historically. On the other hand, carrying out regular monitoring for predator incursions, and monitoring or management of the translocated populations, may be more logistically challenging and expensive on an island than in a mainland exclosure.

Eradications of introduced species from havens, in preparation for a translocation program, can have substantial co-benefits, especially for islands. Although islands cover just over 5% of the world's land surface area, they contain more than 15% of terrestrial plant, bird, and rodent species (Tershy *et al.* 2015). However, this island biodiversity is extinction-prone: ~95% of bird, 90% of reptile and 70% of mammal extinctions have been island endemics (Keitt *et al.* 2011), and 37% of all species listed as Critically Endangered on the IUCN Red List are island endemics (Tershy *et al.* 2015). As well as endemic species, islands also contain important breeding colonies of seabirds, marine mammals and sea turtles (Woinarski *et al.* 2018). Eradicating invasive species from islands is often accompanied by marked benefits to the extant biodiversity (Bellingham *et al.* 2010; Towns *et al.* 2013; Jones *et al.* 2016). These sorts of co-benefits have not been reported as clearly for fenced areas (Burns *et al.* 2012). However, islands cannot easily offer one of the posited co-benefits of mainland fences – a 'halo' effect, whereby the restoration within the fenced area has benefits that spill over into the surrounding area. There is some support for this concept from animal-dispersed plants (and their dispersers) from elsewhere (e.g. Brudvig *et al.* 2009; Tanentzap and Lloyd In press), but to date there is no evidence for halo effects arising from Australian fenced areas.

The smaller size of most fenced areas compared with islands increases the risks associated with small population size (including stochastic events, reduced genetic diversity and inbreeding) as well as the potential for overabundance (Hayward and Kerley 2009; Moseby *et al.* 2018), although these challenges may be countered by treating a set of exclosures as a metapopulation. In addition, some Australian islands have supported populations of predator-susceptible mammals since sea level rise after the last glaciation

(~6000–8000 years ago), indicating that, subject to survival bias, genetic diversity issues may be overstated (Eldridge *et al*. 2004). Other potential disadvantages include collateral impacts from fence strike (Burns *et al*. 2012), and the restriction of animal movement (dispersal and migration; Hayward and Kerley 2009). On the other hand, compared with islands, fenced havens broaden the habitats (and therefore taxa) that can be protected because of flexibility of location; they can be positioned in sites without values such as important seabird colonies that could be at risk from a mammal translocation. They may be used to 'seed' releases immediately outside the fence when introduced predators are adequately controlled; they offer opportunities for expansion, and they are probably more accessible for research (especially into ecological restoration) and public engagement (Russell *et al*. 2015).

Given the contrasting constraints and opportunities presented by fences and islands, a mix of haven types is likely to be most valuable. Ideally each taxon would be represented in havens that were dispersed across its previous distribution, and many taxa could be on islands as well as within fenced areas. The new fenced havens could preferentially be located at sites where potential co-benefits of fenced exclosures could be realised, including research and management of introduced predators that support the potential expansion of threatened mammals out of havens into the broader landscape. Translocations to any haven, island or fenced, entail risks to the recipient site (competition, predation on *in situ* species, resource depletion), and should be based on explicit conservation objectives and supported by a comprehensive risk assessment (IUCN SSC 2013).

Conclusion

Australia's reliance on havens from introduced predators for preventing mammal extinctions has grown strongly since the 1980s, and recent national policy initiatives (Commonwealth of Australia 2015) will support further growth of both mainland fenced areas and island translocations. The approach has been extremely successful in preventing imminent extinctions, but as the use of havens matures, longer-term management issues will need to be addressed. These include how to maintain genetic diversity in these disjunct populations (e.g. by making inter-haven translocations while minimising risks such as disease transfer between populations), how to decide on the minimum population sizes that should be maintained in each haven (and collectively among multiple havens), how many havens each taxon should exist within and how to identify and manage issues of overabundance and impacts on *in situ* biodiversity.

Substantial progress has been made in the representation of predator-susceptible threatened mammals within havens, but the compilation we present here shows that this investment has been distributed unevenly among the mammal taxa that require protection within a haven, such that some predator-susceptible taxa exist in multiple havens but many taxa exist in none (Fig. 3). To date, the growth in the haven network has happened somewhat organically, dependent on the priorities, opportunities, and varied motivations of the management agencies involved (national, state and/or local government, large and small non-government organisations (Ringma *et al*. 2017; Ringma *et al*. 2018); see also (Burns *et al*. 2012) for comparison with New Zealand). Individual organisations make decisions about conservation investment that are most strategic for them; in the extreme case, a community group is unlikely to construct a haven away from their local area. However, looking across organisations and jurisdictions, a more nationally strategic approach could seek to shape future investment so that all predator-susceptible taxa have an adequate level of protection, ideally each with several populations spread across their previous distribution. To achieve this, spatial optimisation could be used to determine the best locations for future havens (Glen *et al*. 2013*b*; Ringma *et al*. 2017). However, because priority havens would be implemented by a decentralised conservation sector, this strategic planning needs to be coupled with collaborations between various levels of government, non-government organisations, community groups and Indigenous organisations. In addition, greater levels of community understanding and support for eradication and translocation programs (Algar *et al*. 2011; Oppel *et al*. 2011) would help to support this conservation approach in the longer term, especially because some of the islands most suitable for transformation to havens are larger islands, which also are more likely to be inhabited by people.

Most of the Australian land area is now effectively uninhabitable for the extant native species most susceptible to predation by just two introduced species. For these taxa, representation in havens where they are protected from cats and foxes is a necessary holding action to avoid extinction in the near-to-medium term. However, for most species, haven areas represent a minute fragment of their former ranges, and a minute proportion of their former population size. Ideally, havens should also serve as a foundation for recovery in the longer term, where the objective is to restore viable, self-sustaining populations of native mammals in open landscapes across most of their former ranges. However, such recovery will require funding and effective and enduring national-scale control or eradication of cats and foxes, a pre-condition that is logistically, financially and technically beyond the current capacity of conservation, but which needs adequate and urgent resourcing (Kinnear *et al*. 2017).

Conflicts of interest

The authors declare no conflicts of interest.

Supplementary material

The supplementary material is an excel spreadsheet with tables containing 1) the details for all Australian islands where the presence/absence of cat- and fox-free islands is known; and, 2) details of representation in fenced and island havens ofr all threatened mammal species.

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