Attachment 2. The status of non-native species in New South Wales – introductions, naturalisations, invasions

Invasive Species Council, November 2023

Mostly based on information extracted from the Invasive Species Council's draft State of Environmental Biosecurity Report. See Attachment 1 for data.

1. Plants

Introductions: The number of introduced plant species traded and cultivated in New South Wales (alien and native species not indigenous to NSW) is unknown. Australia-wide, an estimated 34,650 alien taxa have been introduced to date [1]. At least 11,000 native taxa have been introduced beyond their native range (a 2007 estimate) [2]. Apart from 64 regulated species (prohibited, restricted or under a control order, Attachment 1), non-native species can be freely traded and cultivated in New South Wales (although there may be GBD restrictions in certain regions). This situation was described in the 2009 independent review of the EPBC Act as 'a substantial failure' of state and territory regulation [3].

Naturalisations: About 1,700 plant species have been recorded as naturalised in NSW and more than 100 others are uncertainly naturalised (Table 1). Most are alien species, introduced from other countries for gardening and farming; 5% are native to other parts of Australia (Table 1). More than 1 in every 5 plants in the state is not native (naturalised species make up more than 22% of the total New South Wales flora, consisting of 6,003 native species and 1,707 naturalised species). The state has considerably more naturalised plant species than any other Australian jurisdiction and is recognised as one of the weediest mainland regions in the world [4,5].

Invasions: The invasiveness of the naturalised flora in New South Wales and Australia have not been comprehensively assessed using a consistent method. Based on state/territory weed assessments using a variety of methods, more than half (54%) the naturalised species in NSW are reported as invasive (or having an adverse environmental impact) somewhere in Australia, and another 10% are considered to be potentially invasive (Table 1). About 20% of the naturalised NSW flora (363 plant species) has been rated as having a significant – 'high', 'massive', 'extreme' or 'major' – impact in one or more Australian jurisdictions (but the ratings for each jurisdiction are not comparable) (Attachment 1). A NSW-specific assessment in 2018 rated 225 species and species groups (of 266 assessed) as a high environmental threat [6]. Other estimates of invasive plant numbers in Australia are lower – a 2023 study (based on other datasets) found that about 10% of naturalised plants were 'invasive' (their tally for naturalised was about 4,100 taxa) [1].

Impacts on threatened biodiversity: 149 species naturalised in NSW have been assessed as a threat to nationally listed threatened species somewhere in Australia [7] (Attachment 1), although this is a considerable underestimate as threat descriptions for listed species often refer generically to weed threats without naming species. We have not compiled the relevant data for species listed as threatened by the NSW Government, but recommend this assessment be done, using the methodology of the recent national assessment by the National Environmental Science Program [7]. The only published assessment of weed impacts on threatened biodiversity in NSW is now almost 20 years old – it found that weeds threaten 45% of threatened species, populations and communities listed in New South Wales [8].

66 naturalised plant species in NSW are designated weeds of national significance and 44 species are recognised as key threatening processes (KTPs, Table 2) – 4 as individual species listings, 7 as part of the group listing of perennial grasses and 33 as part of the group listing of exotic vines and scramblers (although it is not made clear in these listings whether each species qualifies as a key threatening process). The KTP listings are far from comprehensive and there are no current threat abatement plans, rendering the listings unhelpful except for information purposes.

Import restrictions: Only about 6% (106) of species naturalised in NSW are prohibited imports into Australia while 47% (846) are permitted imports (Attachment 1). A lack of import restrictions can lead to increased propagule pressure and the importation of new genotypes that could exacerbate the invasive potential of these species. Hybrids are also permitted without risk assessment if their parent species are permitted despite the potentially greater invasive risks of hybrids.

Some of the naturalised species that are neither permitted nor prohibited imports may have an ambiguous status if it is not clear whether they were legally imported into Australia (prior to a requirement for risk assessment). One of the deficiencies of New South Wales' current regulatory approach is that smuggled species would be permitted entry into the state unless they are explicitly prohibited.

State restrictions: Of the >1,800 species naturalised and possibly naturalised, only 4% are restricted or prohibited at a state level and 5% are restricted in one or more regions (Attachment 1), meaning that 90% of naturalised plants can legally be traded and cultivated in the state, a state of affairs likely to exacerbate the invasiveness of many species due to ongoing propagule pressure and the potential for introducing new genotypes. Adding to the invasion risks is the lack of consistency between states and territories in the biosecurity status of weedy plants.

State management: There are very few state weed management plans – 3 that are current and 2 that are recent (Table 2). We have not tallied how many naturalised plants are the focus of management under regional weed management plans in NSW, but this would be a worthwhile focus.

Biocontrol agents have been released for 74 species naturalised in New South Wales, including 23 for lantana and 12 for parthenium (Attachment 1). It is not clear how many have successfully established and mitigated the invasiveness of the target weed. This would be a worthy focus of review.

2. Vertebrate animals

Introductions: The number of introduced vertebrate species present in New South Wales (alien and native species not indigenous to NSW) is unknown. Australia-wide, more than 1,800 alien species have been introduced – mostly as pets or livestock or for zoos. The vast majority are aquarium fish and the numbers present in Australia are highly uncertain, with recent estimates ranging from about 500 to 2,000 [9,10].

Naturalisations: Excluding native fish translocated for conservation purposes, at least 69 vertebrate species have naturalised in NSW (Table 1).Fishes make up a third of the naturalised species (33%), mammals 29%, birds 25%, reptiles 6% and amphibians 3%. New South Wales has the second highest number of naturalised vertebrates in Australia (after Queensland).

Most naturalised species have been introduced deliberately from other countries, but more than a third of naturalised fishes are native to Australia, translocated for recreational fishing. Apart from fish, the majority of naturalised vertebrates have been naturalised for several decades. About 40% of the naturalised fishes, mostly aquarium fish, have been naturalised in Australia only since the 1970s.

Invasions: Most naturalised vertebrates are invasive – adverse environmental impacts in Australia have been recorded for 62% of the naturalised species in New South Wales and the potential for adverse impacts has been noted for another 24% (Table 1).

Impacts on threatened biodiversity: At least 5 species are known to have contributed to national extinctions and 30 have been rated as a medium- or high-impact threat to nationally listed threatened species (Attachments 1). We have not compiled the relevant data for species listed as threatened by the NSW Government, but recommend this be done. An assessment conducted almost 20 years ago found that invasive animals (29 different species) pose a threat to 40% of threatened biodiversity – 154 plants, 186 animals, 17 endangered populations and 31 endangered ecological communities [11].

21 naturalised vertebrate species have been listed key threatening processes in New South Wales or federally (under the EPBC Act) (Table 2). The KTP listings are not comprehensive and none of the listed species has a current threat abatement plan, rendering the listings unhelpful except for information. The one naturalised vertebrate in New South Wales to have a current species-specific management plan – dingo / dog (not a KTP) – is a threat mainly for sheep graziers and attracts a high proportion of public funding despite the benefits being largely private and commercial.

State restrictions: There are no state-wide restrictions on the trading or keeping of any naturalised vertebrate species.

3. Invertebrate animals

It is not feasible to comprehensively compile information on naturalised invertebrates, for too little is known about the species present in New South Wales and Australia and their impacts.

The most impactful group in the environment have been the social insects – ants, bees and wasps. At least 33 alien hymenopteran species have naturalised in New South Wales, of which at least 6 ant, 1 wasp and 2 bee species are considered invasive or potentially invasive in Australia (Attachment 1). Three have been rated as a threat to nationally threatened species.

Of at least 26 naturalised mite species, one is known to cause severe disease and others are considered potentially invasive (Attachment 1). The recent naturalisation of varroa mite in New South Wales may prove highly beneficial for native bees (by reducing populations of feral honey bees) and for reducing the impacts of weeds that rely on honey bee pollination or it could prove highly detrimental if future mite incursions bring pathogens that infect native bees. As a high priority the NSW Government should fund research to document the impacts of varroa mite on the natural environment.

Of at least 9 crustacean species naturalised in New South Wales, 2 are known to have adverse impacts and others are considered to be potentially invasive (Attachment 1).

Table 1. Naturalised plants and vertebrates in NSW and their invasiveness / potential invasiveness across Australia

Species group	**Number naturalised species**	**Number naturalised alien species**	**Number naturalised native species**	**Number species for which adverse impacts have been reported in Australia**	**Additional species with potential for adverse impacts**
Mammals	20 [+2]	20 [+2]	0	19 (95%)	2 (10%)
Reptiles	4 [+2]	3 [+2]	1	2 (50%)	1 (25%)
Birds	17 [+1]	14 [+1]	3	9 (53%)	7 (41%)
Amphibians	2	1	1	1 (50%)	1 (50%)
Fishes	26 [+2]	17	9 [+2]	14 (54%)	9 (35%)
All vertebrates	72 [+7]	55 [+5] (76%)	17 [+2] (20%)	45 (62%)	17 (24%)
Plants	1,707 [+144]	1,621 [+91] (95%)	86 [+23] (5%)	920 (54%)	177 (10%)

Note: Data and sources are in Attachment 1. The number of species considered uncertainly naturalised is indicated in square brackets. Three of the naturalised native fish species were translocated for conservation reasons.

Table 2. Invasive species in NSW listed in NSW recognised as key threatening processes and species (not necessarily a KTP) with a state management plan

Species group	**Number species listed as key threatening processes**	**Number of state management plans**	Species with a current state management plan (≤10 years old)

	(national or NSW)		
Vertebrates	21	1	NSW wild dog management strategy 2022–2027
Invertebrates	0	0	
Plants	46	5	NSW Black Knapweed Strategic Plan (2023), NSW Parthenium Weed Strategic Plan (2022), NSW Parkinsonia Weed Strategic Plan (2022), Orange hawkweed strategy 2011-2017, NSW Alligator weed strategy 2010-2015

References

1. Bartlett AC, Blackburn TM, Randall R, Catford JA. Characteristics of Australia's alien flora vary with invasion stage. Global Ecology and Biogeography. 2023.
2. Randall RP. The Introduced Flora of Australia and its Weed Status. Cooperative Research Centre for Australian Weed Management; 2007.
3. Hawke A. The Australian Environment Act – Report of the Independent Review of the Environment Protection and Biodiversity Conservation Act 1999. Australian Government; 2009.
4. Van Kleunen M, Dawson W, Essl F, Pergl J, Winter M, Weber E, et al. Global exchange and accumulation of non-native plants. Nature. 2015;525: 100–103.
5. Pysek P, Pergl J, Essl F, Lenzner B, Dawson W, Kreft H, et al. Naturalized alien flora of the world: species diversity, taxonomic and phylogenetic patterns, geographic distribution and global hotspots of plant invasion. Preslia89: 203-274. 2017.
6. Dorrough J, Oliver I, Wall J. Consensus when experts disagree: A priority list of invasive alien plant species that reduce ecological restoration success. Management of Biological Invasions. 2018;9.
7. Ward M, Carwardine J, Yong CJ, Watson JE, Silcock J, Taylor GS, et al. A national-scale dataset for threats impacting Australia's imperiled flora and fauna. Ecology and Evolution. 2021;11: 11749–11761.
8. Coutts-Smith A, Downey P. The Impact of Weeds on Threatened Biodiversity in New South Wales. CRC for Australian Weed Management; 2006. Available: https://www.researchgate.net/publication/264240230_The_Impact_of_Weeds_on_Threatened_Biodiversity_in_New_South_Wales
9. Moore A, Marton N, McNee A. A Strategic Approach to the Management of Ornamental Fish in Australia: Communication Strategy and Grey List Review, a Report to OFMIG. Bureau of Rural Sciences; 2010.
10. Millington M. The Underbelly of the Ornamental Industry – Unregulated trade and invasive species raise concern for unique native freshwater ichthyofauna. PhD thesis, Griffith University. 2023.
11. Coutts-Smith, Mahon P, Letnic M, Downey P. The threat posed by pest animals to biodiversity in New South Wales. Invasive Animals Co-operative Research Centre, Canberra; 2007.

Attachment 3. Extinctions and imminent extinctions

Invasives Species Council, November 2023

1. NSW's extinctions and invasive species

Thirty-one animal species (30 vertebrates, 1 invertebrate) are recognised as extinct under the NSW Biodiversity Conservation Act 2016 (Attachment 1). Reflecting the situation nationally, most have been mammals (n=23) or island birds (n=6).

New South Wales is also likely to have recently suffered Australia's first fish extinction – the Kangaroo River Macquarie perch (Box 1) (the Pedder galaxias is 'extinct in the wild'). Although no cause has been specified, the rapidity of the loss in the absence of habitat degradation strongly suggests an introduced pathogen was responsible [1].

A NSW frog, the yellow-spotted tree frog (*Litoria castanea*), has also been assessed as likely to be extinct – due to chytrid fungus and gambusia [2,3] – but there are doubts about whether it is a distinct species [4].

Attributing causes is necessarily speculative for many early extinctions. But, reflecting the situation nationally, invasive species are likely to have been the dominant cause of animal extinctions in NSW – the main cause or a major (≥30%) contributor to at least 20 (of 31) extinctions (65%) (Attachment 1). The main invasive species responsible have been cats (n=12), foxes (n=12) and black rats (n=4).

Nationally, the rate of animal losses appears to have been accelerating, with 19 confirmed or likely extinctions and 3 confirmed or likely extinctions in the wild since the 1960s (Table 1, [5]). More than 80% are thought to have been caused by invasive species – introduced predators or pathogens. The invasive causes of extinctions have become more diverse in recent decades, with the main drivers being cats, foxes, rats, wolf snakes, *Trypanosoma lewisi*, chytrid fungus and trout [5].

Offering the potential for species restoration in future, 18 animal extinctions in New South Wales have been at a state level only – for example, numbats, bilbies, greater stick-nest rats, western quolls and Tasmanian bettongs. Some have recently been reintroduced or there are plans to reintroduce them to fenced predator-free havens. To restore them more widely will require much more effective control of cats and foxes, which is not feasible with current control techniques.

New South Wales' extinct species also include 28 plants according to the list under the Biodiversity Conservation Act, or 14 species according to the Australian Plant Census (8 from the NSW mainland and 6 from Lord Howe Island). Most have presumably been lost to habitat destruction or livestock grazing. *Solanum bauerianum* (endemic to Lord Howe Island and Norfolk Island) was lost mainly to black rats [6].

Box 1. The likely extinction of the Kangaroo River Macquarie perch

An extract from a 2023 report by the Invasive Species Council on modern extinctions [5].

The Kangaroo River Macquarie perch was once plentiful in the Kangaroo River, a largely undisturbed tributary of the Shoalhaven River in coastal New South Wales. That was until introduced carp (*Cyprinus carpio*) were illegally freed in the river in the 1990s and there was stocking of hatchery-bred Australian bass (*Macquaria novemaculeata*), which are native to the river. In that same decade the perch declined very rapidly to extinction, and by 1998 none could be found despite many searches. One individual survived in captivity until 2008.

A genetic study provided the basis for distinguishing the Kangaroo River Macquarie perch as a species by indicating a substantial genetic divergence from other Macquarie perch populations, implying separate evolution for about 2 million years.

Fish expert Simon Kaminskas of the Murray-Darling Basin Authority proposed that the ‘rapid and so far unexplained collapse’ strongly suggests a pathogen was introduced into the catchment with one of the introduced fish species. He nominated epizootic haematopoietic necrosis virus (EHNV), or some other introduced virus of the Iridoviridae family, as a likely culprit. EHNV is known elsewhere to have caused declines of Macquarie perch (*Macquaria australasica*), silver perch (*Bidyanus bidyanus*) and galaxias species (*Galaxias* spp.). Proving that a virus caused the sudden disappearance is not possible, but no other explanation has been suggested.

The Kangaroo River Macquarie perch is Australia’s first completely extinct fish species, and it’s unlikely it will be the last. Fish experts have nominated 22 species of small stream fish at imminent risk of extinction, mainly from trout and other translocated fish species.

Table 1. Extinctions and likely extinctions of Australian animals since the 1960s and their likely causes

Decade	Invasive species	Habitat destruction, degradation	Altered hydrology	Climate change	Uncertain
1960s	Yallara (Macrotis leucura)				
	Central hare-wallaby (*Lagorchestes asomatus*)				
	Northern Mulgara (*Dasycercus woolleyae*)				
1970s	Desert bandicoot (*Perameles eremiana*)		Lake Pedder earthworm (*Hypolimnus pedderensis*)		
	Southern day frog (*Taudactylus diurnus*)				Kuchling's long-necked turtle (*Chelodina kuchlingi*) (70%)
1980s	Southern gastric brooding frog (*Rheobatrachus silus*)				
	Northern gastric brooding frog (*Rheobatrachus vitellinus*)				
	Gravel-downs ctenotus (*Ctenotus serotinus*) (72%)				
	Christmas Island shrew (*Crocidura trichura*) (92%)				

1990s	Mountain mist frog (*Litoria nyakalensis*) (85%, 93%)				Kangaroo River Macquarie perch (*Macquaria* sp.) (89%)
	Sharp-snouted day frog (*Taudactylus acutirostris*)				
	Pedder galaxias *(Galaxias pedderensis*)*				
2000s	Northern tinker frog (*Taudactylus rheophilus*) (86%, 90%)			Bramble Cay melomys (*Melomys rubicola*)	
	White-chested white-eye (*Zosterops albogularis*)				
	Christmas Island pipistrelle (*Pipistrellus murrayi*)				
2010s	Christmas Island forest skink (*Emoia nativitatis*)				
	Blue-tailed skink (*Cryptoblepharus egeriae*)*				
	Lister's gecko (*Lepidodactylus listeri*)*				

Notes: The likely extinct species included in this table have a likelihood of extinction rating in brackets that was assigned in a series of expert elicitation processes under the National Environmental Science Program [2,7–10]. We have included those assessed as at least 70% likely to be extinct. Two species assessed as likely to be extinct have been rediscovered since the assessments and are not included here. The references for all except two species are in reference [5]. Since the publication of that report, additional likely extinct mammals – 4 newly described mulgara species, probably extinct due to cats and foxes – have been reported for Australia [11]. We include one of those mulgaras here as it was last collected in the 1960s.

2. Imminent extinctions

Following is an extract from the Invasive Species Council's draft State of Environmental Biosecurity Report [12]. The information is national, not specific to New South Wales.

With about 100 plant and animal species facing a high risk of imminent extinction, Australia is on the brink of an extinction catastrophe. Invasive species are a significant threat to almost three-quarters of these predicted extinctions. These figures have come from a series of studies under the National Environmental Science Program in which experts rated the extinction risks for the most imperilled species (in structured elicitation processes) – freshwater fishes, mammals, birds, reptiles, frogs, butterflies and plants [2,7–9,13,14].

Of the 32–42 vertebrate species with a high risk (>50% likelihood) of extinction within 20 years, freshwater fishes are the most imperilled, with 22 species at risk [9].

Frogs are the second most imperilled group, with 8 species facing a high risk of extinction, although 4 are probably already extinct [2,10]. Likewise, 6 reptile species face a high risk of extinction, but 2 are probably already extinct [7,10]. Four bird species face a high risk (as do an additional 8 subspecies), with 3 probably already extinct, and 2 mammals, with 1 probably already extinct [8,10]. Although many more mammals are highly threatened, most are now safer from extinction because they have been introduced (or reintroduced) to islands and fenced reserves free of foxes and cats [15].

Continuing the pattern of the past 2 centuries, invasive species are the most prevalent threat to the species at highest risk of extinction. Of the 37 at-high-risk animal species for which threats have been rated, 31 (86%) are threatened to a high degree by invasive species and 36 (97%) to a medium or high degree. The invasive threats comprise more than 20 different species. Predators and pathogens dominate, with the most prevalent threats being chytrid fungus (the main threat to frogs) and trout (the main invasive threat to freshwater fishes). All it would take to eliminate a galaxiid fish endemic to a waterway would be for 'an uninformed or unsympathetic angler' to introduce brown or rainbow trout or another predatory fish [9]. Several invasive ungulates (pig, deer, horse) are medium-impact threats.

Most at-risk species are threatened by several factors – an average of 3.7 high-impact threats per at-risk species (including 1.2 invasive species on average). The other major threats are climate change and extreme weather events (23 species), habitat loss, degradation and fragmentation (21 species), disrupted population processes (20 species) and adverse fire regimes (19 species). The threats to reptiles are poorly understood; no threats to 4 at-risk species could be rated [16].

Although there have been surprisingly few verified plant extinctions in Australia, the large numbers of highly threatened plants suggest a 'looming extinction debt' [17]. Close to half of >600 species listed as endangered or critically endangered by federal or state/territory governments are known from fewer than 250 individuals and about 10% from fewer than 50 individuals.

A recent expert assessment identified 49 species (and 6 subspecies) at high risk of extinction within 10 years and another 187 taxa at medium risk of extinction (10–100 years) [17]. At high risk are extremely rare plants (<250 plants or a single population) with continuing declines. Plants at medium risk have low numbers (typically <2500) and continuing declines.

Most at-risk plants have suffered historical declines due to habitat destruction, and survive as small, fragmented populations vulnerable to loss and degradation through a myriad of threats acting in concert [17]. Invasive species (disease, feral herbivores and weeds) are a major threat to at least a third of the species, along with adverse fire regimes (24%), urbanisation (21%), climate change (13%) and grazing by native or domestic herbivores.

However, a recent invader is about to dramatically increase the extinction risks for plants in Australia's most iconic family, the Myrtaceae. A study published in 2021 has predicted the likely extinction of 16 widespread rainforest trees within one generation due to myrtle rust – 'a plant extinction event of unprecedented magnitude' [18]. Another 20 species may also be at risk but require more monitoring. Although myrtle rust has been in Australia only a short time (first detected in 2010), it is already infecting more than 350 species. Native guava (*Rhodomyrtus psidioides*), formerly common on rainforest edges, is already nearly extinct and likely to be replaced in many places by lantana, a weed that increases the flammability of rainforests [19].

Taking these additional extinctions into account, invasive species – myrtle rust, phytophthora, feral herbivores (rabbits, goats, deer, horses) and weeds – are significant drivers of at least 35 (54%) predicted imminent extinctions of plants.

Overall, invasive species are the most prevalent driver or contributor to the decline of animal and plant species at high risk of imminent extinction – impacting to a medium or high degree 74% of the species. Other major threat categories are habitat loss, degradation and fragmentation (42%), climate change (38%); disrupted population processes (32%) and adverse fire regimes (29%).

The 15 invasive species (plus several unspecified weed species) most likely to cause or contribute to imminent extinctions include those that have been long established in Australia, such as trout, phytophthora and cats, but also more recent arrivals. Chytrid fungus probably arrived in the late 1970s, and myrtle rust, now the most prevalent risk for imminent extinctions, just over a decade ago.

References

1. Kaminskas S. Alien pathogens and parasites impacting native freshwater fish of southern Australia: a scientific and historical review. Australian Zoologist. 2020.
2. Geyle HM, Hoskin CJ, Bower DS, Catullo R, Clulow S, Driessen M, et al. Red hot frogs: identifying the Australian frogs most at risk of extinction. Pacific Conservation Biology. 2021.
3. Gillespie GR, Roberts JD, Hunter D, Hoskin CJ, Alford RA, Heard GW, et al. Status and priority conservation actions for Australian frog species. Biological Conservation. 2020;247: 108543.
4. Threatened Species Scientific Committee. Conservation Advice Litoria castanea yellow-spotted tree frog. Australian Government; 2017.
5. Low T, Booth C. GONE: Australian animals extinct since the 1960s. Invasive Species Council; 2023.
6. Woinarski JC, Braby M, Burbidge AA, Coates D, Garnett ST, Fensham RJ, et al. Reading the black book: the number, timing, distribution and causes of listed extinctions in Australia. Biological

Conservation. 2019;239: 108261.
7. Geyle HM, Tingley R, Amey AP, Cogger H, Couper PJ, Cowan M, et al. Reptiles on the brink: identifying the Australian terrestrial snake and lizard species most at risk of extinction. Pacific Conservation Biology. 2020.
8. Geyle HM, Woinarski JC, Baker GB, Dickman CR, Dutson G, Fisher DO, et al. Quantifying extinction risk and forecasting the number of impending Australian bird and mammal extinctions. Pacific Conservation Biology. 2018;24: 157–167.
9. Lintermans M, Geyle HM, Beatty S, Brown C, Ebner BC, Freeman R, et al. Big trouble for little fish: identifying Australian freshwater fishes in imminent risk of extinction. Pacific Conservation Biology. 2020.
10. Garnett ST, Hayward-Brown BK, Kopf RK, Woinarski JC, Cameron KA, Chapple DG, et al. Australia's most imperilled vertebrates. Biological Conservation. 2022; 109561.
11. Newman-Martin J, Travouillon KJ, Warburton N, Barham M, Blyth AJ. Taxonomic review of the genus Dasycercus (Dasyuromorphia: Dasyuridae) using modern and subfossil material; and the description of three new species. Alcheringa: An Australasian Journal of Palaeontology. 2023; 1–38.
12. Booth C, Crossland MR, Isla F. Australia State of Environmental Biosecurity. DRAFT REPORT. Invasive Species Council; 2023.
13. Silcock J, Fensham R. Using evidence of decline and extinction risk to identify priority regions, habitats and threats for plant conservation in Australia. Australian Journal of Botany. 2019;66: 541–555.
14. Geyle HM, Braby MF, Andren M, Beaver EP, Bell P, Byrne C, et al. Butterflies on the brink: identifying the Australian butterflies (Lepidoptera) most at risk of extinction. Austral Entomology. 2021;60: 98–110.
15. Legge S, Woinarski JC, Burbidge AA, Palmer R, Ringma J, Radford JQ, et al. Havens for threatened Australian mammals: the contributions of fenced areas and offshore islands to the protection of mammal species susceptible to introduced predators. Wildlife Research. 2018;45: 627–644.
16. Chapple D, Tingley R, Mitchell N, Cox N, Bowles P, Macdonald S, et al. The action plan for Australian lizards and snakes 2017. CSIRO Publishing; 2019.
17. Silcock J, Fensham R. Using evidence of decline and extinction risk to identify priority regions, habitats and threats for plant conservation in Australia. Australian Journal of Botany. 2018;66: 541–555.
18. Fensham RJ, Radford-Smith J, Collingwood T. Unprecedented extinction of tree species by fungal disease. Biological Conservation. 2021;261: 109276.
19. Fensham RJ, Carnegie AJ, Laffineur B, Makinson RO, Pegg GS, Wills J. Imminent extinction of Australian Myrtaceae by fungal disease. Trends in Ecology & Evolution. 2020;35: 554–557.

Invasive species and climate change

fact sheet

RELEASED DECEMBER 2009

Living in a warmer, wilder, weedier world

Climate change is expected to cause extinctions when native plants and animals are prevented from migrating out of their hotter or drier habitats to more suitable climates. But for many species a more imminent or serious threat will be the opportunities created by climate change for invasive species to proliferate and cause more harm.

Invasive species have already caused many extinctions and are one of the major causes of decline of native species and ecosystem degradation. The 2009 assessment of the vulnerability of Australia's biodiversity to climate change noted that in many cases the impacts of invasive species benefiting from climate change are likely to exceed the direct impacts of climate change.[1]

The extinction toll of Australian animals due to invasive species[4]

22 mammals[5] (16 species, 6 subspecies) due largely to predation by foxes and/or cats, with rabbits also implicated as a contributing factor in some cases.

Across much of Australia all native mammals weighing between 35 grams and 5.5 kilograms have disappeared.

Nine species survive only on cat- and fox-free islands or inside large fenced enclosures.

13 island birds (3 species, 10 subspecies) due to predation by black rats (*Rattus rattus*), cats and pigs, and competition from introduced birds and honeybees.

4 (but probably 6) frogs due to infection by chytrid fungus (*Batrachochytrium dendrobatidis*) in eastern Australia.

2 endemic rodents on Christmas Island due to infection by a trypanosome blood parasite from introduced black rats.

Pig Footed Bandicoot ((*Chaeropus ecaudatus*).

1. Devastating invaders

Globally, invasive species have been recognised as the most serious threat to biodiversity after habitat loss.[2] Along with habitat loss and climate change, they are one of the top three threats to Australian species.[3]

Australia has lost by far the highest number of mammal species in recent times, with foxes or cats (and rabbits to some degree) implicated in most of these extinctions. Many birds on islands have been wiped out by introduced rats, and an exotic fungus has caused the extinction of at least four frog species (see Box).

The threats are escalating as new species become established and as existing invaders proliferate and spread. Just one exotic pathogen *Phytophthora cinnamomi* threatens hundreds of endemic plant species in Western Australia,[6] and numerous mammal species need protection from foxes and cats. Weeds are increasingly dominating many ecosystems, fundamentally altering their composition and function. More than 80% of federally threatened ecological communities are threatened by weeds.[7] Rabbits have prevented woodland regeneration over vast areas, and goats, pigs and other hard-hoofed feral animals are causing widespread degradation. Marine invaders have transformed coastal ecosystems, becoming dominant predators or filter feeders.

2. Climate change – driving diverse changes

Since 1950, Australian average temperatures have increased by 0.9ºC, and average rainfalls have dropped in coastal eastern Australia, Victoria, and south-west Australia.[8] Climate models suggest these trends will intensify as atmospheric carbon dioxide levels continue to rise (see box next page). Emissions are increasing at a rate currently exceeding the worst-case emissions scenarios of the Intergovernmental Panel on Climate Change.[9]

3. Climate change impacts on species and ecosystems

Different species will respond to climate change in different ways. CSIRO researchers Mike Dunlop and Peter Brown outline three models of response.[11]

The most prevalent model predicts that species will move gradually and at different rates as the climate changes – 'gradual changes in distribution' – to maintain a similar climatic niche. The obvious conservation response is to ensure that species are able to migrate, by removing barriers to movement and creating corridors to potential habitats. However, many species will not move: plants are often constrained by soils rather than climate and other species are constrained by biological factors such as competition or predation. Although the model is "intuitively appealing", and allows for simple, directional predictions, Dunlop and Brown caution that the preference for it may not reflect reality. For invasive species, this model implies their ranges will also gradually change in response to changing climatic conditions.

Another model – "rapid changes in distribution"[12] – predicts range expansion for some species that can take advantage of changing conditions. Fire pioneers, for example, will benefit from more fires; wind- and water-dispersed species may benefit from more cyclones and floods; and higher CO_2 levels will give some plant species a competitive edge. This model is particularly pertinent for those invasive species likely to benefit from more extreme events or more CO_2. The impact of these climate change "winners" may be detrimental to some native species. In some cases, native species that benefit from the changes may also become invasive. Conservation responses to this model include addressing the threats caused by climate change "winners".

A third model – "changes in abundance" – predicts that climate change will affect the abundance of some species rather than their distribution. Some species will decline and others will proliferate, and that in turn will affect ecosystem structure and function. Species vulnerable to climate change may retract to climate refuges, such as cooler or wetter locations in their range. Some invasive species are likely to become more abundant and increase pressure on declining species. Conservation responses to this model include protection of refugia for declining species and control of threats deriving from more-abundant species.

Climate change predictions for Australia

By 2050, annual warming in Australia is predicted to range from 1.5 to 2.8ºC for the highest emissions scenario, increasing to 2.2 to 5.0ºC by 2070.

Reduced average rainfall is predicted over most of Australia.

By 2070, for the highest emissions scenario the predicted range of change in southern areas is from a 30% decrease to a 5% increase, little change in the far north and from -30% to +20% in other areas.

More droughts are expected over most of Australia: by 2070 up to 40% more droughts in eastern Australia and up to 80% more in south-western Australia.

There is a substantially increased fire risk in south-eastern Australia; the risk has not been assessed elsewhere.

Source: CSIRO and the Bureau of Meteorology[10]

All three models are likely to account for some changes,[13] and under each, it is likely that invasive species will strongly affect how native species and ecosystems fare under climate change.

4. Invasive species – overall winners under climate change

Under climate change, some species will decline and others will thrive. Winners and losers will include invasive species. The cane toad, for example, is expected to expand its range further south,[14] but rising temperatures would constrain rabbit breeding.[15] Some invasive species will benefit in some places and decline in others.

This does not mean there will be an overall balancing out: for a variety of reasons invasive species are overall likely to cause more harm under climate change.

One reason is that many invasive species are generalists and highly adaptable, able to tolerate or take advantage of change and disturbance.[16] Many weeds are weedy because they thrive over a wide range of climatic conditions.

An increase in extreme events in particular will offer new opportunities for invasive species to proliferate and spread – weeds colonise bare patches after droughts, fires and cyclones; and foxes and cats prey on animals whose shelter is destroyed by those events.[17] We know from past experience that extreme events promote invasions: floods in the 1970s spread carp (*Cyprinus carpio*) throughout the Murray-Darling system[18] and athel pine (*Tamarix aphylla*) along hundreds of kilometres of the Finke River in central Australia.[19] Carp are now the most abundant big fish in the Murray-Darling and athel pine is a weed of national significance.

Native species and ecosystems stressed by climate change will be less competitive and more vulnerable to threats by invasive species. Stressed plants, for example, would be more vulnerable to diseases like phytopthora dieback or displacement by weeds.

Human responses to climate change are likely to provide new invasive opportunities – with the introduction of weedy biofuel crops or the spread of weeds in fodder after droughts and other extreme events – and less control of existing invaders. If farmers are under economic stress due to extreme weather events and governments have other climate-related budgetary demands, we can expect less focus on weed and pest control. In addition, some herbicides and biological control agents may be rendered less effective under climate change.

5. Interactions between climate change and invasive species

Climate affects the distribution, abundance and behaviours of invasive species. It also affects native species and ecosystems, and human behaviours with invasive species (see Figure 1). Conversely, some invasive species exacerbate climate change (see section 5.5). There are uncertainties with all these factors – climate, its impacts on native and non-native species, and future human actions – which make predicting interactions very difficult.[20] Invasive species can initiate complex, unpredictable cascades of change. High levels of uncertainty are unavoidable, and policies therefore should make allowances for inevitable "ignorance, imprecision, stochasticity, and surprise".[21]

However, we can identify likely trends and patterns of change, which is essential to developing strategies to prevent the interacting threats. Here we give examples of likely changes in three interactive categories: the interactions of invasive species with climate factors (abiotic interactions), with other species affected by climate change (biotic interactions) and with human actions in response to climate change (anthropogenic interactions). Table 1 (page 6) also exemplifies the variety of predicted interactions that are likely to lead to increased weed, pest and disease threats.

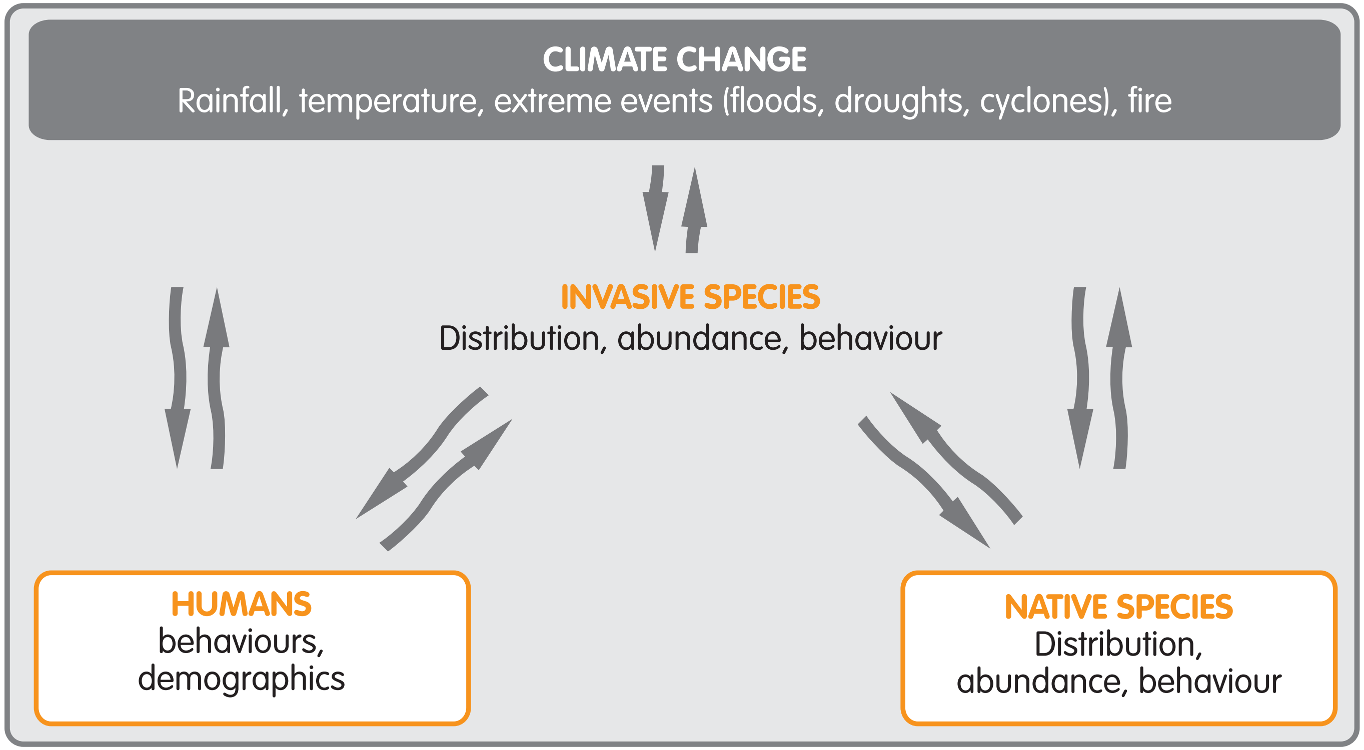

Figure 1. Complexity of interactions between climate change and invasive species.

5.1 Interactions with abiotic changes – temperature, rainfall, CO_2, extreme events, fire

Following are a few examples of invasive species expected to directly benefit from future climate patterns, such as higher average temperatures and more extreme events. They are predictable to some extent based on current patterns of invasion.

- **Changed rainfall patterns:** Southwest Western Australia is in the grip of a plant disease – phytophthora dieback – that has infected a million hectares of native bush, threatening dozens of species found nowhere else.[22] Climate change is expected to bring more rain during summer, which would spread the disease more rapidly because the spores travel with flowing rainwater. This could result in plant extinctions and ecosystem collapse.[23] The disease could also worsen in south-eastern Australia if there are wetter summers and warmer winters under climate change.[24]

- **More-intense cyclones:** Lurking in many gardens in the Wet Tropics are exotic plants that have not yet had the right conditions to spread beyond the garden fence. More-intense cyclones under climate change bringing forest damage and flooding could provide opportunities for their spread. Many of them are rainforest plants that could colonise clearings in rainforest.[25]
- **Warmer temperatures:** Foxes are already increasing their numbers at higher altitudes in the Australian Alps as the climate warms. Vulnerable native animals include the endangered mountain pygmy possum and broad-toothed rat. Weeds too will spread further up the slopes, pushing out less competitive native species.[26]

  Most aquarium fish are from tropical waters, so increases in average water temperatures will provide more habitat for released or escaped fish.[27]
- **More fire:** Exotic pasture grasses in northern Australia up to 4 metres tall fuel fires so intense they can kill trees. In a damaging cycle that can turn native woodlands into exotic grasslands, such fires promote yet more grass invasion.[28] Climate change could increase the frequency of fires, facilitating the further invasion of exotic grasses.

5.2 Interactions with biotic changes

Following are examples of how invasive species may benefit from changes to other organisms caused by climate change. They are much harder to predict because they involve a sequence of interactions.

- **Reduced competitiveness and increased vulnerability of native species:** Plants and animals stressed by climate change-induced drought are likely to be more susceptible to disease – during drought southern hairy-nosed wombats are more susceptible to mange caused by an exotic mite, for example.[29] (Conversely, native animals under stress due to predation by foxes or cats or habitat degradation by goats or deer are likely to be more vulnerable to stress caused by a changing climate and less able to adapt.)

  When plants die due to drought and other climate stresses, their place is likely to be taken by weeds such as serrated tussock (*Nasella trichotoma*), which are often rapid colonisers.[30]

  More fires under climate change can lead to less vegetation cover for native species, such as endangered eastern bristlebirds,[31] exposing them to more predation by foxes and cats.
- **Less effective control of invaders:** Some biological control agents may become less effective under climate change. Under experimental conditions of high CO_2 and temperature, a leaf-miner (*Dialectica scalariella*) introduced as biocontrol for Paterson's curse (*Echium plantagineum*) became less effective because of reduced nutritional quality of leaves.[32] (Conversely, some biocontrol agents are likely to become more effective.) Glyphosate, the most important herbicide, is also likely to become less effective under climate change.[33]
- **Compromised dispersal of native species:** Many native plants that need to migrate southwards in response to higher temperatures rely on birds to

Why invasive species will be overall winners under climate change

- Many invasive species are highly adaptable, tolerant of a wide range of conditions and advantaged by disturbance.
- Extreme events often facilitate biological invasions.
- Native species under stress are less competitive with and more vulnerable to invasive species.
- Human responses are likely to provide more invasive opportunities and may result in less effective control.

spread their seeds. But in many areas fruit-eating birds, including currawongs, figbirds and silvereyes, now live largely upon the fruits of weedy garden plants, and the seeds of weedy camphor laurel, privet and others are more likely to be dispersed than the seeds of native plants. Weedy shrubs and trees can produce larger crops of fruit than native plants because they are not attacked by insects or diseases that control them in their countries of origin.[34]

5.3 Interactions with anthropogenic changes

Following are examples of how invasive species may benefit from human responses to climate change.

- **New agricultural and horticultural products:** There are plans to grow vast areas of biofuels such as giant reed (*Arundo donax*) and jatropha (*Jatropha curcas*) in Australia. Giant reed is a catastrophic riparian weed in the US, costing millions of dollars to control, and jatropha is also a significant weed.[35]

  Breeders are developing new drought-tolerant and hardier plant varieties for gardens and pastures. Many of the species are already weedy, and hardier cultivars could increase their invasion into natural areas.[36] With an increased potential for hybridisation and genetic recombination, some could become super-invaders.[37] New drought-hardy breeds of goats could breed with feral goats, exacerbating their impacts.

- **Introductions in new areas:** There is considerable talk of agriculture moving north as conditions become drier in southern Australia under climate change. This would inevitably result in the introduction of new potentially invasive species.

- **Less control effort:** A recent NSW survey found that feral animal numbers did not decline during a drought, attributed to fewer control efforts by farmers under economic stress.[38] The challenge of coping with climate change events may compromise the control of pests and weeds. Governments may have less money to direct to such efforts.

See Table 1 (next page) for further examples of potential interactions between climate change and invasive species, with more detailed interaction categories.

5.4 Native invaders under climate change

Some native species are likely to do much better than others under climate change – surviving extreme events, migrating into new areas, or flourishing under new weather patterns – and the more successful species could become so dominant they suppress biodiversity, and effectively become native weeds or pests.

Australia already has many native plants considered weeds[39], either because they have spread from cultivation into new areas or because they have multiplied from human impacts and outcompete other native species. Because of this we need to think carefully about what "invasive" may mean in the future. Is a newly arriving native plant or animal an invader or something responding as it should?

Laughing kookaburras are an example. They have moved higher in the Australian Alps and are hunting alpine skinks, which have not previously been subject to bird predation and are highly vulnerable because they are live-bearers and need to bask in the sun for incubation.[40]

Climate change is likely to result in more invasions by native species when they shift or are shifted due to climate change. Some of the worst weeds – eg. pittosporum (*Pittosporum undulatum*) and cootamundra wattle (*Acacia baileyana*) – are Australian. Native species threatened by climate change may be deliberately shifted to new locations with more suitable climates, running the risk that they will become invasive.[41]

5.5 Invasions that increase greenhouse gas emissions

Some invasive species can exacerbate climate change by increasing greenhouse gas emissions (and some have the opposite effect[42]). But this has not yet received much research focus.

Weeds can change rates of carbon sequestration and decomposition and promote fire. Flammable weeds such as gamba grass and mission grass promote more and higher intensity fires that kill sapling trees and sometimes adult trees and promote grass invasion – a positive feedback loop (see Box 3).[43] Lower tree density reduces carbon storage in woodlands. Many of Australia's major weeds are large flammable grasses: molasses grass (*Melinis minutiflora*), para grass (*Urochloa mutica*), veldt grass (*Ehrhata calycina*), buffel grass (*Pennisetum ciliare*), and African lovegrass (*Eragrostis curvula*) and the proposed biofuel giant reed (*Arundo donax*) as a potential major weed).

Weeds can increase emissions by stimulating higher rates of soil carbon decomposition and reducing carbon stores.[44] Some weeds that invade wetlands – willows (*Salix spp*.), for example – release methane, which they

Invasive species and climate change

fact sheet

RELEASED DECEMBER 2009

Changed conditions	Introduction & naturalisation of invasive species	Spread & proliferation of invasive species	Other potential advantages for invasive species
ABIOTIC CONDITIONS (climate, fire & CO_2)			
Altered temperature and rainfall patterns	A warmer Antarctic peninsula is more favourable for establishment of seeds, insects or spores transported by visitors or blown by wind or stuck to birds. Alpine areas become suitable for more garden plants to establish. Warmer temperatures create more favourable habitats for released tropical aquarium fish.	*Phytophthora cinnamomi* spreads in south-western WA due to a greater coincidence of warmer and wetter conditions. Weeds and feral animals (eg. foxes) move higher into alpine areas. Warmer temperatures accelerate the life cycle of invasive pathogens and insects.	
More droughts	More drought tolerant plant species/varieties are introduced.	Weeds (eg. serrated tussock) colonise bare patches, replacing native plants killed by drought. Some invasive animals increase populations more quickly after droughts.	Invasive plants and animals are able to dominate resources and refuges during drought and recover more quickly.
More/more-intense cyclones & floods	Exotic fish are washed out of ponds into wetlands. Weed seeds are washed/ blown from gardens and paddocks into bushland.	Weeds spread with flood waters, eg. athel pine, lippia, and they may be able to colonise faster than native species.	Violent weather destroys competing native vegetation.
Intensifying fire regimes		Flammable pasture grasses spread with more fire and promote fire. Weeds spread along fire tracks.	Wildlife is more exposed to foxes and cats due to loss of vegetation cover.
Higher CO_2 levels		Weeds that become more water efficient under higher CO_2 levels spread into drier areas. Increased asexual reproduction of weeds due to greater below-ground growth of rhizomes and roots.	Some biocontrol agents and herbicides become less effective. Some native species benefit less from CO_2 fertilisation than competing weed species.
BIOTIC CONDITIONS (other species affected by climate change)			
Native species moving	Some native species moving to new ranges become invasive.	Hosts or vectors (eg. mosquitoes) of invasive pathogens move into new areas. Changed migration patterns of frugivores spread weeds into new areas.	Movement of native species provide more resources for invasive species, eg. prey for predators.
Native species & ecosystems stressed		Plant death creates spaces for colonisation by weeds. Animal deaths create more resources for some invaders.	Stressed organisms are more vulnerable to invasive pathogens, eg. wombats to mange and plants to phytophthora dieback.
ANTHROPOGENIC CONDITIONS (human responses to climate change)			
New products & industries, relocations	Agriculture shifts north, and new weed, pest and disease species are introduced. Climate refugees inadvertently or deliberately introduce new invasive species into the country.	Disturbance/clearing in new areas for agriculture provides opportunities for invasive species to spread.	
Climate change mitigation & adaptation, response to extreme events	Weedy biofuel plants are cultivated. Invasive trees are cultivated for carbon credits. New drought-hardy plants are introduced for gardens and pastures. Some native species shifted into new areas to save them from climate change become invasive.	Fodder distributed in response to droughts and floods spreads weed seeds.	Due to economic stress, there is less control of feral animals by landowners and governments. Governments reduce budgets for control programs.

Table 1 Examples of potential interactions between climate change and invasive species.

extract from the mud they grow in.[45]

Below-ground invaders such as earthworms can increase decomposition rates and reduce soil carbon stores – by making conditions favourable for more-rapid decomposers (eg. bacteria over fungi) and for low-biomass tree species, for example.[46]

Worldwide, emissions from livestock are estimated to account for about 14% of greenhouse gas emissions.[47] Most feral animals in Australia – pigs, goats, deer, donkeys, horses, cattle, buffalo, rabbits – emit methane and nitrous oxide (as byproducts of bacterial fermentation of cellulose) and therefore contribute to greenhouse gas emissions. Feral animals are responsible for an estimated 4-5% of the Northern Territory's emissions.[48]

These herbivores can also contribute to climate change by changing the structure and composition of the ecosystems they invade. The most profound impacts occur when herbivory both damages trees and prevents subsequent recovery of forests.[49]

Invasive leaf-eating insects and plant pathogens can also substantially reduce carbon uptake by forests. Large-scale disease and herbivory is turning some northern hemisphere forests from carbon sinks into carbon sources.[50] Longer-term impacts on carbon uptake depend on which species replace trees killed.

Predators can also affect the carbon dynamics of forests. Invasive yellow crazy ants (*Anoplolepis gracilipes*) are changing the structure and composition of forests on Christmas Island. By preying on the red crabs that process leaf litter, they reduce the decomposition of forest litter (which would reduce emissions). But by protecting honeydew-secreting scale insects from predators, they increase the growth of sooty mould, which reduces photosynthesis and leads to canopy dieback and sometimes tree death (which is likely to increase emissions).[51]

6. Responding to the double trouble of climate change and invasives

Worldwide, climate mitigation efforts so far have failed dismally and trends in greenhouse gas emissions exceed worst-case IPCC scenarios.[54] Attention is turning increasingly to how native species and ecological communities can be supported to survive the inevitable changes.

Invasive species are already a major threat to biodiversity, and likely to cause more extinctions in Australia even without climate change. Climate change strengthens the imperative for addressing such threats.

Climate adaptation measures should address invasive species threats in three ways:

(1) Reduce existing invasive species threats to increase the capacity of native species and ecosystems to adapt to climate change;

(2) Control invaders or potential invaders likely to benefit under climate change; and

(3) Prevent new introductions, ensuring that responses to climate change do not create new invasive species problems.

Climate mitigation measures should also include addressing invasive species threats:

(4) Control invasive species that contribute to greenhouse gas emissions.

Reduce invasive threats to increase capacity for adaptation

Extinctions are often the result of multiple, cumulative threats. Reducing other threats is essential to providing species with the best prospects of surviving and adapting to climate change. With invasive species one of the top three threats to biodiversity, they should be a very high priority in efforts to facilitate adaptation to climate change.

Some species have survived past climate change by retracting to refuges. Identification and protection of refuges from invasive species and other threats should be a high priority. Fire refuges, for example, need protection from invasion by flammable weeds and drought refuges from predation by cats and foxes and exotic competitors for resources.

Control invaders likely to benefit under climate change

Climate change will change priorities for managing invasive species, with new threats emerging, some existing threats increasing and others declining. It is prudent to substantially reduce the number of potential invasive species (eg. eradicate sleeper weeds) and control species likely to exert the most serious threats. For example, there should be programs to eradicate garden plants that could spread into the Wet Tropics after cyclones or invade warming alpine areas. A national priority should be fighting the dieback disease *Phytophthora cinnamomi*, as it is a major threat that could get much worse in some areas under climate change.

Prevent new harmful introductions

While Australia has a good risk assessment process for introductions of new species from overseas, most species imported prior to 1997 (when risk assessment was introduced) have never been assessed and can be freely imported. Most states and territories regulate the use of only a very small proportion of invasive species, allowing new introductions without risk assessment. For example, the highly invasive riparian weed giant reed (*Arundo donax*) that costs millions of dollars annually to control in California can be grown for biofuels in Australia without risk assessment. New hardier varieties of existing weedy garden plants or pasture plants that could greatly exacerbate their threats can also be introduced without assessment.

It is also important to ensure that any translocation of native plants and animals to more suitable habitats under climate change does not lead to them becoming invasive.

Reduce greenhouse gas emissions by reducing invasive threats

Some invasive species threats could be addressed as part of efforts to reduce Australia's greenhouse gas emissions. A high priority should be to limit the spread of flammable weeds that both increase fuel loads well beyond natural levels and increase emissions due to more fires and in some cases the death of trees.

There would be both biodiversity and mitigation benefits in reducing the numbers of feral animals in many areas.

It is also very important to ensure that climate mitigation efforts do not increase invasive species threats. For example, trees planted as carbon sinks should not be invasive species.

Positive feedback loops of invasive species and climate change

Some interactions between invasive species and climate change are particularly worrisome because they exacerbate positive feedback loops – problems cyclicly begetting worse problems.

Flammable invasive pasture grasses such as gamba grass (*Andropogon gayanus*) and mission grass (*Pennisetum polystachion*) promote fire by providing very high levels of dry fuel for fire.[52] They also benefit from fire by increasing in its wake. Climate change is likely to intensify fire regimes, which in turn will promote more exotic grass invasion, tree death and higher greenhouse gas emissions.

The damage that cyclones cause to rainforests promotes invasion by exotic vines such as blue thunbergia (*Thunbergia grandiflora*) and turbina (*Turbina corymbosa*). Vine invasion prevents canopy recovery, rendering forests more vulnerable to future cyclone damage and vine invasion. Climate change is predicted to increase the intensity of cyclones, exacerbating this cycle.[53]

Tree pathogens that benefit under climate change – *Phytophthora cinnamomi* in southwest Australia, for instance – can render trees more vulnerable to the impacts of climate change (eg. drought or fire) and contribute to greenhouse gas emissions when trees are killed. Weeds may take the place of trees killed.

There are human-based feedback loops as well. The more invasive species that establish, the less many people are inclined to do about it – due to the feeling that the problem is too big and hopeless. Climate change will exacerbate this trend by driving even more environmental problems. Promoting motivation to avert invasive species threats is a key climate change challenge.

7. Conclusion

The already dire impacts of invasive species are likely to be exacerbated under climate change. That invaders are increasing most where temperatures have risen the most – the Australian Alps – is an early warning of potentially momentous changes. More frequent or severe extreme events are of particular concern as previous experience shows they can dramatically boost weed and pest invasions.

Invasive species management should be a major part of adapting to climate change. Some of the new spending for climate change adaptations should go to understanding and reducing climate-boosted invasive species threats. There needs to much greater public support for action on invasive species. And as well as taking public transport and using low-energy lightbulbs, householders should remove potential invaders from their environment as part of their own climate change response.

Summary of recommendations

Reduce invasive threats to increase capacity for adaptation

- Reduce invasive species and other threats to native species and ecological communities likely to decline under climate change.
- Protect likely climate change refuges from threats, including those due to invasive species.

Control invaders likely to benefit under climate change

- Develop programs to prevent potential invasive species threats under climate change, including eradicating potential weeds from gardens in the Wet Tropics and alpine areas.
- Direct strong research and control efforts to invasive species likely to exert the highest threats to biodiversity under climate change, eg. *Phytophthora cinnamomi* and flammable invasive pasture grasses.

Prevent new harmful introductions

- Adopt a permitted list approach to exotic species at the state level that permits release only if they pose low invasive risks.
- Ensure that all new cultivars or breeds of existing weedy or pest species undergo risk assessment and are permitted for import or release only if they pose low risk.
- Subject biofuel crop species and other species proposed for widespread cultivation to risk assessment, permitting cultivation only for low-risk species.
- Develop a national policy on translocation of native plants and animals that requires rigorous risk assessment of the invasive threat.

Reduce greenhouse gas emissions by reducing invasive threats

- Develop programs to limit the spread of flammable weeds to limit the risk of intensified fire regimes and increased greenhouse gas emissions.
- Fund control programs for feral animals as a mitigation measure.
- Ensure that climate change mitigation programs do not increase invasives species threats, eg. ensure that plants used for carbon sinks and biofuels are non-invasive.

Endnotes

1 Steffen et al. (2009).

2 Sandlund et al. (2001); Walker and Steffen (1997); World Resources Institute et al. (1992).

3 Booth (2009a), and references therein.

4 Booth (2009a)

5 The 23rd extinction of an Australian mammal species due to invasive species is likely to have occurred in 2009 with the loss of the Christmas Island pipistrelle (Pipistrellus murrayi) (see Low 2009).

6 Cahill et al. (2008); Commonwealth of Australia (2007).

7 See http://www.environment.gov.au/cgi-bin/sprat/public/publiclookupcommunities.pl. Accessed October 2009.

8 CSIRO and Australian Bureau of Meteorology (2007).

9 Raupach et al. (2007).

10 CSIRO and Australian Bureau of Meteorology (2007).

11 Dunlop and Brown (2008).

12 Dunlop and Brown (2008)

13 Dunlop and Brown (2008)

14 Kearney et al. (2008); Sutherst et al. (1995).

15 Marai et al. (2002).

16 Rejmánek (1996); Sutherst et al. (2007).

17 Friend (1993); Clarke (2008); Low (2008a).

18 Koehn et al. (2000).

19 Agriculture & Resource Management Council of Australia & New Zealand and Australian & New Zealand Environment & Conservation Council and Forestry Ministers (2000).

20 Dukes et al. (2009).

21 Dukes et al. (2009).

22 Cahill et al. (2008).

23 Invasive Species Council (2009).

24 Department of Sustainability and Environment (2008).

25 Low (2008a).

26 McDougall et al. (2005); Low (2008a).

27 Corfield et al. (2007).

28 Rossiter et al. (2003).

29 Ruykysa et al. (2009).

30 Weeds CRC (2003).

31 Lindenmayer et al. (2009).

32 Johns and Hughes (2002).

33 Ziska and Runion (2007).

34 Keane and Crawley (2002); Mitchell and Power (2003).

35 Low and Booth (2007).

36 Booth et al. (2009).

37 Wilson et al. (2009); Booth (2009b).

38 West and Saunders (2007).

39 According to Randall (2007), more than 600 of about 11,000 Australian native plant species in cultivation are invasive.

40 Low (2008b).

41 Ricciardi and Simberloff (2009).

42 Wolkovich et al. (2009), for example, found that exotic grass invasion of a shrubland in the US turned it from a carbon source to a sink by increasing carbon storage 1.4 times.

43 Rossiter et al. (2003); Peltzer et al. (2009).

44 Strickland et al. (2009) found that an exotic grass invading many US forests, Japanese stiltgrass (Microstegium vimineum), stimulates higher rates of decomposition in the soil and reduces soil carbon stores.

45 Jamie Smialek et al. (2000).

46 Peltzer et al. (2009); McLean and Parkinson (2000)

47 Goodhand and Anlang (2009)

48 Northern Territory Government (2008), citing Price et al. (2007).

49 Peltzer et al. (2009).

50 Clark et al. (2010); Kurz et al. (2008).

51 O'Dowd et al. (2003)

52 Rossiter et al. (2003).

53 Low (2008a).

54 Raupach et al. (2007).

References

Agriculture & Resource Management Council of Australia & New Zealand and Australian & New Zealand Environment & Conservation Council and Forestry Ministers (2000). Weeds of National Significance Athel Pine (Tamarix aphylla) Strategic Plan. National Weeds Strategy Executive Committee, Launceston.

Booth C (2009a). Invasive Species: One of the Top Three Threats to Australian Biodiversity. Invasive Species Council. www.invasives.org.au.

Booth C (2009b). The invasion risks of introducing new genetic variants of exotic plants and animals. Invasive Species Council. www.invasives.org.au/documents/file/backgrounder_genetic_variants.pdf.

Booth C, Carr G and Low T (2009). Weedy pasture plants for salinity control: sowing the seeds of destruction. Invasive Species Council.

Cahill DM, Rookes JE, Wilson BA, Gibson L and McDougall KL (2008). Phytophthora cinnamoni and Australia's biodiversity: impacts, predictions and progress towards control. Australian JOurnal of Botany 56(4): 279-310.

Clark K, Skowronski N and Hom J (2010). Invasive insects impact forest carbon dynamics. Global Change Biology 16: 88-101.

Clarke M (2008). Catering for the needs of fauna in fire management: science or just wishful thinking? Wildlife Research 35(385-94).

Commonwealth of Australia (2007). Draft background document for the threat abatement plan: Disease in natural ecosysstems caused by Phytophthora cinnamomi. Department of Water, Heritage and the Arts, Canberra.

Corfield J, Diggles B, Jubb C, McDowal R, Moore A, Richards A and Rowe D (2007). Review of the impacts of introduced aquarium fish species that have established wild populations in Australia. Draft final report for public comment. Department of the Environment and Water Resources, Australian Government, Canberra.

CSIRO and Australian Bureau of Meteorology (2007). Climate Change in Australia - Techincal Report 2007, CSIRO.

Department of Sustainability and Environment (2008). Victoria's public land Phytophthora cinnamomi management strategy. Victorian Government, Melbourne.

Dukes JS, Pontius J, Orwig D, Garnas JR, Rodgers VL, Barazee N, Cooke B, Theoharides A, Stange EE, Harringto R, Ehrenfeld J, Gurevitch J, Lerdau M, Stinson K, Wick R and Ayres M (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? Canadian Journal of Forest Research 39: 231-48.

Dunlop M and Brown PR (2008). Implications of climate change for Australia's National Reserve System: A preliminary assessment. Report to the Department of Climate Change. Department of Climate Change, Canberra.

Friend JA (1993). Impact of fire on small vertebrates in mallee woodlands and shrublands of temperate Australia - a review. Biological Conservation 65: 99.

Invasive Species Council (2009). Killer plant disease could devastate WA biodiversity hotspots. Double Trouble Ebulletin Edition 1(February 2009). http://www.invasives.org.au/article.php?ArticleId=21.

Jamie Smialek, Virginie Bouchard, Becky Lippmann, Martin Quigley, Timothy Granata, Jay Martin and Larry Brown (2000). Effect of a woody (Salix nigra) and an herbaceous (Juncus effusus) macrophyte species on methane dynamics and dentrification. Wetlands 26(2): 509-17.

Johns CV and Hughes L (2002). Interactive effects of elevated CO2 and temperature on the leaf miner Dialectica scalariella Zeller (Lepidoptera: Gracillariidae) in Paterson's Curse, Echium plantagineum (Boraginaceae). Global Change Biology 8: 142-52.

Keane R and Crawley M (2002). Exotic plant invasions and the enemy release hypothesis. Trends in Ecology and Evolution 17(4): 164-70.

Kearney M, Phillips BL, Tracy CR, Christian KA, Betts G and Porter WP (2008). Modelling species distributions without using species distributions: the cane toad in Australia under current and future climates. Ecography 31: 423-34.

Koehn J, Brumley A and Gehrke P (2000). Managing the impacts of carp. Bureau of Rural Sciences, Canberra.

Kurz WA, Dymond CC, Stinson G, Rampley GJ, Neilson ET, Carroll AL, Ebata T and Safranyik L (2008). Mountain pine beetle and forest carbon feedback to climate change. Nature (London) 452(7190): 987-90. <Go to ISI>://BIOSIS:PREV200800311283.

Lindenmayer D, MacGregor C, Wood JT, Cunningham RB, Crane M, Michael D, Montague-Drake R, Brown D, Fortescue M, Dexter N, Hudson M and Gill AM (2009). What factors influence rapid post-fire site re-occupancy? A case study of the endangered Eastern Bristlebird in eastern Australia. International Journal of Wildland Fire 18: 84-95.

Low T (2008a). Climate Change and Invasive Species: A Review of Interactions. Canberra, Biological Diversity Advisory Committee.

Low T (2008b). Climate change and invasive species: a review of interactions. Department of the Environment, Heritage, Water and the Arts, Canberra. www.environment.gov.au/biodiversity/publications/interactions-cc-invasive.html.

Low T (2009). Christmas Island verging on collapse. Feral Herald October 2009(22).

Low T and Booth C (2007). The weedy truth about biofuels. Invasive Species Council, Inc. www.invasives.org.au/home.

Marai I, Habeeb A and Gad A (2002). Rabbits' productive, reproductive and physiological performance traits as affected by heat stress: a review. Livestock Production Science 78: 71-90.

McDougall K, Morgan J, Walsh NG and Williams R (2005). Plant invasions in treeless vegetation of the Australian Alps. Perspectives in Plant Ecology, Evolution and Systematics 7: 159-71.

McLean MA and Parkinson D (2000). Field evidence of the effects of the epigeic earthworm Dendrobaena octaedra on the microfungal community in pine forest floor. Soil Biology and Biochemistry 32: 351-60.

Mitchell CE and Power AG (2003). Release of invasive plants from fungal and viral pathogens. Nature 421: 625-27.

Northern Territory Government (2008). Discussion paper on NT climate change issues. Department of the Chief Minister, NT Government. http://www.dcm.nt.gov.au/strong_territory/climate_change/discussion_paper.

O'Dowd DJ, Green PT and Lake PS (2003). Invasional 'meltdown' on an oceanic island. Ecology Letters 6: 812-17.

Peltzer D, Allen R, Lovett G, Whitehead D and Wardle D (2009). Effects of biological invasions on forest carbon sequestration. Global Change Biology doi: 10.1111/j.1365-2486.2009.02038.x

Randall RP (2007). The introduced flora of Australia and its weed status. CRC for Australian Weed Management and Department of Agriculture and Food, Western Australia, Adelaide. http://www.weeds.crc.org.au/weed_management/intro_flora.html.

Raupach MR, Marland G, Ciais P, Le Quere C, Canadell JG, Klepper G and Field CB (2007). Global and regional drivers of accelerating CO2 emissions. Proceedings of the National Academy of Sciences of the United States of America 104(24): 10288-93. <Go to ISI>://BIOSIS:PREV200700405429

Rejmánek M (1996). A theory of seed plant invasiveness, the first sketch. Biological Conservation 78: 171-81.

Ricciardi A and Simberloff D (2009). Assisted colonization is not a viable conservation strategy. Trends in Ecology and Evolution 24(5): 248-54.

Rossiter NA, Douglas MM, Setterfield SA and Hutley LB (2003). Testing the grass-fire cycle: Alien grass invasion in the tropical savannas of northern Australia. Diversity and Distributions 9: 169-76.

Ruykysa L, Taggart DA, Breed WC and Schultz D (2009). Sarcoptic mange in southern hairy-nosed wombats (Lasiorhinus latifrons): distribution and prevalence in the Murraylands of South Australia. Australian Journal of Zoology 57: 129-38.

Sandlund OT, Schei PJ and Vilken A (2001). Introduction: the many aspects of the invasive alien species problem. Invasive Species and Biodiversity Management, Springer: 1-10.

Steffen W, Burbidge A, Hughes L, Kitching R, Lindenmayer D, Musgrave W, Stafford Smith M and Werner P (2009). Australia's Biodiversity and Climate Change: A strategic assessment of the vulnerability of Australia's biodiversity to climate change. Technical synthesis of a report to the Natural Resource Management Ministerial Council commissioned by the Australian Government. Department of Climate Change, Canberra. www.climatechange.gov.au/impacts/biodversity_vulnerability.html.

Strickland MS, Devore JL, Maerz JC and Bradford MA (2009). Grass invasion of a hardwood forest is associated with declines in belowground carbon pools. Global Change Biology doi: 10.1111/j.1365-2486.2009.02042.x.

Sutherst RW, Baker RH, Coakley SM, Harrington R, Kriticos DJ and Scherm H (2007). Pests under global change - meeting your future landlords? Terrestrial ecosystems in a changing world. J Canadell, D Pataki and L Pitelka. Berlin, Springer-Verlag: 211-26.

Sutherst RW, Floyd RB and Maywald GF (1995). The potential geographical distribution of the cane toad, Bufo marinus L. in Australia. Conservation Biology 9(6): 294-99.

Walker B and Steffen W (1997). An overview of the implications of global change for natural and managed terrestrial ecosystems. Conservation Ecology [online] 1(2): 2. http://www.consecol.org/vol1/iss2/art2.

Weeds CRC (2003). Serrated tussock – Nassella trichotoma. CRC for Australian Weeds Management.

West P and Saunders G (2007). Pest animal survey: 2004-2006. A review of the distribution, impacts and control of invasive animals throughout NSW and the ACT. NSW Department of Primary Industries. http://www.invasiveanimals.com/publications/research-reports/index.html.

Wilson JRU, Dormontt EE, Prentis PJ, Lowe AJ and Richardson DJ (2009). Something in the way you move: Dispersal pathways affect invasion success. Trends in Ecology and Evolution 24: 136-45.

Wolkovich EM, Lipson DA, Virginia RA, Cottingham KL and Bolger DT (2009). Grass invasion causes rapid increases in ecosystem carbon and nitrogen storage in a semiarid shrubland. Global Change Biology doi: 10.1111/j.1365-2486.2009.02001.x.

World Resources Institute, The World Conservation Union and United Nations Environment Program (1992). Global Biodiversity Strategy: Guidelines for action to save, study and use the earth's biotic wealth sustainably and equitably. WRI, IUCN, UNEP, Washington.

Ziska LH and Runion GB (2007). Future weed, pest, and disease problems for plants. Agroecosystems in a Changing Climate. Advances in Agroecology series, Vol 12. PCD Newton, G Edwards,

A Carran and P Niklaus. Boca Raton, CRC Press.

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Invasive animals and climate change

fact sheet

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Invasive animals – particularly foxes, cats, rabbits and rats – have caused or contributed to dozens of extinctions in Australia, and threaten many of our most vulnerable native species. Goats, pigs, horses and other hard-hoofed feral animals cause serious degradation.[2]

As with native species, climate change will benefit some invasive animals and cause others to decline.

However, because disturbance and stress to native species and ecological communities often benefit invasive species, and because climate change will bring new invasive threats, the overall threat from invasive species is likely to increase.

In many cases the increased threats from invasive species are likely to exceed the direct threats of climate change to native species.[3]

Here are some examples of what can be expected.

1. Range changes due to new temperature and rainfall patterns

New temperature and rainfall patterns may facilitate the establishment of new invaders and increase the impacts of others.

There is already evidence of this occurring. After existing along the Victorian coast for almost a century, European green crabs (*Carcinus maenas*) invaded Tasmanian waters after a run of unusually warm winters in 1988 to 1991.[4] As the climate warms, cane toads are predicted to expand southwards,[5] and cats may be able to spread to some islands currently too wet for them that serve as sanctuaries from exotic predators.[6] Tropical aquarium fish – the largest category of invasive animals in Australia – are likely to establish and spread further as waters become warmer.[7]

There are many changes afoot in the Australian Alps as temperatures rise. Foxes, hares (*Lepus europaeus*), house mice (*Mus musculus*), and feral horses (*Equus caballus*) are increasing at high altitudes.[8] Bogong moths are arriving later, forcing endangered mountain pygmy possums (*Burramys parvus*), which eat them, to forage more widely. This makes them more vulnerable to predation by foxes, which also eat bogong moths.[9]

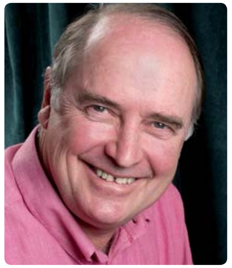
However, some invasive species will suffer. Higher temperatures will disadvantage rabbits because they need cool weather for breeding.*10*

2. Invasion opportunities with extreme events

Climate change is predicted to increase the frequency or severity of extreme events, such as cyclones, floods, droughts and fires, to the benefit of some invasive animals.

By linking outdoor ponds with waterways and waterways with each other, floods spread feral fish, such as cichlids (*Cichlidae*) and carp (*Cyprinus carpio*).[11] Storms and cyclones can destroy fences, allowing animals to escape from deer farms, game reserves and zoos. During cyclone Larry more than 200 deer of various species escaped in the Wet Tropics.[12]

> "The ultimate outcomes are expected to be declines in biodiversity favouring weed and pest species (a few native, most introduced) at the expense of the rich variety that has occurred naturally across Australia."
> – The Garnaut Climate Change Review[1]



More fires could increase predation by cats and foxes on declining species, by removing protective vegetation cover.[13] Predation after fires is believed to be reducing numbers of the endangered eastern bristlebird,[14] and probably contributed to the disappearance of numbats from arid Australia.[15] In Victoria, predation of endangered pygmy possums increased after fires on Mount Buller.[16]

After fires, feral herbivores can prevent regeneration. The entire population of the endangered tree *Nematolepis wilsonii* was destroyed during the 2009 Victorian fires. Fences are needed to protect replanted saplings from feral sambar deer,[17] which are the tree's major threat.[18]

Feral animals can compromise the capacity of native species to survive droughts – by depleting limited resources and dominating refuge areas. Rabbits probably contributed to the decline of rufous hare wallabies during droughts in central Australia.[19]

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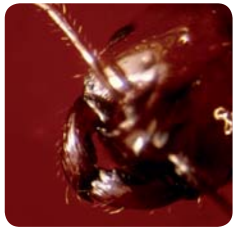
3. Increased vulnerability to feral threats

The stress imposed by climate change is likely to increase the susceptibility of species to invasive animals. Increased fox predation on pygmy possums in the Australian Alps is an example of this.

The converse is also true – that species or ecosystems threatened by invasive species are likely to be more vulnerable to climate change. For example, the grazing pressure of rabbits, goats and other invasive herbivores reduces the resilience of native plants to drought.

Many marsupials – including bridled nailtail wallabies (*Onychogalea fraenata*), golden bandicoots (*Isoodon auratus*), banded hare wallabies (*Lagostrophus fasciatus*) and rufous hare wallabies (*Lagorchestes hirsutus*) – which survive only in the northern parts of their former range – may be particularly vulnerable because they have suffered from fox predation in the southern parts of their range but may no longer be able to survive further north.[20]

Human responses can increase threats



Some human responses to climate change may exacerbate feral animal problems. If water is spread between catchments to avert shortages, aquatic pests such as tilapia (*Oreochromis mossambicus*) will have an opportunity to spread.

Farmers struggling with drought or floods are less likely to control feral animals – this may have led to an increase in the abundance of some pest species in NSW from 2002-04.[21] Invasive ants can be transported when debris is cleaned up after cyclones,[22] and fire breaks and tracks created for fire control can serve as conduits for feral animals.[23]

New agricultural products or the shift of agriculture to new areas can also increase the threat of invasive species. For example, farmers may farm goats, which may escape into the wild, or introduce new hardier breeds that are more invasive.

Invasive animals can increase emissions

Feral herbivores – including camels, goats, horses, donkeys, rabbits – emit potent greenhouse gases (methane, nitrous oxide) as a byproduct of cellulose digestion, accounting for more than 4% of estimated emissions in the Northern Territory.[24] Feral herbivores also indirectly increase emissions by limiting tree regeneration and thereby reducing carbon sequestration.

Reducing the impacts of invasive animals and preventing their spread are essential to increasing the capacity of native species and ecosystems to adapt to climate change. See the Invasive Species Council fact sheet 'Policy solutions for climate change and invasive species'.

Endnotes

1 Garnaut R. 2008. The Garnaut Climate Change Review. Final Report. Commonwealth of Australia.www.garnautreview.org.au/index.htm.

2 Booth C. 2009. Invasive Species: One of the Top Three Threats to Australian Biodiversity. Invasive Species Council.www.invasives.org.au.

3 Steffen W, Burbidge A, Hughes L, Kitching R, Lindenmayer D, Musgrave W, Stafford Smith M, Werner P. 2009. Australia's Biodiversity and Climate Change: A strategic assessment of the vulnerability of Australia's biodiversity to climate change. Technical synthesis of a report to the Natural Resource Management Ministerial Council commissioned by the Australian Government. Canberra: Department of Climate Change.www.climatechange.gov.au/impacts/biodversity_vulnerability.html.

4 Thresher R, Proctor C, Ruiz G, Gurney R, MacKinnon C, Walton W, Rodriguez L, Bax N. 2003. Invasion dynamics of the European shore crab, Carcinus maenas, in Australia. Marine Biology 142: 867–876.

5 Kearney M, Phillips BL, Tracy CR, Christian KA, Betts G, Porter WP. 2008. Modelling species distributions without using species distributions: the cane toad in Australia under current and future climates. Ecography 31: 423-434.

6 Steffen W, Burbidge A, Hughes L, Kitching R, Lindenmayer D, Musgrave W, Stafford Smith M, Werner P. 2009. Australia's Biodiversity and Climate Change: A strategic assessment of the vulnerability of Australia's biodiversity to climate change. Technical synthesis of a report to the Natural Resource Management Ministerial Council commissioned by the Australian Government. Canberra: Department of Climate Change.www.climatechange.gov.au/impacts/biodversity_vulnerability.html.

7 Low T. 2008a. Climate Change and Invasive Species: A Review of Interactions. Canberra: Biological Diversity Advisory Committee.

8 Green K, Pickering CM. 2002. A scenario for mammal and bird diversity in the Australian Snowy Mountains in relation to climate change in Koerner C, Spehn EM, eds. Mountain Biodiversity: a Global Assessment. London: Parthenon Publishing.

Pickering C, Good R, Green K. 2004. Potential Effects of Global Warming on the Biota of the Australian Alps Canberra: Australian Government Greenhouse Office.

9 Ken Green cited by Low T. 2008a. Climate Change and Invasive Species: A Review of Interactions. Canberra: Biological Diversity Advisory Committee.

10 Climate change impacts on pest animals and weeds. Department of Agriculture, Fisheries and Forestry; Bureau of Meteorology; Meat & Livestock Australia. August 2008.

11 Low T. 1999. Feral Future: The Untold Story of Australia's Exotic Invaders. Ringwood, Victoria: Viking.

12 Kaufman O. 2006. Hungry aftermath. Australian Geographic 85: 109.

13 Gill AM, Woinarski JCZ, York A. 1999. Australia's biodiversity - Responses to fire. Biodiversity Technical Paper No. 1 Canberra: Environment Australia.

14 Lindenmayer D, MacGregor C, Wood JT, Cunningham RB, Crane M, Michael D, Montague-Drake R, Brown D, Fortescue M, Dexter N, Hudson M, Gill AM. 2009. What factors influence rapid post-fire site re-occupancy? A case study of the endangered Eastern Bristlebird in eastern Australia. International Journal of Wildland Fire 18: 84-95.

15 Friend JA. 1990. The Numbat Myrmecobius fasciatus (Myrmecobiidae): history of decline and potential for recovery. Proceedings of the Ecological Society of Australia 16: 369-377.

16 Low T. 2008a. Climate Change and Invasive Species: A Review of Interactions. Canberra: Biological Diversity Advisory Committee.

17 Victorian Bushfire Reconstruction and Recovery Authority. 2009. Rebuilding together: A statewide plan for bushfire reconstruction and recovery.

18 Murphy AH, White M, Downe J. 2006. National recovery plan for the Shiny Nematolepis Nematolepis wilsonii. Victorian Department of Sustainability and Environment.

19 Lundie-Jenkins G, Corbett LK, Phillips CM. 1993. Ecology of the rufous hare-wallaby, Lagorchestes hirsutus Gould (Marsupalia: Macropodidae), in the Tanami Desert, Northern Territory. III Interactions with introduced species. Wildlife Research 20: 495-511.

20 Low T. 2008b. Climate change and invasive species: a review of interactions. Canberra: Department of the Environment, Heritage, Water and the Arts.www.environment.gov.au/biodiversity/publications/interactions-cc-invasive.html.

21 West P, Saunders G. 2007. Pest animal survey: 2004-2006. A review of the distribution, impacts and control of invasive animals throughout NSW and the ACT.: NSW Department of Primary Industries.http://www.invasiveanimals.com/publications/research-reports/index.html.

22 Low T. 2008a. Climate Change and Invasive Species: A Review of Interactions. Canberra: Biological Diversity Advisory Committee.

23 Ibid.

24 Discussion Paper on NT Climate Change Issues. Department of the Chief Minister. June 2008.

Double trouble: climate change and weeds

fact sheet

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When the climate changes, some species benefit and others lose out. This is the case with exotic weeds as well as native species. So, with global warming, might a balance of sorts be struck, with those weeds at the limits of their heat tolerance being pushed back while those that tolerate warmer conditions expanding?

That might be the case if climate change just involved increases in mean temperatures, but it is far more complicated than that.

Climate change means more extreme weather events, greater stresses on native species and ecosystems, and climate-driven activities, such as the introduction of new, hardier pasture and garden plant varieties.

Combined, these factors can be expected to push Australia towards an overall much weedier state.

Often outcompeting native species, weeds are already one of the most serious threats to Australian biodiversity.[2] There are at least 2700 exotic plants established, and many thousands more potential weeds.[3]

Native species stressed by climate change will become more susceptible to destruction or displacement by weeds. Transformed ecosystems composed largely of weeds and vigorous native species may result.[4]

With most terrestrial animals dependent on plant production, weed invasion can profoundly alter ecosystems and ecological processes.[5] In many cases the impacts of invasive species benefiting from climate change are likely to exceed the direct impacts of climate change.[6]

Here is an outline of some of the complex ways that

Many weedy species will thrive in climate change's wilder weather

Many of Australia's worst weeds benefit from extreme events, including at least 13 of the country's 20 Weeds of National Significance.[9] Athel pine (*Tamarix aphylla*), for example, spread along 600km of the Finke River in central Australia after severe flooding in the 1970s and 1980s, replacing river red gums. It could spread much further under climate change.[10]

Photo: Athel pine infestation, courtesy Colin Wilson

climate change and weeds will interact to cause harm to Australian biodiversity (and agriculture as well).

Extreme weather equals more weed opportunities

When native vegetation is stressed or destroyed by droughts, fires, floods or severe storms, weeds gain new opportunities to replace native species.[7]

There is a huge pool of invasive plants available to colonise bare spaces left by drought, fire and storm damage,[8] and wind and flooding waters help spread weeds.

Many of Australia's worst weeds benefit from extreme events, including at least 13 of the country's 20 Weeds of National Significance.[9] Athel pine (T*amarix aphylla*), for example, spread along 600km of the Finke River in central Australia after severe flooding in the 1970s and 1980s, replacing river red gums. It could spread much further under climate change.[10]

Serated tussock (*Nassella trichotoma*) benefits from bare patches created by droughts, marram grass (*Ammophila arenaria*) and bitou bush (*Chrysanthemoides monillfera rotundata*) from storms, and willows (*Salix spp.*) from floods. Climate change-altered fire regimes will also favour some weeds, particularly fire-promoting exotic pasture grasses (see below).

Range shifts due to temperature and rainfall changes

As mean temperatures increase, some weeds will be able to expand their range into new areas. The tropical weed prickly acacia (*Acacia nilotica spp. indica*) is likely to spread south[11] and athel pine could spread throughout inland rivers as far south as the Murray River in Victoria.

Lowland species such as lantana (*Lantana camara*)

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may be able to shift into the uplands.[12] Weeds moving into alpine areas could have a particularly severe impact because many alpine plant communities are localised with rare endemic species, and there are numerous weed species at lower altitudes.[13] On subantarctic Heard Island, the weed winter grass (*Poa annua*) has been spreading rapidly on deglaciated sites.14

Weeds constrained by rainfall may also find new habitats under new climate conditions. Lantana and mist flower (*Eupatorium riparium*), for example, could expand if rainfall increased in some areas.[15]

Increased invasiveness due to carbon dioxide fertilisation

C3 weeds (using one of two types of photosynthetic pathway, which responds to higher levels of CO_2) such as parthenium (*Parthenium hysterophorus*) may grow more rapidly under higher carbon dioxide levels and become more competitive.[16]

CO_2 can affect plant and leaf size, seed size and production, the nutritiousness of leaves to herbivores, plant toxicity and pollen production.

Nitrogen-fixing weeds, such as brooms, gorse and acacias may especially benefit because growth stimulated by CO_2 will not be constrained by low nitrogen levels.[17]

Under high CO_2, C3 plants are likely to become more water-efficient,18 potentially allowing weeds such as prickly acacia and rubber vine (*Cryptostegia grandiflora*) to move into drier habitats.[19]

Vines respond strongly to higher CO_2 levels,[20] and there are many highly damaging invasive vines (eg. cat's claw *Macfadyena unguis-cati* and rubber vine) that could benefit.

Higher CO_2 levels are likely to reduce the effectiveness of glyphosate, the main chemical used to control environmental weeds in Australia.[21]

Increased dispersal & pollination of weeds from animal behaviour changes

If fruit-eating birds arrive earlier and leave later for migration, as has been occurring, fruit-bearing weeds may benefit from greater dispersal.

Higher temperatures and other factors are likely to increase insects' breeding cycles and provide more weed pollination.[22]

As animals, including invasive species, move into new areas in response to climate change, they are likely to spread weeds or create disturbance advantageous for weeds.

Transformations due to feedback loops

Some weeds create positive feedback loops that may be exacerbated by climate change, and result in ecosystem transformations.

Flammable weedy pasture grasses, such as gamba grass (*Andropogon gayanus*) and mission grass (*Pennisetum polystachion*) may convert large tracts of eucalypt woodland into treeless plains, as they both promote fire and are promoted by fire, a trend likely to be exacerbated by climate change.[23]

When weedy vines flourish after cyclones, they retard rainforest regeneration and increase the vulnerability of rainforests to future cyclone damage, which benefits vines.[24]

Native ecological communities already under pressure from weed invasions are likely to be more vulnerable to climate change, which in turn will render them more vulnerable to weed invasion, creating a feedback loop leading to greater losses of native species.

Climate change will render native species more vulnerable to weeds either directly or indirectly, for example by facilitating the spread of the serious plant disease caused by *Phytophthora cinnamomi*, which is expected to benefit from wet periods increasingly coinciding with warm soil temperatures.[25]

More weed opportunities due to human climate change responses

In their responses to climate change, humans are likely to introduce more weeds and create more opportunities for invasion.

Many crops proposed for biofuels – jatropha (*Jatropha curcas*) and giant reed (*Arundo donax*) for example – are serious weeds.[26]
New hardier pasture and garden plants developed to withstand drier conditions expected under climate change are likely to have a high weed risk.[27]

Agricultural adaptations to climate change, including

Double trouble: climate change and weeds

new products and shifts into new areas, will also create more opportunities for weeds.

More weeds will be one of the inevitable results of the proposed shift of more intensive agriculture into northern Australia. If graziers switch from sheep to cattle, prickly acacia will spread, as cattle disperse more seeds.[28]

Behavioural changes in response to extreme weather events often facilitates weed invasion: weed control is a lower priority when there are floods or droughts, clean-ups after cyclones may spread weeds and overgrazing during droughts promotes unpalatable weeds.[29]

Reducing the impacts of weeds and preventing new weeds are essential to increasing the resilience of ecosystems and giving native species the best chance to deal with the adverse impacts of climate change.

Endnotes

Booth C. 2009. Invasive Species: One of the Top Three Threats to Australian Biodiversity. Invasive Species Council. www.invasives.org.au.

Booth C, Carr G, Low T. in preparation. Invasive pasture plants promoted for salinity mitigation. Invasive Species Council.

Chakraborty S, Murray GM, Magarey PA, Yonow T, O'Brien RG, Croft BJ, Barbaretti MJ. 1998. Potential impact of climate change on plant diseases of economic significance to Australia. Australian Plant Pathology 27: 15-35.

Cox GW. 2004. Alien Species and Evolution: The Evolutionary Ecology of Exotic Plants, Animals, Microbes, and Interacting Native Species. Washington: Island Press.

Csurhes S. 2005. An assessment of the potential impact of Andropogon gayanus (gamba grass) on the economy, environment and people of Queensland. Brisbane: Queensland Department of Natural Resources.

D'Antonio CM, Vitousek PM. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23: 63-87.

Dukes JS. 2000. Will the increasing atmospheric CO^2 concentration affect the success of invasive species? in Mooney HA, Hobbs RJ, eds. Invasive species in a Changing World. Washington: Island Press

Dukes JS, Mooney HA. 1999. Does global change increase the success of biological invaders? Trends in Ecology and Evolution 14: 135-139.

Gallagher R, Beaumont L, Downey PR, Hughes L, Leishman MR. 2006. Assessing the potential impacts of climate change on weeds in New South Wales: establishing priorities.

Garnaut R. 2008. The Garnaut Climate Change Review. Final Report. Commonwealth of Australia. www.garnautreview.org.au/index.htm.

Ghannoum O, Searson MJ, Conroy JP. 2007. Nutrient and water demands of plants under climate change. in Newton PCD, Edwards G, Carran A, Niklaus P, eds. Agroecosystems in a Changing Climate. Advances in Agroecology series, Vol 12. Boca Raton: CRC Press.

Groves RH, Hosking JR, Batianoff GN, Cooke DA, Cowie ID. 2003. Weed Categories for Natural and Agricultural Ecosystem Management. Canberra: Department of Agriculture, Fisheries and Forestry.

Howden SM, Harle KJ, Dunlop M, Hunt L. 2004. The Potential Impact of Climate Change on Wool Growing in 2029. A research brief conducted by CSIRO Sustainable Ecosystems for Future Woolscapes. Canberra.

Kriticos DJ, Sutherst RW, Brown JR, Adkins SW, Maywald GF. 2003a. Climate change and the potential distribution of an invasive alien plant: Acacia nilotica spp. indica in Australia. Journal of Applied Ecology 40: 111-124.

Kriticos DJ, Sutherst RW, Brown JR, Adkins SW, Maywald GF. 2003b. Climate change and biotic invasions: a case history of a tropical woody vine. Biological Invasions 5: 145–165.

Low T. 2008. Climate Change and Invasive Species: A Review of Interactions. Canberra: Biological Diversity Advisory Committee.

Low T, Booth C. 2007. The weedy truth about biofuels. Invasive Species Council, Inc. www.invasives.org.au/home.

McDougall K, Morgan J, Walsh NG, Williams R. 2005. Plant invasions in treeless vegetation of the Australian Alps. Perspectives in Plant Ecology, Evolution and Systematics 7: 159-171.

McFadyen R. 2008. Invasive Plants and Climate Change. Weeds CRC Briefing Notes. CRC for Australian Weed Management.

Poorter H, Navas M. 2003. Plant growth and competition at elevated CO2: on winners, losers and functional groups. New Phytologist 157: 175-198.

Randall RP. 2007. The introduced flora of Australia and its weed status. Adelaide: CRC for Australian Weed Management and Department of Agriculture and Food, Western Australia. http://www.weeds.crc.org.au/weed_management/intro_flora.html.

Rossiter NA, Douglas MM, Setterfield SA, Hutley LB. 2003. Testing the grass-fire cycle: Alien grass invasion in the tropical savannas of northern Australia. Diversity and Distributions 9: 169-176.

Scott JJ, Kirkpatrick JB. 2005. Changes in Subantarctic Heard Island vegetation at sites occupied by Poa annua, 1987–2000. Arctic, Antarctic, and Alpine Research 37: 366-371.

Steel J, Kohout M, Newell G. 2008. Climate change and potential distribution of weeds: Whither the weeds under climate change? Frankston, Victoria: Department of Primary Industries.

Steffen W, Burbidge A, Hughes L, Kitching R, Lindenmayer D, Musgrave W, Stafford Smith M, Werner P. 2009. Australia's Biodiversity and Climate Change: A strategic assessment of the vulnerability of Australia's biodiversity to climate change. Technical synthesis of a report to the Natural Resource Management Ministerial Council commissioned by the Australian Government. Canberra: Department of Climate Change. www.climatechange.gov.au/impacts/biodversity_vulnerability.html.

Sutherst RW, Baker RH, Coakley SM, Harrington R, Kriticos DJ, Scherm H. 2007. Pests under global change - meeting your future landlords? Pages 211-226 in Canadell J, Pataki D, Pitelka L, eds. Terrestrial ecosystems in a changing world. Berlin: Springer-Verlag.

Walther GR. 2000. Climatic Forcing on the Dispersal of Exotic Species. Phytocoenologia 30: 409-430.

Zaveleta ES, Royval JL. 2002. Climate change and the susceptibility of U.S. ecosystems to biological invasions: Two cases of expected range expansion in Schneider SH, Root TL, eds. Wildlife Responses to Climate Change. Washington: Island Press.

Ziska LH, Goins EW. 2006. Elevated atmospheric carbon dioxide and weed populations in glyphosate treated soybean. Crop Science 46: 1354-1359.

Ziska LH, Runion GB. 2007. Future weed, pest, and disease problems for plants. in Newton PCD, Edwards G, Carran A, Niklaus P, eds. Agroecosystems in a Changing Climate. Advances in Agroecology series, Vol 12. Boca Raton: CRC Press.

Attachment 5. Considerations for biodiversity and carbon markets relevant to invasive ungulates

Invasive species Council, November 2023

1. Payments should be linked to demonstrated population reduction and environmental benefits at a landscape scale.

2. There must be ongoing suppression after the population has been reduced. The majority of payments shouldn't be linked to the initial population reduction, but to the ongoing maintenance of a low population density (below a damaging threshold). Credits must be lost/repaid if populations rebound due to inadequate management.

3. Programs should be focused on the management of all ungulates, not just particular species.

4. There must be rules to stop landholders allowing invasive ungulate numbers to build up prior to participating in the market to make it easier to access credits.

5. There must also be rules to ensure additionality where land managers already have responsibility to control invasive species.

Attachment 6. Strengthening regulation of plant pathways

Invasive Species Council, November 2023

Extracted and modified from the Invasive Species Council's draft State of Environmental Biosecurity Report. While additional information relevant to New South Wales has been added, much of the focus is not specific to New South Wales.

What are the naturalisation trends in New South Wales?

New South Wales is undergoing extensive botanical homogenisation – at least 22% of the state's flora is now non-indigenous (Table 1), although most introduced species are far from achieving their full potential distribution.

New South Wales faces an enormous plant invasion debt due to the large number of:

- locally naturalised species with the potential to spread and become invasive
- potential weeds (based on an invasion history elsewhere) present but not (yet) naturalised – cultivated in gardens or paddocks
- non-native species present in Australia that are permitted for trade into the state.

Although new potentially invasive plant species will continue to enter Australia – (a) through permitted imports (because risk prediction is fallible), (b) as new, more invasive cultivars of species already present in Australia, and (c) by being smuggled – the majority of plants likely to become invasive are already here, due to rampant introductions over the past 230 years. Few have been assessed for their invasive risks and few are prohibited for trade and cultivation under state and territory laws.

A recent compilation of plant introductions into Australia since 1770 identified 34,650 alien species [1] – about 1.5 times the number of Australian native species [2], and almost 10% of the world's known flora (>357,000 species) [3]. Several thousand species with a weed history overseas have not naturalised in Australia (an estimated 5,900 in 2007 [4]) indicating that weeds-in-waiting could considerably exceed the number of weeds already naturalised. Plants with a history of invasion elsewhere do not fully constitute the pool of risk species, given that many other species do not have a history of introduction elsewhere to draw from, that changing conditions in Australia may facilitate future invasions, and that what is benign elsewhere may find conducive conditions for invasion among the highly diverse ecosystems in Australia.

The pool of risk species also includes native plants – more than 11,000 species were reported to be in cultivation in 2007 [4] (equivalent to almost half Australia's native plant species), mostly for ornamental reasons. About 500 (5%) of these have naturalised beyond their native range (Table 1).

The rate of new naturalisations of alien species in Australia appears to be consistently about 20 new species a year (Table 1). The reported rate since 1990 has been 13 a year in NSW (Table 1). Whether there has been an escalation in recent times is not clear for the rate is highly biased by the intensity of searches for new plants. Concerted searching from 2000 to 2005, for example, yielded 118 new records for New South Wales, an average of 20 a year [5].

There have been no comprehensive public analyses of the potential invasiveness of recent naturalisations in New South Wales, including whether they are likely to result in more or less serious environmental consequences than earlier naturalisations. Of the 118 newly detected naturalisations from 2000 to 2005, 10 species (8%) were assessed as having a 'major' or 'moderate to major' weed potential in NSW and 28 (24%) as having a moderate potential [5].

What are the primary pathways of concern?

Most of Australia's introduced, naturalised and invasive plant species were intentionally introduced – many for multiple purposes. Of the alien plant species for which there is information about their pathway to Australia (n=30,721), almost all (>95%) have been cultivated in domestic or botanic gardens for ornamental purposes (Table 2) [1]. A surprising number have also been cultivated for medicinal purposes – 26% of introduced species and 45% of naturalised species. More than a quarter of introduced species and more than a third of naturalised species have been used in primary industries – for cropping, livestock pastures or forestry. Species associated with multiple pathways are more likely to have naturalised and become invasive [1].

The dominant future pathways for the naturalisation of species already present in Australia will undoubtedly continue to be gardening. The risks have escalated in recent decades with (a) continued population growth and urban expansion and (b) the rise of internet trading, which provides greater choice to consumers and is much harder to regulate than local nursery sales.

Pasture plantings are also high risk due to their scale, high propagule pressure, frequent proximity to remnant bushland, and the qualities selected such as persistence, vigour, competitiveness and tolerance of environmental stress that make them likely to become invasive [6]. A recent survey of pasture plants developed or promoted by 17 organisations in 8 countries on 6 continents found that 91% of taxa developed by agribusinesses were listed as weeds [6]. Pasture grasses often form vast monocultures and can transform ecosystems by altering nutrient cycles, soil water regimes, geomorphology and sedimentation and intensifying fire regimes [7–9]. For example, a Victorian study found that native grasslands invaded by canary grass (*Phalaris aquatica*) had 3–5 times more fuel mass and fire intensity was 3 times higher than in native kangaroo grass grasslands [10]. The continued planting and spread of invasive pasture grasses is one of New South Wales's most neglected environmental threats.

Although the large publicly funded pasture breeding programs of the 1950s to 1990s no longer exist (Box 1), there is 'continued impetus to develop new pasture plants' – so as to increase productivity (biomass and feed quality), impart tolerance to diseases and insect pests, develop new crop/graze systems and summer-active grasses for temperate areas and fill production gaps (e.g. for beef production on vertisol soils) [11]. Climate change will likely add to the incentive to develop hardier, more drought-tolerant varieties. The Australian Pastures Genebank contains more than 80,000 varieties of grasses and legumes that were previously imported into Australia and are potentially available for the development of new cultivars [12]. There is also a focus on importing ‘elite’ varieties from overseas, reselecting plants from old plant evaluation sites and some plant breeding [11]. Although there has been some acknowledgement by pasture researchers of the invasive risks of alien pasture species, the industry continues to research and promote damaging species [6,13].

How are pathway risks assessed and regulated?

There are 2 different systems for regulating plant pathways within Australia:

> Permitted-list approach: Like the system applying at the national border, since 1998 Western Australia has required any proposed new plant introductions to pass a risk assessment. Currently, about 47,000 species are permitted entry to Western Australia and about 870 are prohibited. The Northern Territory applies this approach for aquatic plant introductions (regulated under the Fisheries Act). A permitted-list approach ‘embraces the precautionary principle’ insofar as species proposed for introduction are treated as potential risks unless assessed as ‘safe’ [14]. The effectiveness of this system depends on the rigour of assessment, degree of applied precaution and enforcement.
>
> Prohibited-list approach: The other state and territory governments generally permit the trade and cultivation of any plant taxa except those that are expressly prohibited (typically no more than 100–200 species), meaning there are no clear restrictions in most jurisdictions on more than 99% of the >34,000 plant species present in Australia.

In New South Wales, fewer than 100 species are prohibited – listed under Schedule 2 of the Biosecurity Act as prohibited matter, under Schedule 3 of the Biosecurity Regulation as weeds or subject to a control order (see NSW database). There are also regional priority weeds that may be subject to restrictions on the basis of the ‘general biosecurity duty’.

There is a requirement under the NSW Biosecurity Regulation (section 34) for people proposing to import a vascular plant species not present in the state to notify the government of their intention to do so at least 20 working days prior to importation. What this leads to (a risk assessment?) is not specified and there do not appear to have been any species added to Schedule 3 of the Biosecurity Regulation as a result. Given the obscurity of this requirement, we suspect it is often (or mostly?) ignored.

Although priority 1.2 of the Australian Weed Strategy is to ‘adopt consistent risk assessment and prioritisation approaches within Australia’, most states and territories apply different methods of risk assessment. It is not clear in most jurisdictions how systematically risks are assessed and how the regulatory and management priorities are determined.

The NSW Government has said its weed risk management system (developed in 2009) is best practice and ‘aims to provide a standard, nationally accepted and transparent process’, including for [15]:

- deciding which plants should be approved for release in NSW
- identifying which plants require further research prior to release in NSW
- prioritising weeds for the allocation of limited management resources
- determining the appropriate legislative status for undeclared naturalised plants
- reviewing the legislative status of currently declared weeds.

As far as we are aware, there has been no independent evaluation of the reliability of this risk assessment method for the different specified purposes [16,17]. Although uncertainty is measured, there is no information about how this influences risk ratings and whether the precautionary principle is applied in decision-making.

There does not appear to be any current public information about which plant species have been risk-assessed in New South Wales and the risk basis for current priorities for state-based regulation and eradications. Weed risk assessments are not published. There is no obvious reason for keeping risk assessments confidential and they would add to the body of often-scarce available knowledge about weed risks in Australia.

A 2014 paper reports that the NSW Government undertook a process to identify and prioritise new and emerging environmental weeds [18]. Of 218 identified species there was sufficient information to assess the risks of 149 species (72 lacked sufficient data) and assign them to categories – eradicate (36 species), contain spread and manage. The results were used to update weed priorities for the National Parks and Wildlife Service [18].. Whether this assessment process has been regularly repeated and the outcomes used to inform state and regional priorities is not clear. There was an intention to apply the approach Australia-wide to identify new and emerging weeds and to publish the results in an online database, but this does not appear to have occurred either for the NSW or national results [19].

Apart from genetically modified plants, which are assessed nationally by the Office of the Gene Technology Regulator, there appear to be no regulatory requirements for the assessment of the risks of introducing new cultivars of invasive pasture plants or other high-risk categories of plants cultivated over large areas [20].

Under the current regulatory approach, there is little or no incentive for industries that profit from selling invasive plants to consider, assess or manage the risks of the plants they sell – for it is the public and private land managers who pay for management of environmental weeds. Due to a lack of systematic processes for assessing and managing risks, agricultural departments managing biosecurity also avoid taking responsibility for permitting the trade and cultivation of high-risk species (and sometimes also for breeding or funding the breeding of new invasive taxa).

In addition to a regulatory approach, since 2017 the NSW and ACT governments with the Nursery and Garden Industry have been working to develop a voluntary certification scheme. It was launched in 2022 with a website (gardeningresponsibly.org.au/) containing information on low risk ‘certified’ plants and suppliers committed to the scheme (currently 9 retail nurseries and 14 wholesale nurseries). It has not yet been adopted by any large retailers.

A similar scheme operating in California since 2005, PlantRight, has achieved some positive outcomes, with annual surveys (by volunteers) finding that nurseries selling one or more of a subset of 7 locally invasive plants dropped from 44% in 2014 to 20% in 2021 [21] (20% is equivalent to more than 300 nurseries). The outcomes were mainly achieved by the commitment of Box Stores (large retailers) to stop selling invasive plants. Chain retailers were the store type most likely to sell invasive plants (47%). Despite some success, voluntary certification seems a laborious, slow and uncertain way of reducing the risks of this pathway. The pivotal question is whether people should be given the choice of selling and growing plants likely to become invasive. Regulation would surely be a much more effective, efficient and fair approach.

How effective is pathway regulation for limiting the trade and cultivation of high-risk plants?

The 2009 independent review of the EPBC Act found that the movement of plants within Australia is ‘effectively unconstrained’, that they ‘represent a vast reservoir of potential future problems’, and that there has been ‘a substantial failure’ of regulation by the state and territory governments [22].

Assuming that species weedy in other countries are potential weeds somewhere in Australia, there are at least 9,000 weeds or potential weeds in Australia [3] but fewer than 500 are subject to any form of legislative control in any one of Australia’s states/territories apart from the Northern Territory (for aquatic plants) and Western Australia. That is, there are no restrictions on the sale or planting across most of Australia on about 95% of weeds/potential weeds and about 85% of already naturalised species.

The 2009 review recommended that the Council of Australian Governments:

> develop criteria and management protocols for the movement of potentially damaging exotic species between State and Territories, working towards a list of ‘controlled’ species for which cost-effective risk-mitigation measures may be implemented.

This has not occurred. Since then, Australia has made little, if any, progress in reducing the risks of plant pathways within Australia. The risks have likely grown given the greater number of alien species now present in Australia and intensification of land uses in some areas.

For a quarter of a century, there have been many unrealised intentions to reduce plant pathway risks, particularly of the garden plant trade. A 1998 national strategy called *Garden Plants under the Spotlight,* developed by the Weeds Cooperative Research Centre, the Nursery Industry Association, and the federal, state and territory governments, outlined strategies to [23]:

- educate and inform the Australian gardening public about invasive garden plants
- educate the plant industry and horticultural media about invasive plants
- obtain cooperation from industry and media in the promotion, sale and distribution of environmentally friendly alternative plants.
- increase sales of non invasive garden plants.

From a compilation of 860 species identified as 'garden thugs', a list of 100 was presented to the nursery industry for comment and a final list of 52 plants was identified by the strategy as ones to be 'discouraged' from use in Australians gardens [24]. But not all nurseries agreed to withdraw these few dozen plans from sale and several years later 60% were still being sold – contradicting the assumption in the strategy that 'when notified of a problem, many if not the great majority of nurseries voluntarily stop sales of the worrisome plants' [23,25]. This and other failed efforts at self-regulation are a reason to be sceptical that the current NSW PlantSure scheme will significantly reduce pathway risks.

Since then, no national weed strategy (2007, 2017) has even specified a goal to reduce the risks of domestic trade in potentially invasive plants. Intended or not, the perpetual promises to solve the problem by voluntary actions have done a good job of staving off regulation. There are tighter laws against littering in Australia than there are to prevent people spreading invasive plants.

For several reasons, the current regulation of plant pathways is guaranteed to exacerbate Australia's already severe weed problems. Under the current permissive approach:

- dozens more plant species will continue to naturalise each year, including many known to be invasive elsewhere
- the invasive risks of some species will increase due to continued importation (increasing the propagule pressure), and the importation or breeding of new varieties, boosting their adaptive capacity
- smuggling – likely to be a 'significant problem' [14] – is facilitated by internet commerce and because there are mostly no state/territory rules to prevent the sale of illegally imported plants once they have crossed the Australian border.

All of these reasons, combined with population growth (more gardeners), internet trade and increasing environmental disturbance, mean that the current rate of naturalisations and invasions is likely to grow. The lack of regulation of plant pathways is among the greatest gaps in Australian environmental law.

In 2006, weed officers from 6 state/territory governments (including New South Wales) published a paper, 'Turn the tap off before you mop up the spill', recommending that the state and territory governments consider implementing a nation-wide permitted-list approach [14]. The prohibited list approach, they said, 'struggles to keep pace with the tens of thousands of potentially invasive plant species' currently offered for sale. A permitted-list approach may be 'a more effective and efficient way' to deal with such a large number of potentially invasive plant species. Almost 2 decades later, no progress has been made and the number of naturalised plants in Australia has increased by several hundred species (Table 1).

To strengthen environmental biosecurity

To significantly reduce the rate of naturalisation of new invasive plants, the states and territories need to greatly strengthen their regulation of plant pathways to reduce the number of invasive and potentially invasive plants being traded and cultivated. The most feasible way of doing so is to permit the trade and movement only of species assessed as a low invasive risk and prohibit all others (except those widely cultivated for which a ban will not reduce risks or is not feasible).

- All states and territories should apply a permitted list approach as the basis for regulating plant trade. Ideally, this would be applied consistently across Australia, with permitted and prohibited lists based on an agreed best-practice risk assessment method and taking into account the risks for neighbouring states or territories of permitting particular species. Sharing resources and assessments and harmonising the lists for each state and territory would optimise the effectiveness and save on costs. Box 1 suggests a process for developing a permitted list approach.

Box 1. A suggested approach for developing a permitted-list approach

Assess existing permitted-list approaches to evaluate their effectiveness and the lessons that can be learned.

Review and revise risk assessment methodologies to ensure that environmental risks are optimally covered and that the precautionary principles applies.

Compile a list of plant species traded by commercial entities within the past 5 years – including garden and agricultural species – as potential candidates for a permitted list.

Undertake risk assessments of these species and treat them as follows:

- low-risk species -- add to the permitted list
- medium-risk species – require further assessment
- high-risk species – add to the prohibited list (except if already naturalised across the state and prohibition is unlikely to reduce the invasiveness risks)

Undertake further assessments of medium-risk species:

- low commercial value – add to the prohibited list
- high commercial value – if not added to the prohibited list, impose a levy on all sales to cover the costs of eradication or control of escapes and permit only existing variants
- extensively naturalised species – add existing variants to the permitted list if additional propagule pressure is unlikely to boost invasiveness, but prohibit the introduction of additional variants.

For non-permitted species, set transition conditions for species already in cultivation:

- high-risk species (gardens) – require removal/destruction in gardens and offer 2-for-1 low-risk replacements
- high-risk species (commercial use) -- depending on feasibility and costs, require removal/destruction (with compensation) or measures to reduce the risks such as buffer zones and insurance to cover the costs of controlling escapees
- medium-risk species – permit current plants to be retained but not traded or newly planted; all escapees must be controlled

Require risk assessment for additions to the permitted list. This should include new variants and subspecies of permitted medium-risk or high-risk species.

- Australian governments should develop a strategy to identify and reduce the risks (by prohibition, eradication or containment) of high-risk potential invasive plants present in Australia. This could include support for the relevant industries to develop safe alternatives to favoured high-risk species and programs to encourage people to remove high-risk species from their gardens and a joint compliance taskforce to monitor online trade.
- Australian governments also need an agreed policy approach to the breeding or release of proposed new variants of invasive or potentially invasive species, particularly those likely to be cultivated over large areas with the potential to spread to areas of conservation importance or to intensify fire regimes. New genotypes should be banned unless assessed as low risk.
- Regulations should prohibit governments from engaging in activities or funding others to engage in activity likely to promote the introduction or spread of invasive species. This is similar to a US presidential order (#13112) introduced in 1999, which forbids such actions 'unless the purported benefits clearly outweigh the potential harm'.

Table 1. Naturalised plant species in New South Wales and Australia

	New South Wales	**Australia**
Current status		
Native plant species	6,083	22,864
Naturalised plant species (alien and native)	1,707	3,541
Naturalised plant species (alien)	1,621	3,057
Proportion of flora that is not native	22%	12%
Rate of naturalisation		
Naturalised species reported 1990 (alien species only)	1,253	1,952
Average annual reported naturalisations (alien species only) since 1990	11	33

Naturalised species reported 2005 (NSW) /2000 (national) (alien species only)	1,386	2,699
Average annual reported naturalisations (alien species only) since 2005 (NSW) /2000 (national) (alien species only)	14	16
Average annual reported naturalisations (alien and native species) since 1788	7	15

Sources: Native plants: Australian Plant Census. Naturalised plants: Attachment 1 (NSW), Australian herbarium database (national). Naturalised plants (1990): Australian Flora Statistics [26]. Naturalised plants (2000): Dodd et al. 2015 [27]; NSW naturalised plants (2005): Coutts-Smith and Downey 2006 [28].

Table 2. Introduction pathways for introduced and naturalised plant species

Pathway	Number of plants introduced	Proportion of introduced plants	Number of plants naturalised	Proportion of naturalised plants
Ornamental	29,777	96.9%	3,888	95.3%
Medicinal	7,968	25.9%	1,647	45.7%
Cropping	6,211	20.2%	1,291	35.8%
Contaminant	2,474	8.1%	1,137	31.6%
Pasture	1,515	4.9%	490	13.6%
Forestry	828	2.7%	176	4.9%
Total for which pathway data was available	30,721		4,081	

Source: Bartlett et al. 2023 [1].

Notes: Many plants have multiple potential pathways – for example, grown in gardens both for ornamental and medicinal reasons or introduced both for intentional use and as a contaminant. The medicinal pathway includes plants traded among herbal medicine enthusiasts and those sold in nurseries for use as herbal medicine.

Box 2. A history of weedy introductions for livestock pastures

Many of Australia's worst environmental problems – land clearing, erosion, soil acidification, salinisation and weed invasions – have arisen from a vision transplanted from Europe of sheep and cattle fattening in fertile green paddocks [31]. From about the 1880s, acclimatisation societies, supported by government botanists, started importing hundreds of 'superior' pasture species so as to increase the land's productive capacity [32,33]. Other species arrived accidentally – buffel grass, stylo, burr medic and subterranean clover among them [34].

An 'urgent need' to develop Australia's grasslands, particularly in semi-arid regions, led to the establishment in 1930 of the Commonwealth Plant Introduction program, which operated until 2000 and imported about 145,000 varieties of about 8,300 species to Australia for crops, pastures and unspecified uses [32]. Australian researchers travelled the world, collecting plants mainly from Central and South America, Africa and the Mediterranean [34]. About 22% of the world's 10,000 grass species and 18% of the world's 12,000 legume species were brought to Australia, double the number of native species in each of these families [32].

The vision of the CSIRO for a 'new Australia' was the complete replacement of native vegetation with 'improved pastures' across almost 20% of the continent, covering almost all available land where rainfall exceeded 500 mm in the north and 375 mm in the south [32]. In 2016–17, more than 35 million hectares (about 5% of the continent) were classified as 'improved' pastures, down from 47 million hectares in 2010–11 [35,36].

Very few introductions proved useful in northern Australia. Of 463 potential pasture species – 186 grass and 277 legume species – introduced to the north between 1943 and 1984, 95% were assessed as not useful [37]. All 21 species considered useful have since become weedy. At least 64 species (14% of the introductions), and probably more by now, have become weeds – spreading from paddocks or trial sites. They include devastating invaders such as gamba grass, guinea grass and buffel grass [37].

In 2014, the various state collections of pasture seeds were combined into the Australian Pastures Genebank, with more than 80,000 varieties stored in cold rooms (at –20 degrees) [12] – a giant repository of potential future weeds. The pasture seeds industry, responsible for introducing some of Australia's worst weeds, may have lost momentum since the late 1990s but doesn't appear to be daunted by this history from pursuing more weedy introductions. Recent introductions include a new cultivar of the highly invasive tall wheatgrass (*Thinopyrum ponticum*) [38]. Current research by government and university research teams includes the development of new legumes for beef production in seasonally dry areas of Queensland and northern New South Wales [34] and the development of new cultivars of widely sown weedy species, including genetically modified cultivars.

Box 3. Illegal internet trade in plants

Asian watergrass (*Hygroryza aristata*) has recently appeared in the aquarium trade – being sold in Australian retail outlets and online even though it is not on Australia's permitted imports list. There are no records of it naturalising anywhere, but it is described as weedy in its native Asian range and various descriptions – 'hardy', 'fast growing', 'can form dense floating mats' – sound deeply concerning. Is this smuggled but unregulated plant destined to become a major aquatic weed in Australia when people start dumping the contents of their aquaria?

The internet trade in plants is high volume and high risk, but mostly unregulated and unmonitored [39]. A recent 12-month web-scraping study of one public e-commerce website yielded 235,000 plant advertisements. From 10,000 advertisements (4.25% of the total), the researchers found advertisements for 155 taxa that were prohibited in at least one state or territory (12.5% of all prohibited taxa). The sale of plants in 411 advertisements would have breached state or territory laws. The most frequently advertised declared plants were Opuntia cactuses and aquatic weeds. Frequently advertised declared plants included bunny ears cactus (*Opuntia microdasys*), drooping prickly pear (*Opuntia monacantha*), water hyacinth (*Eichhornia crassipes*), Amazon frogbit (*Limnobium laevigatum*), arum lily (*Zantedeschia aethiopica*), gazanias (*Gazania* spp.), English ivy (*Hedera helix*), topped lavender (*Lavandula stoechas*), blackberry (*Rubus fruticosus*), carrion flower (*Orbea variegata*) and neem (*Azadirachta indica*) [39].

References

1. Bartlett AC, Blackburn TM, Randall R, Catford JA. Characteristics of Australia's alien flora vary with invasion stage. Global Ecology and Biogeography. 2023.
2. Fensham RJ, Laffineur B. Defining the native and naturalised flora for the Australian continent. Aust J Bot. 2019;67: 55–69. doi:10.1071/BT18168
3. Kew Science. Plants of the World Online. In: Plants of the World Online [Internet]. 2023. Available: https://powo.science.kew.org
4. Randall RP. The Introduced Flora of Australia and its Weed Status. Cooperative Research Centre for Australian Weed Management; 2007.
5. Hosking JR, Conn BJ, Lepschi BJ, Barker CH. Plant species first recognised as naturalised or naturalising for New South Wales in 2004 and 2005. Cunninghamia. 2011;12: 85–114.
6. Driscoll DA, Catford JA, Barney JN, Hulme PE, Inderjit, Martin TG, et al. New pasture plants intensify invasive species risk. Proceedings of the National Academy of Sciences. 2014;111: 16622–16627.
7. Godfree R, Firn J, Johnson S, Knerr N, Stol J, Doerr V. Why non-native grasses pose a critical emerging threat to biodiversity conservation, habitat connectivity and agricultural production in multifunctional rural landscapes. Landscape Ecology. 2017;32: 1219–1242.
8. Read JL, Firn J, Grice AC, Murphy R, Ryan-Colton E, Schlesinger CA. Ranking buffel: Comparative risk and mitigation costs of key environmental and socio-cultural threats in central Australia. Ecology and Evolution. 2020;10: 12745–12763.
9. Setterfield SA, Rossiter-Rachor NA, Hutley LB, Douglas MM, Williams RJ. Biodiversity research: turning up the heat: the impacts of Andropogon gayanus (gamba grass) invasion on fire behaviour in northern Australian savannas. Diversity and distributions. 2010;16: 854–861.
10. Walker ZC, Morgan JW. Perennial pasture grass invasion changes fire behaviour and recruitment potential of a native forb in a temperate Australian grassland. Biological Invasions. 2022;24: 1755–1765.
11. Cox KG. Recent development of pasture plants in Queensland: a mosaic approach. 2013.
12. South Australia Department of Primary Industries and Regions. Australian Pastures Genebank. In: Government of South Australia [Internet]. 14 May 2022. Available: https://pir.sa.gov.au/research/services/australian_pastures_genebank
13. Silcock RG, Finlay CH. Perennial pastures for marginal farming country in southern Queensland. 1. Grass establishment techniques. Tropical Grasslands-Forrajes Tropicales. 2015;3: 1–14.
14. Csurhes S, Randall R, Goninon C, Beilby A, Johnson S, Weiss JE. 'Turn the tap off before you mop up

the spill': exploring a permitted-list approach to regulations over the sale and interstate movement of potentially invasive plants in the States and Territories of Australia. 2006. pp. 95–98.
15. NSW Department of Primary Industries. NSW Weed Risk Management system - Background information. In: NSW Government [Internet]. 2017. Available: https://www.dpi.nsw.gov.au/biosecurity/weeds/strategy/nsw-weed-risk-management-system/background-information
16. Lonsdale W, Smith C. Evaluating pest-screening systems—insights from epidemiology and ecology. Weed risk assessment. CSIRO Publishing; 2001. pp. 52–60.
17. Hulme PE. Weed risk assessment: a way forward or a waste of time? Journal of Applied Ecology. 2012;49: 10–19.
18. Hamilton MA, Cherry H, Martin LJ, Turner PJ, Johnson S. Using Weed Risk Management assessments to inform on-ground action for new and emerging environmental weeds in New South Wales. Tasmanian Weed Society Inc; 2014. pp. 269–272.
19. Auld B, Johnson S. Online weed risk management database for new and emerging weeds. Tasmanian Weed Society Inc; 2014. pp. 405–408.
20. Agtrans Research, Dawson N. Review of progress on invasive species. Final report to Department of Environment and Heritage. 2005.
21. Lee G. Results of PlantRight 2021 Spring Retail Nursery Survey. Plant California Alliance; 2021.
22. Hawke A. The Australian Environment Act – Report of the Independent Review of the Environment Protection and Biodiversity Conservation Act 1999. Australian Government; 2009.
23. Garden Plants Under the Spotlight. An Australian strategy for invasive garden plants. Draft. Cooperative Research Centre for Weed Management Systems and Nursery Industry Association of Australia; 1999.
24. Randall R. Garden thugs, a national list of invasive and potentially invasive garden plants. Plant Protection Quarterly. 2001;16: 138–171.
25. Groves R. CAWS Oration. Weed management at the border, at the garden fence and in the bush. 2004. pp. 1–9.
26. Australian National Botanic Gardens PA. Australian Flora Statistics - Australian Plant Information. Australian National Botanic Gardens, Parks Australia; 2012. Available: https://www.anbg.gov.au/aust-veg/australian-flora-statistics.html
27. Dodd AJ, Burgman MA, McCarthy MA, Ainsworth N. The changing patterns of plant naturalization in Australia. Diversity and Distributions. 2015;21: 1038–1050.
28. Coutts-Smith A, Downey P. The Impact of Weeds on Threatened Biodiversity in New South Wales. CRC for Australian Weed Management; 2006. Available: https://www.researchgate.net/publication/264240230_The_Impact_of_Weeds_on_Threatened_Biodiversity_in_New_South_Wales
29. Dellow J, Groves R. Some recent incursions of weeds to New South Wales. Council of Australasian Weed Societies Inc. Sydney, Australia; 1999.
30. Johnson SB. Some weeds have no boundaries. What are the next steps we need to take with species that jump the fence. 2013. pp. 61–9.
31. Whalley R, Friend D, Sanford P, Mitchell M. Evaluation of native and introduced grasses for low-input pastures in temperate Australia: rationale and scope. The Rangeland Journal. 2005;27: 1–9.
32. Cook GD, Dias L. It was no accident: deliberate plant introductions by Australian government agencies during the 20th century. Australian Journal of Botany. 2006;54: 601–625.
33. Department of Primary Industries. Grassed up - Introduction. In: NSW Government [Internet]. 2017. Available: https://www.dpi.nsw.gov.au/agriculture/pastures-and-rangelands/rangelands/publications-and-information/grassedup/intro
34. Smith R, Harris C, Cox K, McClements D, Clark S, Hossain Z, et al. A history of Australian pasture

genetic resource collections. Crop and Pasture Science. 2021.
35. Australian Bureau of Statistics. Land Management and Farming in Australia, 2016-17. 2018. Available: https://www.abs.gov.au/statistics/industry/agriculture/land-management-and-farming-australia/latest-release#data-downloads
36. Australian Bureau of Statistics. National Land Account, Experimental Estimates. 2021. Available: https://www.abs.gov.au/statistics/environment/environmental-management/national-land-account-experimental-estimates/latest-release
37. Lonsdale W. Inviting trouble: introduced pasture species in northern Australia. Australian Journal of Ecology. 1994;19: 345–354.
38. Booth C, Carr G, Low T. Weedy pasture plants for salinity control: sowing the seeds of destruction. Invasive Species Council. 2009. Available: https://invasives.org.au/wp-content/uploads/2014/02/rpt_weedypastureplants.pdf
39. Maher J, Stringham OC, Moncayo S, Wood L, Lassaline CR, Virtue J, et al. Weed wide web: characterising illegal online trade of invasive plants in Australia. NeoBiota. 2023;87: 45–72.

Attachment 7. Strengthening regulation of pet pathways (excluding fish)

Invasive Species Council, November 2023

Extracted (with modifications) from the Invasive Species Council's draft *State of Environmental Biosecurity Report*.

What are the environmental risks of this pathway?

Although it is prohibited to trade or keep corn snakes in Australia, since 2000, they have regularly been found in the wild, particularly in New South Wales – 79 were captured in the Greater Sydney region by just 3 wildlife organisations at an increasing rate between 2004 and 2012 [1]. Nine were recorded within 200 metres of bushland. Corn snakes are shy, secretive and mostly nocturnal, so many escapes have probably gone undetected. It would take very little for a population to establish – an invasive population in the Cayman Islands is believed to have developed from a single clutch of eggs [1]. If corn snakes do naturalise (or are already naturalised), it could take several years to detect them. Other illegally kept pets recently detected at large in NSW (but not naturalised) are a panther chameleon, racoon, Hermann's tortoise and golden flying snake [2]. Each was removed.

Most of the 21 mammals, 17 birds, 4 reptiles and 2 amphibians known to have naturalised in NSW were introduced long ago for agriculture, hunting or biological control (many by acclimatisation societies) (Attachment 1). The only naturalisations of non-fish vertebrates detected in NSW since 2000 (a gecko and a frog) were both accidental introductions.

Globally, an astonishing number of wildlife are traded and kept as pets – at least 3,749 bird species (36.3% of all birds), 1,857 reptile species (17.5% of all reptiles), 591 amphibians species (8.0% of all amphibians), and 506 mammals (8.4% of all mammals) [3]. As many as half the invasive vertebrate species globally have been introduced by the pet trade [3,4]. While this is true for aquarium fish in Australia, the pet trade has been responsible for few other vertebrate invasions in Australia. For most taxa, this is largely due to import restrictions – no reptiles or frogs and few mammals have been permitted into Australia for pet-keeping.

Aquarium fish trading has been a major invasion pathway in Australia since the 1970s (Attachment 1). Now, the trade and keeping of non-fish animals is also emerging as a potential significant pathway [5,6]. Smooth newts, found in a pool of water at a Melbourne construction site in 2011 after being prohibited the year before, exemplify the risks. This population marks the establishment of an entirely new taxonomic order in Australia – the salamanders – and the addition to southern Australian freshwater ecosystems of a highly adaptable predator and competitor and potential transmitter of diseases to Australian frogs [7]. Several other species kept as pets, particularly snakes (e.g. corn snakes, boa constrictors, sand boas), birds (e.g. rose-ringed parakeets) and turtles (mainly red-eared sliders) have increasingly been detected at large since 2000 [8–10].

The diversity of alien vertebrate species detected in Australia for the first time is increasing, with no saturation evident in the rate of new interceptions from 1999 to 2016 at the Australian border and post-border [5]. Globally, the illegal trade in vertebrate pets is highly lucrative – conservatively worth US$20 billion a year (about AUS$30 billion) [5]. The black market is facilitated by the sharing of information on social media, which generates demand for new species, and the rise of e-commerce platforms nationally and internationally [9,11]. A recent study of online advertising in Australia tallied advertisements over a 14-week period for about 67,000 birds (37% alien species), 12,000 reptiles (all native) and 200 amphibians (25% alien species) [12].

Reptiles are often kept illegally in Australia. Although the Australian Government does not permit their importation for pet-keeping, they are the group of vertebrates most commonly intercepted at the border and by state and territory biosecurity agencies [6,13]. From 1999 to 2016, there were more than 100 seizures each of corn snakes, boa constrictors and Gaboon vipers [8].

From 1999 to 2012, the Victorian Government detected 33 alien reptile species being illegally traded in the state, including 28 not previously recorded in Australia [6]. This was due to a concerted enforcement effort, which included an amnesty for those prepared to voluntarily forfeit illegally kept wildlife. About 12 of the 28 new species were assessed as likely to naturalise if released into the wild a 'modest' number of times (3 times, in the absence of incursion management) and all 28 species are likely to establish if released at least 7 times [6]. Ten of the 28 are venomous snakes. The species most likely to establish with 3 releases are [6]:

- common snapping turtle
- Burmese python
- yellow anaconda
- puff adder
- Gaboon adder
- monocled cobra
- Russel's viper

Also at risk of establishing are corn snakes and boa constrictors, based on the frequency of detection. Since 1999, there have been seizures of at least 21 alien species of snake, including more than 100 each of corn snakes, boa constrictors and Gaboon adder [8].

Even worse than a new reptile in the wild could be a new pet-borne disease that spreads to native wildlife. This is a risk associated with any escapes, whether or not the species is native or alien and whether or not it naturalises [14,15]. Diseases suffered by captive snakes and lizards in Australia that are not known to be in the wild include inclusion body disease (a fatal disease caused by reptarenaviruses) [16] and snake fungal disease (caused by *Ophidiomyces ophiodiicola*) [17]. Since 2000, at least 2 disease agents are believed to have spilled from captive animals into native reptiles – a mite that causes abnormal abnormal shedding, anaemia and death in captive snakes and lizards is now parasitising native sleepy lizards in South Australia [14], and a fungus, *Nannizziopsis barbatae*, which causes systemic fatal disease in captive lizards, has been detected in several native species (eastern water dragon, tommy roundhead dragon, eastern blue-tongue skink, shingleback skink and a freshwater turtle) [18].

Pet birds are another group at high risk of adding to Australia's naturalised fauna and introducing diseases to native birds. The Australian List of Threat Categories of Non-Indigenous Vertebrates lists 262 introduced alien bird species, many in private keeping as pets. Most species have been assessed as an 'extreme' threat – often as a precautionary rating because there is insufficient information to reliably assess their threat [19]. An extreme rating means they 'should not be allowed to enter, nor be kept in any State or Territory unless sufficient risk management measures exist to reduce the potential risks to an acceptable level'. But the majority are not prohibited by the states and territories – in large part because it is not thought to be feasible to ban the keeping of popular species [15].

One species highly likely to establish in the near future is the rose-ringed parakeet, the most widely introduced parrot in the world, with an extensive invasion history. From 1999 to 2013, there were at least 864 reports of escaped parakeets, mostly comprising postings in 2011–2013 on a missing animals website – far higher than the 96 recorded by biosecurity agencies [20].

Even worse than a new bird in the wild could be a new pet-borne disease that spreads to native birds. In 1997 proventricular dilatation disease was reported in a captive green-winged macaw that had been imported in 1993 [21]. Parrot bornavirus can cause severe chronic disease in captive parrots, often leading to death. Seroreactivity against the virus was detected recently in a wild little corella, but infection could not be confirmed by direct virus detection [22]. Most native parrot species are likely to be susceptible. This disease is listed by the Australian Government as one of the highest risks that Australia should seek to prevent [23].

Another pathogen of parrots – psittacid herpesvirus-1, which causes the rapidly fatal Pacheco's disease – has recently been reported for the first time in wild Australian birds, after having been previously detected in imported green-winged macaws that had been imported in 1993. This virus 'could be devastating to recovery programs for threatened avian species' [24]. There has been little testing of captive and wild birds to assess other disease spillover risks from pet birds.

The most dangerous pet for native wildlife has long been the cat, a primary cause of at least 25 mammal extinctions. Even though pet cats are known to be rampant killers of urban wildlife, few Australian councils have enacted containment laws. Another potential predator of wildlife popular as a pet is the ferret. Although there is uncertainty about its capacity to establish wild populations, the threat is rated as extreme (Box 1).

Even pet ants are emerging as a potential invasion risk. Ants are apparently surging in popularity – in 2002 there were only a couple of websites globally selling queen ants or ant colonies; now there are more than 100 online traders offering more than 500 ant species [3]. Ants are easy to send around the world, because a queen, a few workers and some brood can easily be posted in a test tube as standard mail. The species being sold include at least 57 invasive ants, including the notorious red imported fire ant, tropical fire ant, electric ant, and yellow crazy ant.

Native pets can also be invasive risks. No alien frog species are permitted imports to Australia for pet-keeping but many native frogs are being shifted into new regions as pets. At least 56 traded native species have been shifted out of their native range [10]. There has been no assessment of the risks of trade in native frogs.

In 2022, an African pygmy hedgehog was found wandering in a Sydney backyard. In 2014, a man from near Newcastle was fined a mere $770 for illegally keeping one [25]. Another was found in a home in Illawarra in 2013 [26]. Hedgehogs are apparently among the most desired alien pet species, attracting more inquiries than any other species to a hotline maintained by the Australian Government for people to inquire about the legality of importing or owning particular species [9]. The African pygmy hedgehog has been smuggled into Australia, and can be captively bred and sold on the black market, apparently for up to $4,500 [26].

Based on other inquiries to the hotline, some Australians also desire to keep fennec foxes, African grey parrots, monkeys and pygmy marmosets as well as tarantula spiders and freshwater atyid shrimp [9]. An analysis of the inquiries revealed that the desires for illegal alien pets appear biased towards species that are threatened, have a history of invasions elsewhere and that are frequently imported into the United States, where pet-trade regulations are less stringent [9].

How effective is pathway regulation for preventing the keeping and sale of species likely to become invasive?

This is an emerging invasion pathway whose risks – highlighted in a series of recent research papers [5,6,9,10,12,15] – have not yet been comprehensively assessed and addressed by Australia's governments. The extent of smuggling, trade and keeping of prohibited species in Australia is poorly understood.

The rules for pet keeping and the species permitted vary among the states and territories. Most jurisdictions maintain a list of prohibited species; some specify permitted species. Some require licences for the keeping of particular species. There are also major disparities between species present and not prohibited in Australia but not permitted as imports. Very few of the birds present in Australia are permitted for import as pets (18 of 262 species). But most are permitted for sale and keeping in the states and territories. Only 9 are prohibited in New South Wales.

Biosecurity authorities have thus far not comprehensively addressed the rapidly rising risks of rising internet trade as the pet trade has undergone a rapid transition from 'traditional brick-and-mortar marketplaces' to online e-commerce platforms [12]. The ease-of-access, anonymity and large consumer base afforded by e-commerce has increased both the scale and diversity of pet trade. There is a lack of consistent surveillance of alien pets held, legally or otherwise, within Australia [9].

Pet-keeping is a difficult regulatory challenge because many species currently permitted for trading and keeping in Australia should be prohibited on the basis of invasive risks. But this is mostly not feasible for species that are traded and kept in large numbers; enforcement would be impracticable and likely result in perverse outcomes, with the release of large numbers.

There is apparently no systematic monitoring of trade in prohibited species by the Australian or state and territory governments [12]. Prosecutions are rare. Under the EPBC Act, the maximum penalty for illegal possession is imprisonment for 5 years and/or a fine of up to $210,000. This is a substantial potential penalty but actual sentences for wildlife crimes are often very low – unreflective of the potential for environmental harm or the financial gains that could have been made (in the case of prohibited species). Imprisonment is 'extremely rare' [27]. In one recent case, an Australian man who posted himself 68 snakehead fish, 23 Chinese soft-shelled turtles, 20 sugar gliders, 15 veiled chameleons, 15 alligator snapping turtles and 11 neotropical stingrays from Thailand (91 animals died in transit) and was about to post 34 live lizards and turtles to Sweden was sentenced only to a good behaviour bond. Fortunately, this was appealed and replaced by a 4-year jail term [28].

One issue undermining enforcement is the discrepancy between the EPBC Act's permitted list, specifying what species can be imported into Australia, and the state/territory laws, prohibiting a small subset of species present in australia and by default permitting all others, including those that have been smuggled into the country or their progeny. While the onus of proof is on the possessor to prove that individuals in captivity were legally acquired, the lack of harmonisation and consistency between laws makes enforcement more difficult [9].

The discrepancies between state and territory laws are likely to also undermine compliance and enforcement.It would be easy for even well-intended pet sellers to make mistakes about which species are permitted in which states or territories. One notorious disparity between different jurisdictions is the status of ferrets – rated an extreme threat in the Australian List of Threat Categories of Non-indigenous Vertebrates [19]:

- Australia: permitted for import only to high-security facilities for research
- Queensland and the Northern Territory: prohibited
- Victoria and the Australian Capital Territory: permitted for keeping under licence
- New South Wales, Western Australia, Tasmania and South Australia: permitted without restrictions.

None of the states permitting ferret keeping have publicly justified this on the basis of risk. While ferret advocates have argued that ferrets are not an invasive risk because they have been in Australia for 140 years without forming feral populations this may be due to good fortune rather than biology (Box 1). There is no information about the number in each state and territory currently keeping ferrets, without which it is difficult to consider feasible risk-reduction measures. In 2005 it was estimated that up to 150,000 ferrets were kept as pets in Australia [29].

A sustained enforcement effort by the Victorian Government from 1999 to 2012 has been applauded as exemplary, resulting in the surrender or seizure of reptiles of 33 species [6]. An essential element of the program was an ongoing amnesty for pet-keepers who voluntarily surrendered illegally kept animals.

To strengthen environmental biosecurity

One of the most difficult challenges for Australia's biosecurity agencies is to mitigate the risks of private keeping and trading of high-risk pets, some legal and others smuggled or the progeny of smuggled animals. Online trading has exacerbated the risks. To more effectively identify, assess and mitigate the risks, we recommend the following:

- Research and monitoring: To better predict and manage emerging biosecurity threats, Australian biosecurity agencies need a more comprehensive understanding of the pet trade, including the species currently in Australia and their risks, and trading trends. Online trade should be subject to consistent surveillance via web-scraping applications and investigative work (e.g. joining members-only online forums). One vital area of research are the risks of disease spillover from captive animals to native species.

- Data collection and analysis: Australia needs a standardised national reporting system to record all incidences of illegal wildlife detections and incursions. Such information is essential for determining patterns and identifying emerging risks.

- Risk assessment, priority risk list and strategy: The risks of this pathway and the risks of particular species should be assessed nationally. Australia needs a pathway mitigation strategy. Just as there is a national environmental priority list of species that Australia wants to prevent entering the country (the EEPL [23]), so we should have a priority list of species already present, but not naturalised or sparingly naturalised, to spur risk-reduction measures. The priorities should include all types of taxa, including pathogens carried by captive species.

- Prevention as the priority: Consistent with other taxa, and recognising there are likely to be many species in Australia not known by biosecurity authorities to be present (as the Victorian Government found when they implemented an amnesty [6]), a permitted list approach should be applied for all vertebrate taxa – not permitted unless on a permitted list with new species added to the list only if they pass a risk assessment.

- Risk assessment, reduction and national harmonisation: The regulation of particular species should be proportional to their risk. Where feasible, high-risk species should be prohibited. This could be facilitated by grandfathering (permitting the keeping of animals until the end of their life). But where this is not feasible – where there are too many of particular taxa already in private keeping – we recommend a permit system, with categories and restrictions based on the assessed risk and feasibility [15]. Permits should specify reporting requirements and the minimum standards required to minimise the risk of escape and optimise animal welfare. Such an approach should be adopted nation-wide with consistent classifications and measures. Enforcement will be essential.

- Strong enforcement and community education: We commend the approach taken by Victoria from 1999 to 2012 and recommend it be implemented nation-wide: an ongoing amnesty for anyone who voluntarily forfeits prohibited species coupled with ongoing investigation of illegal keeping and strong enforcement. Penalties should be commensurate with the biosecurity risks and the potential environmental consequences of a new invasive species. Enforcement needs to be coupled with community education about the risks of illegal pet-keeping.

Box 1. Ferret risks

Ferrets were first brought to Australia in the 1880s for rabbit control. They are likely to have established feral populations since then, as indicated by several sightings in the wild, but there is no firm evidence of a persistent population [30,31].

Ferret advocates have argued that the presence of ferrets in Australia for 140 years without naturalising is evidence they are not an invasive risk. Periods of decades and even centuries between introduction and naturalisation are not unusual [REF]. Even the rabbit took more than 70 years to become established in Australia [32]. Higher propagule pressure from more escapes, a run of favourable seasons, the decline of a predator (such as the Tasmanian devil), the introduction of new variants – any of these could make the critical difference [30,31].

Australia's governments should not be supporting a dangerous ecological experiment by allowing the unrestricted trade and keeping of an alien predator. The several alien predators already naturalised in Australia – cats, foxes, rats, trout – have already caused the majority of animal extinctions.

The ferret is a 'small, intelligent, fast-moving and wide-ranging carnivore' [31]. Its impacts in New Zealand, which now hosts the world's largest ferret population, have been 'particularly severe' on native birds, including penguins, wekas and kiwis. Several species cannot coexist with ferrets.

Most of Australia south of the tropic of Capricorn is likely to provide suitable habitat for ferrets, particularly southern coastal regions [29]. If they became established, they are likely to prey on the likes of possums, bandicoots, birds, bird eggs, lizards, frogs, fish and invertebrates. Ground-dwelling and ground-nesting birds are likely to be at particular risk [29].

References

1. McFadden MS, Topham P, Harlow PS. A ticking time bomb: is the illegal pet trade a pathway for the establishment of corn snake (Elaphe guttata) populations in Australia? Australian Zoologist. 2017;38: 499–504.
2. NSW Department of Primary Industries. State of Biosecurity Report 2018-2021. NSW Government; 2022.
3. Gippet JM, Bertelsmeier C. Invasiveness is linked to greater commercial success in the global pet trade. Proceedings of the National Academy of Sciences. 2021;118: e2016337118.
4. Saul W, Roy HE, Booy O, Carnevali L, Chen H, Genovesi P, et al. Assessing patterns in introduction

pathways of alien species by linking major invasion data bases. Journal of applied ecology. 2017;54: 657–669.
5. Toomes A, García-Díaz P, Wittmann TA, Virtue J, Cassey P. New aliens in Australia: 18 years of vertebrate interceptions. Wildlife Research. 2020;47: 55–67.
6. García-Díaz P, Ross JV, Woolnough AP, Cassey P. The illegal wildlife trade is a likely source of alien species. Conservation Letters. 2017;10: 690–698.
7. Tingley R, Weeks AR, Smart AS, van Rooyen AR, Woolnough AP, McCarthy MA. European newts establish in Australia, marking the arrival of a new amphibian order. Biological Invasions. 2015;17: 31–37.
8. Christy M. National Incursion Response Plan: Terrestrial Snakes. Endorsed by the Invasive Animals and Plant Committee. Invasive Animals Cooperative Research Centre; 2016.
9. Toomes A, Stringham OC, Mitchell L, Ross JV, Cassey P. Australia's wish list of exotic pets: Biosecurity and conservation implications of desired alien and illegal pet species. NeoBiota. 2020;60: 43.
10. García-Díaz P, Cassey P. Patterns of transport and introduction of exotic amphibians in Australia. Diversity and distributions. 2014;20: 455–466.
11. Ebner B, Millington M, Holmes B, Wilson D, Sydes T, Bickel T, et al. Scoping the biosecurity risks and appropriate management relating to the freshwater ornamental aquarium trade across northern Australia. Centre for Tropical Water and Aquatic Ecosystem Research, James Cook University; 2020.
12. Toomes A, Moncayo S, Stringham OC, Lassaline C, Wood L, Millington M, et al. A snapshot of online wildlife trade: Australian e-commerce trade of native and non-native pets. Biological Conservation. 2023;282: 110040.
13. Henderson W, Bomford M, Cassey P. Managing the risk of exotic vertebrate incursions in Australia. Wildlife Research. 2011;38: 501–508.
14. Norval G, Halliday B, Sih A, Sharrad RD, Gardner MG. Occurrence of the introduced snake mite, Ophionyssus natricis (Gervais, 1844), in the wild in Australia. Acarologia. 2020;60: 559–565.
15. Toomes A, García-Díaz P, Stringham OC, Ross JV, Mitchell L, Cassey P. Drivers of the Australian native pet trade: The role of species traits, socioeconomic attributes and regulatory systems. Journal of Applied Ecology. 2022;59: 1268–1278.
16. Chang L-W, Jacobson ER. Inclusion body disease, a worldwide infectious disease of boid snakes: a review. Journal of Exotic Pet Medicine. 2010;19: 216–225.
17. Schilliger L, Paillusseau C, François C, Bonwitt J. Major Emerging Fungal Diseases of Reptiles and Amphibians. Pathogens. 2023;12: 429.
18. Peterson NR, Rose K, Shaw S, Hyndman TH, Sigler L, Kurtböke Dİ, et al. Cross-continental emergence of Nannizziopsis barbatae disease may threaten wild Australian lizards. Scientific reports. 2020;10: 1–12.
19. Environment and Invasives Committee. Australian List of Threat Categories of Non-indigenous Vertebrates. Australian Government; 2023.
20. Vall-llosera M, Woolnough AP, Anderson D, Cassey P. Improved surveillance for early detection of a potential invasive species: the alien Rose-ringed parakeet Psittacula krameri in Australia. Biological Invasions. 2017;19: 1273–1284.
21. Rubbenstroth D. Avian bornavirus research—A comprehensive review. Viruses. 2022;14: 1513.
22. Sutherland M, Phalen DN, Herzog S, Maier-Sam K, Lierz M. Detection of Immunoreactivity to Psittaciform Bornavirus in the Serum of a Wild Cacatuid in Victoria, Australia. Journal of Wildlife Diseases. 2021;57: 471–473.
23. ABARES. National Priority List of Exotic Environmental Pests, Weeds and Diseases (EEPL). Australian Government Department of Agriculture; 2020.
24. Kasimov V, Wille M, Sarker S, Dong Y, Shao R, Hall C, et al. Unexpected Pathogen Diversity Detected

in Australian Avifauna Highlights Potential Biosecurity Challenges. Viruses. 2023;15: 143.
25. Kelly M. African pygmy hedgehog earns Raymond Terrace man $770 fine. Newcastle Herald. 1 Sep 2014. Available: https://www.newcastleherald.com.au/story/2527707/african-pygmy-hedgehog-earns-raymond-terrace-man-770-fine/. Accessed 1 Nov 2023.
26. Holland M. Spike in finds fuels fear of hedgehog black market. news.com.au. 29 Jan 2013. Available: https://www.news.com.au/nsw-act/spike-in-finds-fuels-fear-of-hedgehog-black-market/news-story/90126b3e727b786dcadee274f8863f2f
27. Ciavaglia S, Dridan H, Paul Kirkbride K, Linacre A. Current issues with the investigation of wildlife crime in Australia: problems and opportunities for improvement. Journal of International Wildlife Law & Policy. 2015;18: 244–263.
28. Office of the Director of Public Prosecutions. Case study: Wildlife trafficker has sentence increased on appeal. In: Transparency Portal [Internet]. Transparency Portal; 15 Oct 2020 [cited 14 May 2023]. Available: https://www.transparency.gov.au/annual-reports/office-director-public-prosecutions/reporting-year/2019-20-16
29. Markula A, Hannan-Jones M, Csurhes S. Invasive animal risk assessment: Ferret/polecat Mustela furo and M. putorius. Queensland Government; 2016.
30. Tasmanian Department of Environment. Pest Risk Assessment: Ferret/Polecat (Mustela furo and M. putorius). Tasmanian Government; 2011.
31. Department of Agriculture, Water and the Environment. Department Risk Analysis. Application to add Mustela putorius furo (domestic ferret) to the Environment Protection and Biodiversity Conservation Act 1999 List of Specimens taken to be Suitable for Live Import. Australian Government; 2020.
32. Cooke BD. Rabbits: manageable environmental pests or participants in new Australian ecosystems? Wildlife Research. 2012;39: 279–289.

Attachment 8. Strengthening regulation of the aquarium fish pathway

Invasive Species Council, November 2023

Extracted and modified from the Invasive Species Council's draft *State of Environmental Biosecurity Report*.

What are the environmental risks of this pathway?

The aquarium trade is an extremely high-risk pathway – for introducing invasive fish and their pathogens, as well as other aquatic organisms such as plants and snails. It has been responsible for the establishment of more invasive vertebrate animals than any other pathway into Australia (at least 27 naturalised species, with more likely not yet detected), as well as severe pathogens that infect native fish [1]. Despite this, the ornamental fish pathway has received limited biosecurity attention – probably because it is one of the most complex, difficult and contentious pathways to regulate.

Australia imports an enormous number of ornamental fish: 10–15 million a year, although this is less than 1% of the estimated 2 billion or more traded globally [2,3]. The diversity of species permitted entry to Australia is also high, comprising several thousand species – 233 species and 27 entire genera of freshwater fish (about 1,500 species in all [4]). Each imported fish brings with it a community of live organisms – the ornamental fish trade 'is an efficient system for the translocation of aquatic pathogens' [5].

Since 2000, at least 7 naturalised aquarium fish species have been detected in Australian waterways for the first time – jaguar cichlid, Jack Dempsey, Siamese fighting fish, blue-eye cichlid, white cloud mountain minnow, jewel cichlid, blue acara. Several other aquarium species have also been detected for the first time in Australian waterways since 2000 but were either eradicated or probably did not survive – redhead cichlid, peacock bass, crucian carp and black sharkminnow. As an indication of the prevalence of fish releases, in the Northern Territory, from 2000 to 2018, there were 61 reports of aquarium fish sighted in natural waterbodies and artificial ponds, an average of 7–8 a year, resulting in responses by biosecurity officers ranging from site inspections to eradication [6]. About two-thirds of the 11 species detected in waterways are not on Australia's permitted imports list and may have originally been smuggled into Australia.

There has been a recent escalation of naturalisations in New South Wales, with at least 6 new naturalised fish species detected since 2000 – Jack Dempsey (failed eradication attempt), southern platyfish (failed eradication attempt), pearl cichlid (eradication not feasible), white cloud mountain minnow (failed eradication attempt), Mozambique tilapia (eradication not feasible) and speckled livebearer (eradicated). Several of these new fish species represent significant environmental threats, particularly tilapia and other cichlids.

New fish pathogens have also been detected in Australia since 2000, including the bacterium *Edwardsiella ictaluri* in wild native catfish in Queensland, presumed to have spread from aquarium fish and able to cause severe and fatal diseases in a variety of fish species [7].

Australia's invasive fish and fish disease threats are set to steadily worsen – inevitable due to the large number of alien fish species kept in Australia, many assessed as high risk [8–11]; the highly deficient regulation of fish-keeping; and the propensity of people to dump unwanted fish into waterways. The aquarium industry globally 'remains largely unregulated or regulated but unenforced', including in Australia [12]. The tropical origins of most aquarium fish suggest the risk will be greatest for northern Australia [13].

It was said, in 2006 by the Bureau of Rural Sciences, that almost any alien aquarium fish species sought by a hobbyist is 'effectively available in Australia' [14]. That is probably not true given that worldwide more than 5,300 freshwater species are reportedly traded [12,15]. But the number of alien aquarium fish species in Australia is highly uncertain – an indication in itself that management of this pathway is deficient [16]. In the late 1980s, there were probably fewer than 500 species, with 164 species and 25 genera permitted as imports and another 190 species known to be present [17]. In the late 1990s, the estimate was 1,500 or more species being traded in Australia [18]. In 2010, that number was estimated at 2,000 species [10]. A recent 14-week analysis (by website scraping) of online trade within Australia suggests a lower number, with advertisements for 509 species, as well as others identified only by genus or family [19,19]. Other species may circulate within hobbyist groups and not be publicly advertised, particularly if they are prohibited species.

How are pathway risks assessed and regulated?

While the importation of fish into Australia is prohibited except for species on a permitted list (assessed under the EPBC Act), the opposite approach is taken by most states and territories – any species is permitted unless expressly prohibited. Only the Northern Territory takes a permitted list approach, by permitting the introduction only of species that are nationally permitted imports (specified in the NT Fisheries Regulations 1992).

Based on their national import status and state/territory status under biosecurity laws, there are 3 categories of introduced freshwater fish in Australia:

- Permitted for import and permitted for sale and keeping in Australia: About 1,500 species are on the permitted import list, 99% of which have not been subject to modern risk assessment (only 8 species have been assessed and added to the permitted list since 2000). The number of permitted fish actually present in Australia is an estimated 214 species [20].
- Not permitted for import and prohibited for sale and keeping in Australia: 274 species, 31 genera and 5 families or subfamilies species are prohibited by at least one state/territory jurisdiction and 85 species and 13 genera are prohibited by all jurisdictions. The recent monitoring of online trade documented 7 prohibited species being traded [20].

- Not permitted for import but not prohibited for sale or keeping by most states and territories: These are known as greylisted species. Some were brought to Australia prior to import restrictions (first introduced in 1963 [21]), but a significant proportion were probably smuggled in. The keeping and selling of smuggled fish or their progeny is illegal, but it is difficult to enforce this because it is difficult to prove their origins and many are widespread in the industry. Greylists compiled since 2006 have listed 1,166 species in total [8–11], but many are considered of no interest to the industry [16]. A recent 3-month study of species traded online suggests that about 300 species are the focus of current interest [20].

How effective is pathway regulation for limiting the trade and keeping of high-risk fish?

Australia's governments have recognised that the current permissive approach to regulating freshwater fish is deficient – 'inconsistent and poorly enforced' controls and fish shifted across borders 'with impunity' [14], 'largely unregulated at the retail level' [22] – and have long sought to rectify it.

Almost 20 years ago, after various efforts to better regulate the trade foundered in the face of strong opposition by the aquarium industry, the federal, state and territory governments set up a national working group with industry and hobby representatives to jointly negotiate and implement a better approach. A 2006 strategic plan included actions to review grey list species, develop a national list of high-risk noxious species to be adopted by each state and territory, develop a list of low risk permitted species, establish a regulatory framework and licensing to manage large fish-breeders and ornamental fish importers and prepare a national communications plan [14]. The work was expected to take 2–3 years [18].

But progress was slow and limited. A preliminary national noxious list of species was compiled, but on the basis of no clearly specified criteria, and state and territory governments added many of these to their prohibited lists, although inconsistently so. A grey list of 806 species and their potential for establishment and impact were reviewed in a rapid risk screening process [8–10]. About two-thirds (564 species, 70% of species assessed) were scored as high risk. The national working group agreed that high-risk species of no interest to the industry or hobby representatives should be added to the national noxious list (and listed by each jurisdiction) and that high-risk species of value for the aquarium industry or hobbyists should be reviewed in more detail to determine which to prohibit. But the process of further review stalled.

While the state and territory lists of prohibited species are now considerably longer than they were 20 years ago, there are no state or territory restrictions, except in the Northern Territory (and perhaps in Western Australia), for the majority of grey list species assessed as high risk. The species that were prohibited mostly did not include the high-risk species valued by the aquarium industry or hobbyists – the very species at greatest risk of being released into the wild. Only 5 of the 96 cichlid species scored as high risk were prohibited and only in 1–2 jurisdictions. Once again, in the face of industry opposition, state and territory governments resiled from managing this high-risk pathway. The trade of greylisted species continues to be 'prolific' [11].

It appears that a new attempt at pathway regulation is now underway, with the recent compilation of a new greylist with 447 species nominated by industry representatives as currently traded and of ongoing interest to the industry and a new risk screening process [11]. There is limited overlap with the previous grey list, with only 87 species in common (20% of the most recent grey list). And in contrast to the previous risk assessments, only 12 species (3% of assessed species vs 70% in the previous assessments) were scored as high risk, and 35 (8%) as medium risk.

But the researchers concluded that the risk assessment method was deficient, resulting in risks being underestimated [11]. The final scores for a 'considerable proportion of low-risk species' was 'not congruent with posteriori knowledge' (the known invasion risks).

The main reason for the disparity in results was the failure of the recent methodology to account for uncertainty. About 90% of the assessments were rated as data deficient (>30% of questions in at least one of the 3 risk assessment categories could not be answered), but the precautionary principle was not applied [11]. Further compounding the problem of data deficiency, a lack of information about the consequences of invasion had to be scored in many questions as 'no impact' – even though 'no evidence does not equate to no impact' [11]. The potential for hybridisation between alien fish species was ignored, even though hybrid vigour can increase the invasive risks. Other problems noted by the assessors were that the climate matching method was unable to account for the broad temperature range across Australia, recording a low climate match for some species despite large suitable areas, particularly in northern Australia, and it ignored the climate of invaded ranges and climate change [11]. The assessors recommended several improvements to the risk assessment method to make it more suitable for Australia-wide assessments and better account for invasive risks.

The noted deficiencies of the risk assessment method are serious and render most of the low risk scores unreliable – particularly for the 90% of species with 'unacceptable levels of data deficiencies'. It is clear that a new risk screening method should be applied. Ideally, this would be the same method recently introduced for proposed import assessments under the EPBC Act (the FISK tool). Limiting prohibitions to the few species assessed as high or medium risk will do little to reduce pathway risks.

Biosecurity authorities are understandably concerned that prohibiting fish species with commercial value or desired by some hobbyists could lead to perverse outcomes – the deliberate release of these fish into waterways. (Cichlid groups have reportedly threatened this [23].) But the short-term risks arising from prohibitions have to be balanced against the longer-term risks arising from a lack of restrictions. The short-term risks also have to be balanced against the ongoing risks of smuggling, which is incentivised by the difficulty of proving that species not on the permitted import list have been smuggled. The development of an effective policy approach will need deep consideration, based on analysis of comparative risks, and informed by advice from social scientists. The process should be transparent and open, recognising that many Australians, in addition to aquarium fish sellers and hobbyists, have a strong stake in the outcomes.

How effective is pathway regulation for limiting the risks of illegal fish-keeping?

The enforcement of illegal aquarium fish trading and keeping is extremely poor – as evidenced by the open advertising of species illegal to import into Australia, some of which would have been smuggled into the country and some of which are prohibited by state and territory jurisdictions [19,20]. The scale of advertising of such species indicates there could also be a substantial 'black market' trade, including in species prohibited by the states and territories, via inaccessible social networking sites. Many social networking sites for aquarium fish are invitation-only, so are difficult to monitor [13]. The inconsistency of regulations – between the federal and state/territory jurisdictions and between the states and territories – adds considerably to the difficulties of enforcement and makes it easy for even well-meaning aquarium owners to make mistakes about what is legal.

We could find no instances of prosecutions for illegal keeping of prohibited aquarium fish, although there has been at least one prosecution for the selling of smuggled shrimp species popular in aquariums [13]. Enforcement in Tasmania is facilitated by a regulation permitting only registered dealers to import and sell freshwater fish (Tasmanian Inland Fisheries Act 1995, s62).

How effective is pathway regulation for limiting the risks of people releasing fish into the environment?

The high frequency of reported detections of aquarium fish in the wild – 7 to 8 a year in the Northern Territory alone [6] – indicate a failure of community education and options for owners to dispose of fish in non-lethal or humane ways. Fish owners are likely to be motivated to release fish into their local creek if they grow too big or aggressive or become illegal to keep, or if the owner has to move or fancies them as a fishing target. Recent Australian research suggests the highest risks are for species popular in the aquarium trade, cheap to buy, available online, aggressive, long-lived and large-bodied [20]. This can help guide strategies to reduce the risks of fish dumping. One limitation in Australia that should be addressed is the limited services for humanely disposing of or rehoming fish (we could find only 3 advertised services).

Most unwanted fish are released in waterways around population centres [24], and certain waterways are well known for regular detections of aquarium fish (for example, the Ross River in Townsville). In all cases we are aware of, state and territory biosecurity or fisheries officers have been quick to respond to reports of new fish species and have sought to remove them if that is feasible. But in most cases, it is either too late (the fish are too widespread) or there is no feasible method for removal. Most eradications have been achieved by the use of the non-specific poison rotenone or by electrofishing. To date, all eradications have been funded by the relevant state or territory government. The development of a national action plan for emergency fish responses would facilitate nationally cost-shared programs where eradication is feasible.

To strengthen environmental biosecurity

Mitigating the extremely high risks of the aquarium fish pathway should be a top national priority for reform. Essential for managing this pathway is a better understanding of the nature of the aquarium industry and the species being kept and traded in Australia:

- Undertake a national audit of aquarium fish species in Australia [13] and consistently monitor retail sales and hobbyist trading to maintain an accurate account of species present and their relative popularity [20].
- Undertake social science research to develop an understanding of the different segments of the aquarium fish-keeping community and their motivations for risk behaviours such as smuggling, illegal keeping and releasing fish into the environment.

To reduce the risks of this pathway requires reducing the number of high-risk fish kept and traded in Australia – as governments have intended to achieve since at least 2006 [14]. This will inevitably be a politically fraught process due to opposition by the aquarium industry to prohibitions on favoured fish species and thus requires a well considered strategy:

- Establish a national freshwater invasive species committee: A national committee equivalent to the Marine Pest Sectoral Committee is warranted given the extreme biosecurity risks and high environmental values at stake [13].
- Develop a national aquarium fish strategy with clear goals, targets and processes to significantly reduce the risks of aquarium fish-keeping in Australia: The strategy should be developed with experts and stakeholders and be subject to public consultation. It should set out a transparent process for determining the appropriate biosecurity status of fish species consistent with their invasive risks. For 'conflict' species – those favoured by sellers or hobbyists and for which prohibition may not be feasible – the proposed approaches should be based on a comparative risk analysis of options such as licensing (fish and sellers), grandfathering, buybacks and microchipping. Recognising that there are no easy ways to eliminate risks, the focus should be on long-term risk reduction taking into account the shorter-term risks of retributive fish release.
- Undertake risk assessments using best practice methodology: All fish species, whether on the permitted import list or not, should be assessed and rated for their invasive risks, except for the species assessed since 2000, with a priority focus on species known to be traded and kept within the previous 5 years. The risk screening and assessment methods should meet best practice standards (as specified in Box X, section 6.2.X). Because little is known about the invasion risks of most fish species, due to the lack of an introduction history, it is essential to apply the precautionary principle (as is required under the EPBC Act).
- Apply a precautionary permitted-list approach to aquarium fish regulation and develop one national list: Because there are many hundreds of aquarium fish permitted entry to or present in Australia, the most effective regulatory approach is to specify which fish are permitted (assessed as low risk or with selling and keeping requirements to reduce the risk) and ban all others. The optimal system would be to have one national permitted list for selling and keeping in Australia. This could be achieved under national environmental regulations (currently s301A of the EPBC Act) mirrored, if necessary, by state/territory regulations (such as occurs with chemicals approved by the Australian Pesticides and Veterinary Medicines

Authority). A nationally harmonised scheme will facilitate enforcement and make it much easier for fish-sellers and -keepers to know and comply with the law.

- Provide support and incentives with an adjustment package for the aquarium fish industry to develop appealing low-risk replacements for prohibited fish: The aquarium industry is based mainly on alien fish species, with about 65 native species also in the retail trade [20]. Keeping in mind that native fish can become invasive if transported out of their range, an adjustment package could help the aquarium industry develop a more sustainable range of fish options that are locally bred. This would also greatly reduce disease risks.

Enforcement, education and safe disposal options are essential complements to effective regulation:

- Require anyone who trades aquarium fish to become a registered biosecurity entity under the Biosecurity Act and record and report fish sales: This was previously recommended by the Natural Resources Commission, based on a Tasmanian precedent, where only registered dealers are permitted to import or sell freshwater fish [25].
- Strengthen compliance with a multi-pronged strategy of online monitoring and rigorous enforcement, combined with amnesties and surrender options: Monitor compliance online using web-scraping tools [19].
- Conduct regular or continuous amnesties for prohibited fish species: A 2004 2-month national amnesty for exotic reptiles significantly increased the seizure rate of illegally kept reptiles [26]
- Reduce the rate of fish releases with educational programs and services for humane disposal and rehoming: Based on social science research, develop education and marketing programs [13]. Develop a national rehoming and humane disposal service funded by governments and run by the aquarium industry. Target high-risk categories such as transient mining and defence workers in northern Australia [13].

By the time aquarium fish are detected in a waterway it is often too late to remove them. Surveillance in high-risk waters, including by citizen scientists, is needed to optimise the chances of early detection:

- Identify the highest-risk waterways for fish release and undertake regular surveillance: A priority list of waterways for surveillance could be developed based on past detection data (most are near population centres). Surveillance can be facilitated by eDNA technology [REF].
- Encourage surveillance by citizen scientists, particularly recreational fishers.
- Develop a national response plan to facilitate rapid eradication of new fish incursions, under nationally cost-shared arrangements if that will assist with more difficult eradications.

References

1. Kaminskas S. Alien pathogens and parasites impacting native freshwater fish of southern Australia: a scientific and historical review. Australian Zoologist. 2021;41: 696–730.
2. ITC. Trade Map - Trade statistics for international business development. In: International Trade

Centre [Internet]. 2023. Available: https://www.trademap.org/
3. Monticini P. The Ornamental Fish Trade. Production and Commerce of Ornamental Fish. Technical-Managerial and Legislative Aspects. Food and Agriculture Organization of the United NationsGlobefish Research Programme; 2010.
4. Webb AC. The ecology of invasions of non-indigenous freshwater fishes in northern Queensland. PhD thesis, James Cook University. 2003.
5. Becker JA, Tweedie A, Rimmer A, Landos M, Lintermans M, Whittington RJ. Incursions of Cyprinid herpesvirus 2 in goldfish populations in Australia despite quarantine practices. Aquaculture. 2014;432: 53–59.
6. Hammer MP, Skarlatos Simoes MN, Needham EW, Wilson DN, Barton MA, Lonza D. Establishment of Siamese Fighting Fish on the Adelaide River floodplain: the first serious invasive fish in the Northern Territory, Australia. Biological Invasions. 2019;21: 2269–2279.
7. Kelly E, Martin P, Gibson-Kueh S, Morgan D, Ebner B, Donaldson J, et al. First detection of Edwardsiella ictaluri (Proteobacteria: Enterobacteriaceae) in wild Australian catfish. Journal of fish diseases. 2018;41: 199–208.
8. Fredberg J, McNeil DG. Review of non-native ornamental fish species grey listed in Australia. SARDI Aquatic Sciences; 2010.
9. Beyer K, Fredberg J. Review of Grey Listed Non-native Ornamental Fish Species: Report to the Ornamental Fish Management Implementation Group (OFMIG). SARDI Aquatic Sciences; 2010.
10. Moore A, Marton N, McNee A. A Strategic Approach to the Management of Ornamental Fish in Australia: Communication Strategy and Grey List Review, a Report to OFMIG. Bureau of Rural Sciences; 2010.
11. Millington M, Sierp M, Gaylard S. Assessing the Invasiveness Risk of Non-Indigenous Fish in the Australian Ornamental Trade: Implementing the Risk Assessment Tool. Queensland Department of Agriculture and Fisheries; 2022.
12. Chan FT, Beatty SJ, Gilles Jr AS, Hill JE, Kozic S, Luo D, et al. Leaving the fish bowl: the ornamental trade as a global vector for freshwater fish invasions. Aquatic Ecosystem Health & Management. 2019;22: 417–439.
13. Ebner B, Millington M, Holmes B, Wilson D, Sydes T, Bickel T, et al. Scoping the biosecurity risks and appropriate management relating to the freshwater ornamental aquarium trade across northern Australia. Centre for Tropical Water and Aquatic Ecosystem Research, James Cook University; 2020.
14. Bureau of Rural Sciences. A strategic approach to the management of ornamental fish in Australia. Natural Resource Management Ministerial Council; 2006.
15. Evers H, Pinnegar JK, Taylor MI. Where are they all from?–sources and sustainability in the ornamental freshwater fish trade. Journal of Fish Biology. 2019;94: 909–916.
16. Millington MD, Holmes BJ, Balcombe SR. Systematic review of the Australian freshwater ornamental fish industry: the need for direct industry monitoring. Management of Biological Invasions. 2022;13: 406.
17. McKay R, Halliwell N. The ornamental fish farming industry in Australia. Aquarium Life Australia. 1987.
18. O'Sullivan D, Morison J, Clark E. The Australian ornamental fish industry in 2006/07. Fisheries Research and Development Corporation; 2008.
19. Toomes A, Moncayo S, Stringham OC, Lassaline C, Wood L, Millington M, et al. A snapshot of online wildlife trade: Australian e-commerce trade of native and non-native pets. Biological Conservation. 2023;282: 110040.
20. Millington M. The Underbelly of the Ornamental Industry – Unregulated trade and invasive species raise concern for unique native freshwater ichthyofauna. PhD thesis, Griffith University. 2023.
21. Kailola P. Translocated and exotic fishes-- towards a cooperative role for industry and government.

Proceedings of the Australian Society for Fish Biology Workshop, Magnetic Island, Townsville, Queensland, 24-25 August 1989. . Bureau of Rural Resources; 1990.

22. Department of Agriculture, Water and the Environment. National policy guidelines for the translocation of live aquatic animals. Australian Government; 2020.
23. Wilson D. Submission to the EPBC Act review. Matters relating to ornamental aquarium and pond industry. 2020. Available: https://epbcactreview.environment.gov.au/sites/default/files/2020-09/ANON-K57V-XZRS-4.pdf
24. García-Díaz P, Kerezsy A, Unmack PJ, Lintermans M, Beatty SJ, Butler GL, et al. Transport pathways shape the biogeography of alien freshwater fishes in Australia. Diversity and Distributions. 2018;24: 1405–1415.
25. Natural Resources Commission. Shared problems, shared solutions. State-wide review of pest animal management. NSW Government; 2016.
26. Henderson W, Bomford M, Cassey P. Managing the risk of exotic vertebrate incursions in Australia. Wildlife Research. 2011;38: 501–508.

Attachment 9. Eradications – mainland, islands, havens

Invasive Species Council, November 2023

Based on data extracted from the Invasive Species Council's draft State of Environmental Biosecurity Report. See Attachment 1 for data.

1. Mainland eradications

New South Wales has mostly not been ambitious to eradicate emerging naturalised invaders. We have been able to document only 26 eradications at the state level attempted or ongoing since 2000 (Table 1). There may be several more that have not been documented. To share information about what can be achieved and to demonstrate a NSW Government commitment to eradications, it would be useful to record the details of all attempts and outcomes on a public database.

We particularly commend the NSW Government on the eradications of ants – 2 achieved (yellow crazy ants and red imported fire ants) and 1 ongoing (yellow crazy ants). The NSW Government also appears to have systematically considered opportunities to eradicate recently naturalised aquarium fish, although most have failed due to the difficulties of eradication in freshwater habitats. It is also encouraging to see a stronger focus on weed eradications after a long history of neglected eradication opportunities.

However, there does not appear to be a systematic approach to identifying, assessing and prioritising opportunities to eradicate emerging invaders across all taxa. One obvious neglected opportunity is to eradicate red slider turtles, which have been recognised as a priority national risk [1] and mostly eradicated by Queensland. Given the high rate of new plant naturalisations (Attachment 6), there are likely to be many more species that could be eradicated with limited investment.

We recommend that the NSW Government adopt a systematic approach to identify potential candidates for eradication and eradication programs for the highest priorities based on highest biodiversity returns.

Table 1. Eradications of environmental relevance at the state level attempted or ongoing since 2000

	Eradications achieved (or probably achieved)	Eradications not achieved	Eradications ongoing
Fishes	1	3	0
Plants	3	1	12
Invertebrates	2	1	1
Fungi	0	1	0
Total	6	6	13

Data: See Attachment 1.

2. Island eradications of vertebrate animals

We commend the NSW Government for supporting the recent eradications on Lord Howe Island. The elimination of black rats and mice is an outstanding achievement, expected to reduce predatory pressures on at least 22 animal species, 51 plant species and 12 vegetation communities, prevent 7 extinctions over the next 20 years and enable the reintroduction of 4 species [2,3]. This comes on top of several other eradications that have done much to protect the high conservation values of Lord Howe (Box 1).

However, New South Wales has undertaken very few other island eradications – fewer than 30 on 12 islands in total and only 12 on 7 since 2000, including 4 on Lord Howe Island. The largest eradications by far have been on Lord Howe Island (by an order of magnitude). The number of island eradications is fewer than most other jurisdictions have achieved. We recommend that the NSW Government continue to support the exemplary weed eradications program on Lord Howe Island (Box 1).

Table 2. NSW island eradications of vertebrate animals attempted or ongoing since 2000

	Eradications achieved (or probably achieved)	Eradications not achieved	Eradications ongoing
Black rat	5	0	0
Rabbit	2	0	0
Goat	1	0	0
House mouse	3	0	0
Bird	1	0	0
Total	12	0	0

Box 1. Eradications on Lord Howe Island

Size: 1,500 hectares

Island values: A World Heritage property – ‘remarkable example of isolated oceanic islands’, ‘spectacular topography’, ‘home to numerous endemic species’. Endemic taxa include 4 land birds (previously 13), 113 plants, 6 invertebrates. Extensive nesting seabird colonies.

Eradications (year achieved):

- Cats (1980): Contributed to extinctions (pigeon and parakeet). Eradication methods were trapping and shooting (with dogs).
- Pigs (1981): Eradication method was shooting (with dogs).
- Goats (2001): Eradication methods were aerial shooting and ground shooting with dogs.
- Myrtle rust (2018): Eradication method was removal of infected plants. 320 staff hours for surveillance, treatment and communication.
- African big-headed ants (2020): Eliminated from 50 ha. Eradication method was baiting.
- Black rats and house mice (2023): Rats implicated in the extinction of at least 20 endemic taxa (5 birds, 13 invertebrates, 2 plants) and a major threat to extant wildlife. Eradication methods were aerial baiting and ground baiting.
- Masked owls (?): Introduced for control of black rats, the owl could have detrimental impacts on seabirds and endemic landbirds when rats are eradicated. Eradication method is shooting.
- Weed eradications (in progress): At least 68 species identified for eradication over a 30 year period. Intensive control since 2004 has achieved an 80% reduction in weed density and 90% reduction in the presence of mature weeds.

Costs: $16 million for rat and mouse eradication.

Outcomes: After the eradication of black rates, numbers of the flightless woodhen doubled within 2 years. The Lord Howe currawong, an endemic subspecies, declined after baiting due to poisoning (as predicted), but the population is expected to recover quickly (30–40% of the population was taken into captivity during the baiting). There was a high breeding success after the baiting. More food resources and reduced competition may increase suitable habitat for the currawong. The breeding success of black-winged petrels increased substantially, from as low as 2.5% in 2017 to 67% in 2020 and 50% in 2021. Rat eradication will enable the reintroduction of species such as the Lord Howe phasmid.

3. Mainland predator-free havens

We also commend the NSW Government for its recent focus on creating fenced havens for mammals threatened by invasive predators. Since 2000, the NSW Government has created 4 havens across a total area of more than 27,000 hectares, 3 in partnership with the Australian Wildlife Conservancy and another in partnership with the University of New South Wales (Attachment 1). A fifth smaller haven was created by an NGO. They are expected to protect at least 15 threatened mammal species. We recommend the NSW Government continue to invest in creating fenced havens and conducting research to investigate ecological interventions that may help mammals threatened by foxes and cats survive outside fenced reserves.

References

1. ABARES. National Priority List of Exotic Environmental Pests, Weeds and Diseases (EEPL). Australian Government Department of Agriculture; 2020.

2. Lord Howe Island Board. The Project. In: Lord Howe Island Rodent Eradication Project [Internet]. 2022 [cited 28 Sep 2022]. Available: https://lhirodenteradicationproject.org/the-project/
3. Gillespie Economics. Economic evaluation of the Lord Howe Island Rodent Eradication Project. 2016. Available: chromhttps://www.lhib.nsw.gov.au/sites/lordhowe/files/public/images/documents/lhib/Publications/Reports/Economic%20Evaluation%20of%20LHI%20REP%20-%20231116.pdf