Half of Australia's highly imperilled narrow-range species habitat is outside protected areas

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Acknowledgements

We acknowledge the Traditional Owners of Country throughout Australia. We recognise their continuing connection to land, waters and community and acknowledge that Traditional Owner sovereignty was never ceded. We pay our respects to their cultures and elders past, present, and emerging. AITT was supported by an ARC Future Fellowship FT210100655. B.C.S. was supported by the ARC through a Discovery Early Career Research Award (DE200100121). WWF-Australia financially supported this work.

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Keywords: species conservation; habitat loss; halting extinctions; tenure; conservation decisions; biodiversity conservation

Abstract

Species with small distributions face disproportionate extinction risk, with the impacts of land use change and extreme disturbance events (such as severe wildfire) more likely to have catastrophic consequences. Protecting and managing sites where such species occur is essential for minimising their extinction risk. Yet, across Australia, efforts to protect and manage such species' habitats have hitherto been insufficient. We identified 307 Australian Critically Endangered species that also have narrow ranges (<20,000km^2), and are distributed in fewer than six discrete patches, according to the Australian Government's publicly available threatened species distribution data. We refined species' habitat maps with advice from 18 experts via a modified Delphi approach, and then assessed how much of each species' habitat is found within the national protected area estate, as well as how much of the habitat outside protected areas was considered to have agricultural capability, elevating potential risk of conversion. We identified ~85,000km^2 of habitat (1.6% of Australia) for these 307 species that must receive conservation attention if Australia is going to meet its commitment to halt any new extinctions. Approximately half (~41,366km^2) of this is outside public or private protected areas, Indigenous Protected Areas, or World Heritage Areas, which included the entire distribution of 40 (13%) species. Approximately 23,000km^2 (55%) of the habitat outside of protected areas was found

to have agricultural capability. Most of these unprotected, agriculturally suitable areas are found in eastern Victoria, eastern New South Wales, and northern parts of the Northern Territory. Protecting and managing these high priority areas should be a central focus of state and national conservation policy, including investment in threat abatement, protected areas designation and sustainable development planning.

Introduction

Globally, ~60% of terrestrial surfaces have been directly modified by industrial human activities (Williams et al., 2020), 97% of the ocean has been altered (Jones et al., 2018), and freshwater extraction has now surpassed planetary boundaries (Richardson et al., 2023). Consequently, habitat loss is unsurprisingly a key threat for most threatened species (Kearney et al., 2023; Maxwell et al., 2016; Lintermans et al. 2024). While drivers of habitat loss are numerous, including native forest logging, urban development, mining and other industrial development, land conversion for agriculture is a leading cause of extinctions globally (Lughada et al. 2020) including Australia (Adams et al. 2023; Enger et al. 2023; Kearney et al. 2018; Grill et al. 2019; Morden et al 2022; ABS 2024).

Threatened species with narrow ranges tend to have few habitat patches available (Tulloch, et al. 2016), often due to land use change, or have always occupied only a few discrete areas across a small distribution (Bertola et al., 2018). These species are particularly vulnerable to actions that cause habitat loss, as even localised impacts (such as small scale habitat destruction or severe wildfire) can have large consequences for their persistence (Staude et al., 2020; Harvey 2002; Harvey et al.

2011). With climate change directly impacting species' habitat and population structure through many mechanisms (Scheffers et al. 2016), the risk to those species that have a small amount of habitat remaining is amplified (Pearson et al., 2014; Purvis et al., 2000). It is not surprising the two most recent Australian extinctions were of species with very small ranges: the *Banksia montana* mealybug *Pseudococcus markharveyi* (range <100 m^2) [extinct in 2020] (Moir 2021) and Bramble Cay melomys *Melomys rubicola* (0.05 km^2) [extinct between 2009 and 2014] (Woinarski et al. 2017).

Disturbance events like land clearing, wildfires, long-term drought, alien invasion, or diseases (Bertola et al., 2018; Legge et al., 2022; Ward et al., 2020; Lughada et al. 2020; Humphreys et al. 2019; Gallagher et al. 2023; McDowall 2006) can reduce population size, deplete already scarce resources, and increase competition. While species occupying larger ranges or larger areas of habitat may have multiple refugia that buffer against such events, those occupying small areas within a limited set of patches often have less resilience. Proactively identifying and safeguarding these habitats is therefore crucial (Bertola et al., 2018; Grace et al., 2021; Spiliopoulou et al., 2023; Woinarski et al. 2023; Jones et al. 2021), especially as climate-driven disturbance events are predicted to increase in frequency and severity (Dowdy et al. 2020), and are coupled with high rates of habitat loss (World Resources Institute, 2024).

Habitats for narrow-range species are often considered irreplaceable under methods to identify areas most important for biodiversity; as such, they should be considered a high priority when considering site-based conservation efforts (Pressey et al., 1993). Here, using expert knowledge and recent species occurrence records, we provide the first attempt to produce maps of the remaining habitats of Critically Endangered, narrow-range (defined here as having an Extent of Occurrence <20,000km^2) species, with <6 patches of habitat remaining across Australia. To understand potential threats to these narrow-range species, we assessed data on both the tenure and the agricultural capability of the land on which this habitat occurs. We concentrated on agricultural capability because agriculture currently drives more habitat loss than do logging, urban development, mining or other industrial developments (Evans, 2016). For example, in Queensland alone, 6,800km^2 of woody vegetation was cleared in 2018-2019, most of which was for agriculture (Queensland Government, 2020). We assessed land tenure (ABARES, 2021) and the agricultural capability (Adams and Engert, 2023) of the land on which this habitat occurs to examine one factor that contributes to the risk of clearing for agriculture. By identifying the habitat remaining for narrow-range species, we provide the baseline data which is essential for policy development and conservation action that should lead to their conservation, whether through formal protection, collaboration with land managers or other site-based activities.

Methods

Identifying species most at risk of extinction

Under Australia's national environmental legislation, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), species (and subspecies; referred to here as species) can be listed as Extinct, Extinct in the Wild, Critically Endangered, Endangered, or Vulnerable based on listing criteria that largely resembles the International Union for Conservation of Nature (IUCN) criteria (IUCN, 2024;

Commonwealth of Australia, 1999; Petrov et al., 2023). We excluded all Vulnerable and Endangered species due to their lower probability of extinction, retaining only species listed as Extinct in the Wild, and Critically Endangered, and those currently under formal assessment for potential inclusion as Critically Endangered. Using the Australian Government's publicly available 1 km^2 resolution Species of National Environmental Significance Distributions (hereafter SNES data; downloaded 30 September 2023) (Commonwealth of Australia, 2022b; Tulloch et al., 2016), we extracted the habitats for species listed as . In the dataset, these mapped areas of habitat for species listed as Extinct in the Wild, and Critically Endangered, and under formal assessment. These maps are divided into two categories: 'Species or species habitat likely to occur' (this is a combination of both known and likely to occur categories) and 'Species or species habitat may occur'. We used the 'species or species habitat likely to occur' category as they represent more accurate maps of habitat. Using these data, a patch was defined as a contiguous polygon not directly connected to or touching any other polygon mapped within a given taxon's known and likely habitat based on their SNES distribution (Commonwealth of Australia, 2022b; Tulloch et al., 2016). As the resolution was 1 km^2, species with many scattered, nearby records would be counted as one patch, although this variation depends on how the sightings were processed—whether they were simply buffered or modelled. For example, if sightings were buffered but occurred within 2 km of one another, they might be treated as a single patch. For others, species distribution models (SDMs) are used or a combination of SDMs and expert refinement, and this may result in contiguous habitat areas, rather than separate patches. We counted the number of patches for each species using ArcPro (version 3.4) and included only species with <6 patches of habitat. Species restricted to fewer than six patches of habitat generally have a higher risk of extinction (McCarthy et al., 2005).

We further refined our group of species by including only those listed as Critically Endangered pursuant to EPBC Act criterion 2 (species that have restricted ranges, very few locations, continued decline or fluctuations) or criterion 3 (very restricted population size), because any habitat loss for these species could be disproportionally detrimental. To identify these species, we used a combination of Australian Government documents (i.e., Recovery Plans, Conservation Advices, and Listing Advices). Many species listed under older legislation were grandfathered into contemporary lists when the EPBC Act came into force. To overcome this issue, and as we are only focused on small-ranging species, we exclude all species with habitats >20,000km^2 (Commonwealth of Australia, 2022b).

We recognise that the data used to develop these habitat maps describe contemporary presence only and operate on the assumption that presence is the main driver of habitat detection via observations. While mapping of presence-derived habitat does not guarantee the presence of a species throughout that habitat type, in some cases, the mapping used here will not capture all areas where a species might occur, and falsely give the impression of the distribution being <20,000km^2 in extent. There are likely to be unmapped areas of habitat due to poor or limited survey data, poor historical knowledge of the species, or unoccupied or temporally-dynamic habitats (e.g., ephemeral streams that sometimes support freshwater species). Some species (in particular plants) can be present at a site but virtually undetectable (e.g., genera like *Thismia* that reside almost entirely underground and/or are obscured by leaf litter) and animals will not be detected if surveys are conducted at an inappropriate time of year. While this is less of a problem than under-estimating, it can lead to sub-optimal allocation of resources. Nevertheless, we argue that mapping areas where such species have been detected is crucial until more accurate data become available.

Refining habitat maps

We drew on knowledge from 18 experts to help provide more complete occurrence data, and to review and refine the known and likely Australian Government habitat maps for all animal species. Due to the high number of plants on our list, plant maps were not refined. The expert elicitation process to refine animal habitat maps was done using an online modified Delphi approach (Northcote et al. 2008). Experts were defined and chosen based on if they had conducted recent research on the specific species of interest and were invited via email to participate in the elicitation process, as well as co-author the manuscript. In the first round of communication, experts were asked to check whether maps matched their knowledge of species occurrence, add any additional species that were considered Critically Endangered and their accompanying habitat maps, and, if necessary, modify the boundaries of habitat maps. These modifications were implemented using a variety of different data including vegetation (e.g., extracting rainforest vegetation only), removing cleared areas, geology, new occurrence records, and elevation, with the final maps re-checked by the experts. We then rechecked to ensure every species still had <6 habitat patches and had <20,000km^2 of habitat. These final single species maps were merged to create one final layer of habitat. We recognise that the condition and occupancy of the habitat identified in these maps is uncertain given issues of mapping resolution and spatial/temporal dynamics. Nonetheless, given the data at hand, these refined maps represent a logical starting point for guiding conservation decision making.

Some species were removed from the analysis due to taxonomic uncertainty (i.e., Glenelg freshwater mussel (*Hyridella glenelgensis*) and Round Island petrel (*Pterodroma arminjoniana*)). The Phillip Island helicarionid snail (*Mathewsoconcha phillipii*), *Banksia montana* mealybug (*Pseudococcus markharveyi),* Christmas Island shrew (*Crocidura trichura*), mountain mistfrog (*Litoria nyakalensis*), Stoddart's helicarionid land snail (*Quintalia stoddartii*), and Tiwi Island hooded robin (*Melanodryas cucullata melvillensis*) are listed as Critically Endangered under the EPBC Act but were also removed from this analysis as they are likely now Extinct (Ward et al., 2022; Woinarski et al. 2024; Woinarski et al. 2025). In addition, while Gray's helicarionid land snail (*Mathewsoconcha grayi*) was recently rediscovered on Phillip Island, a lack of survey data did not allow us to accurately undertake the mapping of the species, thus we removed it from the analysis (Hyman, et al. 2023). Seventeen additional species (beyond those found on the EPBC list) that are currently being assessed for Critically Endangered status as of September 2023 were included in the assessment as the expert elicitation described found they should be treated as Critically Endangered.

Identifying tenure and land capability of habitat patches

Finalised habitat maps were overlayed with maps of land tenure including Freehold, Multiple-use public forest, Nature conservation reserve, Other perpetual lease – Indigenous, Other Crown land, Other Crown purposes, Other Crown purposes – Indigenous, Other lease, Freehold – Indigenous Freeholding lease, Other perpetual lease, Other term lease, Pastoral perpetual lease, and Pastoral term lease (ABARES, 2021). We also investigated how habitats overlapped with Australia's protected area network in 2020 (Collaborative Australian Protected Areas Database, 2020), bioregions (*n*= 89; Commonwealth of Australia, 2018), and state and territory boundaries.

We also built upon previous assessments of Australian plants at risk when considering land use change (Adams et al., 2023) and evaluated how much narrow-range Critically Endangered species' habitat has 'Very low' to 'Extremely high' agricultural capability (Adams and Engert, 2023). This layer harmonized state agricultural land capability datasets and modelled pastoral capability to map land capability. Land capability mapping is broadly defined as applying a classification system that ranks land according to the capability to support agricultural production, based on various uses such as broadscale grazing and cropping (Wang et al. 2020; Office of Environment and Heritage, 2021). Lands in agricultural classes 'Extremely high' – 'Moderate' (i.e., 1 – 4) would be expected to primarily be in agricultural uses including all types of cropping. Land in classes 'Moderate – low' and 'Low' (i.e., 5 and 6) is generally unsuitable for intensive agriculture and would be expected to be used for grazing and forestry. Land in class 'Very low' (i.e., 7) is expected to be restricted to use for low intensity production such as native vegetation grazing and forestry, or non-productive land uses such as conservation. Land in class 'Extremely low' (i.e., 8) is unsuitable for any productive land uses and is expected to be primarily intact vegetation. As this land capability layer is tenure blind, it does cover areas unlikely to be lost to agriculture such as protected areas, World Heritage Areas, and public native forests. Therefore, we assume that habitat in protected areas, World Heritage Areas, and Nature conservation reserves have no agricultural capability.

We also assessed the extent of inter-specific overlap amongst the habitat patches identified to explore where expanding protection and subsequent management could be efficient and cost-effective for supporting multiple species.

Results

We identified 307 narrow-range, critically endangered species with less than six patches of habitat remaining (making up ~15% of the species listed as threatened under the EPBC Act in Australia). Most species assessed were plants (228 species), followed by reptiles (20 species), frogs (14 species), invertebrates (other than freshwater crayfish; 14 species), freshwater crayfish (11 species), fish (12 species), birds (five species), mammals (three species; **Supplementary Table 1**). The 307 narrow-range Critically Endangered species occurred across 85,000km^2 (1% of Australia; **Supplementary Table 2**). We found that the habitat of 180 species (59%) overlapped spatially with at least one other narrow-range Critically Endangered taxon, and the highest number of overlapping species within any one habitat patch was 14 (**Fig. 1**).

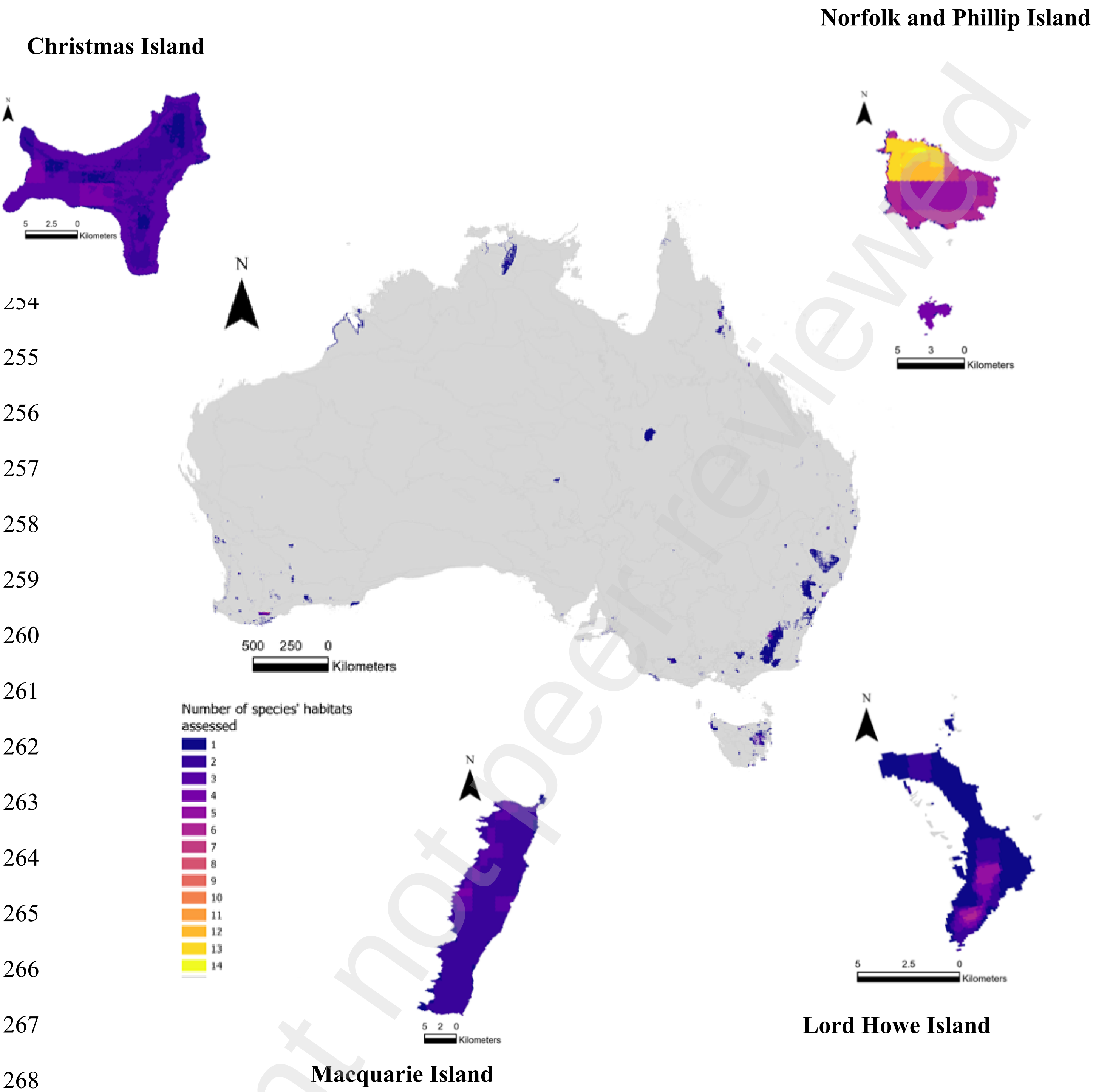

Fig. 1. Habitats for 307 narrow-range Critically Endangered species in Australia. Five key islands have been enlarged, including Christmas Island (top left, located in the Indian Ocean, 1,500km west of the Australian mainland and 2,600km from Perth), Norfolk and Phillip Islands (top right, located in the southwestern Pacific Ocean, 1,676km northeast of Sydney), Lord Howe Island (middle right, located

approximately 700km northeast of Sydney and southeast of Brisbane), and Macquarie Island (bottom right, located 1,500km south-south-east of Tasmania).

Roughly 51% of the combined habitat area for the 307 narrow-range Critically Endangered species fell within protected lands, including government, Indigenous and privately protected areas and World Heritage Areas (44,000km^2), closely followed by freehold land (17,000km^2), and multiple-use public forest (excluding protected areas; 7,000km^2; **Supplementary Table 3**). Freehold land held the highest proportion of habitat for other invertebrates. Protected areas and World Heritage Areas held the highest proportion of habitat for birds, frogs, crayfish, plants, mammals, fish and reptiles (**Fig. 2**).

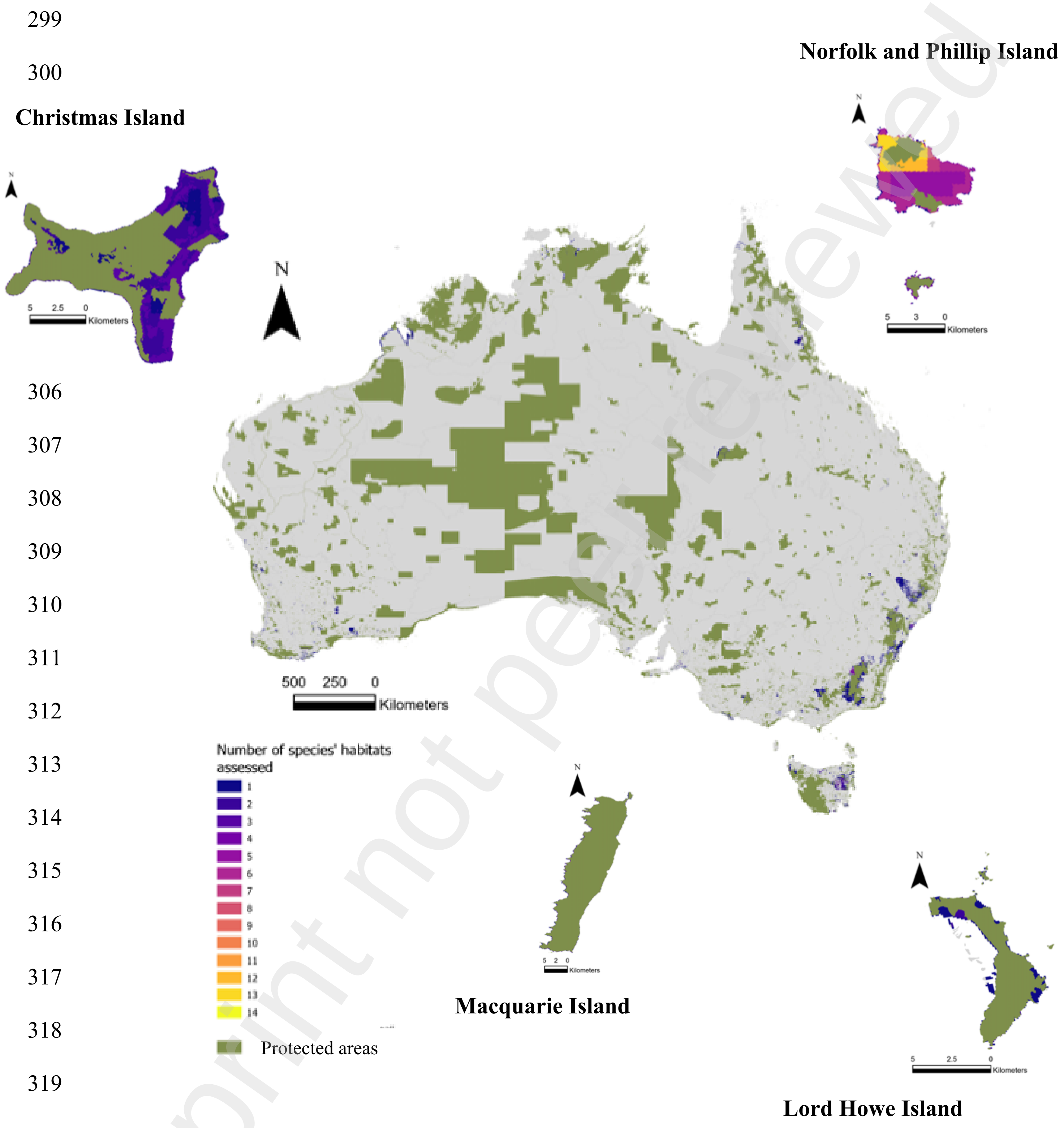

Figure 2). The number of habitats for narrow-range Critically Endangered species outside protected and World Heritage Areas (green). The entire protected and World Heritage Areas as of 2020 are shown in green. Five key islands have been enlarged,

including Christmas Island (top left, located in the Indian Ocean, 1,500km west of the Australian mainland and 2,600km from Perth), Norfolk and Phillip Islands (top right, located in the southwestern Pacific Ocean, 1,676km northeast of Sydney), Lord Howe Island (middle right, located approximately 700km northeast of Sydney and southeast of Brisbane), and Macquarie Island (bottom right, located 1,500km south-south-east of Tasmania).

When simply considering area-based protection mechanisms, approximately half (41,000km^2) of the combined habitat area for the narrow-range Critically Endangered species is outside public or private protected areas, or Indigenous Protected Areas or World Heritage Areas (from hereon, 'protected areas'), with 40 species having their entire habitat outside protected areas (32 of which were plants; **Fig. 3**). Approximately 29,500km^2 (72%) of this habitat outside protected areas, covering 221 species, also overlaps with land categorized 'Very low agricultural capability land' and above (**Supplementary Table 4)**. We found that 116 species had >50% of habitat outside of protected areas and overlapping with very low to extremely high agricultural capability, 77 species had between 10–50%, and 28 species had between 1–10% (**Supplementary Table 5-6**).

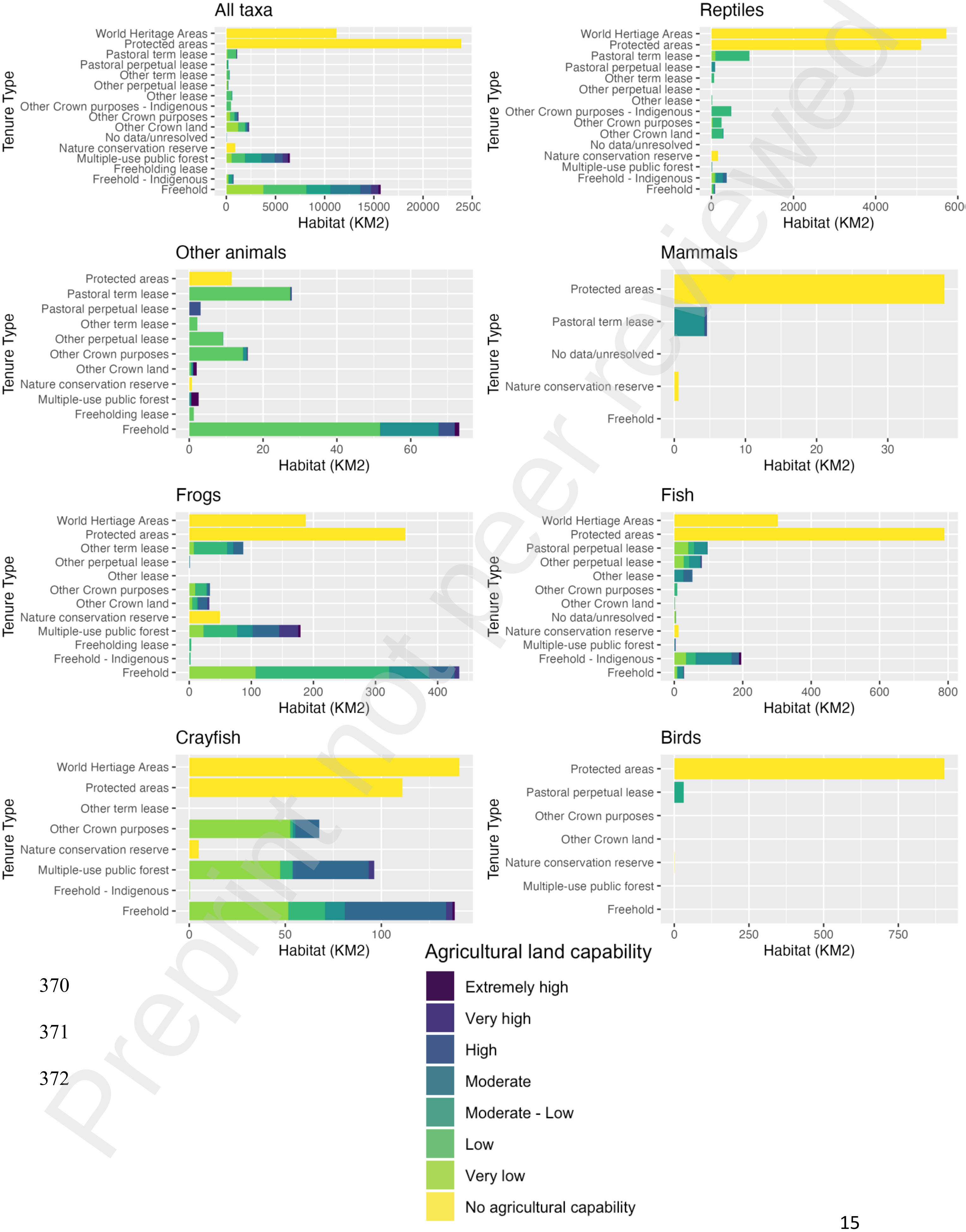
All taxa
Reptiles
Other animals
Mammals
Frogs
Fish
Crayfish
Birds
Tenure Type
Habitat (KM2)
World Heritage Areas
World Hertiage Areas
Protected areas
Pastoral term lease
Pastoral perpetual lease
Other term lease
Other perpetual lease
Other lease
Other Crown purposes - Indigenous
Other Crown purposes
Other Crown land
No data/unresolved
Nature conservation reserve
Multiple-use public forest
Freeholding lease
Freehold - Indigenous
Freehold
Agricultural land capability
Extremely high
Very high
High
Moderate
Moderate - Low
Low
Very low
No agricultural capability

Figure 3. Mapped taxon habitat area for 307 narrow-range Critically Endangered species in Australia. Habitat area varies across tenure for each group. Areas that have no to extremely high agricultural capability are shaded from yellow to dark purple.

Habitats for narrow-range Critically Endangered species were identified in every state and territory, with 76 species occurring in New South Wales (NSW), 72 in Western Australia, and 41 in Queensland. Some bioregions had habitat areas for many narrow-range species within them, including the South Eastern Highlands (*n* = 33 species) across NSW and Victoria, the Jarrah Forest bioregion of Western Australia (*n* = 29 species), and the Sydney Basin in NSW (*n* = 26 species). Several islands were identified as hotspots including Norfolk Island, Lord Howe Island, Macquarie Island, and Christmas Island (**Fig. 2**).

Discussion

Here we identified and mapped 307 narrow-range Critically Endangered Australian species to evaluate the distribution of their potential habitat in relation to tenure and land capability. We found that the habitat for these species covered ~85,000km^2 (1% of Australia) and that approximately half of that habitat is distributed across protected areas and World Heritage Areas. Most habitat outside the protected area and World Heritage Area estate was found on freehold land (~17,000 km^2 or 20% of all habitats) and multiple-use public forest (~7,000 km^2 or 9%). Approximately 72% (~29,500km^2) of the habitat outside the protected area estate had some mapped agricultural capability.

We found that 40 species had their entire habitats outside of the protected area estate. Most of these were plants (*n*=32), but also included four invertebrates (Margaret River burrowing crayfish *Engaewa pseudoreducta,* short-tongued native bee *Hesperocolletes douglasi,* southern sandstone cave cricket *Micropathus kiernani,* a land snail *Ordtrachia septentrionalis*), two reptiles (Lyon's snake-eyed skink *Austroablepharus barrylyoni* and Pinnacles leaf-tailed gecko *Phyllurus pinnaclensis*), one bird (thick-billed grasswren *Amytornis modestus obscurior*), and one fish (red handfish *Thymichthys politus*).

If Australia is to achieve its 2030 'no new extinctions' commitment (Commonwealth of Australia, 2024) and its global commitment to halting species extinctions (as per the Kunming-Montreal Global Biodiversity Framework) (Convention on Biological Diversity, 2022), the habitat we have identified must be managed to ensure the persistence of each species. Areas not already receiving attention should be treated as high priorities for any future species conservation initiatives. These mechanisms may include private protected areas, Indigenous protected areas, government protected areas, other effective area-based conservation measures and adequate financial incentives for activities that are needed for the conservation of the affected species. In addition to regulatory protection and management mechanisms, voluntary initiatives (e.g., Land for Wildlife; Prado et al. 2018) that engage private landholders in conservation will be important to ensure Australia meets conservation goals (Munro and Lindenmayer, 2011). Rigorous regulation of development impacts should also be a key focus (Thomas et al. 2024; Ward et al. 2019). The maps we have refined are instructive here, as they could guide application of the mitigation hierarchy (namely, avoidance of impacts), as well as broader planning initiatives like regional planning (as currently proposed under reform of Australian environmental law).

While safeguarding habitat (and any additional buffer zones or areas required for connectivity) in the protected area estate will likely ensure species are protected from most direct destructive activities, a sole focus on protected areas will not secure all species from extinction (Moir 2021). This is because formal designation of a protected site does not always result in species 'protection' against threats such as inappropriate fire regimes, climate change, disease, reservoir construction, and invasive species (Legge et al., 2017; Kearney et al., 2020). In many Australian protected areas, recreational harvest of native fish is still permitted (Jackson et al., 2004; Jarvis et al., 2019; Lintermans, 2020). In fact, four of the five most recent Australian extinctions were of species for which occurrences were entirely or largely already within protected areas. Active management and policy change is commonly needed to combat these threats. Given so much habitat occurs on freehold land (**Fig. 3**), incentives for landholders to manage for positive biodiversity outcomes is essential (McDonald et al., 2018). In other cases, management of Indigenous-owned lands for the health of Country and people is a key mechanism for achieving good outcomes for nature, but must be adequately funded and it is acknowledged that Indigenous people may have priorities for their land that are independent of conservation (Corrigan et al., 2018; Renwick et al., 2017).

While some legislative levers such as the USA Endangered Species Act or the EU Habitat Directive work by conserving habitats, many require reform (Henson et al., 2018). In Canada, habitat located outside of Federal land can be destroyed or degraded (Palm et al., 2020). Similarly in Australia, under the EPBC Act, habitat identified on the Register of Critical Habitat is only protected by law if that habitat is on Commonwealth land or sea, or on private land with agreement of the landholder. While some Australian state-based legislation has greater provision for identifying and listing of critical habitat on private land, this has only been done sparingly to date (Fitzsimons, 2020). Our results highlight that ~20% of habitat occurs on freehold land, suggesting the critical importance of partnerships with private land holders to manage and conserve these areas. In some instances, where illegal conversion continues to be a key threat, enforcement of environmental law to ensure habitat is protected is clearly needed. This must be coupled with appropriate public funding to support the delineation, mapping, protection, and recovery of other threatened species and ecosystem habitats — funding that is currently inadequate (Wintle et al., 2019).

We recognise that our habitat maps have been refined based on best available information skewed to species' current known ranges. Historically, many now-threatened species had large distributions and possibly a slightly different range (due to climate change), with some current habitats arising from species persisting in suboptimal areas where the threat load is lowest, rather than where the habitat is most suitable (Raadik, 2014; Britnell et al. 2023). For example, many threatened galaxiid species are now confined to small, upland streams above barriers that exclude introduced trout (*Salmonidae*), but they were likely much more widespread before trout invasion (Raadik et al. 2014). In cases where habitat persists, but species have been locally extirpated, habitat protection remains imperative as the loss of unoccupied habitat reduces opportunities for natural recovery, future reintroductions, and movement under climate change (Ward et al. 2022).

While we used the best available information, uncertainties persist in our analysis, especially regarding false absences and positives in habitat mapping. It remains unknown if the current extent of habitat mapped here represents the habitat necessary to meet the persistence, let alone recovery potential, of each species, especially if the needs of species shift over time as climate changes. It is therefore important to ensure that effort and resources are also directed towards gathering new information on species, especially to determine recovery potential as per the IUCN Green Status of Species methodology (Akçakaya, et al. 2018). This new information must then be used to update and refine habitat maps. Effort and funding to reduce those uncertainties is required. Improved and regularly updated mapping should be complimented by clear written descriptions of the characteristics of each species' habitat as environments are dynamic and the distributions of habitat will change with season, climate, land use, and/or disturbance for some species (Brooks et al., 2019). Further, the existence of maps does not diminish the need for robust ground-truthing assessments in areas of uncertainty or where local knowledge exists that differs from what maps indicate.

Australia is in the midst of an extinction crisis (Commonwealth of Australia, 2021) and a recent independent review of the EPBC Act (Samuel, 2020) found that reform is needed to establish new, legally enforceable National Environmental Standards, which will in part depend on mapping and protecting habitat for threatened species. This is particularly important given proposed new environmental law implies that Australia will contribute to 'Nature Positive' outcomes, which requires identifying and protecting habitats that are irreplaceable. The refined habitat areas identified here for species most at risk of extinction are an important first step towards identifying those areas that are vital for conservation, particularly in identifying the habitat areas outside protected areas. Future development should be avoided in these areas, and they should be prioritized for focused conservation efforts. By safeguarding and overseeing these crucial areas, Australia can make significant strides towards fulfilling its commitment to preventing extinctions and help fulfill its Nature Positive promise.

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