









CONTRIBUTED PAPER

Saving species beyond the protected area fence: Threats must be managed across multiple land tenure types to secure Australia's endangered species

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Abstract

The main effort to secure threatened species globally is to set aside land and sea for their conservation via governance arrangements such as protected areas. But not even the biggest protected area estate will cover enough area to halt most species declines. Consequently, there is a need for assessments of how species habitats are distributed across the tenure landscape, to guide policy and conservation opportunities. Using Australia as a case study, we assess the relationship between land tenure coverage and the distributions of nationally listed threatened species. We discover that on average, nearly half (48%) of Australian threatened species' distributions occur on privately owned (freehold) lands, despite this tenure covering only 29% of the continent. In contrast, leasehold lands, which cover 38% of Australia, overlap with only 6% of species' distributions while protected area lands (which cover 20%) have an average of 35% of species' distributions. We found the majority (75%; $n = 1199$) of species occur across multiple land tenures, and those species that are confined to a single tenure were mostly on freehold lands (13%; $n = 201$) and protected areas (9%; $n = 139$). Our findings display the opportunity to reverse the current trend of species decline with increased coordination of threat management across land tenures.

KEYWORDS

conservation, extinction, habitat destruction, invasive species, national park, threat management, threatened species

1 | INTRODUCTION

Human activities are causing a decline in native species at a rate and scale unprecedented in recent history

(Butchart et al., 2010; Maxwell et al., 2016). In response, the global community is working together to halt this decline (United Nations, 1992), an effort that is recognized as one of the greatest challenges for humanity

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(IPBES, 2019). To date, considerable and increasing action is being conducted across Earth (Tittensor et al., 2014), the cornerstone of which has been the designation of protected areas (Watson et al., 2014), which now cover 15% of the global land surface (Maxwell et al., 2020). However, collective conservation efforts have so far had limited success in slowing the rate of decline in these threatened species (Maxwell et al., 2020). While there are localized success stories of efforts to arrest decline of a limited number of threatened species (Bolam et al., 2021; Butchart et al., 2006), numerous examples highlight site-based conservation efforts failing to halt the decline of many species (Craigie et al., 2010; Wayne et al., 2017; Woinarski et al., 2017).

The vital importance of the ~15% of terrestrial earth within the protected area estate for threatened species is well established (Watson et al., 2014; Woodley et al., 2019); and while there are global discussions around the fact that land area under protection should be far larger (Dinerstein et al., 2017; Wilson, 2016), at present the management of the other 85% of Earth will likely have far greater implications for threatened species outcomes (Maron et al., 2018; Watson et al., 2021). The non-protected landscape is a complex matrix of ownership and use regimes, with some areas consistent with, or at least not impeding, positive conservation outcomes (e.g., some military lands; Stein et al., 2008) while others are far less compatible (e.g., freehold land under intensive agriculture; Dudley & Alexander, 2017). Historic and current ownership and use regimes have significant implications for the legal and policy approaches taken for threatened species conservation and threat management (Fischer & Lindenmayer, 2007). Hence, mapping and understanding the tenure landscape is critical for guiding policy, understanding collaborative pathways to effective management, and maximizing conservation opportunities to respond to the species extinction crisis.

Land tenure is the legal regime under which land is owned, accessed, and used (FAO, 2002). In some regions, it has been found that land tenure impacts environmental outcomes (Robinson et al., 2014; Woinarski et al., 2013) and tenure can influence (or at least is correlated with) threatening processes to biodiversity (Evans, 2016; Fensham et al., 1998). This is consistent with the foundational concept of common law systems that owning land carries the right to exploit the natural resources on that land, though that right is regulated via legislation (Bates, 2019). Important mechanisms available to manage the processes threatening species vary across land tenure, with specific laws only applicable on some land tenure types and jurisdiction (e.g., land clearing laws in Queensland, Australia; Hamman, 2019). Other legal mechanisms theoretically apply regardless of land

tenure type but relate to activities that are more likely to occur on private land (e.g., liability for pollution dependent on the degree of environmental harm caused; Bates, 2019). Furthermore, it is increasingly established that achieving effective environmental management often relies on coordination across the tenure landscape (McCune & Morrison, 2020). Therefore, understanding the distribution of threatened species across an entire tenure landscape may provide critical insights into the law and policy options as well as opportunities for landholder contributions to halt the on-going decline of threatened species.

Here, using Australia as a case study, we integrate a current land tenure map with distribution maps of nationally listed threatened species to assess how these species are distributed across the entire tenure landscape. Australia is one of only 17 megadiverse countries (Mittermeier et al., 1997) and is a continent in the grips of an extinction crisis, having already lost 10% of the terrestrial mammal fauna (Woinarski et al., 2015) and with an additional 1797 species at high risk of extinction in the near-term (Commonwealth of Australia, 2017a, 2017b). The decline of the continent's threatened species is driven by an array of threatening processes, including habitat loss, inappropriate fire regimes and invasive species (Kearney et al., 2019). Although our knowledge of the distribution of species threatened with extinction across parts of the Australian landscape has improved in recent years (e.g., protected areas: Watson et al., 2011; cities and urban areas: Ives et al., 2016; Soanes & Lentini, 2019; Indigenous owned and managed lands: Renwick et al., 2017), a comprehensive understanding of how tenure overlays with threatened species is lacking. A quantification of species across different tenures is needed to formulate appropriate conservation actions that can be implemented in line with relevant legal frameworks; and therefore, critical if Australia is to improve its response to the extinction crisis. We explore this concept with a particular focus on the variation across taxonomic groups, range size and extinction risk categories as well as the importance of single and multi-tenure approaches to conservation efforts.

2 | METHODS

2.1 | Land tenure

In Australia, land tenure is the legal regime within which land is owned and occupied (Walker & Dale, 2013). Tenure defines the responsibilities or required actions of landholders, as well as circumscribing the range of activities or opportunities available to landholders from the

land (Ostrom & Schlager, 1996). Tenure legally mandates the permissible uses of land, constraints to such uses and specific property rights, as well as influencing the objectives of management (Schlager & Ostrom, 1992; van Etten, 2013). For present purposes, there are two high level categories of land tenure in Australia: freehold and Crown land (Geoscience Australia, 2018). Freehold land is that which is owned by the landholder in perpetuity. Crown land includes numerous land tenure types (e.g., leasehold; reserves; unallocated Crown land) owned by the state (the Crown) and leased or licensed to allow particular land uses (Australian Trade and Investment Commission, 2020). Relevant legislative acts govern the use of Crown land for each state and territory. For example, leasehold or pastoral lands acts govern the use of pastoral leasehold lands (e.g., New South Wales: *Crown Land Management Act 2016*) while environmental legislation govern the uses and management of the conservation estates (e.g., Queensland: *Nature Conservation Act 1992*).

At the time of undertaking this analysis (November 2018), there was no single comprehensive and up-to-date map of land tenure in Australia. As such, we created a tenure map by combining multiple datasets (Figure 1a). The basis of this map was Public Sector Mapping Agency's (PSMA) CadLite and Land Tenure datasets (PSMA Australia, 2018) which, while the most up-to-date, are not comprehensive as they contain areas of no data across parts of Western Australia, New South Wales,

and Victoria. Where this spatial dataset was incomplete, we filled those data gaps with information from Geoscience Australia's 1993 Land Tenure map (Geoscience Australia, 1993), the only comprehensive tenure dataset for Australia that we are aware of. Finally, we incorporated protected area spatial data from the Collaborative Australian Protected Area Database (CAPAD; Commonwealth of Australia, 2017c). CAPAD has incomplete coverage of privately protected areas (PPAs; Fitzsimons, 2015; Ivanova & Cook, 2020); as such, PPAs that are in place in some jurisdictions are missed, which could influence the results of our analysis. However, as noted by Fitzsimons (2015), CAPAD contains a significant majority of the total area within PPAs including those of major Australian nongovernment organizations (e.g., Bush Heritage Australia, Australian Wildlife Conservancy), so the PPAs not contained within CAPAD likely only account for a very small proportion of the Australian landmass and therefore threatened species distributions.

The PSMA dataset contains 23 standardized land tenure types (one freehold and 22 Crown land), the Geoscience Australia land tenure dataset has 16 land tenure types (two freehold and 14 Crown land) and the CAPAD dataset has seven protected area management categories. For this analysis, we combined tenure categories within and across data sets to produce seven consistent and mutually exclusive tenure categories relevant to our analysis. These were: (1) Freehold; (2) Leasehold; (3)

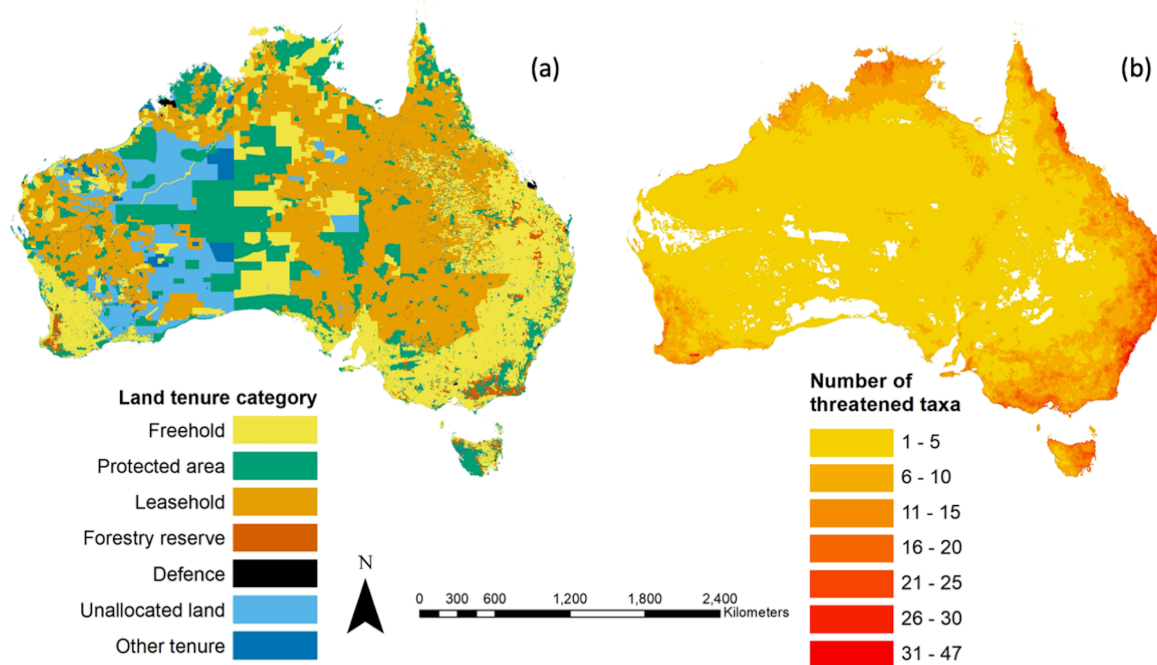


FIGURE 1 (a) The Australian land tenure map produced for this analysis and (b) threatened species distribution density across Australia

TABLE 1 The seven land tenure categories used in this analysis.

Tenure category name	Details	Percent of Australian terrestrial area
Freehold	Lands owned privately and in perpetuity	28.7
Leasehold	Lands owned by the state (the Crown) and leased for various uses	38.2
Protected area	Lands recognized, dedicated, and managed primarily for the conservation of nature (IUCN Categories: I–VI)	19.7
Forestry	Lands that are used or reserved for timber harvest and production (multiple use forest; state forest; timber reserve; other forestry reserve)	1.4
Defense	Lands reserved for use by the armed forces.	0.1
Unallocated Crown land	Vacant, unallocated, unreserved, or other Crown land	9.6
Other tenure	Lands that do not fall within the other categories used in this analysis (e.g., Other reserve; Water reserve; Mining reserve; Stock route; Transportation reserve; Other infrastructure reserve)	2.3

Protected area; (4) Forestry; (5) Defense; (6) Unallocated Crown land; and (7) Other tenures (Figure 1a; Table 1). Categories (2)–(7) are all Crown land, and are differentiated according to whether a private party controls them under a lease (primarily pastoral leases; Category 2), or a state entity for a particular purpose (Categories 3, 4, 5, and 7) or for no designated purpose (Category 6). The category “Other tenures” include the land tenure types from the PSMA and Geoscience Australia datasets that did not fit into any of the other categories (e.g., Other reserve; Water reserve; Mining reserve; Stock route; Transportation reserve; Other infrastructure reserve). These tenures make up 2.3% of the continent.

Land tenure in Australia can be complicated with multiple overlapping tenure arrangements. Often one parcel of land will have a number of tenure interests associated with it (Maguire, 2009). Notably native title can be exclusive or sit alongside other tenures (with the exception of freehold land that extinguishes native title). The *Native Title Act 1993* (Cth) provides a statutory process to protect the rights of native title holders (*Native Title Act 1993*, s. 3). Further, minerals and petroleum belong to the Crown regardless of tenure and mineral rights are governed under individual state and territory acts (e.g., Northern Territory: *Mineral Titles Act 2010*). Thus, for our analysis, we focus on the primary tenure, rather than any multiple overlapping titles which could also affect which conservation actions can take place as well as who to engage with (Adams & Moon, 2013).

The focus on primary tenure was particularly prominent in our treatment of protected areas (tenure Category 3). Although some protected areas have underlying tenure categories, such as freehold lands leased back to government for protection (e.g., some parts of Kakadu National Park; Director of National Parks, 2016) and conservation covenants over private land (Fitzsimons, 2015),

we were primarily interested in the protected area designation. As such, if an area was within the official protected area network of Australia (as recognized in CAPAD), the protected area superseded the underlying tenure type because to be named a protected area, the primary goal must be nature conservation (Dudley, 2008). For these areas, the tenure underlying the protected area designation were not considered in this analysis. It is also important to note that there are many legal mechanisms that pursue nature conservation goals on certain lands, which are not included in the CAPAD database. For example, legal land use instruments are used to designate areas of environmental significance (Nelson, 2019) or conservation-oriented legal agreements between municipal councils and landowners (Harwood et al., 2016). These differ between states, are not aggregated in centralized databases even at the state level and lie outside the scope of the present analysis.

Further details on the land tenure categories reported on here and the corresponding PSMA and Geoscience Australia tenure categories and CAPAD protected management categories are provided in Supplementary Table 1.

2.2 | Species data

We focus on terrestrial and freshwater species and subspecies (hereafter, taxa) listed as threatened (Vulnerable, Endangered and Critically Endangered) under Australia's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). This includes taxa from vertebrate (Classes: *Mammalia*, *Aves*, *Amphibia*, *Reptilia*, *Chondrichthyes*, *Actinopterygii*, *Sarcopterygii*), invertebrate (Classes: *Insecta*, *Bivalvia*, *Malacostraca*, *Gastropod*, *Arachnid*, *Onychophora*, *Remipedia*, *Oligochaeta*) and plant (Classes: *Bryopsida*, *Cycadatae*, *Liliopsida*, *Lycopodiatae*, *Magnoliopsida*, *Pinatae*, *Polypodiatae*, *Psilotatae*, *Streptophyta*)

taxonomic groups. At the time of writing, 1797 (1342 plant, 455 animal) taxa were listed as threatened under the EPBC Act.

Distribution data for these taxa are made available by the Australian Government through the Species of National Environmental Significance (SNES) database (Commonwealth of Australia, 2018). Taxa distribution data are classified into three categories based on the degree of certainty that a taxon is present: “known to occur”; “likely to occur” and “may occur.” Following previous studies (Ives et al., 2016; Renwick et al., 2017; Ward et al., 2019; Watson et al., 2011), we included only the two categories of higher certainty (known and likely to occur) and combined them into a single category for this analysis (Figure 1b).

2.3 | Analysis

We quantified the overlap of each threatened taxon with each tenure category by intersecting taxa distribution maps with the Australian land tenure map. In the spatial overlay analysis, 1602 taxa were included. Spatial analyses were undertaken in ArcMap 10.6 (ESRI, 2011). We explored the variation across taxonomic groups, range sizes and extinction risk categories. Although, we acknowledge that taxa range size and extinction risk are related, as range size thresholds can be used to assign extinction risk category. However, it is still valuable to

explore both factors as not all small range taxa have higher extinction risks (e.g., Lancelin Island skink [*Ctenotus lancelini*]; SNES known and likely distribution ~ 0.2 km²; EPBC Act status: Vulnerable) and not all higher extinction risk taxa have small ranges (e.g., plains-wanderer [*Pedionomus torquatus*]; SNES known and likely distribution: $>175,000$ km²; EPBC Act status: Critically Endangered). We also quantify the number of tenures that a taxon is distributed across to understand the importance of single and multi-tenure approaches to threatened species conservation.

3 | RESULTS

3.1 | Threatened taxa distribution across each tenure category

The three dominant tenure types across Australia were leasehold (38%), freehold (29%), and protected areas (20%) (Table 1), although their importance for threatened taxa varied considerably (Figure 2). The greatest proportion of Australian threatened taxa distributions occurred on freehold land, accounting for an average of nearly half of all threatened taxa distributions (average and median taxa overlap: 48%; Table 2, Figure 3). Protected areas facilitated an average of 35% of taxa distributions (median: 24%; Table 2, Figure 3), while leasehold lands contained an average of just 6% of threatened taxa

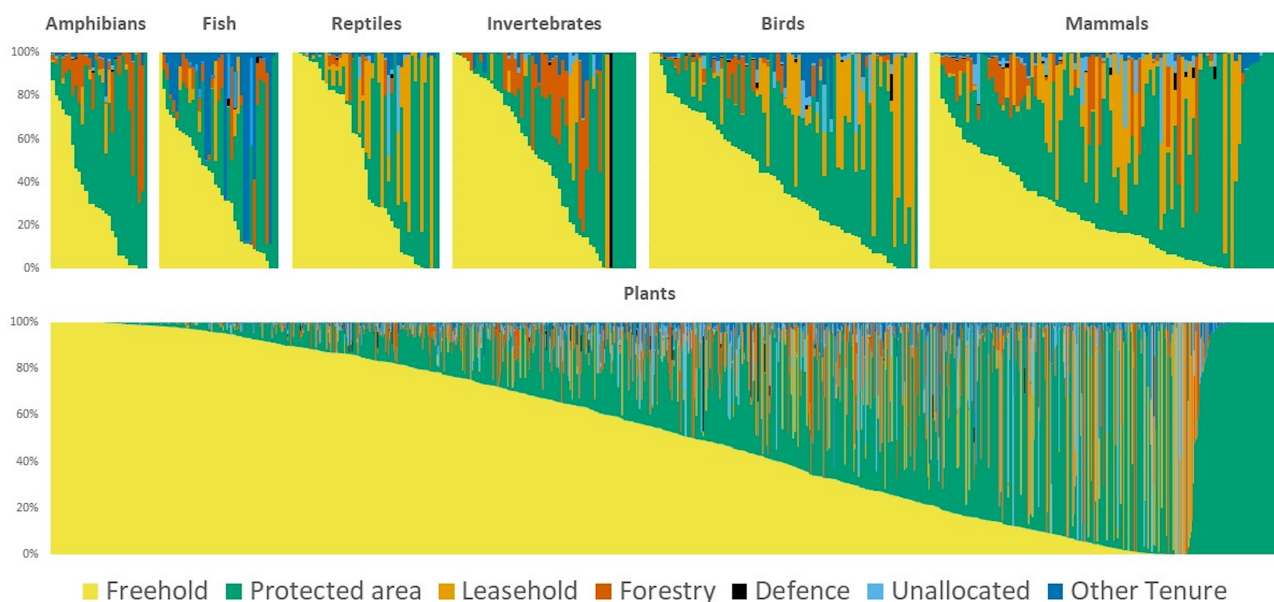


FIGURE 2 The distribution (%) of threatened taxa within each taxonomic group across each broad land tenure category in Australia. Each vertical bar represents one Environment Protection and Biodiversity Conservation Act listed taxa. (amphibians: $n = 29$; fish: $n = 37$; reptiles: $n = 45$; invertebrates: $n = 54$; birds: $n = 76$; mammals: $n = 99$; plants: $n = 1262$)

TABLE 2 The average and median species distribution overlap with each land tenure category ($n = 1602$). The number of species in each overlap category is also shown.

	Freehold	Protected areas	Leasehold	Forestry	Defense	Unallocated land	Other tenure
Average (%) species overlap with tenure	48.0	35.0	5.8	5.9	0.3	2.4	2.6
Median (%) species overlap with tenure	48.0	23.9	0.0	0.0	0.0	0.0	0.4
The number of species (and % of total) that fall into the range overlap categories for each tenure							
>95%	201 (13%)	139 (8%)	14 (1%)	6 (<1%)	1 (<1%)	5 (<1%)	0 (0%)
50–94.9%	576 (36%)	331 (21%)	58 (4%)	35 (2%)	0 (0%)	12 (<1%)	10 (<1%)
5–49.9%	559 (35%)	783 (49%)	166 (10%)	341 (21%)	24 (2%)	117 (7%)	182 (11%)
<5%	266 (17%)	349 (22%)	1364 (85%)	1220 (76%)	1577 (98%)	1468 (92%)	1410 (88%)

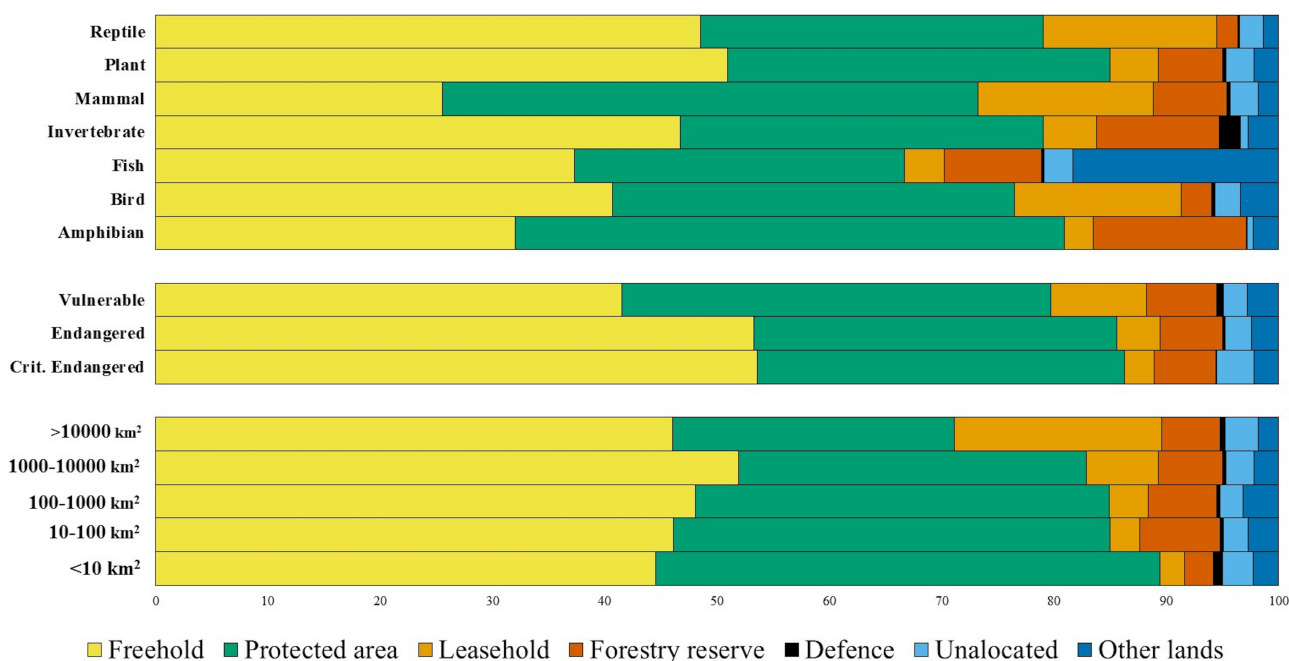


FIGURE 3 The average distribution overlap (%) of each species group (taxonomic group, extinction risk category, and range size category) with each land tenure. (Amphibians: $n = 29$; fish: $n = 37$; reptiles: $n = 45$; invertebrates: $n = 54$; birds: $n = 76$; mammals: $n = 99$; plants: $n = 1262$; Vulnerable: $n = 729$; Endangered: $n = 660$; Critically Endangered: $n = 213$; >10,000 km²: $n = 205$; 1000–10,000 km²: $n = 364$; 100–1000 km²: $n = 566$; 10–100 km²: $n = 349$; <10 km²: $n = 118$)

distributions (median: 0%; Table 2). In contrast, a similar proportion of threatened taxa distributions (5.9%) occurred on forestry reserves while only occupying 1.4% of the Australian landmass (Table 2).

3.2 | Taxonomic groups across tenures

The majority of taxonomic groups had the greatest overlap with freehold lands (plants 51%, reptiles: 49%, invertebrates 47%, birds: 41%, fish: 37%; Figure 3;

Supplementary Table 3), while protected areas covered the greatest proportion of average taxa distributions for amphibians (49%) and mammals (48%) (Figure 3, Supplementary Table 3).

Mammals, reptiles, and birds had the greatest overlap with leasehold lands (15.6, 15.5, and 14.8%, respectively), while amphibians and fish have the least (2.6 and 3.5%, respectively). Amphibian and invertebrates have the greatest overlap with forestry reserves (13.6 and 10.9%, respectively), while reptiles and birds had the least (1.9 and 2.7%; Figure 3, Supplementary Table 3).

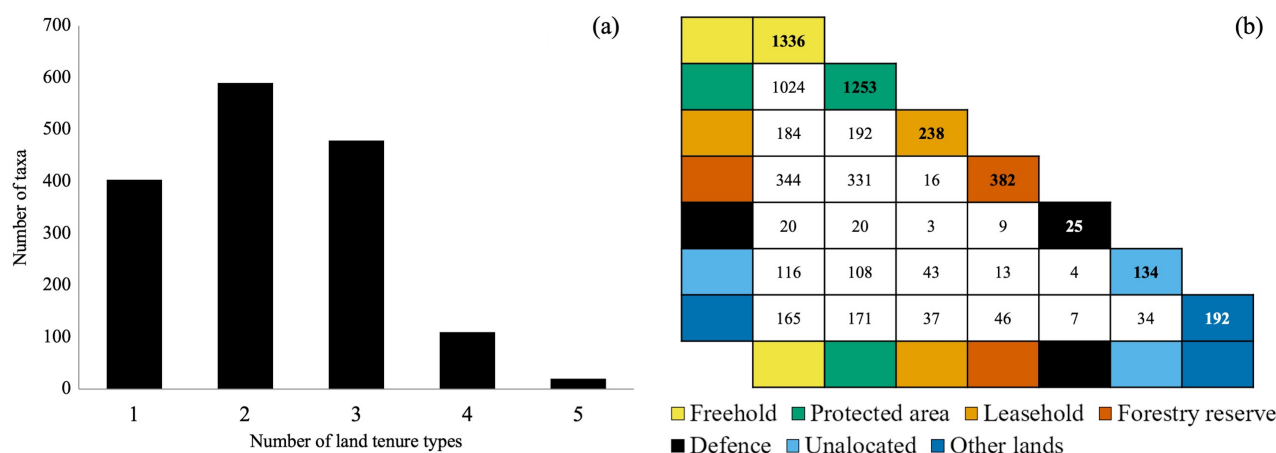


FIGURE 4 (a) The number of taxa that are distributed across one or more land tenure types, when tenures making up <5% of their distribution are removed; and (b) the number of species that had ≥5% of their distribution overlapping with each land tenure (colored cells) and the paired combination of each land tenure (intersecting cells)

3.3 | Land tenure and extinction risk category

On freehold lands, average taxa overlap decreased with decreasing extinction risk, with Critically Endangered and Endangered taxa having over half of their distributions (54 and 53%, respectively) and Vulnerable taxa having 42% on this tenure type (Figure 3, Supplementary Table 3). Vulnerable taxa had the greatest overlap with almost all other tenure types, including protected areas, which accounted for an average of 38% of these taxa distributions (EN: 32%; CR: 33%) and leasehold lands, accounting for 9% of their distribution (CR: 3% and EN: 4%; Figure 3, Supplementary Table 3).

3.4 | Land tenure and range size

Freehold lands accounted for the greatest proportion of distributions for taxa within each range size category except for narrowly distributed species (<10 km² distribution; Figure 3). These narrowly distributed taxa had, on average, 44.9% within protected areas, followed closely by 44.5% on freehold lands. The average taxa distribution overlap with protected areas decreased with increasing range size (<10 km²: 44.9%; >10,000 km²: 25.0%; Supplementary Table 3), while average taxa overlap with leasehold lands increased with increasing range size (<10 km²: 2.2%; >10,000 km²: 18%; Supplementary Table 3).

3.5 | Single- and multi-tenure species

The majority of Australian threatened taxa occurred on multiple land tenure categories (Figure 4a). When tenure

categories making up less than 5% of a taxon's distribution were disregarded, 75% of taxa ($n = 1199$) occurred across two or more tenure categories, with 38% ($n = 609$) occurring across three or more (Figure 4a). One-quarter of taxa ($n = 366$, 22.8%) had the vast majority (>95%) of their range on a single tenure type. Over half of these ($n = 201$, 12.5% of all taxa) occurred almost solely on freehold lands, while 139 taxa (8.7% of all taxa) occurred almost solely on protected lands and 14 (1% of all taxa) on leasehold lands (Table 2). Of the combinations (pairs) of tenure categories, two-thirds (64%) of species ($n = 1024$) had >5% of their distributions on both protected areas and freehold lands (Figure 4b). The combination of tenure categories that had the next highest taxa count was forestry and freehold lands, with 21% of species ($n = 344$) having >5% of their distributions on both tenure types (Figure 4b). The overlap of each EPBC Act listed threatened taxa with each land tenure category included in this analysis is provided in Supplementary Table 4.

4 | DISCUSSION

Our study revealed that freehold lands and protected areas covered the largest proportion of species distributions, with freehold lands being particularly important for those species at greatest risk of extinction (i.e., Endangered and Critically Endangered) and protected areas for narrow-range species. The majority of species (75%) occurred across multiple land tenures, highlighting the critical need for multi-tenure efforts in Australia's response to the species extinction crisis. This effort in its nature needs to be inclusive and account for the values and preferences of local land managers,

landowners and custodians, creating environmental co-benefits and job opportunities. Supporting Indigenous leadership in decision-making and culturally appropriate management will be critically important for species and places with Indigenous interests (Ens et al., 2016; Moorcroft et al., 2012), which overlap with all of the land tenure categories considered in this analysis (Garnett et al., 2018; Renwick et al., 2017).

4.1 | Conservation on freehold land has significant benefits for Australia's biodiversity

Our analysis showed how important freehold land management is when it comes to abating species extinction in Australia. Freehold land accounts for the greatest proportion of threatened taxa distributions (48%) and a majority of the distributions of those species at greatest risk of extinction (Endangered: 54%; Critically Endangered 53%). It is not surprising that many threatened species are known or are likely to exist on freehold land, given that these lands have seen the greatest impact of some processes that cause species endangerment in the first place (e.g., land clearing and other forms of habitat loss and degradation, Evans, 2016). However, our analysis and a recent analysis by Ivanova and Cook (2020) highlight the great urgency and enormous potential of achieving positive biodiversity outcomes on privately owned lands if Australia employs different strategies to landscape conservation.

Building on opportunities for farmers and other landholders and custodians to contribute to cross-tenure and landscape-wide threat management therefore has significant benefits for Australia's threatened species. There are a multitude of instruments and mechanisms available to governments and nongovernment entities to achieve positive threatened species outcomes across the tenure landscape, particularly in relation to habitat retention, a critical action needed for many (86%) Australian threatened species (Kearney et al., 2020). These include government, private and Indigenous protected areas (Archibald et al., 2020), economic incentives (e.g., biodiversity stewardship: Burns et al., 2016; carbon farming: Evans, 2018), disincentives (e.g., land-clearing legislation: Evans, 2016), educational programs (Byron et al., 2014) as well as income diversification and influencing reduced demand for products that drive habitat loss and degradation (e.g., beef: McAlpine et al., 2009; Selinske et al., 2020). Often it is a mix of these interventions that generates the most cost-effective outcome, informed by understanding public and private benefits and costs (see Pannell (2008) for more on this balance). The many mechanisms and

instruments available for retaining habitat quality and quantity need to be activated across a spectrum of tenures to overcome this prevailing threat (Ward et al., 2019).

4.2 | Securing the fate of range-restricted species

Our analysis shows that one in seven ($n = 227$) Australian threatened taxa occur almost entirely (>95% of distribution) on a single non-protected tenure type, with the majority of these ($n = 201$) occurring solely on freehold lands. The pygmy blue-tongue lizard (*Tiliqua adelaidensis*; Endangered), endemic to South Australia, occurs only on freehold lands in a highly fragmented landscape dominated by agriculture (predominantly sheep grazing). For this species, mitigating the impacts of the identified threats from intensive agriculture, pollution, and urban development (Fenner et al., 2018) on private lands is now vital to its persistence. Furthermore, the 2012 recovery plan for the species noted that all known habitat is critical to the survival of the species (Duffy et al., 2012, p. 10), highlighting that the recognition and effective management of species' critical habitats is vital to the persistence of this freehold-endemic species. Likewise, the shapely zieria (*Zieria formosa*, Endangered), a plant species endemic to south-eastern New South Wales, occurs only on privately owned lands. Known only from a single population across three rural residential properties (Threatened Species Scientific Committee, 2016), the species persistence now relies on actions to ensure agriculture, pollution, invasive species, and fire are effectively managed on these properties.

On leasehold lands, the Carpentarian rock-rat, Aywalirroomoo (*Zyzomys palatalis*; Endangered), is known only from a single pastoral property in the Northern Territory (Puckey et al., 2003). Management of fire regimes is the primary action needed, along with management of introduced herbivores and predators (i.e., feral cats) and mitigation of the impacts of climate change (e.g., through translocation; Threatened Species Scientific Committee, 2019). The persistence of these (and the other >200) species depends on effective, coordinated threat management and conservation efforts on non-protected lands. These species and their critical habitats must be the focus of specific planning that works with all relevant stakeholders to ensure their extinctions are prevented. At present, most species do not have adequate recovery plans (McDonald et al., 2015) to ensure their persistence, particularly on non-protected lands. Greater effort to tailor strategies to other land tenures, especially private lands, is required.

While working with existing private landholders will be critical, another important component of securing the fates of threatened species, particularly range restricted ones, on private land is through the direct acquisition and protection of this land. Nongovernment organizations have become involved in proactively securing important habitat on non-protected tenures and safeguarding it for conservation. This has been a successful mechanism for securing habitat for species like the night parrot (*Pezoporus occidentalis*; Endangered) in eastern Australia. After the night parrot's rediscovery, Bush Heritage Australia purchased 56,000 ha of land that was previously under pastoral lease (Bush Heritage Australia, 2020). The reserve has since been declared Australia's first Special Wildlife Reserve, providing National Park (IUCN category II) level protection of the species habitat on private land (Bush Heritage Australia, 2020). However, this level of protection for private land is currently only available in Queensland, demonstrating the importance of more widespread legal support for innovative conservation mechanisms.

4.3 | Coordination across multiple tenures is needed to recover the majority of species

Coordination and collaboration of efforts within and across tenure types is vital to halt Australia's biodiversity loss as three-quarters of species occur across multiple tenures. This requires integrating multiple tenures into regional planning initiatives up front, to understand which policies are appropriate where (Karimi & Adams, 2019). Regional natural resource management groups play a key role in the coordinated and collaborative management of biodiversity across Australia (Youl et al., 2006), and the private land conservation sector is growing (Fitzsimons, 2015). However, critical deficiencies remain in the size and coordination of these efforts to ensure their potential benefits can be fully realized (Robins, 2018). Although coordinated and broadscale cross-tenure management of some threats occurs in some regions of Australia (e.g., European red fox; Saunders et al., 2010; Fleming et al., 2014), many are not. For example, feral cats, a nationally recognized key threatening process, lack a coordinated large-scale management and monitoring initiative (Garrard et al., 2020). Similarly, despite the 2006 and 2016 Threat Abatement Plan for chytrid fungus calling for national coordination of management efforts (Commonwealth of Australia, 2006, 2016), such an approach is still lacking (Skerratt et al., 2016).

Many Australian species are also highly mobile (Runge et al., 2015) and use different parts of the

landscape depending on lifecycle stages or the need to follow ephemeral resources (Griffioen & Clarke, 2002; Kerecsy et al., 2013). Species such as regent honeyeater (*Anthochaera phrygia*; Critically Endangered), swift parrot (*Lathamus discolor*; Critically Endangered) and gray-headed flying-fox (*Pteropus poliocephalus*; Vulnerable) have very large distributions and are highly dependent on seasonal and shifting resources (Franklin et al., 1989; Roberts et al., 2012; Saunders et al., 2007). These species are in decline due to acute threatening processes, particularly habitat destruction due to logging, urban development, and agriculture, operating in parts of their range that are periodically critical for the species survival. Multi-tenure actions are now vital for these and similar species to secure them from extinction.

Recognizing the multi-tenure distribution of many EPBC-listed species also points to the need for legal reform to improve the implementation of recovery plans and threat abatement plans (EPBC Act sections 188, 270A) across a broad range of tenure types. At present, both recovery plans and threat abatement plans bind only the Commonwealth (EPBC Act sections 139(1) (b), 268) and lack requirements of implementation outside Commonwealth land (section EPBC Act 269(2)), a subset of Crown land. As a result, threatening process can occur across many tenure types where Commonwealth approvals or actions are not involved.

While the findings of our analysis highlight the broad trend of the importance of freehold lands and protected areas for many species, the reality is that the intersection between threatened species and land tenure across Australia is highly diverse, with many unique combinations of land tenures being important for species. These combinations present unique opportunities and challenges to coordinating conservation efforts across Australia. As highlighted by our analysis, the most species-rich tenure combination is freehold lands and protected areas, with over 1000 taxa having >5% of their distribution on both tenures. Approaches to landscape-scale and cross-tenure conservation, such as Biosphere Reserves and Conservation Management Networks, provide a means of coordinating conservation efforts across public and private lands (Fitzsimons et al., 2013; Wyborn, 2011). Concerningly, land tenure combinations including forestry (e.g., freehold and forestry; forestry and protected areas) are important for the conservation of hundreds of Australian threatened taxa. At present, forestry remains a troublesome land tenure in terms of threatened species conservation efforts in Australia (Lindenmayer & Burnett, 2021), especially as forestry is a major threatening process to many endangered species (Kearney et al., 2019; Ward et al., 2021), making cross-tenure conservation efforts difficult (Webb et al., 2018).

Managing threats that impact imperiled species beyond protected area boundaries can drive a multitude of co-benefits such as increased agricultural profitability (Rees et al., 2020) and carbon sequestration (Carwardine et al., 2015; Evans et al., 2015). A growing body of evidence suggests that many threats to biodiversity are having increasingly negative impacts on other land uses as well as human livelihoods and well-being. For example, widespread land clearing in many areas has had significant impact on local weather and climate in Australia (Andrich & Imberger, 2013; Pitman et al., 2004) and elsewhere (McAlpine et al., 2018; Salazar et al., 2016), impacting agricultural productivity and water sources for human settlements. Similarly, widespread land clearing across large parts of Australia has resulted in major salinity issues, rendering these areas inhospitable for agriculture and biodiversity alike (Murray-Darling Basin Authority, 2015). Furthermore, the management of numerous invasive species has obvious benefits for agricultural activities and other ecosystem services (Pejchar & Mooney, 2009), as invasive species in Australia cost billions in economic losses and control measures (Hoffmann & Broadhurst, 2016). The European rabbit (*Oryctolagus cuniculus*), an invasive species most commonly listed as impacting threatened species in Australia (Kearney et al., 2019), has an estimated economic impact on Australian agriculture in excess of AUD\$200 million annually (Gong et al., 2009). Similarly, lantana (*Lantana camara*) impacts nearly 100 Australian threatened species (Kearney et al., 2019) and costs the livestock industry over AUD\$100 million in lost productivity and management expenses annually (Grice et al., 2014). Obviously, those threats to biodiversity that have already been identified to impact human livelihoods should not be the sole focus of management interventions; however, it does provide useful insights into threat management opportunities and co-benefits.

Conservation success for threatened species requires going beyond active threat management (e.g., invasive species control; habitat restoration), to ensure that the management and use of habitat on non-protected lands becomes more compatible with the persistence of threatened species (and maintaining common species, preventing their decline into threatened status). Technology and innovation will have a role to play in this (Sayer & Cassman, 2013), as will landscape-scale planning and a shift toward biodiversity-compatible and regenerative agriculture (Fischer et al., 2008; White, 2020) and multifunctional landscapes (Kremen & Merenlender, 2018). In addition, many threatened species are unable to tolerate negative human disturbances, so intact areas free from incompatible human pressures are critical to their survival (Di Marco et al., 2018; Nori et al., 2018). Ambition and leadership are urgently needed to establish institutions that signal the public desire for long-term sustainable production and biodiversity

conservation (Leclère et al., 2020; Springmann et al., 2018). Fundamental to this is mapping the core habitats of threatened species, monitoring their trajectories, and making this information available to prioritize the most important locations for these efforts. The Key Biodiversity Area (KBA) process provides a useful framework within which to achieve this (Langhammer et al., 2017). KBAs are sites that contribute significantly to the global persistence of biodiversity, including threatened species (IUCN, 2016). The KBA criteria are globally standardized, consistent, repeatable, quantitative, and transparent and provide a tenure-blind approach to identifying significant sites for threatened species. The recognition of a site that is important for a threatened species as a KBA can help inform land management practices and provides a clearly delineated area that is priority for the management of threatening processes.

5 | CONCLUSION

Understanding the distribution of threatened species across the human landscape is critical to informing how best to respond to species decline. We assessed this in the context of Australian land tenure, to help inform the response to the extinction crisis by combining threatened species distributions maps with land tenure spatial data. Our research points to the need for strengthening Australia's multi-tenure approach to the conservation of threatened species. Working with landholders and custodians across all tenures is critical for better threatened species outcomes, as coordinated actions by land managers are essential to the persistence of many species. Key to achieving this will be mapping out the key habitat areas and gaining agreement and resources for the critical actions needed to secure threatened species from extinction, as well as ensuring that the benefits of this management to the broader environment and its people, are realized. Furthermore, threatened species survival hinges on a step change in both the laws that manage conservation outcomes across tenure types and the opportunities available for landholders to contribute to threat management and positive threatened species conservation outcomes on their lands.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Stephen G. Kearney, Josie Carwardine, Vanessa M. Adams, and James E. M. Watson conceived the idea and designed the research. James E. M. Watson acquired the data. Stephen G. Kearney analyzed and interpreted the data, with assistance from all authors. Stephen G. Kearney, Josie Carwardine, and James E. M. Watson drafted the manuscript with input from all authors. All authors contributed to critically editing and revising the manuscript.

DATA AVAILABILITY STATEMENT

This study used a combination of commercial, restricted access, and freely available datasets. The species' distribution data was provided by the Australian Government's Department of the Environment via a Data License Deed. A publically available (and lower resolution) version of this dataset is available from the URL link in the reference list. The PSMA CadLite and Land Tenure data are commercial products which require a paid subscription to access and use. The Geoscience Australia land tenure dataset and the Collaborative Australian Protected Areas Database are freely available via the relevant URL links in the reference list.

ETHICS STATEMENT

No ethical approval was required for this study.

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SUPPORTING INFORMATION

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