A composite measure of habitat loss for entire assemblages of species

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Abstract

Habitat destruction is among the greatest threats facing biodiversity, affecting common and threatened species alike. However, metrics for communicating its impacts typically overlook the non-threatened component of assemblages. This risks the loss of habitat for species that comprise the majority of assemblages going unreported. Here, we adapt a widely-used measure for summarizing researcher output (the h index) to provide the first metric describing natural habitat loss for entire assemblages, inclusive of threatened and non-threatened species. For each of 447 Australian native terrestrial bird species, information on their association with broad vegetation groups was combined with distributional range maps to identify the difference between the estimated pre-European and current extents of potential habitat. From this, we calculated the 'Loss Index' (LI), which reveals that 30% of native birds have each lost at least 30% of their potential natural habitat—an LI of 30. At the sub-continental scale, the LI ranges from 15 in arid Australia to 61 in the highly transformed south-east of the country. Further, different subcomponents of the

assemblage have different LI values; for example, Australia's parrots (n=52 species) have an LI of 38, while raptors (n=32 species) have an LI of 25. The LI is simple to calculate, and can be determined using readily available spatial information on species distributions, habitat associations and human impacts on natural land cover. This metric, including the curves that are used to deduce it, could complement other biodiversity indices by being used for regional and global biodiversity assessments, comparing the status of natural habitat extent for assemblages within and among nations, monitoring changes through time, and forecasting future changes to guide strategic land use planning. The LI is an intuitive tool with which to summarise and communicate how human actions affect whole assemblages, and not just those that species identified as threatened.

Introduction

In light of the rapid environmental changes occurring in the Anthropocene (Steffen et al. 2014), numerous indices have been developed to quantify and monitor the status of biodiversity (Scholes & Biggs 2005; Collen et al. 2009; Butchart et al. 2010; Jones et al. 2011; Newbold et al. 2016; Australian Threatened Species Index 2018). Many of these tools focus on defining the conservation status of, and informing management priorities for, threatened species (Possingham et al. 2002; Gaston & Fuller 2008; Mace et al. 2008). Indices such as the number of threatened species occurring in a place (Possingham et al. 2002), or measures of extinction risk and changes thereto (Butchart et al. 2004; Hoffmann et al. 2010; Szabo et al. 2012), guide funding and conservation efforts towards those species at imminent risk of loss (Venter et al. 2014).

A focus on individual threatened species potentially obscures a bigger picture—the broader-scale attrition of entire assemblages. Native species that are non-threatened, including those that are common or abundant, are not typically afforded the same level of protection and monitoring as listed threatened species despite being integral to ecosystem function and service provision, and subject to those same pressures that act on threatened species (e.g. habitat loss) (Gaston & Fuller

2007; Gaston 2010, 2011; Redford et al. 2013; Ceballos et al. 2017). Such declines of common species—for example, farmland birds in Europe (Inger et al. 2015) and woodland birds in Australia (Lindenmayer et al. 2018)—have been linked to a reduction in the provision of key services like pollination and (pest) insect control, which has broader implications for the function and persistence of ecosystems (Sekercioglu 2006). Further, these are the species that most connect people with nature (Redford et al. 2013), and their loss contributes to declining human-nature interactions (Soga & Gaston 2016).

As the footprint of humanity continues to spread (Venter et al. 2016), we are seeing the creeping obliteration of natural habitat for huge numbers of species (Lovejoy 2017). There have hitherto been no standard approaches to quantify and communicate the impacts of this loss as it affects whole assemblages; a gap in conservation policy and practice that warrants urgent attention. To address this, mapping the loss of habitat for multiple species can reveal the severity of this syndrome on assemblages. Taking this a step further, summarizing habitat loss in a simple metric represents a powerful tool by which to communicate and assess the effects of natural ecosystem conversion for entire assemblages of species, and not just the component that is at risk of becoming extinct in the near future as is currently the focus of most conservation metrics.

Here, our aim is to demonstrate that the extent and magnitude of the loss of potential natural habitat for an entire assemblage can be captured in an intuitive metric. Using a case study of Australia's native terrestrial birds, we show that our proposed 'Loss Index' can be used to describe and compare the effect of native vegetation removal on assemblages comprising hundreds of species, in a straightforward and repeatable way. We discuss the policy and applied implications of the Loss Index, while also highlighting the limitations of the approach. Given appropriate data inputs, the approach could be implemented from scales ranging from local to global, and for a wide range of taxonomic groups. In particular, we highlight the utility of this metric, and the maps and curves that are produced to determine it, for informing broadscale conservation efforts, such as listings under the International Union for Conservation of Nature (IUCN) Red List of Ecosystems, and regional, national, and global assessments, such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

Methods

The Loss Index (LI) is based on the h index—a measure used to describe the output of academic researchers (Hirsch 2005). By ranking a researcher's papers based on the number of times each has been cited, a single number can be derived to characterize that researcher's output: "*A scientist has index h if h of his or her N_p papers have at least h citations each and the other (N_p - h) papers have ≤ h citations*" (Hirsch 2005). Because it subsumes two critical pieces of information (number of papers, number of citations), and can be easily computed, it is advocated as a useful way to communicate and compare the broad impact of researchers (Hirsch 2005).

We used this logic to characterize the extent to which loss of native vegetation has affected a multi-species assemblage. Unlike the h index, which uses counts (of papers and citations), we use percentages—the $LI = x$, where $x\%$ of species in an assemblage have each lost at least $x\%$ of their potential natural habitat. Thus, the two key variables that are subsumed into the metric are the number (percentage) of species in the assemblage of interest (e.g. from a particular region and/or taxonomic group), and how much potential natural habitat each of these species has lost (as a percentage of some baseline (for example, pre-clearing or pre-Industrialisation) extent). A higher LI value indicates loss of potential natural habitat that is both more extensive, and affects more species in an assemblage. Because fine-resolution habitat use/occupancy data for multiple species across broad extents is rarely available, the LI focusses on the loss of different types of native vegetation that would be expected to variously provide habitat for different species in an assemblage. The LI thus conveys the loss of *potential* natural habitat for multiple species that comprise assemblages, and is not a direct measure of loss of occupied habitat.

We demonstrate the LI for an assemblage of 447 Australian native terrestrial bird species (representing the vast majority of native species with terrestrial habitat associations). We omitted 16 native species from the analysis because of their highly-specialized habitat associations, which were not likely to be reflected by the resolution of the data inputs we used. Furthermore, habitat loss was assumed to be zero for 20 generalist native species that thrive in highly modified environments (major cities, areas under intensive agricultural production). Australia is an ideal case study to test the LI: large parts of this megadiverse continent have been substantially transformed since European colonization, and it is considered a current global deforestation hotspot as some regions are undergoing rapid transformation (Reside et al. 2017), with more planned for the future (Commonwealth of Australia 2015).

To conduct this analysis, we used maps of native vegetation cover across Australia representing two points in time. The National Vegetation Information System Major Vegetation Groups (NVIS MVG) contemporary (i.e. current) and estimated pre-1750 vegetation maps (1 ha resolution) are produced by the Australian Government using a rigorous and standardized mapping methodology, and are explicitly designed for comparative purposes (Department of the Environment and Energy 2018). The maps are based on vegetation data spanning over 100 individual projects produced over the last 50 years (Department of the Environment and Energy 2016a). While of course an indicative product, given that the pre-1750 NVIS MVG map is produced using such an extensive volume of input data, translated to a common thematic mapping framework which allows for comparison to contemporary native vegetation distribution and extent, we propose that it is appropriate for approximating changes in Australia’s native vegetation coverage between 1750 and now. Indeed, this is the most detailed and comprehensive vegetation mapping that is available for the continent of Australia, and is the best representation we can have of how much of each vegetation type occurred prior to European settlement and has now been lost (in other words, the baseline extent).

The NVIS MVG products map the extent and distribution of 25 different native vegetation groups, including various forms of forest, woodland, shrubland and grassland. We used a database of Australian bird feeding habitat associations—for example "Terrestrial Temperate dry sclerophyll forest and woodland"—that aligns individual bird species with specific NVIS MVGs (Garnett et al. 2015), to produce two maps for each of the 447 species in the study: a pre-1750 (i.e. baseline) and contemporary (i.e. current) map of habitat with which each species is associated. We then used range maps produced by BirdLife International (BirdLife International and Handbook of the Birds of the World 2016) to clip these maps to the current range of each species. For threatened species listed under Australia's *Environment Protection and Biodiversity Conservation Act 1999* (n=29), we had access to range maps produced by the Australian Government (Department of the Environment and Energy 2016b), and as these tended to better represent the known distributions of this subset of birds, we used these where available. We used the maps of pre-1750 and contemporary species-specific habitat associations to calculate the proportion of potential natural habitat that each species has lost, within its currently-described range. Because data on the historic ranges of species are notoriously uncertain, and almost no such maps exist across any taxonomic group, our calculation of loss of potential natural habitat are likely to be an underestimate for those (relatively few) bird species that are known to have experienced substantial range contractions since European settlement of Australia. All extraction and analysis was done using ArcMap 10.5 (ESRI 2016).

In the same way that the h index is calculated, we determined the LI for Australia's native terrestrial birds by ranking species (as a percentage of the total assemblage (n=447)) from highest to lowest proportional potential natural habitat loss. For example, the species that had lost the highest amount of its potential natural habitat was ranked first out of 447 species. By converting the cumulative count of species (as reflected by the rankings: 1 species out of 447 has lost at least x amount of potential natural habitat, 2 out of 447 have lost at least y amount of potential natural habitat etc.) to a percentage, we calculated the LI from a plot where percentage of species in the assemblage (i.e. out of a total of 447 species) was the x-axis, and amount of potential natural habitat that that percentage of species in the assemblage had lost was the y-axis (Fig. 1). We also produced this index for species rich taxonomic groups that make up the broader assemblage (parrots, honeyeaters and chats, thornbills and gerygones, raptors) to explore how the loss of native vegetation has variously affected these birds. Because native vegetation removal has been biased to certain parts of the Australian continent, and to specific habitat types, we examined regional differences in the LI. The regions we examined are those used by BirdLife Australia for the purposes of monitoring sub-continental trends in bird populations (BirdLife Australia 2015), and are based on Australian agro-climatic zones (Hutchinson et al. 2005).

Results

We show that Australia has a LI of 30 (Fig. 1). Despite its relatively small human population, and extensive tracts of wilderness in the arid and tropical zones (Watson et al. 2016), 30% of Australia's bird species have lost at least 30% of their potential natural habitat. This value describes, in relative terms, the amount of potential natural habitat lost, and the number of species this affects, for an assemblage of over 400 primarily common species, at the continental scale. All habitat loss data (for the whole of Australia, and for regions), and the identity of species excluded from the analysis, are presented in Supporting Information.

The LI allows for comparison of habitat conversion implications for sub-components of Australia’s terrestrial avifauna. For example, parrots have an LI of 38 (Fig. 2). Parrots, most of which are considered Least Concern (IUCN Red List of Threatened Species; n=45/52 species), have therefore suffered relatively more loss of potential natural habitat, affecting a greater proportion of species. The lower LI for raptors (LI=25) reflects the wide distribution and broad habitat preferences of many of these birds—while a large amount of natural vegetation has been lost, this is a relatively small fraction of the amount of potential natural habitat remaining in the broad geographic ranges of many of these species.

We demonstrate large differences in LI values for regions that differ in land use intensity and biogeographic characteristics (Fig. 3). For the South-east Mainland region of Australia, most species have lost most of their potential natural habitat, as revealed by an LI of 61. Even without accounting for lost habitat associated with range contractions—the extent of which we will never fully know due to lack of data on historic ranges—this high LI value reveals that native vegetation removal has far-reaching implications for the majority of this region's avifauna, despite most species being considered 'Least Concern' (n=250/262 species). The LI drops to just 15 and 17 for the extensive Arid Zone and Tropical Savanna regions, respectively, both of which support large, diverse bird assemblages, and have been subject to relatively little development.

Discussion

The LI showcases the effect of native vegetation conversion on whole assemblages of species in an intuitive, comparable metric. It can highlight the extent to which native vegetation conversion affects those species which make up the bulk of assemblages, and which receive the least attention—those that are non-threatened, including common and abundant species. Thus, it complements measures that focus only on risk of extinction. For example, although only 7% (n=33) of the species assessed here are categorized as threatened or near threatened by the IUCN Red List of Threatened Species, 30% of Australia's birds have lost at least 30% of their potential natural habitat (LI=30). Notably, potential natural habitat loss is relatively low for a number of Australia's threatened and near threatened birds (triangular points in Fig. 1). For some, this is because they occur in less transformed regions of Australia, and the threats that imperil them are not primarily habitat loss; while for a small number of species, the mapped range corresponds with that species' current area of occupancy, which itself reflects the last remnants of that species' original habitat (e.g. red-lored whistler (*Pachycephala rufogularis*)).

The LI is more informative than statistics on the amount of native vegetation loss in a region, given that it accounts for the habitat associations and range of each species. In our Australian case study, potential natural habitat was defined for each of the 447 species in the assemblage given each species' known association with up to 25 different NVIS MVGs classes as per Garnett et al. (2015). This specificity is reflected by the shape of different LI response curves, three of which we observed from our Australian case study (Fig. 4). These curves can inform our understanding of how the loss of native vegetation (and the habitat this provides) in a region or country acts on entire assemblages, given differences in the number and type of habitats, the extent to which these habitats have been converted, and the number of species in the assemblage affected by these losses.

We did not observe a convex curve—indicative of very high levels of habitat loss affecting most species in an assemblage—in our Australian case study. We propose that this may present in a limited set of circumstances; for example, a system where the assemblage is linked to a small number of very highly depleted natural habitat types. Regions of Australia with the highest LI values are characterized by a sigmoidal curve. In the South-east Mainland region, with a sigmoidal curve and an LI of 61, numerous studies indicate that a number of once common bird species are in decline (Bennett & Watson 2011; Ford 2011). We found a similar LI score, with the same sigmoidal response curve in the Brigalow Belt region, where trends in bird populations are less well known. High levels of native vegetation conversion have and continue to occur in places such as the Brazilian Atlantic Forest (Ribeiro et al. 2009) and rainforests of south-east Asia (Hughes 2017); we hypothesize these regions are likely to have similar response curves that reflect assemblages undergoing severe depletion. Australia's relatively intact Arid Zone and Tropical Savannas have low LI values, and are characterized by a concave curve. We expect that regions with similarly low human pressures, such as the Taiga Biome and parts of the Congo Basin (Venter et al. 2016), are likely to have similar curves.

Areas with a high LI value may benefit from immediate intervention focussing on proactively protecting the last remaining areas of native vegetation and, where appropriate, revegetation and matrix enhancement. The shape of the curve (convex or sigmoidal), in combination with the potential natural habitat loss maps from which they are derived, can guide which actions should be undertaken, and where these should occur to achieve the greatest gains. For example, habitat restoration efforts could be focussed on those places that historically supported high species richness, as revealed by these maps (e.g. Fig. 3). From a monitoring perspective, ongoing conversion of natural areas leading to a departure from a concave LI curve towards a sigmoidal or convex LI curve may be indicative of a system in which an assemblage is being substantially eroded by the loss of native vegetation.

The maps of loss of potential natural habitat that underpin calculation of the LI could be used to forecast future changes in the LI. This is particularly relevant for parts of our Australian case study—namely, the relatively intact Tropical Savanna region, where substantial future development is planned (Commonwealth of Australia, 2015). Because the LI is sensitive to species-specific habitat associations and species' ranges, different scenarios of future land cover change will result in different LI values. Thus, the LI could play a role in guiding land use planning decisions to help reduce the cumulative impact of habitat conversion on whole assemblages. Crucially, strategic use of the LI in this way may reduce the syndrome of 'death by a thousand cuts', whereby habitat for species that typically escape the scrutiny of assessment (i.e. non-threatened species), is eroded by numerous (often small) losses.

Like any biodiversity metric, the accuracy and precision of the LI will depend on the input data. This has implications for how the metric is interpreted and used. For example, where data of adequately fine resolution that reflect the known or likely habitat use or occupancy of individual species are available, and are used to calculate loss of potential natural habitat, the LI could be used in combination with other indicators and monitoring data to guide land use planning decisions. The coarser the data on species-habitat associations (in spatial resolution, and/or the specificity of associations), the more approximate the LI will be; in such instances, the LI is better viewed as a communications tool by which to shine a light on the broad issue of habitat attrition for whole assemblages, again as a complement to other metrics that describe the status of and trends in species and habitats across regions, nations and globally. Further, as with all broad-scale analyses, caution should be used in comparing LI values where the input data—including the resolution of the input data and the habitat classification system used—differ. In this regard, global-scale datasets on species ranges (e.g. IUCN Red List Spatial Data; BirdLife International), broad habitat/ecosystem types (Olson et al. 2001) and levels of anthropogenic land conversion (Venter et al. 2016), lend themselves to development of a systematic habitat classification scheme, and standardized and comparable LI values.

In an era of more readily-available data on species, ecosystems and human impacts, the LI provides an inexpensive and quick approach for summarising and communicating the effects of natural habitat conversion. It is not reliant on comprehensive (expensive) species monitoring data; thus, it could be used by nations to provide a quantitative estimate of the extent to which conversion of the natural environment has affected its various native biotic assemblages (and regional subsets of these). In turn, such information could be reported on in National Biodiversity Strategies and Action Plans under Aichi Biodiversity Target 17 (including the establishment of targets for assemblages), and/or assessments needed for national-level reporting required by signatory nations to the Convention on Biological Diversity, and regional and global assessments undertaken by IPBES. Additionally, the LI could be a useful input to assessments of risk of ecosystem collapse in accordance with the criteria for the IUCN Red List of Ecosystems. For example, when assessing

"Criterion D: Disruption of Biotic Processes and Interactions", a high LI value for a taxonomic group that (1) overlaps in space with the ecosystem under assessment; and (2) contributes to the function of that ecosystem via biotic processes and interactions, may be an instructive complement to other metrics used to address this Criterion.

When considered alongside local extirpation metrics based on species inventory data (Pärtel et al. 2011), and/or more complex measures that document population trends for a subset of species (e.g. Living Planet Index (Collen et al. 2009)), the LI underscores the vast toll that habitat conversion is having on assemblages. We propose that the LI could be a useful complement to these, and other tools—for example, the Red List Index (Butchart et al. 2004) and the Biodiversity Intactness Index (Newbold et al. 2016). While its focus on loss of potential natural habitat for all species in an assemblage is a novel message, and a crucial (missing) part of the overall picture, numerous threats other than habitat loss are also acting on species, thereby underscoring the need for a complementary suite of metrics to communicate and track biodiversity change. Further, given their capacity to subsume complexity into a simple metric, there remains scope to adapt other bibliometric indices, such as the i10 index (number of papers cited at least 10 times) to help communicate and track the status of and trends in biodiversity.

We stress that the LI should be interpreted and used with care, given several key limitations. First, not all potential natural habitat for a particular species will actually be occupied, due to other factors such as degradation or overexploitation. For example, in the Australian context, threats such as predation by feral animals (Woinarski et al. 2017) and inappropriate burning regimes (Woinarski & Legge 2013) may render potentially suitable (remaining) natural habitat unoccupied. Therefore, because the LI does not account for the condition of potential natural habitat (only the amount), it should not be viewed as an estimate of the loss of occupied habitat. Second, for some species, some habitat may be available despite the removal of native vegetation (indeed a small number of species will benefit from such transformation)—in these cases, estimates of habitat loss will be an overestimate. We dealt with this by specifying that the LI relates to loss of potential *natural* habitat, and we also assumed that for 20 generalist species, habitat loss was zero. Third, past distributions of species are not well known in most instances. By calculating loss of potential natural habitat within the currently known range of species, we were not able to account for range contractions, meaning that calculations of habitat loss for some species would have been underestimates. This point should be considered in communication of the LI—it reflects changes in the amount of potential natural habitat given what we know now of where species are distributed.

We reiterate that the LI is not a direct measure of species loss, and should not be used in this way. Because the LI is a composite measure of loss of potential natural habitat, it does not reflect other factors that further act on an individual species' occurrence within potential habitat, such as habitat degradation or the presence of invasive species. An LI of 30 should not be literally interpreted as 30% of species having lost at least 30% of their *occupied* habitat. Rather, the LI is a simple, indicative measure which highlights the effects of the removal of native vegetation that is potential habitat—an issue that extends far beyond threatened species.

We currently lack metrics that convey the plight of whole assemblages that are (1) easy to calculate and communicate; and (2) actionable via policy and on-the-ground interventions. The LI addresses both of these challenges. It allows for the implications of native vegetation conversion (and the loss of habitat this entails) on whole assemblages to be quantified, communicated and compared in a simple, intuitive way. This is relevant for informing policy and management: it addresses the bias towards metrics focussed on threatened species (Gaston & Fuller 2008), and provides a systematic tool by which to report on and monitor assemblage-level trends. This is especially timely as the world decides upon the post-2020 biodiversity agenda, and the tools by which to enact it. By including all species, the LI shows starkly how conversion of the Earth's surface for human activities profoundly impacts nature. This illuminates the need for us to re-focus our efforts on the full gamut of species that maintain functioning ecosystems, and connect us with nature.

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Supporting Information

Species-specific habitat loss data and the identity of excluded species (Appendix S1), and Loss Index plots for each of the nine regions of Australia considered in this study (Appendix S2), are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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Figures with legends

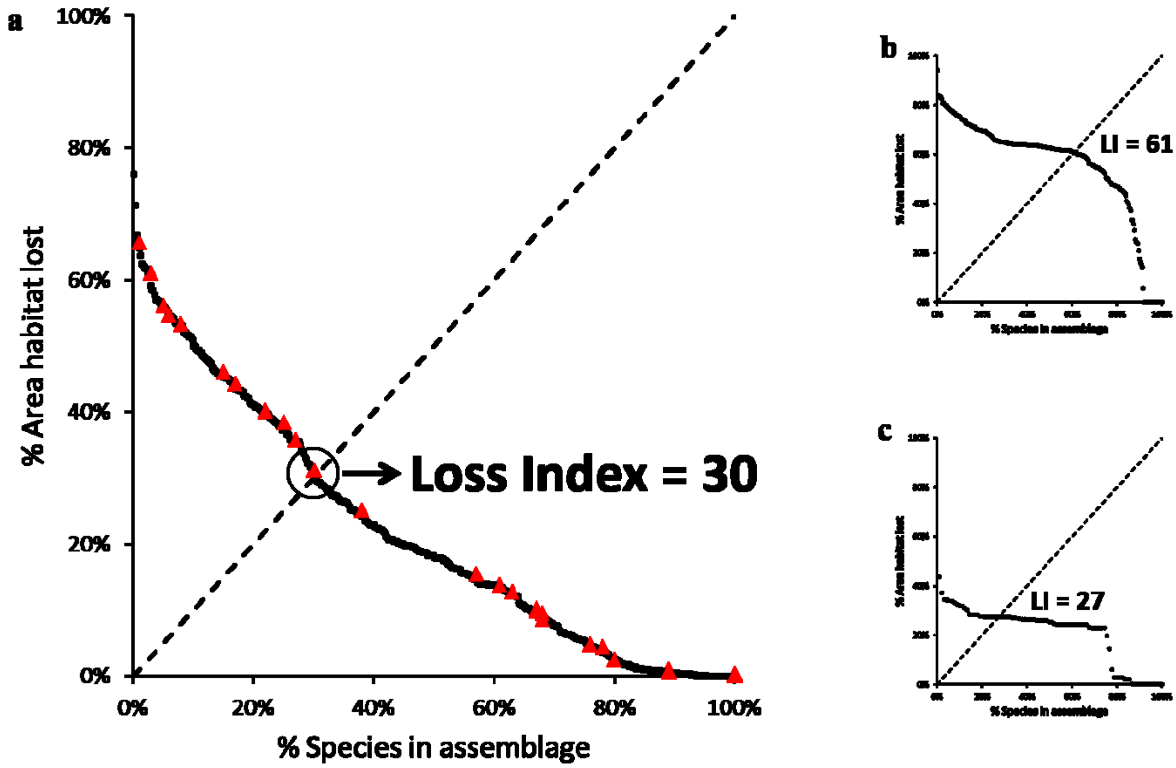

Figure 1. Loss Index plots for Australia's native terrestrial birds (n=447 species) (a). Here, the x-axis represents the cumulative count of species, converted to a percentage of the total number in the assemblage. This can be interpreted as follows: 30% of species in the assemblage (x-axis) have each lost at least 30% of their potential natural habitat (y-axis). This corresponds with the LI, where the 1:1 line intersects the plotted data points. Triangular points on this plot indicate the amount of

potential natural habitat loss for species in the assemblage identified as threatened or near threatened by the IUCN Red List of Threatened Species. Examples of LI plots with different shapes, representing two sub-regions of Australia, are also presented: (b) South-east Mainland (n=262 species); (c) Tasmania (n=90 species).

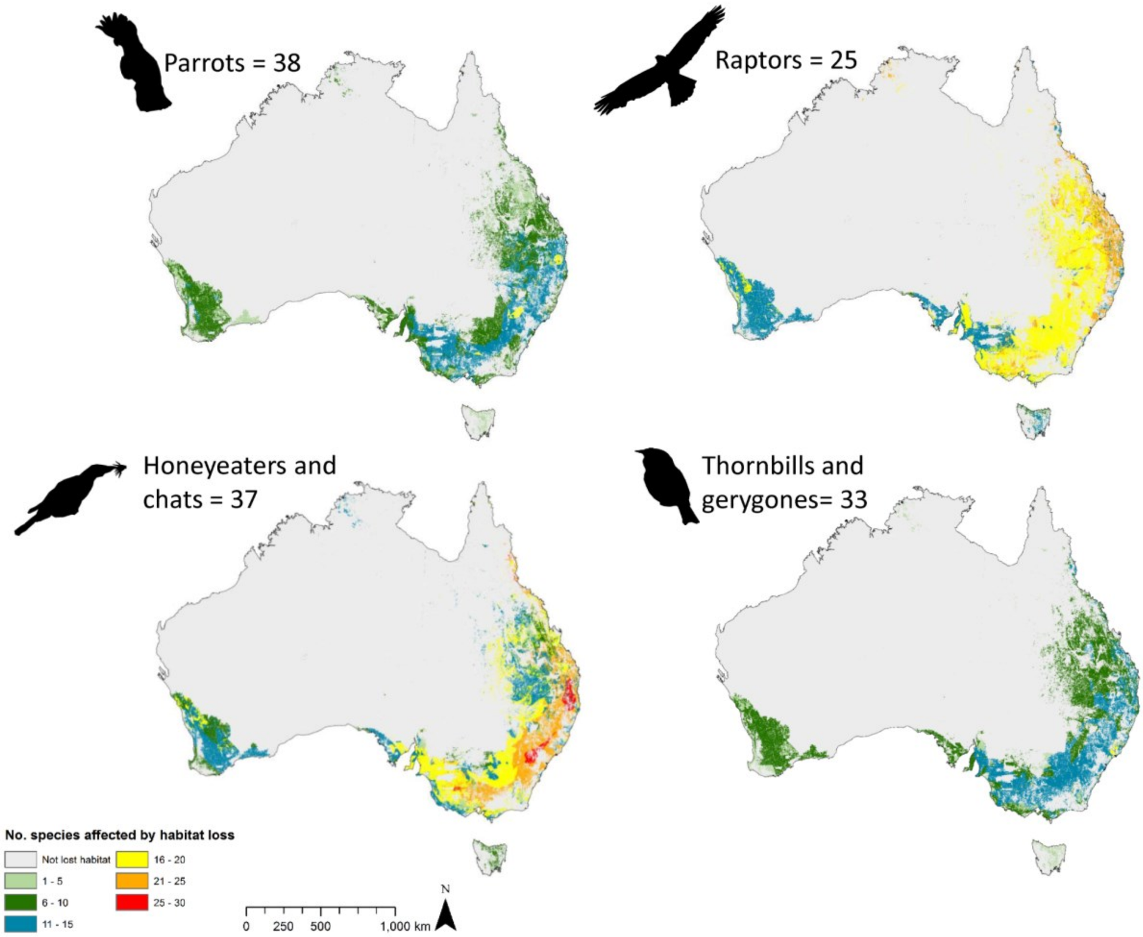

Figure 2. Loss Index for four of Australia's major bird groups. The map for each group (parrots (Families: Cacatuidae and Psittaculidae (n=52 species)); raptors (Families: Accipitridae, Falconidae, Strigidae and Tytonidae (n=32 species)); honeyeaters and chats (Family: Meliphagidae (n=73 species)); thornbills and gerygones (Family: Acanthizidae (n=39 species)) shows the LI, lost potential natural habitat (shaded pixels), and the number of species that are affected by that loss.

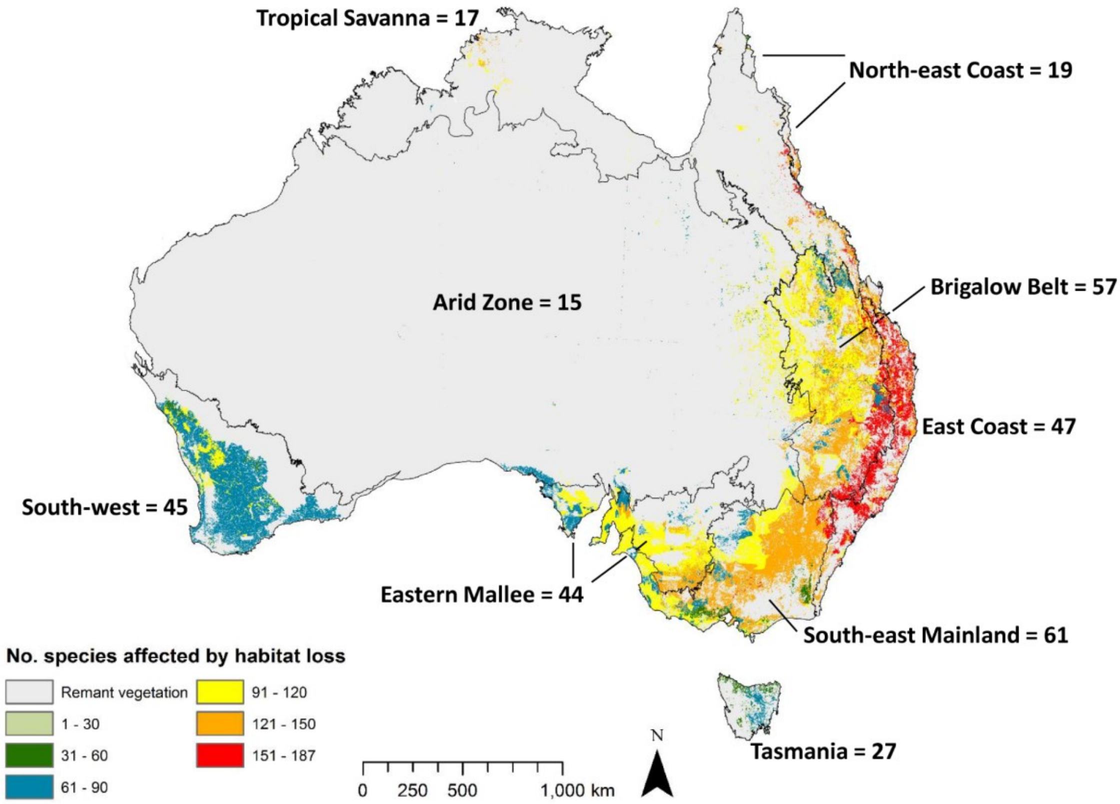

Figure 3. Loss Index for different regions of Australia. Shaded pixels represent natural vegetation that has been converted. The colour scale reveals the number of species (in brackets of 30) that each lost pixel of natural vegetation potentially supported—that is, how many species have potentially been affected by that conversion. See Supporting Information for the LI plots and number of species considered for each of the nine regions.

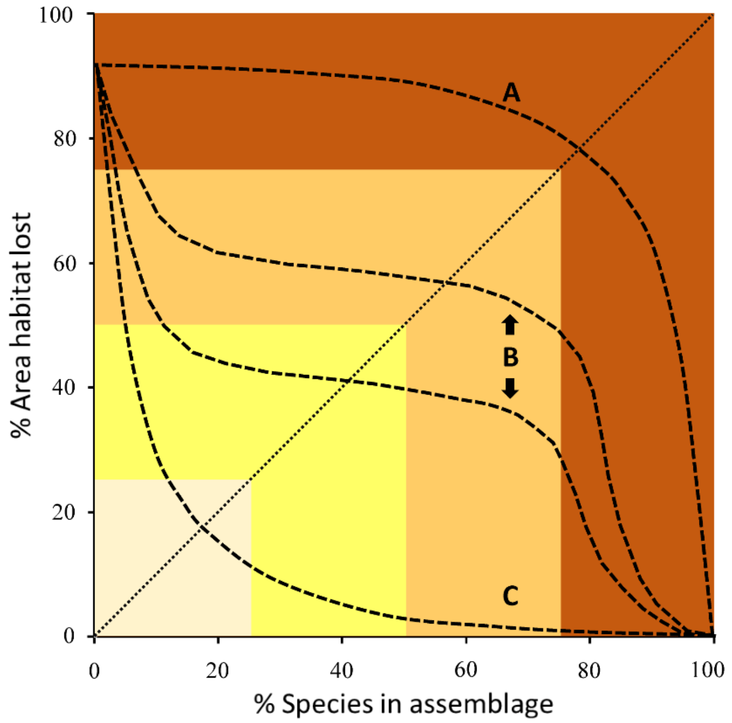

Figure 4. Representation of different Loss Index curves, three of which were observed in our Australian case study. A convex curve (A) indicates a system where natural vegetation removal affects most species in the assemblage. Sigmoidal curves (B) may reflect a heterogeneous system where some habitats are more depleted than others, and/or instances of very high or low losses for some species whose range does not completely encompass the extent being assessed. A concave curve (C) represents a system where large amounts of habitat remain for most species in the assemblage. The shading represents a gradient of LI values (lightest to darkest, respectively): 0-25; 25-50; 50-75; 75-100.