Identifying Hotspots for Threats to Koalas Using Spatial Analysis

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EXTENDED ABSTRACT

Wildlife populations throughout the world are under pressure as human activities expand into previously natural ecosystems. Human population growth is resulting in the rapid development of sensitive coastal regions that frequently coincide with areas of high biodiversity and significant populations of fauna - such as koalas (*Phascolarctos cinereus*). As a consequence, these wildlife populations are increasingly faced with a range of threats associated with anthropogenic activity. While land clearing for urban development results in direct impacts on wildlife populations through habitat loss, the associated effects, including habitat fragmentation and elevated levels of anthropogenic mortality are indirect, insidious and much more difficult to detect or quantify.

Habitat loss has long been regarded as the single biggest threat to the persistence of many species, and the main factor responsible for declining koala populations. Clearing not only results in net loss of habitat, but the fragmentation of the remaining habitat also contributes to a permanent decrease in population size and reduced long term population viability. Degradation of habitat is often associated with fragmentation through edge effects, or through logging regimes, thinning; destruction of mid-storey shelter trees; fire regimes; excessive nutrient input; or introduction of weeds (ANZECC 1998). As a consequence of urban development, koala populations have to contend with the additional threats posed by vehicles, dogs and disease, which are frequently regarded as the main agents of injury and mortality of koalas in or near urban areas (Martin and Handasyde 1999).

This study relates the spatial pattern of threats to wildlife populations with landscape processes culminating in localised extinctions. By examining both habitat fragmentation effects and the major causes of koala mortality (vehicle, dog and disease) the study provides information and techniques to develop management options for wildlife populations in rapidly urbanising areas.

In the Koala Coast region of South East Queensland, threats to koalas were modelled spatially by integrating a forest fragmentation model derived from Landsat TM satellite imagery with threat surface models derived from koala mortality reports. To determine whether the spatial patterns could be related to ecological processes, evidence of localised koala extinctions was also investigated.

The fragmentation model identified and mapped six categories of fragmentation and also provided valuable contextual and descriptive information, essential for assessing potential impacts and management decisions. The Koala Coast was found to be highly fragmented, with only 21% of the study area classified as “interior forest” which represents the most suitable habitat for koalas. By identifying “hotspots”, or spatial concentrations of threats from the surface models using GIS, it was possible to estimate that the anthropogenic mortality risk in the high threat zone (4.5 koala 100ha^{-1} yr^{-1}) was 7.5 times higher than the low threat zone. These threats are already impacting on koala population viability, with 18% ± 5% of the Koala Coast affected by localised extinctions. It is concluded that human-influenced mortality and not habitat loss *per se*, is the greatest threat to koala population viability in these rapidly urbanising areas.

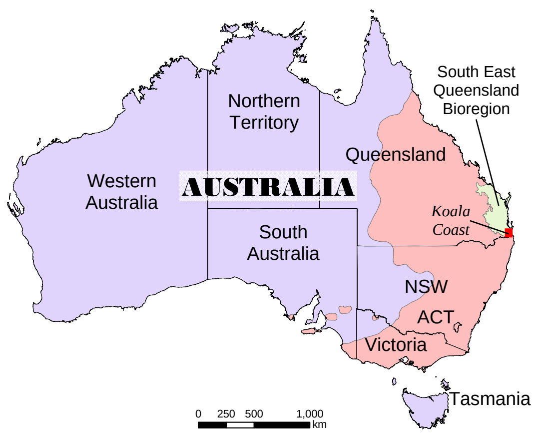

Figure 1. Koala distribution in Australia and location of Koala Coast study area.

1. INTRODUCTION

As human populations continue to grow and become more urbanised, the demands of development and associated infrastructure increasingly impact on local ecosystems. These negative effects are exacerbated where the growth occurs in regions of high biodiversity and are an ongoing source of conflict between wildlife and humans. In Australia the "sea change" phenomena (Burnley and Murphy 2003) is resulting in the rapid development of sensitive coastal regions – to the detriment of irreplaceable plants and animals such as the koala. South East Queensland, home to Australia's most significant natural koala population, has become the fastest growing metropolitan region in the country (Qld Government 2005). This rapid urban expansion threatens the persistence of koalas and many other species and poses significant challenges for managers and decision makers throughout the region.

Threats to wildlife in rapidly urbanising landscapes are characterised by a complex inter-relationship between the direct impacts of habitat loss and the indirect effects associated with habitat fragmentation; habitat degradation; and elevated levels of anthropogenic mortality.

Fragmentation reduces the total habitat area as well as the number of animals supported by the habitat. With the division of a patch into smaller pieces, the reduced habitat supports fewer animals until each patch becomes an unviable resource on its own. In addition, the patches tend to become separated from one another and surrounded by an inhospitable matrix. Individuals attempting to move between patches are subject to higher levels of mortality, and are more vulnerable to predators such as dogs; collisions with vehicles; harsh environmental conditions; stress; or starvation which may exacerbate the effects of diseases such as Chlamydia. Animals can also become isolated within their patch when all the surrounding patches are destroyed. The dangers of the surrounding matrix reduce successful movements between patches ("death by dispersal"), resulting in isolated populations that are prone to decline due to inbreeding, overexploitation of their habitat and localised extinctions (Begon *et al.* 1996).

Land-cover maps derived from satellite imagery offer excellent opportunities for assessing forest fragmentation and its impacts, consistently and at many scales (Loveland *et al.* 1999). On their own, landcover maps indicate only the location, context and forest type, with additional processing needed to quantify and map forest fragmentation (Turner and Gardner 1991, Gustafson 1998). Most studies have focused on the amount, rather than the pattern of forest, with the important forest edge often visualised as a fixed-width buffer around delineated patches of forest (Skole and Tucker 1993; Laurance *et al.* 1998). However, Riitters *et al.* (2000) developed a methodology to map and compare patterns of forest fragmentation at the global scale using a model that distinguishes six different types of fragmentation (interior forest, perforated, edge, transitional, patch and undetermined). This additional information provides critical contextual and descriptive information that is vital for assessing potential impacts and management decisions.

Hotspot analysis provides a powerful tool for analysing and visualising threats to wildlife populations such as koalas. By constructing continuous surfaces using density functions or kernel estimators it is possible to take known quantities of events and spread them across the landscape based on the quantity that is measured at each location and the spatial relationship of the locations (Silverman 1986). By calculating density, it is possible to create a surface showing the predicted distribution throughout the landscape in association with other factors such as mortality risk. Surfaces are a powerful visualisation technique, straightforward to construct and readily communicated. Surfaces, created using the kernel estimator or harmonic mean method, are frequently used in wildlife studies to represent animal home range, movement, or activity centres. While the generation of surfaces is a common GIS technique, their use represent threats to wildlife is not well known in the literature, and there are no previous studies utilising these techniques to model threats in relation to the koala.

In this study, threats were investigated by developing: (1) a spatial fragmentation model to describe the different types of fragmentation; (2) a threat surface model to examine the spatial pattern of mortality, identify hotspots for threats, quantify mortality risk; and (3) a localised extinction model to assess the observed impact on the persistence of the koala population. Through a detailed examination of a sub-regional koala population in South East Queensland, the study develops techniques to addresses the questions: (i) What threat does fragmentation pose to the koala population? (ii) Where are the high threat zones and where are koalas most at risk from anthropogenic mortality? (iii) Is the impact of koala threats already causing localised extinctions?

2. STUDY AREA

The study area, known as the "Koala Coast" (27˚35'S, 153˚10'E), is located within the South East Queensland (SEQ) Bioregion, 20km south-east of Brisbane, Queensland, Australia (Figure 1). It is regarded as one of the most significant koala regions in Australia, primarily due to the relatively high density and large size of the koala population (~6,245 koalas in 1997, Dique *et al.* 2004); the natural condition of the population; and the close proximity to humans. The Koala Coast (37 403ha) is a biogeographically diverse and rapidly urbanising landscape characterised by its semi-rural setting with large areas of relatively contiguous bushland (forest or woodlands dominated by eucalypt and allied species) and primary industries such as grazing. However, human population growth is driving rapid urban development in the region, with the population of SEQ expected to double between 1986 and 2016, reaching four million people by 2026 (Queensland Government 2005).

3. METHOD

3.1. Forest Fragmentation Threat Model

A spatially explicit forest fragmentation threat model, mortality hotspots and threat surfaces were developed to assess the threat to the koala population created by the breaking apart of intact habitat within the Koala Coast. Forest landcover, extracted from a 2003 Landsat-5 Thematic Mapper (TM) landcover classification, was used by a raster model to identify six categories of fragmentation: interior; patch; transitional; perforated; edge; and undetermined. The model determined the category from both the total amount of forest and the spatial context of adjacent forest pixels (Figure 2).

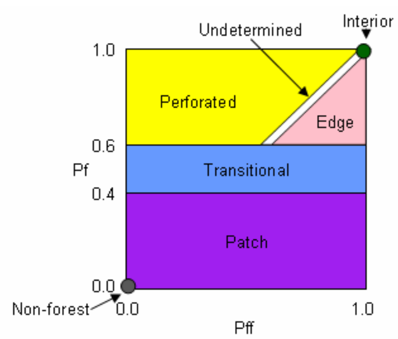

Figure 2. Model used to categorise forest fragmentation. Adapted from Riitters *et al.* (2000) and Civco *et al.* (2002).

The algorithms used for the spatial modelling were developed by the University of Connecticut's Center for Landuse Education and Research (CLEAR) to identify fragmentation of forested landscapes (Civco *et al.* 2002) and were based on the fragmentation model developed by Riitters *et al.* (2000). The algorithms were adapted to work with Landsat 25m landcover data and run in ERDAS Imagine® Macro Language.

The forest fragmentation model calculates two values, Pf and Pff, to characterise a pixel at the centre of a 5x5 moving window. Pf (Proportion forest) represents forest density or the proportion of pixels that are forest; and Pff represents forest connectivity and is a measure of the conditional probability that a pixel adjacent to a forest pixel is also forest. Both Pf and Pff values range from 0.0 to 1.0, with larger values of Pff indicating a higher connectivity of forest pixels (Stauffer 1985).

3.2. Mortality Hotspots and Threat Surface

Mortality threat surfaces were created to represent the major causes of koala mortality as continuous surfaces and to identify hotspots or regions where the death rate was higher than average. This was achieved by interpolating road, dog and disease related mortality using a density function to estimate the death risk across the whole study area. A combined threat surface was also created to estimate the total mortality risk, by combining the three individual cause grids (road, dog and disease) using simple grid addition with no weights. To create a categorical grid showing: high; medium; and low threat level, an equal interval classification scheme was used to recode the threat density. By overlaying the combined threat surface with other data layers, it was possible to create a "threat matrix" and determine the areal extent and magnitude of the impacts in relation to (i) landcover; (ii) koala abundance; and (iii) forest fragmentation. This provided information relating to the proportion of forest landcover; the number of koalas; and the amount of interior forest in each of the threat zones. For details of the landcover classification and koala abundance see Dique *et al.* 2004.

3.3. Localised Extinctions

To determine whether a decline in the population had already commenced, localised extinctions were investigated using koala sightings obtained from Queensland Parks and Wildlife Service (QPWS) for 1997 – 2004. The absence of koala mortality reports for a period of at least three years was used as the basis for estimating where localised extinctions are occurring within the Koala Coast. The accuracy of these estimates was then tested using non-mortality (incidental) koala sightings. All analyses were done in the grid (raster) environment. The first step was to generate a grid with 25ha cells (500m x 500m) which was intersected with koala mortality point data. Cells with no reports, were excluded from all further analysis by coding as "No Data". Note that these cells were not coded as "absent", because it was not known whether koala mortality was simply unobserved due to the lower number of observers, particularly in bushland areas. Consequently the model primarily represents the anthropogenic (urban) portion of the landscape rather than the bushland areas where little data is available. Next, for each of the eight years a "presence" grid was constructed and converted to an inverse grid showing "absence" (Figure 3). Consequently, the absence grid represents a "temporal absence" or absence of koalas for a particular year, as opposed to a "true" or "pseudo"-absence.

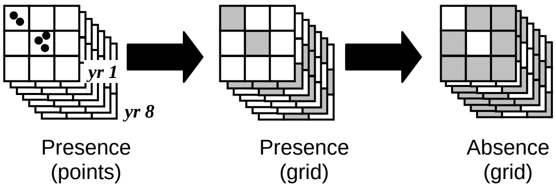

Figure 3. Generation of absence grid used in localised extinction analysis.

The 25ha grid cell size was chosen to ensure an average of at least 5 records per cell and to correspond to the home range size of a male koala. Mortality records from 4886 koalas formed the basis of the analysis with accuracy testing conducted using non-mortality reports (4839 records) which were intersected with the absence grids to determine whether, in the last 3 years, any reports had been made from those cells.

4. RESULTS

4.1. Forest Fragmentation Threat Model

The fragmentation model indicated that only 7843ha (21%) of the Koala Coast can be classified as interior forest, with the majority (51%) classed as non-forest (Table 1). Interior forest represents the best habitat for koalas because they are not edge specialists and the disturbance of intact forest exposes them to penetrating anthropogenic threats associated with dogs, vehicles and disease. Also, the non-interior forest areas present fewer food and shelter trees, lower population densities and associated problems of finding mates or dispersal. While the threat from cars in the interior forest was very low, the threat from dogs still exists because dogs roam these areas and chase or attack wildlife.

Table 1. Fragmentation threat in the Koala Coast.

Category	Total Area (ha)	(%)	Mean (ha)	SD (ha)
Interior forest	7843	21	10.1	129.5
Patch forest	1094	3	0.1	0.1
Transitional forest	2251	6	0.2	0.2
Perforate forest	3072	8	0.3	0.8
Edge forest	3395	9	0.6	1.1
Non-forest	19066	51	7.4	167.5
Water	683	2	1.1	15.8
Total	37403	100	1.0	47.1

Both the "patch forest" and "transitional forest" occurred in very small clumps (45x45m), and were too small to support a female koala which has an average home range size of 5-8ha (Figure 4). Consequently, many koalas are forced to utilise the more dangerous non-forest areas and hostile urban matrix to meet their habitat requirements. Most of the transitional forest appears to be in the process of being converted to non-forest, and is indicative that more than 2000ha of habitat is likely to be rapidly lost. This equates to the potential loss of ~700 koalas or 11% of the koala population.

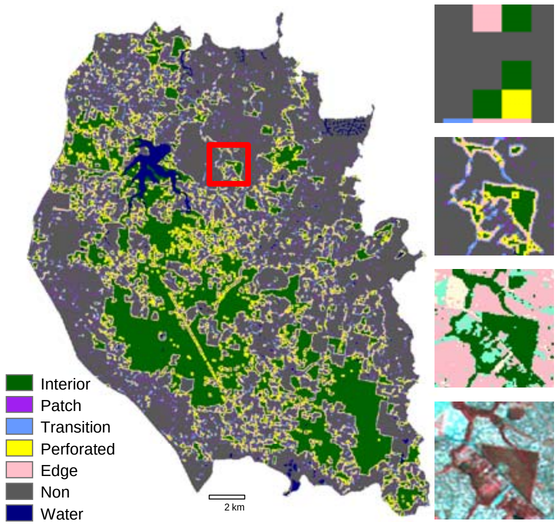

Figure 4. Forest fragmentation threat, showing only 7843ha of interior forest (green) remains. Insets show detail of (a) Forest fragmentation map degraded to 500m pixels. (b) Forest fragmentation map with 25m pixels. (c) Landcover map with four classes (d) Landsat satellite image in false infrared.

4.2. Mortality Hotspots and Threat Surface

The threat surface modelling showed road, dog and disease hotspots (hotzones) concentrated in the urban areas of the Koala Coast. Each threat produced a slightly different hotspot pattern with two or three major threat peaks and several lesser hotspots (Figure 5). The continuous nature of the threat surface enables the individual threat posed by roads, dogs, disease or combined threat to be estimated for any location within the study area.

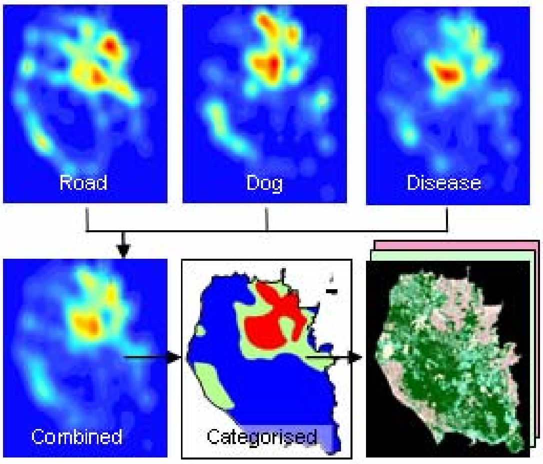

Figure 5. Threat surfaces for road, dog, disease and combined threat. The categorised threat was overlaid on landcover; koala abundance strata; and fragmentation model (landcover shown bottom right). Areas of high threat are shown as hotspots in hot colours (reds) with a gradation in threat through green down to low threat shown in cool colours (blues).

Over 33% of the Koala Coast can be characterised as posing a medium-high threat to koalas, with 67% in the low threat category. The mortality risk in the high threat zone was 4.5 koala $100ha^{-1}yr^{-1}$; and 0.6 koalas $100ha^{-1}yr^{-1}$ for the low threat zone, making the mortality risk in the high threat zone 7.5 times greater than the risk of the low threat zone (Table 2).

Table 2. Combined threat zone mortality risk.

Threat Category	Area (ha)	Area (%)	Mortality Risk koala $100ha^{-1}$ yr^{-1}
High	4613	12%	4.5
Medium	7757	21%	2.3
Low	25033	67%	0.6
Total	37403	100%	1.4

Superimposing the threat surface categories over the landcover to create a threat matrix revealed that the medium-high threat zones affect 22% of the forest landcover. The majority of forest (78%), however, was within the low threat zone. The high threat zones generally coincided with the urban landcover class, with 2027ha (27%) in the high threat zone (see Figure 5). The koala abundance threat matrix showed that 44% of the koala population was living in low threat bushland. However, 18% of the population was living in high threat bushland/remnant/urban areas, with a further 24% living in the medium threat bushland/urban areas. Because of the high densities of koalas in the remnant strata, ~1114 koalas are at high risk, and a further 1509 koalas are at medium risk of being killed due to anthropogenic factors. Compounding these threats to persistence, the forest fragmentation threat matrix showed 270ha (3%) of the important interior forest coincided with high threat and an additional 9% coincided with a medium level of threat.

4.3. Localised extinctions

Up to 7300ha ± 1875ha (18% ± 5%) of the Koala Coast was affected by localised extinctions, with absences of koalas ranging from 3-6 years (Figure 6). In the worst suburbs, koalas have disappeared from up to 58% of their former range. Only five of the 33 suburbs recorded no absence cells, indicating continued koala presence in only a few suburbs. No data were available for 39% of the study area, primarily representing bushland areas. Consequently no trends were detectable in these areas and additional data would be necessary to draw conclusions about these non-anthropogenic landscapes.

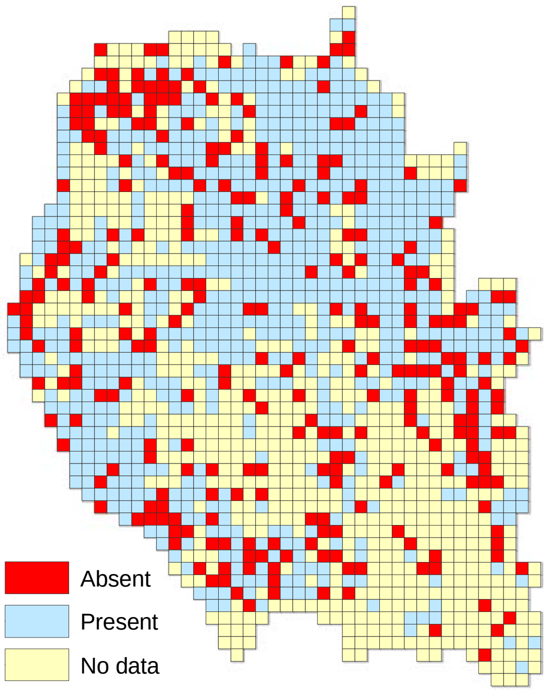

Figure 6. Localised koala extinctions represented by 292 red grid cells. Koala presence confirmed in 693 light blue grid cells. No data available for 628 light yellow cells.

5. DISCUSSION

Spatially modelling threats revealed that high threat and mortality levels are permeating from the urban areas into the bushland refugia and reducing the koala habitat values of the entire Koala Coast. The models demonstrated, that far from being secure havens for wildlife, bushland remnants were subject to unsustainably high rates of koala mortality. Consequently, management actions focussed simply on conserving patches of habitat in a high threat matrix may not be sufficient to maintain population viability unless the threatening processes resulting in elevated levels of anthropogenic mortality are also addressed. Localised koala extinctions affecting 18% ± 5% of the Koala Coast indicates that the process of regional species extinction is already in progress.

The models developed in this study met the need to simultaneously measure both habitat amount and spatial configuration in order to characterise landscapes and their suitability as wildlife habitat (Fahrig 1997). The fragmentation model not only provided information on the amount and configuration of habitat, it also provided information on the different types of fragmentation responsible for the absence of core (interior) forest.

Of particular concern were the numerous forest perforations, which represent an ecologically important type of fragmentation because they introduce potential edge effects deeper into intact forests, compared with the erosion of forest patch perimeters. Perforations are also important because they often represent anthropogenic land uses such as residential development. Because human disturbances tend to be spatially and temporally correlated, perforations may indicate the initiation of future forest loss and fragmentation (Riiters and Coulston 2005).

The model indicated a high fragmentation threat, with only 21% of the Koala Coast classified as interior forest and 56% of all forest in 2003 characterised as fragmented. The remaining forest consisted of significant proportions of edge (19%); perforated (17%); transition (13%); and patch (6%) forest. These categories represent a fragmentation continuum and provide insights into the process of how intact forest is broken apart in a series of steps until only patches remain which are ultimately engulfed by the surrounding hostile urban matrix. This model provided an alarming insight into the possible composition of landscape in the future, by highlighting the large areas of forest that are in the process of conversion to non-habitat.

Management measures aimed at consolidating existing forest by filling in the “holes” could utilise the fragmentation model to identify perforations and prioritise these for restoration activities. Similarly, the model identifies patches with a high risk of becoming isolated through the loss of connective habitat (corridors), categorised as transitional forest, which could be targeted for amelioration measures. The model could be modified to specifically analyse landscape neighbourhoods corresponding to wildlife home ranges or to identify geographic concentrations “hotspots” of perforation (Riiters and Coulston 2005). The ability of the model to spatially identify important linkage habitat might be useful in the assessment of connectivity under the koala habitat offset provisions (Queensland Government 2006).

The erosion of koala habitat values through the ongoing continuum of forest fragmentation is exacerbated by overlying risk to koalas of anthropogenic mortality. The modelled hotspot threat surfaces indicated that ~42% of the koala population (2613 koalas) were living within the combined medium-high threat zone, which was also impacting on 22% of the forest landcover and 12% of important interior forest. The anthropogenic mortality risk in the high threat zone (4.5 koala $100ha^{-1}$ yr^{-1}) was found to be 7.5 times higher than the risk in the low threat zone. This demonstrates that anthropogenic mortality and not habitat loss *per se* is the biggest threat to koala populations in rapidly urbanising areas.

These findings have important implications for management because they highlight the need to broaden conservation actions to address threats in addition to habitat loss. While high anthropogenic mortality threatens only 4% of forest, an estimated 18% of koalas reside in the urban habitats within this high threat zone. Measures directed solely toward bushland in the high threat zone would affect ~37 koalas, while ~533 koalas reside within the urban matrix. This may necessitate more active management in the high threat zones and options that need be considered include translocation (physical removal) of koalas from areas of high threat and elevated mortality to the low threat zone. More emphasis needs to be given to securing the viability of koalas in predominately urban koala areas. Current actions that fail to protect known high density koala populations will have a disproportionately negative impact on species persistence.

The threats to the viability of the koala population through high mortality associated with roads, dogs and disease are easily recognised, however, the threat associated with habitat fragmentation are insidious and more difficult to quantify. While it is possible to compute the direct impact of clearing through the amount of habitat lost and the reduction in wildlife density, the allied impacts tend to go unnoticed. The major concern is that as fragmentation of habitat continues and the surrounding matrix becomes more hostile, at some critical point a threshold will be reached where extinction of the population becomes inevitable. Determining this threshold should be one of the major research objectives for the future.

6. CONCLUSION

The fragmentation model provided very valuable information by simultaneously quantifying both habitat amount and spatial configuration. By also characterising different types of fragmentation, the model was able to move beyond simple patch fragmentation statistics and identify the locations of perforated forest which could be used to target management and restoration actions. Modelling threat surfaces to identify hotspots provided new insights into the severity of the anthropogenic mortality threat, while the identification of localised extinctions has important implications for managing species persistence. Threat zones and hotspots could provide useful support for prioritising the regions in which to conduct mitigation measures.

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