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LETTER

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The extirpation of species outside protected areas

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Abstract

Protected areas (PAs) are fundamental to conservation efforts but they are only part of a successful conservation strategy. We examine biodiversity outside PAs in Sundaland, one of the world's most biologically degraded regions. Using the avian order Galliformes as a case study, we identify species that have not been sighted outside PAs within the last 20 years on each individual landmass (i.e., Malay Peninsula, Borneo, Sumatra, Java, and Bali). We estimate these species' extirpation dates outside PAs using optimal linear estimation and species' sighting records.

We conclude there have been up to 13 extirpations of Galliformes from outside PAs in Sundaland. Three Sundaic endemics now occur only inside PAs. Sumatra has suffered the highest proportion of extirpations (50% of its galliform species). Effective management of Sundaland's PAs is thus critical to species' persistence and the conservation strategy for species outside PAs must be improved.

KEYWORDS

biodiversity, connectivity, extirpation, Galliformes, optimal linear estimation, protected areas, sighting records, Southeast Asia, Sumatra, Sundaland

1 | INTRODUCTION

Protected areas (PAs) spearhead the global conservation effort (Watson, Dudley, Segan, & Hockings, 2014), with 15.4% of the world's terrestrial land surface currently covered by PAs (Juffe-Bignoli et al., 2014) and an increase to 17% by 2020 targeted by the Convention on Biological Diversity (CBD; Convention on Biological Diversity 2010). Indeed, it has even been stated that "protected areas are almost synonymous with conservation" (Lewis et al., 2017). However, we should strive to avoid a future where much of biodiversity exists solely within PAs with widespread species extirpations acceptable in unprotected landscapes (Wilson, 2016). Global policy agreements make it clear that effectively managed PAs are only part of a strategy to conserve biodiversity across the broader landscape. For example, CBD's Aichi Target 11 goes well beyond setting a simple area target for PA expansion, stating that PAs need to be representative, connected and integrated into the wider landscape, and indicating that PAs are not an end in themselves (Carwardine, Klein, Wilson, Pressey, & Possingham, 2009; Woodley et al., 2012). Furthermore, targets agreed under UN Sustainable Development Goal 15 ("Life on Land") do not mention establishment of PAs as an explicit outcome but as an indicator of progress toward ecosystem conservation (United Nations, 2016). Thus for PAs to reach their full conservation potential, biodiversity in the unprotected landscape is required to maintain connectivity and ecosystem function (Woodley et al., 2012). It is therefore critical to know the extent to which species survive outside PAs as human pressures increase.

Nowhere are human pressures more acute and biodiversity loss more rapid than in Southeast Asia (e.g., Duckworth et al, 2012). Southeast Asia's deforestation rate is the highest among tropical regions (FAO, 2006; Rosa, Smith, Wearn, Purves, & Ewers, 2016), above 5% annually in parts of Sumatra and Sarawak (Miettinen, Shi, & Liew, 2011), and it has the highest proportion of threatened species across vascular plants, reptiles, birds, and mammals (Schipper et al., 2008; Sodhi et al., 2010). The southern portion of Southeast Asia comprises the biogeographically distinct Sundaland, one of the world's 25 terrestrial biodiversity hotspots (Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000). Sundaland's lowland forests are rapidly disappearing, negatively affecting at least a third of its diverse lowland forest avifauna (Lambert & Collar, 2002). Sundaland, therefore, gives us an insight into the future conservation status of the remainder of the world if land-use change outside PAs continues unabated.

Biodiversity monitoring in Southeast Asia is biased toward PAs (Boakes et al, 2010), yet documenting extinctions outside PAs requires information on species' presence over time. Such data, when they exist, tend to have been collected opportunistically and to be presence-only. It is thus difficult to distinguish between genuine extirpation and lack of monitoring (Boakes, Fuller, McGowan, & Mace, 2016). However, statistical methods yield opportunities to use the gaps in a species' sighting record to infer the likelihood of extinction at a site. Here, we undertake such an analysis for galliform birds outside PAs in Sundaland. Galliformes have long been popular with museum collectors and birdwatchers, thus have been relatively well recorded across the broader landscape over the last ∼150 years (Boakes et al., 2010). They exhibit a variety of ecological traits and are one of the most threatened avian orders (BirdLife International 2017).

We use sighting records of Galliformes in Sundaland dating from ∼1850 to the present day, collated via a rigorous search of museum collections, peer-reviewed and grey literature, banding records, and online birding reports (see Boakes et al., 2010), to determine which species have not been sighted outside PAs in the last 20 years. We use optimal linear estimation (Roberts & Solow, 2003) to estimate the year by which each extirpation is likely to have occurred. Our results demonstrate that it is now absolutely critical that Sundaland's PAs are managed effectively, and highlight the urgency of conservation strategies for unprotected lands.

2 | METHODS

2.1 | Study area

Sundaland comprises Southern Thailand, Peninsular Malaysia, and Singapore (from here on referred to as the Malay Peninsula) and the islands of Palawan, Borneo, Java, Sumatra, and Bali. Palawan was excluded from our analysis because the entire island is covered by an IUCN category IV PA (UNEP-WCMC 2017b).

2.2 | Data

Sightings were collated for the 30 species of the avian order Galliformes (pheasants, quails, partridges, etc.) found in Sundaland (see Supporting Information). We use the term "sighting" to mean any reliable record of a species' presence, such as a visual observation, museum specimen, acoustic record, or other diagnostic indication of presence. Point locality data at a resolution of ≤30 min (∼50 km) were collected from museum collections, journal articles, personal reports and letters, banding records, ornithological atlases, and birdwatching report websites. Full data collection details for records dating up to 2008 are given in Boakes et al. (2010). Records relating to sightings post 2008 were sourced from a thorough search of specialist ornithological journals covering the Sundaic region, BirdLife data files, and the online citizen science database eBird (https://ebird.org). eBird data undergo automated data filtering and review by a network of local experts (currently 56 in Sundaland), but as with any biodiversity dataset, some errors are inevitable (Sullivan et al., 2009). Sighting records with a date range rather than an exact year were retained if the range was less than 10 years and covered a period for which we had no exact-year records for that species; in these instances, the midpoint of the range was used.

PA shapefiles were downloaded from the World Database of Protected Areas (UNEP-WCMC, 2017b). We used all PAs in the database that overlapped the Sundaic region regardless of IUCN category. To allow for species normally resident within a PA to wander outside the boundary, a 1-km buffer was drawn around the PAs. We spatially extracted all records outside the buffered PAs. Records were deemed to occur within a PA if indicated by their associated verbal locality descriptors but not their given coordinates. This situation might arise through an individual inside a PA being heard and recorded from outside a PA, a georeferencing error, or misplotting of a PA. We suspect an instance of the latter for Bukit Fraser, a well-visited PA in Malaysia, the shapefile of which was empty of records but had a large cluster of points labeled "Bukit Fraser" close by. Although carefully curated, the WDPA is known to contain some missing and incorrect PA boundaries (UNEP-WCMC, 2017a). Spatial procedures were implemented in ArcGIS 10.0 (ESRI, 2011).

2.3 | Inferring extinction date

A species is likely to become increasingly rare as it approaches extinction, and may exist unseen for many years beyond the last known record. The last sighting date may thus be a poor estimate of extinction time. Several statistical models have been developed to infer the likelihood of extinction based on a species' sighting records (Boakes, Rout, & Collen, 2015). Optimal linear estimation (OLE; (Roberts & Solow, 2003), a nonparametric method based on extreme value theory, is one of the more robust frequentist techniques. OLE assumes that sightings occur in a Poisson process and that sighting effort has never fallen to zero. It is based on the result that the joint distribution of the k most recent sighting times has roughly the same "Weibull form" regardless of the parent distribution of the complete sighting record (Cooke, 1980). OLE uses the "tail" of the distribution and there has been discussion over how many sighting records should be used. Collen, Purvis, and Mace (2010) suggest a minimum of five independent sighting records (OLE gives a very high upper confidence limit when data are sparse) and found that error rates increased as k increased up to the maximum of 18 that the study investigated. Clements et al (2013) found k should be small if sighting effort was decreasing but otherwise found no evidence to support using a small k. Following Clements et al. (2013), we thus used $k = n$ (the total number of sighting records). We conducted separate analyses for each land mass, that is, the Malay Peninsula (15 species), Borneo (15 species), Sumatra (14 species), Java (5 species), and Bali (3 species), yielding 52 species/land mass combinations (see Supporting Information for sighting histories). We applied the method to species that had not been recorded outside PAs for >20 years and thus for which we might reasonably expect no further sightings to be made. Dates by which extirpation can assume to have occurred outside PAs were estimated using the sExtinct package (Clements, 2013) in R version 3.2.3 (R Core Team, 2015).

3 | RESULTS

We found no records outside PAs within the last 20 years for 13 of the 52 species/land mass combinations (Table 1; full sighting histories in Supporting Information). In five of these instances, there were fewer than five records in total outside PAs, thus extirpation dates could not be estimated but we presume extirpation because last sightings were in 1898, 1907, 1917, 1936, and 1939; Supporting Information. Extirpation was estimated to occur before 2018 in eight instances, although the upper 95% confidence limit occurs before 2018 in only four of those cases (Figure 1 and Table 1). (High upper confidence limits are caused by data sparsity or a large gap in sightings followed by one or two recent records.) We therefore estimate that there have been 4–13 total extirpations of Galliformes in Sundaland outside PAs, from a total of 52 species/land mass combinations. Six of the potential extirpations occurred in Sumatra (50% of 14 species), two in Java (40% of five species), three in the Malay Peninsula (20% of 15 species), one in Borneo (7% of 15 species), and none in Bali (0% of three species).

Five species (three endemic) appear to be extirpated outside PAs across the whole of Sundaland: *Rhizothera dulitensis* (Dulit partridge, endemic to Borneo), *Arborophila sumatrana* (Sumatran partridge, endemic to Sumatra), *Arborophila orientalis* (Grey-breasted partridge, endemic to Java), *Rheinardia ocellata* (Crested argus), and *Pavo muticus* (Green peafowl; for species' authorities see www.hbw.com). Further species endemic to Sundaland have suffered probable extirpation outside PAs on at least one landmass. These include forest dependent species, such as *Melanoperdix niger* (Black partridge), which has disappeared outside PAs in the Malay Peninsula and Sumatra, and *Arborophila charltonii* (Chestnut-necklaced partridge), *Lophura erythrophthalma* (Malay crestless fireback), and *Caloperdix oculeus* (Ferruginous partridge), which, on Sumatra, appear to be confined to PAs. Additionally, the nonendemic *Synoicus chinensis* (King quail), a more open country species, has seemingly disappeared in Sumatra from outside PAs.

4 | DISCUSSION

We estimate there have been 4–13 instances of extirpations of galliform species outside PAs in Sundaland's 52 individual species/landmass combinations, based on analysis of resightings histories. Three endemic species have their global populations confined to PAs and the regional populations of a further two species are similarly restricted, reflecting their wider decline throughout Southeast Asia (*Pavo muticus*) and Indo-China (*Rheinardia ocellata*).

Sumatra stands out for concern, with seven of its 14 galliform species (50%) extirpated from outside PAs; one of these species is endemic. Three of the seven galliform species that are still extant outside PAs are also endemic to Sumatra. There is a strong likelihood that further loss of suitable habitat outside PAs will mean that their survival prospects will depend upon well-managed PAs. In contrast to Sumatra, only one species has become extirpated outside PAs on Borneo, where eight of the 15 species are endemic to the island.

IUCN threat categories of extirpated species range from Least Concern (*Synoicus chinensis*) to Endangered (*Pavo muticus*) and their habitats from shrubland (e.g., *Synoicus chinensis*) to forest (e.g., *Rheinardia ocellata*), although most are Sundaic forest specialists. Beyond these extirpations, increasingly large gaps in the sighting records of some species indicate worrying levels of declines outside PAs (Supporting Information), for example, *Arborophila campbelli* (Malayan hill-partridge; sighted once outside PAs in the last century) and *Synoicus chinensis* in Java (sighted twice outside PAs in the last 70 years).

We used Galliformes as a case study owing to their extensive historical records. However, it is likely that the extirpations we have identified on Sundaic landmasses extend to other taxa, particularly larger-bodied species, threatened, like the Galliformes, by both land use change and hunting. This is particularly concerning given Southeast Asia's high degree of

TABLE 1 Dates by which extirpation is estimated to have occurred outside PAs for Galliformes species not sighted within each landmass in the last 20 years. IUCN Redlist categories are given in brackets after the species name. An asterisk by a species name indicates it is endemic to Sundaland. [] denote 95% confidence intervals. N = number of years in which the species was sighted; - indicates the species does not historically occur on this landmass

Species (IUCN Red List classification)	Date by which extirpation is estimated to have occurred outside protected areas.				
	Malay peninsula	Borneo	Sumatra	Java	Bali
**Rhizothera longirostris* (near threatened)	–	–	Last recorded in 1936 $n = 4$	–	–
**Rhizothera dulitensis* (vulnerable)	–	Last recorded in 1898 $n = 2$	–	–	–
**Melanoperdix niger* (Vulnerable)	1970[1958–2008] $n = 19$	–	Last recorded in 1907 $n = 4$	–	–
Synoicus chinensis (least concern)	–	–	2006[1994–2048] $n = 15$		
**Arborophila sumatrana* (least concern)	–	–	1921[1919–2007] $n = 5$	–	–
**Arborophila orientalis* (vulnerable)	–	–	–	Last recorded in 1917 $n = 2$	–
**Arborophila charltonii* (vulnerable)	–	–	Last recorded in 1939 $n = 2$	–	–
**Caloperdix oculeus* (near threatened)	–	–	2013[1994–2092] $n = 13$	–	–
**Lophura erythrophthalma* (vulnerable)	–	–	1952[1938–2127] $n = 5$	–	–
Rheinardia ocellata (near threatened)	1995[1992–2027] $n = 7$	–	–	–	–
Pavo muticus (endangered)	1920[1919–1926] $n = 13$	–	–	1995[1994–2000] $n = 25$	–

endemism, large number of threatened species, and high rate of deforestation (Sodhi et al., 2010).

It is imperative that Sundaic PAs are managed effectively—to date, they have not always received adequate protection. Although protection has been shown to reduce deforestation rates in Sundaland (Gaveau et al,, 2009), forest cover in Sumatra's PAs still declined by 5% between 1990 and 2000 (Gaveau et al., 2012) and Kalimantan's protected lowland forests declined by more than 56% between 1985 and 2001 (Curran et al,, 2004). The human footprint within Southeast Asia's PAs has also increased considerably over the last 25 years with nearly 20% of Malaysia's and over 40% of Indonesia's protected land subject to intense human pressure (Jones et al, 2018). Unfortunately PAs are not necessarily permanent institutions; the 87 enacted or proposed instances of downgrading, downsizing, or degazettement of Sundaic PAs equate to a loss of 8360 km^2 of protected land (WWF, 2018).

Climate change throws an additional challenge at PAs and suggests that the landscape matrix surrounding PAs must be managed so that options remain for an adaptive dynamic PA system (Monzón, Moyer-Horner, & Baron Palamar, 2011). As PAs become increasingly isolated in agricultural landscapes or by the spread of roads and other infrastructure, species lose the opportunity to track changing climate conditions; for example, only 12% of Borneo's PAs are sufficiently topographically diverse to allow species to remain in situ under a high warming scenario (Scriven, Hodgson, McClean, & Hilll, 2015).

For long-term conservation goals, PA connectivity is essential. Currently, a range of situations exist from a sharp discontinuity in land cover around the edge of a PA through to a PA being surrounded by a large tract of continuous, intact habitat. A better understanding of the structure of populations outside PAs would be valuable when making decisions over siting new PAs or expanding existing ones. Our analysis

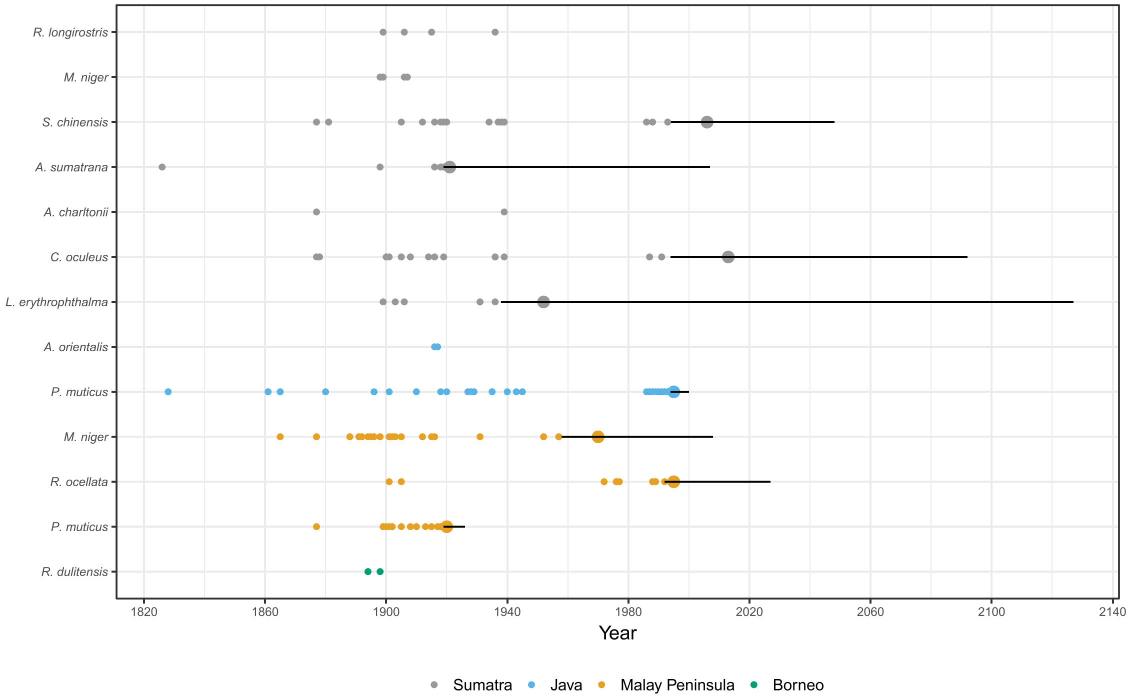

FIGURE 1 Sighting records of species that have not been recorded outside protected areas (PAs) for 20 years or more on individual landmasses in Sundaland. The year by which extirpation outside PAs is most likely to have occurred is represented by a larger circle, 95% confidence limits represented by a line. Extirpation times could not be estimated for species with fewer than five sighting records

will err conservatively if populations external to PAs are not separate from internal populations. For example, although Galliformes tend not to disperse long distances, a lone individual could wander beyond our 1-km buffer, leading to the erroneous conclusion of an extant external population. Some observations do occur close to PA edges (see Supporting Information), but our data preclude the distinction of external populations limited to the periphery of a PA versus those extending further beyond. There is also the question of what an ecologically meaningful buffer might be—our choice of 1 km was to ensure that potential errors would be on the conservative side. Given that the majority of Sundaland's unprotected forest has been selectively logged and is susceptible to further conversion (Giam, Clements, Aziz, Chong, & Miettinen, 2011), it is necessary to look beyond conserving pristine habitat alone. Within Malaysia, our data show that recent galliform sightings outside PAs are often from "forest reserves" (see Supporting Information). These are not PAs but logging reserves, managed by Malaysia's Forestry Department and protected from illegal logging. If human modified habitat is to be an effective tool in Sundaland's conservation armory (Edwards et al., 2010; Giam et al., 2011), it needs to be protected quickly because logged forest is more susceptible to conversion to plantations (Giam et al., 2011). Borneo has the lowest proportion of extirpations and it would seem imperative that greater protection is given to forest outside current PAs. It is essential to act quickly if we are to secure further protected land in a way that maximizes connectivity.

Our analysis assumed at least some level of survey effort in all areas outside PAs, but in reality, there are likely to be areas that are unsurveyed. Records are often biased toward threatened species and PAs (Boakes et al., 2010), but the eBird records appear to be more representative both taxonomically and spatially, particularly in the Malay Peninsula, adding many localities outside PAs (Supplementary Information). Initiatives, such as eBird, are key to future biodiversity monitoring, and camera-trap data is particularly useful for collecting data on elusive species, such as Galliformes (Steenweg et al., 2017). Despite our rigorous data collation efforts, we may have missed some records, or species may have been sighted but not recorded outside PAs. We hope that this work serves as a rallying call to document and store such records in an accessible biodiversity repository. Nevertheless, the fundamental message of this study remains the same.

Galliform species in Sundaland are starting to become confined to PAs. PAs are the last barrier before extinction and must be managed effectively. With continued high levels of land conversion in this region, population losses outside PAs can only increase. The desirable end game of conservation management in Sundaland is surely not an archipelago of its current PAs scattered across a sea of extirpations. More land must be managed in a way that accommodates biodiversity for the long term. Sundaland provides a stark warning for the rest of the world and we must do our utmost to avoid this level of destruction elsewhere.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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