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LETTER

Global Trends in the Status of Bird and Mammal Pollinators

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Abstract

Biodiversity is declining, with direct and indirect effects on ecosystem functions and services that are poorly quantified. Here, we develop the first global assessment of trends in pollinators, focusing on pollinating birds and mammals. A Red List Index for these species shows that, overall, pollinating bird and mammal species are deteriorating in status, with more species moving toward extinction than away from it. On average, 2.5 species per year have moved one Red List category toward extinction in recent decades, representing a substantial increase in the extinction risk across this set of species. This may be impacting the delivery of benefits that these species provide to people. We recommend that the index be expanded to include taxonomic groups that contribute more significantly to pollination, such as bees, wasps, and butterflies, thereby giving a more complete picture of the state of pollinating species worldwide.

Introduction

Biodiversity, a crucial part of the Earth's life support systems, is declining (Tittensor *et al.* 2014) with extinction rates several hundred times higher than the background rate (Barnosky *et al.* 2011). This has direct and indirect effects on human well-being, as nature provides numerous benefits—ecosystem services—to people (Millennium Ecosystem Assessment 2005). However, we know worryingly little about the features of the ecosystems that we are losing, how fast they are declining, how this impacts ecosystem functions, and consequently, the impact on ecosystem services.

Pollination is one such ecosystem service. Over 87% of flowering plant species are pollinated by animals, and humans use many of these plant species for food, livestock forage, medicine, materials, and other purposes (Potts *et al.* 2010; Ollerton *et al.* 2011). Insects, birds, mammals, and reptiles play a role in the pollination of agricultural crops and wild plants, with insects being the primary pollinators, in particular bees (Potts *et al.* 2010). For example, the production of 70% of the 124 main crops consumed by humans worldwide depends on insect pollinators, which thus provide vital benefits to human nutrition (Klein *et al.* 2007; Eilers *et al.* 2011). The total economic value of wild and managed pollination services worldwide was estimated at US $215 billion in 2005 (Gallai *et al.* 2009).

A decline in pollinator abundance and diversity can result in a loss of pollination services that could significantly affect the maintenance of wild plant diversity, wider ecosystem stability, crop production, food security, and human welfare (e.g., Kremen *et al.* 2002; Garibaldi *et al.* 2013). A growing number of studies show that pollinators are declining worldwide (e.g., Biesmeijer *et al.* 2006; Potts *et al.* 2010). Indeed, evidence from the United States and Europe shows that current pollinator stocks are insufficient to supply agricultural demands (Sumner

& Boriss 2006; Velthuis & van Doorn 2006). Despite this, no global monitoring programme exists, and regional monitoring and assessment is only patchy (Lebuhn *et al.* 2013). In order to halt this decline in essential pollination services, information is needed to identify pollinator species impacted, their distribution, the rate of declines, and the consequences on ecosystem functioning and human well-being. This is vital for informing policy and to ensure effective conservation action.

The IUCN Red List is considered the most authoritative and objective system for categorizing the extinction risk of taxa (De Grammont & Cuarón 2006). Species are assigned to categories of extinction risk (ranging from Least Concern to Critically Endangered and Extinct) using criteria with quantitative thresholds for decline, range area, and population size (IUCN 2001). The Red List Index (RLI) has been developed to show trends in survival probability (i.e., the inverse of extinction risk) over time for sets of species using data from the IUCN Red List (Butchart *et al.* 2004, 2007). The RLI is based on the proportion of species that move through the IUCN Red List categories between periodic assessments, either away from or toward extinction, as a result of genuine improvements or deterioration in status. It excludes changes in category resulting from taxonomic revisions or improvements in knowledge (Butchart *et al.* 2004, 2007). Global RLIs have been calculated for all birds (Butchart *et al.* 2004, 2010; BirdLife International 2013), mammals (Hoffmann *et al.* 2010, 2011), as well as amphibians (Stuart *et al.* 2008) and reef-building corals (Butchart *et al.* 2010). The RLI is now widely used to monitor biodiversity trends, for example by the Convention on Biological Diversity (SCBD 2010) and United Nations (UN 2014). In this assessment, we focus on two taxonomic groups, mammals and birds, as other pollinator groups have not yet been comprehensively assessed (i.e., all species evaluated) for the IUCN Red List. For example, among insects, only 152 species of ants, bees, and wasps had been assessed for the IUCN Red List as of 2013 (Gerlach *et al.* 2012). Among other vertebrates, some reptiles are known to play important roles in pollination (e.g., Olesen & Valido 2003); however, the Taxonomic group as a whole has not yet been comprehensively assessed for the Red List (see Bohm *et al.* 2013) and derivation of an RLI is therefore not yet possible. In contrast, birds and mammals have been comprehensively assessed multiple times. Our objective in this article is to calculate Red List Indices (RLIs) in order to assess and compare trends for pollinator and nonpollinator mammals and birds.

Evolutionary shifts to bird-mediated pollination (ornithophily) have occurred independently in many lineages of flowering plants, being present in approximately 65 families (Cronk & Ojeda 2008). Similarly, birds exhibit convergent evolution in nectarivory, with three major radiations of specialized nectarivores on different continents: hummingbirds (Trochilidae) in the Americas, sunbirds and spiderhunters (Nectariniidae) in Africa and Asia, and honeyeaters (Meliphagidae) in Australasia (Nicolson & Fleming 2003; Cronk & Ojeda 2008). Birds are thought to be particularly important as pollinators in situations of limited insect density and activity, such as seasons and areas with low temperatures and high rainfall, dry environments, and isolated islands with poor insect colonization (reviewed by Cronk & Ojeda 2008).

Among mammals, bats are the principal pollinators, pollinating a large number of economically and ecologically important plants known to provide a number of valuable products to humans, such as agave and cacti in the New World (Kunz *et al.* 2011). Most bat pollinators belong to two families, the fruit (or mega-) bats of the family Pteropodidae (Old World), sometimes known as flying foxes, and microbats of the family Phyllostomidae (New World), many species of which are specialized in nectarivory and are morphologically coadapted with flower morphology for pollination (Kasso & Balakrishnan 2013). Many nonvolant mammals such as rodents, marsupials, primates, and small carnivores are also known to contribute to plant pollination. However, the pollination effectiveness of many of these species is still questionable as it is unclear if their contribution outweighs the cost of flower damage (Fleming & Sosa 1994).

Methods

We identified potential and known pollinator bird and mammal species from the literature (Tables S1 and S2). We adopted an inclusive approach, including both entirely nectivorous species and species that occasionally feed on pollen and may thus contribute to plant reproductive success. For mammals, we included species that have been regularly observed sucking or licking flowers' nectar, or carrying pollen load on fur (Muchhala & Thomson 2010), or in the case of bats, those that are predicted to be pollinators based on their tongue morphology (Howell & Hodgkin 1976). For birds, we included all species in the families Coerebidae, Meliphagidae, Mohoidae, Nectariniidae, Promeropidae, Trochilidae, and Zosteropidae, plus selected species of other families including Fringillidae, Icteridae, Psittacidae, and Thraupidae, drawing on descriptions of foraging behavior and diet in del Hoyo *et al.* (1992–2013) as well as other literature (see Table S2).

We calculated the RLI for 1996–2008 for mammals and 1988–2012 for birds following Butchart *et al.* (2007), based on the years of comprehensive Red List assessments for each group, with the number of species in each IUCN

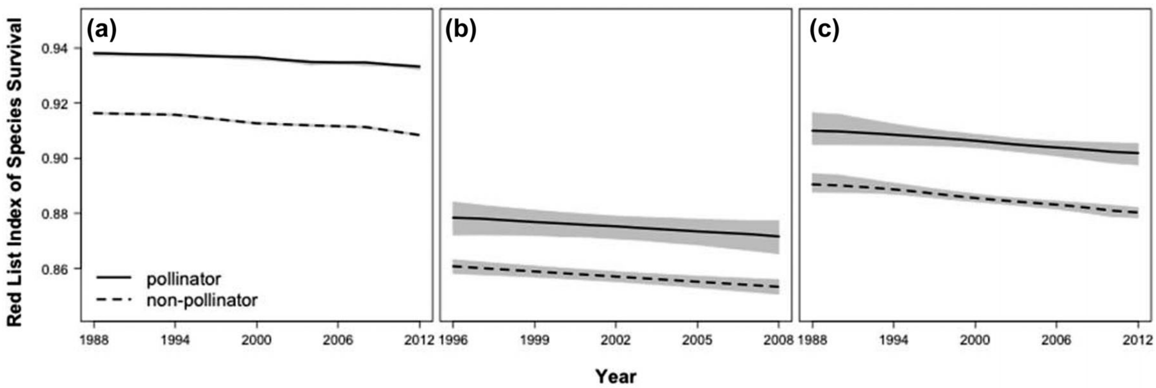

Figure 1 Red List Indices for (a) pollinating and nonpollinating bird species; (b) pollinating and nonpollinating mammal species; and (c) aggregated pollinating and nonpollinating birds and mammals. An RLI value of 1 equates to all species being Least Concern; an RLI value of 0 equates to all species being Extinct. Improvements in species conservation status lead to increases in the RLI; deteriorations lead to declines. A downward trend in the RLI value means that the net expected rate of species extinctions is increasing.

Red List category in a particular year multiplied by a weight (ranging from 0 for Least Concern to 5 for Extinct), with the scores summed and expressed as a fraction of the maximum possible sum (if all species had gone Extinct). The number of species in each category for years prior to the most recent assessment were calculated based on the number of species that qualified for genuine IUCN Red List category changes in each time period between assessments (i.e., excluding changes owing to improved knowledge or taxonomic revision), updated from those given in Hoffmann *et al.* (2010).

Following Butchart *et al.* (2010), we calculated an RLI for each group separately, interpolating indices linearly for years between data points, and calculated an aggregated RLI as the arithmetic mean of the two modeled RLIs. The index for mammals was extrapolated linearly back to 1988 and forward to 2012 (the years of first and last assessment for birds), following Butchart *et al*. (2010). A 95% confidence interval was calculated in order to account for the uncertainty introduced by extrapolation and by temporal variability in the "true" RLI in the multi-year periods between assessments, following the bootstrapping methods given in Butchart *et al.* (2010). We calculated separate RLIs for pollinator birds, nonpollinator birds, pollinator mammals, and nonpollinator mammals, with aggregated indices for all pollinators and all nonpollinators. Finally, following the methodology and data from Hoffmann *et al.* (2010), updated using the latest data held by BirdLife International, we noted the primary driver of decline (or the driver overcome by conservation efforts for those species that improved in status) for each species identified as qualifying for a genuine category change. This allowed us to discern the primary drivers that resulted in changes in extinction risk for pollinator species.

Results

A total of 1,432 vertebrate species (1,089 birds and 343 mammals, ca. 10% and 6% of described species, respectively) were identified as pollinators. Prominent species groups among birds include hummingbirds (Trochilidae, 337 species), honeyeaters (Meliphagidae, 177 species), sunbirds (Nectariniidae, 124 species), and white-eyes (Zosteropidae, 100 species), whereas bats (Chiroptera, 236 species) formed the majority of the mammals.

During the period 1988–2012, 18 of the 1,089 bird species qualified for being "uplisted" to a higher category of threat owing to deterioration in their status. For example, Regent Honeyeater *Xanthomyza phrygia* qualified for uplisting from Endangered (under Red List criterion C2a(ii)) to Critically Endangered (under criterion A2b) during 2008–2012 because the rate of population decline was suspected to have exceeded 80% over three generations (24 years) during this period. The accelerated declines were driven primarily by drought, compounded by habitat loss caused by historic clearance for agriculture, and possibly competition with other native species, particularly Noisy Miner *Manorina melanocephala*. In contrast with the results for nonpollinators, no pollinator bird species qualified for "downlisting" to lower categories of threat as a result of improvements in status resulting from conservation action. The RLI for pollinator birds shows a decline in index value from 0.938 to 0.933, equating to an average of 1.1 species per year moving one Red List category closer to extinction over the period (Figure 1a). Overall, the RLI values for pollinators were higher than for nonpollinator species, indicating that pollinators are less threatened on average.

Among the 343 mammal pollinators, 15 underwent changes in status during 1996–2008 that were

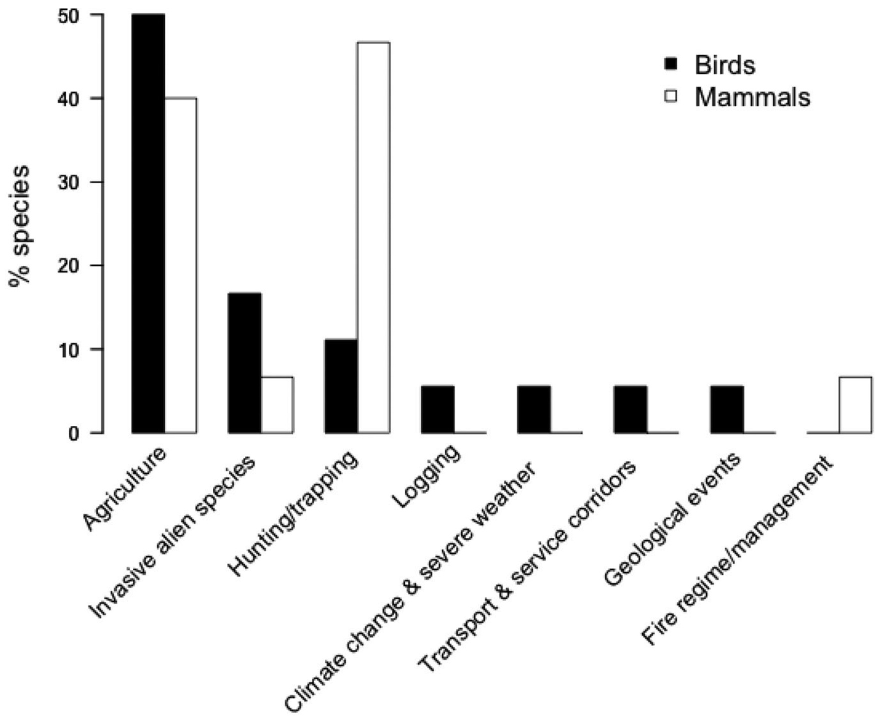

Figure 2 Drivers of declines in status for pollinator birds (1988–2012) and mammals (1996–2008).

sufficiently large for 13 species to qualify for uplisting to a higher category of threat, and for two species (Samoan Flying Fox *Pteropus samoensis* and Pemba Flying Fox *Pteropus voeltzkowi*) to qualify for downlisting to a lower category of threat. For example, the Choco Broad-nosed Bat *Platyrrhinus chocoensis* was uplisted from Vulnerable to Endangered because of the habitat conversion to agriculture for cocoa, whereas among nonvolant mammals, the Sunda Slow Loris *Nycticebus coucang* was uplisted from Near Threatened to Vulnerable due to harvesting for pet trade and habitat loss. On the other hand, Pemba Flying Fox has recovered due, in particular, to community protection at specific roost sites. The RLI for mammal pollinators (Figure 1b) shows an overall decline from 0.886 in 1996 to 0.872 in 2008, equating to an average of 1.9 species per year moving one Red List category closer to extinction over the time period. As with birds, mammal pollinators are less threatened than mammal nonpollinators; however, the situation is reversed when considering bats only, with bat pollinators more threatened than bat nonpollinators (Figure S1).

The aggregated trends for bird and mammal pollinators (Figure 1c) show the average of the two sets of trends, and illustrate the decline in survival probability of vertebrate pollinators over the last two decades. Habitat loss from unsustainable agriculture is the main driver of change for a considerable proportion of species among both mammals and birds, however, mammal pollinators are also severely impacted by hunting for bushmeat, whereas birds are more affected by the impacts of invasive alien species (Figure 2).

Discussion

Nine percent of all currently recognized bird and mammal species are known or inferred to be pollinators. The RLI for these species shows that overall they are deteriorating in conservation status, with more species moving toward extinction than away from it. On average, 2.5 species per year have moved one IUCN Red List category toward extinction in recent decades. Although sounding low, this number represents a substantial increase in extinction risk across this set of species. Owing to the broad nature of IUCN Red List categories, only the most significant changes in status are reflected in the RLI. It is likely that many of the species that did not change category also underwent population declines and range contractions. The negative trends shown by the RLI are likely to reflect broader changes to avian and mammalian abundance that will have contributed to changes in ecosystem structure and decreases in ecosystem functioning and service delivery.

Further research is needed on the precise contributions to realized ecosystem services that pollinating birds and mammals provide, in order to allow inference of the likely relationship between RLI declines and decreases in ecosystem services delivered.

The primary role of agricultural expansion as a driver of declines among mammal and bird pollinators is unsurprising, and mirrors the pattern for mammals and birds in general (Hoffmann *et al*. 2010, 2011; BirdLife International 2013). Land-use change (agricultural expansion, logging, and infrastructure development) is the major driver of declines in bird pollinators. Although hummingbirds in general are regarded as less susceptible to the effects of deforestation and forest fragmentation compared with insectivorous birds, there is evidence that tropical hummingbird species richness decreases with the decreasing size of forest fragments and that the abundance of interior forest hummingbird species is lower in fragments compared with contiguous areas of forest (Borgella *et al*. 2001). Forest loss may also impact the behavior of bird pollinators, with potential implications for the reproduction of the plant species that they pollinate (e.g., Hadley & Betts 2009). The spread of invasive alien species is the second most important threat. However, the most threatened bird pollinators tend to be impacted by many of these threatening processes in concert, and often occur on geographical and ecological islands. On the Hawaiian islands, the transmission of avian pox and malaria by introduced mosquitoes has severely impacted the Hawaiian honeycreepers (Drepanidinae), but they have also suffered impacts from introduced predators, and habitat loss due to agricultural expansion (Benning *et al*. 2002). Furthermore, there is growing concern that climate change is driving phenological shifts in the arrival of migrant hummingbird species in North America and the flowering of their food plants, with potentially negative implications for both hummingbird and plant populations (McKinney *et al*. 2012; Courter *et al*. 2013). The greater importance of hunting as a threat among mammals is likely to be attributable to the high proportion of fruit bats identified as mammal pollinators. Fruit bats are commonly hunted both for local consumption and for commercial trade (Mickleburgh *et al*. 2009). Fire is another driver of declines in pollinating mammals. For example, Australian marsupials are impacted by inappropriate fire regimes over large parts of their range.

Conclusions

Pollinating birds and mammals are in decline, primarily because of unsustainable agricultural expansion, invasive alien species, and hunting. This is the first global assessment of trends in the status of pollinators and should inform the forthcoming "Thematic assessment of pollinators, pollination and food production" by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). However, our approach needs to be expanded to include taxonomic groups that contribute more significantly than vertebrates to pollination, such as bees and wasps (Hymenoptera) and butterflies (Lepidoptera), which will require accelerating the pace of ongoing sampling and global assessments of invertebrate pollinator groups (e.g., Lewis & Senior 2011). By combining RLI trends for these groups with those for pollinating birds and mammals, it will be possible to determine more representative trends in the extinction risk of pollinators. This information will be useful for IPBES as well as for assessing progress toward the Convention on Biological Diversity "Aichi Target 14" and the European Union's 2020 Biodiversity Strategy Target 2, under both of which governments have committed to restoring and safeguarding ecosystem services.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Figure S1 Red List Index for 239 pollinator and 868 nonpollinator bat species.

Table S1. List of mammal pollinator species, reporting the source, degree of specialization (O, Opportunistic; N, Nectarivorous) and Red List status at 1996 and 2008.

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