TITLE

Global trends in the status of bird and mammal pollinators

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This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/conl.12162.

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Short running title: Bird and mammal pollinator trends

Keywords: Ecosystem service; Indicator; Pollination; Pollinators; Red List; RLI; Vertebrates; Mammals; Birds; Extinction risk

Type of article: Letter

No. of words in abstract: 142

No. of words in manuscript: 2876

No. of references: 41

No. of figures and tables: 2

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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 towards extinction than away from it. On average, 2.4 species per year have moved one Red List category towards extinction in recent decades, representing a substantial increase in extinction risk across this set of species. This may be impacting the delivery of benefits to people that these species provide. We recommend that the index is 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 all 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 US and Europe shows that current pollinator stocks are insufficient to supply agricultural demands (Sumner and Boriss 2006; Velthuis and 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 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 and Cuarón 2006). Species are assigned to categories of extinction risk (ranging from Least Concern through 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 towards 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, including 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 taxon 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 paper is to calculate Red List Indices (RLIs) in order to assess and compare trends for pollinator and non-pollinator mammals and birds.

Evolutionary shifts to bird-mediated pollination (ornithophily) have occurred independently in many lineages of flowering plants, being present in c. 65 families (Cronk and Orjeda 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 and Fleming 2003; Cronk and Orjeda 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 and Orjeda 2008).

Among mammals, bats are the principle 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 Phyllostomatidae (New World), many species of which are specialized in nectarivory and are morphologically co-adapted with flower morphology for their pollination (Kasso and Balakrishnan 2013). Many non-volant 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 and Sosa 1994).

Methods

We identified potential and known pollinator bird and mammal species from the literature (Table S1, 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 and Thomson 2010), or in the case of bats, those that are predicted to be pollinators based on their tongue morphology (Howell and 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 behaviour 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 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 modelled 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, non-pollinator birds, pollinator mammals and non-pollinator mammals, with aggregated indices for all pollinators and all non-pollinators. 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 1,430 vertebrate species (1,089 birds and 341 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), while 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 to the results for non-pollinators, 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 0.9306 to 0.9252, equating to an average of 1.0 species per year moving one Red List category closer to extinction over the period (Fig. 1a). Overall, the RLI values for pollinators were higher than for non-pollinator species, indicating that pollinators are less threatened on average.

Among the 341 mammal pollinators, 15 underwent changes in status during 1996-2008 that were 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 due to habitat conversion to agriculture for cocoa while among non-volant 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 (Fig. 1b) shows an overall decline from 0.883 in 1996 to 0.872 in 2008, equating to an average of 1.4 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 non-pollinators; however, the situation is reversed when considering bats only, with bat pollinators more threatened than bat non-pollinators (Fig S1).

The aggregated trends for bird and mammal pollinators (Fig. 1c) shows 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 while birds are more affected by the impacts of invasive alien species (Fig 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 towards extinction than away from it. On average, 2.4 species per year have moved one IUCN Red List category towards extinction in recent decades. While 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 realised 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 to contiguous areas of forest (Borgella et al. 2001). Forest loss may also impact the behaviour of bird pollinators, with potential implications for the reproduction of the plant species that they pollinate (e.g. Hadley and 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 distribution.

Conclusions

Pollinating birds and mammals are in decline, primarily due to unsustainable agricultural, 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 sampled and global assessments of invertebrate pollinator groups (e.g. Lewis and 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 towards 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.

Acknowledgements

We are grateful to all the individuals and organisations who contribute to the assessments of species on the IUCN Red List of Threatened Species, which underpins our analysis. We would like to thank Jeff Ollerton and David Inouye for their very helpful review comments. The writing of this paper was part-financed by the OPERAs project which is a 7th Framework Programme funded by the European Union under Contract No. 308393.

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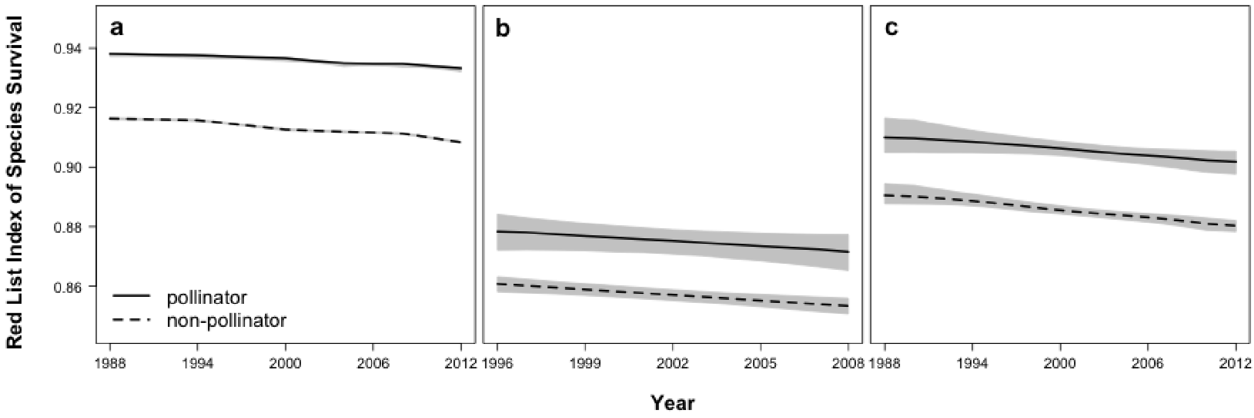

Figure 1 Red List Indices for (a) pollinating and non-pollinating bird species; (b) pollinating and non-pollinating mammal species; and (c) aggregated pollinating and non-pollinating birds and mammals. An RLI value of 1 equates to all species being Least Concern; an RLI value of 0 equates to all species 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.

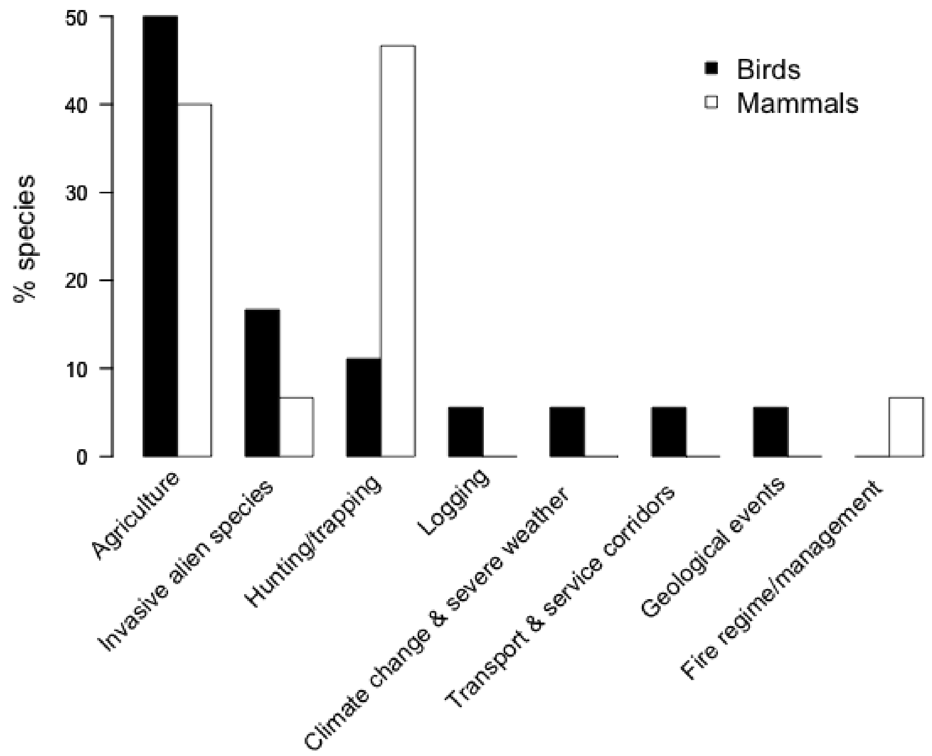

Figure 2 Drivers of declines in status for pollinator birds (1988-2012) and mammals (1996-2008).