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Which bird species have gone extinct? A novel quantitative classification approach

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ABSTRACT

Determining whether species have gone extinct requires considering the timing and reliability of records, the timing and adequacy of surveys, and the timing, extent and intensity of threats. However, previous assessments have either applied qualitative approaches or considered only the first of these factors. We applied quantitative methods encompassing all three factors to a suite of 61 potentially or confirmed extinct species of birds. We tested six different methods, each with a range of thresholds, for assigning species to IUCN Red List Categories, and compared the results with species' current categories. We recommend that if both the probability that a species remains extant based on threats and the probability based on records and surveys fall below 0.5, it should qualify as Critically Endangered (Possibly Extinct), while if both probabilities fall below 0.1 it should qualify as Extinct. This novel approach resulted in an 80% match with the current IUCN Red List classification of species. The exceptions largely reflect species whose reclassification was pending the outcome of this work. Consequently, we recommend that nine species are reclassified on the IUCN Red List, with cryptic treehunter (*Cichlocolaptes mazarbarnetti*), Alagoas foliage-gleaner (*Philydor novaesi*) poo-uli (*Melamprosops phaeosoma*) now qualifying as Extinct. We estimate a revised total of 187 extinctions since 1500, of which 90% have been of insular species. The major drivers were invasive alien species (46%) and hunting/trapping (26%). Application of this approach in non-avian groups would increase the robustness of extinction rate estimates and species' classifications on the IUCN Red List.

1. Introduction

Preventing species from going extinct as a consequence of human activities is one of the ultimate objectives of nature conservation, and has been adopted as a target in the Strategic Plan on Biodiversity through the Convention on Biological Diversity (CBD, 2010). Failure—the declaration of a global species extinction—generates considerable public interest and concern (e.g. Slezak, 2016; Anon., 2017), while estimates that the rate of species extinctions is about 1000 times greater than the background rate (Pimm et al., 2014) have probably helped to elevate concerns and drive policy responses to address the current biodiversity crisis (e.g. CBD, 2010).

Documenting extinctions accurately is therefore important. The IUCN Red List of Threatened Species contains the most comprehensive and regularly updated audit of species extinctions that have taken place since 1500 (IUCN, 2017). Species are classified as Extinct if 'there is no reasonable doubt that the last individual has died' (IUCN, 2001). Determining whether this is true for a particular species is not straightforward, requiring 'exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historical range… over a time frame appropriate to the taxon's life cycle and life form' (IUCN, 2001).

Decisions about which species to classify as Extinct were previously made in an unstructured way based on expert judgement (e.g. Collar and Andrew, 1988; Collar et al., 1994). A series of papers presenting quantitative approaches to estimating extinction probability or extinction date based on the timing of records have been published since the 1990s (e.g. Burgman et al., 1995; Solow, 1993a, 1993b, 2005; Solow and Roberts, 2003; Roberts and Solow, 2003), some of which also consider the likely reliability of records (e.g. Solow et al., 2012; Lee et al., 2015). However, such approaches can estimate high extinction probability for species with no recent records, even when this can be simply explained by a lack of recent searches. They also do not take into account whether there are threats that could have plausibly driven the

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taxon extinct. To emphasise the importance of considering these factors, Butchart et al. (2006) set out a structured (but non-quantitative) framework for assessing these factors when determining which species should qualify as Extinct. A trilogy of papers published in 2017 (Akcakaya et al., 2017; Keith et al., 2017; Thompson et al., 2017) set out complementary methods for estimating extinction probability based on (a) the intensity, extent and timing of threats to a taxon, taking into account its likely susceptibility to particular threats (Keith et al., 2017); and (b) the timing and reliability of records, and the timing, scope and adequacy of surveys, taking into account the ease of detection and identification of the taxon (Thompson et al., 2017). However, these approaches have not yet been tested on more than a handful of examples.

Data on extinctions from the IUCN Red List are used both to monitor extinction rates and to determine which species no longer warrant investment of conservation resources. However, as described by Akcakaya et al. (2017), there is a tension between these two aims: it is important to avoid declaring extinction prematurely, as this may lead to the Romeo error (by which conservationists give up on a species prematurely, presuming incorrectly that they are extinct: Collar, 1998); but failing to recognise extinctions leads to underestimates of extinction rates. Butchart et al. (2006) therefore proposed that a subset of Critically Endangered species be tagged as 'Possibly Extinct': those that are, on the balance of evidence, likely to be extinct, but for which there is a small chance that they may be extant and thus should not be listed as Extinct until adequate surveys have failed to find the species and local or unconfirmed reports have been discounted. 'Possibly Extinct in the Wild' correspondingly applies to such species known to survive in captivity. Possibly Extinct species remain the target of conservation attention and resourcing, but can be included in estimates of extinction rates. This approach was subsequently adopted by the IUCN Red List (IUCN Standards and Petitions Subcommittee, 2017), and such species are identified as 'Critically Endangered (Possibly Extinct)' (i.e. 'Possibly Extinct' is a tag applied to a subset of species categorised as Critically Endangered). Akcakaya et al. (2017) proposed that the methods of Keith et al. (2017) and Thompson et al. (2017) could be used to estimate the probability that taxa survive, and that these estimates could be used to classify species as Critically Endangered (Possibly Extinct or Possibly Extinct in the Wild) or Extinct. However, a methodology for integrating the two approaches is yet to be determined, and Akcakaya et al. (2017) recommended a process of testing and consultation to determine the thresholds of extinction probability to be used for assigning species to IUCN Red List Categories.

Here we carry out such a test, and implement the first comprehensive application of the quantitative methods described by Keith et al. (2017) and Thompson et al. (2017) for estimating the probability of extinction based on threats, records and surveys. We focus on birds as these are the best studied class of organisms, including in relation to extinctions. By comparing the results with the current classifications of species as Critically Endangered, Critically Endangered (Possibly Extinct) and Extinct on the IUCN Red List, we devise a methodology to consolidate the two quantitative approaches to estimating extinction probability, and propose thresholds for assigning species to these classes, leading to a novel approach for classifying species as extinct on the IUCN Red List. Using the revised list of known and suspected extinctions, we then review the distribution and drivers of bird extinctions.

2. Materials and methods

Butchart et al. (2006) examined the probability of extinction of 40 bird species that had a reasonable possibility of being extinct, including any that had not been seen for > 10 years (despite reasonable searches and/or for which there was a plausible threatening process), and any that had last been seen ≤10 years ago for which there had been a well-documented decline of a tiny population. Six of those species (Madagascar pochard (*Aythya innotata*), Beck's petrel (*Pseudobulweria becki*), silvery pigeon (*Columba argentina*), night parrot (*Geopsittacus occidentalis*), Liben (=Archer's) lark (*Heteromirafra archeri*) and Bahia tapaculo (*Scytalopus psychopompus*)) have subsequently been confirmed to be extant (BirdLife International, 2017). In addition, four (hooded seedeater ('*Sporophila melanops*'), Magdalena tinamou ('*Crypturellus saltuarius*'), Liberian greenbul ('*Phyllastrephus leucolepis*') and Bulo Burti boubou ('*Laniarius liberatus*')) have been subsequently shown to be invalid taxa (Remsen Jr. et al., 2006, Nguembock et al., 2008, Areta et al., 2016, Collinson et al., 2017, del Hoyo and Collar, 2014, 2016). 'nukupuu (*Hemignathus lucidus*) has subsequently been split into the long-extinct Oahu nukupuu (*H. lucidus*), plus Kauai nukupuu (*H. Hanapepe*) and Maui nukupuu (*H. affinis*) (del Hoyo and Collar, 2016). We re-examined the evidence for extinction for both these split taxa, plus the remaining 29 species considered by Butchart et al. (2006). Of these 31 species, one is currently listed as Extinct, 13 as Critically Endangered (Possibly Extinct or Possibly Extinct in the Wild) and 17 as Critically Endangered.

We also considered 20 additional taxa that had any reasonable possibility of being extinct, including any that had not been seen for > 10 years (despite reasonable searches and/or for which there was a plausible threatening process), and any that had last been seen ≤10 years ago for which there had been a well-documented decline of a tiny population. These comprised 11 taxa that were not described or treated at the species level until after the publication of Butchart et al. (2006), but that may have already gone extinct (New Caledonian nightjar (*Eurostopodus exul*), Guanacaste hummingbird (*Amazilia alfaroana*), New Caledonian buttonquail (*Turnix novaecaledoniae*), Sinu parakeet (*Pyrrhura subandina*), cryptic treehunter (*Cichlocolaptes mazarbarnetti*), Ua Pou monarch (*Pomarea mira*), South Island kokako (*Callaeas cinereus*), Lendu crombec (*Sylvietta chapini*), Moorea reed-warbler (*Acrocephalus longirostris*), Maui akepa (*Loxops ochraceus*) and Antioquia brush-finch (*Atlapetes blancae*)), three species that were known to survive in 2006 but that may have gone extinct subsequently (Purple-winged ground-dove (*Claravis geoffroyi*), Jerdon's courser (*Rhinoptilus bitorquatus*) and Alagoas foliage-gleaner (*Philydor novaesi*)), and six taxa presumed by Butchart et al. (2006) to survive, but that may now have gone extinct (New Caledonian owlet-nightjar (*Aegotheles savesi*), pygmy-owl (*Glaucidium mooreorum*), ivory-billed woodpecker (*Campephilus principalis*), kinglet calyptura (*Calyptura cristata*), Cozumel thrasher (*Toxostoma guttatum*) and poo-uli (*Melamprosops phaeosoma*)). [Note that concerns over recent possible loss of wild populations of Edwards's Pheasant *Lophura edwardsi* (Eames and Mahood, 2018) were published too late for inclusion in our analysis.]

Finally, we added ten randomly selected (using numbers generated from www.random.org) species classified as Extinct: Amsterdam duck (*Anas marecula*), Bonin woodpigeon (*Columba versicolor*), Rodrigues turtle-dove (*Nesoenas rodericanus*), Hodgen's waterhen (*Tribonyx hodgenorum*), laughing owl (*Sceloglaux albifacies*), Mauritius owl (*Mascarenotus sauzieri*), Guadalupe caracara (*Caracara lutosa*), Mascarene parrot (*Mascarinus mascarin*), mysterious starling (*Aplonis mavornata*) and Norfolk starling (*Aplonis fusca*). Hence we assessed 61 species in total.

For each of these 61 species, we assembled information from published literature, grey literature and personal correspondence with relevant experts on the timing, scope and severity of impacts to the species (and their susceptibility to such threats), confirmed and claimed records, and surveys undertaken. We used this information to estimate the following parameters described by Keith et al. (2017) and Thompson et al. (2017); see Table 1 for definitions and Appendix 1 for estimates. For each species, we assessed $p(local)$: the probability that the combination of threats affecting the species occurred for a sufficient duration and were sufficiently severe that they caused local extinction; and $p(spatial)$: the probability that the threats occurred over the species' entire range. For each record, we assessed $p(ci)$: the probability that the taxon was correctly identified. For each survey, we assessed ε: the