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Inferring extinctions I: A structured method using information on threats

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ABSTRACT

Extinctions are important indicators of biodiversity status. When they are detected, they may trigger the redirection of conservation resources to save other species. Yet declaring extinctions is inherently uncertain. Relevant evidence for consideration includes information on threats, the time series of species records and the effort employed to search for remaining individuals. Quantitative tools have been developed to infer extinctions from data on the timing of records. In contrast, inference of extinction from threats relies on expert judgement and is susceptible to subjective influences. To use qualitative information on threats, we suggest experts should construct an argument map to identify reasons, evidence and sources in support of a claim that a species has gone extinct, as well as objections, evidence and sources as to why the claim may not be true. The reasons must explicitly address: i) whether identified threats are sufficiently severe and prolonged to cause local extinction; and ii) whether such threats are sufficiently extensive to eliminate all occurrences. Transparent mapping of reasons and objections enables experts to estimate subjective probabilities that each alternative claim is true, allowing an overall probability of extinction to be calculated. We provide examples illustrating how typical evidence may be evaluated. To deal with uncertainties, we suggest bounded estimates of subjective probabilities are obtained from multiple experts in a structured elicitation. The method requires no detailed mathematical analysis, but relies on structured reasoning. The subjective estimates of probabilities must be based on the severity and pervasiveness of threats alone, to allow comparison with estimates derived independently from other sources of information such as time series of records.

1. Introduction

Determining whether a species or other taxon (hereafter taxon) is extinct is an uncertain process. The International Union for the Conservation of Nature (IUCN) Red List of Threatened Species criteria permit a taxon to be listed as Extinct when there is no reasonable doubt that the last individual has died (IUCN, 2001; IUCN Standards and Petitions Subcommittee, 2016). The phrase "no reasonable doubt" implies a very small degree of uncertainty that the last individual has indeed died. A false classification can have serious negative implications (Akçakaya et al., 2017-in this issue), especially in jurisdictions in which protective measures and resourcing lapse when the legal status of a taxon changes from threatened to extinct (e.g. *U.S. Endangered Species Act 1973; Australian Environmental Protection and Biodiversity Conservation Act 1999*).

False Extinct classifications arise for two reasons. First, if assessors apply a low threshold for the probability of extinction, above which a taxon is deemed to be extinct, many taxa will be incorrectly classified as extinct by chance, even given error-free data (Regan et al., 2000; Akçakaya et al., 2017-in this issue). Second, the likelihood of extinction may be estimated incorrectly, even if the assessor has a highly conservative attitude to risk and applies a high threshold for the probability of extinction. Although adopting high thresholds will help to reduce false Extinct classifications, one disadvantage of doing so is likely

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under-reporting of extinctions, so that the status of biodiversity is estimated to be better than it actually is. Given the trade-offs and consequences of errors, it is important to employ methods that maximise use of available evidence in a systematic and deductive manner to ensure repeatable and well-justified decisions on extinct listings.

Three main sources of information should be considered in assessing the likelihood that a species has gone extinct: (1) the intensity, extent and timing of threats and the likely susceptibility of the species to these; (2) the time-series of records of the species (sightings, specimen collections, etc.), and the likelihood that each of these are valid; and (3) the timing, extensiveness and adequacy of surveys and searches for the species (Harrison and Stiassny, 1999; Butchart et al., 2006). Inferences drawn from knowledge about threats and species' susceptibility (source 1) rely heavily on expert knowledge and are therefore predisposed to frailties of subjective judgement (Burgman, 2015). Consequently, they have been omitted from most quantitative methods for estimating the probability that a taxon has gone extinct. Most approaches are based exclusively on time series of records alone or include limited analysis of search effort (Solow, 1993, 2005; McCarthy, 1998; Collen et al., 2010). However, assessing probability of extinction based on records alone ignores relevant evidence about threats, their impacts and search effort (Solow, 2005; Collen et al., 2010; Thompson et al., 2017-in this issue). The few studies that have considered all three sources of information do so in a relatively unstructured way (Butchart et al., 2006). A more systematic synthesis of these contrasting sources of information, particularly by producing estimates of the same quantity – the probability that a species has gone extinct – from independent lines of evidence, will support more robust diagnoses of extinction. In this paper, the first in a trilogy, we develop a systematic approach to estimating the likelihood that a species is extinct based only on information about threats. The second paper (Thompson et al., 2017-in this issue) presents a new method for the same task based a time series of records and dedicated surveys, taking into account species detectability and the reliability of surveys. The third paper (Akçakaya et al., 2017-in this issue) focuses on how the likelihood that a species is extinct, as estimated by the previous two papers, is used in conservation assessments, reviews the trade-offs in declaring an extinction when evidence is uncertain, and recommends a decision threshold for assigning species to the Extinct category in IUCN Red Lists.

Qualitative information on threats is particularly important when occurrence records are insufficient or inadequate to estimate extinction probability reliably from time series. For example, 28 Critically Endangered or Data Deficient bird species are known only from the type specimen/series or one additional record. In such cases, information on threats (often with inferences about life history and ecology) may be the only evidence on which to base an assessment. How can this qualitative information be used to produce a quantitative estimate of an extinction probability that is comparable to estimates that can be calculated from quantitative observation data?

We approach this problem by outlining a structured way of inferring a probability that a taxon has gone extinct, using information on threats and species' susceptibility to them. The method requires experts to evaluate the proposition that a taxon has gone extinct by using biological understanding to outline all the plausible reasons why the proposition could be true (supporting reasons) or false (objections). This allows experts to construct an argument map of their reasoning (Walton, 2013), providing a clear and unambiguous platform for quantifying the probability that the taxon has gone extinct, based on the reasons, objections and their weights of evidence. We embed this within elicitation methods that reduce arbitrary and semantic uncertainties. We illustrate the approach by applying it to case studies that result in a probabilistic diagnosis of extinction.

2. A simple threat-based model for diagnosing extinction

The subject of this paper is calculation of the probability that global extinction has occurred, $P(E)$, which comprises two components: a local extinction component $P(local)$, 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 a spatial scale component $P(spatial)$. The latter is the probability that the threats occurred over the entire species range. We assume that if threats caused local extinction, and they occurred over the entire range, then global extinction has occurred. Thus, $P(spatial)$ is actually the conditional probability $P(E \mid local)$, so that by definition

$$P(E) = P(local) \times P(spatial) \quad (1)$$

In practical terms, these represent the proportion of like taxa (ecologically similar or phylogenetically related) that would go extinct when subject to the specified severity, duration and extent of threats. This conceptually generic logical treatment of threats is also applied, for example, to the "severity" and "extent" components within criteria C and D for the Red List of Ecosystems (Keith et al., 2013).

Estimation of $P(local)$ requires assessors to draw on the history of the impacts of threats on populations of the target taxon. A relevant historical observation, for example, would be that the taxon disappeared from an area shortly after the introduction of an invasive alien predator. It may also draw on examples where the threats have caused extirpation of ecologically similar or phylogenetically related taxa. Inferences about which taxa are 'ecologically similar or related' may be based on life history (e.g. life cycle structure, dependence on hosts, body size, diet), habitat ecology (e.g. microhabitat type, breeding sites) and/or phylogeny.

Estimating $P(spatial)$ requires assessors to evaluate two components: i) the likelihood that the threats (with sufficient severity and duration to have caused local extinction) operated throughout the entire range of the taxon (i.e. distribution of habitat and/or individuals, as appropriate); and ii) the certainty with which the range limits are known. Relevant considerations for the first component include whether the threats operated in such a pattern as to have caused extinction throughout the taxon's range. This may be influenced by the spatial occurrence of different threats, dispersal dynamics, migration patterns and patch dynamics, as well as species life-history traits and cultural factors that influence species susceptibility to threats (see Discussion section). Relevant factors to consider for the second component (range limits) include taxonomic uncertainty, reliability of records and whether potential habitat outside the confirmed range has been adequately searched. These uncertainties can be incorporated into estimates of $P(spatial)$ by setting upper and lower bounds taking into account plausible maximum and minimum extents of the species range (see Section 4 below).

Our generic method should cover a wide range of cases, but some specific cases warrant variations in the model. Firstly, for species that are known only to occur in a small number of discrete areas (e.g. islands), $P(E)$ can simply be estimated from the product of local extinction probabilities, taking into account the specific threats in each area. As all local populations are included, $P(spatial)$ can be dropped from the equation. For a species with three populations

$$P(E) = P(pop_1) \times P(pop_2) \times P(pop_3) \quad (2)$$

where $P(pop_n)$ is the probability that threats affecting population n are sufficiently severe and prolonged to cause its local extinction. We stress that Eq. (2) is only appropriate when there is a negligible chance that unknown populations exist within the species range, and when the three probabilities are independent.

Secondly, in more complex scenarios Eq. (1) could be extended to include multiple values of $P(local)$ for different parts of the species range where a different unique combination of threats contributed to extinction risk. For a species in which three different parts of the range were each affected by different and independent combinations of threats