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Inferring extinctions II: A practical, iterative model based on records and surveys

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ABSTRACT

Extinctions are difficult to observe. Estimating the probability that a taxon has gone extinct using data from the field aids prioritisation of conservation interventions and environmental monitoring. There have been recent advances in approaches to estimating this probability from records. However, complete assessment requires consideration of the type, timing and certainty of records, the timing, scope and severity of threats, and the timing, extent and reliability of surveys. Until recently, no single method could integrate these different sources and qualities of data into a single measure. Here we describe a new, accessible method for estimating the probability that a taxon is extinct based on different kinds of both record and survey data, and accounting for data quality. The model takes into account uncertainties in input parameter estimates and provides bounds on estimates of the extinction probability. We illustrate application of the model using information for the Alaotra Grebe *Tachybaptus rufolavatus*. Application of this approach should facilitate more efficient allocation of conservation resources by enabling scenario analyses that inform investments in searches and management interventions for potentially extinct taxa. It should also provide more reliable estimates of recent extinction rates.

1. Introduction

Extinctions of plant and animal taxa are almost never observed directly (Diamond, 1987). However, determining whether a taxon is extinct is important because it affects decisions about priorities for surveys and conservation interventions such as actions to abate threats, and establish and manage protected areas. Estimates of extinction rates are also used to measure biodiversity conservation effectiveness and for reporting on the state of the environment (e.g., Ministry of the Environment, 1997, State of the Environment, 2006, Tittensor et al., 2014, Pimm et al., 2014). The IUCN (2012) defines a taxon as extinct "when there is no reasonable doubt that the last individual has died. A taxon is presumed extinct when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form". Solow (1993) introduced a quantitative way of inferring extinctions from data on the timing of observations. Others have subsequently adapted these ideas, for example, to consider the certainty of observations (Burgman et al., 1995, McCarthy, 1997, Rout et al., 2009, Solow and Roberts, 2003, Roberts et al., 2010, Elphick et al., 2010, Lee, 2014, Jaric and Roberts, 2014). Rivadeneira et al. (2009) assessed some of these models in a comparative study.

However, these approaches do not incorporate information on the adequacy of surveys and searches for the taxon (as specified by IUCN, 2012). There is a need to account for detectability, accessibility of habitat, timing, duration, extensiveness, sampling intensity, survey methods and observer skill (see Clements et al., 2013, 2014). Butchart et al. (2006, see also Szabo et al. 2012) provided a conceptual framework to consider the likelihood that a taxon has gone extinct based on knowledge of the intensity and timing of threats that may have impacted it, and the likely susceptibility of the taxon to such threats, alongside information on the timing and reliability of records and the adequacy of searches. They introduced the concept of 'Possibly Extinct' taxa to recognise uncertainty in judgements of probability of being extinct. However, there is no quantitative approach that incorporates all the kinds of data that may contribute to this assessment.

Thompson et al. (2013) developed a single framework that

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Table 1
Screenshot of a spreadsheet implementation of the model, using data for the Alaotra Grebe *Tachybaptus rufolavatus*. The total number of years T in the observational record up to and including the last survey is 81 (1929 to 2009 inclusive). For an explanation of the parameters, see the text.

Passive surveys					
ε'		p'(i)		p'(r)	
Lower	Upper	Lower	Upper	Lower	Upper
0.00	0.05	0.10	0.65	0.40	0.60

Calendar year	Recordings		Dedicated surveys					
	p(ci)		ε		p(i)		p(r)	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1929	0.99	1.00						
1960	0.95	0.99						
1963	0.75	0.94						
1969	0.75	0.94						
1970	0.10	0.40						
1971	0.10	0.40						
1972	0.60	0.80						
1982	0.60	0.80						
1985	0.20	0.80						
1986	0.20	0.70						
1988	0.20	0.50						
1989			0.80	0.95	0.90	0.95	0.70	0.90
1990			0.80	0.95	0.90	0.95	0.70	0.90
1993			0.80	0.95	0.90	0.95	0.70	0.90
1994			0.80	0.95	0.90	0.95	0.70	0.90
1997			0.80	0.95	0.90	0.95	0.70	0.90
1998			0.80	0.95	0.90	0.95	0.70	0.90
1999			0.80	0.95	0.90	0.95	0.70	0.90
2000			0.70	0.90	0.90	0.95	0.70	0.90
2004			0.80	0.95	0.90	0.95	0.70	0.90
2009			0.80	0.95	0.90	0.95	0.70	0.90

accommodates certain and uncertain observations, together with information from targeted surveys, but the approach is theoretical and unfortunately not straightforward to apply. Lee (2014) published a simplified version of the model, but this requires parameter estimates that are not readily available in practice. Also, in certain cases that can arise in practice, Lee's (2014) model can lead to model probabilities that exceed unity. Here we present a practical adaptation of the approach presented in Thompson et al. (2013) that uses the type of data that can be derived from commonly available information, integrating records and survey data. It may be used to contribute to subsequent benefit-cost analyses (Akçakaya et al., 2017). It generates results that are consistent with the definition of probabilities, and we provide it in an accessible software package to facilitate straightforward application.

2. Methods

In outline, our simplified model provides year-by-year updates for the probability $P(X_t)$, that the taxon is extant in the year t, of a given record. Two types of "years" over a given time-frame are considered depending on whether or not there is a record (or observation) of the taxon in question. Thus for any year, there is either:

(i) a "record"; or
(ii) an "unsuccessful survey" which may be dedicated or passive.

Dedicated surveys are planned surveys devoted to searching for the taxon, in an attempt to determine whether it persists. In the absence of dedicated surveys, it is assumed that there may nevertheless be sightings reported from interested professional or amateur ecologists who happen to observe the taxon in some unplanned way. We call the latter, passive surveys. Note that here we treat all successful survey years as record years.

The model requires experts to provide estimates for inputs. This includes an "initial" $P(X_0)$ (with bounds) that the taxon is extant at the beginning of the time series of records (and independent of them). The initial probability could be based on the severity and pervasiveness of threats and the taxon's likely susceptibility to them. Inputs are required concerning the probability that the taxon was correctly identified. Inputs are also required for the probability that the taxon could have been identified correctly and would have been recorded, were it present, in years when unsuccessful surveys were conducted. In addition to these inputs, the approach also accounts for the proportion of the taxon's remaining range covered by targeted surveys and their extensiveness, sampling intensity, survey methods and observer skill. Uncertainties in these inputs can be accounted for by providing lower and upper bounds on estimates. The bounds represent uncertainties in observations given the type and quality of evidence, the ease of distinguishing the taxon from taxa with which it could potentially be confused, circumstances of the record and the skill and experience of the recorder.

Our iterative model makes it possible to determine the probability that the taxon is extant $P(X_t)$ in any year t of a record period, from the