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Optimal sampling frequency and timing of threatened tropical bird populations: A modeling approach

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ABSTRACT

Conservation of threatened or endangered species relies critically on accurate population counts over time. In practice, many population censuses are conducted by non-governmental organizations or volunteer citizen scientists who are constrained by fiscal and temporal resources. Less than optimal sampling regimens (characterized by infrequent and/or irregular schedules) for conducting population censuses can result in woefully misleading population estimates – and thus have dire consequences for management and conservation. We illustrate this using an East African case study in which 14 years of bird data was collected in the Arabuko-Sokoke Forest in coastal Kenya. We first estimate life history parameters in a discrete matrix model. Desiring a data collection protocol which would lessen observation error and lend to a deeper understanding of population projections and dynamics of a threatened species, we carry out mathematical and statistical modeling efforts with an adaptation of a Leslie model for simulated population estimates stemming from different population sampling schemes. We illustrate how resource managers might take a strategic approach, using simple quantitative models, to develop an optimal sampling scheme that considers important species traits, such as breeding season, and balances the tradeoff between resources and accuracy.

1. Introduction

Conservation science in practice is often constrained by resource availability, which has implications for data analysis and interpretation as well as management. Underpinning most conservation efforts, from local volunteer programs to large-scale population viability analyses, is an ongoing need to characterize population abundance and dynamics based on population census counts (Simberloff, 1988; Brook et al., 2000; Morris and Doak, 2002; Karanth et al., 2003). Scarcity of resources often necessitates making difficult decisions about how often and when to collect data. Although amassing as much data as possible is of course generally recommended, many factors often conspire to prevent frequent and regular sampling of population abundance or diversity. A lack of resources often translates into data that are collected in a haphazard manner, with gaps in data collection during critical times in the life history of species being studied. Resulting poor quality data sets can lead to misleading population estimates and risk assessment (Holmes, 2001).

Bird counts provide an excellent means of illustrating some of the tradeoffs and other considerations implicated by questions of the frequency and timing of data collection. Many bird population estimates rely on the efforts of local non-governmental agencies or citizen-science groups, or other volunteer organizations (Newson et al., 2005; Freeman et al., 2007). Coordinated long-term datasets, such as those generated by Christmas Bird Counts (Link et al., 2006) or the North American Breeding Bird Survey (Kendall et al., 1996) strive to maintain consistency in both the timing and regularity of sampling, although such efforts can present special challenges in data quality and analysis (Dunn et al., 2005). In contrast, other less coordinated efforts, especially those done at a small local scale, are often conducted inconsistently with little regularity due to meager personnel resources. In the tropics, these activities often fall to non-governmental organizations (NGOs) and non-profits with uncertain or ephemeral funding sources, which can result in inconsistent sampling frequencies and timing.

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We describe here work inspired by bird count data collected by staff and citizen-science volunteers from A Rocha Kenya, a non-profit conservation group based at the Mwamba Field Studies Centre in Watamu, Kenya. Like many such conservation groups, A Rocha Kenya aims to gain a deeper understanding of threatened species population dynamics in order to best utilize resources to further protect the species. Mathematical modeling can prove advantageous in order to identify life history parameters of the species in question and gain insight into the reasons for population decline. One particular species, the East Coast Akalat, an Old World flycatcher in coastal Kenya, has been classified as Near Threatened (IUCN, 2014). Accurate estimation of life history parameters can be heavily impacted by a high level of error in the data collection process and an irregular collection schedule. After estimating life history parameters using a discrete matrix model, we identified the prominent weaknesses in the data which contributed to low confidence in the resulting parameter estimates. Motivated by these raw data, we use simulated data to identify an optimal sampling strategy using simulated data. We use this case study to develop a methodology for determining the optimal sampling scheme to accurately estimate population sizes of a threatened bird population given limited monitoring resources. We employ a combined mathematical and statistical modeling approach to determine the optimal frequency and seasonal timing of mist-net capture sessions. Mist netting is a common means of sampling bird populations, providing a standardized mean of estimating species abundance (Karr et al., 1990). While some studies have suggested it is not an optimal technique for comparing species abundance across habitats (Remsen and Good, 1996), it has been shown to be more accurate than point counts in estimating population abundance when employed in breeding habitats because it avoids observer error inherent in point count estimates (Rappole et al., 1993). We explore the accuracy of several different sampling strategies and discuss implications for conservation in practice. In particular, we compare sampling regimes in order to highlight approaches that have the highest potential for accurately describing population dynamics in model projections.

2. Materials and methods

2.1. Study organism/site

The East Coast Akalat (*Sheppardia gunningi sokokensis* Haagner) is a small forest robin that is restricted to small coastal forests in East Africa (Matiku et al., 2000). Distributed among remnant forest patches, *S. gunningi* is vulnerable to continuing habitat threats such as logging and development and has been classified as near threatened (declining population trend) by the World Conservation Union (IUCN, 2014). Formerly abundant along the east African coast from Kenya to Malawi and Mozambique, *S. gunningi* is now found primarily in the coastal forests of Kenya, with the largest remnant population (approx. 7500 pairs) residing year-round in Arabuko-Sokoke Forest (ASF), a 429 km^2 forest reserve that is the largest remnant patch of indigenous coastal forest in East Africa (Bennun and Njoroge, 1999; Birdlife International, 2008; Banks et al., 2012). *S. gunningi* is patchily distributed in ASF, with territories ranging from 100 to 200 m in diameter (Nemeth and Bennun, 2000). It feeds primarily on arthropods, but will also eat seeds and berries. *S. gunningi*'s breeding season is November through January; with an incubation period of around two weeks, a post-breeding birth pulse generally occurs from mid-November until mid-February. Because *S. gunningi* co-occurs with several other highly endangered and rare species, including other bird species as well as the Sokoke Bushy-tailed Mongoose, Aders' Duiker, and Golden-rumped Elephant Shrew, it has become an indicator species for habitat conservation efforts in the Arabuko-Sokoke Forest reserve.

2.2. Data collection

S. gunningi individuals were collected in mist nets by staff from the Mwamba Field Studies Center/A Rocha Kenya in an area in the north-eastern corner of Arabuko-Sokoke Forest known as the Gede Nature Trail from 1999 to 2012. Standard mist netting protocols were followed: for each session, total net lengths measured 180 m and samples consisted of captures from two consecutive dawn capture periods. After removal from the net, plumage characteristics, molt pattern, and age and sex were recorded for each akalat, and bands were placed on birds that had not previously been caught (band numbers were recorded for recaptured birds). Note the research described here does not directly make use of the recapture data, due to the overall low akalat counts, and in particular those who were recaptured. However, this information was used indirectly for the purposes of estimating the lifespan and other poorly known life history attributes of the akalat. Akalats were categorized, where possible, into one of three age-based classes: immature, subadult, or full adult. In cases where a clear designation was not possible, birds were categorized initially as "unknown age". Birds were captured in 24 sessions over 14 years, at non-uniform time intervals with consistent ringing effort. The number of sampling sessions per year ranged from zero to eight, with a mean of approximately two. Data consisting of the number of akalats in each age class for each mist-netting session were then incorporated into a predictive population model. In total, 10 out of a total of 81 captured birds were difficult to age because they were at a transitional stage – these birds were added to the "full adult" category based on the time of year when they were captured and the likelihood that they were subadults transitioning to full adults.

2.3. Mathematical model

We incorporated life history data into an adaptation of the stage structured Leslie matrix mathematical model (Leslie, 1945) – also known as a Lefkovitch matrix model (Lefkovitch, 1965) – to generate *S. gunningi* population projections for the multi-year sampling period. This model is a deterministic, discrete time model projecting a population at time t_j for each of the three classes (and thus projecting a net population), assuming an equal proportion of males and females in the population. Note that the population does change on a continuous time line, and thus this discrete time model has some intrinsic error. The number of individuals in each of the three stage classes is denoted by x_i for $x = 1, 2, 3$, with the population expressed as a vector $\mathbf{X} = [x_1, x_2, x_3]^T$ Then the population growth may be described by the mathematical model:

$$\mathbf{X}(t_{j+1}) = \begin{bmatrix} x_1(t_{j+1}) \\ x_2(t_{j+1}) \\ x_3(t_{j+1}) \end{bmatrix} = \mathbf{f}(\mathbf{X}(t_j), \boldsymbol{q})$$

$$= \mathbf{A}(\boldsymbol{q})\mathbf{X}(t_j) = \begin{bmatrix} 0 & 0 & F_3 \\ G_1 & 0 & 0 \\ 0 & G_2 & P_3 \end{bmatrix} \begin{bmatrix} x_1(t_j) \\ x_2(t_j) \\ x_3(t_j) \end{bmatrix} \quad (1)$$

where the G_i and P_i and represent the rate of individuals surviving from the ith to the $(i+1)$st stage, in which $i = 1, 2$, and 3 represent the immature, subadult and full adult stage respectively ($0 < G_i < 1$, $i = 1, 2$ and $0 \leq P_3 < 1$), F_3 denotes the reproductive rate of full adults (3rd life stage), and time steps are in increments of months (i.e. $|t_j - t_{j-1}| = 1$ month). Note that we do not consider separate classes for male and female birds, as this not only doubles the number of state variables in the model, but also adds another source of error,