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Designing cost-effective capture-recapture surveys for improving the monitoring of survival in bird populations

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ABSTRACT

Population monitoring traditionally relies on population counts, accounting or not for the issue of detectability. However, this approach does not permit to go into details on demographic processes. Therefore, Capture-Recapture (CR) surveys have become popular tools for scientists and practitioners willing to measure survival response to environmental change or conservation actions. However, CR surveys are expensive and their design is often driven by the available resources, without estimation about the level of precision they provide for detecting changes in survival, despite optimising resource allocation in wildlife monitoring is increasingly important. Investigating how CR surveys could be optimised by manipulating resource allocation among different design components is therefore critically needed. We have conducted a simulation experiment exploring the statistical power of a wide range of CR survey designs to detect changes in the survival rate of birds. CR surveys differ in terms of number of breeding pairs monitored, number of offspring and adults marked, resighting effort and survey duration. We compared open-nest (ON) and nest-box (NB) monitoring types, using medium- and long-lived model species. Increasing survey duration and number of pairs monitored increased statistical power. Long survey duration can provide accurate estimations for long-lived birds even for small population size (15 pairs). A cost-benefit analysis revealed that for long-lived ON species, ringing as many chicks as possible appears as the most effective survey component, unless a technique for capturing breeding birds at low cost is available to compensate for reduced local recruitment. For medium-lived NB species, focusing the NB rounds at a period that maximises the chance to capture breeding females inside nest-boxes is more rewarding than ringing all chicks. We show that integrating economic costs is crucial when designing CR surveys and discuss ways to improve efficiency by reducing duration to a time scale compatible with management and conservation issues.

1. Introduction

Studies aiming at detecting the response of wild populations to environmental stochasticity, anthropogenic threats or management actions (e.g. harvest, control or conservation), traditionally rely on the monitoring of population counts. Such data, however, suffers from a variable detectability of individuals that can alter the reliability of inferred temporal trends (Williams et al., 2002). Methods have been developed to account for the issue of detectability, based on the measure of the observer-animal distance (Distance Sampling; Buckland et al., 2001) or on multiple surveys (hierarchical modeling, Royle and Dorazio, 2008). Still, population size being the result of a balance between survival, recruitment, emigration and immigration, inferring population status from counts, whatever detectability is accounted for or not, may impair the assignment of the demographic status of a population (source vs. sink; Furrer and Pasinelli, 2016, Weegman et al., 2016).

Surveys that consist of capturing, marking with permanent tags, releasing and then recapturing wild animals (i.e. capture-recapture surveys, hereafter CR surveys), to gather longitudinal data and hence

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derive survival rates while accounting for imperfect detection (Lebreton et al., 1992), have become highly popular tools in both applied and evolutionary ecology (Clutton-Brock and Sheldon, 2010). Opting for a mechanistic instead of a phenomenological approach has indeed proved to be particularly informative for identifying the response of a population to any perturbation, and ultimately allows to pinpoint the appropriate management strategy. Over the last decade, an increasing number of practitioners have set up CR surveys with the aim of quantifying survival variation in response to i) changing environment such as climate or habitat loss (Grosbois et al., 2008), ii) hunting (Sandercock et al., 2011), iii) other anthropogenic mortality causes (e.g. collision with infrastructures; Chevallier et al., 2015), and iv) the implementation of management/conservation actions (Lindberg, 2012, Koons et al., 2013, review in Frederiksen et al., 2014). In all these contexts, the estimation of survival, and its temporal variation, is particularly informative for building effective evidence-based conservation (Sutherland et al., 2004). As an example, the high adult mortality due to electrocution in an Eagle owl *Bubo bubo* population of the Swiss Alps, as revealed by a CR survey, would have not been detected if the survey was solely based on population counts, that remained stable over 20 years (Schaub et al., 2010).

The effectiveness of a CR survey to detect and explain changes in survival rates over time depends on the levels of field effort dedicated to several survey components: i) the size of the sample population, ii) the proportion of offspring and adults marked, iii) the recapture/resighting rate of previously marked individuals and iv) the number of surveying years (or survey duration; Yoccoz et al., 2001, Williams et al., 2002). In a conservation context, considering only the usual trade-off between the number of marked individuals and the number of surveyed years is of little help when designing a CR survey. Indeed, practitioners need to know as soon as possible whether survival is affected by a potential threat or has alternatively benefited from a management action. Implementing CR surveys is however particularly costly in terms of financial and human resources, as it requires skilled fieldworkers over an extensive time period. Therefore, most surveys are actually designed according to the level of available resources only, and without any projection about the precision they provide for estimating survival and the statistical power they obtain for detecting survival variability.

The life-history characteristics (e.g. survival and recruitment rates) of the study species largely determine which of the different components of a CR survey will provide the most valuable data. For instance, low recruitment of locally-born individuals (due to high juvenile mortality rate and/or high emigration rates) limits the proportion of individuals marked as juveniles recruited in the local population. In such a case, we expect that reducing the effort dedicated to mark offspring in favour of marking and resighting breeding individuals would improve survey efficiency. Therefore, manipulating both sampling effort and sampling design offer opportunities to optimise CR surveys. A few attempts have been made to improve the effectiveness of CR according to species' life-histories, though most of them remain species-specific (Devineau et al., 2006, Williams and Thomas, 2009, Chambert et al., 2012, Lindberg, 2012, Lahoz-Monfort et al., 2014). Moreover, improving CR surveys in regards to the precision of survival estimates constitutes only one side of the coin and yet, the quantification of economic costs in the optimisation process is currently lacking. Assessing costs and benefits is therefore critical if we are to provide cost-effective guidelines for designing CR surveys. This optimisation approach is increasingly considered as an important step forward for improving the robustness of inferences in different contexts such as for population surveys (Moore and McCarthy, 2016) or environmental DNA sampling (Smart et al., 2016).

Here we offer a simulation experiment investigating the relative efficiency of a wide array of CR survey designs in terms of statistical power to detect a change in survival rates. Alongside the usual *how many* and *how long* considerations, we focused our simulations on the *how to* and *what to* monitor. We further balanced the statistical benefit of each survey component with human/financial costs, derived from actual monitoring schemes. Our aim was to provide cost-effective guidelines for the onset of new CR surveys and the improvement of existing ones. Although our work was primarily based on the monitoring of bird populations, we discussed how this approach can be applied to improve the monitoring of other taxa.

2. Material and methods

2.1. Bird monitoring types and model species

Our simulation experiment encompassed the two most common types of bird monitoring when applied on two different life-history strategies: long-lived and open-nesting species with high but delayed local recruitment vs. medium-lived and cavity-nesting species with rapid but low recruitment of locally-born individuals. These two types of monitoring are representative of what practitioners come across in the field and further largely determine the nature of the survey and the level of resources needed. Moreover, another prerequisite of our simulations was to ensure the availability of both detailed demographic data on the model species together with a precise estimation of the human and financial costs entailed by the monitoring.

In open-nesting (ON) surveys, chicks are typically ringed at the nest before fledging with a combination of coloured rings or a large engraved plastic ring with a simple alphanumeric code, in addition to conventional metal rings. Resightings can then be obtained without recapturing the birds using binoculars or telescopes. The identification of breeding birds is typically obtained when monitoring breeding success. For our model species for ON monitoring, we combined life-history and survey characteristics of two long-lived diurnal raptors, the Bonelli's eagle *Aquila fasciata* and the Egyptian vulture *Neophron percnopterus* (Lieury et al., 2015, 2016). Monitoring typically consists of repeated visits of known territories during the breeding season for checking whether breeding occurs and the identity of breeding birds, and eventually ringing chicks. Breeding birds are difficult to capture, therefore limiting the number of newly marked breeders each year, although additional trapping effort can be deployed (adults are occasionally trapped, for fitting birds with GPS). Such captures are however highly time-consuming as it requires monitoring several pre-baiting feeding stations.

The second, highly common, monitoring type concerns cavity-nesting birds, whose surveys typically involve artificial nest-boxes (NB thereafter). All NBs are checked at least once a year, and additional visits concentrate on the restricted set of occupied NBs for ringing/recapturing both chicks and breeding birds. For building simulations on the NB type of monitoring, we combined information on life-history and survey characteristics from two medium-lived nocturnal raptors, the barn owl *Tyto alba* (Altwegg et al., 2007) and the little owl *Athene noctua* (OH & AM, *unpub. data*). These two species are known to prefer NB over natural or semi-natural cavities. NB monitoring typically consists of repeated visits of NB during the breeding season for checking whether breeding occurs, catching breeding females in NB and eventually ringing chicks. Breeding females are usually relatively easy to catch, thus allowing many newly marked adults to enter the CR dataset each year, in contrast to ON. Breeding males are typically more difficult to capture than females and require alternative, time-consuming, types of trapping (Millon et al., 2010).

For the two types of monitoring, the resighting probability of non-breeding individuals (hereafter floaters) is low as such individuals are not attached to a spatially restricted nesting area. Life-cycle graphs and values of demographic parameters are given in the appendix (Table S1; Fig. S1).

2.2. Definition of the main components of CR surveys

We designed a set of surveys for both types of monitoring by varying