

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

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SUPPLEMENTARY INFORMATION

Procedure for simulating Capture-recapture histories.

For long-lived species in ON monitoring, we considered two statuses with territorial birds having higher survival than floaters (Table S1). The total number of ringed chicks depended on survey duration, the number of pairs monitored and the proportion of ringed chicks (Fig. S1). Brood sizes were randomly generated using a multinomial distribution with 0, 1 or 2 chicks (with probabilities of 0.3, 0.6 and 0.1 respectively; Lieury *et al.* 2016), with an even sex-ratio. Females and males are indistinctly ringed and monitored, assuming no differences between sexes. We simulated the life history of each individual, ringed as chick, using binomial processes according to simulated survival and recruitment rates (Fig. S2). Finally, we generated resighting histories according to the observation effort of a given sampling design. When required, we added simulated CR histories of trapped breeders in the CR dataset.

For medium-lived species in NB monitoring, we built a female-based CR survey, considering a single state (territorial breeder). Brood sizes were randomly generated using a Poisson distribution ($\mu = 4$). We simulated the life history of each individual, ringed as chick, using a binomial process according to the simulated survival rates (Fig. S3). From the number of females marked as juveniles (assuming a 1:1 sex-ratio), we recorded the annual number of birds that were breeding and therefore available for capture. Then we derived the number of unmarked breeding females, captured and newly ringed in the first year of the survey. We dispatched this number of unmarked females among yearlings and adults according to the stable age structure obtained from the mean demographic parameters (Table S1). Capture histories were finally simulated, allowing the update of the number of unmarked breeders the following year, and this process was repeated until the whole CR dataset was completed.

Table S1. Average demographic parameters used in the simulation experiment to model the CR histories of long- and medium-lived species.

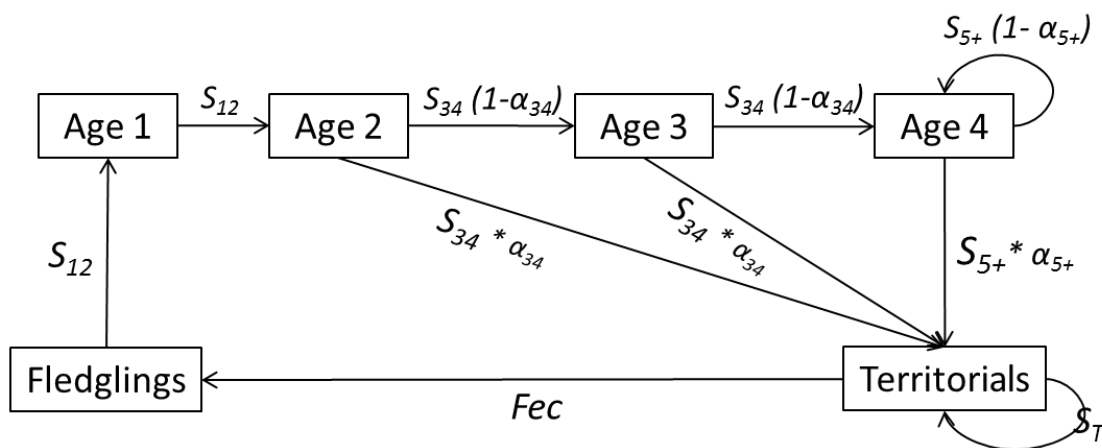
| Demographic parameters | Long-lived species | Medium-lived species |
|---|---|--|
| Probability to survive until age i | $S_{1-2} = 0.6, S_{3-4} = S_{5+} = 0.75$ and $S_T = 0.9$ | $S_1 = 0.05, S_2 = 0.46$ and $S_{3+} = 0.56$ |
| Probability to acquire a territory and first reproduce at age i | $\alpha_{12} = 0; \alpha_{34} = 0.75$ and $\alpha_{5+} = 0.9$ | - |
| Probability of breeding at age i | - | $PB_2 = 0.7$ and $PB_{3+} = 0.9$ |
| Fecundity (mean number of fledglings per successful pairs) | 0.8 (multinomial) | 4 (Poisson) |
| Probability of non-breeders to be resighted / captured at age i | $p_1 = 0.05, p_2 = 0.1$ and $p_{3+} = 0.15$ | $p = 0$ |
| References | (Grande <i>et al.</i> 2009; Hernandez- Matias, Real & Pradel 2011; Lieury <i>et al.</i> 2015, 2016) | (Altwegg <i>et al.</i> 2003; Altwegg, Schaub & Roulin 2007; Hameau & Millon, <i>unpub. data</i>) |

Table S2. Average human effort for building Capture-Recapture data sets for long- and medium-lived species. Human effort in working-day is detailed for each elementary action of the different components of efforts (see Fig. 1).

| Component of effort | Long-lived species | Medium-lived species |
|---|---|----------------------------------|
| Species example | <i>Bonelli's eagle / Egyptian vulture</i> | <i>Barn owl / Little owl</i> |
| Time to monitor a single nest during a season | 14 working -days | 45 min |
| Time to ring a chick or all the chick in a nest | 2 working -days | 15 min per chicks or 40 per nest |
| Time to capture a breeder | 15 working -days | 25 min |
| Time to identify a breeder | 3.8 ± 3.2 [1:14] working -days | — |

Fig. S1. Life-cycle graphs for (a) long-lived and (b) medium-lived species used in the simulations. S_i is the probability for individuals to survive until age i . α_i is the probability for individuals to acquire a territory and start to reproduce at age i . PB_i are the probability of breeding at age i . Fec is the average number of fledglings raised per breeding pair. In medium-lived species, only females were captured and monitored (assuming a 1:1 sex-ratio). Sexes were not distinguished in long-lived species, assuming similar demographic parameters. The average value for each of these parameters is indicated in Table S1.

a) **Long-lived species**



b) **Medium-lived species**

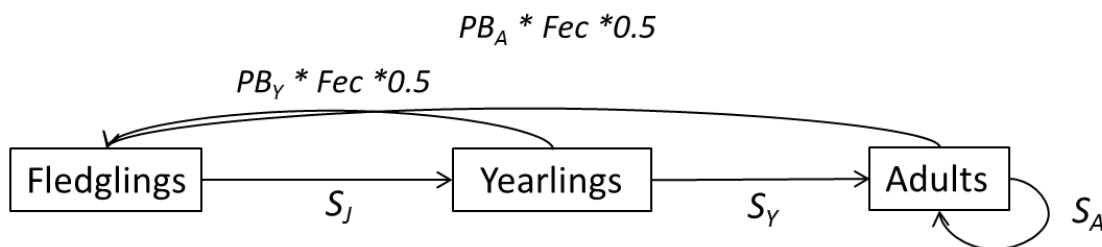


Fig. S2. Schematic representation of the different designs for Capture-Recapture bird survey according to species life-history (medium- vs. long-lived species). A total of 66 sampling designs were performed type of monitoring (NB medium-lived species vs. ON long-lived life-history), the arrows indicating the different combinations. Some extreme combinations were not simulated and are indicated by grey arrows. For instance, the designs involving 15 breeding pairs surveyed for 10 or 20 years consider only the case where 100% of monitored chicks are ringed (the first three arrows corresponding to 25-50-75% are grey) but consider the three levels of the fourth survey components (the three arrows are black). A further option involving the capture of five breeding individuals each year during the first five years of the survey was added, therefore doubling the number of sampling designs (132) for ON monitoring on long-lived species.

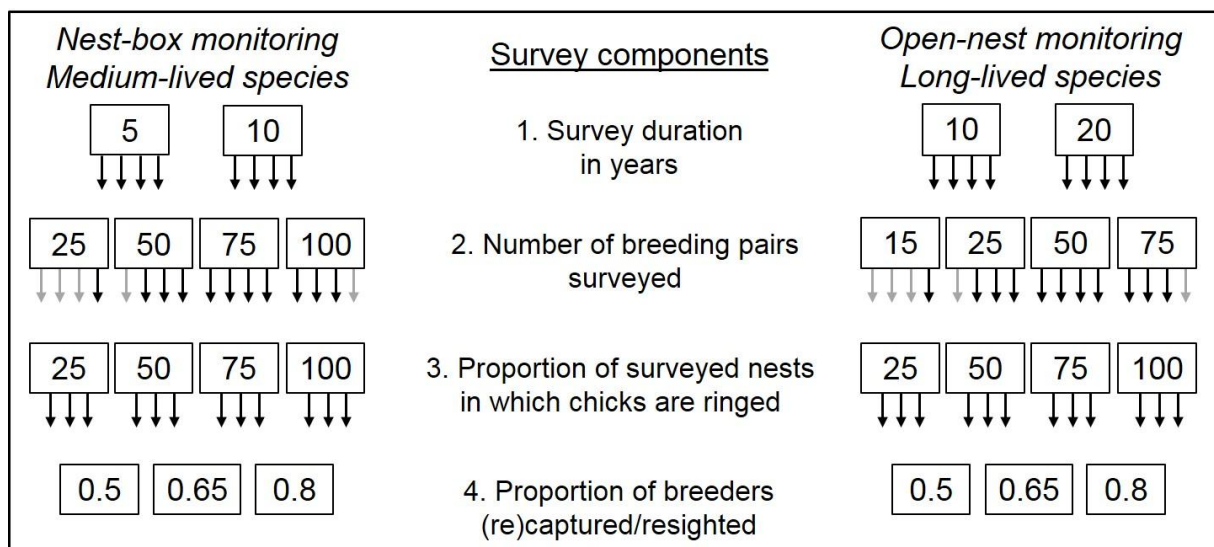
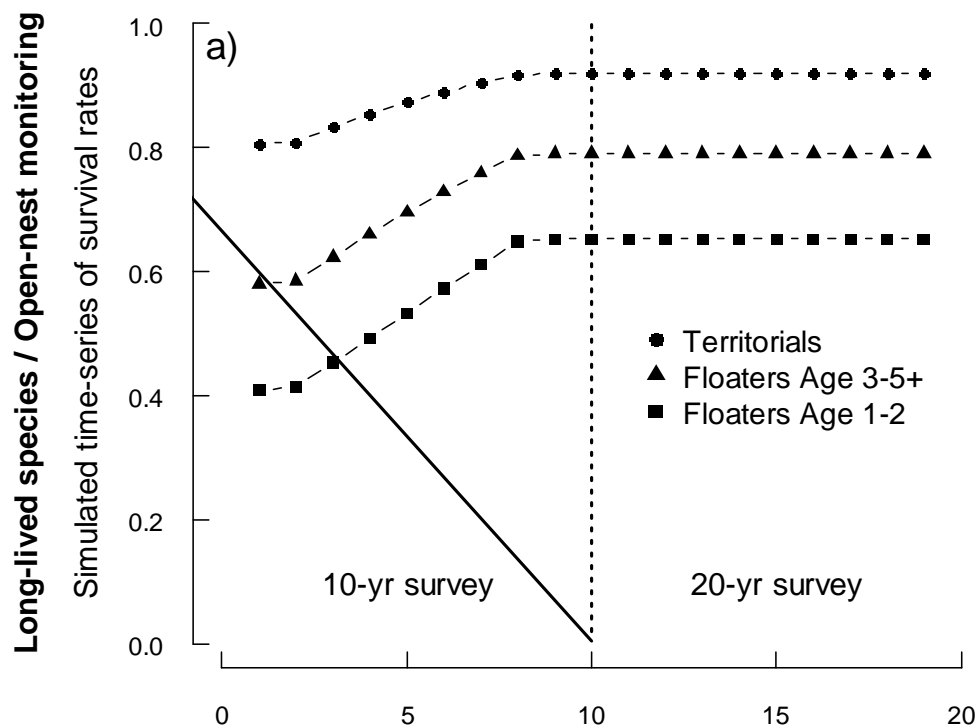


Fig. S3. Simulated time-series of age-specific or stage-specific survival rates according to the implementation of conservation actions for long- (a) and medium-lived species (b). The size of the conservation effect on survival was inspired from real-world examples and was supposed to evenly affect all ages/stages. We used a logit-linear relationship between annual survival rates and annual extent of conservation effort (+0.02 per unit on logit scale, moving from 0 to 50 arbitrary units to mimic the gradual set-up of a conservation action over time), at the time scale of short survey duration. The slope of the conservation effect was scaled in an additive way among ages and/or territorial status. Random environmental noise was added to this main effect (see Methods).



Years

Medium-lived species / Nest-box monitoring

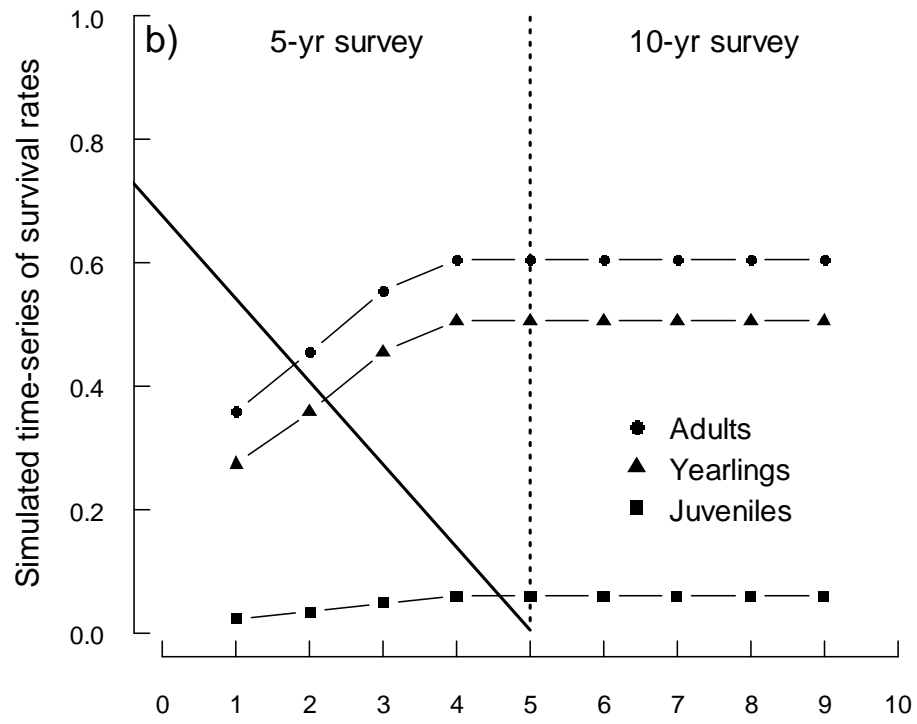


Fig. S4. Distribution of working-days required per individual identification of long-lived breeders. These are empirical distribution observed from 4 years of an intensive resighting survey by a same agent on 10 breeding pairs of the Bonelli's eagle. We distinguish time required for identifying a marked individual (a; $N = 25$) from time required for checking that an individual was unmarked (b; $N = 15$).

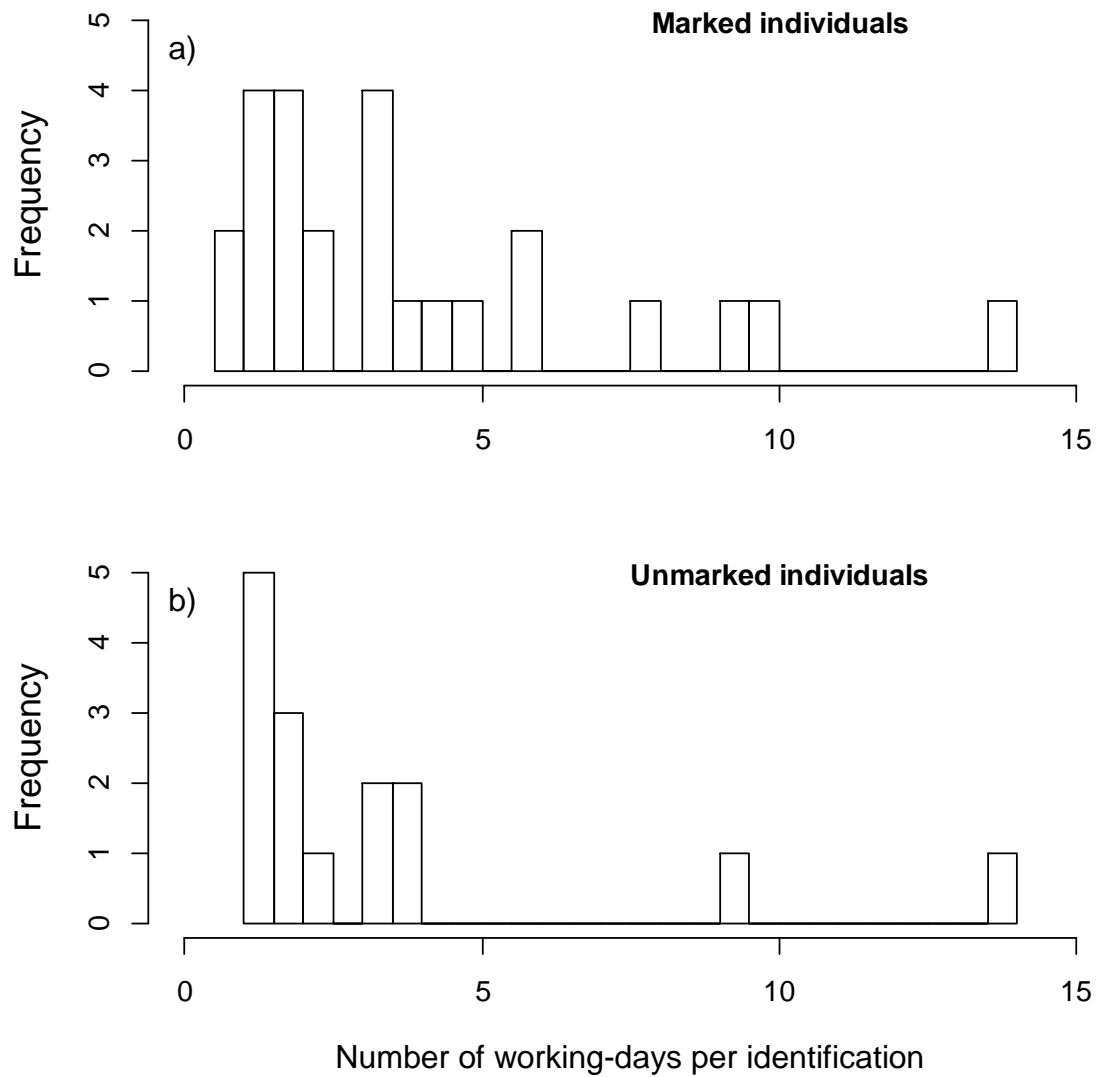
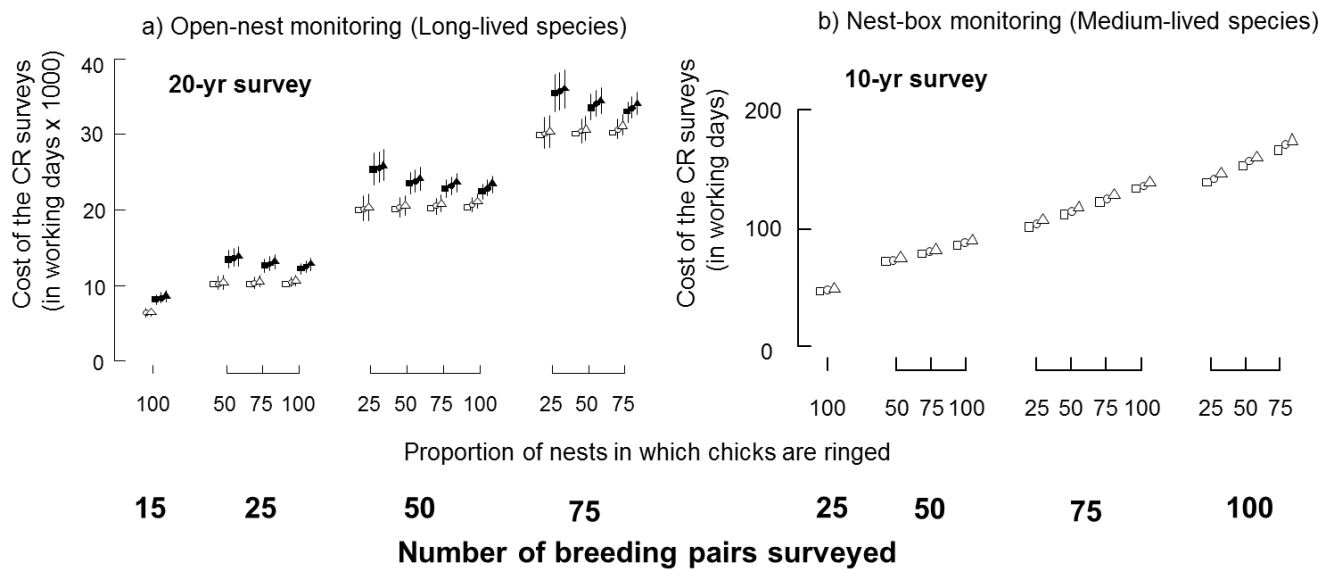


Fig. S5. Total cost in working-days of the different capture-recapture surveys for long- (a) and medium-lived strategies (b) according to different Capture-Recapture survey components.

Only long survey durations are shown here (see Fig. 2 for short durations). The first horizontal dimension (lower x-axis) indicates the number of breeding pairs monitored (component 2 in Fig. S1). The second horizontal dimension (upper x-axis) indicates the proportion of nests in which chicks are ringed (component 3 in Fig. S1). Open symbols represent CR surveys without the capture of breeders, whereas filled symbols represent CR surveys in which 5 breeders are captured during the 5 first years of the survey of ON long-lived species. This component is absent for medium-lived NB species (b). The last CR component, the recapture/resighting probability of breeders is shown by squares (50% of breeders recaptured/resighted), circles (65%) and triangles (80%).



Script S2: R script for simulated CR surveys on long-lived species.

Script S3: R script for simulated CR surveys on medium-lived species.

Script S4: R script for analysing simulated CR surveys on long-lived strategies.

Script S5: R script for analysing simulated CR surveys on medium-lived species.

Appendices *Script S2* and *Script S3* are ready to run CR simulations for a given monitoring design and were largely inspired from Kéry & Schaub (2012). MARK software and RMark Package need to be previously installed on the computer.

Survey duration, population size, proportion of ringed chicks and recapture rate have to be changed one by one to produce the 66 (resp. 33) sets of simulations for long-lived species (resp. medium-lived species). The results of each set of simulations (mainly the deviance of the different CR models) have to be stored in different files.

Parameters followed by ##### can be changed according the studied species life-history. Keep in mind that the matrix dimensions have to be changed accordingly.

Then, appendices *Script S4* and *Script S5* put all the previous results together in a single table for figure and contribution analyses.

The *ANODEV* test is also perform during this step from model deviance.

The different costs of monitoring (indicated by #####) can be changed in this file according field-specific constraints.

Contact nicolas.lieury@orange.fr for any questions regarding these scripts.

References

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