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Estimating breeding population size of the red-crested pochard (*Netta rufina*) in the Camargue (southern France) taking into account detection probability: implications for conservation

Pierre Defos du Rau[1], Christophe Barbraud[2,3] and Jean-Yves Mondain-Monval[1]

[1]Office National de la Chasse et de la Faune Sauvage, CNERA-Avifaune Migratrice, Le Sambuc, 13200 Arles, France
[2]Station Biologique de la Tour du Valat, Le Sambuc, 13200 Arles, France
[3]Centre d'Etudes Biologiques de Chizé, UPR 1934 CNRS, 79360 Villiers-en-Bois, France

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Abstract

The red-crested pochard, a Eurasian diving duck, has seen its numbers declining and has received strong conservation concern. Data on population size and rate of decline are required to establish management plans, none of which is available for this species. Here we present the first population size estimate taking into account detection probability and habitat use in the Camargue, southern France. A non-random sample of 33 lakes was used to estimate detection probability from point-counts. Detectability was low, with only 57.5% of individual broods detected. A random sample of 37 lakes was then used to estimate brood densities. Adjusted densities (taking into account detection probability) were 0.1106 broods per hectare of reedbed. Adjusted densities were extrapolated to the entire surface area of reedbeds in the Camargue estimated from a GIS to obtain abundance estimates of the brood population. A minimum estimate of 559 breeding pairs was obtained (95% confidence interval: 436–855). This estimate is much higher than previous ones (80–100 pairs for the Camargue, 250 pairs for France), and indicates strong underestimation of the population size when not taking into account detectability. Our results suggest that the red-crested pochard may require a reassessment of its conservation status for France and Europe. They further suggest that taking detection probability into account in population estimates of other cryptic species, and notably those of conservation concern, may help clarify their conservation status and may even affect the setting of conservation priorities.

INTRODUCTION

Estimates of population size from animal surveys are a crucial tool for setting conservation priorities (Karanth & Nichols, 1998; Kéry, 2002; Thompson, 2002). However, few studies have taken into account the detection probability (or detectability) of their target species, i.e., the probability of missing an individual given it is present in the sampling area, in estimating its abundance (Rosenstock *et al.*, 2002). Not taking into account the proportion of individuals missed during surveys may lead to serious biases in estimates of abundance (Nichols *et al.*, 2000), and therefore to misleading conservation status and priorities.

The red-crested pochard (*Netta rufina*) is a migratory diving duck that breeds in central Asia, around the Black Sea, and in western Europe. The species is classified as 'Declining' in Europe by Krivenko (1994), and is therefore of strong conservation concern, although it is hunted in France, Portugal, Romania and Spain. Consequently, the European Commission required a management plan for this species (Defos du Rau, 2002). In particular, this management plan stressed the need to update estimates of breeding population size in Europe. In the Camargue, southern France, the latest breeding population size estimates of 80–100 breeding pairs (Rimbert, 1990; Gaillardin, 1991) are still in use in the French Red List of threatened birds, which classifies the red-crested pochard as 'Endangered' on the basis of a French population size estimated at less than 250 breeding pairs and considered to be strongly declining since the 1970s (Dehorter & Rocamora, 1999).

Here, we investigate two different aspects of red-crested pochard broods detectability using two recently developed methods: the double-observer approach (Nichols *et al.*, 2000), and a capture–recapture method based on the Pollock's robust-design approach (Kendall *et al.*, 1997). These detection probabilities are then used to estimate the breeding population size, based on previous findings on habitat requirement of the red-crested pochard in the Camargue.

All correspondence to: Pierre Defos du Rau, ONCFS, Délégation Régionale, 10bis route d'Ax, 31120 Portet/Garonne, France.
Tel: 335 62 20 75 55; Fax: 335 62 20 75 56;
E-mail: p.defosdurau@oncfs.gouv.fr.

METHODS

Study site and species

Red-crested pochards breeding in France are concentrated on three wetlands along the Rhône river (Boutin, 1994; Dehorter & Rocamora, 1999). The southernmost of these strongholds is situated in the Rhône delta, named the Camargue, a vast wetland area of 145,000 ha. Natural habitats account for 58,000 ha and mainly consist of freshwater and brackish marshes, including reedbeds and temporary flooded salt meadows. These natural areas are split into 230 protected or hunted estates.

The red-crested pochard has an extensive breeding season: eggs are laid from late March until early July. The species' breeding habitat has been recently described by P. Defos du Rau, C. Barbraud & J.-Y. Mondain-Monval (unpubl. data), who confirmed that, in the Camargue, surface area of reedbeds of *Phragmites australis* is the main factor positively governing the species' reproduction (see also Llorente & Ruiz, 1985; Schneider-Jacoby & Vasic, 1989; Heiser, 1992; Snow & Perrins, 1998). As in many other duck species, the red-crested pochard is rather cryptic in its breeding behaviour and habits, and broods mostly come out on open water in the late afternoon and the evening.

Estimating detectability parameters

Two aspects of detectability were investigated. The probability of false absence, i.e., the probability of not detecting any pair of the species on a site given it is actually raising ducklings, was used to estimate the probability of missing the presence of one or more red-crested pochard broods during the survey conducted to estimate the brood population size. The other detectability parameter that was estimated was the probability of missing one individually identified brood given it is present on a site. This second detectability parameter was used to correct the observed brood densities and to obtain unbiased abundance estimates.

The red-crested pochard is one of the least abundant breeding waterbirds in the Camargue. Pairs are not widespread homogeneously, but are mainly concentrated in the vast freshwater marshes in the eastern and northwestern parts of the Camargue. Studying detection of the species' broods required performing a specific detection survey in zones of concentrated use. A non-random sample of lakes was therefore necessary to assess detectability parameters using most densely occupied sites, since a random sample would have been inadequate to estimate detectability of such a rare and cryptic breeding bird.

The species is known or suspected to breed regularly and densely in 27 estates (P. Defos du Rau, pers. obs.) when breeding habitat is available, i.e., when flooding and water management conditions are favourable. In such estates, disturbance level is generally kept very low on purpose during the breeding season of the waterfowl. Out of these 27 estates, only 11 were both access-permitted and flooded in 2001. Nine of these 11 estates were chosen for their easy access and the availability of lakes within them. Lakes of these nine estates constituted the non-random sample, with a total of 33 lakes used to estimate the detectability of broods. From 1 June 2001 to 15 August 2001 one point-count was conducted at exactly the same location every 2 weeks (making a total of five point-counts) between 1700 pm and 2100 pm on each lake of this non-random sample. Point-count localizations were chosen to maximize visibility of open water, and on larger lakes an additional point-count was performed on the same five occasions as the first one but on a different location so as to cover a remaining part of the lake. Lake area averaged 10.3 ha (SD = 16.2). For all lakes, it was never possible to survey 100% of open water. Bird counts were only undertaken under favourable weather conditions, i.e., when dry, and not or only moderately windy.

Estimating probability of false absence

The probability of false absence of a species can be estimated using the equation: probability of false absence $= \alpha = (1-p_s)^N$ where N is the number of visits to the site, and p_s is the probability of detecting the species presence (Kéry, 2002). The double-observer approach (Nichols *et al.*, 2000) was used to estimate p_s and the risk of false absence through estimates of species-specific brood detection probabilities. Two observers surveyed lakes from the non-random sample. At each point-count, a designated 'primary' observer indicated to the other ('secondary') observer all broods detected. The secondary observer recorded all detections of the primary observer as well as any brood not detected by the primary observer. Observers alternated primary and secondary roles for a total of 33 point-counts. Computation of detection probability was made with program DOBSERV (Hines, 2000).

Estimating individual brood detectability

The robust-design approach (Pollock, 1982; Kendall, Nichols & Hines, 1997) was used to compute individual brood detection probability and adjusted densities of broods. Because of the rarity of red-crested pochard as a breeding species in the Camargue, the occurrence of two or more broods of exact same age and size in the same lake was considered highly unlikely. Each observed brood was therefore identified (or 'marked') by the combination of its age and size, taking into account that brood size might decrease when getting older. The five successive point-counts performed on each lake of the non-random sample were split into three sub-counts of 15 minutes each, thus constituting three secondary sessions within five successive primary sessions, according to the terminology used in Kendall *et al.* (1997). Within each site's primary session, successive secondary sessions were conducted 20–40 minutes apart from each other. On each of these 15 occasions, successive presence (1) or absence (0) of identified broods was noted. This capture–recapture design provides estimates of local survival (S), temporary emigration (g'') and 1- temporary immigration (g', i.e., the probability that an individual absent during primary session i is absent during primary session i+1) probabilities, as well as capture (p) and recapture (c) probabilities which can be considered here as detection probabilities, since observations of known broods can be viewed as recapture events. Detection probability computed from robust-design thus corresponded to the probability of detecting an individual brood given it is present in the study area. Analyses were conducted with program MARK (White & Burnham, 1999). Following Lebreton *et al.* (1992) and Burnham & Anderson (1998), we used the Akaïke Information Criterion with a correction factor for sample size (AICc) to select the most parsimonious model. The model with the lowest AICc is the one to be selected. As a rule of thumb, two models with a difference in their AICc < 2 were considered as statistically indistinguishable (Lebreton *et al.*, 1992). We initiated model selection with a fully parameterized model without *a priori* hypothesis on any parameters of the model.

Estimating adjusted densities

To estimate the breeding population size, a random sample of lakes, assumed to be representative of the whole Camargue, was used as a basis for inference on densities at the Camargue scale, and extrapolation of a population size. Twenty estates were randomly selected within the 80 largest of the total 230 estates of the Camargue, and two lakes were randomly selected in 17 out of these 20 estates. There was only one lake in the remaining three estates so the total number of lakes of this random sample was 37. Sampling among the 150 smaller estates would have required obtaining more access permits to reach a sample of 37 lakes. A large majority of the total 230 estates are actually contiguous within a few remnant patches of natural landscape, and some fragmentation effect decreasing red-crested pochard densities in the smaller estates was therefore considered unlikely.

On each of these 37 lakes, three monthly visits were conducted in May, June and July during daytime, following traditional design of field surveys for breeding ducks (e.g,. Amat, 1984; Lillie & Evrard, 1994; Green, 1998; Pöysä *et al.*, 2000; Pöysä, 2001). Lake shorelines were visited throughout their length in order to maximize detection of broods. Broods were intensively searched for through telescopes on the visible water surface and, where possible, within surrounding vegetation fringes. On each lake where brood presence was noted, observed peak number of broods (n) was recorded and was then adjusted for incomplete detection of individual broods, using the relation:

$$\hat{N} = \frac{n}{\hat{p}}$$

where $\hat{N}$ is the estimated adjusted abundance, n is the observed peak number among the three monthly visits, and $\hat{p}$ is the individual detection probability estimated from the robust design (Barker & Sauer, 1992).

Adjusted brood counts were then expressed as densities of broods per hectare of reedbeds, since previous work in the Camargue (P. Defos du Rau, C. Barbraud & J.-Y. Mondain-Monval, unpubl. data) has shown that red-crested pochard breeding occurrence is highly dependent upon reedbed area. Density computation over a single habitat type like reedbed permitted stronger inference on abundance over the whole area because of better homogeneity of brood density in reedbeds (owing to causal ecological link) than in any other wetland habitat. On the basis of estimated density in reedbeds and of the total reedbed area for the Camargue calculated from a GIS, an estimate of the brood population size could be calculated.

For both the non-random and the random sample, surface areas of *Phragmites australis* surrounding each lake and forming islets within each lake were located in the field and on aerial photographs, and calculated by GIS (Didger, 2000). Since a unified GIS is not currently available for the entire Camargue area, we used data sets of habitat-specific areas from three geographically distinct GIS provided by the Parc Naturel Régional de Camargue, the Réserve Nationale de Camargue, the Observatoire des Zones Humides et des Habitats de Camargue Gardoise, and the Tour du Valat Biological Station. For two out of the three GIS data sets, reedbed surface areas were available, but for the last GIS data set, only the global area including reedbed and water surface was available. For this particular area, brood densities were expressed in number of broods per hectare of reedbed and water and not in number of broods per hectare of reedbed only. In this case, densities were extrapolated on the basis of the total area of reedbed plus water surface. This discrepancy between GIS use was not considered to bias densities extrapolation severely because water and reedbed surface are positively correlated, and thus red-crested pochard breeding occurrence is linked to both water and reedbed area. Hence, estimating brood densities over water plus reedbed area was assumed to be as meaningful biologically as densities over reedbed area singly.

RESULTS

Detectability parameters

Risk of false absence

The probability of detecting the presence of any brood on a lake given it is present was 0.9259 (SE = 0.1033). With three visits, the probability of a false absence in the data set was α = 0.0004. The presence of any brood was therefore highly unlikely to be undetected with three successive visits. In other words, three visits only were necessary to decrease the risk of false absence below 0.1%. Computation of population densities on sampling sites can therefore be considered with confidence regarding absence assessment.

Detection probability of individual broods

Starting with the general model where all parameters were time-dependent, we did not detect significant time-dependence in survival, temporary emigration and g' (Table

Table 1. Modelling survival, temporary emigration and immigration and capture and recapture probabilities of red-crested pochard broods

Model	AICc	ΔAICc	w	np	Deviance
$S(.)\ g''(.)\ g'(.)\ p(T,.)=c(T,.)$	130.983	0.00	0.691	10	107.435
$S(.)\ g''(.)\ g'(.)\ p(.,.)=c(.,.)$	132.755	1.77	0.285	8	114.505
$S(.)\ g''(.)\ g'(.)\ p(T,t)=c(T,t)$	137.685	6.70	0.024	19	85.346
$S(.)\ g''(.)\ g'(.)\ p(T,t)\ c(T,t)$	169.151	38.17	<0.001	29	70.686
$S(T)\ g''(.)\ g'(.)\ p(T,t)\ c(T,t)$	169.361	38.38	<0.001	31	58.971
$S(T)\ g''(T)\ g'(.)\ p(T,t)\ c(T,t)$	170.509	39.53	<0.001	32	53.709
$S(T)\ g''(T)\ g'(T)\ p(T,t)\ c(T,t)$	177.247	46.26	<0.001	33	53.709

Modelling started from the fully parameterised model $\{S(T)\ g''(T)\ g'(T)\ p(T,t)\ c(T,t)$, where (T), (t) and (.) respectively indicate primary session-dependent, time-dependent and constant parameters. For each model, we give AICc, ΔAICc, AICcWeight (w), number of estimated parameters (np), and deviance. AICcWeights were estimated following Anderson *et al.* (2000).

1). A model where capture and recapture probabilities were set equal but time-dependent was preferred to a model where capture and recapture probabilities differed (ΔAICc = 31.466). The two lowest AICc models included either constant or primary session-dependent capture–recapture rates (Table 1). Parameter estimates from the lowest AICc models are shown in Table 2.

Because our main interest was to obtain an estimate of p with reduced bias and increased precision, we used a model-averaged estimator of p following Anderson, Burnham & Thompson (2000). A model-averaging procedure was run over the two best models to produce an estimate of p with its associated unconditional standard error. The estimate was $\hat{p} = 0.5746$ (unconditional SE = 0.0978), and its 95% confidence interval was 0.3815 – 0.7473. Thus, the probability of detecting one individually identified brood on a lake given it is present was on average 0.5746. This individual detection probability is then used to adjust abundances.

Density and population size estimates

A total of 42 broods were observed in the non-random sample, and a total of 14 broods were observed in the random sample. Total reedbed areas for the non-random and random samples were 232 ha and 217 ha, respectively. Observed densities were 0.181 and 0.065 broods per hectare of reedbed, respectively, and 0.012 broods per hectare of reedbed plus water.

Table 2. Estimates of survival (S), temporary emigration (g''), g', and capture probabilities (p) of red-crested pochard broods

Parameter	Estimate	SE	Lower 95% CI	Upper 95% CI
S	0.598	0.084	0.429	0.747
g''	0.734	0.100	0.504	0.883
g'	…	…	…	…
p session 1	0.588	0.111	0.368	0.778
p session 2	0.662	0.105	0.439	0.831
p session 3	0.391	0.081	0.248	0.556
p session 4	0.708	0.102	0.480	0.865
p session 5	0.475	0.197	0.161	0.810

Estimates are from model $S(.)\ g''(.)\ g'(.)\ p(T,.)=c(T,.)$. Ellipses indicate that g' was not estimable, so SE and lower and upper 95% CI could not be adequately estimated.

Taking into account detectability of individual broods, an adjusted total of 42/0.5746 = 73 broods was estimated to be present in the non-random sample, and an adjusted total of 14/0.5746 = 24 broods was estimated to be present in the random sample. Adjusted densities were thus of 0.3147 and 0.1106 broods per hectare of reedbed, respectively, and 0.0206 broods per hectare of reedbed plus water.

Adjusted density within the random sample was 0.1106 broods per hectare of reedbed with a 95% confidence interval of [0.0863 – 0.1691], and 0.0206 broods per hectare of reedbed and water [0.0161 – 0.0315]. Total reedbed area for both GIS providing details for the reedbed habitat only was 4502 ha and total reedbed plus water area for the one GIS providing details for this particular habitat association was 2964 ha. Total estimated abundance for red-crested pochard broods in the Camargue was thus 559 broods with a 95% confidence interval of [436 – 855].

DISCUSSION

Population size

Our estimates of abundance of red-crested pochard broods in the Camargue are much higher than previous estimates of the breeding population in the Camargue and in France, 80–100 and 190–250 pairs, respectively (Boutin, 1994; Dehorter & Rocamora, 1999). Results from our study indicate that the detection probability used to estimate abundance of broods was low, since the probability of detecting individual broods was only 57%. Not taking into account detectability in estimating abundance of breeding red-crested pochards would thus result in major underestimation. In addition, the robust design approach allowed us to estimate temporary emigration, which was high. The probability that a brood present during one primary session was absent during the next primary session was 73%. For example, this suggests that if 20 broods are counted during a first session nearly 15 of these broods will be absent and not observed during the second session. Furthermore, if ten broods are observed during the second session, nearly half will be new broods undetected during the first session. Thus, not taking into account temporary emigration from one session to another (as is usually done in 'traditional' surveys) may lead to serious underestimation of abundance in this species.

The low detection probability and the high temporary emigration probability are probably a consequence of the preferred habitat used for breeding, extensive reedbeds of *Phragmites australis* with freshwater (P. Defos du Rau, C. Barbraud & J.-Y. Mondain-Monval, unpubl. data). The high temporary emigration found in this study may be explained by families' behaviour, being either in areas of open water or hidden within the surrounding reedbeds from one primary session to another.

For all the above reasons, we believe that previous surveys strongly underestimated the number of breeding pairs of red-crested pochard in the Camargue, and probably in France and Europe. In addition, and as opposed to previous studies, our extrapolation of adjusted densities used three geographic information systems covering the entire Camargue area, and was based on precise knowledge of habitat use by broods of red-crested pochard issued from a companion study (P. Defos du Rau, C. Barbraud & J.-Y. Mondain-Monval, unpubl. data). Previous estimates based upon fieldwork by Rimbert (1990) and Gaillardin (1991) only took into account observed broods and paired adults to sum up an estimated breeding population size. Furthermore, as shown by these authors, the brood-rearing season can last from April until August; since our observations started in May and ended in July, some early and late broods may have remained undetected by our study design, suggesting that our estimate of the number of broods is a minimum.

Use of a non-random sample within areas of concentrated use was necessary to attempt maximizing precision in estimating detection probability and risk of false absence. Use of a random sample was, of course, necessary to calculate a brood density that would be representative of the breeding distribution and density of the species in the Camargue. Overall, within this random sample, 1407 ha of wetland habitats were surveyed for an estimated adjusted abundance of 24 broods. Another approach would have been to survey the species randomly in areas of reedbeds as a mean to increase sample size of detected broods, but access permission to a sufficient number of sampling sites would have been too difficult to obtain from landowners.

Bias

Lack of homogeneity of the three GIS may have biased our extrapolation. Both GIS for the central and western part of the Camargue have been validated in the field, and only 15% of the data set for the eastern part has not been validated, but was only gathered on satellite images. The eastern part of the Camargue is the smallest of all parts, accounting for 19.4% of the wetland habitats and 13.4% of the reedbed area of the whole Camargue. Thus, the uncertainty on the reedbed surface area estimation through GIS concerns about 2% of the total surface area, and is therefore likely to have a negligible impact on our extrapolation of adjusted densities. Indeed, total reedbed area for the whole Camargue was calculated for 1984 to be 5296 ha (Tamisier, 1990), which constitutes a result very comparable to more up-to-date reedbed area estimates used in the present study.

Our estimates of adjusted densities may be biased if model assumptions were not fulfilled. We believe that the two main assumptions of the double-observer approach (independency in detection probabilities, equality in detection distances, Nichols *et al.*, 2000) were fulfilled. A third important assumption (all broods have the same probability of being detected) was verified since when we ran program CAPTURE (Burnham & Overton, 1978; Rexstad & Burnham, 1991) the model selection criteria pointed towards model Mo as the most appropriate model for four out of the five primary sessions, thereby suggesting no heterogeneity in capture rates between individuals. In addition to the assumptions for the Cormack–Jolly–Seber model, the assumptions of analysis under the robust design are (1) within each primary session, the population is closed, (2) survival is equal for animals that are in and out of the study area during any primary session. In our study design, we believe that the time intervals between the secondary sessions were small enough to prevent mortality or permanent emigration from occurring during primary sessions. Because nestlings of broods that temporarily emigrated from the study area (i.e. the open water in each sampled lake) could not fly (once they could fly they probably left the lake and thus were considered as dead or having permanently emigrated), they were probably in reedbeds adjacent to the open water during corresponding point-counts, but mortality risks were assumed not to differ between broods within a primary session

Conservation implications

Our estimate of the number of broods produced annually in the Camargue stands as a minimum estimate of the total breeding population size, since this estimate does not include the breeding pairs that failed to hatch their eggs and remained undetected in our study design. Hatching success is highly variable from year to year and between localities in ducks, and there is no reliable estimate of hatching success for red-crested pochards in the Camargue. However, our estimate of the brood population size, combined with a relatively high hatching success of 80–90% as found in some species of the closely related *Aythya* genus (Del Hoyo, Elliot & Sargatal, 1992), would suggest a breeding population size of some 600–700 pairs in the Camargue. Difficulties in detecting the species explain this revaluation of the population size estimate much more probably than a real increase, although such a rise in the breeding numbers cannot be discounted with certainty. In fact, the red-crested pochard population from the western Mediterranean and central Europe is considered by Wetlands International (2002) to be increasing. Local declines in wintering numbers, as in the Camargue or in northern Spain in the past decades, would actually be due to a major switch in wintering areas from southwestern to central Europe (Keller, 2000). Moreover, the only two published breeding population censuses for the Camargue (Blondel & Isenmann, 1981; Boutin, 1994), which were used to argue for a national decline, were not based on comparable field methods and produced only unadjusted estimates.

We thus believe that the minimum breeding population size of red-crested pochards in the Camargue is close to 600 pairs and shows no clear sign of a decline. Based on a ‘strong decline’ statement and on the previous national overall estimates thought to be below 250 breeding pairs, the species was classified as ‘Endangered’ in the French Red List of threatened birds (Dehorter & Rocamora, 1999). We think such rating may be overpessimistic, but we do not deny that the French population of red-crested pochard may still be threatened, at least by habitat loss and degradation that still occurs in the Camargue (Tamisier & Grillas, 1994; Mathevet & Tamisier, 2002), and remains therefore vulnerable. Moreover, the impact of hunting on the breeding population size remains unknown at present. However, following EU Directive 79/409/EEC on the conservation of wild birds, and for the first time since it first bred in the Camargue in 1894 (Mayaud, 1966), the red-crested pochard will not be hunted in February. In fact, the largest part of the annual red-crested pochard harvest seems to be achieved in February, accounting, in available date, for 23% of the annual harvest (ONCFS, unpubl. data). Therefore we strongly recommend using this change in hunting legislation as an experimental design of adaptive management to evaluate the effect of this reduced harvest at such a critical time in the species' biological cycle on the Camargue breeding population size.

Similar surveys taking into account detection probability need to be undertaken regularly in the future in order to detect trends in this population. Ideally, such surveys should be complemented with some estimates of hatching success. At a larger spatial scale, such surveys should also be undertaken in the major breeding sites of the red-crested pochard in France, but also in Europe. Indeed, we are not aware of any red-crested pochard population size estimate in other European breeding sites that took into account detection probability, thereby suggesting that the present world breeding population size is probably underestimated. If our results are confirmed (i.e., low detection probability), the red-crested pochard may require a reassessment of its conservation status for France and Europe. More generally, adjusting animal abundances with detectability is a growing concern in population biology and conservation (Buckland, Goudie & Borchers, 2000). Design-based ecological studies (e.g., studies of habitat use) and conservation-orientated surveys, like the present one, are both likely to benefit from these developing methodologies. In particular, it is likely that some more or less cryptic species considered as threatened may have been classified as such on the basis of unadjusted population size estimates, and that taking into account their detectability in future field surveys will lead to a reevaluation of their conservation status. Such reevaluation should not decrease attention upon these species, but might rather help to reorient conservation priorities.

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