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Short communication

Temporal pooling of point transect data increases precision in density estimates of southern chamois

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ABSTRACT

Estimating animal abundances in small areas is a difficult task and because a limited number of observations often results in low-precision estimates whose inaccuracies may even be exacerbated if surveys are focussed on clustered populations and/or are only carried out once a year. In an attempt to overcome this problem, we used point transects to monthly survey two small areas of a game reserve to assess the density of Pyrenean chamois (*Rupicapra p. pyrenaica*). The coefficient of variation associated with the density estimates after pooling observations by season was still high but decreased to reasonable values (<20%) when observations were over 29 chamois groups (clusters). Our results suggest that Distance Sampling may be a useful way of estimating the population density of mountain ungulates such as Pyrenean chamois in small rugged areas where only a small or moderate number of observations are to be expected.

Accurate estimates of animal abundances are essential for a proper management of animal populations, particularly for those such as wild Caprinae that are exploited as big-game species.

Distance Sampling (DS) is a well-known method that is used for population density assessment in a wide range of environmental conditions for a broad range of terrestrial and marine mammal species such as mongoose (*Herpestes javanicus*) (Corn and Conroy, 1998), brown bear (*Ursus arctos*) (Becker, 2001), vaquita (*Phocoena sinus*) (Jaramillo-Legorreta et al., 1999) and marmot (*Marmota marmota*) (Pellicioli and Ferrari, 2013). DS consists of a set of techniques based on the measurement of distances between a line (transect) or a point and the target objects, which enable the abundance (density) of these objects to be estimated. Objects are generally animals or clusters of animals (if we use DS as a direct method), while nests, faeces, tracks, songs or other signs of presence are counted if DS is used as an indirect method (Buckland et al., 2001).

This versatile methodology is relatively inexpensive and generates density estimates together with their respective precisions (e.g. associated 95% confidence intervals and/or coefficients of variation) and can be performed on the ground (Jachmann, 2002), from the air (Quang and Becker, 1996) or even underwater (Kulbicki and Sarramégna, 1999). For these reasons, the number of DS users is currently increasing. This method has also been used in research on mountain ungulates such as chamois (*Rupicapra* spp.) (Herrero et al., 2011; Corlatti et al., 2015), Iberian ibex (*Capra pyrenaica*) (see Escos and Alados, 1988; Palomares and Ruiz-Martínez, 1993; P&rez et al., 1994), blue sheep (*Pseudois nayaur*) (Liu et al., 2008), Tibetan antelope (*Pantholops hodgsonii*) (Bleisch et al., 2009; Buzzard et al., 2012), argali (*Ovis ammon*) (Wingard et al., 2011) and Dall's sheep (*Ovis dalli*) (Schmidt et al., 2012), among other species.

Point transects are one of the main approaches used in DS theory and point transect sampling is frequently used for estimating the abundance of songbird populations (Buckland, 2006) and, to a lesser extent, mammals (Potts et al., 2012). Points are considered as line transects of zero length (Buckland et al., 1993). When point transects are used for clustered populations, if we assume that (i) the detection probability is independent of cluster size and (ii) clus-

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ter sizes are accurately recorded, then the estimated cluster density ($\hat{D}s$) is given by

$$\hat{D}s = \frac{n\hat{h}(0)}{2\pi K}$$

and the estimated density ($\hat{D}$) by

$$\hat{D} = \hat{D}s\bar{s} = \frac{n\hat{h}(0)\bar{s}}{2\pi K}$$

$$\hat{h}(0) = \frac{2\pi}{\hat{v}}$$

where n = number of observed clusters, K = number of points sampled, $\bar{s}$ = mean size of detected clusters, $\hat{h}(0)$ = slope of the probability density function evaluated at zero distance, and $\hat{v}$ = effective area of detection.

However, if the number of clusters detected is small, if the cluster size is highly variable or if the mean cluster size is large, this methodology may perform poorly (Buckland et al., 1993). Generating reliable estimates of abundances requires large amounts of data that can be used to model detection probabilities (Litt and Steidl, 2009).

Total counts and capture-mark-recapture methods have been used previously in the southern chamois (*Rupicapra p. pyrenaica*) to assess animal densities (Houssin et al., 1994; Loison et al., 2006; Pañella et al., 2010). Distance sampling (DS), however, has recently been considered one of the best approaches for assessing population density of *Rupicapra* populations (López-Olvera et al., 2016). Other density estimates calculated by using DS (line transects) were compared with those obtained from block counts (BC) (Herrero et al., 2011) and by mark-resight methods (Corlatti et al., 2015). Even though several simulation studies have been focused on predicting the minimum sampling effort to obtain precise density estimations by DS (Franceschi et al., 2014; La Morgia and Focardi, 2016), there is little empirical information in this regard.

Here, we use southern chamois surveys to explore the efficiency of DS methodology in small areas in relation to different sampling efforts, resulting from temporal pooling of data.

Our study was carried out in the Freser-Setcases National Game Reserve (FSNGR) in the eastern Pyrenees (42°17′–42°20′N, 2°1′–2°20′E), which covers 20,200 ha and comprises altitudes ranging from 1800 to 2910 m a.s.l. Southern chamois data were obtained from two areas within the FSNGR, namely Costabona and Fontalba, which are separated by 20 km of rough terrain. The former is located in the northeast part of the FSNGR (42° 24′ N, 2° 20′ E, ranging from 1093 to 2429 m a.s.l., area of 385.4 ha), whereas the later in the central part of the reserve (42° 22′ N, 2° 08′ E, ranging from 1660 to 2248 m a.s.l., and an area of 823.7 ha). Both show similar vegetation composition, although Fontalba has more rocks and grassland than Costabona, which is richer in shrubs and pine wood.

Glacial and peri-glacial activity has generated complex topography with pronounced slopes. The FSNGR has a sub-humid climate, typically consisting of alpine pastures dominated by graminoid species (e.g. *Festuca* spp. and *Carex* spp.), which represent over 70.6% of the plant cover, as well as scattered *Pinus uncinata* forest patches (10%) with a substrate of low woody groundcover of *Artostaphylos uva-ursi*, *Calluna vulgaris* and *Juniperus communis*. Bare rock outcrops represent 20.4% of the surface area.

From May 2009 to January 2013 a total of 98 surveys were carried out, 51 in Fontalba (FONT) and 47 in Costabona (COST) (Tables 1 and 2). Surveys started at 09.00 and finished at 13.00. In brief, during a field journey two observers walked a single transect of about 4 km stopping at three points of good visibility were chamois can be sight in all directions and at maximum distance of 800 m. Each point was surveyed for 30 min and observers recorded the number of clusters, the size of each cluster and their distance from the observation point measured using a laser telemeter (Leica rangemaster LAF 1200).

Mean density estimates were obtained using Distance 6.0 release 2 (Thomas et al., 2009). The following models were used: half-normal with hermite polynomial expansion, uniform with cosine expansion, and hazard-rate with cosine expansion (Buckland et al., 2001). Only two adjustment terms were used to balance between bias and precision, and the lowest AIC value was used for model selection. Data were neither binned, truncated nor grouped into distance intervals for density estimation (Pérez et al., 2015). Variance was estimated empirically and the coefficient of variation (CV) of the density estimates and their associated 95% confidence interval were also obtained. Temporal pooling was carried out for months, when appropriate (see Tables 1 and 2 for details), seasons and years.

Home range and hence group size of chamois varies over the year (Lovari and Consentino, 1985). During the cold season (winter and early spring), chamois flocks are small but increase in size during the warm season (summer and autumn) coinciding with the onset of annual vegetation growth of the Alpine scenaries (Villamuelas et al., 2016). That affects home ranges of chamois (Nesti et al., 2010) and probably the probability of detection.

Neither seasonal (Kruskal-Wallis = 1.3, p-value = 0.7) nor inter-annual (Kruskal-Wallis = 12.5, p-value = 0.08) effects on the detection probability were observed in our data. Finally, for all surveys (including those with pooled observations) we tested for a potential relationship between sample size (the number of chamois clusters observed) and the CV associated with the estimated chamois density using a linear model (LM). Sample size was transformed (natural log), to address the residuals heteroscedasticity. Then, we performed an ANOVA test to evaluate significant differences in the CV among quartile sample sizes. Finally, specific differences in CV between sample sizes were tested by a post hoc Turkey's HSD test. All statistical analyses were conducted in the R software (version 3.3.3. R Development Core Team, 2017).

In the 98 surveys carried out, the number of observations (clusters) ranged between 0 and 47. The cluster size ranged between one animal (n = 4 observations) and 25 chamois (n = 2 observations). Finally, the estimated densities and their associated coefficients of variation ranged between 2.35 chamois/km^2 (8.33% CV; n = 4 observations) and 24.67 chamois/km^2 (833.72% CV; n = 24 observations). When pooling data for seasons and years, the number of observed clusters increased obviously, as did the precision of the estimated density (Table 1). What is more, we

observed a clear negative relationship between sample size (log transformed) and CV ($\beta = -17.4$, SE = 1.84, p-value < 0.01, $R^2 = 32.3$, Fig. 1A).

As expected, our ANOVA analysis confirmed the decrease of CV in chamois density estimates among sample size quartiles ($F_{3,186} = 30.1$, p < 0.01, Fig. 1B). On the other hand, our post hoc Turkey's HDS test revealed that statistical differences in CV among quartile sample sizes were undetectable when sample sizes ranged between <6 to 14 (Q1-Q2, q = 1.56, p > 0.05) and between >14 to 29 and more than 29 observations (Q4-Q3 = −6.36, q = 2.29, p > 0.05). On the other hand, CV differences among all other quartile pairs (Q3–Q1, Q4–Q1, Q3–Q2, and Q4––Q2) resulted statistically significant at p < 0.01.

Adequate survey design is very important for obtaining unbiased and precise density estimates with DS (Porteus et al., 2011) and survey effort is also critical to obtain precise density estimates. Loison et al. (2006) obtained precise indices (CV ≤ 20%) of chamois population size (number of animals observed on a repeatedly surveyed foot transect) after a minimum of 10 surveys per year in the Pyrenees, and three surveys per year in the Alps. In terms of sample size, Herrero et al. (2011) estimate that observations of more than