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THE POTENTIAL OF DISTANCE SAMPLING METHODS TO ESTIMATE ABUNDANCE OF MOUNTAIN UNGULATES: REVIEW OF USEFULNESS AND LIMITATIONS

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ABSTRACT.– Accurate assesment of the populations of mountain ungulates is difficult. Topography and behaviour of animals are important factors influencing detectability, on which direct methods are based. Sympathry with other wild and domestic ungulates increases error of dung identification. Other factors, such as the size of the area to be surveyed, or unmarked populations of the target species, suggests the choice of curvilinear transects. If the basic assumptions of Distance Sampling methodology are met, then estimates of population density and accuracy can be obtained. Current technology (GPS, laser rangefinders, and G.I.S.) can be used to achieve accurate measurements of distances and angles. A crucial problem is to estimate the effective area sampled around each travelling path. Therefore, researchers and managers of mountain ungulates need an adaptation of Distance Sampling methodology to account for a tridimensional scenario imposed by the slope of mountains. There is also a requirement to standardize protocols for collecting data. Alternatives for design surveys and collection data when working with populations of mountain ungulates are discussed.

RÉSUMÉ.– L'estimation précise de l'abondance des ongulés de montagne devient difficile. La détectabilité est conditionnée par la topographie et le comportement des animaux; c'est sur ce dernier cas que les méthodes directes s'appuient. La sympatrie entre les ongulés sauvages et domestiques augmente l'erreur d'identification des excréments. D'autres facteurs, comme par exemple les grandes surfaces à surveiller ou les populations non marquées des espèces-cibles, peuvent nous conduire à des comptages sur transect curvilignes ou sur des points. Si l'on tient compte des idées basiques concernant la méthodologie appelée «Échantillonage à distance», alors les estimations correspondantes de densité avec leurs mesures de précision peuvent être obtenues. La technologie à notre portée (GPS, laser «ran-

gefinders» et GIS) peut aider de manière non négligeable l'obtention de valeurs précises de distances et d'angles. Il devient alors fondamental d'estimer la surface d'échantillonage autour de chacun de nos parcours. Par conséquence, tant les chercheurs que les gestionnaires des ongulés de montagne ont besoin d'une adaptation de l'échantillonage à distance de manière à construire un scénario tridimensionel imposé par les versants des montagnes ; aussi faudrait-t-il développer des protocoles standardisés pour la collecte de données. Dans ce travail, les différentes alternatives pour la mise en place des études et pour la collecte de données concernant les populations des ongulés de montagne sont discutées.

RESUMEN.– Valorar con exactitud la abundancia de ungulados de montaña es difícil. La detectabilidad es la base de los métodos directos, y ésta se ve influida por factores como la topografía y el comportamiento de los animales. La simpatría con otros ungulados, salvajes o domésticos, aumenta el error en la identificación de los excrementos. Otros factores, como la extensión del área a prospectar o la ausencia de poblaciones no marcadas de la especie objetivo, aconsejan el censado a partir de transectos o de puntos fijos. Si los supuestos básicos de la metodología basada en la distancia de detección se respetan, se pueden obtener estimas de densidad y evaluar su precisión. La tecnología actual (GPS, telémetros laser y SIG) permite un cálculo exacto de distancias y ángulos. Un problema crucial es estimar el área muestreada alrededor de cada transecto. Por ello, investigadores y gestores de ungulados de montaña necesitan una adaptación de la metodología basada en la distancia de detección, para reconstruir el área tridimensional impuesta por las montañas, además de estandarizar los protocolos de toma de datos. Se discuten varias alternativas para diseñar el estudio y recogida de datos en poblaciones de ungulados de montaña.

1. Background

Estimating accurate densities for mountain ungulate populations is essential for their management. For this purpose, different direct methodologies have been used. From "traditional" total counts (properly, censuses) (NIEVERGELT, 1981; BERDUCOU *et al.*, 1982; GARCÍA-GONZÁLEZ, 1985; PERACINO & BASSANO, 1991; HABIBI, 1994) and strip censuses (HABIBI, 1994), to counts from observation points (NIEVERGELT, 1981; ESCOS & ALADOS, 1988), line transects (ESCÓS & ALADOS, 1988; GARCÍA-GONZÁLEZ *et al.*, 1992; PALOMARES & RUIZ-MARTÍNEZ, 1993; PÉREZ *et al.*, 1994), or from both points and transects, as in the case of the 'pointage-flash' method (HOUSSIN *et al.*, 1994). Capture, tagging and mark resighting has also been used (GARCÍA-GONZÁLEZ *et al.*, 1992). Aerial counts of mountain goat (*Oeramnos americanus*) marked populations have also been employed (GONZÁLEZ-VOYER *et al.*, 2001) and the responses of this species to helicopter disturbance analyzed (CÔTÉ, 1996). Mean group size, typical group size, or proportion of isolated individuals in an Alpine ibex (*Capra ibex ibex*) population have also been proposed as predictors of population size (TOIGO *et al.*, 1996), as significant correlations between these variables were obtained.

Of course, different methodologies are adapted to a particular species in a concrete habitat, and this results in a wide variety of protocols for collecting data and approaches or ways of estimating densities or absolute numbers. But usually, basic assumptions required by such methodologies are not completely met. Moreover, important factors or variables, such as heterogeneity in detection probabilities, are frequently ignored (when working with unmarked populations, or populations of unknown size it is practically impossible to know the proportion of animals of the population which have been detected) and this can result in significant error of estimates (BORCHERS *et al.*, 2002).

Indirect methods, like pellet groups counts have also been used for estimating abundance of Nubian ibex, *Capra ibex nubiana*, (HABIBI, 1994), or obtaining aggregation and distribution indexes of Spanish ibex, *Capra pyrenaica*, (FANDOS & MARTÍNEZ, 1988). But these kinds of methods are difficult to apply when some sympatric species share the study area (e. g., some cervids, plus some bovids, plus livestock).

Distance sampling methodology, as many other methods for assessing population size, has experienced important developments during last decades: both at theoretical (mathematical) and practical (target species) levels. Its specific software (Distance) is being also increasingly improved in power and versatility (THOMAS *et al.*, 2001). Moreover, this methodology requires relatively less effort than other direct methods do, and this may be one of the reasons for an increasing interest on it. Nevertheless, as it was originally designed to work in flat areas, we need to make some adaptations in mountain habitats because visibility and probability of detection is also influenced by topography. Our aim is to revise inherent factors of both mountain ungulates and habitats, which may compromise the basic assumptions of Distance methodology, and to propose alternatives of solution.

2. Distance Sampling: conceptual basis, operative protocols and assumptions

Distance Sampling comprises a set of techniques based on measuring distances to objects from a line (e. g., line transect sampling) or point (e. g., point transect sampling), in order to estimate the object abundance (density). The objects are usually vertebrate animals, or groups, but these methods are being increasingly applied for invertebrates, plants, nests, burrows, calls, and dung (BUCKLAND *et al.*, 2000; 2001; MARQUES *et al.*, 2001). We can idealize or represent the situation as follows: (i) objects (animals or groups) are spatially distributed throughout the area to be surveyed according to a parameter D (= number per unit area); (ii) randomly placed and non-overlapping lines and/or points are sampled, from which n objects are detected, and their distance measured and recorded.

Statistical inference of such methodology rests on the validity of several assumptions (BUCKLAND *et al.*, 2001): (1) objects located just on the line or point are always detected. If $g(x)$ is the probability of detection of an object at a distance x, then $g(0) = 1$, and this probability decreases as distance increases; (2) objects are detected at their initial location, prior to any movement in response to the observer; and (3) distances (and angles, if so) are measured accurately (if we use ungrouped data) or objects are correctly counted in the proper distance category (grouped data). Several authors include the assumptions that observers must be able to identify the object of interest correctly; and that observations must be independent events (BORCHERS *et al.*, 2002). Moreover, if we assume that the estimated mean density along a transect provides a valid estimate of animal abundance in the study area, we also require that either animals are randomly distributed with constant density through the study area or transects are located independently of animal density (HIBY & KRISHNA, 2001).

Usually, the sampled or covered region is only a part of the whole study area and, therefore, sampling design (observation model as defined by BORCHERS *et al.*, 2002) is made using certain rules, wich introduce stratification and randomness in the survey.

3. Can we meet these assumptions when applying Distance Sampling to monitorize populations of mountain ungulates?

Regarding sampling design, mountainous terrain makes it impossible to fly straight transects (QUANG & BECKER, 1999), even to walk it in most cases. Moreover, they can not be marked on the ground. Curve lines (e. g., trails and roads) may not constitute a random sample and represents poor survey practice in most circumstances (BUCKLAND *et al.*, 2001). On the other hand, on a straight transect, there is a risk that some animals will be seen as they cross the transect well ahead of the observer and will, therefore, assigned a very small or even zero perpendicular distance (HIBY & KRISHNA, 2001). According to these authors, this may cause serious upward bias, although when paths and trails are numerous in the study area they allow some degree of random selection and, therefore, some of them may be eventually choosen as sample units. In any case, coordinates of curvilinear transects may be determined by a global positioning system (GPS) and recorded. Then, the transects may be redrawn, and their lengths can be easily obtained, as well as accurate measures of perpendicular distances, with the aid of a Geographic Information System (GIS), from location data of animals taken with telemeter and compass.

We consider randomness and stratification as basic criteria for designing surveys. Within this context, and taking into account the topography and security of observers, more or less straight transects (including eventually paths and trails) can be designed and selected as sampling units.

The first assumption [g(0) = 1] is not valid in some surveys, mainly because of animals react to the presence of the observers. When this happen, independent observer line transect surveys have been proposed (CHEN, 1999; 2000). Two observers (or teams) detect animals independently. A third person coordinates the survey identifying which sightings have been common to both observers and which have been detected only by one of them. The independent observer surveys are closely related to mark-recapture ones, as the animals or groups sighted by both observers are considered as recaptures. Moreover, by combining line transect and capture-recapture theory, better estimators for the population density can be obtained (ALPÍZAR-JARA & POLLOCK, 1996; 1999).

The probability of detecting a cluster decreases with distance, and at any distance, the probability of detecting a cluster increases with cluster size (TRENKEL *et al.*, 1997; CHEN, 1998; CHEN & COWLING, 2001). These authors developed an estimator of density that takes into account this source of error and corrects it, based on the method of moments for the case of gamma cluster size, randomly placed transect lines, and the generalized exponential detection function.

The topography (e. g., the extent of the horizon which can be monitorized), the activity of the animals and cluster size, or the vegetation cover, among other factors, may contribute to bias the detection ability of the observers. We can account for some of these sources of heterogeneity by considering them as covariates (QUANG & BECKER, 1999; HIBY & KRISHNA, 2001) after establishing ranges of values for each one regarding the target species and the study area. A crucial problem is that topography in mountain habitats also makes difficult to assess the effective area monitorized in a Distance Sampling survey. Telemeters and G.I.S. may be helpful for this purpose. Another option consists of carrying out a running point transect survey (BUCKLAND, personal communication) in order to record data from selected points (those which allow optimal conditions of visibility and potential estimates of the sampled area).

If we work on a marked population, and combine distance sampling with capture-recapture models (e. g., double platform by means of independent observers) we could take into account factors of inherent heterogeneity (that of animals) (ALPÍZAR-JARA & POLLOCK, 1996; 1999).

Some authors consider that for small populations, the line transect method is of limited value (see TRENKEL *et al.*, 1997; BUCKLAND *et al.*, 2001). In such cases a very small number of observations does not allow estimation of the population size or density. In these circumstances, we can use the "encounter rate" or a kilometric index of abundance (e. g., number of animals observed per kilometer and hour) as relative abundance indexes.

4. Discussion and future research

We believe that most of the critical assumptions of the Distance Sampling methodology could be met when applying it to mountainous areas. Moreover, this methodology has developed considerably during last decades such that different models (more or less restrictive with regards to the fundamental assumptions) are available.

By using the Distance Sampling methodology we can obtain estimates of density together with measurements of their precision. Although we also need to assess the accuracy of such estimates (ANDERSON *et al.*, 2001; FOCARDI *et al.*, 2002). For this purpose, we can use independent methods simultaneously and/or to apply this methodology to populations of known size. Despite the problems related to the application of Distance Sampling as a direct method to assess population density in mountain habitats, we think that such methodology may potentially become a useful tool. Further experimental fieldwork is still needed to achieve this goal, and to standardize a protocol for collecting data as well.

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