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Estimating red deer abundance using the pellet-based distance sampling method

R.T. Torres[1], A.M. Valente[1], T.A. Marques[2], C. Fonseca[1]

[1]*CESAM, Department of Biology, University of Aveiro, Aveiro, Portugal*

[2]*Centre for Research into Ecological and Environmental Modelling, University of St Andrews, St Andrews, Scotland*

ABSTRACT: Many European agricultural landscapes have been abandoned facilitating the comeback of large ungulates. In Portugal, the increase in red deer numbers caused local conflicts with landowners reporting economic losses in forest and agricultural plantations. A great effort is needed to mitigate human-red deer conflicts through management strategies. Successful management strategies require reliable information on population trends. Here we propose an easy and readily applied method to estimate an increasing ungulate population. We estimated the red deer population density in a Mediterranean environment located in northeastern Portugal: Lombada National Hunting Area (LNHA) and Serra de Montesinho (SM), using pellet group counts coupled with distance sampling to account for pellet detectability. The estimated red deer density using a stratified detection function was 5.81 indd per 100 ha for LNHA and 1.34 indd per 100 ha for SM (95% CI: 3.65–9.25 and 0.74–2.42, respectively). For the entire area, the estimated density was 3.38 deer per 100 ha (95% CI: 2.18–5.24). Monitoring population trends is crucial to assess the impact of methods aimed at reducing the population size or impact and here we provided an example of a robust method that can be implemented to continuously monitor expanding populations.

Keywords: cervidae; distance sampling; deer density; pellet group counting; rural areas

Man has shaped European landscapes for hundreds of years (Vos, Meekes 1999). Whereas agricultural intensification has increased food production, it also imperilled biodiversity worldwide (e.g. Donald et al. 2001; Benton et al. 2002; Green et al. 2005). Europe, a highly populated continent, with intensive agriculture and heavy industry, has been taming its wilderness. After World War II, agricultural land was abandoned and traditional land use practices declined throughout many of Europe's rural landscapes (Höchtl et al. 2005). This rural depopulation trend is well patent in some Mediterranean areas, which have lost more than half of their population in the last decades (Navarro, Pereira 2012). In Portugal, during the 1970s, big migration waves from rural communities to the cities occurred (Pinto-Correia, Mascarenhas 1999). Thus, arable land was abandoned and resulted in important landscape transformations: cultivated areas were renaturalized, with spread of natural vegetation, including both shrub land and forest. As a result, Mediterranean vegetation areas have increased in cover. As an example, from 1984 to 1999, areas of central Spain have recorded 35% growths in the vegetation (Romero-Calcerrada, Perry 2004). Land abandonment also has implications for biodiversity and ecosystem function. The restoration of natural areas has, in some cases, resulted in the restoration of natural ecosystems functions, facilitating the comeback of native large mammals (Navarro, Pereira 2012). At present, large carnivores are recolonizing Europe, highlighting their capacity to survive in human-dominated landscapes (Chapron et al. 2014). Coordinated legislation across European countries played

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an important role in this process, as did the increasing distribution and number of large wild ungulate populations in the last decades (Apollonio et al. 2010). Undoubtedly large grazers benefited from land abandonment. The paradigm regarding ungulates has changed: from a decrease in numbers and distribution in the 19th century (Côte et al. 2004) to the actual scenario of expanding populations over Europe (Apollonio et al. 2010). As ungulate populations increase, their impacts on the ecosystem tend to inevitably increase, often causing conflicts with human land use goals (see Putman et al. 2011a for a review). Some of the negative effects of such increase include (*i*) damage to agriculture (e.g. Cotê et al. 2004), (*ii*) damage to forestry through browsing and bark stripping (e.g. Cotê et al. 2004), (*iii*) deer-vehicle collisions (e.g. Bruinderink, Hazebroek 1996; Langbein et al. 2011), (*iv*) transmission of diseases to humans (e.g. Tei et al. 2003) and domestic livestock (e.g. Górtazar et al. 2007).

While just a century ago it was almost facing extinction in Portugal, the Iberian red deer *Cervus elaphus hispanicus* is one of the ungulates that has registered a significant expansion in Iberian Peninsula in recent years (Vingada et al. 2010). A sequence of reintroduction programs during the 90's coupled with natural dispersion from Spanish populations led to stable red deer populations. These are now common and widespread throughout Portugal, with the most representative populations located near border areas with Spain (Vingada et al. 2010). With increasing distribution and densities, impacts on the ecosystem are likely to increase, as well as the risk of human-red deer conflict in the future (Torres et al. 2014a). The increase in red deer numbers is causing local conflicts with landowners reporting economic losses in forest plantations and agricultural plantations (Rosa 2006). Impacts from red deer are described as an ever-growing problem in agriculture (e.g. Putman, Staines 2004; Trdan, Vidrih 2008). Conflicts are naturally most evident in areas where forestry and/or agricultural production are the main economic activity. This has been shown to be very relevant in rural mountain communities in Portugal (Rosa 2006). Additionally, rural communities often feel particularly neglected by damage caused by wildlife, particularly in natural parks that they perceive as imposed by more powerful urban elites (Skogen et al. 2008). Local populations are becoming increasingly concerned about the impacts of red deer population increase over agricultural and forestry production as this is their only economic revenue. This can in turn imperil natural and protected areas by poaching and by causing habitat loss. So, a great effort is needed to mitigate human-red deer conflicts through species management strategies. Successful management strategies require reliable information on abundance and population trends. Nevertheless, the choice of any given method depends on the ecology and behaviour of the species of interest, the management questions to be answered, and the type of habitat the species inhabit. Indirect methods (e.g. pellet group counting) have several advantages since they are cheaper than direct methods, they provide a good cost-performance, they enable the prospection of large forested areas and can be performed all the year round and at any daytime, not being dependent on the species ethology, as direct methods are. In fact, according to Marques et al. (2001) in woodland areas (such as our study area) direct methods are not often feasible or they are potentially biased. Furthermore, the non-complexity of this indirect method allows that e.g. park rangers collect the data enabling the continuity of deer monitoring. Here, we propose an easy and readily applied method to estimate the density of red deer in a rural area in the northeast of Portugal. We sought a method to assess population trends considering temporal variation to detect fluctuations on population density, useful at multiple spatial scales that can be easily used by managers across the entire red deer range in Portugal. Additionally, we discuss the importance of social concerns in finding a balance between different stakeholders and wildlife needs.

MATERIAL AND METHODS

Study area. The study was carried out in Montesinho Natural Park (6°30'–7°12'W, 41°43' to 41°59'N), part of the European Union's Natura 2000 Network, covering an area of 75,000 ha (Fig. 1). The terrain consists of rolling hills with elevation ranges from 438 to 1,481 m. The climate is Mediterranean with the mean annual temperature varying between 3°C in the coldest month and 21°C in the warmest month and mean precipitation between 600 and 1,500 mm. The vegetation is diverse, characterized mainly by oak (*Quercus pyrenaica*, *Quercus rotundifolia*, *Quercus suber*), sweet chestnut (*Castanea sativa*) and maritime pine (*Pinus pinaster*). The shrub vegetation is dominated by heather (*Erica* spp.), gum rockrose (*Cistus ladanifer*) and furze (*Ulex europaeus* and *Ulex minor*). The area exhibits a mosaic of deciduous and coniferous forests, fragmented by small cultivated fields. Other ungulates present

Fig. 1. Location of the study area in the Iberian Peninsula (the distribution of sampling plots in the two study sites: SM – Serra de Montesinho, LNHA – Lombada National Hunting Area)

include the wild boar (*Sus scrofa*) and the roe deer (*Capreolus capreolus*). The study area is crossed by some rivers and includes small villages with a low human presence (9.5 people/km^2). Since 1960, the population has decreased about 60%, from ca 3,600 inhabitants to ca 1,400 (INE 1960, 2001). A number of national roads, which provides connection between Portugal and Spain, cross the study area.

Field methods and sampling design. The survey area was divided into 2 geographic strata: Serra de Montesinho (SM: 24,800 ha) and Lombada National Hunting Area (LNHA: 20,830 ha). This was done to allow separate estimates by these relevant management areas (red deer is hunted in LNHA during September – even though the hunting bag is between 5 and 7 animals, in some years that number is not filled – but not in SM). Transect location followed a systematic design with a random start, ensuring that transects were representative of the whole area. In total, there were 49 transects: 27 in LNHA and 22 in SM (Fig. 1). Each transect was 1,000 m long; to maximize spatial coverage while reducing sampling dependence, transects were divided into 100 m on-effort segments spaced by 200 m off-effort segments, in a total of 4 times 100 m on-effort and 6 times 100 m off-effort per transect. The transects were considered the independent sampling units for encounter rate variance estimation (see details below). Fieldwork was performed from January 2012 to October 2013 (2012: January and November; 2013: January, February and October). A handheld Global Positioning System (GPS) unit and a compass were used to ensure straight line transects. A rope was used to facilitate the progress in a straight line in a woodland habitat, ensuring the prospection of 1 m from each side of the line. Additionally, this facilitates accurate measurements of perpendicular distance of the pellet groups to the transect line. Whenever a pellet group was detected, the perpendicular distance from the centre of the group to the transect line was recorded with a measuring tape. Only pellet groups with six or more individual pellets, produced at the same defecation event, identified for similar size, shape, texture and colour (Mayle et al. 1999), were considered to minimize the risk of counting one spread group as more than one pellet group. Four additional observation level covariates potentially influencing detection were collected: (*i*) pellet group size (medium: between 6 to 40 individual pellets vs. large: more than 40 individual pellets); (*ii*) group dispersion (aggregated vs. scattered); (*iii*) habitat type around the pellet group (open vs. closed); and (*iv*) visibility, i.e. if the pellet group was clearly visible or not. Fieldwork was implemented by two observers, one of them constant throughout all surveys.

Density estimation. Taking into account habitat conditions and the available resources, an indirect density estimation method was implemented. Animal density was estimated within a distance sampling framework. Distance sampling, conditional on an adequate survey design, is based on four key assumptions: (*i*) objects (pellet groups in this case) on the transect line are always detected; (*ii*) sampling is instantaneous and objects do not move in response to the observer before being detected; (*iii*) perpendicular distances to the centre of the transect line are accurate and (*iv*) strictly, obtaining estimates for the parameters of the detection function by maximum likelihood requires detections to be independent, but methods are very robust to the failure of this assumption (Burnham, Anderson 1984). Distance sampling allows objects of interest in surveyed plots to be missed (Buckland et al. 2001). The decrease in detectability with increasing distance from the transect line is modelled using a detection function (Buckland et al. 2001; Miller et al. 2013), typically represented by $g(x)$, representing the probability of detecting an object if it is at distance x from the centre of the transect line. This function is then used to estimate the detection probability P within the covered area, as Eq. (1):

$$P = \int_0^w g(x)\pi(x)dx \tag{1}$$

where:

w – truncation distance,

$g(x)$ – probability of detecting an object if it is at distance x,

$\pi(x)$ – distribution of available distances with respect to the line.

This distribution is assumed to be uniform by design, which is reasonable with the random placement of the transect lines. The estimate of P leads to a density estimator as follows. For the n_i detected pellet groups in stratum i, an estimate of animal density $\hat{D}_i$ is given by Eq. (2):

$$\hat{D}_i = \frac{\hat{D}_i^p}{\hat{\alpha}\hat{\beta}} = \frac{n_i}{2L_i w\hat{P}_i \hat{\alpha}\hat{\beta}} \tag{2}$$

where:

$\hat{D}_i^p$ – pellet group density estimator,

$\hat{\alpha}$ – pellet production rate: on average, how many pellet groups a deer produces per day,

$\hat{\beta}$ – decay of pellet groups,

n_i – pellet groups in stratum i,

L_{i} – total on-effort line length in stratum i (i = 1.2),

w – truncation distance,

$\hat{P}_{\mathrm{i}}$ – detection probability of a group within the covered area in stratum i.

How many days does it take a pellet group not to be recognized as a group (> of 6 individuals). This notation implies that both α and β are assumed constant across strata. Note that the animal density estimator is just the pellet group density (D^p) estimator, divided by the required production and decay rates. The global density (D) estimate is obtained as a weighted average of stratum specific estimates, with stratum's areas as weights (Buckland et al. 2001), i.e. Eq. (3):

$$\hat{D} = \frac{\sum_{i=1}^{2} \hat{D}_l A_i}{\sum_{i=1}^{2} A_i} \tag{3}$$

where:

$\hat{D}_l$ – stratum density,

A_i – stratum area.

The variance of the stratum specific estimates is obtained via the delta method, by combining the variances of the random components in the estimator defined above (see Buckland et al. 2001 for details).

In this study α and β were obtained from different sources. The mean number of days that a pellet group takes to disappear (β) was assumed to be 227 ± 24 days, a value provided by Torres et al. (2013) for red deer in MNP. The production rate (α) was considered to be 25, value estimated in the UK (Mayle et al. 1999; The Deer Initiative 2008). We address the plausibility of these values and consequences of bias in these parameters and their precision (or lack thereof) in the final density estimates in the discussion.

Data analysis. Analyses were implemented in Distance 6.0 software (RUWPA, St. Andrews, UK) (Thomas et al. 2010). To evaluate the influence of available covariates in the detection function, we considered Multiple Covariate Distance Sampling (MCDS) analyses (Marques et al. 2007). Data were right-truncated at 5% (95 cm), a standard procedure (Marques 2004; Ward et al. 2004) to facilitate parsimonious model fitting, avoiding fitting spurious bumps in the tail of the detection function (Marques et al. 2001). Three key function models (half-normal, uniform and hazard-rate) were considered, adding adjustment terms (cosine, simple polynomial and Hermite polynomial) as required to improve the model fit (Buckland et al. 2001). Model selection was based on AIC (Burnham, Anderson 1984), with goodness-of-fit tests and visual inspection of the histogram aiding the process. A Cramer-von Mises goodness-of-fit test was used as absolute measures of fit, to evaluate the adequacy of the final model chosen for inference.

RESULTS

In a total of 19,600 m of effort (SM – 8,800 m; LNHA – 10.800 m) 527 pellet groups were detected. As expected, the number of records monotonously decreased with distance. Surprisingly, given the rigorous survey design and field methods, coupled with the fact that objects being detected were immobile, a larger number than expected of small distances (below 7.5 cm) was present, especially for LNHA. Nevertheless, the results were insensitive to this peak with regard to the broad shoulder present in the data. The model that better fitted the distance data was a half-normal model for LNHA (a), and a uniform model for SM (b), both with the cosine adjustment term (Fig. 2). Although a pooled analysis

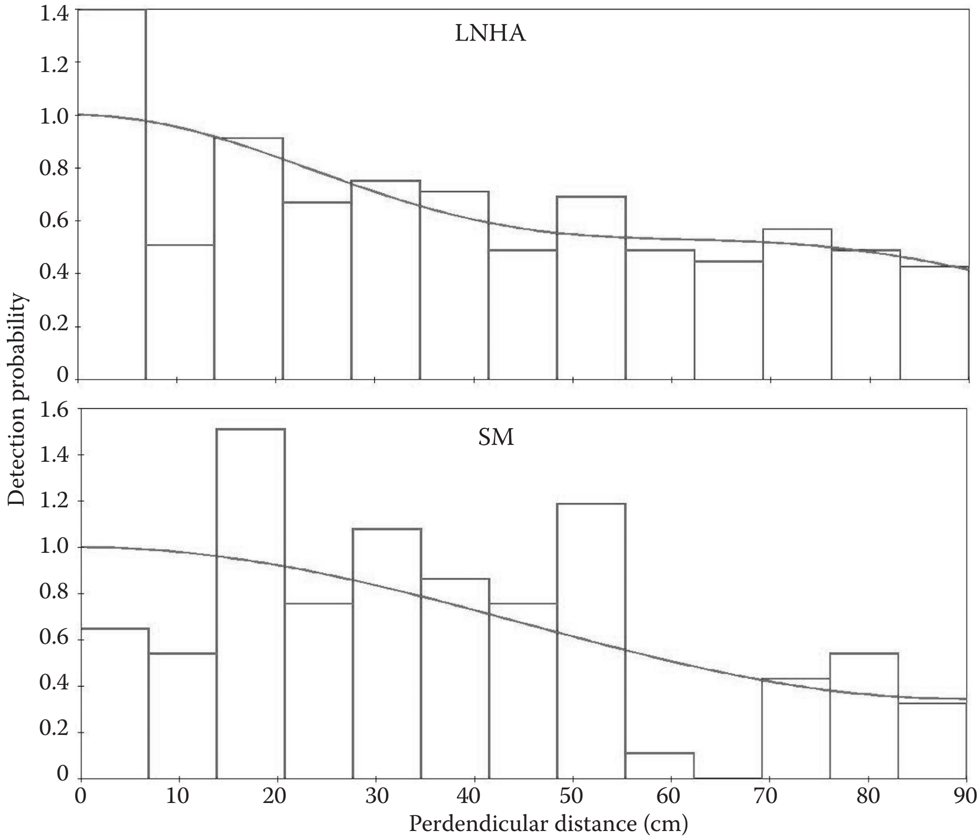

Fig. 2. Stratified detection function of the distance data for study sites (observed distances were right-truncated to eliminate the largest 5% of the distances)

was carried out, the most parsimonious model with regard to AIC was considered the detection function to be stratified by area, with the uniform model with the cosine adjustment term corresponding to a better fit (Fig. 3). Somewhat unpredictably, none of the covariates contributed to a better fit of the model, and thus the model with the distance alone was selected for further inference (further implications of this result can be found in the Discussion). The goodness-of-fit *P*-values for such a model were 0.008 (LNHA) and 0.035 (SM) (Table 1). Deer density estimates per stratum were 5.81 indd 100 ha (95% CI of 3.65 to 9.25) for LNHA and 1.34 indd per 100 ha (95% CI of 0.74 to 2.42) for SM, with the coefficient of variation 23.49%

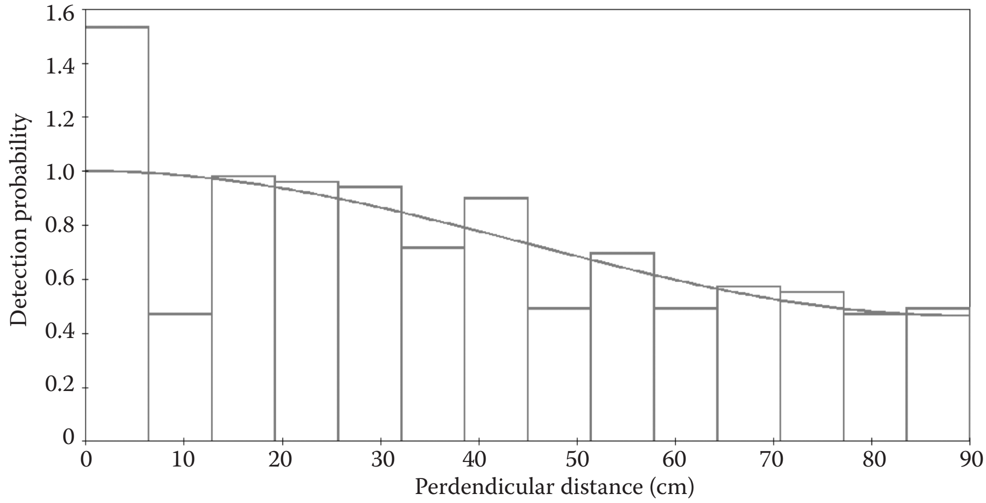

Fig. 3. Pooled detection function of the distance data for survey area using a uniform model key function and a cosine adjustment term (observed distances were right-truncated to eliminate the largest 5% of the distances)

y-axis applies to the detection function only, histogram bars are scaled so that the area of the bars under the curve and the area of the bars above the fitted curve is the same

Table 1. Summary statistics for the detection function models

Detection function		AIC	ΔAIC	CvM
Individual	LNHA	3,762.19		0.010
	SM	721.25		0.400
Stratified		4,483.44*	0.00	
Pooled		4,484.36	0.92	0.010
Covariate	size	4,488.37	4.93	0.010
	shape	4,488.46	5.02	0.010
	detectability	4,488.18	4.74	0.010
	habitat	4,487.70	4.26	0.010

AIC – Akaike Information Criterion, ΔAIC – Differences in AIC scores, CvM – *P*-values associated with the Cramer-von Mises goodness-of-fit tests, LNHA – Lombada National Hunting Area, SM – Serra de Montesinho, Individual LNHA; Individual SM and Stratified – summarize the two individual analyses: LNHA, SM; *sum of the 2 previous individual analyses

and 29.61%, respectively. The global density estimate was 3.38 indd per 100 ha (95% CI of 2.18 to 5.24) with the coefficient of variation 22.18% (Table 2).

DISCUSSION

The estimated red deer density over the study area was 3.38 indd per 100 ha, with densities higher in LNHA than SM (LNHA: 5.81 indd per 100 ha and SM: 1.34 indd per 100 ha). This was expected as this population results from natural dispersion from the Spanish border populations and the first nucleus of red deer populations in MNP was originally established in LNHA and they continued expanding from there (Santos 2009). Santos (2007; 2009) and Carvalho (2011), using conventional animal-based distance sampling, estimated that red deer densities in LNHA were 3.26 indd per 100 ha and 1.75 indd per 100 ha, respectively. Even though our density estimates are slightly higher than those obtained previously, it is difficult to compare our estimates with these two studies because these authors surveyed only the northern part of the LNHA whereas we surveyed the whole area, and field work was from different years.

Ungulates are particularly difficult to monitor (Putman et al. 2011c) but effective monitoring programs are pivotal to cope with their current expansion. A wide variety of techniques have been used to estimate ungulate density (Apollonio et al. 2010). Among indirect methods, pellet group counting has been widely used to estimate deer densities throughout the world (Marques et al. 2001; Jathanna et al. 2003; Smart et al. 2004; Herrero et al. 2013; Valente et al. 2014) and while some authors have argued against it (e.g. Morellet et al. 2007), others have recommended it, claiming that it can be used to efficiently assess the population size and trends (e.g. Acevedo et al. 2008). For many species direct methods are not often feasible and are potentially biased in woodland habitats due to elusive animal behaviour leading to extremely reduced detectability (Torres et al. 2014b; Valente et al. 2014). Advantages of pellet group counts include being easy to implement over large areas, requiring low financial and logistical resources and being especially useful in areas with low visibility (Marques et al. 2001; Smart et al. 2004). Here we used an indirect method based on pellet groups coupled with distance sampling to estimate red deer density. The need of conversion factors (e.g. decay rate and production rate of red deer) can decrease the precision of an estimate (Plumptre 2000). Here we expect minimal bias arising from the decay rate, as it was recently calculated for both the species and the region of interest (Torres et al. 2013). Since decay rates can vary across habitats, the use of a site-specific value for each dominant habitat instead of a mean value should be investigated in future work. The key problem with our estimate is certainly the use of a production rate obtained in another place and time (Mayle et al. 1999). Furthermore, the value used does not have a precision measure associated with it, therefore the variance reported here ignores a potential source of variation. While this is a shortcoming, it also shows a clear strength of the modular form of the estimator used here: as soon as a production rate and corresponding standard error are obtained for our region, the density estimates and

Table 2. Red deer density, abundance and 95% CI in total area, LNHA and SM

	Area (ha)	Total effort (m)	Density			Abundance	
			per 100 ha	95% CI	CV (%)	per 100 ha	95% CI
Total area	45,600	19,600	3.38	(2.18; 5.24)	22.18	1,544	(997; 2,391)
LNHA	20,800	10,800	5.81	(3.65; 9.25)	23.49	1,211	(761; 1,927)
SM	24,800	8,800	1.34	(0.74; 2.42)	29.61	333	(185; 599)

LNHA – Lombada National Hunting Area, Individual SM – Serra de Montesinho, CV – coeficient of variation, CI – confidence interval corresponding variances reported here could be easily updated. Obtaining such production rate should therefore be a major goal for the effective management of these populations.

Surprisingly, none of the available covariates had an impact on the detectability of pellet groups. The distance-only detection function led to the most parsimonious model to explain the pellet group detectability. This reflects the fact that the pooling robustness of distance sampling holds and that sometimes MCDS provides no additional practical gain beyond conventional distance sampling, especially for situations like here where there is a broad shoulder. Nonetheless, under certain circumstances MCDS can be used to reduce variance estimates, by explaining some of the variance in detectability. MCDS might also allow less biased estimates of density, and further, covariate influence on detectability might be interesting in itself. Therefore, we encourage researchers to collect data regarding covariates believed to have an impact on the detectability of the study objects, since they can have an important role in modelling the detection function (Marques et al. 2007). All the distance sampling assumptions were met in this study: (1) it is unlikely that the pellet groups on the transect line were missed; even if they were, as we were looking for static objects in a very narrow transect, g(0) assumption would suffer at worst minor violations, (2) because pellets are immobile, the perpendicular distances to the centre of the transect line measurement error should be negligible. As a result, all the distance sampling assumptions were met, which is obviously a big advantage when compared with the use of animal-based distance sampling. When compared to direct methods, indirect methods have demonstrated to provide feasible and robust results, validating the pellet group count method (Acevedo et al. 2008). In our particular case, the use of pellet group counts (an indirect methodology) allowed the survey of a large forested area, with a good cost-performance and provided estimates of density and abundance over several months. Additionally, after a well-established monitoring protocol, field signs are relatively easy to identify, allowing surveys to be done by non-professionals (e.g. volunteers), obviously decreasing the survey costs while ensuring the continuity of data collection. This approach, applied over time, will allow tailoring management strategies to demographic data, and to assess the results of management measures applied throughout the monitoring plan. Urbanek et al. (2012) showed that pellet group counting coupled with distance sampling provides less biased estimates and was 88% cheaper than aerial surveys. When compared with direct methods, pellet group counting can be performed at any time during the year and does not need elaborate equipment neither professional biologists to perform field work (Marques et al. 2001). While the distance sampling data analysis represents perhaps an additional step over using raw counts, it also allows gains in logistical, financial, and analytical efficiency, with the added benefit of more precise and comparable abundance estimates. This should be a major goal in future studies regarding red deer in our study area.

We proposed an approach to monitor the population abundance. Nevertheless, estimation of the population size should not be considered the only requirement to monitor red deer populations: managers need additional information to be considered and monitored (e.g. habitat composition, impacts on vegetation and agriculture, collisions with vehicles, among others).

Red deer was considered the ungulate with the largest negative impact in Montesinho (Rosa 2006), responsible for significant agricultural and forest damage, so its population management is the most critical wildlife management issue in our study area. Red deer densities have been increasing in Portugal in general, being however smaller than in other areas in Europe (Spain: 19.51 ± 3.19 indd per 100 ha – Acevedo et al. 2008; UK: 14.5 ± 11.25 indd per 100 ha – Smart et al. 2004), so the need to take rigorous measures to prevent the costs of red deer overabundance is evident. Particularly in our study area the locals are becoming more willing to increase Iberian wolf densities so that they can prey red deer, therefore decreasing the impact of deer on agriculture. In our study area, particularly in the LNHA, it was estimated that economic losses caused by wild ungulates have a significant impact on farmers' income (Rosa 2006). Knowing the abundance of deer is vital to make population management decisions. For example, estimates of the population size before and after an action can be used to judge the success of management programs (Rutberg, Naugle 2008). However, accurate estimates of abundance are difficult to obtain, and management is often hindered by the lack of confidence in census methods.

As the problem is currently increasing and will continue to increase in the nearest future, the human-red deer conflict deserves further investigations. The conflict is important and suggests that effective management strategies would need to be considered for mitigating this conflict. Estimating the local abundance or monitoring population trends is crucial to assess the impact of methods aimed at reducing the population size or impact. Interactions between humans and deer have become common, ultimately resulting in management actions to mitigate negative impacts. Changes in, and trends of the population size are generally used not only to judge management actions but also to foresee potential conflict areas. Our study showed that distance sampling applied with an indirect method such as pellet group counting can be successfully applied. The primary advantage of this method is that it can be implemented over large areas, at any time of the year, and by any person, and it is cheap, saving considerable time and money. This paper provides an example of a robust method that can be implemented to continuously monitor expanding populations. Therefore, we recommend that this method should be used consistently through time and space to ensure valid comparisons or assessments of deer populations.

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Corresponding author:

Dr. Rita Tinoco Torres, CESAM, Department of Biology, University of Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal; e-mail: rita.torres@ua.pt