Game species monitoring using road–based distance sampling in association with thermal imagers: a covariate analysis

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Morelle, K., Bouché, P., Lehaire, F., Leeman, V. & Lejeune, P., 2012. Game species monitoring using road–based distance sampling in association with thermal imagers: a covariate analysis. *Animal Biodiversity and Conservation*, 35.2: 253–265.

Abstract

Game species monitoring using road–based distance sampling in association with thermal imagers: a covariate analysis.— Monitoring of game species populations is necessary to adequately assess culling by hunters in areas where natural large predators are absent. However, game managers have to control several species and they often lack of an efficient and convenient survey design method. Monitoring several species at that same time over large areas could thus be cost– and time–effective. We tested the influence of several factors during monitoring of three common game species, (wild boar, roe deer and red fox, using road–based distance sampling in association with thermal imagers. This pilot survey based on 20 night counts in five contrasting sites studied the effect of several covariates (species, thermal imaging, observer, group size, and habitat type) on the detection probabilities (= dp). No differences were observed between thermal imagers ($dp_{JENOPTIK}$: 0.186, dp_{FLIR}: 0.193) and group sizes ($dp_{1ind.}$: 0.243, $dp_{2ind.}$: 0.259, $dp_{>2ind.}$: 0.223), but we found differences between observers (dp_{obs1}: 0.207, dp_{obs2}: 0.274, dp_{obs3}: 0.159). Expected differences were also observed between species ($dp_{wild\ boar}$: 0.22, $dp_{roe\ deer}$: 0.35, $dp_{red\ fox}$: 0.32) and between habitat type (dp_{forest}: 0.27, dp_{edge}: 0.74, dp_{open}: 0.35). Our results show that the detectability of low cost thermal imaging equipment is similar to that of more expensive methods, highlighting new possibilities for the use of thermal imagery by game managers. Although adjustments should be made to the study design our findings suggest that large–scale multi–species monitoring could be an efficient method for common game species.

Key words: Road–based distance sampling, Thermal imaging, Game species, Detectability.

Resumen

Monitorización de especies cinegéticas utilizando el muestreo a distancia con base en una carretera, en combinación con imágenes termográficas: un análisis de covariables.— La monitorización de las poblaciones de especies cinegéticas es necesaria para evaluar adecuadamente las capturas de los cazadores, en zonas que carecen de los grandes depredadores naturales. Sin embargo, los gestores de la caza deben controlar diversas especies y a menudo carecen de un método de control con un diseño conveniente. Por lo tanto, la monitorización de diversas especies al mismo tiempo en áreas muy grandes podría ser eficaz desde el punto de vista de los costes y del tiempo. Estudiamos la influencia de diversos factores durante la monitorización de tres especies cinegéticas comunes (el jabalí, el corzo y el zorro rojo) utilizando un muestreo a distancia desde la carretera, en asociación con imágenes termográficas. Este examen piloto basado en 20 recuentos nocturnos en cinco lugares contrastantes estudió el efecto de diversas covariables (especie, termografía, observador, tamaño del grupo y tipo de hábitat) sobre las probabilidades de detección (dp). No se hallaron diferencias entre las imágenes termográficas ($dp_{JENOPTIK}$: 0,186, dp_{FLIR}: 0,193) y el tamaño de los grupos ($dp_{1ind.}$: 0,243, $dp_{2ind.}$: 0,259, $dp_{>2ind.}$: 0,223), pero sí entre los observadores (dp_{obs1}: 0,207, dp_{obs2}: 0,274, dp_{obs3}: 0,159). También se observaron diferencias esperadas entre las especies ($dp_{wild\ boar}$: 0,22, $dp_{roe\ deer}$: 0,35, $dp_{red\ fox}$: 0,32) y entre los tipos de hábitat (dp_{forest}: 0,27, dp_{edge}: 0,74, dp_{open}: 0,35). Nuestros resultados demuestran que la detectabilidad de los equipos de termografía de bajo coste es similar a la de otros métodos caros, destacando nuevas posibilidades del uso de la termografía para los gestores de la caza. Aunque deberían realizarse ajustes en el diseño del estudio, nuestros hallazgos sugieren que la monitorización de múltiples especies a gran escala podría ser un método eficaz para las especies cinegéticas comunes.

ISSN: 1578–665X

Palabras clave: Muestreo a distancia desde carretera, Termografía, Especies cinegéticas, Especies de caza, Detectabilidad.

Rebut: 19 XII 11; Conditional acceptance: 27 II 12; Final acceptance: 3 IV 12

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Introduction

Increases in large game populations are reported from all over Europe (Saez–Royuela & Telleria, 1986; Jędrzejewska et al., 1997; Panek & Bresiński, 2002). Due to the extinction of large predators in most western areas of Europe, human control of game species through hunting is required to manage their populations (Apollonio et al., 2010). To control these populations efficiently it is important to establish sampling and counting methods that accurately estimate population size on which shooting numbers can be based.

In this context, multiple–species monitoring over larger areas offers a practical means to estimate changes in regional abundance of targeted species (Manley et al., 2004). Multiple–species monitoring is often used for conservation management purposes (Regan et al., 2008; Manley et al., 2004), but is rarely applied in the field of wildlife game management. Manley et al. (2004) demonstrated that coordinated multiple–species monitoring is a robust alternative to intensive single species surveys and can be time and cost–effective for local managers. The challenge while working at a regional or landscape scale is to build up a robust survey design that takes into account variability among habitats and seasons (Jones, 2011). Despite these limitations, if the survey design is approriate, large–scale multi–species monitoring could be an interesting tool to help local stakeholders manage populations of the main, large–game species.

Game species can be counted in the field using various methods. Spotlight (Heydon et al., 2000) is the most popular direct method while pellet count (Acevedo et al., 2010; Heydon et al., 2000) appears to be the most popular indirect method. Nowadays, distance sampling (Thomas et al., 2010), that takes into account variation in visibility (assumed to decrease with perpendicular distance to the surveyed transect), is largely included in these two counting methods (Ruette et al., 2003; Marques et al., 2001) because it allows better precision in estimating animal densities. As this methodology is well–established and widely used, for further details we recommend reading the most recent paper of the Distance development team (Thomas et al., 2010).

Modelling the detection probabilities only in relation to the distance to the transect can be limiting when the surveyed transect crosses different habitats (Parrott et al., 2011) or when the sampling design involves monitoring different species with different morphological characteristics (Parrott et al., 2011; Barbraud & Thiebot, 2009). Variations in detectability may indeed lead to upward or downward estimation biases (Ramsey & Harrison, 2004). Survey conditions (Bozec et al., 2011) as well as observers (Pagano & Arnold, 2009; Marini et al., 2009) can also have an impact on the detection function and should also be included in any probability detection model. Recent work by Marques et al. (2007) demonstrates the importance of including covariates into the detection function modelling process to increase the model's precision, although pooling data by relevant covariates can also be an effective strategy to deal with variability between covariates, *e.g.* grouping data by species (Focardi et al., 2002) or by habitat types (Acevedo et al., 2008). In spite of the role covariates might play in unbiased estimates of population density (Kéry & Schmid, 2004), few studies really focus on how they impact the detection function.

Application of distance sampling using roads as transects implies limitations and benefits. On one hand, using roads to count has been shown to potentially affect animal behaviour (Shanley & Pyare, 2011; Rost & Bailey, 1979; Coulon et al., 2008) and distribution (Venturato et al., 2010; Roedenbeck & Voser, 2008; Erxleben et al., 2010). It can thus violate the assumption of random animal distribution around the transect required by distance sampling; for this reason the use of roads as transect is often considered a convenience sampling approach (Anderson, 2001). On the other hand, using vehicle on roads provides a means to cover large areas in a short time (Butler et al., 2007; Ward et al., 2004; Heydon et al., 2000; Gill et al., 1997) and is known to cause less disturbances to animals than walked transect (Heydon et al., 2000; Marini et al., 2009).

Recently, use of thermal imaging to survey wildlife has gained in popularity (Hemami et al., 2007; Focardi et al., 2001; Gill et al., 1997). First used from the air (Garner et al., 1995), the method has been adapted for ground counts and has proved to be effective for detecting small (European hares *Lepus europaeus* Pallas 1778) to large (white–tailed deer *Odocoileus virginianus* Zimmermann 1780, muntjac *Muntiacus reevesi* Rafinesque 1815, roe deer *Capreolus capreolus* Linné 1758, red deer *Cervus elaphus* Linné 1758, wild boar *Sus scrofa* Linné 1758) game species (Focardi et al., 2001; Collier et al., 2007; Gill et al., 1997; Hemami et al., 2007). The advantages of thermal imagery are the ability to detect animals at night when they are more active due to less human disturbance (Cahill et al., 2003; Gottardi et al., 2010; Doncaster & Macdonald, 1997; Keuling et al., 2008; Kavanau, 1971; Barrio et al., 2010; Boitani et al., 1994). Detecting animals in evenly dense cover is also straightforward with thermal imaging. Compared to other techniques (*e.g.* spotlight counts), imaging techniques also cause less disruption to animal behaviour during counting (Fournier et al., 1995; Ward et al., 2004; Gill et al., 1997). Despite these advantages, wide use of thermal imagery is limited because of the high cost of this equipment compared to other techniques (Focardi et al., 2001).

The objective of this paper was to evaluate the potential sources of inaccuracy and bias during a multi–species (wild boar, roe deer and red fox *Vulpes vulpes* Say 1823) monitoring survey over large areas (± 5,000 ha). We compared the detectability of two thermal imagers that differed in relation to their spatial resolution, visual comfort and price. We also tested for differences in detectability between species (expecting differences regarding their morphology), cluster size (expecting larger group to be more detectable), habitat (expecting higher detectability in open areas), observers (no differences expected) and time of the night (no a priori expectation).

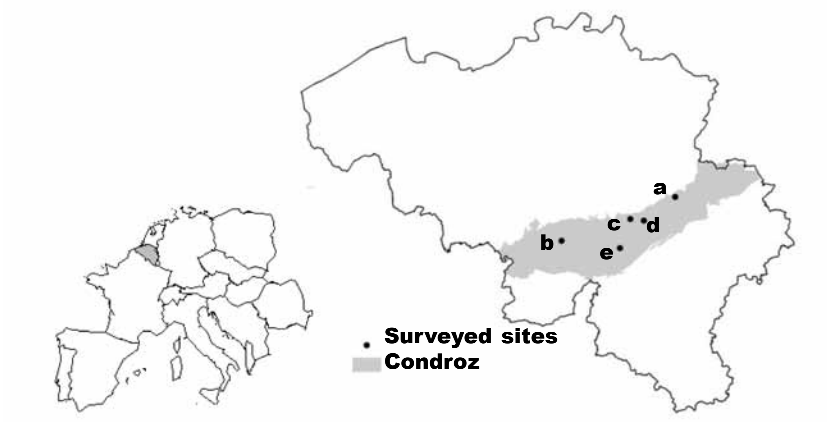

Fig. 1. Localisation of Belgium (left) and the five selected sites within the Condroz eco–region (right).

Fig. 1. Localización de Bélgica (izquierda) y de los cinco lugares seleccionados en la región protegida de Condroz (derecha).

Material and methods

Study area

We conducted our study at five sites in Condroz, a natural region in Belgium situated between the Ardennes and the Meuse River (fig. 1). Condroz is a mosaic of woods and farmland, with 55% of its area consisting of grassland and crops (maize, cereals, beetroot and oilseed rape). The forest is patchily distributed and covers 24.5% of the total area. It lies at between 50 and 350 m above sea level. It has a temperate sub–oceanic climate with a mean annual temperature of 8°C and a mean monthly temperature varying between 2 to 16°C. The mean annual rainfall is 900 mm, and the mean annual duration of snow cover is over 25 days. The study sites covered an extension of between 4,600 ha (fig. 2, site a) and 6,400 ha (fig. 2, site d) with varying forest cover (ranging between 14 and 46%) and were limited either by natural or man–made barriers (highways, large rivers). Impermeability of these barriers is not assured, but for the purpose of this study we assumed that during fieldwork (from 28 II 11 to 15 IV 11) the population of the three studied species remained constant.

Species monitored

In these evenly wooded landscapes the most commonly hunted species are wild boar, roe deer and red fox. No culling strategies currently exist for these three species. Red deer are rarely present in the area and constitute a marginal hunted species in Condroz.

Road transect sampling

Within each study site we randomly selected survey transects among potential road segment (= road network subdivided into 200 m long segment) candidates (fig. 3A) using the following four criteria: (i) distance to forest less than 300 m, (ii) distance to human settlements more than 100 m, (iii) paved, and (iv) low traffic roads. According to these criteria we then pooled each road segment into a suitable or unsuitable group (fig. 3B). For each site we defined a survey route using random selection among the suitable segments. Among the potential survey route candidates we selected the one that maximized the ratio [total length of suitable road segments/total length of survey route] (fig. 3C). If selected survey segments were parallel, we checked for a minimum distance of 500 m between them (Marini et al., 2009; Gill et al., 1997) to avoid potential double counting of animals. When not possible, a new route survey was generated until this condition was fulfilled. Selected survey routes ranged between 40.1 and 63.9 km. These lengths were designed to cover the habitat availability, to allow completion of the count within the lifetime of the thermal imaging battery (approx. 4–5 hours) and to ensure the constant attention of observers and vehicle driver during the count. Road density (mean = 6.3 km/km²) in the study areas was assumed to be sufficient to cover the different habitat conditions of each surveyed site. A mean of 0.9 km/km² was surveyed across study sites, representing a mean sample rate of 14.4% of all (suitable and unsuitable) road segments. A four–wheel vehicle driven at low speed (10–15 km/h) was used to survey the designed road transects. One driver and two observers, one on each side of the vehicle, equipped with a hand–held thermal imager, were required to conduct the night count. Two different thermal imaging devices were used to detect animals, a FLIR ThermaCAM™ HS–324 with a resolution of 320×24 pixels, and a JENOPTIK VarioCAM™ with a resolution of 640×480 pixels. The main differences between the two

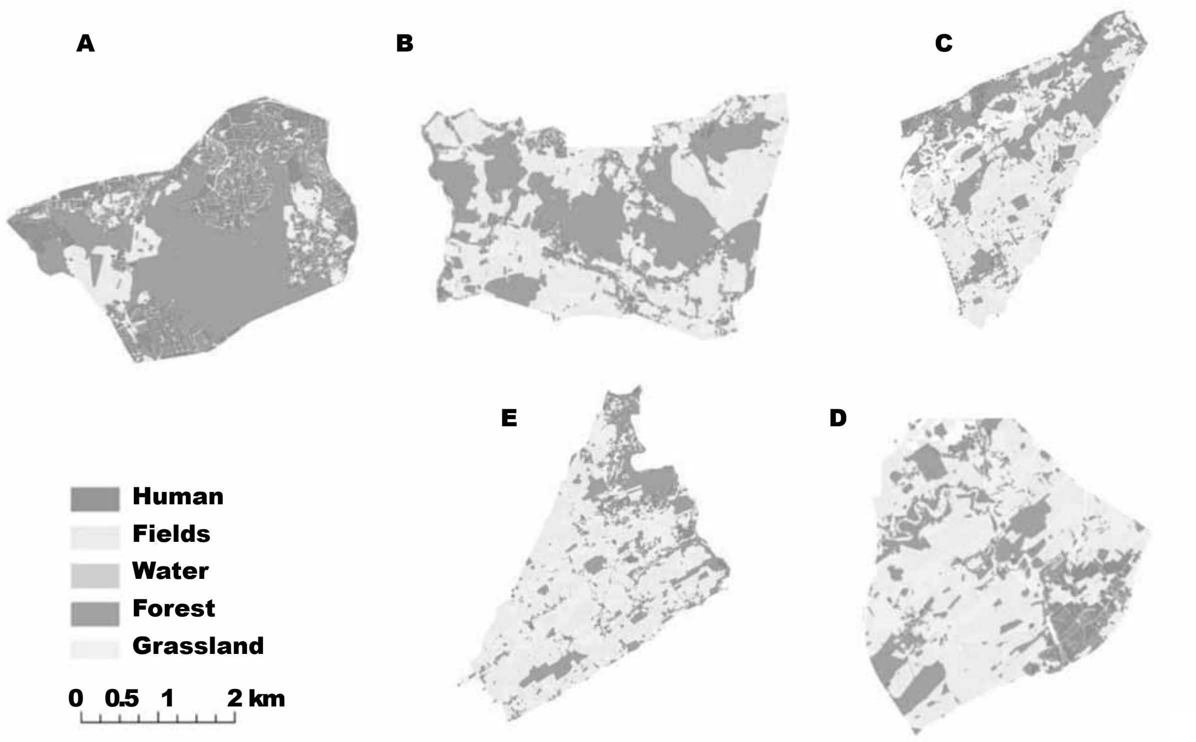

Fig. 2. Habitat composition of the five sites selected for the road–based distance monitoring. Selection was based on their homogeneous size, their gradient in forest cover (A = 46%, B = 37%, C = 25%, D = 18%, E = 14%), and their being limited by either natural or man–made barriers.

Fig. 2. Composición del hábitat de los cinco lugares seleccionados para la monitorización desde la carretera. La selección se basó en su tamaño homogéneo, su gradiente de cubierta boscosa (A = 46%, B = 37%, C = 25%, D = 18%, E = 14%), y por estar limitadas por barreras naturales o hechas por el hombre.

cameras is the price (4585 € for the FLIR *vs.* around 32,000 € for the JENOPTIK), the weight (660 g for the FLIR *vs.* 1500g for the JENOPTIK), the frame rate (8.3 Hz for the FLIR *vs.* 50 Hz for the JENOPTIK) and the visibility (one–eye viewfinder for the FLIR *vs*. 3.5" thin–film transistor (TFT) display for the JENOPTIK). Practically, these characteristics imply better visual comfort with the JENOPTIK camera with possibility of several colour ramps, but lower portability due to its weight. The FLIR camera is much cheaper and lighter but requires slower driving and more breaks for observers due to the lower resolution and eye fatigue using the viewfinder. Once an animal was detected, a spotlight combined with the laser rangefinder VECTOR IV Nite® by Vectronix were used to measure the bearing and distance between the animal and the road. We recorded the habitat context of a sighting (forest, open, edge) and also the fleeing response of the animal to spotlight use. Distinction between habitat contexts was based on animal (or cluster) position in relation to the forest. If an animal was in a 5 m–wide buffer in or outside the forest it was considered as being at the edge, while before or after this limit it was considered as being in open or forest habitat, respectively. A GPSmap 62 receiver (Garmin™) was used to record the location of each sighting.

Nocturnal road counts were conducted between 28 II 11 and 15 IV 11. This survey period was expected to be appropriate for surveying all three species because of the absence of vegetation in forest (favouring better visibility with thermal imagers) and the expected use of open areas (*e.g.* grasslands) at this time of the year (Baubet et al., 2004; Lucherini & Crema, 1994; Barancekova et al., 2010).

To account for changes in animal activity throughout the night, four surveys were conducted in each area; two surveys took place at each site in the first half of the night (between 8 pm and 1 am) and two in the second half of the night (between 1 am and 7 am). For each particular site, the four counts were completed with a minimum of three days between each count. Between each count at a particular site, we alternated the starting point of the survey route (Marchandeau & Gaudin, 1994) and also the observers' position in the vehicle to avoid potential bias. All surveys took place under similar weather conditions (dry conditions and temperatures ranging from 2 to 7°C). We did not therefore consider weather as a covariate in our analyses.

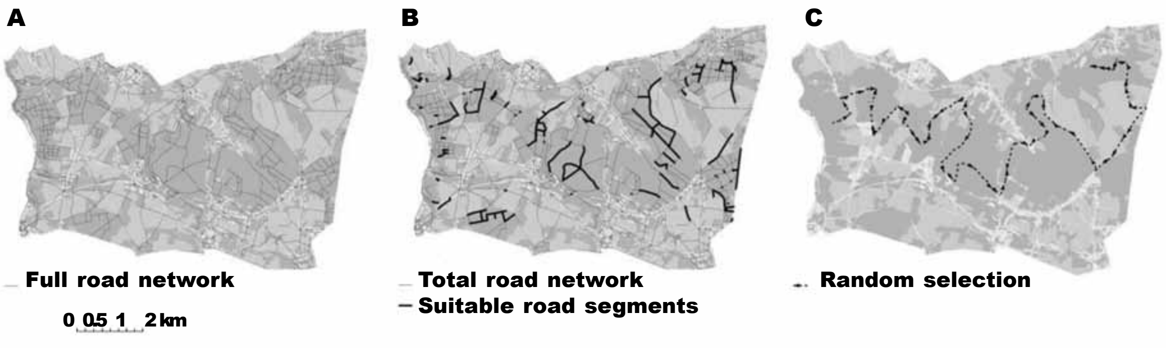

Fig. 3. Stratified random selection process of the survey route: A. Full road network; B. Selection of suitable 200 m long segment (less than 300 m distance to forest, more than 100 m to human settlements, paved roads with little traffic; C. Random selection among potential segment candidates and final survey route.

Fig. 3. Proceso de selección estratificada al azar de la ruta de seguimiento. A. Red de carreteras completa; B. Selección de segmentos de 200 m adecuados (a menos de 300 m de distancia al bosque, más de 100 m a poblaciones humanas, carreteras pavimentadas con poco tráfico); C. Selección al azar entre segmentos candidatos y ruta final del seguimiento.

Statistical analysis

To estimate detection functions, we tested how animal detectability varied according to different levels of measured covariates: habitat type (factor levels: forest, edge and open), observer (obs1, obs2, obs3), time of the night (before/after midnight), camera type (JENOPTIK, FLIR), species (wild boar, roe deer, red fox), and cluster size (1, 2, > 2). The tested null hypothesis was the absence of difference between the detection probabilities of the levels of each of the considered covariates. Data were right truncated at 300 m. Perpendicular distance data and distance break classes were set to 50 m to smooth the detection function. Data collected during the 20 night counts did not allow us to study the effects of species and habitat type independently. Number of required sightings was indeed too low (< 30) to fit a detection function (Buckland et al., 2001). Accordingly, sightings data were pooled across sites and for each covariate analysis we pooled data independently of the species and the habitat type to ensure building detection function based on a sufficient number of sightings.

For each covariate level we then tried to find the best detection function. We selected four potential candidate models: the half–normal, the uniform, the hazard rate and the exponential function. As our aim was to compare detectability and not to fit the best detection probability, no adjustment terms were added to these potential models. To fit these models we used the R package 'unmarked' (Fiske & Chandler, 2011). We used Akaike's information criterion (AIC) to compare models and Mann–Whitney test to evaluate the differences ($P < 0.05$) in the detection probability between the covariate values tested.

Results

Considering a sighting as any observation (an individual or a cluster of animals), we observed a total of 249 sightings: 42 were wild boar, 159 were roe deer, and 49 were red fox (table 1). European hares, rabbits (*Oryctolagus cuniculus* Linnaeus 1758) and occasionally badgers (*Meles meles* Linnaeus 1758) were also observed but not recorded. The mean perpendicular detection distance was 57.6 m (range = 0–230 m) for wild boar, 76.7 m (range = 0–435 m) for roe deer and 87.6 m (range = 5–266 m) for red fox (fig. 4). Detection distance among species varied significantly between wild boar and roe deer (Mann–Whitney test *p*–value = 0.0342) and between wild boar and red fox (Mann–Whitney test *p*–value = 0.0447). No difference between roe deer and red fox was observed. Detection distance was also affected by habitat (Mann–Whitney test *p*–value = 0.0007 for forest *vs.* open habitat and *p*–value = 0.0064 for forest vs. edge habitat), but edge and open habitat did not differ (Mann–Whitney test *p*–value = 0. 85). The mean cluster size was 1.84 for roe deer (range 1–5), 3.45 for wild boar (range 1–12), and 1.08 for red fox (range 1–2). Flight behaviour was observed in 56% of the sighting events for red fox, 31% for wild boar and 14% for roe deer. More than twice the number of sightings of roe deer was made after 1 am, while proportion of sightings for wild boar and red fox were similar before or after 1am (fig. 5).

Covariate analysis

We did not observe differences between the two thermal imagers ($dp_{JENOPTIK}$: 0.186 ± 0.042 and dp_{FLIR} 0.193 ± 0.043, fig. 6C) but we did find differences between observers (dp_{obs1}: 0.207 ± 0.050, dp_{obs2}: 0.274 ± 0.045, dp_{obs3}: 0.159 ± 0.040, fig. 6D). For species

Table 1. Transect characteristics (length of forest and open area surveyed), survey effort and total number of sightings and individuals.

Tabla 1. Características del transecto (longitud del bosque y del área abierta estudiados), esfuerzo de seguimiento y número total de avistamientos de individuos.

	Road transect (km)			Effort		Sightings (individuals)		
Site	Length	Forest	Open	Visits (n)	Survey (km)	Fox	Roe deer	Wild boar
a	48.4	29.4	19	4	193.6	5 (6)	42 (67)	24 (88)
b	64.4	19.2	45.2	4	257.6	3 (3)	68 (111)	2 (9)
c	63.9	9.9	54	4	255.6	18 (20)	18 (36)	6 (24)
d	40.1	8.3	31.8	4	160.4	10 (11)	15 (40)	7 (17)
e	44.6	4.2	40.4	4	178.4	12 (12)	15 (38)	3 (7)
Total	261.4	71	190.4	20	1045.6	49 (52)	158 (292)	42 (145)

covariates, the best model was the negative exponential for wild boar and red fox, and hazard–rate for roe deer (table 2). The probability of detection was significantly lower for wild boar ($dp_{wild\ boar}$: 0.224 ± 0.053) than for roe deer ($dp_{roe\ dee}$r: 0.351 ± 0.079) and red fox ($dp_{red\ fox}$: 0.323 ± 0.046). Differences related to habitat types were also observed (fig. 6B). We did not observe any differences in detectability due to cluster size (fig. 6E) or time factors (fig. 6F) (table 2).

Discussion

Our results showed that thermal imagers with different characteristics can provide similar detectability. The higher spatial resolution of one camera over the other did not seem to benefit detectability, contrary to the expectations of Gill et al. (1997). This could be because it was used to detect animals by looking for "hot spots" rather than identification per se (although in most case identification was possible when the car stopped). The difference in price for these two cameras and the comparable detectability shows the cost to use this technology can be greatly lowered, offering more possibilities for extensive use of this technology in the field, as suggested by Franzetti et al. (2011). However, although the FLIR imager is lighter than the JENOPTIK, observers found it more tiring to use because the viewfinder was more cumbersome than the TFT display of the JENOPTIK. Although it was not the purpose of our study, it is also important to mention that the FLIR imager did not allow us to classify detected animal by age or sex class as some imagers with higher resolution can do (Gill et al., 1997). In our study, thermal imagers were used for animal detection and for this purpose we argue that a lower resolution material can perform similarly. A camera with a medium resolution and a display rather than a viewfinder would be the best compromise. If different material is used in the field, we recommend preliminary tests be performed to confirm similar detectability.

Our study confirmed that roe deer, wild boar and red foxes could be effectively detected during night count surveys with thermal imagers, but our detectability was somewhat lower than in other studies (Ward et al., 2004; Franzetti et al., 2011; Focardi et al., 2001). This could be related to the scale encompassed by our survey and the various habitat types crossed, as these other studies focused on one main habitat type (forest).

The difference that we observed in mean detection distance between species might be due to animal behaviour. Red fox and roe deer were more often detected in open areas than wild boar. Our assumption that wild boar would use more grassland areas at this period of the year (Baubet et al., 2009) was not confirmed. The availability of earthworms for wild boar is higher under cold and rainy conditions (Baubet et al., 2003), and the dry weather conditions during our surveys could explain the low number of wild boar detected in open habitats. Observed differences in detection probability between habitat and species, although obvious and largely documented, emphasize the need to take the variations in cover and animal properties into account to estimate animal density with distance sampling. Differences in behaviour and shape between species can have an impact on detectability and therefore prevent inter–species pooling, although such pooling can sometimes be performed for other animal taxa (Oppel, 2006).

We observed that the time of night seemed to have a potential impact on the number of sightings for roe deer, but not for wild boar or red foxes. In comparison, Heydon et al. (2000) found evidence of a time effect on fox sightings numbers, with more observations after midnight. These peaks of activity for a species can vary locally and should be carefully assessed before allocating survey efforts throughout the night. When the monitoring is done from the

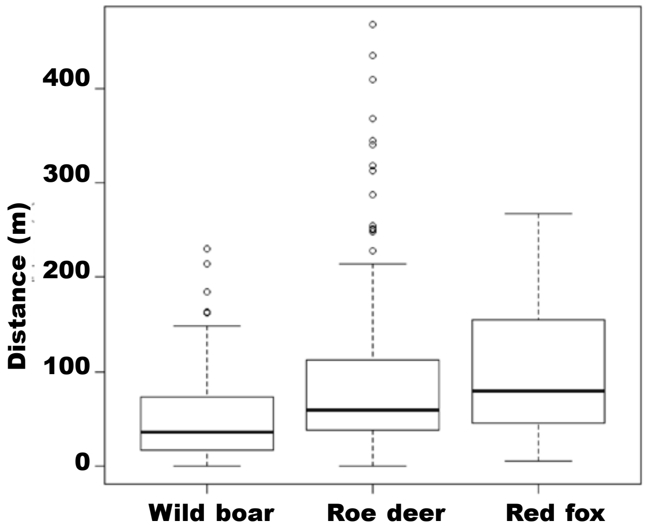

Fig. 4. Box plot of sighting distances for the three surveyed species.

Fig. 4. Diagrama de cajas de las distancias de avistamiento de las tres especies estudiadas.

road, the greater pattern of animal activity may also be the consequence of less traffic between midnight and dawn (Vanhove & Ceuster, 2003).

In previous studies the influence of observers on the detection function showed to impact density estimation (Ringvall et al., 2000). This influence is mostly due to systematic and random errors. In our study we observed differences between observers, highlighting the need to train observers (by means of field trials) before starting the real survey so as to avoid this bias (Franzetti et al., 2011).

In contrast with red fox, most roe deer and wild boar did not show flight behaviour when spotlighted. This confirms that spotlighting has a weak affect on roe deer behaviour during count (Ward et al., 2004; Smart et al., 2004; Gill et al., 1997) although several factors,

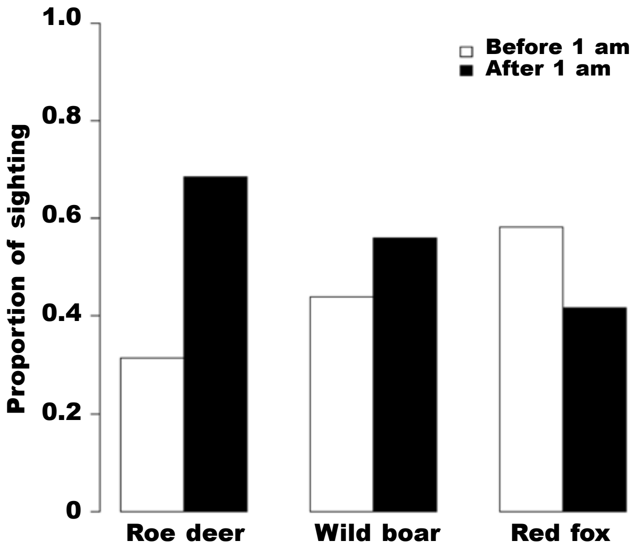

Fig. 5. Effects of time of the night on the number of sightings.

Fig. 5. Efectos del momento de la noche sobre el número de avistamientos.

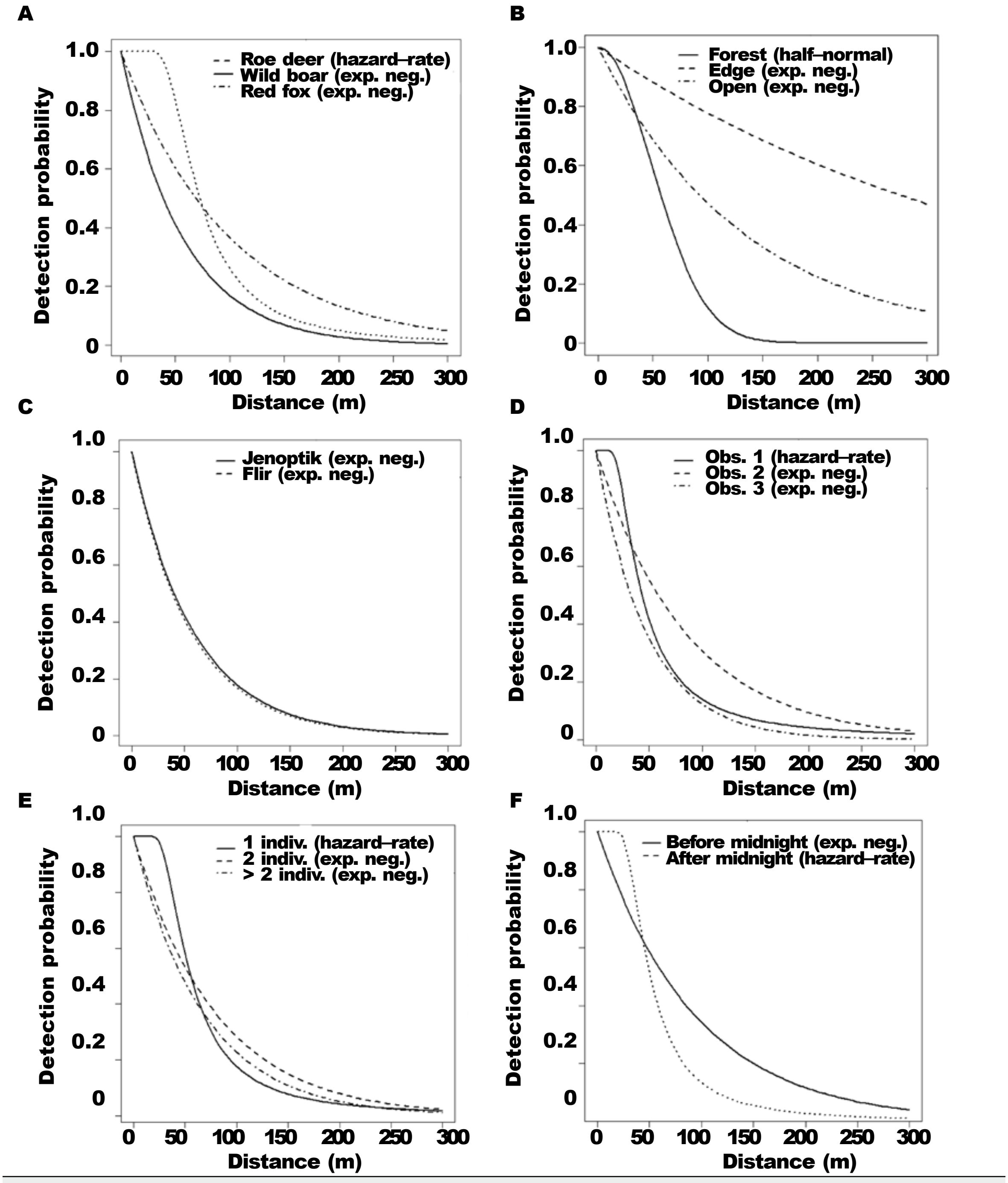

Fig. 6. Detection probability function for (from upper left to lower right) species (A), habitat (B), thermal imager (C), observer (D), group size (E), and time of the night (F).

Fig. 6. Función de la probabilidad de detección para (desde arriba a la izquierda hasta abajo a la derecha): especie (A), hábitat (B), técnica termográfica (C), observador (D), tamaño del grupo (E) y momento de la noche (F).

such as weather conditions and vegetation structure, have been shown to impact roe deer flight distances (De Boer et al., 2004). Wild boar have also showed low reaction to operators walking along transects (Marini et al., 2009), and it has been observed that cars have less impact on animal behaviour than walkers when surveying owl (Manning & Kaler, 2011). We might expect the same conclusion in the case of large mam-

Table 2. Detection probability values for the different covariates tested during the road–based transect survey. Detection probabilities (DP) with the same letter do not vary significantly ($P < 0.05$): [1] Akaike Information Criteria; [2] Effective half–strip widths: distance from the line at which the number of animal detected equals the number of animals missed.

*Tabla 2. Valores de la probabilidad de detección para las distintas covariables estudiadas durante el seguimiento en transectos con base en la carretera. Las probabilidades de detección (DP) con la misma letra no varían significativamente (*P *< 0,05): [1] Criterio de Información de Akaike; [2] Amplitudes efectivas de medio segmento: distancia de la línea en la que el número de animales detectados es igual al número de animales dejados pasar.*

Covariates	Sample size (n)	Model	AIC[1]	ESWH[2] (m)	DP Mean	DP SE
Species						
Wild boar	42	Exp. neg.	90.59	56.1	0.224	0.053[a]
Roe deer	158	Hazard–rate	124.84	88.7	0.351	0.079[b]
Red fox	49	Exp neg.	58.14	94.6	0.313	0.046[b]
Habitat						
Forest	125	Half–normal	135.07	60.9	0.271	0.092[a]
Edge	19	Exp. neg.	39.37	210.6	0.742	0.029[b]
Open	85	Exp. neg.	69.64	119.4	0.354	0.038[c]
Thermal imager						
Jenoptik	144	Exp. neg.	129.49	55.8	0.186	0.042[a]
Flir	105	Exp. neg.	79.44	57.8	0.193	0.043[a]
Observer						
Obs. 1	133	Hazard–rate	95.48	62.2	0.207	0.050[a]
Obs. 2	61	Exp. neg.	61.89	82.1	0.274	0.045[a]
Obs. 3	55	Exp. neg.	57.44	47.7	0.159	0.040[b]
Cluster size						
1	138	Hazard–rate	103.48	72.9	0.243	0.057[a]
2	50	Exp. neg.	70.81	77.6	0.259	0.045[a]
> 2	61	Exp. neg.	96.47	67.0	0.223	0.044[a]
Period of night						
Before midnight	99	Exp. neg.	90.15	89.5	0.30	0.046[a]
After midnight	150	Hazard–rate	140.6	65.6	0.22	0.056[a]

mals accustomed to vehicle sounds. We were unable to find studies that compared motorized and walked transects and found effects on behaviour. Red fox fleeing behaviour has already been reported by other studies (Ruette et al., 2003). High hunting pressure in the study area on wild boar and red fox is likely to motivate flight when disturbed. It is important to note that most flight behaviour occurred after spotlighting and not at the detection time with the thermal imager. This suggests that using a thermal laser rangefinder to measure distances and bearing (instead of spotlight and daylight rangerfinder) may substantially decrease the flight response of animals during count.

Our study design did not allow us to collect sufficient data to estimate the density of the three game species at each site. As no other data on densities were available in our study sites, it remains difficult to know why our methodology did not succeed in collecting sufficient sightings for wild boar and red fox. Was it because the study design was too poor in terms of survey effort? Was it because of the elusive behaviour of these species? Or was it simply because their density was too low in the surveyed sites (Gill et al., 1997)? For further investigations, we suggest parallel studies should be conducted to collect data on abundance for the studied species as this could help to make useful comparisons between methods. Moreover, the low number of wild boar sightings in more open landscape highlights the need for an adapted monitoring design for this species. Increasing the survey effort overall in forest habitat could, for example, favour the number of contacts with wild boar. However, the grouping behaviour of wild boar (Fernández–Llario et al., 1996) decreases the number of detections, and consequently, precise estimates of their population are particularly difficult to calculate. To yield a sufficient number of sightings and adequately estimate population density, we could also improve the design by increasing the number of replicates by site or by increasing the route survey length (with limitation from the road network extent and increase risk of double–counting of animals). Designing the surveys according to weather conditions could also help to increase the number of sightings.

Using roads may also inevitably involve crossing habitats with variable visibility due to edges or topography. Also, the proposed methodology could be improved by adding a determination of the length of the surveyed transects where visibility is obstructed, as achieved by Heydon et al. (2000).

Conclusion

This study is the result of a pilot survey that highlights the limitations and advantages of large–scale multi–species monitoring using thermal imagery and distance sampling. It emphasized the need to develop a design in which covariates that can bias population estimates are taken into account.

Detection probability associated with covariates may play an important role in any counting method and should be taken into account in subsequent density estimation analyses. Road–based distance sampling counts and thermal imagers seem to offer opportunities for detecting and monitoring large game species with patterns of nocturnal activities. However, for more elusive species such as wild boar, a modified monitoring survey should be designed in order to collect sufficient sightings to fit a detection function. As the random placement of transects is not possible, the proposed stratified–random selection method (random selection of suitable transects according to criteria) can help make roads a possibility for large–scale surveys while limiting potentially associated sources of bias. To our knowledge, this study is also the first to compare two types of thermal imager that differ in terms of resolution, portability and cost, and it showed that detectability was similar for both devices, even across highly contrasted habitat conditions. The cost of thermal imaging apparatus has likely prevented wider use of such devices in the field, but now that they are becoming more affordable their use in wildlife ground counts can be expected considering the numerous advantages they offer. However, although such advances may assure robust, valid estimates of animal population size, they will not obviate the need for a well–prepared survey design.

Acknowledgements

This research was supported by the Fonds pour la Formation à la Recherche dans l'Industrie et l'Agronomie (FNRS–FRIA, Belgium). We would like to thank the companies Anatherm SPRL and FLIR Ltd. Particularly Karinna Robe and Jan Delye for the thermography training and the use of the FLIR HS–324 thermal imager. Thanks also to the whole working team, Cedric Geerts, Marie Lebourges, Coralie Mengal, Alain Monseur, Adrien Schot, for their night availability and the good working atmosphere during the field work.

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