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Keywords: abundance/brown hare/Cervus elaphus/Dama dama/deer/density/distance sampling/European rabbit/hare/infrared/Lepus europaeus/Malme/method observation/ Oryctolagus cuniculus/population census/rabbit/red deer/red fox/spotlighting/survey/Sus scrofa/Vulpes vulpes/wild boar

Abstract: Spotlighting (SL) is used widely to estimate animal abundance, but it yields density estimates that are underestimates or biased. Introduction of distance sampling has, to a large extent, contributed to solving these problems, but the reliability of this statistical method depends strongly on sample size. Thermal infrared (TI) imaging may improve number of observations, but very few studies have quantified performance of TI imaging relative to SL. This comparison is relevant because the high cost of a TI device is justified only by a significant increase of observations and a consequent reduction of labor costs. Our objectives were to compare animal detectability by SL and TI imaging as a function of animal size, species (red deer, fallow deer, wild boar, red fox, European rabbit, and brown hare), distance, and season. We also analyzed group size and composition for red deer and effect of grass height on detection of hares and rabbits. On average, TI imaging was more efficient ($P<0.001$) than SL, which detected only 53.8% of the animals observed by TI imaging. This was especially true for wild boar (92.1%), but both devices observed comparable red fox ($P=0.60$) and fallow deer ($P=0.72$) numbers. Relative detectability of the 2 devices was influenced by different factors: for red deer, TI was more efficient than SL in summer and autumn, but not in winter; male groups of red deer were better observed by TI imaging than by SL; and wild boars were better imaged at short (0-100m) distances with TI. Relative effectiveness of both instruments was not influenced by grass height ($P=0.92$). Our results showed that wild boar should only be surveyed using TI imager and that a strong improvement of sample size can be obtained using TI for red deer, brown hare, and European rabbit.

Comparative evaluation of thermal infrared imaging and spotlighting to survey wildlife

Stefano Focardi, Anna M. De Marinis, Maurizio Rizzotto, and Alessandra Pucci

Abstract Spotlighting (SL) is used widely to estimate animal abundance, but it yields density estimates that are underestimated and biased. Introduction of distance sampling has, to a large extent, contributed to solving these problems, but the reliability of this statistical method depends strongly on sample size. Thermal infrared (TI) imaging may improve number of observations, but very few studies have quantified performance of TI imaging relative to SL. This comparison is relevant because the high cost of a TI device is justified only by a significant increase of observations and a consequent reduction of labor costs. Our objectives were to compare animal detectability by SL and TI imaging as a function of animal size, species (red deer [*Cervus elaphus*], fallow deer [*Dama dama*], wild boar [*Sus scrofa*], red fox [*Vulpes vulpes*], European rabbit [*Oryctolagus cuniculus*], and brown hare [*Lepus europaeus*]), distance, and season. We also analyzed group size and composition for red deer and effect of grass height on detection of hares and rabbits. On average, TI imaging was more efficient ($P<0.001$) than SL, which detected only 53.8% of the animals observed by TI imaging. This was especially true for wild boar (92.1%), but both devices observed comparable red fox ($P=0.60$) and fallow deer ($P=0.72$) numbers. Relative detectability of the 2 devices was influenced by different factors: for red deer, TI was more efficient than SL in summer and autumn, but not in winter; male groups of red deer were better observed by TI imaging than by SL; and wild boars were better imaged at short (0–100-m) distances with TI. Relative effectiveness of both instruments was not influenced by grass height ($P=0.92$). Our results showed that wild boar should only be surveyed using TI imager and that a strong improvement of sample size can be obtained using TI for red deer, brown hare, and European rabbit.

Key words brown hare, census, *Cervus elaphus,* Dama dama, European rabbit, fallow deer, infrared, *Lepus europaeus, Oryctolagus cuniculus,* red deer, red fox, spotlighting, *Sus scrofa, Vulpes vulpes,* wild boar

Spotlighting (SL) has been used to study the abundance, sex and age structure, movements and migratory patterns, activity rhythms, distribution, habitat use, and social ecology of deer (Carbaugh et al. 1975, Gunson 1979, McCullough 1982, Wood et al. 1985, Fafarman and De Young 1986). Spotlighting also has been used to locate deer and wild boars (*Sus scrofa*) for capture (Sparrowe and

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Springer 1970, Fournier et al. 1995) and to study the ecology of red fox (*Vulpes vulpes*; Stahl 1990, Weber et al. 1991) and hares (*Lepus* spp.; Smith and Nydegger 1985, Kovacs 1986, Langbein et al. 1999).

Thermal infrared (TI) imaging is a seldom used but promising technique that has been used to survey wildlife in large-scale field studies (Garner et al. 1995, Havens and Sharp 1998). Only recently, this technique was applied to aerial and ground surveys of several species of deer and hares (Wiggers and Beckerman 1993, Boonstra et al. 1994, Gill et al. 1997).

These techniques yield underestimated and biased density estimates because 1) some animals are not detected and 2) detectability changes as a function of environment. The introduction of distance sampling (Buckland et al. 1993) has to a large extent contributed to solving these problems. However, reliability of density estimates from distance sampling depends strongly on sample size. Gill et al. (1997) was the first to obtain distance sampling estimates of several deer species (red deer [*Cervus elaphus*], fallow deer [*Dama dama*], roe deer [*Capreolus capreolus*], muntjac [*Muntiacus reevesi*], and sika deer [*Cervus nippon*]) using a portable infrared imager. However, the high cost of a TI device is justified only by a significant increase of observations and a consequent reduction of labor costs. Despite the potential of applying TI imaging to assess animal abundance, there are few studies quantifying performance of TI cameras relative to other methods (Naugle et al. 1996). We expected the performance of TI imaging to be a function of the studied species and environmental features. Therefore, our objectives were to compare animal detectability by SL and TI imaging as a function of animal size, species, detection distance, season, group size and composition (only for red deer), and grass height (only for lagomorphs).

Study area

We conducted our study in La Mandria Regional Park (1,345 ha), hereafter park, located 10 km north of Torino, Italy (45°10'N and 4°54'W), ranging from 254 to 402 m a.s.l. Permanent meadows were the most prevalent habitat type (42.3%). Most of the forested areas were secondary forest (32% of the park) dominated by red oak (*Quercus rubra*), sessile oak (*Q. petraea*), sweet chestnut (*Castanea sativa*), smoothed-leaved elm (*Ulmus minor*), common alder (*Alnus glutinosa*), and false acacia (*Robinia pseudacacia*). Remnant forest represented only 13% of the park and was dominated by a *Querco-Carpinetum* community (English oak [*Q. robur*], sessile oak, hornbeam [*Carpinus betulus*], common ash [*Fraxinus excelsior*], small-leaved lime [*Tilia cordata*], and Norway maple [*Acer platanoides*]), with an undergrowth of hazel (*Corylus avellana*) and spindle-tree (*Euonymus europaeus*). The remaining area of the park was covered by moor (6.4%, heather [*Calluna vulgaris*] and purple moor-grass [*Molinia coerulea*]), agricultural areas, settlements, and pens for livestock (6.3%).

Mean rainfall was 961.4 mm (minimal in January, 37.9 mm; maximal in May, 124.9 mm); mean temperature was 12.4°C (minimal in January, 1.7°C; maximal in July, 22.8°C; Cagnazzi and Marchisio 1998).

We studied red deer, fallow deer, wild boar, brown hare (*Lepus europaeus*), European rabbit (*Oryctolagus cuniculus*), and red fox. Red deer were hybrids of *Cervus elaphus* × *C. e. canadensis* imported from Wyoming (USA) in 1865. Fallow deer were from a group of animals escaped from a paddock in 1988. Wild boar (now hybridized with domestic pig) were introduced in 1975.

Methods

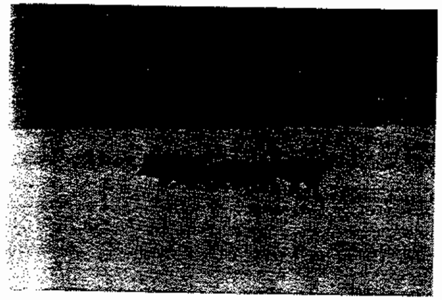
Equipment

We conducted SL surveys using 2 observers in a motor vehicle (5 km/hr) equipped with an 800,000-candlepower spotlight. We used binoculars (8 × 30 and 10 × 40) to facilitate animal identification.

We conducted TI surveys using a Galileo Unit for Fauna Observation (GUFO) manufactured by Galileo S.p.A. (Campi Bisenzio, Firenze, Italy). We used 2 lenses with magnification of 5X and 30X. This device resolved temperature differences of 0.2°C with a temperature range of –5°C to 100°C. The device required liquid nitrogen as a coolant, and power was supplied through a 12-volt battery set that lasted approximately 2 hours. We had 2 sets available, with a recharging time of 12 hours. We mounted the GUFO on a van to conduct surveys. We viewed images on a television monitor and recorded them on a VHS tape.

Data collection

During 1997, we conducted 2 experimental surveys each in summer (4 and 11 July), autumn (10 and 24 October), and winter (12 and 22 December)



Thermal infrared image of a female wild boar with a group of 5 subadults in La Mandria Regional Park, Italy, winter 1997. The image shows that it is possible to distinguish among age classes.

Thermal infrared image of a female fallow deer (note the rump patch) in La Mandria Regional Park, Italy, winter 1997. The image demonstrates that animals can be observed even behind vegetation. During the night branches appear much cooler than animal's body.

on a 19.3-km standard circuit along park roads. We began observations one hour after sunset, and 5–6 hours were necessary to complete the circuit. To insure similar conditions for both devices, we conducted surveys using both methods during the same night. We conducted the TI survey first, followed by the SL survey within 15 minutes. We expected that number of animals potentially available for observation was the same for both devices. Our vehicle was very similar to vehicles driven within the park, and because park animals are familiar with them, we assumed no disturbance effect. However, we also tested for such effect by comparing number of animals seen during experimental SL surveys (i.e., when the TI imager also was used) with control SL surveys (conducted without TI imager). We conducted control SL surveys under weather conditions similar to those of the experimental SL surveys and within a 2-week lapse. We conducted 11 control SL surveys in 1997: 4 in summer (21 and 30 June, 19 and 26 July), 5 in autumn (24 September; 4, 18, and 31 October; 8 November), and 2 in winter (5 and 20 December).

Thermal infrared image of a group of male red deer in La Mandria Regional Park, Italy, winter 1997. Note that the antlers of the 2 closest animals can be seen even though they have no velvet.

We classified observed animals by species and number of individuals/group. In addition, we distinguished 3 group types of red deer: male only, female and young only, and mixed (male, female, and young). We recorded sightings of all animals on a 1:5,000 map. Red deer classification was aided by relative body size, general appearance, and gait (Gill et al. 1997). We did not record the few cases where it was not possible to surely distinguish red from fallow deer.

Meadows ranged in size from 0.04 to 0.75 km^2. To evaluate effect of grass height on lagomorphs counts, we randomly selected 24 plots within meadows. Each plot had 2 orthogonal transects (10 m long) oriented north-south and west-east. We measured grass height along the transect every 20 cm, using a wooden rule with a precision of one cm. For convenience, we recorded average grass height of plots into 3 classes: ≤10 cm, 11–20 cm, and >20 cm. We surveyed monthly the same set of 24 plots during our study. We conducted analyses on a meadow-by-meadow basis. We associated each lagomorph sighting with a grass-height class, considering 1) the meadow where the observation occurred and 2) the grass-height measurement closest in time. If the meadow has been mowed between the grass-height measurement and the survey occasion, we assigned the least grass-height class to the lagomorph observation.

Table 1. Median number of animals observed by spotlight (SL) in experimental (n = 6) and control (n = 11) surveys, in La Mandria Regional Park, northwestern Italy, 1997.

Species	Experimental[a]	Control[b]	Wilcoxon Test (P)
European rabbit	5.0	4.0	0.720
Brown hare	4.0	5.0	0.840
Red fox	16.0	18.0	0.610
Wild boar	4.5	28.0	0.006
Fallow deer	8.5	13.0	0.220
Red deer	102.5	111.0	0.290

[a] We conducted experimental SL surveys with thermal infrared (TI) surveys.

[b] We conducted control SL surveys within 2 weeks of the TI survey.

Table 2. Number of animals/species recorded by spotlight (SL) and thermal infrared (TI) imager and percentage of underestimation (U) by SL from 6 surveys in La Mandria Regional Park, northwestern Italy, 1997.

Species	SL	TI	P	U
European rabbit	20	51	<0.001	60.8
Brown hare	29	89	<0.001	67.4
Red fox	116	105	0.600	–10.5
Wild boar	38	481	<0.001	92.1
Fallow deer	49	54	0.720	9.3
Red deer	563	983	<0.001	42.7

Data analysis

We stored and analyzed spatial data using geographical information systems (ARC/INFO 7.2. ESRI 1995; ARCVIEW 3.1, ESRI 1996). We digitized the road network and animal sighting coordinates and calculated the minimum distance between sighting points and the survey circuit. We classed detection distances as ≤50 m, 51–100 m, 101–150 m, 151–200 m, or >200 m.

We usually performed data handling and statistical procedures by SAS (SAS Institute 1988). We compared median number of animals observed with control and experimental SL surveys using the Wilcoxon 2-sample test (Z approximation).

We estimated underestimation (U) of number of animals observed for SL compared to TI by

$$U = 100\left(1 - \frac{\text{number of animals observed by SL}}{\text{number of animals observed by SL}}\right).$$

Note that negative U values indicate that we observed more animals with SL than with TI. For some hypotheses, we grouped species according to size. We considered red and fallow deer as large; wild boar as medium; and European rabbit, brown hare, and red fox as small. We also tested whether species of similar size were observed at the same distance from the road by the 2 devices using the Wilcoxon 2-sample test. We tested the null hypothesis that the 2 devices detected the same number of animals using a Binomial test assuming equal probability ($p=q=0.5$, SPSS 1998).

After normalization by Blom's score, the comparison of factors that we expected to influence effectiveness of the 2 devices (season, distance and group type, for red deer only) was performed by a nested ANOVA model where effect of distance was evaluated within group type, season and device, effect of group type within season and device, and effect of season within device. At each hierarchical level, the sum-of-squares for the dependent variable was computed within the factors that preceded it in the model and corrected for the factors that followed it. Thus, the between-device comparison was corrected for the effect of other independent variables. We used a Type III sum-of-squares because variable classes were unequal in size. For red deer, we tested whether the 2 devices recorded the same number of groups (Binomial test) and the same median group size (Wilcoxon 2-sample test). Males in velvet appeared very conspicuous because vascularization of antlers produced an intense heat emission. We tested the hypothesis that presence of velvet may increase detectability of male red deer by TI using a 2-tailed Fisher's Exact test, comparing number of males with number of females and young. We considered 2 sets of data: the summer set (when antlers have velvet) and the set including data from the rest of the year (when antlers are bare). If the ratio males/females and young was similar, we concluded that velvet had no relevance in animal detectability. We analyzed influence of grass-height classes on detectability of lagomorphs with a chi-square test. All tests were considered significant at $\alpha=0.05$.

Results

Number of animals observed during experimental and control SL surveys did not differ significantly ($P=0.22$), except for wild boar ($P=0.006$, Table 1), which were less detectable during experimental SL surveys.

Thermal Infrared Imaging was more efficient than SL ($P<0.001$, average $U=53.8$ %). The TI imager was significantly more efficient than SL for all

body-size classes (small size, $U=32.7$, $P<0.001$; medium, $U=92.1$, $P<0.001$; large, $U=41.0$, $P<0.001$).

Within the 3 small size species, red foxes were always observed farther from roads than lagomorphs for TI (red foxes, median = 84 m; lagomorphs, median = 64.5 m, $Z=3.9$, $P<0.001$) and for SL (red foxes, median = 78.3 m; lagomorphs, median = 47.7 m, $Z=2.3$, $P=0.02$). We also detected a difference between sighting distances of deer groups between red and fallow deer for TI (red deer, median = 106.3 m; fallow deer, median = 85.7 m, $Z=2.6$, $P=0.008$) and for SL (red deer, median = 127.5 m; fallow deer, median = 96.4 m, $Z=2.1$, $P=0.03$), the latter species closer to roads.

Red fox ($P=0.60$) and fallow deer ($P=0.72$) were detected similarly by both devices, whereas red deer ($P<0.001$), brown hare ($P<0.001$), and European rabbit ($P<0.001$) were underestimated by SL (Table 2). We did not further consider red fox and fallow deer because there were no between-device differences. The strong difference between the 2 devices for wild boar (Table 2) may have been influenced by our experimental conditions because we showed that experimental SL counts were biased low for this species (Table 1). However, a significant between-device difference remained if we compared control SL and TI counts (average U = 67.1%, $Z=3.3$, $P=0.001$), which suggests that wild boar were better detected by TI than by SL.

Device influenced detectability of red deer (P = 0.04). Both season ($P=0.03$) and group type (P = 0.002) affected detection by the 2 devices, but not distance ($P=0.28$). Number of red deer groups detected by TI was greater than SL in summer (P< 0.001) and autumn ($P<0.001$) but not in winter (P = 0.54). Considering separately the 3 kinds of group (male, female, and mixed), number of animals observed by TI imager was greater than SL for male ($P<0.001$) and mixed ($P<0.001$) groups, whereas no difference was found for female groups (P = 0.73). Greater detectability of male groups resulted from larger number of groups detected by TI imager ($P=0.02$) and not from median group size (P = 0.11). However, number ($P=0.20$) and size (P = 0.58) of mixed groups were similar for the 2 devices. We found no variation in male detectability using TI ($P=0.23$) in the ratio between number of males and number of females and young, comparing velvet and nonvelvet periods.

Number of boar sightings was affected by survey device ($P<0.001$) and distance from road ($P=0.02$). Device type explained 60.2% and distance from road 23.8% of total variance. The greatest difference in detectability between the 2 devices was in the 51–100-m distance class.

Device type ($P<0.001$) influenced detectability of lagomorphs. The ratio between number of animals observed in the 3 grass-height classes did not differ for the 2 instruments ($\chi^2_1=0.01$, $P=0.92$).

Discussion

Our experiment did not allow us to evaluate absolute performance of the 2 sighting methods (i.e., which fraction of the population can be detected) but only to evaluate their relative performance to quantify potential improvement in sightability with TI relative to SL. Number of animals seen by the TI imager was much greater for most of the studied species (except red fox and fallow deer). Naugle et al. (1996) found similar results when comparing reliability of SL surveys and aerial surveys with a TI sensing system to detect white-tailed deer (*Odocoileus virginianus*).

Despite a similar size, red fox and lagomorphs were detected with a different effectiveness by the 2 devices. Our results suggest that foxes seem to avoid those parts of a meadow closer to the road and, in so doing, they remained in a range of distance (>100 m) where the performances of SL and TI were similar.

Spotlight strip-counts in open areas are perhaps the most widespread method to assess population density and trends of brown hare (Langbein et al. 1999). Such counts are preferentially performed in winter, when grass is short, assuming almost perfect visibility. However, our findings showed that lagomorphs were underestimated by SL relative to TI. This observation casts some doubts on reliability of SL strip-counts.

Deer species showed a different relative detectability with the 2 devices: red deer were underestimated by SL, whereas no difference was recorded for fallow deer. Fallow deer on our area were observed much closer to the roads than red deer, possibly due to their being more comfortable with roads because they are from semi-domestic stock. Under these specific conditions, SL performs quite well for fallow deer, while its performance decreases with the wilder red deer mainly observed in the more remote areas of the park.

More intriguing is the between-device difference in relation to the group type in red deer.

Underestimation of number and size of male groups by SL may be related to a sex-specific behavior, such as a greater mobility of male groups. This may indicate SL is not effective to assess sex structure of deer populations.

The difference between the 2 devices for detectability of wild boar may be explained by the lack of a well-reflecting *tapetum lucidum* in the eyes of this species, which reduces its visibility with SL. We cannot say why wild boars are so rare in SL counts associated with TI surveys, because the hypothesis that these animals are disturbed by the moving van appears quite unlikely. However, even comparing TI with control SL surveys, we found a sharp improvement in detectability of wild boar.

In general, the TI camera did not seem more efficient than SL at long distance, as one may expect.

Management implications

In conclusion, wild boar should be counted only with TI devices, and a strong improvement of sample size would be expected using TI for red deer, brown hare, and European rabbit. Presence of red fox and fallow deer on our area may be assessed using SL or TI. We expect that using TI cameras may improve results of distance sampling surveys. TI also may increase the power of a regression analysis in trend detection by reducing the sampling variance. which is inversely proportional to sample size. Several conditions influenced effectiveness of the 2 devices in the park so that the extrapolation of these results to other areas must be carefully evaluated. Pilot studies may help in deciding the convenience of adopting a TI imager under specific environmental conditions. Also, our results suggest strongly that behavioral differences (e.g., between red fox and lagomorphs or between male and female red deer) are relevant in determining animal detectability during TI surveys.

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