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Title

Improving daytime detection of deer for surveillance and management

Abstract

1. Maximising the detection of a target species reduces uncertainty of survey results and can improve management outcomes. Deer (Cervidae) populations are managed worldwide due to their impacts on anthropocentric interests. In the UK, deer can only lawfully be shot during the daytime, from one hour before sunrise to one hour after sunset, when deer activity is at its lowest. We evaluated performance of a thermal imager relative to binoculars for their ability to detect deer during the daytime and at twilight (one hour either side of dawn and dusk).
2. Transect surveys on Thorne Moors, UK, revealed that more roe and red deer were observed using a thermal imager than when using binoculars. More deer and in much larger groups were observed at twilight than during the other daylight hours.
3. Variation in animal detectability at different times of the day must be considered during wildlife surveys if their outputs are to be as accurate and precise as possible.
4. The results support the continued focus of deer culling efforts during the hours of twilight. They also highlight the potential utility of thermal imagers for maximising detection probability at twilight.

Key-words:

Cervus elaphus, *Capreolus capreolus*, binoculars, detection, survey, thermal imager

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Compliance with ethical standards

All procedures were performed in accordance with the ethical standards of the University of Hull. Ethical Review reference U151.

Introduction

Accurate estimates of animal occupancy and population size depend on high detection probability (MacKenzie *et al.* 2002; Field *et al*. 2007; Petrovan *et al*. 2011), yet many wildlife surveys suffer low detection rates (Legg and Nagy 2006), leading to elevated uncertainty (Nichols 2019). Detection can be impacted by animal behaviour; animals that are crepuscular or nocturnal can be more difficult to detect than those active during the daytime (Jiang *et al*. 2008). Consequently, technology, including artificial light, night vision and thermal imagery, has been employed to improve the detection of wild animals at night, (Gill *et al*. 1997; Allison and Destefano 2006), resulting in significant improvements in the accuracy and precision of population estimates derived from field surveys (Smart *et al*. 2004). However, daytime surveys have been used (Fragoso *et al*. 2016) and even advocated by some researchers (Vincent et al. 1991; Trenkel et al 1997), and in our experience, such surveys are often preferred by land managers. Nevertheless, the relative performance of technologically-supported surveys during the hours of daylight and the hours of darkness has not, to our knowledge, been evaluated.

Much of the focus of surveys for wild deer (Cervidae) has been to support their management (Smart *et al*. 2004). Deer populations are often culled to control their impacts on anthropocentric interests (Putman and Moore 1998). Thermal imagery has been used extensively to survey wild deer at night (Gill *et al*. 1997; Focardi *et al*. 2001; Wäber *et al*. 2013) since hunted populations tend to be crepuscular or nocturnal (Beier and McCullough 1990; Meng *et al*. 2002). However, its use for management by most hunters has only recently become feasible due to declining costs and improving functionality. Nevertheless, costs of hand-held thermal imagers suitable for hunting are currently comparable to the costs of high-end rifle telescopic sights, so substantial enhancement of deer detection, leading to improved culling efficiency, is required to justify investment.

Across much of Europe deer may be hunted at night (Putman *et al*. 2011a), but in the UK primary legislation limits their lawful shooting to the daytime only. The Deer Act 1991 requires that no deer may be shot between one hour after sunset until one hour before sunrise. To control or reverse the continuing growth and spread of British deer populations (Ward 2005; Matthews *et al*. 2018) and hence their impacts on anthropocentric interests, deer managers may benefit from enhanced deer detection rates during the daytime.

We sought to identify times of day when deer detection rates were at their highest and compared the daytime deer detection performance of a thermal imager with the more traditional use of binoculars so that researchers and managers alike can make informed choices about technological aids and times of day when planning deer surveys.

Materials and Methods

Transect surveys for red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) took place on Thorne Moors, UK (53.636654, -0.898764) from 21/02/2018 to 14/03/2018 between the hours of 05.00 and 19.00. The site is a National Nature Reserve of approximately 19km^2, managed for its nationally and seasonally important populations of water birds, but with significant areas of scrub and deciduous woodland.

Transects were approximately 500m in length, with at least 1km between the end of one and the start of the next to avoid double-counting deer fleeing between transects and hence to avoid pseudo-replication (Focardi *et al*. 2002). Each transect was surveyed on foot eight times; twice with binoculars (10x50 magnification, SkyGenius, Massachusetts, USA) and twice with the thermal imager (FLIR BHS-XR, FLIR Systems, Inc., Oregon, USA) during each of the hours of daylight (between sunrise and sunset) and at twilight (the hour before sunrise and after sunset). The thermal imager was chosen since it is an older model with a lower specification than many more recent products, but which nevertheless had a sensitivity of 30mK. The choice to start a survey with binoculars or thermal imager was decided by a coin toss, with the subsequent survey of the same transect conducted with the other detection method. A period of at least 24 hours was maintained between surveys of the same transect. Data collected were species, number of groups detected, number of animals per group and time of day.

To compare the detection of deer between detection methods (1 = binoculars and 2 = thermal imager) and time of day (either as a covariate: the absolute number of hours from 07.00 or the signed number of hours from 07.00, or as a binary factor: 1 = daylight and 2 = twilight), general linear mixed models (GLMMs) with a Poisson distribution and a log link function were fitted to the count data (Zuur *et al*. 2007) using R package "lme4" (Bates *et al*., 2014). Separate models were built for each deer species and when detections were summarised as number of deer groups per transect and number of individuals per transect. 'Transect' and 'date sampled' were fitted as random effects and 'detection method' and 'time of day' as fixed effects, including an interaction effect. Model fit was evaluated by visual examination of residuals versus fitted values, which is one of many accepted quality assurance procedures (Zuur et al. 2007; Harrison et al. 2018). All statistical analysis was performed in R 3.4.4 (R Core Team, 2018).

Results

In total, 63 roe deer and 463 red deer were observed in groups of 1-6 (median = 1) and 5-187 (median = 12) respectively at a mean of 1.64 roe deer and 7.68 red deer per km surveyed. Air temperature varied little during the study, from -0.4ºC to 7.7ºC. Sunrise occurred at approximately 07.00 and sunset at approximately 17.30.

In no model was time of day, when entered as a covariate, associated with the number of deer detected ($P<0.001$ in all cases), so it was included as a binary variable only during subsequent models. However, the total number of deer and number of deer groups detected was considerably higher during twilight than during the hours of daylight for both species (Fig 1 and Table 1), but was of marginal significance ($p = 0.069$) for red deer groups. Time of day and detection method had an interaction effect, with number of deer and number of groups detected higher at twilight using the thermal imager than using binoculars, apart from detection of red deer groups, which was not discernibly different, whether using binoculars or thermal imager. More roe deer were detected with the thermal imager than with binoculars during daylight hours, but this result did not extend to red deer (Table 1).

Discussion

More deer were observed using the thermal imager than with binoculars, especially at twilight. This is unsurprising, since this technology was developed to enhance detection rates of heat-emitting objects. However, while thermal imagery has traditionally been used to survey deer at night (Gill *et al*. 1997; Wäber *et al*. 2013), we have demonstrated that deer may be more easily detected during the daytime, particularly around dawn and dusk, but also that roe deer may be more easily detected during the hours of daylight.

Higher detection rates at twilight was somewhat surprising because deer are actively culled on farmland around the study site at this time, but there is currently no culling of deer on the nature reserve. It is nevertheless consistent with the crepuscular/nocturnal behaviours expressed by deer in hunted populations, and those exposed to high predation pressure (Hewison, *et al*. 2001; Benhaiem, *et al*. 2008; Jiang *et al*. 2008).

Variation in gregarious behaviours across different times of the day by red deer, as observed in Scotland (Mitchell *et al*. 1977) caused the lack of difference in the number of red deer groups detected despite the higher number of individual deer observed at twilight. Red deer simply formed fewer, larger groups at twilight. Differences in behaviour and hence detectability at different times of day have important implications for wildlife surveys, since high detectability is required for accurate estimates of a species' occurrence and population size (MacKenzie *et al*. 2002; Nichols 2019). Moreover, users of the results of wildlife surveys should also consider the consequences of these sources of variability in detection. Increasingly, researchers seeking to estimate wildlife distribution and abundance patterns use third party data, often produced during surveys undertaken by amateur surveyors (Horns *et al*. 2018; Massimino *et al*. 2018). Surveys that are not designed to account for, or take advantage of, variation in detectability within and between species risk mis-estimating species occurrence and abundance, with errors being perpetuated or amplified in modelled outputs (Legg and Nagy 2006).

In countries where the shooting of wildlife at night is lawful and considered acceptable by society (see Putman *et al*. 2011a), thermal imagers offer the clear advantage of detecting animals while the observer remains concealed by darkness. However, even in more restrictive countries such as the UK, thermal imagers offer tactical advantages over binoculars. We have demonstrated that during twilight, when deer can lawfully be shot, the number of deer and roe deer groups detected was significantly higher using the thermal imager. In a management context, this could translate as more shooting opportunities per day, or a higher probability of at least one successful shooting opportunity per day. While it is illegal to use thermal imaging telescopic rifle sights to shoot deer in the UK, a hand-held thermal imager can lawfully be used at any time of the day or night. It is thus conceivable that thermal surveillance of land for deer during the hours immediately before they can lawfully be shot could inform the deer manager on whether they should remain in position to await twilight or should move to a different location where deer are detected. Either way, thermal imagers offer significant potential for improving the culling efficiency of deer populations, at a time when their distributions and abundances (Matthews *et al*. 2018) and hence probably their impacts too (Putman *et al*. 2011b) have never been greater.

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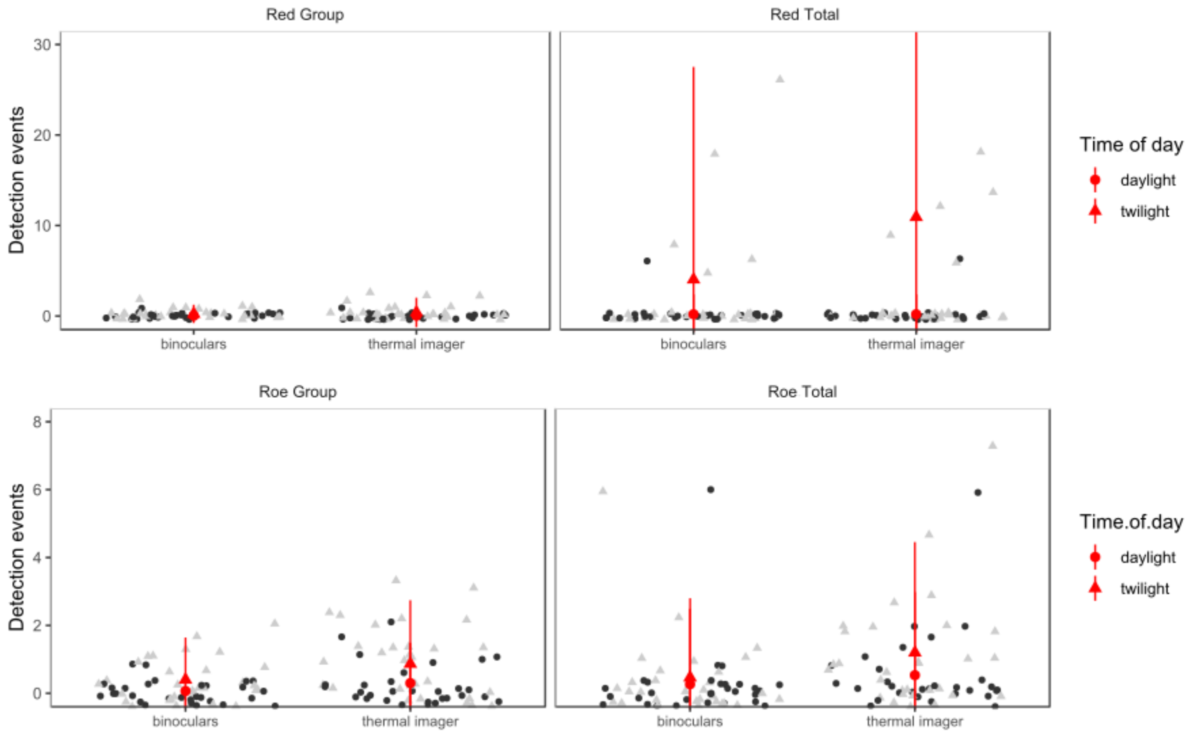

Fig 1 Number of deer detection events per transect, for groups of red and roe deer and total individuals, using binoculars and thermal imaging cameras. Mean values are in red with bars showing the standard deviation.

Table 1 GLMM outputs. Number of deer or groups of deer as response variables with sampling time and method as fixed effects including an interaction effect denoted by *. All means are relative to the intercept (Day and binoculars) and p-values denote statistical significance (<0.05) in bold. Confidence intervals are presented to 2 decimal places, so their limits may appear no different for coefficient estimates with low uncertainty.

	Total red deer			**Red groups**			**Total roe deer**			**Roe groups**		
Predictors	*Coefficient (log-mean)*	*95% CI*	*p*	*Coefficient (log-mean)*	*95% CI*	*p*	*Coefficient (log-mean)*	*95% CI*	*p*	*Coefficient (log-mean)*	*95% CI*	*p*
Day/binoculars (intercept)	-10.80	-16.05 – -5.55	**<0.001**	-4.40	-6.81 – -1.99	**<0.001**	-1.95	-1.95 – -1.94	**<0.001**	-2.91	-4.35 – -1.46	**<0.001**
twilight	2.20	1.32 – 3.07	**<0.001**	1.95	-0.15 – 4.04	0.069	0.59	0.58 – 0.59	**<0.001**	1.79	0.29 – 3.29	**0.019**
Thermal imager	-1.17	-2.35 – 0.01	0.053	-0.00	-2.77 – 2.77	1.000	0.76	0.76 – 0.76	**<0.001**	1.50	-0.03 – 3.04	0.054
Twilight*thermal	2.56	1.33 – 3.79	**<0.001**	0.54	-2.38 – 3.46	0.718	0.29	0.29 – 0.30	**<0.001**	-0.73	-2.41 – 0.95	0.393