Day or night? Testing thermal imaging technology for estimating ungulate population densities in southern Sweden

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Day or night? Testing thermal imaging technology for estimating ungulate population densities in southern Sweden.

Dag eller natt? Utvärdering av värmebildskikare som redskap i täthetsuppskattningar av klövvilt i södra Sverige.

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Abstract

To be able to make a proper judgement and choose the best management or conservation solution when working with populations of wild ungulates or any other wildlife, it is important to obtain good estimates of population densities. Inventing or improving wild animal monitoring methods is a key to protect what may be endangered or to avoid human-wildlife conflicts. That thought has inspired me to test an advanced, modern equipment to investigate whether upgrading traditional point transect monitoring method by using a thermal imaging device and conducting the observations during the night will show a potential to become more implemented in wildlife monitoring. For my study location I have chosen Öster Malma area in southern Sweden. I decided to focus on ungulates, with fallow deer being the main target. Night observations with thermal imaging binoculars Pulsar Merger LRF XP50 were compared with day observations with day optics binoculars Minox X-range 10x42. Collected data were also compared with data from dung counts conducted through other projects in the same study area. I have specifically tested four hypotheses: more animals in general and more different species will be observed during the night observations than during day observations; fallow deer will be the most spotted species; there will be a correlation between data collected during my observations and the dung counts and; that the density estimates from the night observations will be more accurate than the ones based on day observations. The results confirmed that there were more successful observations during the night observations. Fallow deer occurred to be the most spotted species in the area. There was a correlation between data from dung counts and data from day and night point transects observations and this correlation occurred to be stronger with the day observations than with the night observations. Surprisingly the density estimates, for the average number of clusters, after distance sampling analysis in R was similar for both day and night observations, but overall the estimates are more accurate for the data from night observations. In general, the findings support that implementing night wildlife monitoring with usage of thermal imaging technology can improve monitoring methods and provide more detailed information.

Keywords: monitoring, ungulates, thermal imaging, population density, distance sampling, *Dama dama*

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Abbreviations

AIC	Akaike's Information Criterion
GoF	Goodness of Fit
LRF	Laser Range Finder
SLU	Swedish University of Agricultural Sciences

1. Introduction

1.1 Increasing ungulate populations in Europe

Ungulates are the major group of large mammalian herbivores living on earth nowadays. There are a lot of different ungulate species all over the world and they have an impact on almost all existing terrestrial biomes (Putman, 1996).

In Europe, ungulate numbers have increased and their ranges expanded very much lately. The reasons of that increment are partly species translocations, reintroductions and well-adapted harvesting strategies (Ferretti & Lovari, 2014). Another factor that has a key role in ungulates increment in Europe is the fact that humans are using lands much more intensively and the way that for example forestry or agriculture is managed more advanced today. These actions have created new suitable habitats and easily accessible food sources for animals (Presley et al., 2019). The phenomenon of increasing ungulate populations can bring advantages, as it provides ecosystem services like wildlife watching or hunting, but big numbers of ungulates can also become the reason of human-wildlife conflicts, as increases in ungulate populations may cause very strong grazing and browsing pressures, influencing agriculture and forestry, and disease transmissions to livestock or ungulate-vehicles collisions (Reimoser & Putman, 2011; Carpio et al., 2021). As both increases and decreases in wildlife populations may lead to large changes in the ecosystems or conflicts it is very important to monitor the numbers of wild animals and their impact on environment.

Ungulates have a strong impact on vegetation, which in-turn influences ecosystem processes such as energy flow or nutrient cycling that can lead to cascading effects on other wildlife like invertebrates or birds (Moe et al., 2018). Two of the main reasons of conflicts between ungulates populations and humans are ungulates' adverse impact on crops and timber (Bleier et al., 2012) and Sweden is a good example of these conflicts appearing. In Sweden, where the landscape is intensively managed by forestry and agriculture, such conflicts often appear, resulting in a strong incentive to put significant efforts into wildlife monitoring in this country.

1.2 The reasons for and challenges of wildlife monitoring

There are many reasons why we should monitor populations of wild animals. The population can be an important game species, actual or potential invasive or pest species, a species that is or may become threatened or endangered. It can be also needed to get to know biological diversity and follow changes and the impact of management actions in selected areas (Caughley, 1977).

A proper density estimation of a wildlife population is challenging and it demands time and resources. Often that kind of data is expected from the scientists or wildlife managers to be found in a short time and at the lowest possible costs. However, managers and researchers need to face many logistical problems, and the biology and behaviour of the species of interest may be poorly studied or influenced by intensive human activity. That is why wildlife populations monitoring methods should be constantly tested, upgraded and validated (Witmer, 2005).

Many species of mammals are difficult to monitor because of their covert habits, small size or bleak body colouring (Engeman & Witmer, 2000). In addition, many of these animals are spending daylight hours in dense, closed habitats or are nocturnal and show up on the open areas only at night (Tracey et al., 2005).

Wildlife monitoring is crucial for undertaking proper conservation and management actions (Nichols & Williams, 2006). Sustainable use of natural resources, data-based management decisions and conservation activities are built upon assumptions that the deterioration in resources and populations can be noticed in the right moment. The accuracy of the data and time optimization are essential to make sure that the right decision is made on time. Modern technologies significantly interfere in humans' relation with wildlife as thanks to them we are able to follow and analyse many aspects that were difficult to be monitored before. That can have a big impact on chosen and implemented types of conservation policies (Büscher, 2016). That is why improving and developing new census methods with usage of new available technologies is so important (Díaz et al., 2020).

1.3 Wildlife monitoring methods

There are many indirect monitoring methods, meaning that they do not rely on direct contact (hearing or seeing) with the animals, but instead are based on some kind of sign confirming animal presence, such as: faecal counts, runway counts, track stations, burrow counts, responses to audio calls or snow tracks. In case of direct monitoring, i.e. "straight" contact with monitored animals, we can think about for example direct day or night observations of individuals, transect and plot surveys, removal or mark-recapture methods (Engeman & Allen, 2000). In the last years, technology has developed rapidly, giving scientists new tools that allow collection of more detailed data even in difficult conditions like for example dense, bushy habitats or during periods with limited light, such as close to dusk or dawn and during the night. Examples of the latest technologies are: GPS devices, electronical tags and radio collars, camera traps, drones, and night vision thermal imaging equipment (Pimm et al., 2015).

When developing new methods for wildlife monitoring it is important to try to assure the quality of the estimates provided, for example by comparing with already established methods, such as dung counts conducted on the same locality.

1.4 Thermal imaging – the technology used in this study

Thermal imaging, originally developed by the military for detecting and identifying enemy equipment and personnel, is nowadays also used for many civilian purposes, such as firefighting activities, surveillance, police work, border patrols work, medical, construction or industrial applications and environmental work like monitoring for energy conservation or control of pollution (Havens & Sharp, 2015).

Thermal imagers are infrared radiation detectors which can be used to achieve non-contact thermal mapping of any object, system, device or animal that emits heat - infrared radiation. Simply put, thermal imaging is the process of converting IR - infrared radiation – heat, into visible images that can present the spatial distribution of differences in temperatures in the scene observed by a thermal device (Havens & Sharp, 2015).

When planning a survey with usage of thermal imaging devices, it is important to take into consideration different processes that can have an impact on the radiative component of heat coming from the observed animal and from the background that it is compared to. The real temperature of the background is actually not as crucial as the difference in temperature between the animal and the background. There are many factors that can influence the significance of the background radiation. It can be affected by weather conditions, location, the direction of observation relative to the surface of the earth, altitude or time of the day (Havens & Sharp, 2015).

Many animals are poikilothermic (exothermic), which means that their body temperature is gained from or lost to the heat from the environment, rather than the heat produced from their own metabolism. Mammals are however homothermic (endothermic). Their body temperature (ordinarily 36-38°C) is primarily controlled by metabolic activity, which is adjusted by exchange of heat with the environment. If the observed object is exposed to snow or rainfall, at least in short term, it will affect the apparent temperature of the object. Such weather conditions have an impact both on the observed animals and the background and the processes that happen in these conditions can reduce the difference in temperatures between observed animal and the scene around it. Thermal imagers allow us to "see at night" and the technology has developed so much, that the images provided by these devices are in a very high resolution. It is crucial for the research to get the best images possible to be able to bring out detailed data that allow us to detect, recognize and identify the animals that the study focuses on (Havens & Sharp, 2015).

1.5 The purpose of this study

Most wildlife census techniques such as direct counts are conducted during the day time. The ungulates, that are the main focus of my study, are (with some differences between the species) crepuscular, but they go out into more open areas, where they can be more easily observed and studied mostly during the night. Consequently, we can expect that there is a difference between data collected from day and night observations.

Therefore, the purpose of my study was to investigate these differences by comparing day versus night observations of wildlife on point transects and to test whether it would be meaningful to conduct more studies on population densities of wild animals during the night in the future with help of newest technologies such as thermal imaging.

Specifically, I tested the following hypotheses:

H1: more animals will be detected during the night observations with thermal imaging device than during day observations with day optics binoculars.

H2: more different species will be observed during night observations than during the day observations.

H3: There will be a correlation between distance sampling derived estimates and dung counts carried out on the same locality.

H4: The density estimates based on night observations will be more accurate than the ones based on day observations.

2. Methods and data analysis

2.1. Study area and site selection

2.1.1. Study area

The study area is located in southern Sweden, in Sörmland region, near Öster Malma (Fig. 1). The landscape for the area has been modified by humans and it is mostly a mosaic of agricultural lands, mires and boreal forests. Agriculture is based mostly on small to medium arable and pastoral farms and growing of grain, fodder and root vegetables and animal husbandry are common agricultural practices in this area (Åberg, 2016). Forestry is practiced throughout the area using the the system of clear-cutting and replanting. Pre-commercial thinning is often applied in young stands. Common tree species on the study site are: Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), birch (*Betula* spp.), willows (*Salix* spp.), poplar (*Populus* spp.) and oak (*Quercus* spp.). Various grasses, lichens, mosses and ericaceous shrubs such as lingonberry (*Vaccinium vitis-idaea*), bilberry (*Vaccinium myrtillus*) and heather (*Calluna vulgaris*) are common for the forest field layer in the area. Moose (*Alces alces*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus),* fallow deer (*Dama dama*), and wild boar (*Sus scrofa*) are the ungulate species sympatrically occurring in the area.

2.1.2. Site selection

The site had an already established sampling grid that consists of 50 square transects (1x1km) that initially were a part of continuous environmental monitoring program (FOMA, 'Fortlöpande miljöanalys', Edenius (2012)) and the Beyond Moose research program (Pfeffer et al., 2018). The transects were spaced 3-6km apart and each transect contained 16 evenly-spaced sampling plots, 4 on each side and 200m away from each other. Due to limited time and staff resources the study was conducted on 20 out of the 50 different transects located on the western part of the study area. On each of those 20 square transects, I chose one location for a point count (see section 2.3.1).

Figure 1. The location of the study area marked on the map of Sweden (source: BaseCamp software).

2.2. Distance sampling using point transects (assumptions)

Buckland et al. (1993) have introduced the “distance sampling” term to include a set of methods, including point and line transect sampling, where animal abundance or density is estimated from a specimen of distances to detected individuals. Other methods can be considered as extensions to these two basic methods. In principle, distance sampling is a form of plot sampling, where not all animals existing in the plot can be detected.

The method used in this study is the point transect sampling method. The design for point transect sampling method consists of a random grid set of points. The observer needs to get to each point and note each animal spotted from the point together with the distance from the point to the observed animal.

There are four key assumptions of distance sampling:

1) animals are distributed independently of the points
2) distance measurements are exact
3) objects at the point are detected with certainty
4) objects are detected at their initial location (Buckland et al., 2015).

2.3. Data collection

2.3.1. Plot selection

The field work for this study was conducted during the period from 3rd to 26th of March 2023. 20 transects (out of 50 in total) were randomly chosen from the western part of the study area. Each transect from earlier established sampling grid contained 16 evenly-spaced sampling plots. One of the sixteen plots from each of the 20 transects were chosen to be the observation point, that is 20 observation points in total. The outermost observation points formed a polygon which encompassed an area of 13 940 ha. The per hectare density estimates in this thesis are therefore based on this area. Due to the working conditions during the study (also working at night, in the darkness) the decision about choosing the plot within each transect was made based on the easiest accessibility to the plot location by car.

2.3.2. Defining day and night

Observations were conducted at 1 plot per day. Day and night observations were conducted at each location (each plot) during the same calendar day, where for this study as “day” I defined the time from 30 minutes before the sunrise till 30mins after the sunset and as “night” I defined the time from 31mins after the sunset till 31mins before the sunrise.

Day observation was conducted at each location for 90 minutes, starting 90 minutes before the end of the “day” time till the end of the “day” time, e.g., if the sunset was at 17:30, the day observation period started at 16:30 and lasted for 90 minutes, till 18:00.

Night observation was conducted at each location for 90 minutes, starting 60 minutes after the sunset, e.g., if the sunset was at 17:30, the night observation period started at 18:30 and lasted till 20:00.

2.3.3. Data recording

Every time, the I arrived to the location approximately 30 minutes before the observation period begins, to be sure to get to the right spot, prepare all equipment and not make too much unnecessary movement and noises just before the observation period starts. For both day and night observations the data was recorded every 10 minutes, which gives 10 recordings per observation. Every 10 minutes I did two 360-degree turns and recorded every spotted object: the species of an animal, the number of the animals in the group and the distance from the observer to the spotted object. Each individual spotted were counted only once, so if the same individual were spotted during next observation period, it was not included in the data again.

2.3.4. Example photographs from the day observations and video-captures from the night observations

Figure 2. Photos of fallow deer (Dama dama) taken during the day observations.

Figure 3. Video-captures. Examples of detecting different species (wild boars (Sus scrofa); fallow deer (Dama dama) and different group sizes with thermal binoculars Pulsar Merger LRF XP50 during night observations.

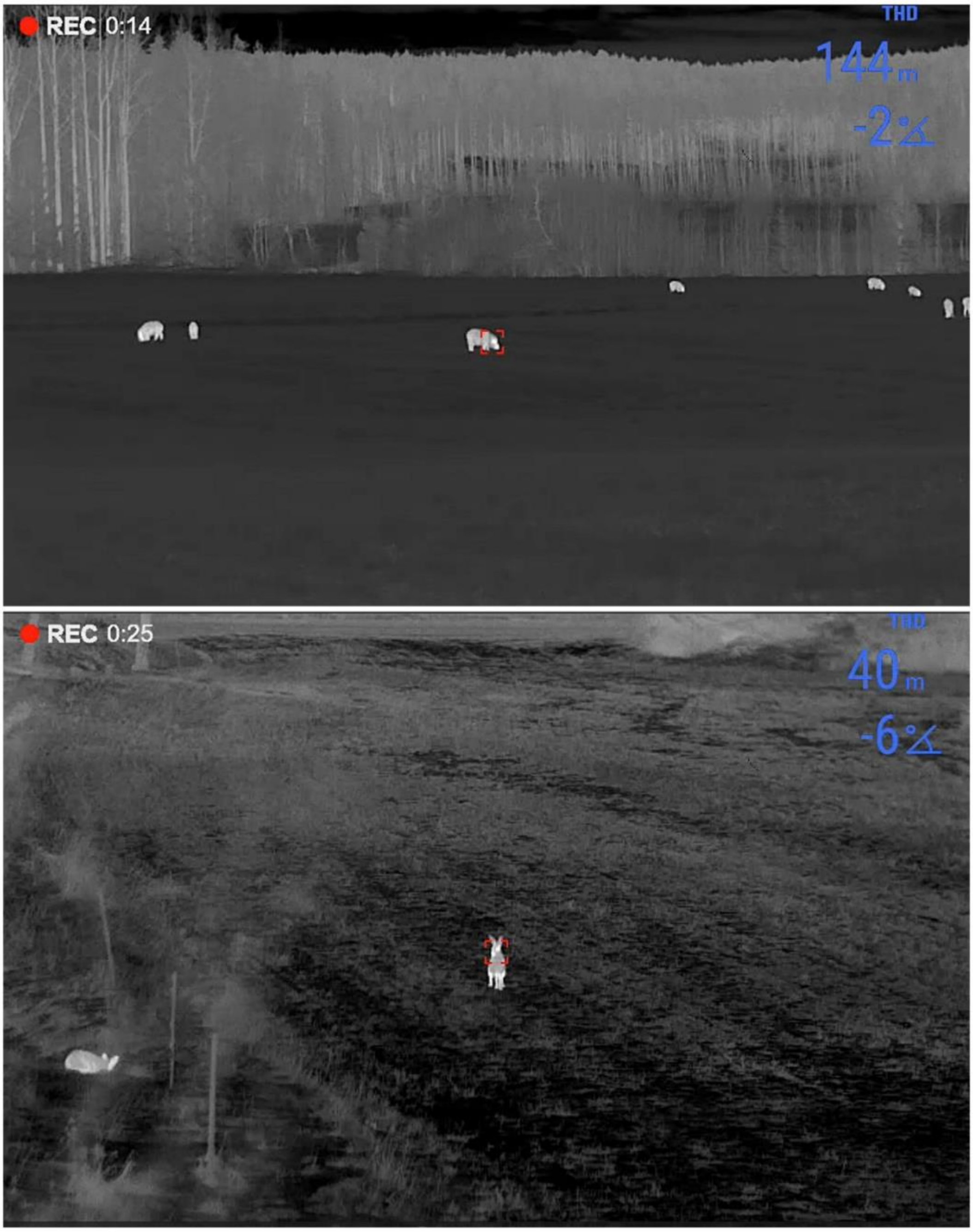

Figure 4. Video-captures. Examples of distance measurements made with the thermal binoculars Pulsar Merger LRF XP50. Wild boars (Sus scrofa) in the upper picture and hares (Lepus europaeus) in the lower picture.

2.3.5. Equipment

The equipment used for the day observations were day optics binoculars with range finder Minox X-Range 10x42. The device used for the night observations were thermal imaging binoculars with built-in laser rangefinder and photo and video recorder Pulsar Merger LRF XP50.

2.4. Data analysis and statistics

Each animal spotted during the day observation was noted on a field sheet and later transferred to an Microsoft Excel sheet. Using the built-in photo and video recorder in the device used for night observations, the observations were recorded and saved and the videos from the night observations were later analysed and the Excel sheet was filled in based on the recorded videos.

Collected data were analysed in Microsoft Excel and R version 4.3.0. (R Core Team, 2023), using the packages *distance, tidyverse* and *ggpubr*.

2.4.1. Hypotheses testing

Basic analysis of collected data: Testing hypotheses:

1: More animals will be detected during the night observations with thermal imaging device than during day observations with day optics binoculars.

2: More different species will be observed during night observations than during the day observations.

The data was analysed separately for day and night observations. To answer the questions in hypotheses 1 and 2 I produced the following descriptive summary statistics of the collected data: species observed, total observations per species and a graphic visualization where total number of observations reported per species from day and night observations are compared.

Comparison with dung counts. Testing hypothesis no 3: There will be a correlation between distance sampling derived estimates and dung counts carried out on the same locality.

To test this hypothesis fallow deer density index data from dung counts collected from the same locations thanks to the FOMA,'Fortlöpandemiljöanalys' (Edenius, 2012) and the Beyond Moose research program (Pfeffer et al., 2018) were used and compared with the fallow deer total observations data collected in this study. The dung counts data used for the analysis comes from 2020 and were collected through pellet group counts. Pellet-group counting is a method used commonly for estimating the densities of various ungulates' populations (Mandujano, 2014). Pellet-group counting for FOMA and Beyond Moose research program consisted of identifying (into species) and counting groups of pellets in circular sampling plots ($10m^2$ each for fallow deer and roe deer counts) spaced evenly on each transect. To consider a dung pile as a pellet group it had to include at least 10 individual pellets. Based on the data collected in the field, the pellet group counts got standardized to the unit of pellet groups/$1000m^2$ (Spitzer, 2019), which can be understood as the density index (e.i., fallow deer density index that I have looked at in my study). Simple linear regression test with basic linear model lm() function was run in the R programme to test the correlation between the fallow deer density index data from dung counts and the fallow deer total day and night observations data collected in this study. The estimates of R^2 and p-value were analysed, where R^2 is the square of the correlation coefficient between two variables and it gives a measure of the proportion of variation in one variable accounted for by another variable. It assesses how strong the linear relationship is between two variables. The p-value (p) tells whether there is a statistically significant relationship between predictor variable and the response variable or not (Birks, 2012).

Distance sampling. Testing hypothesis no 4: The density estimates based on night observations will be more accurate than the ones based on day observations.

'More accurate' in this context refers to 'more likely to be closer to the real density'. In correspondence with hypothesis 1, I assumed fallow deer to be more active during the night and thus be detected more frequently than during the day, which in turn would result in higher density estimates. Prior to thermal imaging technology, such night observations were not feasible.

To test this hypothesis distance sampling needed to be conducted. Distance sampling can be described as set of methods, where distances from point or line to detections are recorded and that allows to estimate abundance or density of observed objects. Fitting a detection function to the observed distances and using it to estimate the proportion of objects that got overlooked in the survey when the proportion of spotted objects is known – it is a key to distance sampling analyses. In general, the detection function decreases with increasing distance to the point (Thomas et al., 2010).

To conduct the distance sampling analysis, the programme R version 4.3.0. and package *Distance* were used. The distance sampling data were analysed only for fallow deer, as there were not enough recorded observations of the other species to conduct distance analysis. The data were analysed separately for day and night observations. All data were organised in the following manner: Region.Label (the study area, in this case only 1), Sample.Label (point transect identifier: total of 20 points), Effort (number of visits to each point), object (unique identifier for each spotted animal), distance (radial distance in meters to each detection) and Study.Area (the whole study area in hectares). Truncation of 5% was applied to the data. Truncation deletes from the data outliers that make the modelling of detection function incohesive (Buckland et al., 2001). In this study it means, that 5% of the observations most distant from the points were removed from the data.

To estimate density for both: groups (clusters) and individual fallow deer during day and night, I used function ds() from the R-package *distance*, set to "point transect" estimates. The ds() function allows for fitting different detectability functions to the data (i.e., half-normal, hazard rate and uniform) with further adjustments (e.g., cosine, hermite polynomial and simple polynomial). Each of the fitted detection function produced a different estimate of abundance and density for the fallow deer. Model fit was assessed visually using Q-Q plots and the goodness of fit test. Final selection from suitable candidate models was based on lowest AIC (Akaike's Information Criterion) value and Goodness of Fit estimates (GoF). GoF tests allow to do formal testing to check if a detection function model provides a sufficient fit to data. While looking at the output from GoF test, the lower the "t-statistics" value the better and the closer the "p-value" gets to 1 the better, as it is unwanted to be significant. To asses GoF the Kolmogorov-Smirnov test was applied. Analysing both numerical and graphical results will lead to making the best fitting data model choice (Buckland et al., 2015).

3. Results

3.1. Basic analysis of collected data: hypotheses no 1 and 2.

The results supported hypotheses 1 and 2. In total, 129 animals were spotted during day observations and 393 animals were spotted during night observations (Tab.1). In total, during the day observations individuals or groups of animals were spotted 20 times and during the night observations 74 times (Tab. 2). The frequency of night observations was consistently higher than day observations throughout the whole survey (Fig. 5). There were 6 species spotted during the survey: fallow deer (*Dama dama*), red fox (*Vulpes vulpes*), hare (*Lepus europaeus*), mouflon (*Ovis aries musimon*), roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*) (Tab. 1 and Tab. 2).

Table 1. Total number of animals observed during field work, reported per species.

Species	Day observations	Night observations
Fallow deer	111	307
Red fox	1	4
Hare	0	23
Mouflon	7	9
Roe deer	10	16
Wild boar	0	34
TOTAL:	**129**	**393**

Table 2. Total number of observations of groups, reported per group of species.

Species	Day observations	Night observations
Fallow deer	15	39
Red fox	1	3
Hare	0	17
Mouflon	1	1
Roe deer	4	8
Wild boar	0	6
TOTAL:	**20**	**74**

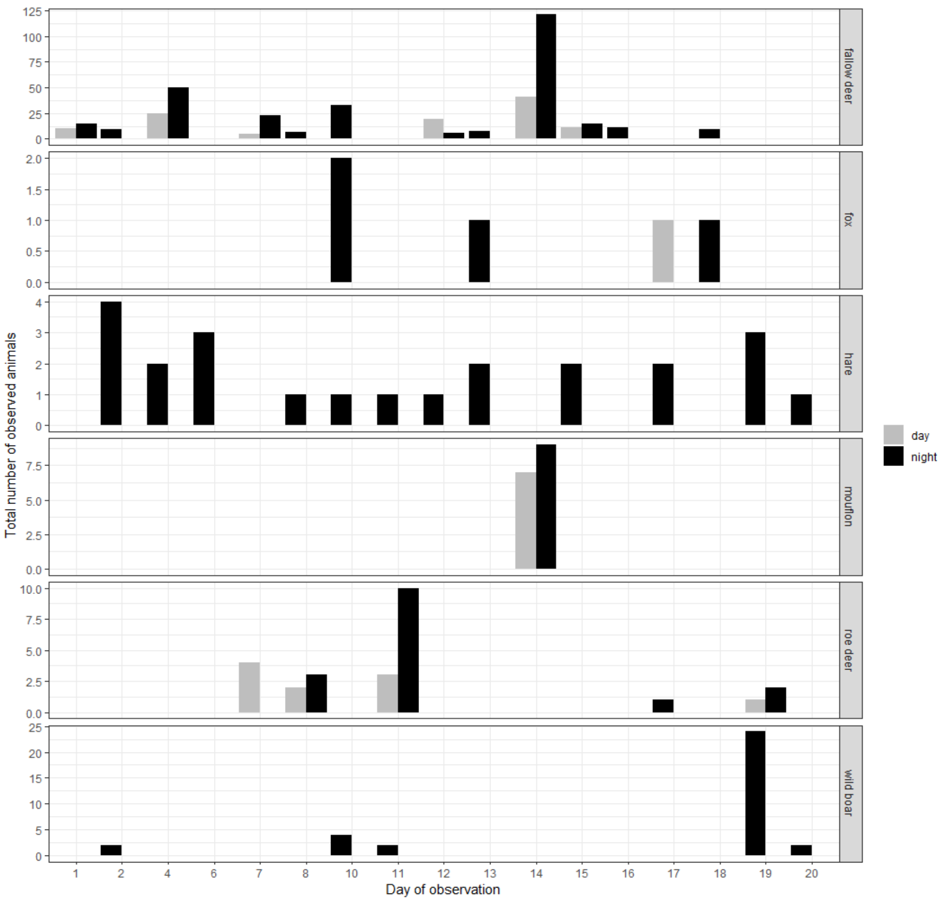

Figure 5. Bar graph of total number of observations during the day (grey) and night (black) for each of the species observed during a 20-day observation period.

3.2. Fallow deer total observations from point transects vs fallow deer density index from dung counts: hypothesis no 3.

Linear regression revealed good correlation between distance sampling based density estimate and pellet group counts in the study area. Pellet group counts showed a stronger relationship with day observations ($p < 0.001$; $R^2 = 0.54$) than night observations ($p = 0.047$, $R^2=0.20$; Fig.6). This supports my hypothesis that there will be a correlation between density indices collected by the two methods.

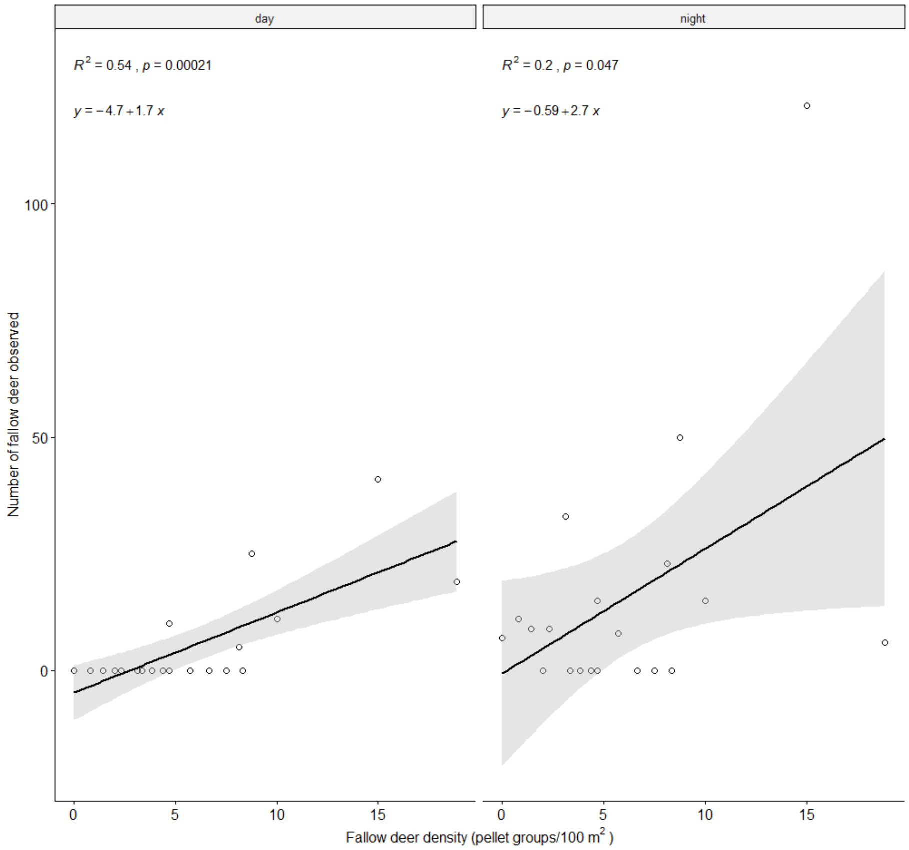

Figure 6. Linear regression between fallow deer pellet group counts (x-axis) and distance sampling based estimates for day and night observations across 20 point transects. Each point represents a different point transect.

3.3. Distance sampling: hypothesis no 4

After analysing and comparing 11 variants of models with different functions, separately for day and night observations, based on AIC (day= 178.11; night= 442.35 and GoF values (Appendix 1 and 2) the model with Hazard rate key function and Cosine adjustment was chosen as the one fitting the data best for both day and night observations (GoF values presented in Tab. 3).

3.3.1. Detection probability

The slope indicates how the detection function decreases in relation to the distance. At the interval 0-~160m the detection function ≠ 1. This occurs when the expected values are lower than the observed values. The slope of the detection function indicates that the probability to detect a fallow deer decreases with increasing distance. There is a very good probability to detect a cluster in a range 0- ~160m from the transect point and the detection probability decreases quite strongly on distances longer than approximately 160m (Fig. 7A).

The slope indicates how the detection function decreases in relation to the distance. At the interval 0 -~80m the detection function ≠ 1. This occurs when the expected values are lower than the observed values. The slope of the detection function indicates that the probability to detect a fallow deer decreases with increasing distance. There is a very good probability to detect a cluster in a range 0 to ~80m from the transect point and the detection probability decreases on distances longer than approximately 80m. (Fig.7B).

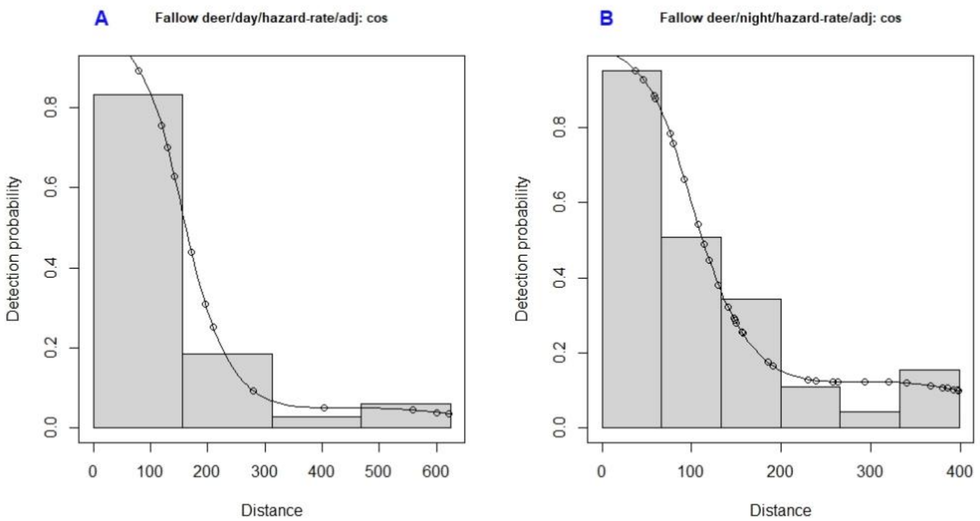

Figure 7. Detection probability for Fallow deer from day (A) and night (B) observations with applied Hazard rate model with Cosine adjustment.

3.3.2. Goodness of Fit

Table 3. Goodness of fit estimates (t-statistics and p-value) summary for distance analysis with applied Hazard rate Cosine model.

GoF	DAY	NIGHT
t-statistics	0.07472	0.09138
p-value	0.72297	0.62878

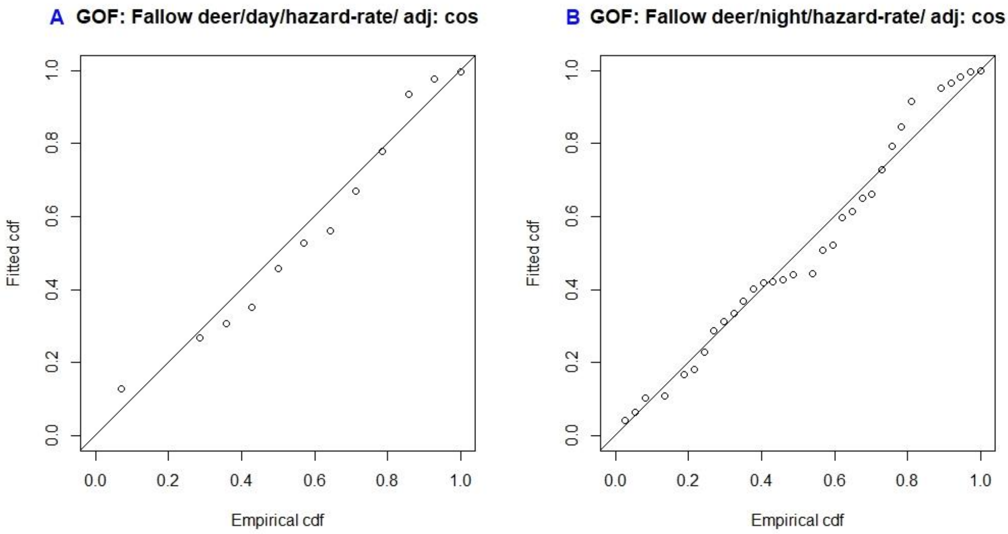

Figure 8. Q-Q plot for the Goodness of Fit (GoF) for day (A) and night (B) observations data for fallow deer with applied Hazard rate Cosine model.

3.3.3. Model estimates for clusters and individuals

The abundance estimate for clusters (groups) for night observations is 1153.42, which means that the model calculated that there are 1153.42 groups of fallow deer in the total area of 13940 ha. The density estimate for clusters for night observations is 0.083, what means that according to the model there is 0.08 groups of fallow deer per hectare. The expected cluster size based on the night observations data is 8.027, which means that there should be on average 8.03 fallow deer in one group. The abundance estimate for individuals from night observations is 9258.53, which means that there should be 9258.5 fallow deer in the whole area and the density estimate for individuals is 0.66, what tells that there should be 0.7 fallow deer per hectare (Tab. 4).

For the day observations, the abundance estimate for clusters is 657.08, which means that the model calculated that there are 657.08 groups of fallow deer in the total area of 13940 ha. The density estimate for clusters for day observations is 0.047, what means that according to the model there is 0.05 groups of fallow deer per hectare. The expected cluster size based on the day observations data is 7.714, which means that according to the day observations data estimates, there should be on average 7.71 fallow deer in one group. The abundance estimate for individuals is 5068.87 according to the data from day observations, which means that there should be 5068.9 fallow deer in the whole study area and the density estimate for individuals = 0.364, which means that there should be 0.36 fallow deer per hectare (Tab. 4).

Table 4. Night and day observations estimates summary for distance analysis with applied Hazard rate Cosine model.

	Abundance estimate [fallow deer/total area]	**Density estimate** [fallow deer/ha]	**Expected cluster size** [individuals/group]
NIGHT			
For clusters	1153.42	0.083	8.027
For individuals	9258.53	0.66	
DAY			
For clusters	657.08	0.047	7.714
For individuals	5068.87	0.364	

4. Discussion

The key findings of this study were that thermal imaging technology can be used to estimate population density of ungulates (here specifically fallow deer), and that monitoring efforts conducted during day and night observations produce different estimates for the same location. Additionally, according to my assumptions, I observed that there were more species spotted at night, than during the day, what may suggest that night time is more universal if the aim would be to focus on several species at once. In combination the results suggest that to survey some of the species monitoring not only can, but even should be conducted during the night.

4.1. Hypotheses:

1: More animals will be detected during the night observations with thermal imaging device than during day observations with day optics binoculars.

2: More different species will be observed during night observations than during the day observations.

Hypotheses 1 and 2 assumed that in general more animals will be spotted during the night than during the day and also that the variety of species will be higher during the night observations. These hypotheses got supported by the results.

Night observations, chiefly when using thermal imaging technology, is a very good solution for conducting population density surveys of wild ungulates, especially that majority of them is crepuscular or nocturnal (Beier and McCullough, 1990; Meng et al., 2002) and also because many animals are shifting their activity patterns nowadays, especially on more open areas, more and more into night time, partly as a result of anthropopressure (Clinchy et al., 2016). According to Gaynor et al. (2018) animals' nocturnality increased by an average factor of 1.36 in response to disturbance and pressure from humans.

Previous studies conducted in the same area (e.g. Spitzer et al., 2021; Edenius 2012) have shown that fallow deer is the most abundant ungulate species in the study area. The results from my study confirm this (Tab. 1 and Tab. 2)

4.2. Hypothesis 3: There will be a correlation between distance sampling derived estimates and dung counts carried out on the same locality.

For the day observations and dung counts the coefficient of determination $R^2 = 0.54$ and p-value < 0.001, which suggest that there is a relationship between the number of observed fallow deer during this study and the fallow deer density index from dung counts and the p-value suggests that the relationship between the variables is significant. There is much weaker linear relationship for the fallow deer density index from dung counts when compared with night observations as the $R^2 = 0.2$ and p-value $= 0.047$. However, the data with no recorded observations for some point transects may affect the estimated values in this comparison. Nonetheless, the trend between point transect observations and dung counts seems to be positive, as in the locations with low values from dung counts survey the data from this study also show low values, and where higher fallow deer densities were calculated based on dung counts also usually more fallow deer were observed.

4.3. Hypothesis 4: The density estimates based on night observations will be more accurate than the ones based on day observations.

Accurate estimates of population size and animal presence highly depend on probability of detection (Petrovan et al., 2011). For both day and night observations the slope of the detection function indicates that the probability to detect a fallow deer decreases with increasing distance, which is a logical phenomenon (Fig. 7 & Fig. 8). For the night observations the probability to detect a cluster is very good in a range from 0 to ~80m from the transect point and then the probability declines. For the day observations the detection probability is very high up to approximately 160m and then it rapidly declines. When it comes to night observations with thermal imaging device, I would rather claim that most of the animals were spotted quite close from the transect point during this study and that is why the graph shows a decline of detection probability already after ~80m, but from the technological point of view thermal imaging allows to detect and recognize objects on much bigger distances (for the device used in this study – Pulsar Merger LRF XP50 the maximum detectability distance given by producent is 1800m), which is not necessarily the case with day optics binoculars, especially when it is getting closer to twilight. According to Logan et al. (2019) thermal imaging not only increase the detectability at night but also around twilight, when theoretically it is still a day, but the source of light is already getting limited.

Looking at the abundance and density estimates for clusters and individuals and taking into account that in general there were much more fallow deer spotted during the night (what obviously shows that these animals are there in real life), I would claim that the hypothesis number 4 is supported. The data from night observations provide more detailed and probably more accurate estimates than the data from day observations. However, the estimates for expected cluster size do not differ much between day and night observations, which brings a conclusion, that for some general insight the estimates from the point transect observations conducted during the day with day optics may be enough for fallow deer in southern Sweden, but to get much more detailed idea about the population density it would be worth to conduct observations at night with help of thermal imaging technology. By maximizing the effort to detect the target objects/species the uncertainty of the study results is reduced and management outcomes can be improved (Logan et al., 2019).

4.4. Limitations and possible improvements for future

There is no perfect survey, so I would like to mention some limitations that occurred when planning and conducting my study:

- Limited time and field staff – as this study was conducted as my Master thesis project I had a limited time to do the field work and I was the only person actually being out in the field and collecting data. If I could plan and repeat this survey in the future, having more time for the field work and a team of people – observers, it would be possible to conduct the survey during a longer period of time and on a bigger area and not only for fallow deer, but other ungulates too. Additionally, not only the abundance could be surveyed, but for example the activity, behaviour and gender and age (at least at adult/juvenile level) structure, as the footage from used thermal binoculars Pulsar Merger LRF XP50 is in a very high quality.

- Observation time – as autumn and winter are the heart of the hunting season and during summer in this part of Sweden it basically does not get dark at night, I decided to do the field observations in early Spring, in March – just after most of the hunting season is ended. From the perspective of not creating conflicts between doing the observations and interrupting hunters it was a perfect time for this field work, but the weather conditions in March are not friendly to sit still for few hours in temperatures below 0^{o}C, especially during the night. While planning the field work, there need to be balance between what needs to be done and what can be done by the people that need to do it in the field. If not these circumstances it would be good to extend day and night observation periods.

- Weather conditions – as the field work was conducted in March, there were days with constant snow or rain fall, what was both – making it more difficult for the observer and devices to work and also it could have slightly, locally affected animals' activity. Sitting still for a longer period during snow or rainfall create physically difficult conditions for the observer as it is much easier to freeze and also the visibility is weaker, so it requires much more effort from the observer to make sure to not miss any observation. The observer also need to take care of the equipment – so the lenses of the binoculars are clear and dry. Very strong fog or rainfall can also have an impact on laser range finder and make it more difficult to measure the distances. Strong and sudden weather changes can affect the activity of animals, as they can become less active for some period of time and focus more on saving their energy resources (Mörschel and Klein, 1997).

5. Conclusion

Thermal imagery allows to see what could be often impossible to notice by human eye on its own. In the paper by Collier et al. (2007) the effectiveness of two methods (thermal imagers and spotlight counts) to detect white-tailed deer populations were compared. Thermal imagers detected 92.3% of the deer, while through the spotlights counts only 54.4% of the animals were detected. According to Hodnett (2005) thermal imaging showed also the best results in detecting white-tailed deer in urban areas. In a study by Logan et al. (2019) the effectiveness of observations of roe deer and red deer conducted with day optics binocular and thermal imaging device were compared. It occurred that thermal imagery is not only coping better when it goes to night observations, but also is more effective in detecting animals during the day and at twilight. As the thermal imaging technology is getting more and more popular, it is becoming more accessible and more affordable nowadays, I think it should become more implemented for research purposes and perhaps also in practical management. All the more that it is extremely important to design research surveys the way, to get the most precise and accurate outcome. That will result in the best preservation and management solutions for wildlife populations.

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Appendix 1

Table A1. Values of AIC and GoF for all 11 model variants, based on the night observations.

					GOF	
KEY Function	**Adjustment**	**adj shortcut**	**Model nr**	**AIC**	**test statistic**	**p value**
Half-normal	NA	NA	1	449,047	0,461313	0,05001
Half-normal	Cosine	cos	2	444,351	0,154327	0,37666
Half-normal	Hermite polynomial	herm	3	449,047	0,461313	0,05001
Half-normal	Simple polynomial	poly	4	449,047	0,461313	0,05001
Hazard-rate	NA	NA	5	442,849	0,135553	0,43676
Hazard-rate	Cosine	cos	6	442,351	0,0913845	0,62878
Hazard-rate	Hermite polynomial	herm	7	442,849	0,135553	0,43676
Hazard-rate	Simple polynomial	poly	8	442,849	0,135553	0,43676
Uniform	Cosine	cos	9	440,87	0,0934764	0,61781
Uniform	Hermite polynomial	herm	10	454,166	1,06528	0,00173
Uniform	Simple polynomial	poly	11	447,157	0,242919	0,19771

Appendix 2

Table A2. Values of AIC and GoF for all 11 model variants, based on the day observations.

KEY Function	Adjustment	adj shortcut	Model nr	AIC	GOF test statistic	GOF p value
Half-normal	NA	NA	1	183,674	0,402697	0,07107
Half-normal	Cosine	cos	2	179,472	0,106665	0,55318
Half-normal	Hermite polyı	herm	3	183,674	0,402697	0,07107
Half-normal	Simple polyno	poly	4	183,674	0,402697	0,07107
Hazard-rate	NA	NA	5	178,882	0,0978283	0,59563
Hazard-rate	Cosine	cos	6	178,107	0,0747152	0,72297
Hazard-rate	Hermite polyı	herm	7	178,882	0,0978283	0,59563
Hazard-rate	Simple polyno	poly	8	178,882	0,0978283	0,59563
Uniform	Cosine	cos	9	178,852	0,0970617	0,59947
Uniform	Hermite polyı	herm	10	189,571	1,00234	0,00243
Uniform	Simple polyno	poly	11	185,743	0,605246	0,02172

Appendix 3

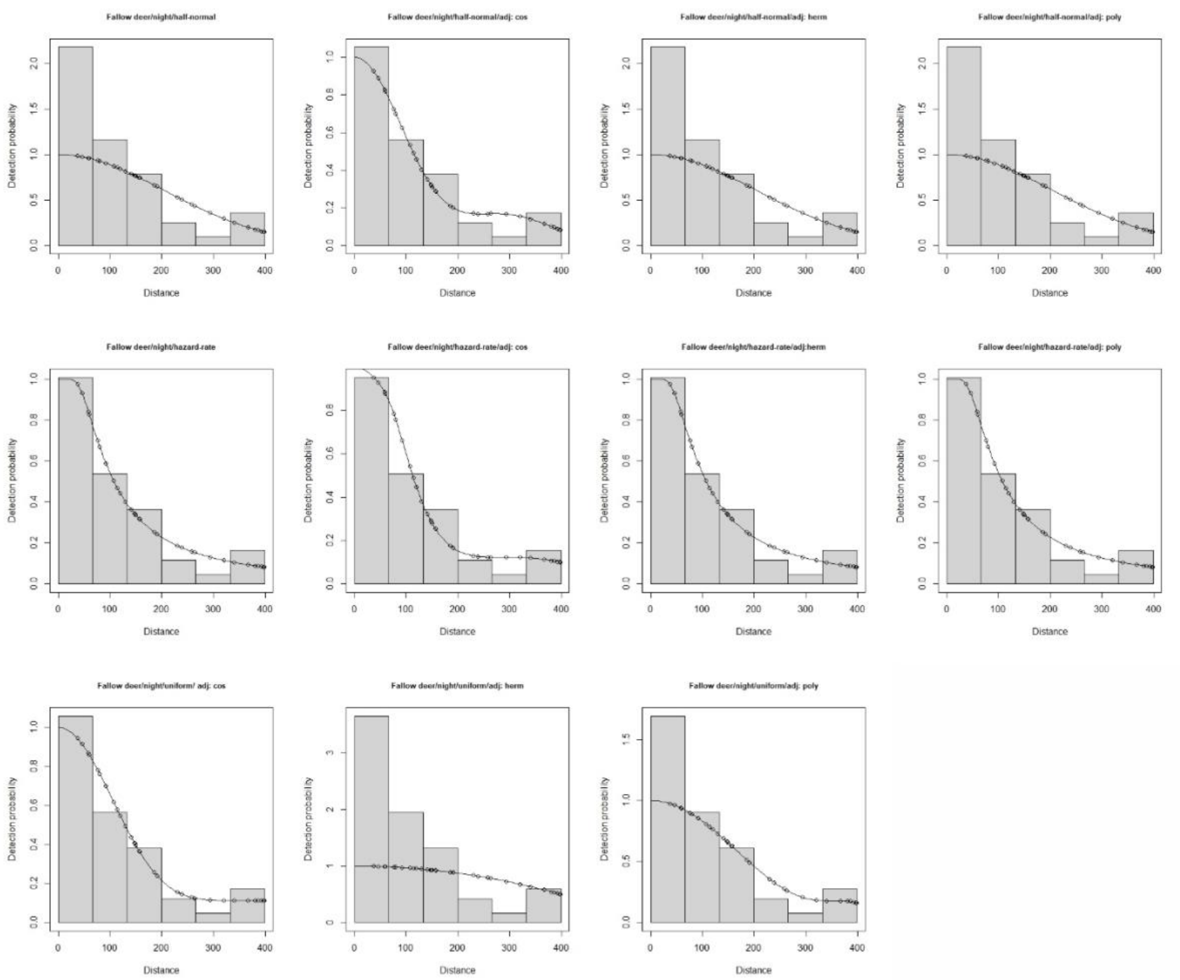

Figure A1. Detection probability plots for all 11 model variants, based on the night observations.

Appendix 4

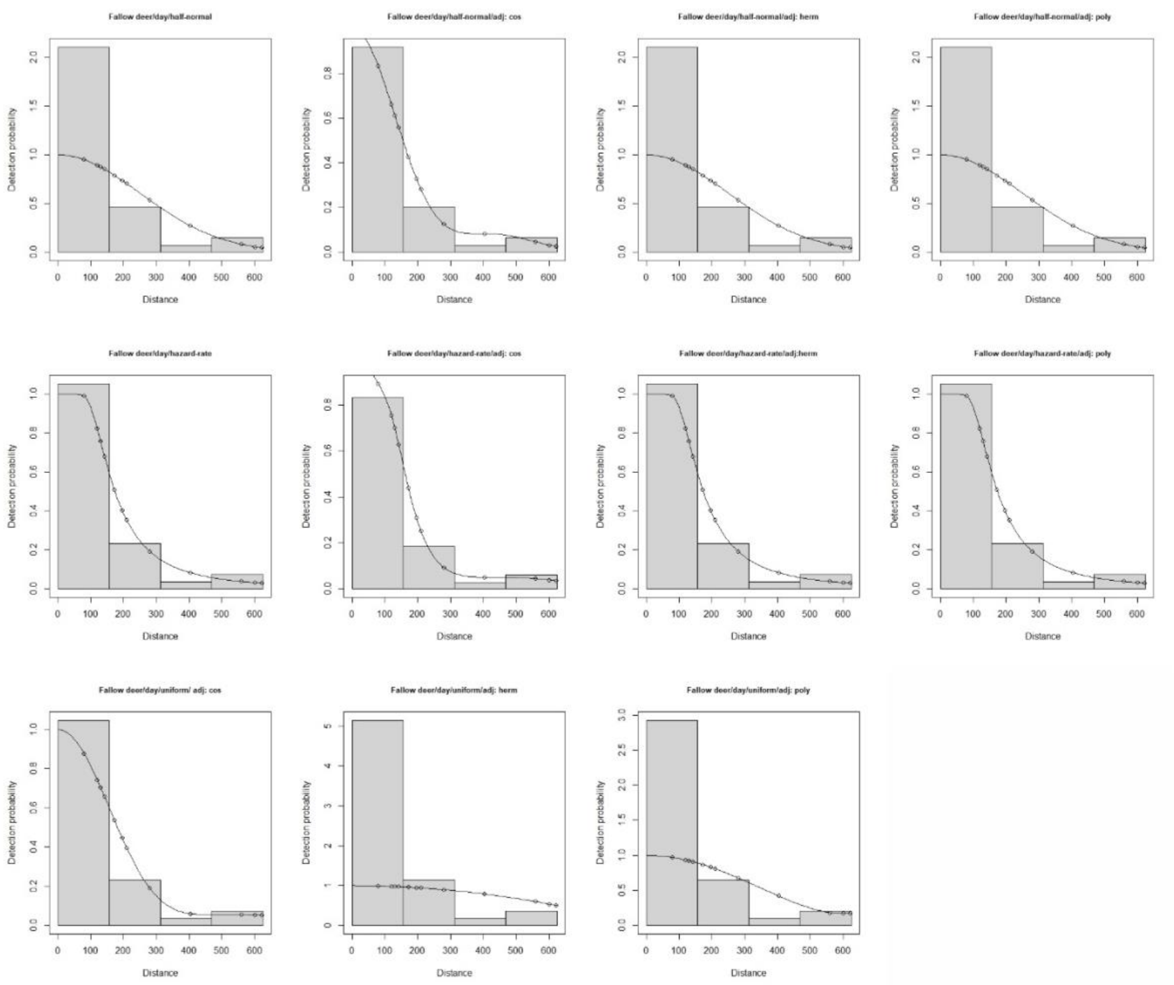

Figure A2. Detection probability plots for all 11 model variants, based on the day observations.

Appendix 5

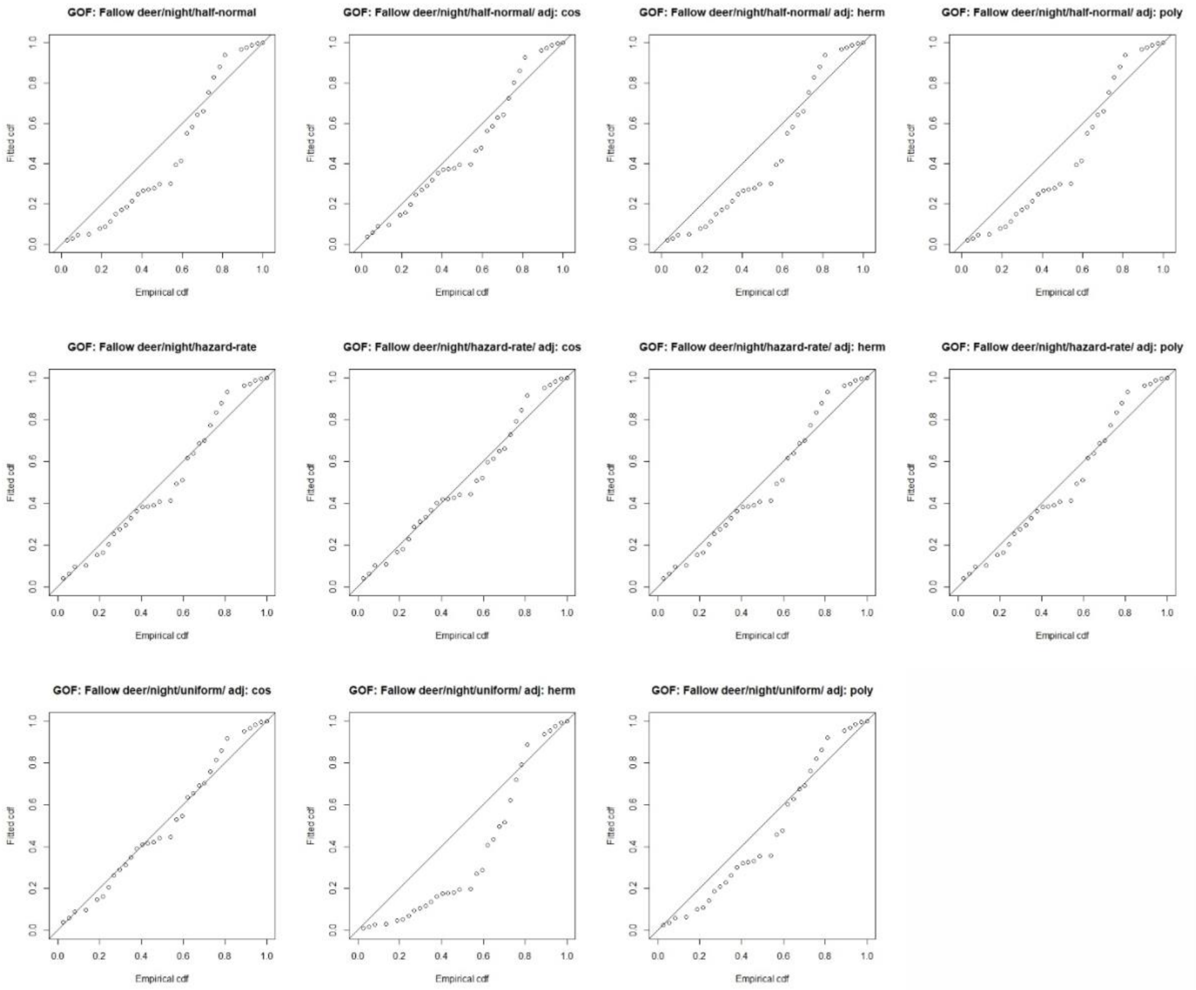

Figure A3. Goodness of Fit plots for all 11 model variants, based on the night observations.

Appendix 6

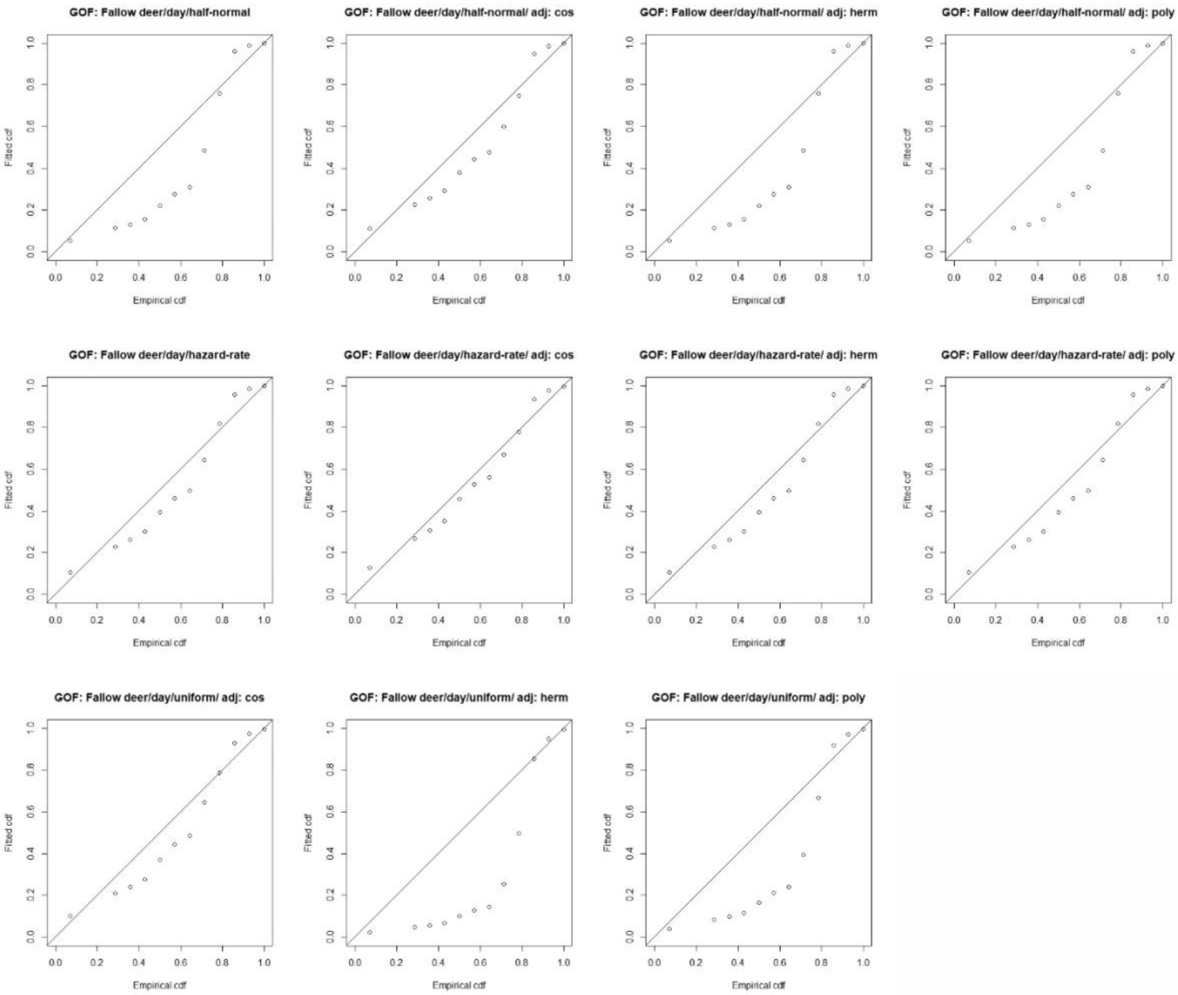

Figure A4. Goodness of Fit plots for all 11 model variants, based on the day observations.

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