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An Assessment of Roe Deer (*Capreolus capreolus*) Occupancy in a Wet Temperate Climate to Determine Habitat Preferences using Camera Traps and Occupancy Modelling in Scotland.

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Abstract

Due to the global increase in ungulate populations, numerous concerns are being raised regarding widespread issues. These challenges are caused by overpopulated areas of deer, including but not limited to, an increase in wildlife related road accidents, loss in agricultural lands and spread of zoonotic diseases, thus costing countries millions financially. There are multiple population control strategies being implemented to counteract these issues. To aid in the development of said strategies, the aim of this research is to understand the habitat preferences of roe deer (*Capreolus capreolus*) and if weather conditions influence their distribution. Camera traps (CTs) were deployed across a rural and semi-urban space within a wet temperate climate. Within this area, multiple variables were considered when distributing the CTs such as, distance to areas with high levels of human activity, habitat type and weather conditions. Due to the limitations of using CTs, an occupancy model using R statistical software was deemed the most appropriate to carry out statistical analysis of the data. Out of nine covariates researched within the study, only three were included within the model due to Akaike information criterion (AIC) scores. Despite the expectations within this study, it was observed that roe deer kept distance from any area with high levels of human activity. This included distance, measured in kilometres (km), to the closest minor road, major road and housing areas, as well as if there was a difference in occupancy estimates when dogs were present and if the habitat type was urban or rural. Additionally, no weather conditions influenced the detection rates of roe deer. Finally, contrary to the predictions, distance to river (km) had a strong negative relationship, as roe deer had a higher detection rate when in close proximity to a river. To conclude, hunting and fencing were recommended as population management strategies to ensure the safety of both humans and roe deer. However, roe deer within Scotland are not of concern regarding spread of zoonotic diseases and damage to property.

Introduction:

Over the past few decades, the population of wild ungulates has experienced significant growth, leading to the widespread recolonisation across vast areas over multiple continents (Carpio et al, 2021). This trend can be attributed to a combination of factors, including the increase of restrictions in hunting legislation, a decline in natural predators of ungulates and the restoration of natural habitats, all of which contribute to an increase in food availability and decrease in mortality rate (Côté et al, 2004; Valente et al, 2020). Thus, leading to an array of problems for both humans and a variety of plant species. The global rise in deer populations has led to substantial economic, ecological and public health issues (Côté et al, 2004). Economically, wild deer populations have reduced productivity and value of agricultural lands, as well as increasing the number of vehicle collisions (McLeod, 2023). In Australia alone it was estimated that $93.3 million was lost due to the wild deer population, among other costs, $69.1 million in agricultural losses and $3.3 million in road vehicle collisions, (McLeod, 2023). Furthermore, within Europe, the majority of deer related accidents are caused by roe deer (Sáenz-de-Santa-María & Tellería, 2015; Steiner et al., 2021), resulting in countless human lives being endangered. Highlighting the importance of this, throughout the duration of this research there was a warning for high risk of road collisions caused by roe deer across Scotland and in particular the Aberdeenshire area (Fleming, 2024, NatureScot, 2024a), the focus area of this study. This issue is not specific to Australia and Europe as Sharma & Khanal (2024) reported 29,000 injures and 200 human deaths were due to deer related accidents within the United States. Therefore, highlighting the urgent need for deer population control internationally.

Ecologically, the lack of natural predators of ungulates has caused an imbalance in the ecosystem. Specifically, in habitats containing herbivores, such as deer, carnivores will typically play a crucial role in maintaining the herbivore population to keep the balance between predator, prey and plants equal (McShea, 2012). The result of overpopulated areas of deer has caused a decline in plant biodiversity. This has led to biotic homogenization and adverse impacts on the dynamics of a wide variety of plant species (Perea et al, 2014). Furthermore, the increase in deer has amplified the spread of zoonotic diseases that present as a health risk to humans and cattle, complicating disease management (Hearst et al, 2023, Palmer et al., 2004). Specifically, Kilpatrick et al (2014) found a positive correlation between the number of black legged ticks and white-tailed deer reporting an 80% reduction of Lyme disease reports in the area after a decline in the deer population. These reasons underscore the importance of addressing deer population management. Accordingly, this study focuses on the habitat preferences of roe deer (*Capreolus capreolus*), to assist on future population management strategies.

There are various population management strategies available to utilise. A popular option is hunting, as this not only reduces population size but, in some cases, can also prevent loss of plant biodiversity (Griesberger et al, 2023). Their study suggested that hunters picking specific locations led to a reduction in forest diversity due to deer browsing. Additionally, fencing can be used to direct deer away from roads to prevent wildlife related road accidents, however this can be a costly solution (Donaldson & Elliott, 2021). Neverthless, their study also noted that this method was deemed most effective when the habitat preferences were taken into consideration during fence construction, eliminating unnecessary costs. Therefore, understanding habitat preferences can aid in multiple management strategies when deciding on locations for both hunting and fencing.

Roe deer distribution and behaviour can be significantly influenced by weather conditions, understanding these impacts and spatiotemporal patterns can aid hunters in developing new strategies for population management. This is highlighted by Baur et al (2021), whose study found that various weather conditions, including temperature, rain hours and snow depth, had a measurable impact on deer harvest numbers in Italy. The paper concluded that future deer hunting strategies could in fact use spatiotemporal patterns as a guide for an interval-hunting strategy, highlighting the importance of understanding weather preferences of roe deer. Distribution of roe deer can also be greatly influenced by the structure of their habitat as roe deer will typically avoid roads due to their distance from food sources (Torres et al, 2011). Understanding the distribution patterns can not only support hunters but also assist with other management strategies to avoid human-wildlife conflict, such as creating wildlife crossings in necessary areas.

The natural biological cycles of roe deer can be negatively affected by the presence of artificial light and noise pollution (Ciach & Fröhlich, 2019). Not only can this knowledge help with choosing hunting areas, but it can also aid with utilising fencing to avoid human/wildlife interactions. Additionally, deer breeding cycles can be influenced by high temperatures leading to a decrease in reproductive success (Chirichella et al, 2019). This knowledge in turn can aid hunters in anticipating population growth or decline, to then determine optimal hunting seasons and quotas.

Camera Traps

Due to the high accuracy level of species identification, a common tool used for observing moderately sized mammals are camera traps (CTs) (Lyra-Jorge et al, 2008). Furthermore, Pfeffer et al (2018) highlights the accuracy of utilizing CTs and recommends them for use in future research. CTs are particularly effective when studying species that are very wary of humans (Lyra-Jorge et al, 2008). This wariness is highlighted by roe deer's avoidance of highly noise polluted areas (Ciach & Fröhlich, 2019), thus CTs are an appropriate tool when obtaining occupancy data. Despite the advantages of the CTs, it is difficult and time consuming to set them up. CTs can be falsely triggered by crowding vegetation and so need to be mounted at the correct height and angle to capture the target species (Apps & McNutt, 2018). Moreover, CTs need to be checked regularly for breakages and battery changes (Apps & McNutt, 2018). CTs are also limited by their ability to only observe the target species when it passes directly in front of the CT (Hofmeester et al, 2021). This may lead to the target species being falsely recorded as undetected, despite them being present in that location (Hofmeester et al, 2021). Due to this limitation, this study deemed it appropriate to use an occupancy model to account for these issues.

Occupancy Model

Occupancy models mitigate these limitations by using environmental covariates and previous detection data to then estimate the detection and occupancy probabilities (MacKenzie et al, 2002). The model does this by differentiating between whether the animal was detected and if it was likely to be present in the area, accounting for imperfect data (Doser et al., 2022). Therefore, if roe deer were occupying the area but did not pass in front of the camera, the occupancy model estimates the probability of the roe deer occupying the area. Using R statistical software, (Version 4.2.2, R Core Team, 2022), the model used to estimate the occupancy of roe deer in each location was a single-season model, implemented using the *unmarked* R package (Version 1.4.1, Fiske & Chandler 2011; Kellner., et al 2023). Despite the model counteracting these limitations, the *unmarked* R package does have its disadvantages, the model does not account for spacial autocorrelation (Doser et al, 2022; Version 1.4.1, Fiske & Chandler 2011; Kellner., et al 2023). Overlooking spatial autocorrelation can lead to bias within the estimates (Johnson et al, 2013).

Research question:

Based on surrounding environmental factors what are the habitat preferences of roe deer (*Capreolus capreolus)*?

Predictions:

Based on the trends observed in the evidence above, this study presents five predictions:

1. Roe deer will have a substantial presence in areas with human activity.
2. Roe deer will avoid rivers due to the climate type of Scotland.
3. Temperature will cause a decline in detections.
4. Wind and precipitation will have no impact on the detection rate of roe deer.
5. Areas with dogs assumed as present will have a reduced number of detections and occupancy.

Methods

Study Design

The fieldwork spanned over a five-week period (7/05/2024 – 30/06/2024) in Stonehaven Aberdeenshire, Scotland. The study was conducted during the summer months, within a wet temperate climate. Nine CTs were used within this study, deployed across eighteen locations (Figure 1). Due to logistics and availability, the cameras were separated into two groups and moved bi-weekly. Each CT had a minimum of 500 metres distance between them to decrease the risk of the same deer being detected, while still being near allowing for movement of cameras due to land permissions.

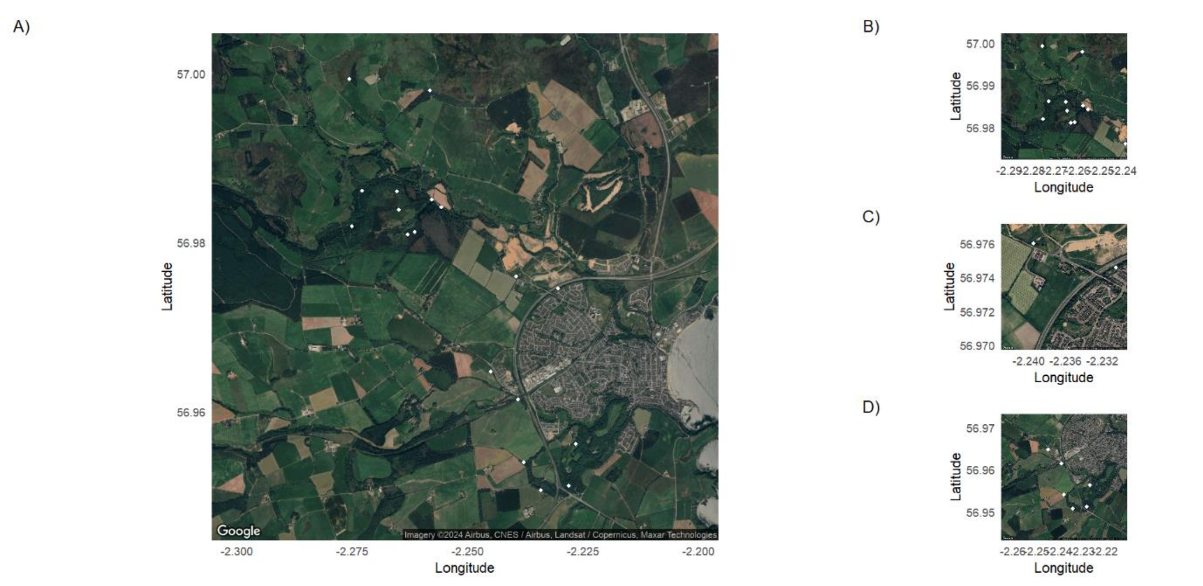

Figure 1 – **A**: A map derived from Google Maps, presenting all CT locations across the study area. Each CT location is represented by white dots. **B:** A close-up version of the map from figure 1A depicting the locations of eleven of the CTs. **C:** An additional close-up of the map from figure 1A representing two CT locations. **D:** A close-up version of the map seen in figure 1A illustrating six CT locations.

There were weekly site visits for data collection and equipment maintenance. This was essential for several reasons, firstly, the memory cards were wiped after data collection to prevent them from reaching capacity, which would risk losing data. Secondly, the batteries were changed when required, the CTs were also checked to confirm there was no damage to them and had not been tempered with or stolen. Additionally, at each location, the coordinates were recorded to ensure no cameras were lost. Google maps was used to obtain the coordinates of each location, as well as calculate the distance from each CT to several of the covariates using the map measure tool (Google Maps, 2024). The CTs were set to picture mode, again to prevent the SD cards reaching capacity. For several of the covariates weather conditions per day of the study were required. This data was obtained from the weather archive for Stonehaven (Historical Weather & Weather Archive, 2024). As there is one weather station in Stonehaven, it was only possible to have each location have the same weather conditions per day.

CT Placement:

The location of the CT placements was chosen prior to the cameras being deployed in each location. This was due to required permission from landowners before any CTs could be placed. Furthermore, an even spread between semi-urban and rural habitats were chosen to ensure generalisability of results. An even spread was ensured by picking different locations based on housing, roads and environmental surrounding, such as rivers, tree coverage and assumed presence of dogs in the area.

The CTs were placed in areas unlikely to have people in close proximity, to avoid General Data Protection Regulation (GDPR) issues. Furthermore, the placement was designed for the CTs to be hidden to prevent people spotting any CTs from a distance. The CTs had to be facing north to prevent the sun shining straight into the lenses and they were then strapped onto a tree or post. Each CT was around one metre off the ground as to avoid false triggers from ground vegetation and as this is the average height of a roe deer. The locations as shown in Figure 1B, were chosen as they are located within a wooded area and include many features that could affect the occupancy of roe deer. This area is the most distant from the dual carriageway yet has a high-speed road nearby. The site is characterised by minimal housing, a large river and frequent dog walkers. In contrast, locations displayed in Figure 1C were selected for their more urban settings. One was situated in the middle of a housed area and near a major road, whilst the other was close to buildings but further away from the major road. Finally, the locations shown in Figure 1A were chosen to have a balanced mix of housing density, road proximity, and assumed presence of dogs, ensuring a strong spread of factors that could affect the occupancy of roe deer.

Occupancy Model

The data was recorded in the form of a binary string (1 = detection and 0 = non-detection). Each detection per day was counted as that space being occupied for that 24-hour period, the number of detections was not accounted for. Firstly, the occupancy model was fitted without including any variables, a "null" model, to estimate the probability of detection (p) and occupancy (ψ).

Initially six occupancy covariates and three detection covariates were included within the occupancy model. The occupancy covariates are distance, measured in kilometres (km), to the closest river, minor road, housing area and the dual carriage way (major road), habitat type (urban/rural), and if dogs were assumed as present in the area. Dogs were considered present in the location, if one of two criteria were met, if they were seen whilst deploying the CT or if captured by the CT. The detection covariates are temperature degree Celsius (0^c), precipitation in millimetres (mm) and wind speed metres per second (m/s) for each day the CTs were in each location. Raw data for each detection covariate can be viewed in Figure 2. However, based on the comparison of the Akaike's Information Criterion (AIC) scores from each model, the following covariates were removed; distance to housing, dual carriageway, river, presence of dogs, temperature, precipitation and wind speed per day as the model fit was stronger and less complex without them.

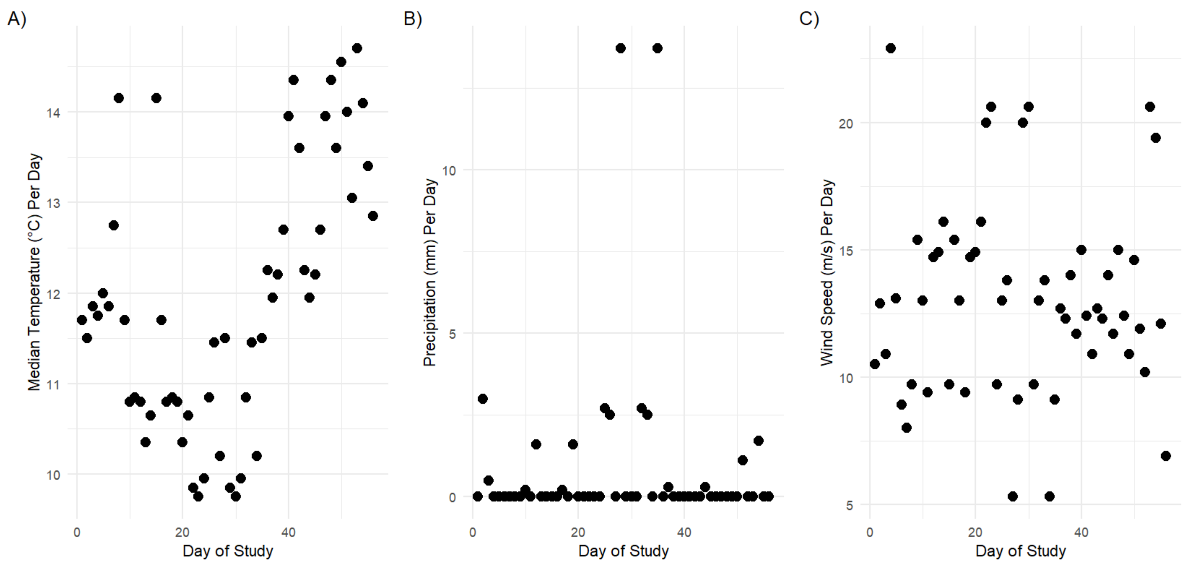

Figure 2: A visual representation of the raw data for each weather condition with each data point depicting the daily measurement per day of the study. **A:** The median temperature (ºC). **B:** Precipitation (mm) **C:** Wind speed (m/s).

The following four-lined equation represents the final model used to estimate the occupancy of roe deer, incorporating occupancy covariates.

$$z_i \sim \text{Binomial}(\psi_i)$$

$$\text{logit}(\psi_i) = \beta_0 + \beta_1 \times Road_i + \beta_2 \times Dog_i + \beta_3 \times Urban_i$$

$$y_{i,k} \sim Binomial(p_{i,k})$$

$$logit(p_{i,k}) = \alpha_0$$

where z is the absence or presence of roe deer, $_i$ is each location, assumed to be generated according to a binomial distribution, Ψ is the probability of absence and presence. ψ is estimated from the data and z is a latent variable. Fit on the logit link function, β_0 is the intercept and β_1 is the slope of distance to road and $\beta_{2\,\&\,3}$ is the contrast of assumed dog presence and habitat type. Where y is the absence or presence of roe deer, $_k$ is the day and α_o is the intercept.

Results

Roe Deer Habitat and Weather Preferences

Covariates associated with occupancy are as follows; assumed presence of dogs, habitat type (urban/rural), distance (km) to road, dual carriageway, river and housing. Detection covariates are as follows; temperature (ºC), precipitation (mm) and wind speed (m/s) per day of the study. Visualisation of each covariate can be viewed in figure 3.

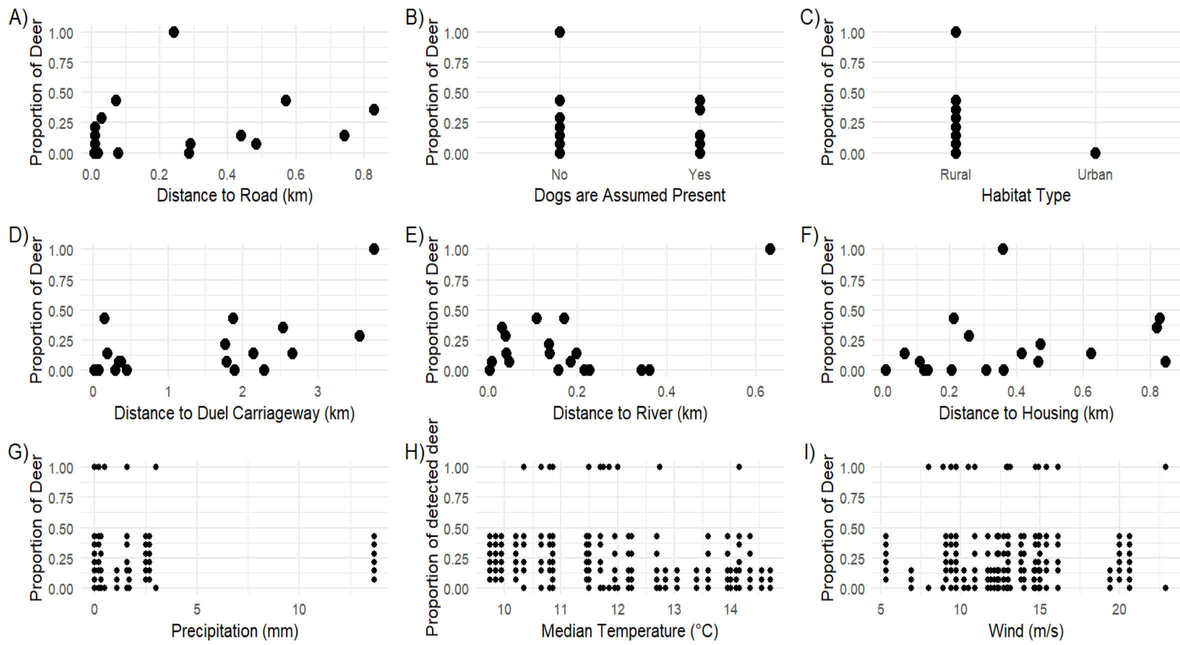

Figure 3 – Proportion data with roe deer detections against six occupancy covariates and three detection covariates. Figures A-F presented are occupancy covariates and Figures G-I are detection covariates. **A:** The proportion of deer detected versus the distance to road (km). Data points relatively sparse wth slight skew of higher proportion to the left indicating negative relationship. **B:** Proportion of roe deer against the assumed presence of dogs. Negative relationship indicated by higher proportion of roe deer in areas wth no dogs presumed as present. **C:** Habitat type versus the proportion of roe deer. Clear trend of higher proportion of roe deer in rural areas. **D:** Relationship between distance to dual carriageway (km) and proportion of roe deer. Data points sparse with slight skew to left of the plot, indicating positive relationship. **E:** Negative relationship between distance to river (km) and proportion of roe deer, with skew to right of the plot. **F:** Effect of distance to housing (km) of proportion of roe deer. Data points indicate higher proportion as distance increases. **G:** Negative relationship between precipitation (mm) and proportion of roe deer, clear skew to the right of the graph. **H:** Proportion of roe deer against median temperature (ºC), no relationship shown as data points are too spread. **I:** Wind (m/s) versus proportion of roe deer, no relationship observed through data points.

Occuancy Models and Roe Deer Habitat Preferences

Multiple models were fitted to the data including a ‘null’ model which did not include any covariates. The ‘null’ model resulted in an estimated occupancy probability of 67% (logit 0.73) and a detection probability of 28% (logit -0.96), as well as a Confidence 95% interval (CI) of 0.35 for detection and CI of 0.85 for occupancy. The next model incorporated all covariates from which AIC variable selction was applied resulting in the final model which only included three occupancy covariates; distance to road, habitat type and assumed presence of dogs, with no covariates influencing detection.

AIC-based variable selection led to the selection of the minimum adequate model, which retained the impact of the distance to road (km), habitat type and assumed presence of dogs. Both the model’s estimate (Table 2) and Figure 4A illistrate a negative relationship between assumed presence of dogs and the probability of roe deer occupancy. Probability of roe deer occupancy sits at approximately 87%, in comparison to 32% when dogs are assumed as present. However, the estimates have a high level of uncertainty given the 95% confidence intervals (CI) overlap considerably. Distance to road demonstrated a strong positive relationship (Table 1 & Figure 4B). This is evident in Figure 4B, as the trend line increases close to 100% from approximately 25%. Roe deer prpobability is substantially higher when in a rural area than in an urban one, when in an urban area the probaility is 0% whilst rural has a probability of approximately 87% (Figure 4C). In combination with this and the estimate (Table 1), a strong negative relationship is exhibited. However the estimates portray uncertainty within the model as the 95% CI overlap substantially coupled with the standard error of 32.63 (Table 2).

Table 2 – The parameter estimates (on the logit link scale) from the final model, including covariates; distance to road (km), habitat type and assumed presence of dogs.

Parameter	**Estimate**	**Standard Error**
Occupancy		
Intercept	1.39	1.20
Road slope	5.96	3.76
Urban contrast	-8.52	32.63
Dogs present contrast	-2.62	1.63
Detection		
Intercept	-0.96	0.175

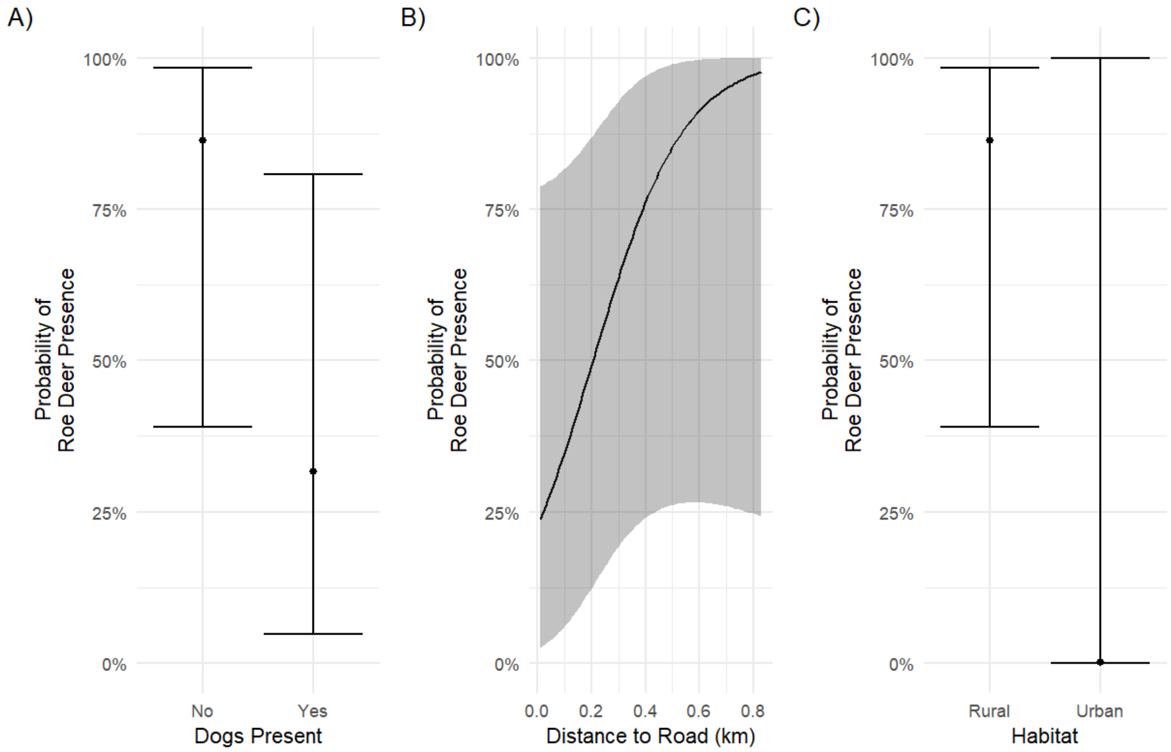

Figure 4 – Two dot plots and a line graph representing the occupancy model output of estimated probability of roe deer presence versus three covariates associated with occupancy. **A:** The influence of assumed presence of dogs, demonstrating a negative relationship. **B:** The positive trend between distance to road (km) and the probability of roe deer presence. The steep trend line indicates a strong relationship; however, the 95% CI (grey ribbon) indicates high uncertainty in the relationship. **C:** The negative relationship portrayed by the substantial difference in probability between rural and urban habitats.

Table 1 – The AIC results and number of parameters for models performed as a comparison for the best fitting model. Covariates are as follows; temperature (ºC) for each day (temp), precipitation (mm) for each day (precip), wind speed (m/s) per day (wind), assumed presence of dogs (dogsYes), distance to river (km) (river), distance to road (km) (road), distance to dual carriageway (km) (dual), distance to housing (km) (housing), the type of habitat (habitatUrban).

Model	**AIC**	**No. of Parameters**
Occupancy ~dogsYes + river + road + dual + housing + habitatUrban *Detection* ~Temp + precip + wind	230.6274	11
Occupancy road+habitat+dogs *Detection* ~ 1	221.3495	5
Occupancy ~ 1 *Detection* ~ 1	225.8202	2

Discussion

The overarching aim of this research was to collect evidence of roe deer habitat preferences with consideration to a population management plan. In total, six occupancy covariates and three detection covariates were investigated to determine the habitat roe deer favour in a wet temperate climate. Whilst the results of this study all have relatively strong relationships, high uncertainty is observed within the occupancy model. Therefore, when reviewing the results from this research, the small sample size should always be considered. Ideally a larger sample size and utilising a model that could account for all four seasons would be recommended for any future population management plans.

It was determined that the median temperature per day of the study did not have an influence on the proportion of roe deer detected. This result did not align with prediction 3. This contrasts with existing research observing lower deer distribution during higher temperatures, such as Van Beest et al (2013). However, it is of note that their study was completed in southern Manitoba, Canada. The mean temperature of Manitoba during summer is 27ºC with a maximum of approximately 38ºC (Bumsted et al, 2024), whilst the mean and maximum temperature throughout this study was substantially lower at 11.9ºC and 16.1ºC. This difference of results is also evident within a study by Pérez-Barbería et al (2020). Their research noted that mothers and fawns reduce movement during high temperatures in an attempt to avoid heat stress in temperatures >16ºC. Despite the duration of this study being shortly after fawning season (Gaillard et al, 1993), the mean temperature was 11.92ºC. Therefore, the colder wet temperate climate of Scotland may explain the insignificant effect of temperature on roe deer. Furthermore, the difference between the lowest and highest mean temperature was merely 4.95°C, indicating that the temperature range was insufficient to accurately assess the impact on roe deer detections. Therefore, a limitation within this study is the research spanning only 5 weeks during one season, not allowing for substantial change in temperature that can influence detection rate of roe deer. For future improvement, it is recommended to span research over four seasons to get a true representation of the effect of temperature, to give a more holistic understanding when considering population management control. Additionally, wind speed per day also had no influence on the proportion of detected roe deer, and thus, aligning with prediction 4. While two studies observed wind speed influencing activity patterns of white-tailed deer, this has been only under extreme weather conditions, either when temperatures were higher than normal (Beier & McCullough, 1990), or extremely low (Lang & Gates, 1985). The lack of temperature change within this research may give reason to why there was no impact of wind speed on detection of roe deer. To the knowledge of this study, there is limited research on the impact of wind speed on cervid species, thus making it difficult to determine if the result of no effect is a true result or due to study limitations. Being aware of the impact weather conditions have on the detection and distribution of roe deer would contribute to a hunting strategy for population control of roe deer. Therefore, a future management plan would benefit from researching each season of the year.

The relationship between distance to major roads (dual carriageway) and minor roads (road) with roe deer have both shown to be negative, contradicting prediction 1. It was found that distance to dual carriageway presented a stronger relationship than distance to road (Figure 3A & 3D). Whilst ungulates typically avoid roads, Meisingset et al, (2013) observed red deer crossing roads at night, in low disturbance areas. This result is further supported by studies observing that deer and ungulates overall tend to avoid major roads with high traffic and disturbance levels (Kušta et al, 2017; Meisingset et al, 2013). Therefore, the weaker relationship of distance to road can be attributed to the differing disturbance levels between major and minor roads. This can also explain the uncertainty within the occupancy model, as roe deer may have avoided minor roads during daytime but not during the night. This in turn leads to the conclusion that deer related vehicle incidents should not be of priority in a deer management plan. However, contradicting to the results, throughout the duration of this study there was a high-risk warning for deer related road accidents within the study area (Fleming, 2024, NatureScot, 2024a). Due to the dangerous nature of road accidents, the final conclusion of this result is to sustain all efforts towards preventing wildlife related road accidents. Additionally, a recommendation for future research would be to split day and nighttime as there is the possibility of roe deer crossing roads during the night, allowing for these differences to be accounted for. Moreover, knowledge of ungulate avoidance of major roads could aid in a management plan to control an outbreak of zoonotic diseases. This can be attributed to roads acting as barriers for migration and therefore, host gene flow (Trombulak & Frissell, 2000). As a result, avoidance of major roads can be used to identify areas with a high abundance of deer with restricted movement, aiding in highlighting potential areas for investigation.

Two habitat types were researched within this study, urban and rural. The result for habitat type indicates that roe deer prefer spaces that are rural instead of urban, thus not aligning with prediction 1. It was observed by Ciach & Fröhlich (2019) that roe deer favour areas that do not have any artificial lighting and tend to avoid the areas that do. Urban areas typically have artificial lighting which in turn could drive roe deer away from the location. This is further supported by a study completed by Jasińska et al (2021), as it was observed that when roe deer enter urbanised areas, the locations had minimal light pollution and land fragmentation. This evidence also presents an explanation for the uncertainty within the occupancy model, if roe deer were to go into urban areas with minimal light pollution and human disturbance, this could skew the results. This provides further justification for separating night and daytime for a future study, as this would account for roe deer entering in urbanised areas during daylight hours when artificial lighting will not have an effect. The above evidence also supports the negative relationship seen for distance to housing. The results for distance to housing, reveal a trend of higher proportion of roe deer when further away from housing, remaining inconsistent with prediction 1. Housing schemes are classified as an urban space, providing an explanation for the results being consistent with one another. Although, it is possible for deer to enter urbanised and housing areas by mistake, deer can misinterpret rivers as migration corridors into urban areas (Ciach & Fröhlich, 2019). This is especially evident within this study as there are two rivers running through rural areas and into urbanisation, the Carron and Cowie rivers.

The relationship between precipitation and roe deer detections, appears to be strongly negative, with a slight skew in the data when the detection rate of roe deer increases when precipitation is higher. However, figure 2B illustrates said relationship is not accurate, for the most part precipitation remained low below 3mm for the duration of the experiment, despite two occasions where precipitation was above 13mm. Throughout the experiment precipitation remained consistently low hence why this relationship is illustrated as strongly negative as this is the only time roe deer could have been detected. Moreover, the skew in the data can be attributed to the two bouts of high precipitation. As such, roe deer were detected when precipitation was both high and low, and no relationship can be determined due to the limited data. Contrasting to prediction 2 of this study a strong negative relationship between distance to river and roe deer detections was observed. There is limited research on the effect of rivers in a wet climate, as most current studies investigate this effect in a hot arid environment or with the presence of predators (Long et al, 2009; McKee et al, 2015). Deeming these studies as incomparable as there are no natural predators of wild deer within Scotland (NatureScot, 2024b) and this study is based in a wet climate. A likely justification for the unexpected result is the lack of precipitation leading to a decline in rain dependent water resources, turning rivers into a valuable water supply. Eom et al (2023) observed a similar response in Siberian roe deer, as seasonal movement of deer was strongly influenced by resource availability. The results have highlighted a knowledge gap between the influence of rivers in the summer months of a wet climate and deer. Due to this future research would be recommended to investigate the differences between low and high precipitation on influencing resource tracking.

Roe deer had an aversion to locations with assumed dog presence, aligning with prediction 5. This is not uncommon amongst deer as it can be seen in numerous studies. An example of this was observed in white-tailed deer which exhibited the highest levels of avoidance when dogs were accompanied by owners, rather than humans or dogs by themselves (Parsons et al, 2016). This correlates to this study as all dogs seen at each location were accompanied with an owner, giving reason to why roe deer would have avoided these locations. Furthermore, Padié et al (2015), also observed roe deer fleeing at the sight of a human, as well as auditory stimuli of dogs barking. This reinforces the idea of roe deer favouring areas without any humans or dogs present. However, their research was based in a popular hunting zone which was suggested as a possible reason for their flight response. Hunting at each location within this research cannot be accounted for as this study is unaware of any hunting at each site. That said, if roe deer within this study were to associate humans as accompanied with dogs, this could lead to the same fleeing response that the hunters cause, as locations with dogs were also popular walking trails. This association could be a possible explanation for the uncertainty seen within the model as it could lead roe deer to flee even in cases where no dogs were present. Moreover, the appearance of a human when CTs were being deployed could have also triggered a flight response, thus causing uncertainty within the model. The awareness of roe deer avoidance of humans and dogs can prove essential in multiple population management strategies. For instance, this could aid hunters in picking locations in the case of a cull for population reductions, as well as locations for fencing roe deer into quiet and peaceful spaces to prevent any stressors.

The findings of this study provide important insights into the habitat preferences of roe deer and how weather conditions may alter their behaviour. The predictions of this research anticipated roe deer would be observed in spaces with substantial human activity, despite the disadvantages for the roe deer. Due to the outcome of these findings, roe deer are unlikely to pose as a threat in consideration to zoonotic diseases and damage to property. However, regarding deer related road accidents, although the results suggest roe deer avoid major and minor roads, precautions should be taken to protect both roe deer and humans. Therefore, two population management plans are recommended from this study; hunting to regulate population size and fencing to protect deer from hazardous areas. Awareness of such preferences can aid in developing a population management plan for both strategies. The use of hunting to reduce population sizes can be benefited by understanding habitat preferences as it can provide insight into where roe deer are likely to be situated. Moreover, using the knowledge gathered within this study, fencing can be implemented to ensure roe deer are kept in a safe and undisturbed environment. Due to the limitations of the occupancy model not accounting for spatial autocorrelation, it is suggested that future investigations incorporate this to alleviate risk of bias within the results. Conversely, Diniz-Filho, Bini & Hawkins (2003) highlight that deploying a statistical model that fails to include spatial autocorrelation does not necessarily invalidate the results. Thus, the results from this study should not be disregarded as it does not account for spatial autocorrelation. Additionally, future research including a larger sample size and a longer time span would allow for true representation of the influences environmental factors can have on the distribution of roe deer.

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Bibliography:

Apps, P.J. and McNutt, J.W., 2018. How camera traps work and how to work them. *African Journal of Ecology*, *56*(4), pp.702-709.

Auguie B (2017). _gridExtra: Miscellaneous Functions for "Grid" Graphics_. R package version 2.3, <https://CRAN.R-project.org/package=gridExtra>.

Baur, S., Peters, W., Oettenheym, T. and Menzel, A., 2021. Weather conditions during hunting season affect the number of harvested roe deer (Capreolus capreolus). *Ecology and Evolution*, *11*(15), pp.10178-10191.

Beier, P. and McCullough, D.R., 1990. Factors influencing white-tailed deer activity patterns and habitat use. *Wildlife Monographs*, pp.3-51.

Bumsted, J.M., McLintock, P. and Coates, K.S. (2024) *Manitoba*, *Encyclopædia Britannica*. Available at: https://www.britannica.com/place/Manitoba (Accessed: 16 December 2024).

Carpio, A.J., Apollonio, M. and Acevedo, P., 2021. Wild ungulate overabundance in Europe: contexts, causes, monitoring and management recommendations. *Mammal Review*, *51*(1), pp.95-108.

Chirichella, R., Pokorny, B., Bottero, E., Flajšman, K., Mattioli, L. and Apollonio, M., 2019. Factors affecting implantation failure in roe deer. *The Journal of Wildlife Management*, *83*(3), pp.599-609.

Côté, S.D., Rooney, T.P., Tremblay, J.P., Dussault, C. and Waller, D.M., 2004. Ecological impacts of deer overabundance. *Annu. Rev. Ecol. Evol. Syst.*, *35*(1), pp.113-147.

D. Kahle and H. Wickham. ggmap: Spatial Visualization with ggplot2. The R Journal, 5(1), 144-161. URL: http://journal.r-project.org/archive/2013-1/kahle-wickham.pdf. Version 4.0.0.

Deer Management in Scotland - frequently asked questions (faqs); Why are wild deer managed? (2024) *NatureScot*. Available at: https://www.nature.scot/doc/deer-management-scotland-frequently-asked-questions-faqs#:~:text=Wild%20deer%20have%20no%20natural,to%20nature%2C%20forestry%20and%20agriculture (Accessed: 19 December 2024). - B

Diniz-Filho, J.A.F., Bini, L.M. and Hawkins, B.A., 2003. Spatial autocorrelation and red herrings in geographical ecology. *Global ecology and Biogeography*, *12*(1), pp.53-64.

Donaldson, B.M. and Elliott, K.E., 2021. Enhancing existing isolated underpasses with fencing reduces wildlife crashes and connects habitat. *Human–Wildlife Interactions*, *15*(1), p.20.

Doser, J.W., Finley, A.O., Kéry, M. and Zipkin, E.F., 2022. spOccupancy: An R package for single-species, multi-species, and integrated spatial occupancy models. *Methods in Ecology and Evolution*, *13*(8), pp.1670-1678.

Eom, T.K., Lee, J.K., Lee, D.H., Ko, H. and Rhim, S.J., 2023. Adaptive response of Siberian roe deer Capreolus pygargus to climate and altitude in the temperate forests of South Korea. *Wildlife Biology*, *2023*(6), p.e01138.

Fleming, G. (2024) *Aberdeenshire charity issue warning ahead of peak deer season after 'significant increase' in accidents*, *Press and Journal*. Available at: https://www.pressandjournal.co.uk/fp/news/aberdeen-aberdeenshire/6614027/significant-increase-deer-accidents-warning/ (Accessed: 13 November 2024).

Gaillard, J.M., Delorme, D. and Jullien, J.M., 1993. Effects of cohort, sex, and birth date on body development of roe deer (Capreolus capreolus) fawns. *Oecologia*, *94*, pp.57-61.

Garrett Grolemund, Hadley Wickham (2011). Dates and Times Made Easy with lubridate. Journal of Statistical Software, 40(3), 1-25. URL https://www.jstatsoft.org/v40/i03/. Version 1.9.3.

Google Maps (2024) Google maps. Available at: https://maps.google.com/ (Accessed: 23 November 2024).

Griesberger, P., Kunz, F., Reimoser, F., Hackländer, K. and Obermair, L., 2023. Spatial Distribution of Hunting and Its Potential Effect on Browsing Impact of Roe Deer (Capreolus capreolus) on Forest Vegetation. *Diversity*, *15*(5), p.613.

H. Wickham. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016. Version 3.5.1.

Hearst, S., Huang, M., Johnson, B. and Rummells, E., 2023. Identifying potential super-spreaders and disease transmission hotspots using white-tailed deer scraping networks. *Animals*, *13*(7), p.1171.

Historical Weather & Weather Archive - Stonehaven (2024) *To the main page of Meteocentre weather*. Available at: https://www.meteocentre.co.uk/historical-weather/stonehaven (Accessed: 23 November 2024).

Ian Fiske, Richard Chandler (2011). unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance. Journal of Statistical Software, 43(10), 1-23. URL https://www.jstatsoft.org/v43/i10/.

Jasińska, K.D., Jackowiak, M., Gryz, J., Bijak, S., Szyc, K. and Krauze-Gryz, D., 2021. Habitat-related differences in winter presence and spring—Summer activity of roe deer in Warsaw. *Forests*, *12*(8), p.970.

Johnson, D.S., Conn, P.B., Hooten, M.B., Ray, J.C. and Pond, B.A., 2013. Spatial occupancy models for large data sets. *Ecology*, *94*(4), pp.801-808.

Kellner KF, Smith AD, Royle JA, Kery M, Belant JL, Chandler RB (2023). The unmarked R package: Twelve years of advances in occurrence and abundance modelling in ecology. Methods in Ecology and Evolution, 14(6), 1408-1415. URL https://doi.org/10.1111/2041-210X.14123

Kellner, K.F., Smith, A.D., Royle, J.A., Kéry, M., Belant, J.L. and Chandler, R.B., 2023. The unmarked R package: Twelve years of advances in occurrence and abundance modelling in ecology. *Methods in Ecology and Evolution*, *14*(6), pp.1408-1415.

Kilpatrick, H.J., Labonte, A.M. and Stafford III, K.C., 2014. The relationship between deer density, tick abundance, and human cases of Lyme disease in a residential community. *Journal of Medical Entomology*, *51*(4), pp.777-784.

Kušta, T., Keken, Z., Ježek, M., Holá, M. and Šmíd, P., 2017. The effect of traffic intensity and animal activity on probability of ungulate-vehicle collisions in the Czech Republic. *Safety Science*, *91*, pp.105-113.

Lang, B.K. and Gates, J.E., 1985. Selection of sites for winter night beds by white-tailed deer in a hemlock-northern hardwood forest. *American Midland Naturalist*, pp.245-254.

Long, R.A., Kie, J.G., Terry Bowyer, R. and Hurley, M.A., 2009. Resource selection and movements by female mule deer Odocoileus hemionus: effects of reproductive stage. *Wildlife Biology*, *15*(3), pp.288-298.

MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Andrew Royle, J. and Langtimm, C.A., 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, *83*(8), pp.2248-2255.

McLeod, R., 2023. Annual costs of feral deer in Australia. *Report prepared by eSYS Development Pty Ltd, Centre for Invasive Species Solutions, Canberra. Print ISBN*, pp.978-1.

McShea, W.J., 2012. Ecology and management of white-tailed deer in a changing world. *Annals of the New york Academy of Sciences*, *1249*(1), pp.45-56.

Meisingset, E.L., Loe, L.E., Brekkum, Ø., Van Moorter, B. and Mysterud, A., 2013. Red deer habitat selection and movements in relation to roads. *The Journal of Wildlife Management*, *77*(1), pp.181-191.

NatureScot (2024). *Warning of high risk of deer on roads*. [online] NatureScot. Available at: https://www.nature.scot/warning-high-risk-deer-roads [Accessed 20 Nov. 2024] - A

Padié, S., Morellet, N., Cargnelutti, B., Hewison, A.M., Martin, J.L. and Chamaillé-Jammes, S., 2015. Time to leave? Immediate response of roe deer to experimental disturbances using playbacks. *European Journal of Wildlife Research*, *61*, pp.871-879.

Palmer, M.V., Waters, W.R. and Whipple, D.L., 2004. Investigation of the transmission of Mycobacterium bovis from deer to cattle through indirect contact. *American Journal of Veterinary Research*, *65*(11), pp.1483-1489.

Parsons, A.W., Bland, C., Forrester, T., Baker-Whatton, M.C., Schuttler, S.G., McShea, W.J., Costello, R. and Kays, R., 2016. The ecological impact of humans and dogs on wildlife in protected areas in eastern North America. *Biological Conservation*, *203*, pp.75-88.

Pebesma, E., & Bivand, R. (2023). Spatial Data Science: With Applications in R. Chapman and Hall/CRC. https://doi.org/10.1201/9780429459016. Version 1.0.16.

Pebesma, E., 2018. Simple Features for R: Standardized Support for SpatialVector Data. The R Journal 10 (1), 439-446, https://doi.org/10.32614/RJ-2018-009. Version 1.0.16.

Pedersen T (2024). _patchwork: The Composer of Plots_. R package version 1.3.0, <https://CRAN.R-project.org/package=patchwork>.

Perea, R., Girardello, M. and San Miguel, A., 2014. Big game or big loss? High deer densities are threatening woody plant diversity and vegetation dynamics. *Biodiversity and Conservation*, *23*, pp.1303-1318.

Pérez-Barbería, F.J., García, A.J., Cappelli, J., Landete-Castillejos, T., Serrano, M.P. and Gallego, L., 2020. Heat stress reduces growth rate of red deer calf: Climate warming implications. *PLoS One*, *15*(6), p.e0233809.

Pfeffer, S.E., Spitzer, R., Allen, A.M., Hofmeester, T.R., Ericsson, G., Widemo, F., Singh, N.J. and Cromsigt, J.P., 2018. Pictures or pellets? Comparing camera trapping and dung counts as methods for estimating population densities of ungulates. *Remote Sensing in Ecology and Conservation*, *4*(2), pp.173-183.

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for StatisticalComputing, Vienna, Austria. URL https://www.R-project.org/.

Sáenz-de-Santa-María, A. and Tellería, J.L., 2015. Wildlife-vehicle collisions in Spain. *European Journal of Wildlife Research*, *61*, pp.399-406.

Sharma, S. and Khanal, P., 2024. Factors associated with deer vehicle collisions in South Carolina (SC), USA.

Steiner, W., Schöll, E.M., Leisch, F. and Hackländer, K., 2021. Temporal patterns of roe deer traffic accidents: Effects of season, daytime and lunar phase. *PLoS One*, *16*(3), p.e0249082.

Torres, R.T., Santos, J., Linnell, J.D., Virgós, E. and Fonseca, C., 2011. Factors affecting roe deer occurrence in a Mediterranean landscape, Northeastern Portugal. *Mammalian biology*, *76*, pp.491-497.

Valente, A.M., Acevedo, P., Figueiredo, A.M., Fonseca, C. and Torres, R.T., 2020. Overabundant wild ungulate populations in Europe: management with consideration of socio-ecological consequences. *Mammal Review*, *50*(4), pp.353-366.

Van Beest, F.M., Vander Wal, E., Stronen, A.V. and Brook, R.K., 2013. Factors driving variation in movement rate and seasonality of sympatric ungulates. *Journal of Mammalogy*, *94*(3), pp.691-701.