What makes for a good location?

Terrain ruggedness and reindeer drive detection of Eurasian lynx (*Lynx lynx*) by camera traps in northern Sweden.

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Swedish University of Agricultural Sciences, SLU
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Abstract

As all large carnivores in Europe, the Eurasian lynx's presence in a landscape now dominated by human activities often leads to conflictual situations and management challenges. To overcome these issues, different monitoring programs are developed all over Europe to assess for the abundance and distribution of this elusive feline. Camera trapping could become a substantial monitoring census tool in Sweden were the decrease in snow cover through climate change and the expansion of the lynx towards southernmost areas could lead to a necessity in changing the current monitoring program based on snow-tracking. The purpose of this study was to understand, looking into the future implementation of camera trap-based lynx monitoring programs, the impact of different environmental variables on the detection of the Eurasian lynx by camera traps. To do so, I designed and ran a camera trap study to detect lynx in Northern Sweden while extracting environmental variables on each camera location. These included habitat variables – terrain ruggedness, field cover, water body proximity –, microsite variables – microsite type – as well as prey prevalence variables – reindeer, roe deer and mountain hare passage rate – I then computed Generalized Linear Models (GLM) to compare each variable between each other regarding lynx detection probability and determine the ones with the greater impact on lynx detection. I found that terrain ruggedness and reindeer passage rate had the greater impact on the detection of lynx. In conclusion, while most variables did not affect the detection of lynx, these two had a significant impact on lynx detection, showing how focusing on specific environmental features might increase the quality of a lynx monitoring program based on camera trapping. With more focus placed on understanding what other variables or factors could impact lynx in other areas in Southern Sweden, camera trapping could become a realistic alternative to the current monitoring programs.

Keywords: Eurasian lynx, *Lynx lynx*, camera trapping, large carnivore monitoring, Västerbotten, habitat preference, reindeer predation, *Rangifer tarandus,* climate change.

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Abbreviations

CAB	County Administrative Board of Västerbotten
GLM	Generalized Linear Model
SLU	Swedish University of Agricultural Sciences

1. Introduction and background

1.1 Introduction

While during most of the Holocene, large carnivores roamed through a major part of Europe, the beginning of the 20th century was marked by their drastic extinction in a big part of their ancestral range (Trouwbourst 2010, Linnell et.al 2009, Chapron et.al 2014). In fact, targeted persecution, habitat loss and decreasing prey population furthered their demise, leading to large carnivores being found only in Eastern Europe where some robust populations remained (Trouwbourst 2010). However, the last decades have been the theatre of an exceptional comeback, with brown bear (*Ursus arctos*), Eurasian lynx (*Lynx lynx*) and grey wolf (*Canis lupus*) recolonizing some parts of the continents where they once prevailed (Trouwbourst 2010, Linnell et.al 2009, Chapron et.al 2014). This astonishing comeback was the result of the implementation of new wildlife policies and a change in attitude from the general public towards large carnivores in the mid 20th century (Linnell et.al 2009). After reaching bottom, forests and key prey populations recovered allowing the reinstatement of suitable habitats for large carnivores while they also showed extreme resilience with great adaptative capacity to the new European landscape (Trouwbourst 2010).

Nevertheless, as inspiring and positive this comeback is, the reestablishment of viable large carnivore populations in Northern and Western Europe rises new challenges and issues. In the past century, as wild carnivore populations increased, they became problematic to human activities impacting farming by killing livestock, hunting by competing against humans, recreational activities by discouraging tourists as well as human safety in general (Trouwbourst 2010). In the eyes of these rising challenges, developing and implementing efficient large carnivore management policies has become crucial (Trouwbourst 2010). Regarding that matter a key point in managing large carnivores is to assess and estimate their abundance as well as their distribution by implementing effective and adaptative monitoring programs (Boddicker et.al 2002).

Three main large carnivores are found throughout different parts of central, eastern and northern Europe – the above-mentioned Eurasian lynx, brown bear and grey wolf– while a fourth one, the wolverine (*Gulo gulo*) is restricted to Scandinavia and northern Europe (Chapron et.al 2014). Out of them all, the Eurasian Lynx is arguably the most elusive one. In fact, the largest wild felid found in Europe is considered an extremely shy and rare predator who usually selects for habitats of low Human pressure (Filla et.al 2017). Its elusive nature makes it therefore extremely challenging to monitor. One of the main areas where lynx is found in Europe is Scandinavia (Chapron et.al 2014). In the peninsula, a defined number of individuals is culled each year to limit the impact of the Eurasian lynx on domestic livestock as well as to limit competition with hunters (Andrén et.al 2002, Hellström et.al 2019, Elofsson et.al 2021). Moreover, the presence of the lynx is a constant threat to reindeer husbandry in the reindeer husbandry area covering half of Scandinavia. In fact, the comeback of large carnivores in Scandinavia Sweden led to this new management issue, with predators taking down large numbers of this iconic arctic cervid. This supposes heavy losses to the indigenous Sámi people that extensively manage reindeers in Scandinavia (Mattisson 2022). The lynx is known to be one if not the major threat to reindeers when it comes to predation and therefore the culling quotas also insure the limitation of their impact on reindeer husbandry (Mattisson 2022, Andrén et al. 2011). To define culling quotas and manage the issues risen by the Eurasian lynx, implementation of strong monitoring methods and robust census data is required (Andrén et.al 2002).

In the Scandinavian peninsula, the main methods used to monitor the Eurasian lynx are both snow-tracking based family groups count in northern Sweden and Norway as well as one day snow tracking censuses in southern and central Sweden (Hočevar et.al 2020, Andrén et.al 2002). Since its comeback, the lynx has been recolonizing areas found always more south and its monitoring program has been taken to a broader scale. However, the evolution of climate change poses a threat to the current monitoring methods used for lynx. As climate warms up, winters in Europe including Scandinavia shorten up, with late first snowfalls and early snowmelts (Moen 2008). Monitoring seasons are also getting impacted, especially in the south, and developing new methods is becoming necessary.

One monitoring method that has been already largely used for the Eurasian lynx in other parts of Europe is camera trapping (Hočevar et.al 2020). Camera trapping is a non-invasive census method that comes with great advantages when it comes to monitor elusive and highly mobile species such as the Eurasian lynx (Swann et.al 2011). The implementation of camera trapping can be done year around, doesn't is economically advantageous in comparison to other census methods and the data obtained can be used for other species than the targeted one (Swann et.al 2011). Advancing technologies and the rise of new picture classification softwares are helping in the development of this tool which is becoming growingly important in ecological research (Bubnicki et.al 2016).

While being used in central Europe for lynx, camera trapping needs to be readjusted to Scandinavian conditions as lynx densities are way lower in the peninsula (SCANDCAM, ResearchGate). Regarding that matter monitoring the Eurasian lynx through camera traps in Scandinavia will require to understand how they use the habitat and how to select for the best locations. The quality of the locations at which the cameras are set up will determine the detection probability of the Eurasian lynx and therefore impact the robustness and quality of the census. The Eurasian lynx is known to select for semi-modified landscapes in some parts of southern Scandinavia, favoring Mountainous isolated areas to move while generally necessitating a certain amount of field cover as a key prey species, such as the roe deer (*Capreolus capreolus*), foraging ground (Bouyer et.al 2015). However, the habitat can vary greatly from northern to southern Scandinavia and most studies based on GPS, snow tracking and other census methods do not bring information on microsite scale characteristics that impact the detection of lynx by camera traps. For example, animals tend to favor easier ways to move through the landscape by using paths and roads in the forest and targeting these features could be beneficial for a higher detection of the Eurasian lynx (Swann et.al 2011). Finally, previous studies have shown that in southern Scandinavia the Eurasian lynx selects for specific habitats that are linked to prey species habitat use (Bouyer et.al 2015). And while prey species composition in southern Scandinavia is mainly made up of roe deer (*Capreolus capreolus*) and mountain hare (*Leptus timidus*), the presence of the reindeer husbandry area in northern Scandinavia adds a thirds main species into the diet of the Eurasian lynx: the semi-domestic reindeer (*Rangifer tarandus*) (Kjellander et.al 2010). Therefore, detection of the lynx by camera traps might differ as main preys' community varies.

Before selecting for locations and implementing camera trapping to monitor lynx in Scandinavia, it is therefore crucial to understand what habitat characteristics make for the best locations, what features at a microsite scale enable a better detection and how the prevalence of a certain prey species community impact the detection of the Eurasian lynx by camera trapping. Regarding the latest point, the presence of the reindeer husbandry area could be a determining factor into how the different main lynx prey prevalence impact its detection. Therefore, in this master thesis, I aim to test the implementation of camera traps as a monitoring tool for the Eurasian lynx in Northern Sweden. I specifically evaluate which environmental variables – terrain ruggedness, distance to fields, water body proximity, microsite composition, field cover and main prey prevalence – impact the detection of lynx by camera traps. This will hopefully help future projects and studies to select for the best locations based on habitat and microsite criteria to optimize the monitoring of the Eurasian lynx with camera traps in Northern Sweden and in the rest of Europe where some of these environmental conditions could be found. It will also hopefully help with the potential development and implementation of the Eurasian lynx monitoring through camera traps by the county administrative board of Västerbotten in the County and in the rest of Sweden.

I hypothesize that (i) lynx detection increases with terrain ruggedness, field cover, water body proximity and distance between camera and nearest field, (ii) lynx detection increases in specific microsites characterized by isolation and movement facilitators, and (iii) lynx detection increases with main prey prevalence, especially reindeer.

2. Materials and methods

2.1 Study area

The study area is located on the eastern part of the Västerbotten County in Northern Sweden (figure 1). The Västerbotten County is the second largest county in Sweden and is characterized by diverse landscapes with mountain ranges in the west and more flat terrain with mires and water bodies on the east as we get closer to the coast (Schneider 2006). As one of the most northerly counties in Sweden, it is also known to receive cold winters with important snowfalls. It is home to five large predators: brown bear, wolverine, golden eagle (*Aquila chrysaetos*), the wolf (to a minor level) and Eurasian lynx (Schneider 2006). Finally, as one of the most northerly counties, Västerbotten is also characterized by the strong presence of reindeer husbandry which complexifies the management of large carnivores such as the Eurasian Lynx (Danell 2009, Pedersen 1999).

As the county itself, the study area is largely composed by coniferous forests, used by extensive forestry, as well as by small mountains and mires, with scarce agricultural land (Schneider 2006). Agricultural land cover is however slightly higher in the study area than the average in Västerbotten due to the proximity of two major cities. In fact, the area is located south of Skellefteå, and surrounds Umeå, two big cities of northern Sweden.

The whole study area consists of ninety 50km^2 cells covering a total area of 4500 km (Figure 1). These 50km^2 have been used to correspond to the cells used by the SCANDCAM project that uses this scale for lynx monitoring through camera traps in different parts of Scandinavia (Hofmeester et.al 2021). The SCANDCAM project is a collaborative work between different researchers from SLU and other universities that aim to optimize the Eurasian lynx monitoring by using camera traps in Scandinavia (SCANDCAM, ResearchGate). The project aims to implement camera trapping in Västerbotten and for this reason my thesis project was created.

The area can be divided in three sub-areas: the core area, the south area and the north-east area (Figure 1). The core area was already known to be home to the Eurasian lynx prior to this study. The two other areas, found respectively south-west of Umeå (South Area, in purple, Figure 1) and south of Skellefteå (North-east Area, in Red, Figure 1), were thought to be potential good areas for Lynx monitoring. I have selected these two areas in collaboration with the wildlife managers of the County Administrative Board (CAB) as the CAB had a specific interest in monitoring lynx in areas closer to the coast. Finally, the light purple and light blue areas visible in Figure 1 were added to match the number of cameras available on the same principle of collaboration with the CAB.

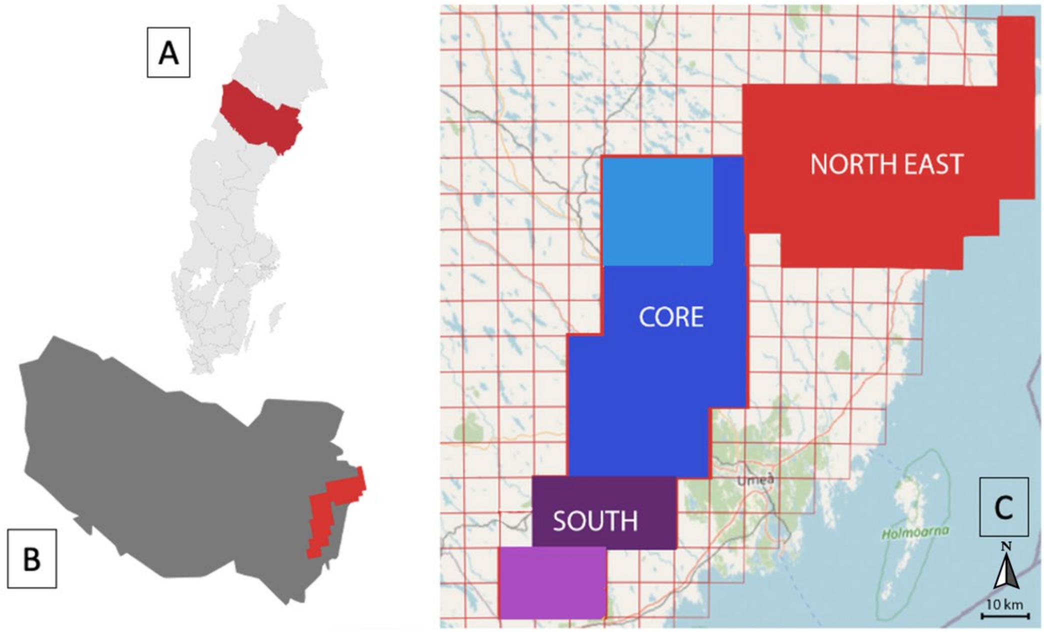

Figure 1: Study area. A) Map of Sweden showing the position of the Västerbotten County in red. B) Map showing the position of the study area inside the Västerbotten County in red. C) Map of the study area and its different parts. Created in Photoshop.

2.2 Camera trapping

I placed one camera trap in each 50km^2 grid cell of the study area in collaboration with staff of the CAB of Västerbotten, for a total of 90 cameras and 90 grid cells covering the whole study area. Fifty camera traps (Recony HC500) where placed in the centre of the study area, while 40 camera traps (model of CAB) were placed closer to the coast (Figure 2). I assumed that the difference in detection between the two models is not relevant for this thesis as both camera models had rather similar characteristics.

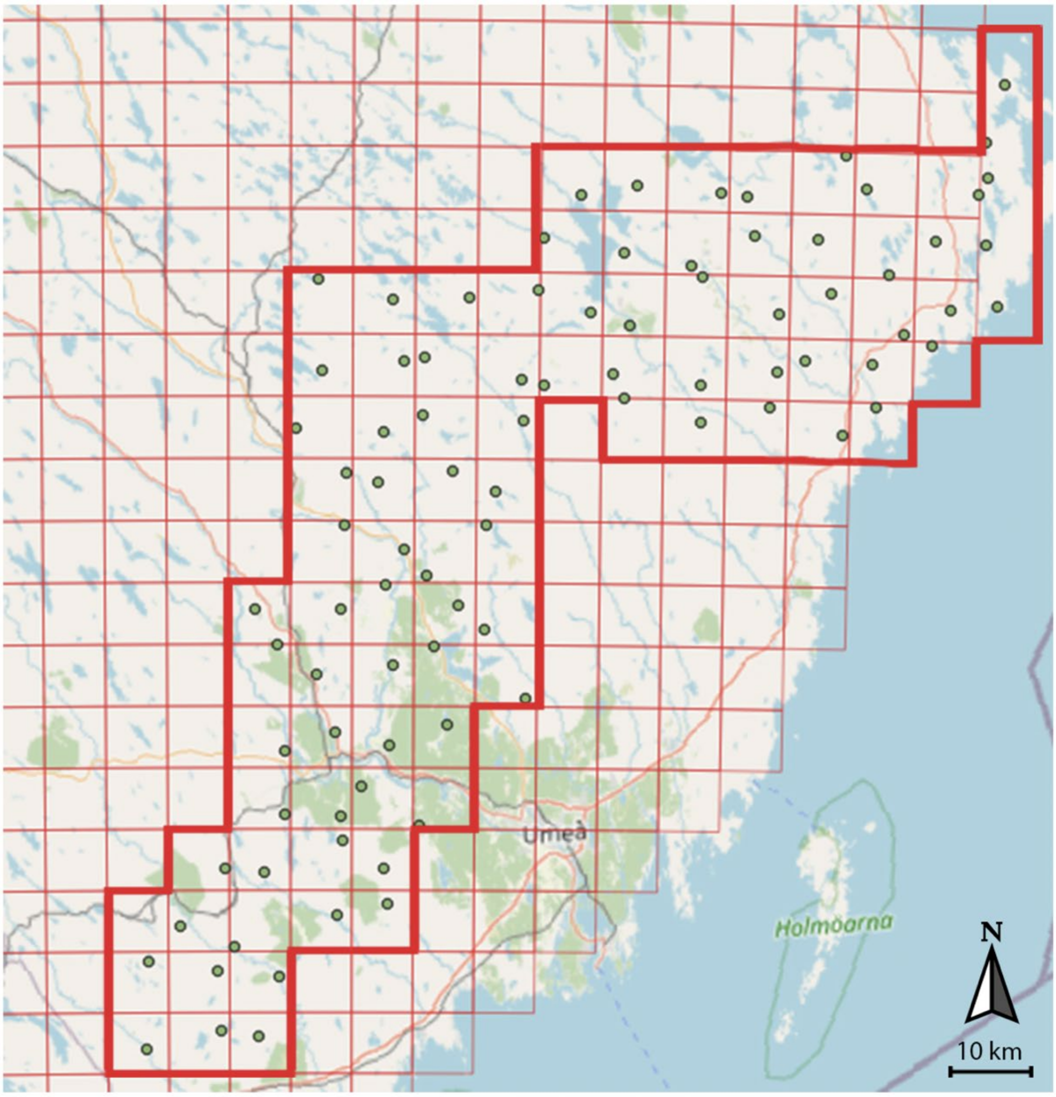

Figure 2: camera trap locations. The red delimitation shows the boundary of the study area while each green point corresponds to a camera location. One camera was set in each 50km² grid cell. Created in Photoshop.

The targeted cameras where set-up on mature trees at approximately 90cm height to aim specifically for the Eurasian lynx while some of them located in low densities forest were put a bit higher on the tree to prevent as much as possible the snow to cover the camera. The cameras were targeted towards animal paths or corridors in the forest, cliff edges and passages between boulders or forest roads and powerlines, when it was possible, to increase the chances of detecting an animal that would pass in the area of the camera.

The cameras were all set to fast trigger and high sensitivity to prevent missing an animal passing by. They were also set to burst mode with 3 pictures in a row for each detection. Finally, laminated signs were put up next to the SLU cameras as an informative tract to inform potential people passing by. The signs were placed in such way that they would not face the path or corridor towards which the camera was aimed to prevent as much as possible from animals to be either scared or attracted.

2.3 Camera locations selection

The camera locations have been thoroughly selected to test for different habitat types based on certain criteria: terrain ruggedness (variability in elevation: the more the elevation varies in a certain measured patch of the habitat, the more rugged the terrain is in that patch), distance to the nearest field, tree cover and overall topography. The study area being mostly represented by rather flat terrain with low or medium covered managed forests and mires, the cameras in grid cells presenting potential locations with different habitat types with more dramatic topography, terrain ruggedness and higher tree cover would be placed on these locations to enable for greater variation in habitats. This is even more important based on previous studies in southern Norway and Sweden that tended to show that the Eurasian lynx seem to favor rugged terrain and higher elevations especially in human-modified areas (Bouyer et.al 2015). Similarly, river edges and dramatic terrain on lake banks were also selected when available.

The locations were therefore chosen by looking at different geographical features using predominantly the Geographic Information System program QGIS version 3.20.3-Odense, as well as Google maps (QGIS.org, 2022). For each grid cells, I selected two potential locations based on terrain ruggedness, tree cover, distance to nearest field and overall topography.

The first step was to look at the terrain ruggedness. I generated a Terrain Ruggedness Index (TRI) layer from an elevation raster layer in QGIS that enabled me to observe the variation of terrain ruggedness in each cell (Riley et.al 1999). The terrain ruggedness index reveals topographic heterogeneity thanks to a graduated coloration for ruggedness in each 3x3 pixel patch (Riley et.al 1999). The whiter the patch, the more rugged the terrain is in this patch (Figure 3). As previously explained, the mean ruggedness in the study area is very low and in most grid cells, the highest ruggedness is also low, especially for the North-East area were flat terrain and mires are predominant. Therefore, whenever a cell would show a specific location with higher ruggedness I would select for this location. This implies that the design of this study is a structured targeted sampling, which was in accordance to the elusiveness of this extremely rare carnivore.

On top of that, I uploaded a generalized Sweden land cover layer from 2018 showing the different land cover types that enabled me to differentiate forests from fields, mires, clear-cuts and so on (Figure 3). After looking at the terrain ruggedness, I focused on this feature for the location selections to make sure I wouldn’t place the camera on a location where the land cover would be unsuitable. In fact, from previous studies (Bouyer et.al 2015, Filla et.al 2017, Podgórski et.al 2018) and knowledge acquired by speaking with researchers working on the Eurasian lynx and people directly involved in the Eurasian lynx management, I decided to avoid certain land cover types such as mires, fields, urban areas or quarries. A lynx could definitely move through these areas, but the goal of the study is to identify the best habitats to detect the Eurasian lynx. Having set-up cameras on these specific terrains would have most probably been a waste of time and resources and would have brought way less results in my opinion.

Finally, I looked at the available QGIS Open Street Map and at the satellite view from google maps (Figure 3). This allowed me to identify better the potential human settlements close to the cameras, roads, paths but also accessibility to the location. This is the style

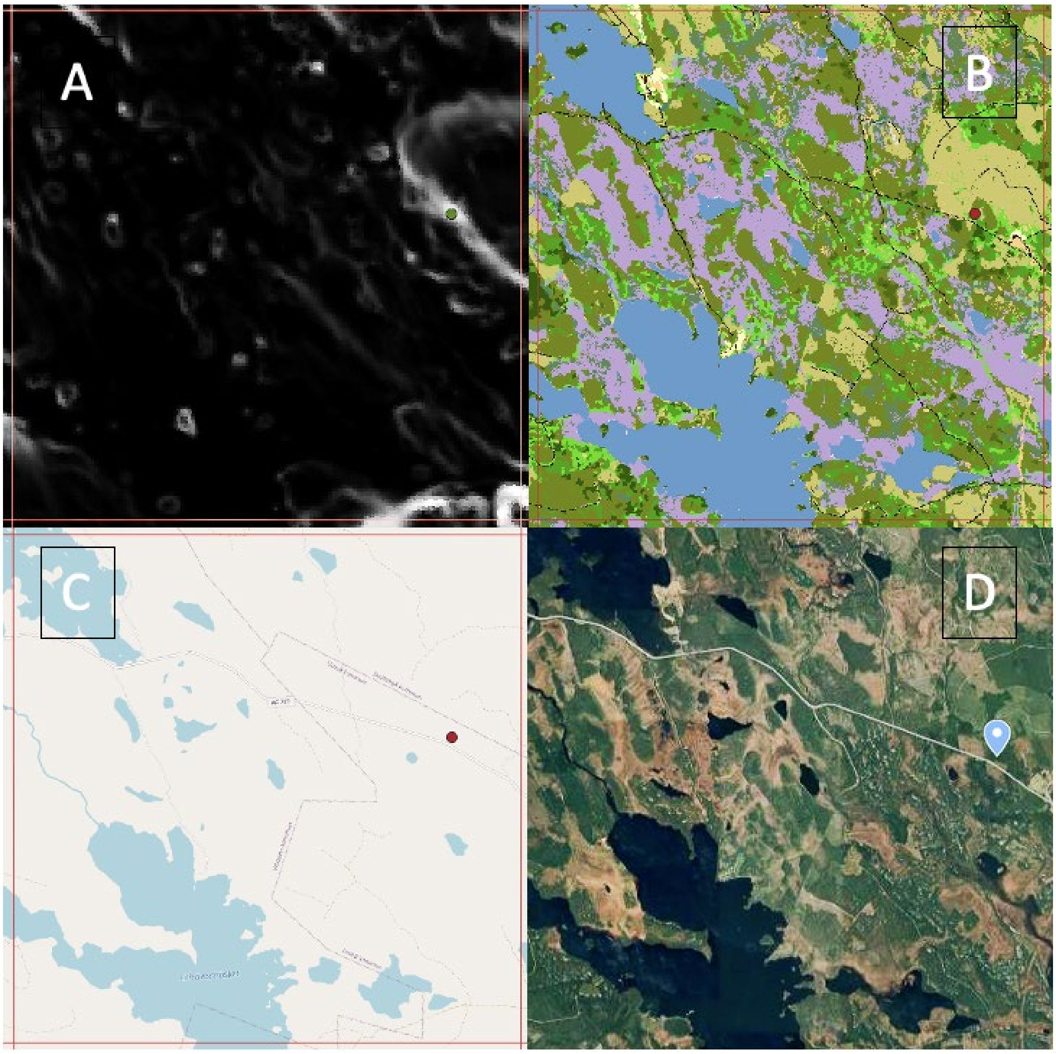

Figure 3: different layers used for camera-trap location selection. A) Terrain ruggedness index layer: layer generated from QGIS where the whiter areas correspond to the patches where the index is higher and therefore where the terrain is more rugged. B) Land-cover layer: QGIS layer showing the different land-covers thanks to a color code. For example, the purple areas represent mires while the small light beige patches are representative of fields. C) Open Street map: available in QGIS, it shows the main roads and paths. D) Satellite layer: available in google maps, it shows a real view of the area.

The next step consisted in comparing my two locations per grid cell with previous data from the CAB to see if any of the locations corresponded to an area where Lynx had been seen and/or monitored. Although this happened rarely, there were some locations that were corresponding to places where lynx had been recorded. For these few grid cells, the cameras were placed on the area where Lynx had been previously spotted.

The selection was made to enable to have a variation in habitats but also in microsites. In fact, I arbitrarily selected for specific features at smaller scale to test for different microsites. This includes forest roads, powerlines, bridges over small streams and so on. I chose these features upon knowledge that the CAB and researchers from SLU shared with me. While I chose some of these features during the QGIS locations selection, such as powerlines or forest roads which are clearly visible at these scales, I selected others such as small bridges and snowmobile paths directly on the field. These specific microsites used for some of the locations, together with the other natural ones enabled to obtain five microsite types, each represented by a rather similar number of cameras, that will be described further below.

2.4 Microsite Classification

In order to get a clear depiction of different microsites, I made sure during the setting of the cameras on the field to write down for each camera a detailed description of the microsite where it was set up. I noted down tree cover, overall description and specific features. This being done only for the Recony HC500 cameras managed by myself, I also focused on the pictures obtained by both Recony HC500 and CAB camera model, to depict the microsite as best as possible. I came up with descriptions mentioning overall microsite type, tree density, steepness and specific features. After doing so, I decided to arrange the different microsites into 5 main different microsites categories that would be used for the analysis, classifying all cameras into one of these 5 categories.

These categories follow the main criteria cited above (tree cover, steepness, specific features, etc.) and are arranged so that each category is representative of a specific microsite. From previous studies (Bouyer et.al 2015, Filla et.al 2017, Podgórski et.al 2018) and discussions with people having previously studied the Eurasian lynx, I hypothesized the types of microsites that the Eurasian lynx would favor, those which should in theory be avoided and others for which it was unclear and built the 5 categories accordingly. In fact, these studies and discussions have taught me that the Eurasian lynx generally uses isolated microhabitats with rather high tree cover to avoid humans and move through the landscape while also avoiding totally open areas. Moreover, when possible, as other big predators the Eurasian lynx tends to favor paths through forests to move with ease. I therefore came up with microsites depending on the degree of isolation relative to steepness, tree cover and features such as boulders and rocks as well as the degree of facilitation of movement with paths, trails and roads through the landscape.

Microsite 1

Cameras on forest roads, forest trails, powerlines and other clear paths in flat and semi steep terrain going through rather dense forests (Figure 4). My preliminary thought was that this microsite type would feature some lynx detection as being a movement facilitator through areas where tree densities and global isolation is relatively high.

Figure 4: red fox (Vulpes vulpes) on a forest road crossing a dense forest, typical from microsite 1.

Microsite 2

Cameras in the middle of clear cuts, fields and other exploited terrains with low or no tree cover and flat terrain as well as low covered flat forests (Figure 5). My preliminary thought was that this microsite could possibly feature some lynx detections, as roe deer tend to forage in such areas and I always tried to target a movement facilitator such as the bridge shown in figure 5.

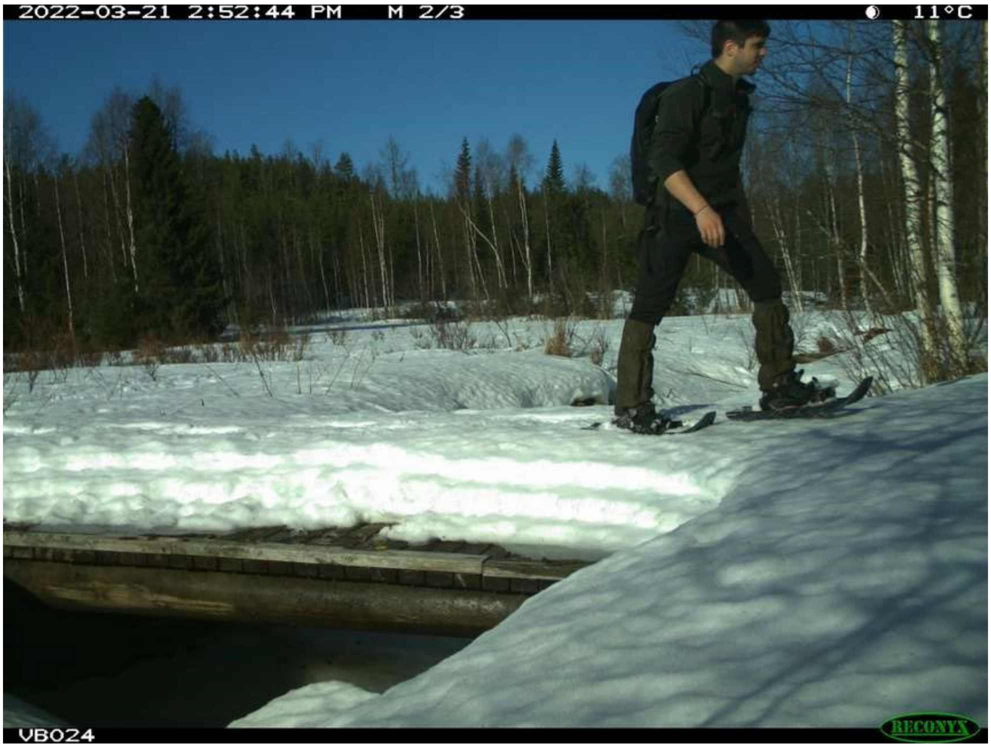

Figure 5: myself on a bridge between two fields with no tree cover and flat terrain, characteristic of microsite 2.

Microsite 3

Cameras in the middle of flat high covered forests, semi-steep medium-covered forests and mountain tops (Figure 6). My preliminary thought was that this microsite could be both a rather good one for lynx detection with rather high isolation but no clear movement facilitator.

Figure 6: roe deer (Capreolus capreolus) on a mountain top with medium tree cover, typical from microsite 3.

Microsite 4

Cameras on boulders and cliff areas with medium to high tree cover with semi-steep and steep terrain (Figure 7). I directly thought this microsite could feature most of lynx detections for its characteristics. Boulders and cliff paths can facilitate the movement of lynxes and are found most of the time in isolated mountains at high elevation. The huge rocks and cliff walls make it also trickier for silviculture and accentuates isolation.

Figure 7: reindeer (Rangifer tarandus) in a boulder area in a steep forest with medium tree cover, typical of microsite 4.

Microsite 5

Cameras in steep forests as well as high covered semi-steep forests (Figure 8). My preliminary thought regarding this microsite was that it could feature multiple detections of lynx given the degree of isolation. Steep dense forests would in fact enable them to avoid disturbance.

Figure 8: picture of a semi-steep high covered forest with high tree density, typical of microsite 5.

Table 5: Number of cameras and cameras having detected the Eurasian Lynx per microsite as well as percentage of cameras having detected lynx per microsite.

Microsite	N° of cameras	N° of cameras detecting lynx	Percentage of lynx detections (in %)
1	15	2	25
2	16	0	0
3	17	0	0
4	19	5	62.5

The microsite categories were also made to be roughly balanced to be able to compare the impact of each microsite on lynx detection.

2.5 Picture classification

The pictures taken by the camera traps were all uploaded into an open-source web-based application called TRAPPER for classification. TRAPPER is in fact an online based software created and designed from the programming language PYTHON that enables to manage and classify pictures from camera traps (Bubnicki et.al 2016). In addition to that, TRAPPER enables camera trap data reuse and facilitates collaborative work on camera trapping projects (Bubnicki et.al 2016).

Therefore, the data obtained during this thesis project will be available for future studies.

TRAPPER enabled me to upload the pictures for each camera alongside their location and therefore made it easier for me to understand what picture was taken where. The classification was done through a specific process, as I classified the pictures from each camera one by one until I was done with all cameras. I went over 35000 pictures to identify if and what animals were present in each of them. After the classification, TRAPPER allowed me to export an excel file from the classification project showing each camera and location of the camera with each passage of animals corresponding to it. For my thesis, I focused on the detections of lynx as well as its three main preys as stated in the introduction (reindeer, roe deer, mountain hare).

When a picture was not showing anything except from the environment, I classified it as "empty" while the presence of an animal, person or vehicle would be classified as such. For animals, TRAPPER also enables to state the species, the number, the sex the age and other characteristics. Although I didn't specify the sex or age as it wasn't important for my study, I always stated the species and number of individuals in the picture as both would be important for the analysis. In TRAPPER one can also specify what's called the "count new" which enables to mention when a new individual would appear in the picture to facilitate the total count of a group of animals. For example, if in one picture 6 reindeers would be captured and in the next one a 7^{th} would appear, I would enter in the interface in the "count new" box 1 for one new individual. This aspect would be very important for the analysis as the "count new" would be visible in the excel sheet exported after the classification, enabling me to calculate the total number of individuals for each passage.

2.6 Additional data extraction

To obtain more habitat data to understand the variables that impact the detection of lynx at larger scale, I extracted additional information from QGIS.

I wanted to understand if field cover was a criterion that would impact the detection of lynx by camera traps. Consequently, I first focused on field cover within a nearby area of the camera. To do so, I created a 1km buffer area around each camera and calculated the field cover of field polygons within these buffers. I created the polygons using the "add polygon feature" tool available on QGIS. After calculating the total field area within each buffer, I converted the values into percentage of field cover for each camera within a buffer of 1km. This gave me the percentage of field cover 1km around each camera.

Moreover, after discussing with people that worked on the Eurasian lynx, I learnt that the Lynx often uses river banks and steep terrain close to lakes to move through the landscape. I then decided to test for that by extracting more geospatial data around the camera. I observed using QGIS and google maps if the camera was within 200m of either a lake or a river to understand if this variable would impact lynx detection. I measured the distance between the nearest water body and the camera, using the measure tool in QGIS, to see if indeed the water body was within that distance or not. This would eventually give me a binary variable for my analysis with Lake presence within 200m of the camera being coded as “1” and Lake absence within 200m of the camera being coded as “2”. I chose the value of 200m arbitrarily because it seemed close enough to the camera to represent a potential impact of this variable, while incorporating at least some locations.

2.7 Analysis

2.7.1 Data importation, exploration and manipulation

From the data extracted from QGIS, the microsite classification as well as the picture classification’s excel sheet, I created a spreadsheet that would be used for the entire analysis. The csv spreadsheet featured all cameras with all habitat and microhabitat variables corresponding. It also featured the data extracted from TRAPPER meaning the lynx detections, the effort in days as well as the total amounts of detections of the three main Eurasian lynx preys (roe deer, reindeer and mountain hare). Additional columns were added to obtain the rate of detection per day.

I then imported the csv spreadsheet into R, an open-source high-level programming language largely used for applications in ecology (R Core Team 2013, Sihaloho et.al 2015). The model that I eventually computed for the analysis was a Generalized Linear Model (GLM). One important assumption used in linear modelling is the independence of the covariates (Smith et.al 2019). Covariates that are correlated lead to inflated standard errors and no significant predictors (Smith et.al 2019). In the eyes of that assumption, I had to make sure that the covariates I would use wouldn’t be correlated. I first plotted histograms of my variables to understand which ones were toughly normally distributed as this is required to run a Pearson’s correlation test (Obilor et.al 2018). For the covariates that were already approximately normal, no modification was required but for the the others, a manipulation was necessary. For this purpose, I used a logarithmic transformation with the aim of obtaining normality for these covariates (Althouse 2015). I then ran my Pearson’s correlation test for my now normally distributed continuous variables to assess for the existence of linear relationship between them and to measure the strength of these relationships (Samuels et.al 2014). I did not include my categorical variables in this test as it is suited for normally distributed continuous variables (Obilor et.al 2018, Arize 2022). To run the correlation test and visualize its outcome, I used packages “corrplot” (Wei et.al 2021) and “psych” (Revelle 2022).

2.7.2 Statistical analysis

To test my hypotheses, I applied Generalized Linear Models (GLM), with a Binomial distribution and a log-link function (log10) as well as an offset of trapping effort to correct for differences between cameras. I generated four preliminary GLMs to decide for the covariates that would be featured in my final model. In fact, having a low number of lynx detections, I couldn’t include all my covariates into one model. The different models I computed also link to my different hypotheses : the first model featured the habitat variables (field cover, terrain ruggedness and water body proximity), the second model featured the reindeer passage rate (as both reindeer passage rate and mountain hare passage rate are significantly correlated from Pearson’s correlation test and could therefore not be fitted in the same model), the third model included the rest of my prey prevalence variables (roedeer passage rate and mountain hare passage rate) and the fourth included the microsite type. For the microsite GLM, I ran a Tukey test as post-hoc to compare the different categories using the package “multcomp” (Hothorn et.al 2018). Finally, to select the covariates for my final model, given the size of my sample, I decided to reject the null hypothesis whenever the p-value would be <0.1 (Thiese et.al 2016, Kim et.al 2019).

After I obtained the results of the four preliminary models, I computed my final model that featured the variables that were significantly correlated with the detection of lynx in the four models mentioned above. To visualize the impact of both covariates on lynx detection, I generated two effect plots using the package “jtools” (Long 2022).

3. Results

3.1 Camera trapping

Out of the 90 camera traps, 3 of them were not included in the study either because the camera was completely empty or malfunctioning, or because the camera was lost. A total of 8 cameras captured lynx (figure 9), 25 captured reindeer, 12 captured roe deer and 39 captured mountain hare. The cameras that did capture lynx detected from 1 to 7 passages for an average of 2.5 lynx passages (Reindeer: range from 1 to 163 with average of 23.92 passages; Roedeer: range from 1 to 37 with average of 8.83 passages; Mountain Hare: range from 1 to 21 with average of 2.92 passages) Out of the 8 cameras that captured the Eurasian lynx, one camera captured a family group. Finally, out of these 8 cameras, two of them were located in a microsite of type 1, four of them in a microsite of type 4 and one of them in a microsite of type 5. No camera placed in microsites 2 and 3 detected lynx.

Individual cameras were deployed for a period of 98 to 134 days. This variation was due to differences in accessibility of the sites and the need to use part of the cameras for monitoring in another project.

Figure 9: locations where cameras detected lynx (Obtained from @googlemaps, edited in @Photoshop)

3.2 Analysis

As stated in the methods, the first four preliminary GLM's I computed were fitted to identify, per category of variables (habitat, prey, microsite), the ones that were impacting significantly the detection of lynx.

Model 1: habitat covariates

Table 6: table of the results obtained from the first computed GLM. (Water YES = category featuring the cameras having a water body in their proximity). Highlighted p-values are the ones <0.1 corresponding to significant estimates with a confidence interval of 90%.

	Estimate	*Std. Error*	*p-value*
(Intercept)	-7.99668	1.10033	<0.001
FIELD	-0.04917	0.06309	0.4358
Ruggedness	0.13882	0.07900	**0.0789**
Water YES	-0.29777	0.95675	0.7556

The GLM predicted a positive relationship between terrain ruggedness and lynx detection (table 2). Other relationships were either insubstantial, such as the relationship between field cover and lynx detection, or insignificant such as the relationship between water body proximity and the detection of lynx.

Regarding terrain ruggedness, I decided based on this result to include the variable into my final model.

Model 2: reindeer passage rate

Table 7: table of the results obtained from the second computed GLM. Highlighted p-values are the ones <0.1 corresponding to significant estimates with a confidence interval of 90%.

	Estimate	*Std. Error*	*p-value*
(Intercept)	-5.4775	0.8361	<0.001
Log10Reindeer	0.9505	0.5214	**0.0683**

The GLM predicted a strong positive relationship between the log10 transformed reindeer passage rate and lynx detection with a significance of less than 10% (table 3). This led me to include the log10Reindeer into my final model.

Model 3: prey covariates

Table 8: table of the results obtained from the third computed GLM. Highlighted p-values are the ones <0.1 corresponding to significant estimates with a confidence interval of 90%.

	Estimate	*Std. Error*	*p-value*
(Intercept)	-7.6897	3.1960	0.0161
Log10Hare	-0.6696	1.3782	0.6271
Log10Roedeer	0.2737	1.0702	0.7982

The GLM didn't predict any significant relationship between either of these two variables and the detection of lynx (table 4). For this reason, none of them were included into my final model.

Model 4: microsite type

Table 9: table of the results obtained from the post-hoc Tukey test associated with the fourth GLM. Highlighted p-values are the ones <0.1 corresponding to significant estimates with a confidence interval of 90%.

	Estimate	*Std. Error*	*p-value*
2 – 1	-17.80476	2684.06485	1.000
3 – 1	-17.78351	2605.42013	1.000
4 – 1	0.69240	0.92511	0.926

5 – 1	-1.25477	1.27848	0.823
3 – 2	0.02125	3740.64393	1.000
4 – 2	18.49716	2684.06479	1.000
5 – 2	16.55	2684.06494	1.000
4 – 3	18.47591	2605.42007	1.000
5 – 3	16.52875	2605.42022	1.000
5 – 4	-1.94716	1.14998	0.361

The post-hoc Tukey test associated with the GLM didn't predict any significant relationship between any of the microsite types and the detection of lynx (table 5). For this reason, none of them were included into my final model.

Final Model

My final model featured the two covariates that I selected based on the initial modelling: terrain ruggedness and log 10 transformed reindeer passage rate (table 6).

Table 10: table of the results obtained from the final GLM. Highlighted p-values are the ones <0.05 corresponding to significant estimates with a confidence interval of 95%.

	Estimate	*Std. Error*	*p-value*
(Intercept)	-6.84318	1.12420	<0.001
Ruggedness	0.20237	0.09284	**0.0293**
Log10Reindeer	1.41971	0.62961	**0.0241**

Based on the final model, I found evidence for an increase in lynx detection with terrain ruggedness (table 6, Figure 12) as well as an increase of lynx detection with the passage rate of reindeer (table 6, Figure 13)

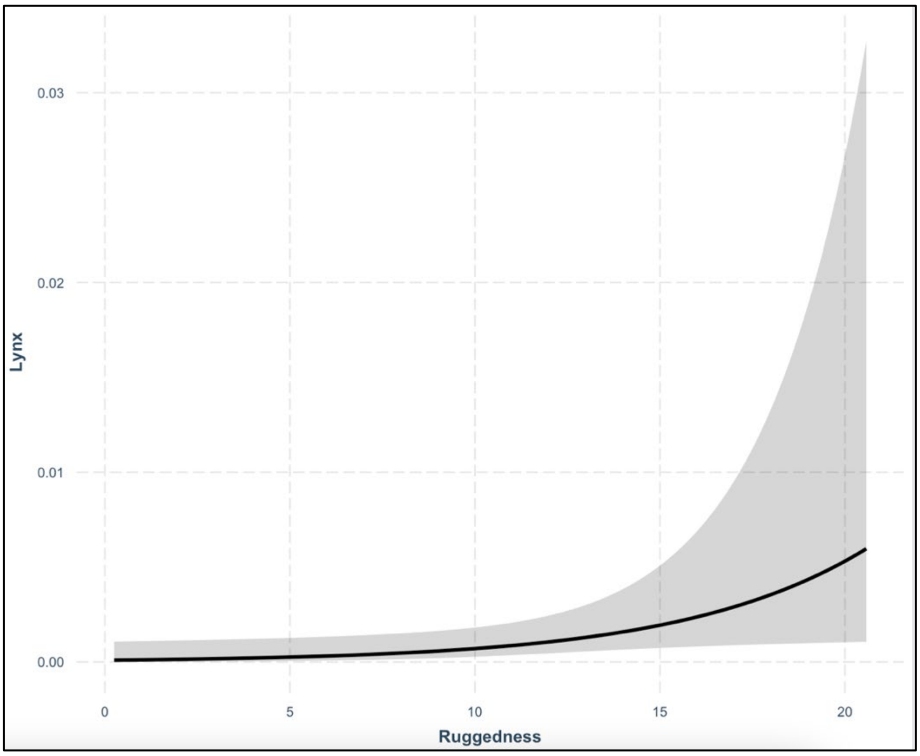

Figure 10: effect plot of estimated lynx detection frequency increasing with terrain ruggedness. The plot shows the prediction of the GLM with a 95% confidence interval.

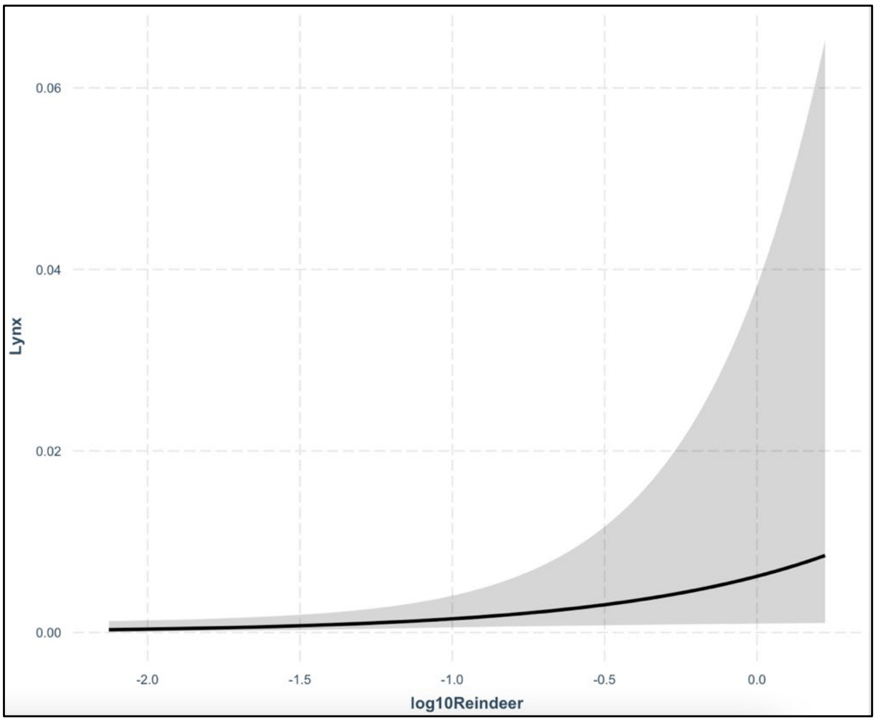

Figure 11: effect plot of estimated lynx detection frequency increasing with log 10 transformed reindeer passage rate. The plot shows the prediction of the GLM with a 95% confidence interval.

4. Discussion

In this thesis, I studied the impact of different environmental variables on the detection of the Eurasian lynx by camera traps. My analysis showed that the reindeer passage rate and the terrain ruggedness index were positively correlated with lynx detection. In other terms, cameras that are set up in locations with a higher reindeer prevalence and a higher terrain ruggedness index should have an increased probability of detecting this elusive large carnivore. In contrast, other variables – microsite type, water body proximity, roedeer and mountain hare prevalence as well as field cover and distance to nearest field – did not impact the detection of the Eurasian lynx in this study according to my analysis.

4.1 Impact of habitat variables on lynx detection

While I hypothesized that all my habitat variables would impact significantly lynx detection, it appears that only terrain ruggedness did so.

When it first comes to distance to nearest field and field cover, which are closely related, I had based my hypothesis on the fact that in southern Scandinavia, lynx tend to favor medium levels of modification of the landscapes, with prevalence of agricultural crops, as being the foraging ground of one of their main preys, the roe-deer, as suggested by Bouyer et.al (2015). Moreover, as the Eurasian lynx avoids highly modified landscapes, even when they associate with higher roe deer densities in southern Scandinavia, I had thought that the relative decreased human impact on the landscape in Northern Scandinavia compared to the south would result in lynx favouring these areas where field cover is higher. However, the results showed no correlation between field cover/distance to nearest field and lynx detection. Additionally, the Pearson's correlation test I ran during the analysis had also shown a significant positive relationship between roedeer prevalence and both field variables. Finally, the results showed no influence of roedeer prevalence on lynx detection. Therefore, the presence of a different prey community in Northern Sweden, with the reindeer husbandry area (Kjellander et.al 2010), might impact the way the Eurasian lynx uses the landscape to a degree I wasn't expecting.

Regarding water body proximity, the researchers I talked to had emphasized the fact that Eurasian lynx movement might be guided by bodies of water areas that presented specific features as steep terrain and cliffs. While I did select for these features when choosing the locations, it makes more sense that it is the terrain itself and the according features that would impact the detection of lynx rather than the presence of water itself. To test for the actual impact of water ponds on lynx detection, I should have probably selected areas with different terrain types rather than rugged and isolated terrain close to water. However, in a country such as Sweden where water is far from scarce, it is unlikely that the presence of a water pond would have greatly, if it would have, impacted the detection of the Eurasian lynx.

Finally, the terrain ruggedness was the only habitat variable that did impact the detection of the Eurasian lynx by camera traps, according to my results. This aspect of my study seems to follow what was already known for more southern populations of lynxes in Scandinavia and the rest of Europe (Bouyer et.al 2015, Filla et.al 2017).

4.2 Prey prevalence and Lynx detection

While I had hypothesized that the prevalence of the three main preys of the Eurasian lynx would impact its detection, the results of my thesis showed otherwise.

As I predicted, reindeer prevalence had the greatest impact, with higher reindeer passage rate corresponding to an increase in lynx detection. However, the prevalence of the other two main lynx prey species – roe deer and mountain hare – did not impact its detection for this study. At a camera trap scale, lynx seems therefore to favor reindeer rather than other species. As stated above, the fact that lynx detection also does not seem to be affected by field habitat variables supports in some way this hypothesis. It also reflects in the inexistence of a relationship between roe deer prevalence and lynx detection by camera traps. These results strongly echo the conflict between reindeer husbandry and lynx management and support the need for the development and evolution of effective monitoring programs.

When it comes to the mountain hare, it is always possible that the height at which the camera was set up didn’t fit the size of the rodent. In fact, cameras were aimed at the Eurasian lynx and other species with comparable sizes would normally also have a greater chance of being detected, while smaller species could be missed. However, out of the three prey species, the mountain hare was the one that was captured the most by different cameras, with almost half of the cameras of the study having captured it. It is therefore very likely that results effectively showed that there is no impact between mountain hare prevalence and lynx detection.

4.3 Microsite type

For the microsite type, there seem to be no correlation between the probability of detecting the Eurasian lynx by a camera trap and the type of microsite the camera trap is set in. In fact, the results have shown no significant relationship between, any of the microsites and the lynx detection.

However, out of my five microsites, two of them did not have any detections of lynx at all. This could suppose an issue when computing the GLM as it compares the different categories of this covariate based on their differences relatively to the number of cameras detecting lynx in each category. Statistical models generally have a hard time dealing with categories that have only one value, such as my two categories that didn't detect lynx showing only zeroes.

Nonetheless, the categories that did detect lynx did not statistically differ from each other either. And while I did think there was a potential correlation between microsite and lynx detection after plotting my microsites as a function of lynx detection, I realized when discussing the matter with my supervisor, that the pattern I had found could be based on chance. In fact, as the general detection probability of the Eurasian lynx is supposedly very low, the difference between one or two detections for a given set of cameras in a category could both be the result of the same detection probability. Therefore, it is more likely that finding no statistical difference could be explained by the fact that there is actually no difference between different microsites regarding lynx detection.

Finally, I still believe it would be interesting to look at microsite type while using a bigger sample with more detections, as it would greatly diminish the probability of obtaining an intriguing pattern only by chance and would bring clearer answers upon the question of the impact of microsite type on lynx detections.

4.4 Camera trapping: Implications and recommendations for future lynx monitoring

This study underlined the difficulties of monitoring a species as elusive as the Eurasian lynx. While I tested many environmental variables to understand what would make for a perfect to detect lynx with camera traps, I quickly realized that it was an unrealistic concept. However, the study did lead to convincing results that could help for future lynx monitoring projects and raised new questions on the potential improvement of lynx detection through camera traps.

First of all, the different camera trap pictures obtained in this thesis helped to underline camera trapping factors that, when considered, could help improving the detection of lynx in my opinion. While this is not touched upon in the study itself, I would in fact strongly recommend any project focusing on detecting lynx with camera traps to respect the rule of thumbs where cameras are set towards paths, corridors, passage between two rocks (etc.) in the forest or any other habitat. In fact, all lynx pictures obtained in this study showed the different individuals using different types of paths to move with ease through the forest, cliffs (etc.). It also appears that the lynx remains on the path when looking at sets of 3 pictures from one detection. In the eyes of this pattern, would setting the camera facing the path rather than the flank of the path enable to increase the chance of detecting the Eurasian lynx as it would remain in the camera field of view for a longer period?

Moreover, as camera trap is not limited by seasonality, it could be interesting to run a similar study in summer as semi-domesticated reindeers migrate in spring and the Eurasian lynx do not appear to migrate with them according to Danell et.al 2006. The results could therefore be totally different and comparing the impacts of different seasonal environmental variables on the detection of lynx could enable to identify which variable in which season would have the bigger impact on lynx detection. Could indeed a specific season benefit the monitoring of the Eurasian lynx by camera traps?

Finally, the result of my study also implies that specific attention could be set upon reindeer herd winter feeding grounds for monitoring lynx. However, as reindeer herds expand through a large part of the landscape in northern Sweden, focusing only on this aspect wouldn't be of great use to understand which locations to select for. I therefore suggest combining this factor with terrain ruggedness to reduce the potential locations for monitoring lynx in Northern Sweden. For other regions in Europe, conducting a similar study could enable to identify if other preys' prevalence such as the roe deer or wild boar (*Sus scrofa*) could impact the detection of lynx in a way that is comparable to reindeer and lynx in northern Sweden. Terrain ruggedness having already been shown to be selected by lynx in other regions in Europe, as stated above, using this index to choose for locations could be a great asset for increased detection.

In conclusion, with issues driven by the presence of lynx in the reindeer husbandry area and the rise of new challenges led by the recolonization of southern Scandinavia by the Eurasian lynx and the acceleration of climate change, camera trap-based lynx monitoring in Sweden seems to be more than ever an interesting alternative to the current monitoring program. As elusive as the Eurasian lynx is, it can be captured through camera traps all year long and implementing knowledge to target specific locations can increase its detection by camera traps and therefore the monitoring of lynx by cameras overall, as shown in this study.

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Popular science summary

The presence of the Eurasian lynx can be conflictual with different human activities. In Sweden, as the lynx hunts reindeer, sheep but also roe deer and other wildlife, it impacts both livestock and farming activities, reindeer husbandry in the north and hunting. To understand and predict the true impact of this animal on human activities locally but also at a regional and national scale, it is important to understand how many there are and where they occur.

For this reason, wildlife management focuses on what is called monitoring, which is a way to get information annually about where and how many lynxes are. This is done by counting their tracks in the snow, enabling to identify the number of individuals in the different areas where these counts are done. However, as the climate is changing, snow is becoming scarcer, and this monitoring technique is under threat. An alternative method is to use camera traps, which are basically cameras set up in the forest, attached to a tree, that take a picture of whatever animal passing by thanks to a sensor that detects it. However, the Eurasian lynx is an extremely rare and shy animal and setting up a camera randomly in the forest would probably lead to not taking any picture of lynx and therefore not having proper information according to where they occur and how many there are.

It is therefore crucial to understand where to set up the camera traps to have proper results. In the eyes of that problem, I focused with this thesis on understand what factors can help increasing the chance of capturing a lynx with a camera trap. These factors consist of topographic and geographic factors, prey factors as well as camera site factors. After setting up 90 cameras in the forest and obtaining the factor's information, I did some statistical analysis to understand which factors had the more impact on the chance to capture lynx with a camera trap. My results showed that both the presence of reindeers and high terrain ruggedness, which is a topographic index informing on the variation of altitude and steepness in a specific patch, were the two main factors that impacted the chance of capturing lynx with camera traps.

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