Master Thesis

for the master's degree Programme in Biology of Environmental Change

THE EFFECT OF FOREST STRUCTURE ON THE NUMBER OF MOOSE VEHICLE COLLISIONS IN FINLAND

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Abstract

Ungulate-vehicle collisions are an increasing threat to traffic safety. Collisions with moose in Nordic nations comprise nearly 80% of accidents resulting in death, injuries, and notable economic losses. This study focuses on the use of finer spatial data resolution and explores the distribution of accidents on different roads and during different seasons, the effect of forest structure on moose-vehicle collisions (MVCs) recorded in two distinctive regions of Finland (North Karelia and Ostrobothnia), and the various mitigation measures currently in place. A total of 1123 collisions were obtained from the registry of wildlife damages and accidents for North Karelia and Ostrobothnia, 78% and 65% of which respectively occurred on highways. Nearly 53% of collisions in both areas were recorded during the hunting season. The effect of the density of moose observations and 18 forest structure variables was tested for all recorded MVCs. Both the density of moose observations and canopy cover were positively related to the variation of MVCs in both areas. The model of Ostrobothnia reports that the volume of spruce trees and deciduous trees is positively related while the mean height of spruce trees is negatively related to the spatial variation of MVCs. In contrast, the model of North Karelia describes only a positive relationship between the stem count of deciduous trees and collisions. This study suggests that efforts to minimize the risk of MVCs require alternative technological advancements. The use of finer spatial data resolution to train systems to detect landscape features as well as to better inform drivers through dynamic warning signs is essential.

Acknowledgments

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Abbreviations and Definitions

AVC	Animal-vehicle collision
MVC	Moose-vehicle collision
UVC	Ungulate-vehicle collision

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1. INTRODUCTION

1.1 A brief overview

Road network expansion increases ecological impacts and exacerbates the ongoing conflict between wildlife and urban infrastructure (Freitas, Hawbaker & Metzger, 2010). As roads permeate and traffic volumes increase, the number of Animal-vehicle Collisions (AVCs) escalates, becoming a significant threat to human and wildlife safety (Lao et al., 2011, Gunson et al., 2011). Each year, approximately one million accidents with large wild ungulates occur in Europe (Niemi et al., 2017), and these numbers are more likely to increase as the population of large ungulates continues to grow (Apollonio, Andersen & Putman, 2010). Studies on human safety and injury rates in AVCs are limited (Haikonen and Summala, 2001; Niemi, 2017), but literature reports that Moose-Vehicle Collisions (MVCs) in Nordic nations comprise up to 80% of the total animal-related accidents that result in death, injuries, and notable economic losses (Seiler, 2005). The complex nature of moose-vehicle collisions can be explained by the spatial-temporal modelling of influencing factors such as animal behaviour, landscape structure and traffic characteristics. However, several of the projects focusing on the issue have been independent small-scale studies that do not provide enough information regarding specific species and environmental factors (Pagany, 2020).

The remaining sections of the introduction cover a literature review that includes information on moose populations in Finland, the environmental factors explaining the variations in MVCs, and the applied mitigation measures to reduce and minimize the effect of MVCs. In the end, the section estates the aim of this study.

1.2 Moose in Finland

The nature of moose (*Alces alces*) in Finland is largely discussed amongst scholars. Despite the increasing number of accidents resulting in broad socio-economic losses, moose is also considered a valuable game species (Niemi et al., 2015). An approximate 80000 individuals are hunted yearly (Finnish Wildlife Agency, 2021), and its meat represents a near 40 million euro in revenue. The species also play an important role in boreal forest ecosystems. McInnes et al., 1992 found long-term moose browsing may decrease the frequency of fires, increase species richness, and influence the nutrient cycling rates. It is thus important to understand the complex spatial-temporal relationship of moose and their habitat.

The seasonal habitat uses and migratory patterns of moose in Finland are well understood. (Melin, 2014). It is widely suggested that moose habitat selection is the result of trade-offs between minimizing energy lost (migratory distance), reducing predation (cover), and maximising energy intake (food) (Dussault et al., 2005, Singh et al., 2012). Moose winter habitats are often characterized by Scots pine (Pinus sylvestris) forests, shrub lands and peatlands (Nikula et al. 2004). Because of its abundant availability in seedling stands over the winter, pine is the most eaten source of food in Finland, as seen by the significant browsing damage witnessed each year (Heikkilä and Härkönen, 1993). During summer, moose graze primarily at night in areas that supply high quality and energy rich foods (Hjeljord 1990, Dussault et al., 2004). No single plant appears to influence moose nutrition and habitat selection in summer, but it was discovered that young forests and cultivated fields are common night feeding grounds, while mature old forests provide protection from the heat during the daytime (Nikula et al., 2004, Melin et al. 2014).

The effects of thermal stress on moose fade throughout autumn, and their habitat narrows down to mature forests where blueberry and mushrooms predominate (Hjeljord 1990, Bjørneraas et al., 2011). Much of the autumn migratory patterns have been linked to moose being active during the rut (Neumann and Ericsson, 2018). However, it has also been proposed that hunting disturbance in autumn increase large ungulates mobility and the likelihood to cross roads (Sudharsan et al., 2006). According to Neumann et al. (2012), individual male moose are more vulnerable to hunting pressure than the general population. He suggests that moose may perceive human predation equally dangerous than other predators leading to a range of behavioural responses. It is expected to observe higher number of moose vehicle collisions during this period because of higher traffic volumes and larger number of individual moose crossing roads. In fact, in Nordic areas the number of MVCs peaks during autumn and winter (Haikonen and Summala, 2001). This thesis focuses on moose seasonal patterns to explore the temporal variability of moose vehicle collisions in Finland.

1.3 Factors influencing Moose Vehicle Collisions.

In principle, animal population size and traffic volume describe animal-vehicle collisions on a large spatial scale (Lao et al., 2011; Gunson et al., 2011). Simply stated, an increasing population in areas with increasing traffic volumes leads to more animal-related accidents. This relationship, however, is not always linear. Kušta et al. (2017) observed fewer ungulate-vehicle collisions (UVCs) during peak traffic volumes and suggested that higher traffic volume prevents wildlife from crossing roads. Similarly, Laurian et al. (2008) observed that moose habitats have well defined avoidance zones near highways that vary seasonally. Laurian's study maintains that male moose avoidance zones are wider, suggesting that road disturbance is generally more aggravating for male moose. Different demographic structures appear to influence the relative number of animal-vehicle collisions in more than one way. Male mortality rates have been found to be biased for large ungulates such as the white-tailed deer and mule deer (Olson et al., 2014; Etter et al., 2002; Philcox et al., 1999). Male moose also tend to cross roads more frequently than female moose, thus increasing male biased moose-vehicle collisions (Laurian et al., 2012). The literature thus indicates that traffic and demographic characteristics of UVCs at a population level vary spatially and across species.

Moving down the spatial scale, the relationship between animal behaviour, landscape structure, traffic and moose-vehicle collisions become more complex, and likely influenced by various local factors. Moose have been observed avoiding forest roads more consistently than highways (Seiler, 2005; Laurian et al., 2012), particularly during summer and autumn when road traffic is denser and trucks with large loads are common (Langevelde et al., 2009). This behavioural pattern may be attributed to the effects of roadside management, and the availability of food sources and mineral salts alongside highways. Rea (2003) found that roadside brush-cutting perpetuates green forages thus creating an attractive highway corridor for large ungulates. Although the presence of preferred feeding grounds may increase the risk of UVCs, alternative roadside mitigation practices have been recorded to decrease the risk of collisions. According to the findings of small-scale experiments, fences longer than 5km may reduce large mammals collision rates by 80% (Huijser et al., 2016), whereas removing cover and forage that attract ungulates may result in a 20% reduction in accidents (Clevenger et al., 2001). There are, therefore, scale-dependent factors affecting the number of collisions.

In addition to factors affecting animals and their behaviour, an important component of small-scale influencing factors is the role of the driver and the driving conditions. While vehicle speed is one of the most significant factors contributing to local-scale collisions (Seiler, 2005), restricted visibility and the topology of the road and surrounding landscape can inhibit the driver's ability to react to animals crossing the road. Pagany (2020) found that, regardless of species or region, dusk, and dawn, are characterized as periods of high collision risk. The driver’s visibility can also be impaired by weather conditions (Dussault et al., 2006), thus increasing the likelihood of animal-vehicle collisions. Snow depth and accumulation in particular are factors known to be one of the most important weather variables affecting the total number of MVCs in Nordic countries (Olson et al., 2015; Rolandsen et al., 2011). Comparatively to other factors, forest structure is less often examined (Pagany, 2020), but studies have found that the closer the forested area is to the road, the higher the risk of collisions (Carvalho-Roel et al., 2019; Bartonicka et al., 2018; Snow et al., 2014). More specifically, the effect of the proximity to deciduous and coniferous forest has been assessed as riskier than other land uses and vegetation (Pagany, 2020). Yet the effect of forest structure differs based on the characteristics of the wider landscape; for example, areas where low light and poor road conditions are common the risk of moose vehicle collisions increases (Neumann et al., 2012). Based on the potential impact on visibility, forest structures are deemed to be an important factor in determining collision risk, thus further studies are necessary.

1.4 Mitigation measures

Traffic accidents involving large ungulates are considered more than just a traffic safety issue. In Finland, nearly every MVC results in a personal injury and the calculated economic losses are twice as high as those caused by deer crashes (Niemi 2015, 2017). The traffic mortality of this animals can also pose a conservation and management challenge; harvest quotas, for example, need to include road-kills in order to keep hunting at a sustainable level. Likewise, there are cases where mortality rates have reach levels that can negatively affect the population level (Seiler, 2004). In order to prevent these collisions and minimize their negative impacts, various mitigation measures have been developed and implemented with considerable effort. It is possible to categorize mitigation measures in different ways, but this study focuses on the Mastro et al. (2017) categorization, which suggests reducing collision involves preventing animals from crossing roads and modifying driver behaviour.

The number of ungulate road-crossings are mostly prevented by population control, wildlife passages and fencing. A generally used mitigation method with a high degree of efficiency is to systematically reduce the animal population size through hunting. (Lavsund et al. 2003). In fact, since the size of the ungulate population has been identified as a significant variable for determining the frequency of ungulate-vehicle collisions (Seiler 2004), it is not surprising that controlling population size will eventually decrease collision rates. A combination of green bridges and tunnels is also a recommended method to minimize animal-traffic interactions (Glista et al. 2009). The presence of wildlife passages may also help maintain habitat connectivity and facilitate genetic continuity for various species (Beckmann, 2010). The knowledge concerning the effectiveness of passages, however, is still limited and subject to change. On the other hand, exclusion fencing to prevent animal road-crossings has been well documented (Pagany, 2020). The general trend indicates that fences are effective at reducing the number of AVCs, however, a few studies suggest that fencing alone is not a significant indicator of reduced risk of collision. For instance, Seiler (2005) found that fencing is mostly effective at reducing accidents when combined with controlled speed limits and roadside clearing.

This study is particularly focused on the role that drivers and the surrounding environment play in wildlife-related accidents. Åberg (1981) argues that the ability of the driver to detect moose or other large ungulates is ineffective, as a driver routinely and instinctively scans their environment ahead. Additionally, Neumann et al. (2012) argues that the low driver awareness towards animal-vehicle collisions may increase their risk. As a response, road administrations use warning sings to affect the driver’s behaviour and to reduce the potentially harmful interactions with wildlife. Typically, warming signs are placed in areas where AVCs and wildlife corridors have been located by hunting clubs. Some studies argue that this method is not systematic and does not follow transparent procedures (Al-Kaisy et al., 2008; Krisp and Durot, 2007; Rytwinski et al., 2016), rendering its effectiveness uncertain and ambiguous. As of today, there have been a number of promising studies that tested dynamic and animated warning signs at smaller scales (Neumann et al., 2012; Jägerbrand and Antonson, 2016), yet the effectiveness of this approach remains unclear in the long term. Alternative mitigation measures such as raising public awareness and vehicle smart animal detection systems are also commonly used, but their effectiveness is poorly understood (Meena and Loganathan, 2020). Kucas and Balciauskas (2020) posit that instead of focusing on animal behaviour, efforts to reduce wildlife collisions should instead focus on driver behaviour and road conditions. Accordingly, this study investigates the impact of forest structure on the number of moose vehicle collisions, since drivers' visibility may be impaired by characteristics of the road surroundings. To develop and optimize effective mitigation strategies, it is essential to gain a deeper understanding of the factors that drive animal-vehicle collisions.

1.5 Aim of the study

The overall aim of this thesis was to study how the forest structure influenced the number of moose vehicle collisions. This study focuses on the use of fine-scale spatial data to explore the assumption that different forest structures influence the presence of moose near road networks thus increasing the risk of collision. The assumption that the driver's visibility is hampered under certain conditions is also considered throughout this thesis. To further understand the spatial and temporal patterns of MVCs, two distinctive regions in Finland were selected. Finally, the thesis aims to discuss whether our findings could be adopted to improve strategic mitigation measures used to reduce the number of collisions occurring in areas characterized by similar landscapes.

2. MATERIALS AND METHODS

2.1 Study parameters

2.1.1 Study area

The data used in this study comprised the spatial distribution of moose vehicle collisions (MVC) in two regions in western and eastern Finland (Fig. 1) with different landscape characteristics.

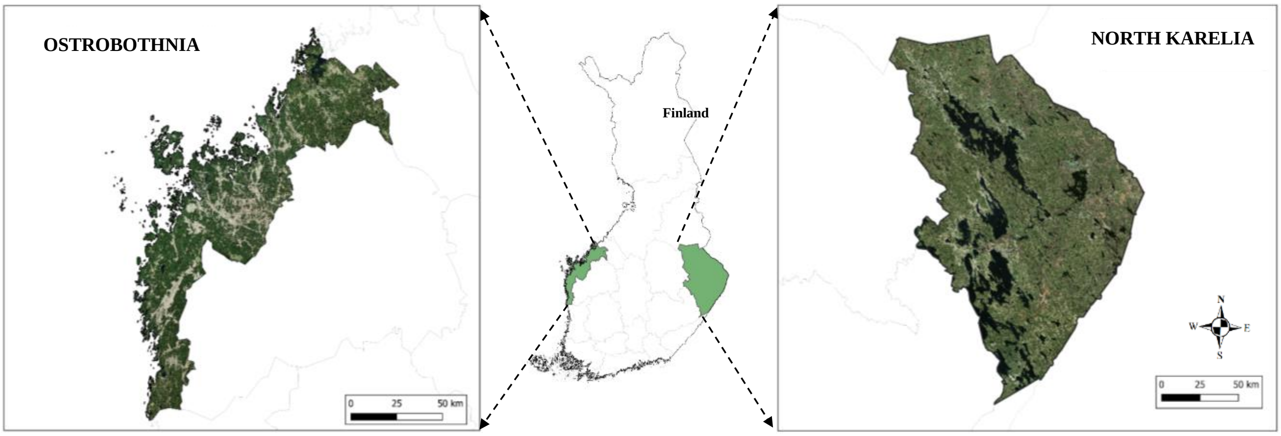

Figure 1 - A map of Finland and the two areas of study, Ostrobothnia (Pohjanmaa) and North Karelia (Pohjois-Karjala) correspondingly.

The western most region, Ostrobothnia (Finnish: *Pohjanmaa*), covers approximately 8000 km^2 of lands characterized for having flat areas with little topographical variation. The landscape is dominated (62% cover) by coniferous and mixed forests that provide continuous patches of moose habitats. Lowland areas dominated by non-forested arable lands comprise 18% of the study area. whereas urban areas, industrial buildings and roads comprise up to 5%. Water bodies, open rocky and sandy areas, and inland and outland wetlands cover the remaining 15 % of the areas.

In the east, the North Karelia (Finnish: *Pohjois-Karjala*) region covers nearly 21600 km^2 of hilly landscapes and is located adjacent to the border with Russia. The forests cover up to 70 % of the study area, 44% of which are coniferous dominated. Unlike the Ostrobothnia area, North Karelia has less than 5% of non-forested areas used for agricultural purposes. Large water bodies are also characteristic of this area covering 18% of the total North Karelia region alone. The remaining 7% of the landscape comprises urban, recreational, and industrial areas.

2.1.2 Landscape data and density of moose observations

Forest structure data included the horizontal and vertical distribution of layers in a forest such as trees, shrubs, and ground cover. Canopy cover and Volume of growing stock data were obtained from the Finnish Multi-Source National Forest Inventory, MS-NFI (Luke, 2021). The volume of growing stock map was based on the total volume for all tree species, and the canopy cover was assessed as the vertical projection area on the horizontal planes of individual trees. In addition, a 16 x 16m grid comprising forest stand characteristics (Table 1) was obtained from the Finnish Forest Centre's database on private forests (Metsäkeskus, 2021). This data, based on airborne laser scanning data and field measurements, held more specific information on forest structure and tree-species composition and it has been successfully used in the past to describe moose habitats (Pusenius et al. 2020)

According to official density estimates (Luke 2021), the moose densities during the survey years varied between 3.8 – 4.5 moose per 1000 hectares in Ostrobothnia, and 2.4 – 3 moose per 1000 hectares in North Karelia. Throughout both study areas, moose densities were largely different. To work with finer spatial resolution, this study used hunter-moose observations as a relative measure of population density. The data used contained the number of moose observation made by moose hunters during hunting season and registered to Oma Riista webservice managed by the Finnish Wildlife Agency. The observations were added to a 5 x 5 km grid that was then interpolated with the Kriging tool into a continuous raster surface of 200 m cell size. Hunting clubs' moose observations varied between 14 moose per 1000 hectares in Ostrobothnia, and 6 moose per 1000 hectares in North Karelia.

2.1.3 Road and traffic data

Data on road characteristics was obtained from the file service of National Land Survey of Finland (MML, 2021). The roads were divided into 5 categories, Main roads Class I (Finnish: Valtatie), Main roads Class II (Finnish: Kantatie), Regional roads (Finnish: Seututie), Connecting roads (Finnish: Yhdystie), and Local roads (Finnish: Paikallistie). Forest roads were excluded given the lack of data on traffic characteristics and animal collisions related accidents. Generally, main roads class 1 and 2 are considered highways and are characterized for having low to intermediate traffic volume and high-speed limits, whereas local roads, also known as rural roads, may have anything from low to high traffic volume, but with lower speed limits.

2.1.4 Data on moose-vehicle collisions

Data on moose-vehicle collision was obtained from the registry of wildlife damages and accidents maintained by the Ministry of Agriculture and Forestry (MMM, 2021). The distribution of MVC records in Ostrobothnia and North Karelia from 2015 to 2019 amounted to 1123 in total, 629 and 495, respectively (Fig.2). Data regarding accidents occurring in forest roads was limited to 3 recorded cases; these were excluded from the dataset. Each data point contained information on the date and time of the accident. Based on the month of the collision, a variable for each of three, summer, winter, and hunting seasons, were defined. Unlike conventionally defined seasons in the norther hemisphere, summer corresponded to the months of May, June, July, and August, and winter comprised accidents occurring on January, February, March, and April. The hunting season was defined between September and December in accordance with the hunting licence information provided by the Finnish Wildlife Agency. It is noteworthy to state that the autumn months are largely included within the hunting season. This is relevant given that most of the literature will be referring to this season as autumn.

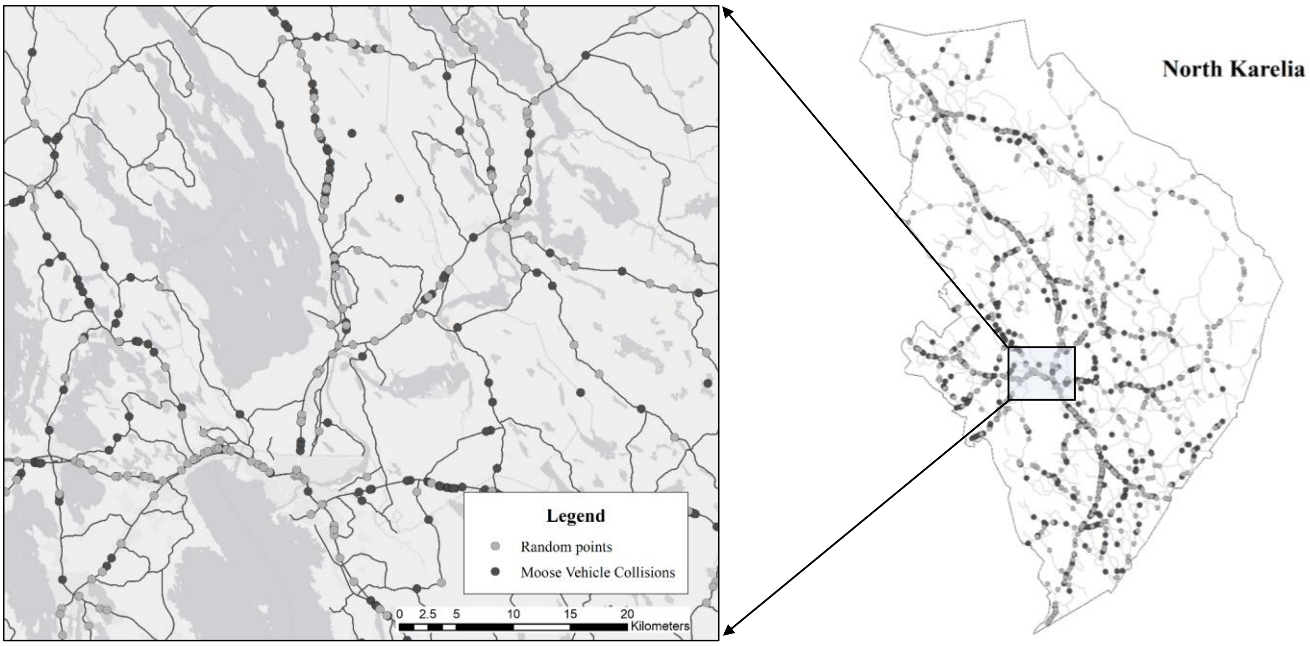

Figure 2 - Distribution of reported moose vehicle collisions in on the road network in North Karelia

2.2 Statistical analysis

2.2.1 Model composition

The nature of this study is observational (case-control study) given the interpretation and comparation of the parameters influencing moose-vehicle collisions in two distinctive study areas. Prior to the spatial and statistical analysis, non-collision points (control points), were created randomly matching the patterns found in the number of collisions occurring in each road category (Fig.3). The distance between each control point was selected to be minimum 100m, however, there was not a limit set to the distance between control points and moose vehicle collisions. A number between 1 and 12 was randomly assigned to each control point, this aimed to define a random temporal factor representing hunting, summer, or winter seasons.

Spatial data processing tools such as ArcGIS and QGIS, were used to extract the forest structure characteristics and moose density that distinguished MVC sites and control points. At each MVC and control point, a 100-m buffer was developed to account for the driver's visibility distance. Within each buffer, 19 spatial parameters were considered to be influential on the odds of MVC (Table 1). To minimise intercorrelation between the 19 selected variables, the age of pines, spruce and deciduous trees, and the dominant height of tree species were omitted from the analysis due to the high correlation coefficient ($R>0.9$) between them.

Binomial logistic regression analysis was used to evaluate the remaining 15 continuous variables. The binary response variable has value 1 for the moose-vehicle collision points and 0 for control points. Generalized Linear Modelling was used to quantify the relationship between such a binary response variable and n number of predictor variables, which include the landscape variables and the density of moose observation. Logistic regression models were created for both study areas. Conventionally, logistic regression uses the logit, or logarithm of the odds of an event to represent a linear combination between independent variables. The odds is the probability that an event will happen divided by the probability the same event will not occur. In this study, for the purpose of clarity, the odds ratio and confidence interval were calculated to obtain a clearer measure of the likelihood of Moose-Vehicle Collisions. The models were formulated as:

$$\ln\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \dots + \beta_n x_{ni} \quad (1)$$

Where β_0 and β_n are parameters of the model, and p_i is the probability of collision at a point i..

The best models were selected by using a backward stepwise regression analysis based on Akaike's Information Criteria (AIC) corrected to include the road category. The AIC is formulated as:

$$AIC = 2K - 2In(L) \quad (2)$$

Where L represents the maximum value of the likelihood function for the model, and k represents the number of estimated parameters in the model. An open-source statistical analysis tool, R (http://www.r-project.org/, 2020), was used in this research for statistical analysis and model estimation.

Table 1 - Spatial and Temporal variables measured within 100-m radius buffers surrounding moose vehicle collision sites and control points

Continuous variables	
Moodensity	Moose occurrence density
Laserh	Laser height
Laserd	Laser density
agepine	Age of pine trees
stemco_pi	Stem count of pine trees
meanhe_pi	Mean height of pine trees
vol_pi	Volume of pine trees
agespr	Age of spruce trees
stemco_spr	Stem count of spruce trees
meanhe_spr	Mean height of spruce trees
vol_spr	Volume of spruce trees
agedec	Age of deciduous trees
stemco_dec	Stem count of deciduous trees
meanhe_dec	Mean height of deciduous trees
vol_dec	Volume of deciduous trees
domihe	Dominant height of tree species
volume	Overall volume of tree species
cancov	Canopy cover
treevol	Volume of growing stock
Categorical variables	
Collision	Occurence of collision, "1"for collision"0" for control points
RoadCat	Road categories
Season	Seasons named "Hunt", "Summer"," Winter"

3. RESULTS

3.1 Spatial and temporal distribution of Moose-Vehicle Collisions

During the period of 2015 – 2019, the temporal distribution of collisions along different public roads was not random. About 57% of all reported MVCs occurred in Ostrobothnia, and more than 78% of these MVCs happened in highways (Valtatie) and regional roads (Seututie), see figure 3. In a like manner, 43 % of all reported MVCs took place in North Karelia, 65% of which occurred in highways and regional roads. Moose vehicle collisions were less common in narrower roads with intermediate speed limits and less traffic.

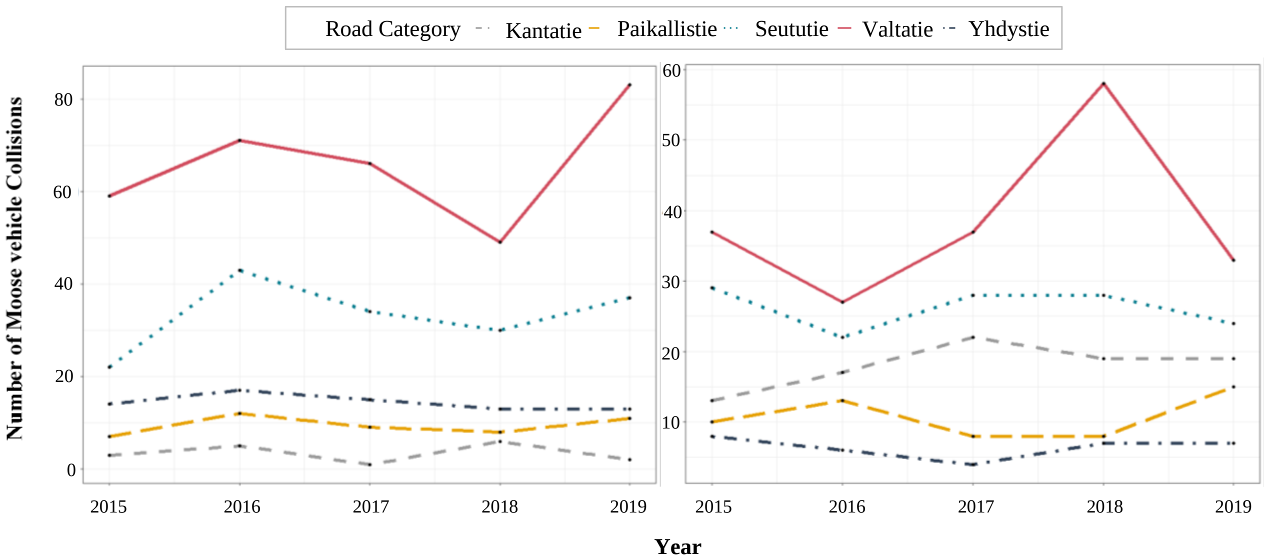

Figure 3 - The number of moose vehicle collisions in a 5-year period for Ostrobothnia (left) and North Karelia (right)

The number of MVCs differed between hunting, summer, and winter seasons (Fig.4). The hunting season was the period with the highest proportion of moose vehicle collisions. Nearly 52% of the recorded MVCs in Ostrobothnia took place during this period of time. Likewise, close to 53% of collisions occurring in North Karelia were recorded between September and December. Collisions were not frequent during summer and winter in either of the study areas. They were, however, less frequent during winter when the speed limits are lower than in the other seasons. Visual examination of Figure 4 showed the expected lack of variation in the number of control points assigned to a given season. Originally, the random values representing the months of the year were assigned to the entire data set. Subsequently, the dataset was divided between Ostrobothnia and North Karelia. On those grounds, the number of control points assigned to each area differed. However, this does not impact the results of the modelling process.

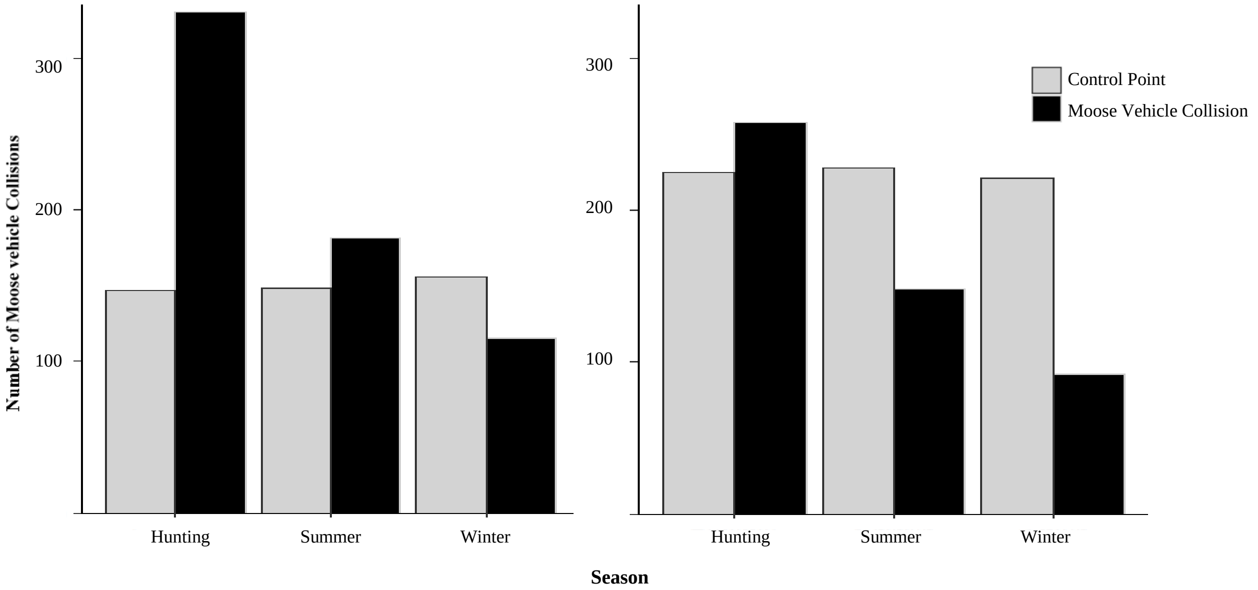

Figure 4 - Number of moose vehicle collisions in different seasons for Ostrobothnia (left) and North Karelia (right).

3.2 Role of forest structure in MVCs

The estimated parameters, their standard errors, odds ratios, confidence intervals and p-values for the Ostrobothnia and North Karelia models are presented in Tables 3 and 4, respectively. The stepwise logistic regression analysis revealed a clear difference in the type of environmental variables describing the odds of moose vehicle collisions in each study area (Table 2).

Table 2 - Models used to assess the environmental variables influencing MVCs in both study areas.

Model	Model Structure
Ostrobothnia	Moose observation density – Mean height of spruce + Volume of spruce + Volume of deciduous tree + Canopy cover
North Karelia	Moose observation density + Stem count of deciduous trees + Canopy cover

In Ostrobothnia, the odds of MVCs increased in areas where the density of moose observations was higher. A decimetre increase in the mean height of spruce decreased the odds of collision by a factor of 0.83. Based on the odds ratio estimates, forested areas characterized by higher volume of spruce or deciduous trees, and canopy cover favoured the conditions for MVCs. It could also be observed that for both models winter and summer decreased the odds of a moose related accident.

Table 3 - Description of explanatory variables in the Ostrobothnia Model.

Explanatory variables	Estimate	Std. error	Odds ratio	95%CI	Pr(>|z|)
(Intercept)	-1.26	0.47	0.28	0.11 – 0.71	0.0071
Moose observation density	0.09	0.02	1.09	1.06 – 1.13	3.43E-07
Mean height of spruce	-0.19	0.05	0.83	0.76 – 0.90	2.30E-05
Volume of spruce	0.02	0.01	1.02	1.01 – 1.03	0.00166
Volume of deciduous trees	0.03	0.01	1.03	1.02 – 1.05	8.26E-05
Canopy cover	0.04	0.00	1.04	1.03 – 1.05	<2E-16
Summer	-0.60	0.16	0.55	0.40 – 0.75	0.00019
Winter	-1.21	0.17	0.30	0.21 – 0.42	2.19E-12

Unlike Ostrobothnia, the North Karelia model presented a smaller number of environmental variables influencing the number of MVCs (Table 3). This can be because there are less collisions in North Karelia, thus less data and more difficult to get a significant p-value. When the same explanatory variables found to be significant in the Ostrobothnia model were used to model North Karelia, the effect size was smaller. According to the North Karelia model both the moose observation density and canopy cover also increased the odds of collisions. In fact, the odds ratios suggest that all the variables in this model increased the odds by a factor >1. Despite being a largely forested region, the only landscape variable increasing the odds of MVCs was found to be the stem count of deciduous trees. This can be attributed to denser forested areas dominated by young deciduous trees reducing the driver's visibility of upcoming moose.

Table 4 - Description of explanatory variables in the North Karelia Model

Explanatory variables	Estimate	Std. error	Odds ratio	95%CI	Pr(>|z|)
(Intercept)	-1.26	0.27	0.28	0.17 – 0.48	3.15E-06
Moose observation density	0.12	0.02	1.12	1.08 – 1.18	1.09E-08
Stem count of deciduous trees	0.00	0.00	1.00	1.00 – 1.00	0.000866
Canopy cover	0.02	0.00	1.02	1.01 – 1.03	6.71E-06
Summer	-0.46	0.15	0.63	0.47 – 0.84	0.001484
Winter	-1.04	0.16	0.35	0.26 – 0.48	8.33E-11

4. DISCUSSION

4.1 Temporal patterns of MVCs in Ostrobothnia and North Karelia

The spatial distribution of MVCs observed on different road categories in both Ostrobothnia and North Karelia is consistent with previous studies (e.g., Rolandsen et al., 2011): we observed that the number of collisions is higher in main roads and regional roads, both characterized for having intermediate to low traffic volume and intermediate to high-speed limits. This distinctive distribution can be explained by the predominantly positive effect that traffic has on AVCs (Pagany, 2020), in other words, collision risk increases with traffic volume. While most studies agree with this general trend, Visintin et al. (2016) argued that weather variations and traffic speed have a greater influence than traffic volume. In a similar study, Kušta et al. (2017) observed fewer road UVCs during peak traffic volumes, suggesting that traffic served as a barrier to prevent animals from crossing the road. Correspondingly, Seiler (2005) noted that wildlife are repelled from crossing roads with traffic volumes exceeding 10 000 vehicles per day. One interesting explanation for collisions occurring during low traffic periods could be that ungulates tend to move at their peak before sunrise or after sunset (Steiner et al., 2014). In terms of the unimodal effect of traffic volume on AVCs, it appears to be a small-scale phenomenon that is largely the result of animal behaviour only and is not comparable to the linear correlation found between the number of collisions and traffic volume on a broad scale.

This study observed that most of the MVCs occurred during the hunting season and the least number of collisions during winter. It is necessary to emphasize on the fact that the hunting season in our study was defined mostly by months corresponding to autumn, thus our observations are congruent with other studies investigating the temporal variations of AVCs (e.g., Haikonen and Summala 2001). It is apparent that for this phenomenon to occur, several factors must operate directly and indirectly on animal behaviour and their traffic encounters. The coincidental timing between the autumn peak of MVCs and the rutting period, normally occurring between September and October, suggests that moose mobility related to the rut is a predominant influential factor of the autumn peak trend. Alternatively, the increasing mobility of moose has been attributed to the pressure exerted by hunting seasons (Henderson et al. 2000). The distribution of MVCs during autumn observed in our study corresponded with findings by Niemi et al. (2017), but the winter distribution differed as the author found that MVCs also peak during winter. This may be due to the differing environmental conditions and landscapes characteristics of the study areas used in our study. In Finland, moose may reduce their mobility during winter due to the snow depth increase; a condition often resulting in less traffic encounters (Olson et al., 2015). Another putative explanation for the observed autumn trends might be the shortened daylight hours towards winter in Nordic countries and reduced visibility at dusk and dawn. Mastro et al., (2010) observed that the driver's ability to perceive danger and react to wildlife crossing roads was hampered at dawn. This could also be explained by the two diurnal peaks, close to dusk and dawn, in which ungulates and other animal species are highly active (Aschoff, 1966). Interestingly, Borowik et al., (2021) also observed that specific foggy conditions increased the risk of Moose-vehicle collisions.

Although the spatial and temporal patterns described in our study are congruent with other studies, changes in traffic volume or speed, and limited visibility due to darkness or other weather conditions cannot explain the nature of MVCs alone; consequently, it is necessary to consider other factors that might influence this risk.

4.2 The effect of moose density

Our study confirmed the positive relationship between the density of moose observations and vehicle collisions previously documented (e.g., Seiler, 2005; Rolandsen et al., 2011). In Finland, Niemi et al., (2017) observed that both moose density and traffic volume explained nearly 60% of the variation in the numbers of UVCs. This suggests that an increase in moose population and in traffic volume would increase the risk of collisions independently of other parameters. It is important to state that the density of moose observation used in this study might underestimate the population density. This might be because the searching efficiency of hunters decreases when moose density increases (Ueno et al., 2014). Similarly, during Seiler (2004) study, hunting did not correlate with the frequency of MVCs, prompting the question of whether hunting statistics are useful in detecting differences in moose densities between different localities. Based on the results of this and previous studies, it appears that understanding the impact of moose density on MVCs is vital from a management perspective, but moose population structure needs to be further explored. For instance, based on the demographic structure of the deer population, male deer encounter traffic more often than expected (Olson et al., 2014). This study thus suggests that future research should focus not only on the relationship between population density and the number of MVCs, but also on the effect of different demographic structures.

4.3 The role of forest structure

This thesis found that canopy cover was an important factor influencing moose vehicle collisions in both study areas. One way to explain this phenomenon is by understanding the effect of canopy cover on surface temperature and the ability of moose to cope with warmer temperatures. Generally, areas with high canopy cover have a lower surface temperature and provide shelter to animals with low thermal stress thresholds (Demarchi & Bunnell, 1993). According to Renecker & Hudson (1986), moose experience thermal stress at a temperature higher than 5°C during winter and higher than 14°C during summer. It is thus safe to suggest that the threshold for moose is relatively low, and to assume that they will tend to actively look for forested areas that provide shelter against higher temperatures. In fact, Schwab and Pitt (1991) found that temperature and forage explained moose canopy cover selection in both summer and winter. Interestingly, Melin et al. (2014) also observed that moose tend to use areas with higher canopy coverage during the day than they do at night. It can also be noted that moose movement and habitat selection can be altered by changing landscape structures near the roads (Seiler, 2005). This enable us to speculate why the effect of canopy cover is slightly lower in Ostrobothnia than North Karelia. The flat arable lands in Ostrobothnia reduce the forested areas available for moose habitat, pushing moose to comprise in smaller continuous or noncontinuous patches. Moose habitat selection might therefore be influenced largely by more than canopy cover alone. This relationship between canopy cover, temperature and moose behaviour is interesting, but it was not within the scope of our analysis.

Possibly one of the most important observations in this study was that both areas have distinctive forest structures that influence the number of moose-vehicle collisions. While forests are largely found in North Karelia and Ostrobothnia, covering 70% and 62% of the total areas respectively, the results indicate that there were more forest related factors affecting the risk of collision in Ostrobothnia than in North Karelia (see Table 3 and Table 4). This suggests that small changes in the landscape may influence moose movements and behaviour, two important aspects when determining the risk of collision as Seiler (2005) indicated. Because there are more agricultural fields and fragmented forested areas in Ostrobothnia, moose may be more inclined to select forests to either maximize their energy intake or to find shelter. To further elaborate on this point, the Ostrobothnia model shows that the risk of moose-vehicle collisions decreases in road sections surrounded primarily by tall spruce trees and increases where the volume of deciduous trees is high. Similarly, the North Karelia model describes a positive relationship between the stem count of deciduous trees and MVCs.

There is some evidence to suggest that this has something to do with moose diets, as several studies demonstrate that moose do not feed from certain types of spruce trees (Newbury et al., 2007), but they do prefer deciduous forests for foraging and hiding (Zuberogoitia et al., 2014). Indeed, as Pagany (2020) notes, a large body of literature agrees that AVCs are generally more likely to occur along road sections near or between deciduous forests.

A discrepancy was observed in the model of Ostrobothnia regarding the positive relationship between the volume of spruce trees and MVCs. Generally, the height and volume of spruce are positively correlated (Makinen & Isomaki, 2004), the higher the tree the bigger the volume of the tree, yet the model shows that both have contrasting effects on the risk of MVCs. This can be explained by considering the driver's perspective rather than the moose behavioural patterns. Although, to reiterate, moose do not prefer forests characterized by spruce trees, those who do move between them might be less likely to be spotted by a driver. As opposed to deciduous trees, spruce trees retain their foliage all year long, which may allow moose to blend in better with the surrounding landscape. In support of this assumption, Wood and Owens (2005) found that the contrast between an object and its background reduces a person's ability to see obstacles and identify them. A visual deficiency that, according to Mastro et al., (2010) may cause a driver to fail to detect or to evade large ungulates. It is worthy to notice that a similar phenomenon might be occurring in North Karelia. The stem count of deciduous trees can be used as a proxy for tree density; thus, the denser the forested area, the more difficult it is to distinguish an object from the landscape and the greater the risk of collisions. Overall, there is a general understanding that forested areas increase the risk of animal-vehicle collisions (Pagany, 2020), however, the number of studies focusing on more specific landscape features is limited, rendering thus the need to better understand the relationships discussed in this section.

4.3 Optimizing existing mitigation measures

The results of this thesis emphasize the need for various mitigation measures to prevent and minimize the severity of moose-vehicle collisions. The spatial and temporal distribution of MVCs show that there is a clear pattern of accidents occurring throughout the year. While many MVCs occur during autumn, various mitigation measures could be considered regardless of the season. For instance, a driver could be warned by using different dynamic and animated warning signs. Interestingly, Jägerbrand and Antonson (2016) found that drivers decelerate more quickly and strongly when warned by radio messages, wildlife warning signs, and moose decoys, effectively reducing the risk of collisions. Although promising, the effectiveness of these mitigation measure remains unclear in the long term, so further research is needed to determine their reliability. An alternative method could be to launch driver education and awareness campaigns during times when collisions peak. Currently, studies on the effectiveness of public awareness in reducing the risk of MVCs are limited, but this study suggests that active participation of road management entities and stakeholders in promoting public awareness is critical to successfully controlling the number of collisions occurring alongside roads.

The effect of moose density on the number of MVCs observed in this thesis renders it necessary to adopt population control as an effective mitigation measure. Because moose is not considered a vulnerable species in Finland and other Nordic countries, but rather a heavily managed game species (Niemi et al., 2015), population control through hunting is an appropriate way of reducing the risk of collision at the national level (Hedlund et al., 2004). This method, however, may be counterproductive, as studies have found an increase in the number of animal-vehicle collisions linked to hunting pressure and unpredictable animal movement patterns (e.g., Sudharsan et al., 2006). Population control can also be controversial. For example, Stout et al. (1993) observed that the public opinion largely opposed to the reduction of deer species in the wild for management purposes. Nevertheless, even if no issues are associated with moose, population control is not the only approach to reduce encounters between moose and vehicles. Wildlife fencing provides a non-lethal physical barrier that has been largely documented as an effective method for reducing MVCs (Pagany, 2020). One disadvantage is that effective fencing is expensive (Hedlund et al., 2004), and can serve as barriers that may limit the accessibility to resources (Olsson and Widen, 2008). Fencing together with wildlife passages could be effective at reducing both the risk of collision and the barrier effect roads. Yet, it has been observed that some large ungulates are reluctant to use wildlife passages even when motivated to cross a road to forage (Hedlund et al., 2004; Niemi et al., 2015).

The relationship between forest variables and MVCs investigated in this thesis could be used to deduce strategic mitigation measures that contribute to traffic safety. Although Seiler (2005) argues that many of the landscape factors associated with an increased risk of MVCs are the responsibility of landowners and beyond the influence of road administration entities, this paper encourages alternative technical approaches to deliver information regarding the risk of collision and influence the driver’s behaviour. Alongside technological advancements, there is a concerted effort to apply automatic collision avoidance systems to increase the driver's ability to detect and avoid obstacles (Katzourakis et al., 2014). Modern cars are often equipped with passive and active sensor systems that detect obstacles that could potentially detect collision risk factors (Hartbauer, 2017). In fact, Sharma and Shah (2017) proposed a low-cost animal detection and avoidance system using sensors and computer vision techniques that detected animals with 82.5% accuracy. Similarly, Mammeri et al. (2017) proposed a method where roadside cameras detect large ungulates and sends a warning message to the flashing system of a warning sign. Given the capacity of this proposed methods, this study suggests exploring similar approaches to train systems to recognize the forest structure near roads. It is assumed that active sensors could determine areas with higher density of deciduous trees, for instance, and recommend the driver to reduce the speed and to have greater awareness of the surroundings. Likewise, this study propose the use collected data to upgrade dynamic traffic warning signs. Since Finland has 100% coverage of airborne laser scanning data, aerial images and an automatically updating forest stand database, the high-risk areas based on their forest structure could be mapped beforehand. This, together with local estimates of moose density and knowledge of crossing sites, could be used to map the high-risk areas in relation to not only where a moose may cross the road, but also on the structure of the surrounding forest: where it is less likely to be detected by the driver.

5. CONCLUSION

The results of this thesis present the positive relationship between more specific forest parameters and moose-vehicle collisions, suggesting that mitigation measures focused on road-side forest management may affect the overall likelihood of MVCs. Many of the forest and landscape parameters are the responsibility of landowners and fall beyond the influence of road administration, thus it is imperative to inform and increase public awareness regarding the consequences of MVCs. When mitigation options are limited to the road and near surroundings, it is advised to opt for a combination between fencing and road clearance, since they have been observed to provide the strongest mitigation against MVCs (Seiler, 2005). This thesis also emphasizes on fine-tuning existing traffic warning signs and their placement. The positive effect of the forest structure in the number of MVCs suggests that placing warning signs based on moose movements or population hotspots alone is inaccurate, thus the available finer resolution landscape data should also be used to define high-risk hotspots. Even though this and other studies focus on explanatory analysis as well as mitigation measures, the problems arise when considering the extent of the risk that can be predicted. Furthermore, the models often used in the literature regarding moose-vehicle collisions return high risk areas and factors in areas that may not be applicable for other regions. This study focused on two rather distinctive areas that may not serve as a surrogate for other parts of Finland, nor other countries.

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