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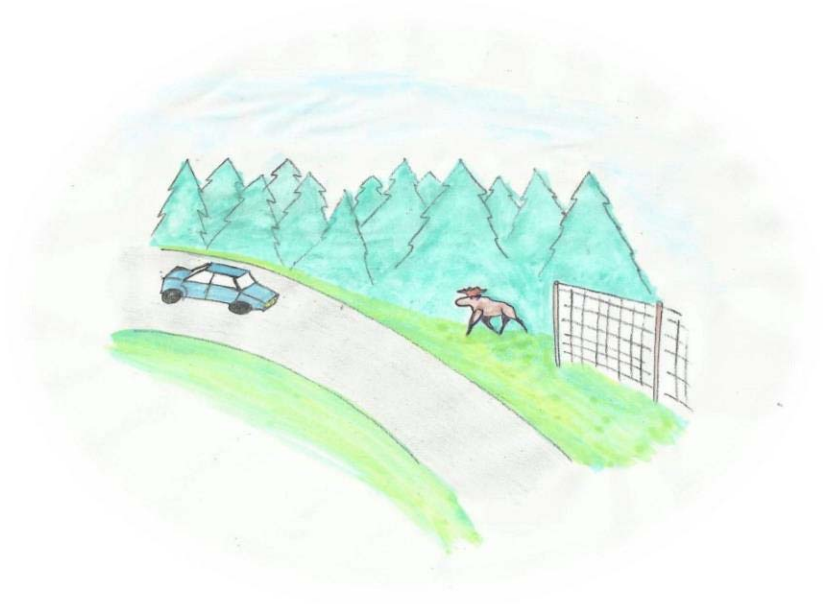
Department of Wildlife, Fish, and Environmental Studies

The effect of wildlife fences on ungulate vehicle collisions

Freja De Prins



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The effect of wildlife fences on ungulate vehicle collisions

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Abstract

Many of Sweden's roads are fitted with wildlife fences to decrease the risk of ungulate vehicle collisions (UVCs). Nevertheless has it been observed that at the ends of these fences, the number of collisions actually increases. In this thesis, I examined if collision probability decreased with an increasing distance from the fence end. In addition, I examined whether the landscape surrounding the fence end and the characteristics of the road influenced this. Lastly, I studied if two wildlife fences between Mellerud and Tösse were successful in reducing the number of UVCs. To test my hypotheses, I analysed collision data collected all over Sweden between 2008 and 2017.

I found that collision probability was highest within the first 100 m from a fence end, and that the decrease in collision probability was not influenced by different landscapes and road types. Only one of the two wildlife fences I studied was able to decrease the number of UVCs, where the collision rate was decreased by up to 78%. This information can be used for planning future mitigation efforts, such as the construction of under- or overpasses.

Keywords: ungulate vehicle collision, UVC, roe deer, moose, red deer, fallow deer, wild boar, mitigation, fence end, wildlife fence

Sammanfattning

Många av Sveriges vägar är försedda med viltstängsel för att minska risken för viltolyckor. Ändå har man observerat att risken för kollision faktiskt ökar nära slutet av stängslet. I det här examensarbetet har jag undersökt om sannolikheten för kollision minskade när avståndet till slutet av stängslet ökade. Därtill har jag undersökt om landskapets och vägens egenskaper påverkade detta. Slutligen har jag undersökt om två viltstängsel mellan Mellerud och Tösse lyckades minska sannolikheten för kollision med vilt. För att testa mina hypoteser har jag använt mig av kollisionsuppgifter som samlades i hela Sverige mellan 2008 och 2017.

Jag kom fram till att kollisionssannolikheten var störst inom de första hundra meter från stängselslutet, och att minskningen i sannolikheten för kollision inte var påverkat av landskapets och vägens egenskaper. Bara en av de två stängselen som jag undersökte kunde minska kollisionssannolikheten, så var minskningen var upp till 78%. Denna information kan användas vid planeringen av nya åtgärdar, så som konstruktionen av övergångsbroar eller tunnlar.

Nyckelord: viltolyckor, UVC, rådjur, älg, kronhjort, dovhjort, vildsvin, viltstängsel

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1 Introduction

Animals move through the landscape for a variety of reasons (Fahrig, 2007). The increasing traffic volume and raising number of roads hamper these animal movement patterns and increase the risk of animals being injured or killed in vehicle collisions (Groot Bruinderink & Hazebroek, 1996).

Ungulate vehicle collisions (UVCs) are not randomly distributed over time and space. In terms of time, collision risk is influenced by the time of day, day of the week and the time of the year (Groot Bruinderink & Hazebroek, 1996; Haikonen & Summala, 2001; Steiner et al., 2014; Hothorn et al., 2015). In terms of space, collisions are more likely to happen on level terrain with habitat that is preferred by ungulates, like pastures, clear-cuts and young forest plantations rather than in more urbanised areas (Groot Bruinderink & Hazebroek, 1996; Seiler, 2005; Danks & Porter, 2010; Gunson et al., 2011; Meisingset et al., 2014). Roe deer (*Capreolus capreolus*) collisions, on the other hand, have been seen to increase with more urban area, because these animals occur in rural areas, agricultural land and clear-cuts (Seiler, 2004). Where dense forest cover occurs together with open areas, collision risk increases as well (Malo et al., 2004). Areas where vegetation comes close to the road also exhibit more collisions due to bad visibility for the drivers (Madsen et al., 2002).Traffic volume and speed are important factors as well. The amount of UVCs increases with traffic speed (Danks & Porter, 2010; Gunson et al., 2011; Meisingset et al., 2014) because drivers have a shorter time to react. According to Seiler (2005), most moose vehicle collisions occur at a speed limit of 90 km/h. An intermediate traffic volume has been found to be the most dangerous in connection to UVCs. The reason for this is that at low traffic volumes, ungulates can cross the road relatively safely, while high traffic volumes have a deterring effect (Seiler, 2003; Thurfjell et al., 2015). When it comes to road curvature, Gunson et al. (2011) suggested more wildlife vehicle collisions happen on straight roads. The reason for this is that drivers tend to drive faster here than on curved roads. In this thesis, I focus on the spatial distribution of UVCs.

Even though a variety of species, including a broad range of different taxa, is influenced by roads, mitigation efforts to decrease their impact do not focus equally on all species. In Sweden, mitigation measures are often directed towards the prevention of ungulate-vehicle collisions (UVCs). An important reason for this is the high economic importance of UVCs. Ungulates have a relatively large body size. As a consequence, UVCs can cause substantial damage, not only to the animals involved, but also to vehicles and humans (Seiler et al., 2015). In Sweden, collisions involving moose (*Alces alces*), roe deer, and wild boar (*Sus scrofa*) amount to a yearly cost of about 1300 million SEK. This corresponds to 0,03% of the country's gross domestic product in 2015 (Gren & Jägerbrand, 2017). Additionally, around 600 reported collisions with moose and roe deer result in human injuries every year. Up to 25% of people who got heavily injured during a wildlife collision even experience physiological trauma (Pynn & Pynn, 2004). Moreover, 10 – 15 people are killed in Sweden every year as a result of UVCs (Davenport, 2006). Ungulates make up an important part of Sweden's fauna and occur in higher densities than other large-bodied wildlife. UVCs are thus much more common than collisions with species like wolves (*Canis lupus*) and bears (*Ursus arctos*). (Seiler et al., 2015; Nationella Viltolycksrådet, 2018). In 2017 alone, 60 853 ungulates were reported to be involved in UVCs in Sweden (Appendix 1, Nationella Viltolycksrådet, 2018).

Several mitigation measures to prevent UVCs have been tested in the past. Examples are the placing of wildlife fences along roads, possibly combined with over- or underpasses, roadside clearing, traffic signs, installing more street lights, reduced speed limits, and use of repellents like whistles, reflectors, flags and chemical repellents (Mastro et al., 2008; Gunson et al., 2011). Especially fencing has been proven to be a successful way of reducing UVCs and can decrease the collision rate by up to 80 % (Clevenger et al., 2001) by discouraging animals from attempting to cross the road (Olsson & Widen, 2008). Despite several successes in decreasing collision rates, not all fences have been proven to be equally effective (Feldhamer et al., 1986). The effectiveness of wildlife fences can be influenced by their length. Fences shorter than five km may lower the number of collisions with large mammals by only 50% (Huijser et al., 2016). Despite their general efficiency in reducing UVCs, fences also have a negative impact on wildlife since they interrupt movement patterns. To accommodate for this, over-and underpasses can be build (Olsson & Widen, 2008). The fence can then be used to funnel the animals towards them (Jakobi & Adelsköld, 2012). In Sweden, these are in particular adapted to moose, because their large body size demands more of mitigation measures. In other words, if over- and underpasses work for moose, they will likely work for other ungulates too, and even be suitable for large predators like wolves, lynx (*Lynx lynx*), badgers (*Meles meles*) and foxes (*Vulpes vulpes*) (Seiler, 2004; Seiler et al., 2015). Another downside of wildlife fences is that the number of UVCs declines along the fences, but increases at the fence ends (Clevenger et al., 2001; McCollister & Van Manen, 2010; Cserkész et al., 2013). Wildlife vehicle collisions, including UVCs, have been reported to be more frequent within one km (Clevenger et al., 2001), 480 m (Feldhamer et al., 1986) or 400 m (Cserkész et al., 2013) from fence ends. The reason for the increased collision numbers is that animals tend to follow fences and cross the road at the fence end or move onto the road and consequently get trapped between the fences (Cserkész et al., 2013). To this date, few studies have focussed at this particular aspect of wildlife fences (Clevenger et al., 2001; Cserkész et al., 2013). Neither did the aforementioned studies differentiate between different ungulate species when quantifying the length of this “danger zone” along fence ends, nor did they take the surrounding landscape and road features into account.

In this thesis, I studied the effect of the ends of wildlife fences along Swedish roads on UVCs with different ungulate species, in relation to the surrounding landscape and road features. Additionally, I investigated if the wildlife fences along highway E45 between Mellerud and Tösse, Sweden have been successful in decreasing the number of UVCs. Using the national wildlife collision data set (Swedish Transport Administration, 2017), I analysed vehicle collisions involving moose, roe deer, red deer (*Cervus elaphus*), fallow deer (*Dama Dama*) and wild boar.

My first hypothesis is that UVCs decrease with increasing distance from the fence ends throughout Sweden. To test this, I divided the area around the fence ends into buffer zones and calculated the collision risk per buffer zone for the different ungulate species. Previous research has shown that certain landscape features and road characteristics can influence the risk for UVCs (e.g. Groot Bruinderink & Hazebroek, 1996; Madsen et al., 2002; Malo et al., 2004; Danks & Porter, 2010; Gunson et al., 2011). Therefore, my second hypothesis is that, within a given buffer zone, higher amounts of straight road stretches with intermediate traffic volume and relatively high speed limits, along preferred habitat for ungulates will increase the probability for UVCs. My third hypothesis is that the placement of wildlife fences between Mellerud and Tösse, Sweden has decreased the number of UVCs.

2 Area

For my first and second hypothesis, I studied the whole of Sweden. The majority of the country's landscape is characterised by coniferous forest. Agricultural landscapes and deciduous forests are mainly limited to the south of the country (SMHI Vattenwebb, 2017). Human population density is highest in the south of Sweden and along the Baltic coast line (Svanström, 2013). Ungulate populations are also highest in these areas (ArtDatabanken, 2018). Moose and roe deer are spread over most of the country, but have a higher population density in the south and along the coastline. Fallow deer and wild boar are limited to the south of the country. Red deer occur in most of the country, but with a patchy distribution and at low densities. This is especially the case in Västerbotten and Norrbotten (ArtDatabanken, 2018). My third hypothesis involves a case study where I focused on two fences located along highway E45 between Mellerud and Tösse in the county of Västra Götaland, Sweden. The most prominent landscape feature in this county is production forest, covering 44,8% of the total area (Regionfakta, 2018). Another characteristic is Lake Vänern which is located in the north of the county. The road stretch I studied runs near the western bank of the lake.

3 Materials and methods

3.1 Data sets

The collision data I analysed covered the period from 2008 to 2017, and was kindly provided by Sweden's National Wildlife Accident (Nationella Viltolycksrådet, 2017). Each collision between 2010 and 2017 contained information about which ungulate species had been hit. The ungulates involved were moose, roe deer, fallow deer, red deer and wild boar. This information was incomplete in the collision data gathered in 2008 and 2009, which I analysed in the case study.

In order to address my second question - how the number of collisions is affected by the landscape and road characteristics of the areas surrounding the fence ends – I described the area in buffer zones around each fence end using data on habitat distribution, distance to the nearest forest edge, and terrain ruggedness. To analyse the habitat distribution, I calculated the percentage of each habitat class per buffer zone. To account for the effect of road characteristics on the number of collisions, I also considered road curvature, traffic density, and traffic speed. I categorised all roads as being either curved or straight, and calculated the total length of curved and straight roads in meters per buffer zone. Only the straight roads were taken into account in the analyses, because wildlife vehicle collisions have been suggested to be more prevalent on straight than on curved roads (Gunson et al., 2011). This way I tested if a higher amount of straight roads (expressed in meters per buffer zone) within a given buffer zone around the fence end influenced the number of UVCs. I also classified traffic density into low, middle and high, and calculated the amount of meters of each class per buffer zone. I based the division on previous research on moose-vehicle collisions done by Seiler (2003), who found that moose were able to cross roads with less than 2 500 vehicles per day relatively safely. Roads with more than 10 000 vehicles per day had a repelling effect, discouraging the animals to cross. Roads with intermediate traffic density, were found to be the scene of a higher number of collisions. Therefore, I only used roads with a traffic density classified as "middle" in the analyses, to test if a given buffer zone with a higher amount of roads with middle density had a higher probability for UVCs. Lastly, I calculated the length of roads per speed limit category in meters per buffer zone to test if a higher amount of roads with a speed limit of 80 to 90 km/h increased the amount of UVCs. The speed classification was also based on Seiler (2003), who found that most moose-vehicle collisions happened on unfenced roads with a speed limit of 90 km/h. I chose to use roads with a speed limit of 80 km/h – 90 km/h in the analyses, because several roads throughout the country had their maximum speed lowered from 90 km/h to 80 km/h in 2016-2017 (Swedish Transport Administration, 2016). Because this change was fairly recent, not all drivers might have adjusted to the new speed limit yet (Table 1).

Table 1: Characteristics used to describe the area around the fence endpoints

Landscape	To describe the landscape, I used smd data from 2002, which I updated with clear-cut data from Skogsstyrelsen. I divided the different landscapes into the following categories: - open area - forest - clear-cuts, young stands, thickets updated with annual clear-cut data - wetlands and water - non-habitat and human modified areas
Terrain ruggedness	Defined using DEM data from 2009 with pixel size set to 50m (Riley, 1999).
Distance to forest edge	Defined using smd data from 2002, analysed with morphological spatial pattern analysis (smpa) to define forest edges, generating a distance raster of 25m (Vogt & Riitters, 2017).
Road curvature	I calculated the sinuosity of the roads in every buffer zone and classified them as being either “straight” or “curved” based on road data from the Swedish Transport Administration (2017).
Traffic density	I classified the roads in the buffer zones into three categories depending on the number of vehicles they averagely accommodate per day: - < 2500 vehicles per day =“ low” - 2500 – 10 000 vehicles per day =“middle” - > 10 000 vehicles per day = “high” Information on traffic density was provided by the Swedish Transport Administration (2017).
Traffic speed	Traffic speed information was provided by the Swedish Transport Administration (2017). Based on this, I divided the roads in the buffer zones into three categories depending on their speed limit: - >80 km/h - 80 km/h – 90 km/h - >90 km/h.

For my first two hypotheses, I used wildlife fences which were located throughout Sweden (Swedish Transport Administration, 2017). Because of the coinciding locations of high human and ungulate densities, it is not surprising that the majority of the fenced roads was in the south of the country and along the Baltic coastline (mostly along highway E4, Figure 1).

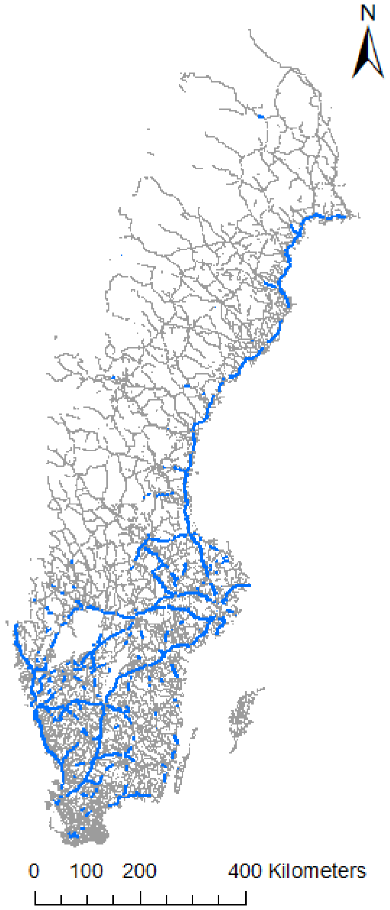


Figure 1: Overview of the locations of wildlife fences in Sweden. Grey lines are the main roads, blue lines are wildlife fences.

For my third hypothesis, I examined two relatively newly placed wildlife fences (Swedish Transport Administration, 2017) and one unfenced road stretch as a control. The southern fence was built in 2010 and consists of 12 smaller fence segments, which were interrupted at road crossings. The fence segments differed in length and range from 214 m to 3113 m (mean ± SD = 815,92 - 2709,24). Because the distance in between two fence segments was maximum 446 m, I treated all segments as one, interrupted fence. The northern fence was built in 2016 and consisted of one, consecutive fence, which was 8027 m in length. The control road was a 10207 m long, unfenced part of the same road (Figure 2).

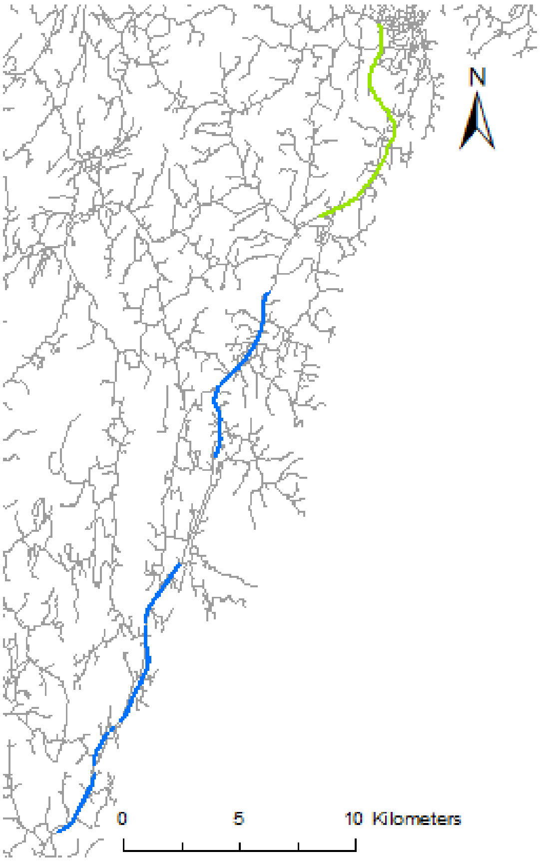


Figure 2: The lower blue lines are the southern fences built in 2010, upper blue line is the northern fence built in 2016, and the green line is the unfenced control. The grey lines are roads.

3.2 Study on national scale

I generated an endpoint at the end of each wildlife fence. Around the endpoints, I created different five circular buffer zones:

- 0 m-100 m from the fence endpoint.
- >100 m-250 m from the fence endpoint.
- >250 m-500 m from the fence endpoint.
- >500 m-1000 m from the fence endpoint.
- >1000 m-1500 m from the fence endpoint.

I based the size of the buffer zones on previous studies by Feldhamer et al. (1986) who focused on white-tailed deer, Clevenger et al. (2001) who looked at moose, North American elk (*Cervus elaphus*), deer (Odocoileus spp.), bighorn sheep (*Ovis canadensis),* coyote (*Canis latrans*), black bear (*Ursus americanus*) and wolf, and Cserkész et al. (2013) who looked at roe deer, red deer, wild boar, fox, otter (*Lutra lutra*) and badger. Clevenger et al. (2001) concluded that most wildlife vehicle collisions occurred within one km from the fence end, Feldhamer et al. (1986) found this to be 480 m, and Cserkész et al. (2013) found most collisions occurred within 400 m from the fence ends.

I created the buffer zones around the fence ends rather than around individual collisions, because the collision data were not very accurate in terms of location (e.g. collisions, which should have fallen on a certain road, were instead projected next to it). Moreover, the fence layer and the lines representing traffic speed and traffic density were projected next to their corresponding roads and sometimes intersected with them. This made it impossible to link the collisions and wildlife fences to the correct roads, especially on a national scale where manually selecting and linking features was not a realistic option. By using buffer zones around the fence ends, I was able to link collisions to the fence ends. Another problem with the collision data was that they represented where an animal died. This could have been on the road, but also away from the road if a hunter was called to go after the wounded animal. This made it impossible to tell where the collision occurred exactly.

I made the buffer zones in such a way that a larger buffer zone did not contain the smaller buffer zones around the same fence endpoint. For example, buffer zone >100 m - 250 m did not contain buffer zone 0 m - 100 m, but was instead placed around it like a ring (Figure 3). To be able to make buffer zones of different sizes, without the larger buffers containing the smaller buffers, I clipped the smaller buffer zones out of the larger ones. This clipping was the reason that buffer zones of the same size category actually could differ in size. To account for this, I included the actual surface area of the buffers as the weights in the models.

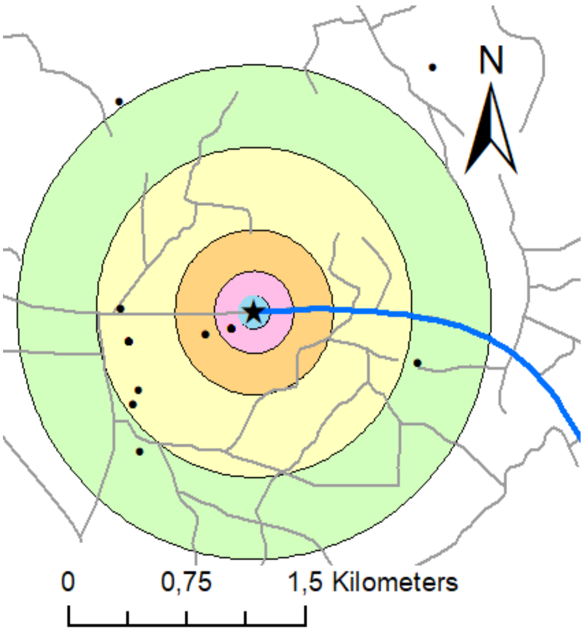


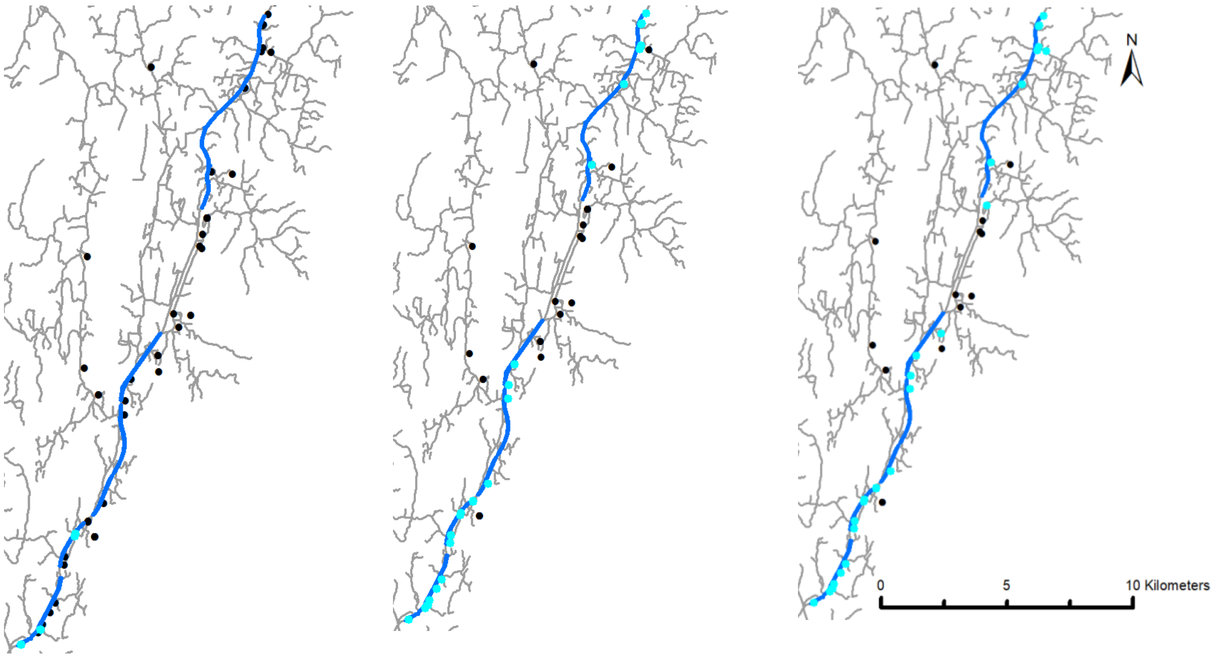
Figure 3: Buffer zones around a fence end (star). Larger buffer zones were placed around the smaller ones like a ring; they did not overlap. Grey lines are roads, blue lines are wildlife fences, and dots are ungulate-vehicle collisions.

A disadvantage of the buffer zones was their shape. Since they were circular with the fence end as their centre, the buffer zones included information on landscape and road features both before and after the fence end. This means that the larger the buffer zone, the more generalised the information about landscape and road features. This was not necessarily a problem for the smallest buffer zone, but the largest buffer zone summarised spatial information of locations, which were up to three km apart. Rectangular buffer zones of equal size, starting at the fence end and following the road in both directions, would have been a much more precise way to select information about landscape and road characteristics and to select the collisions. However, to my knowledge, there was no tool available to generate such shaped buffer zones automatically. Consequently, this kind of buffer zones would have to be drawn by hand. Considering the size of my study, which was on a national scale, this was not a feasible option.

Several fence ends were closer together than the size of the buffer zones around them. As a result, their buffer zones often overlapped with each other. I excluded all collisions which fell in more than one buffer zone from my analysis. This resulted in a total amount of 15540 collisions remaining for the analysis, including: 10761 roe deer, 191 red deer, 2612 moose, 492 fallow deer and 1484 wild boar. Roads either had a wildlife fence on one side, or both sides. I did not distinguish between roads with a double or single wildlife fence, because the objective of the study was to test the effect of the fence ends, not the difference between single and double fencing. In cases where double fences stopped simultaneously on both sides of the road, I placed only one fence endpoint to reduce the number of overlapping buffer zones.

3.3 Case study

Collision points fell slightly next to the roads due to the low accuracy of the data. This made it difficult to define whether a collision had occurred on the fenced road or on an adjacent road. I therefore linked the wildlife fences to all collisions, which happened in distance classes of 100 m, 250 m and 500m away from the fence. Collisions which occurred up to 500 m from the fenced road included both collisions which actually occurred on the fenced road, but also collisions which occurred on secondary roads (Figure 4). As such, I evaluated the collision risk not only for the fenced road itself, but also for the surrounding roads. Fencing one road can in fact also affect the surrounding roads, because the fence can act as a barrier hampering natural migration patterns. This can lead to increased animal densities on one side of the fenced road (Seiler et al., 2003), which in turn can lead to an elevated number of UVCs (Seiler, 2004). The collisions linked to the fences built in 2010 were pooled together, because I regarded the fence as one, interrupted fence.



100 m 250 m 500 m

Figure 4: Collisions in the different distance classes. The light blue collisions are the ones included in the distance class indicated below the map. Black dots are collisions that fell outside of the specified distance class. Grey lines are roads.

Here, I made no difference between the different ungulate species, because this information was incomplete for this set of collision data. For the fence built in 2010, I tested the effect of the fence by comparing the average amount of collisions occurring two years before (2008 - 2009) with the average amount of collisions occurring two years after (2011 - 2012) the installation of the fence. Decimal numbers were rounded up to the nearest integer. I excluded collisions that happened in 2010, because the exact building date of the fence was not available.
A third, unfenced stretch on the same road functioned as a control. Including such a control road allowed me to rule out the possible effect of changes in ungulate population sizes. If the amount of UVCs stayed the same along the unfenced road, but declined along the fenced roads, the decline was most likely an effect of the fences. If the amount of UVCs increased or decreased along both the fenced and unfenced roads, I would conclude this was not an effect of the fence. Instead, I suggest the change was caused by another factor such as, for example, a change in population density.

3.4 Data analysis

To test the hypothesis that the number of UVCs decreases with an increasing distance from the fence end, I applied a multinomial logistic regression model (R package nnet, Ripley, 2002). This model assumed Independence of Irrelevant Alternatives (IIA). The assumption was fulfilled, because adding or removing a buffer zone would not affect the amount of collisions in the other buffer zones (UCLA: Statistical Consulting Group, 2018). To account for the differences in buffer size, I added the collision frequency per individual buffer divided by the surface area of each individual buffer as weights to the model. I used “buffer zone” (one to five) as response variable, and set “buffer zone one” as baseline. This means that the model compared the collision probability in every buffer zone with that in buffer zone one. First, I calculated the collision probability per buffer zone by taking the exponential value of the coefficients produced by the model (UCLA: Statistical Consulting Group, 2018). Based on these collision probabilities, I calculated the corresponding confidence intervals (PennState, 2018a). Next, I calculated the difference in collision probability between buffer zone one and each of the other buffer zones. For each of these differences, I calculated the confidence interval (PennState, 2018b). Based on these confidence intervals, I then calculated the p-values to indicate how significantly different the collision probability in buffer zone one was compared to the collision probability in the other buffer zones (BMJ, 2011).

To analyse if landscape and road features influenced the collision probabilities, I added the different explanatory variables to the model (Table 1). Here, I tested whether a higher amount of straight roads, of roads with intermediate traffic densities, of roads with speed limits (80-90 km/h), and whether higher terrain ruggedness, larger distance to the nearest forest edge, and higher amounts of preferred habitat influenced the collision probability within a buffer zone at a given fence end. I expected different certain habitat classes to be important for the collision probability for different ungulate species. For roe deer, I expected habitats like “open area” and “clear-cuts, young stands and thickets” to be most important (Groot Bruinderink & Hazebroek, 1996; Madsen et al., 2002). For moose, I expected “forest” and “clear-cuts, young stands and thickets” to be important (Danks & Porter, 2010). For red deer, fallow deer and wild boar, I expected “forest” and “open area” to be most important (Groot Bruinderink & Hazebroek, 1996; Colino–Rabanal et al., 2012).I determined the most parsimonious model among my set of alternative models per species, using the Akaike Information Criterion (AIC, Appendix 2). Models with a Δ AIC of less than two, were regarded as equally good (Bozdogan, 1987; Anderson & Burnham, 2002).

To study the effect of the wildlife fences between Mellerud and Tösse, I compared the average number of collisions before and after the building of the fence by using a Chi-square test of goodness-of-fit (Clevenger et al., 2001; Olsson & Widen, 2008) with Yates' correction to account for the small sample sizes (McDonald, 2014). I set the expected proportions to 50:50 (R package stats, R Core Team, 2016). I repeated the test for all collisions that happened within three different distance classes: 100m, 250m and 500m from the fence. The same analyses were done for the fence built in 2016, though here only data for one year after the fence installation were available. As a result, I compared the average amount of collisions that occurred in 2014 and 2015 with the amount of collisions that happened in 2017. I chose not to increase the low amount of data by pooling both fences together because of the different fence designs: interrupted versus consecutive. For the control site, I compared the average number of collisions occurring in 2008 and 2009 with those in 2011 and 2012, and to compare the average number of collisions happening in 2014 and 2015 with those in 2017. Like before, I repeated this analysis for all collisions which happened within 100m, 250m and 500m from the road.

I used ArcMap 10.5 and ArcMap 10.6 to carry out all spatial analyses. For the statistical analyses, I used R Studio versions 3.3.0 and 3.5.0 (R Core Team, 2016). For all analyses, I used a statistical significance of $p<0.05$. The reason for using several versions of both programmes was that the computers were updated during the writing of this thesis.

4 Results

4.1 Study on National scale

For all species, buffer zone one had the highest collision probability. The chance of a collision was around 50%, while it was significantly lower in the other buffer zones. The decrease in collision probability between the different buffer zones differed slightly between the different animals (Table 2).

Table 2: The collision probability and its confidence interval per buffer zone for roe deer, red deer, moose, fallow deer and wild boar. The difference in collision probability compared to buffer zone one and the corresponding confidence interval were given for buffer zone two to five. The p-values indicate how significant the difference between buffer zone one and the other buffer zones was. The buffer zone with the highest collision probability is given in bold.

			Roe deer		
Buffer zone	**1**	**2**	**3**	**4**	**5**
Collision probability	**0,55**	0,30	0,10	0,03	0,02
Confidence interval probability	0,53 - 0,58	0,28 - 0,32	0,08 - 0,11	0,02 - 0,04	0,01 - 0,03
p-value		1,4e-285	0	0	0

			Red deer		
Buffer zone	**1**	**2**	**3**	**4**	**5**
Collision probability	**0,59**	0,29	0,08	0,03	0,01

Confidence interval probability	0,56- 0,61	0,27 - 0,32	0,06 - 0,09	0,03 - 0,04	0,00 - 0,01
p-value		2,8e-09	1,6e-33	1,6e-43	7,3e-52
			Moose		
Buffer zone	**1**	**2**	**3**	**4**	**5**
Collision probability	**0,55**	0,3	0,1	0,03	0,02
Confidence interval probability	0,52 - 0,57	0,28 - 0,32	0,09 - 0,12	0,02 - 0,04	0,01 - 0,03
p-value		2,8e-68	1,7e-289	0	0
			Fallow deer		
Buffer zone	**1**	**2**	**3**	**4**	**5**
Collision probability	**0,57**	0,31	0,07	0,04	0,02
Confidence interval probability	0,54 - 0,59	0,29 - 0,33	0,05 - 0,08	0,03 - 0,05	0,01 - 0,02
p-value		6e-16	9e-79	6e-93	7e-111
			Wild boar		
Buffer zone	**1**	**2**	**3**	**4**	**5**
Collision probability	**0,49**	0,36	0,1	0,03	0,02
Confidence interval probability	0,46 - 0,51	0,33 - 0,38	0,08- 0,11	0,02 - 0,04	0,01 - 0,03
p-value		1,8e-12	8e-129	2,4e-207	1,7e-232

Out of my set of alternative models, the most parsimonious model was the null model. For all species, models including landscape and road characteristics had a Δ AIC larger than two compared to the null model (Table 3). As a result, distance to the fence was the most important factor to explain the decrease in collision probabilities in the buffer zones. Neither landscape nor road characteristics influenced the collision probabilities in the different buffer zones.

Table 3: Δ AIC for models with one explanatory variable compared to the null model, for all species.

Variable	roe deer	red deer	moose	fallow deer	wild boar
Null model	0	0	0	0	0
Open area	8	8	-	8	8
Clear-cuts*	8	-	8	-	-
Forest	-	8	8	8	8
Straight	7,88	8	7,98	8	7,99
Speed80-90	7,99	8	8	8	8
Middle traffic density	7,97	8	8	8	8
Distance to forest	8	8	8	8	8
Ruggedness	8	8	8	8	8

* Clear-cuts included clear-cuts, young stands, and thickets updated with annual clear-cut data.

4.2 Case study

The effectiveness of the fences in reducing the number of UVCs differed between the two fences and between the distance classes (Table 4). The segmented fence reduced collisions significantly (p-value = 0,035) when including all collisions up to 250 m from the fence. When including all collisions up to 500 m, the fence tended to reduce the number of collisions (p-value = 0,052). For the consecutive fence, I did not find any significant reductions of the number of collisions (p-value > 0.05). It is important to note that when including all collisions up to 100 m and

250 m from the fence, the sample size was too low to test statistically. When including all collisions up to 500 m from the fence, the number of collisions the year after the fence was built even increased by two. The unfenced control road did not show any significant differences in the number of collisions over the years (Table 4).

Table 4: Number of collisions along each fence or unfenced control road and for every distance class. The p-values indicate the difference before and after the fence was built. Expected proportion = 50:50.

Fence	**Distance class**	**Collisions before fence**	**Collisions after fence**	**p-value**
Segmented fence	Within 100m	3	1	*
	Within 250m	9	2	**0,035**
	Within 500m	10	3	**0,052**
Consecutive fence	Within 100m	1	0	*
	Within 250m	2	0	*
	Within 500m	8	10	0,637
Unfenced control for the segmented fence	Within 100m	19	11	0,144
	Within 250m	22	12	0,086
	Within 500m	22	12	0,086
Unfenced control for the consecutive fence	Within 100m	19	30	0,116
	Within 250m	20	33	0,074
	Within 500m	31	35	0,623

* = too low sample size to test statically.

5 Discussion

5.1 Study on National scale

In accordance with my first hypothesis, I found a significant decline in the probability of UVCs with an increasing distance from the fence end. For roe deer, moose, fallow deer and red deer, more than 50% of the collisions happened within the first buffer zone, i.e. within 100 m in any direction from the fence end. For wild boar, the collision probability in the first buffer zone was only slightly less (49%). Nevertheless, the collision probability in buffer zone one was still significantly higher than in the other buffer zones. My results fall in line with previous studies, notwithstanding that these studies found that the majority of their collisions fell within a larger distance from the fence end (Feldhamer et al., 1986; Clevenger et al., 2001; Cserkész et al., 2013). This difference could be due to the fact that these studies were performed in different countries and partly included different animals. Another reason could be that Fahrig (2007) and Clevenger et al. (2001) carried out their study on a much smaller scale. All three of the studies gathered their data in a more precise way by using the locations of the actual collision locations instead of the locations where the animals died. This enabled them to pinpoint the exact road where every collision took place, making the use of buffer zones redundant. In my thesis, I used buffer zones to be able to link collisions to the fence ends, because the exact collision location was unknown, and because collisions were projected slightly next to the roads instead of on them. The downside of this approach was that it generalised the data per buffer zone, because the collision probabilities I calculated are for all roads in the buffer zones instead of only the fenced road. On the other hand did my study include data that had been collected on a nationwide scale. My results are thus less influenced by local differences than the studies on smaller scale.

Based on my results I recommend future mitigation actions, such as warning signs to be prioritised within the first 100 m before the fence ends. Huijser et al. (2008) concluded that fences should always be combined with under- or overpasses to prevent animals from attempting to break through the fence. Jakobi and Adelsköld (2012) even suggested that fences can be used to funnel animals towards the under-and overpasses. McCollister and Van Manen (2010) suggested that the effective area of an underpass is limited to several hundred meters from the entrance and proposed continuous fencing in between them. When a new fence is installed, under- or overpasses should be built as close to the animals' original migration routes as possible (Sawyer et al., 2012). In places where the animals have learned to go around a fence and cross at the end, making the effective area of the under- or overpasses coincide with the fence end might be an effective way to decrease the collision risk. Therefor I suggest to build such constructions well before the fence ends, but in such a way that their effective area still includes the fence end. This way, animals that follow the fence will be able to cross the road before the fence ends. According to my results, collision probability was highest close to the fence end. By building under- or overpasses in such a way that their effective area includes the fence end, the maximum amount of animals should be funnelled towards the under- or overpass.

It might even be interesting to inform the public that collision probability is highest in the first 100 m around the fence end. Furthermore would it be useful to warn drivers that the fence is ending before they reach the last 100 m before the fence end. This way they are aware of the increasing collision risk.

In contrast to my expectations, I did not find any significant effects caused by the landscape or road features in the buffer zones. The null model, which only accounted for the increasing distance from the fence end, was the most parsimonious one. Based on this, I concluded that distance from the fence end was the most important factor in predicting collision risks in my study. The reason for this result was likely that the model compared the characteristics in buffer zone one with those in the other buffers around the same fence end. The distance between the fence end and the outer border of the furthest buffer zone was 1,5 km. The landscape and road characteristics presumably did not differ enough to affect the collision probabilities in the different buffer zones around the same fence end. I might have been able to observe a stronger effect if I would have compared the collision probability within buffer zones of the same size, but around different fence ends. Another explanation for the lack of effect can be that the fence ends are not chosen randomly. Swedish Transport Administration has compiled a protocol that determines where the fence end should be in order to minimise drivers being surprised by crossing wildlife. The fence end should, for example, be in open terrain and at least 50 m away from the nearest forest edge (Swedish Transport Administration, 2002).

A way to investigate the effect of landscape and road characteristics using my dataset would be to compare the landscape and road characteristics in buffer zones one around the different fence ends. Due to the aforementioned clipping, not all buffer zones of the same size category cover the same surface area. An exception to this is buffer zone one, where all buffer zones are exactly equal in size. Moreover, the collision probability in this buffer zone was significantly higher than in the other ones, which implies that mitigation efforts would be most efficient here. By analysing whether the collision probability differed between all buffer zones one, depending on the landscape and road characteristics, mitigation efforts could be

applied even more efficiently. If it is known which landscape and road characteristics increase collision probability, fence ends in these particular areas should be prioritised.
For future research on this topic, I recommend to improve the accuracy of the collision data to enable the analysis of landscape features around individual collisions instead of buffer zones. Future research questions could be if all roads within 100 m of the fenced area have the same collision probability, and if the area with a higher collision risk is equally long in both directions of the fence end.

5.2 Case study

Given the way I selected the data, my results did not show the effect of wildlife fences on the fenced road itself, but on all roads up to 500 m away from the fenced road. Contrary to my expectations, not all of the fences between Mellerud and Tösse decreased UVCs as effectively as found in previous research (Clevenger et al., 2001; McCollister & Van Manen, 2010; Huijser et al., 2016). Only the segmented fence reduced the number of UVCs when I considered all collisions up to 250 m from the fence. This is a reduction of 78% , which is comparable to the expected reduction of 80% as described by Clevenger et al. (2001). When I considered the collisions up to 500 m from the segmented fence, I found a trend with a reduction of 70%. A reason for the decrease in efficiency could be that the presence or absence of the fence might not have influenced the collisions that occurred on unfenced roads furthest away. My results are in contrast to findings of previous research that shows that wildlife fences could hamper animal movement and as such lead to an increase in ungulate densities on the fenced side of the road (Seiler, 2003), and that higher ungulate densities lead to more UVCs (Seiler, 2004). When only including collisions within 100 m from the fenced road, the reduction was not significant, suggesting that when only selecting collisions within 100 m of the fenced road, not all collisions that actually happened on that road are included due to the inaccuracy of the collision data.
The amount of UVCs along the control road for the segmented fence showed no significant changes, suggesting that collision probability on the unfenced road stretch did not change over time. It is important to note that in 2010, the year the segmented fence was built, Sweden's hunting regulations were changed in a way that made it compulsory for drivers to report collisions with bears, wolves, wolverines (*Gulo gulo*), lynx, moose, red deer, roe deer, otters (*Luttra luttra*), wild boar, mouflons (*Ovis orientalis orientalis*) and eagles (Accipitridae) (Jaktförordning, 1987). As a result, the reporting of collisions in 2011 and 2012 might have been lower than in 2014 and 2015. Yet, I suggest that this change in law likely did not affect my results, because the number of collisions on the unfenced control road did not change, nor did the number of collisions on the fenced road change when including all collisions up to 100 m and 500 m. In contrast, I found a decrease in collisions when including all collisions up to 250 m.

As opposed to the segmented fence, the continuous fence did not reduce UVCs in any distance class, nor did the control road for the consecutive fence show any changes in the amount of UVCs. Huijser et al. (2016) suggested that fences shorter than five km are less successful in preventing wildlife vehicle collisions. This however does not explain the lack of significant effects of the consecutive fence in my study since it was 8027 m long. According to Feldhamer et al. (1986), white tailed deer are able to crawl underneath the fence in cases where it does not go down all the way to the ground, for example because of rugged terrain or erosion. As mentioned (see 3.1 Data sets), in my case study, the collision data for 2008 and 2009 often lacked information about which species were involved. For the collisions where species was stated, roe deer collisions were most prevalent. Considering that the fences were newly built, gaps due to erosion are unlikely. Gaps due to rugged terrain on the other hand are possible, but I have not inspected the fence personally. Considering that roe deer are smaller than white tailed deer, they should also be able to enter the road by going underneath the fence if there is a gap. If these gaps occurred along the consecutive fence, this could explain for the low efficiency. An inspection of the fence thus is needed to be able to confirm this. Last but not least, A last explanation for the lack of a significant reduction in UVCs along the continuous fence is the low amount of data. More specifically, when I analysed the effects of the fence on collisions within 100 m and 250 m, the number of collisions before and after the installation of the fence was too low for a robust analysis.

For future evaluations of fence performance, I suggest to use collision data from more than two years before and after fencing. Additionally, I recommend monitoring collisions more accurately so the data represent the place where the animal was hit rather than the place where it died. This way, collisions are projected exactly on the road where they happened, providing more specific information about where on the roads collisions are happening. Collecting collision data this way would render the use of buffer zones redundant. By circumventing the use of buffer zones, the analysis can be carried out more precisely. It should be kept in mind, however, that I did use buffer zones to select collisions in three different distance classes from the fence. This means that my results indicated how successful the fences where in reducing UVCs in the three different buffer classes around the fence, rather than only on the fenced road stretches themselves.

In general, I found that a more accurate and detailed collection of collision data would be helpful for future research. I suggest that collision data should be collected by noting the place of the accident rather than the place where the animal died. Moreover, it could be interesting if the approximate age (young or adult) and sex of the killed animal were included in the records. Hunters who go after injured animals report this information (personal communication Tanja Janjic, 30 May 2018), but this information was not included in the collision data I analysed. Including this information would make it possible to investigate whether animals of a certain age or sex have a higher collision risk during certain times of the year, for example during dispersal and rutting periods (Groot Bruinderink & Hazebroek, 1996).

Conclusion

With my thesis, I have shown that the amount of UVCs decreased with an increasing distance from the fence end. Moreover, I found that, in Sweden, the majority of these collisions occur within 100 m of the fence end. The way the collision risk decreased with increasing distance from the fence end was not influenced by landscape or road features.

Concerning the prevention of UVCs, I found that wildlife fences can decrease the amount of UVCs by up to 78%. However, my results were not equally as successful as in previous studies. This was most likely due the low sample sizes.

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Lastly, I want to thank my parents, for everything.

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Appendix 1

Table 5: Reported numbers of animals killed in collisions in Sweden in 2017. Translated from www.viltolycka.se

Year 2017 Species	January	February	March	April	May	June	July	August	September	October	November	December	Total
moose	554	337	227	182	307	300	356	432	733	780	754	978	**5 940**
Roe deer	3 792	3 166	2 690	3 073	4 950	4 578	3 564	3 006	2 577	5 057	5 220	4 188	**45 861**
Red deer	42	31	30	26	17	14	14	11	51	70	72	47	**425**
Fallow deer	239	156	128	112	99	91	107	144	154	421	535	360	**2 546**
Wild boar	550	443	463	279	279	232	262	346	509	963	975	780	**6 081**
Bear	0	0	0	0	1	1	3	1	1	0	0	0	**7**
Wolf	0	1	1	0	1	0	0	1	0	0	0	1	**5**
Wolverine	0	0	0	0	2	0	0	0	0	0	0	0	**2**
Lynx	1	1	3	1	0	0	2	0	3	1	4	1	**17**
Otter	9	3	3	8	3	1	5	6	15	11	6	3	**73**
Eagle	1	1	3	1	2	2	5	5	5	1	1	4	**31**
Mouflon	0	0	0	1	0	0	0	0	0	0	0	1	**2**
Other	11	14	26	21	34	23	49	29	27	15	19	21	**289**
Total	5 199	4 153	3 574	3 704	5 695	5 242	4 367	3 981	4 075	7 319	7 586	6 384	**61 279**

Appendix 2

Table 6: List of alternative models

Explanatory variable	Model
Null model	multinom(BUFF_DIST ~ 1)
Open area	multinom(BUFF_DIST ~ open)
clear-cuts, young stands, and thickets	multinom(BUFF_DIST ~ young)
forest	multinom(BUFF_DIST ~ forest)
Sraight road	multinom(BUFF_DIST ~ straight)
Traffic speed 80 – 90 km/h	multinom(BUFF_DIST ~ Speed80to90)
Middle traffic density	multinom(BUFF_DIST ~ Middle)
Distance to the nearest forest edge	multinom(BUFF_DIST ~ DistanceToForest)
Terrain ruggedness	multinom(BUFF_DIST ~ Ruggedness)

SENASTE UTGIVNA NUMMER

2018:8	Resource distribution in disturbed landscapes – the effect of clearcutting on berry abundance and their use by brown bears Författare: Matej Domevščik
2018:9	Presence and habitat use of the endangered Bornean elephant (Elephas maximus borneensis) in the INIKEA Rehabilitation project site (Sabah, Malaysia) - A pilot study - Författare: Laia Crespo Mingueza
2018:10	Why have the eggs in Baltic salmon (Salmo salar L.) become larger? Författare: Shoumo Khondoker
2018:11	Consequences of White Rhinoceros (Ceratotherium simum) Poaching on Grassland Structure in Hluhluwe-iMfolozi Park in South Africa Författare: Emy Vu
2018:12	Effects of Body Condition on Facultative Anadromy in Brown Trout (Salmo trutta) Författare: Samuel Shry
2018:13	Biodiversity in assisted migration trials – A study comparing the arthropod diversity between different populations of cottonwood (Populus Fremontii) translocated to new areas Författare: Maria Noro-Larsson
2018:14	Nutrient distribution by mammalian herbivores in Hluhluwe-Imfolozi Park (South Africa) Författare: Laura van Veenhuisen
2018:15	Status of supplementary feeding of reindeer in Sweden and its consequences Författare: Anna-Marja Persson
2018:16	Effects of wolf predation risk on community weighted mean plant traits in Białowieża Primeval Forest, Poland Författare: Jone Lescinskaite
2018:17	Sexual Dimorphism in the migratory dynamics of a land-locked population of Brown Trout (Salmo trutta) in central Sweden – A study at three temporal scales Författare: Carl Vigren
2018:18	Impact of Great cormorant (Phalacrocorax carbo sinensis) on post-smolt survival of hatchery reared salmon (Salmo salar) and sea trout (Salmo trutta). Författare: Carolina Gavell
2018:19	Influencing factors on red deer bark stripping on spruce: plant diversity, crop intake and temperature Författare: Anna Widén
2018:20	Estimating the timing of animal and plant phenophases in a boreal landscape in Northern Sweden (Västerbotten) using camera traps. Författare: Sherry Young

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