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Moose-Vehicle Collisions in Northern Norway: Causes, Hotspot Detection and Mitigation

Elg-kjøretøy-kollisjoner i Nord-Norge: årsaker, hotspot-kartlegging og forbygging

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Preface

This study was conducted at the Norwegian University of Life Sciences in Ås, Norway, under supervision of Leif Egil Loe, Christer Moe Rolandsen (Norwegian Institute for Nature Research) and Henrik Wildenschild (Norwegian Public Road Administration, Region North). I would like to thank my supervisors for excellent guidance and help throughout the time I have worked with my thesis. A special thanks to my main supervisor, Leif Egil Loe, for quick replies on my numerous questions, always being available and guiding me through the process of analyses. Many thanks go to Christer Moe Rolandsen for sharing his knowledge on moose and traffic accidents and excellent feedback, and to Henrik Wildenschild for the opportunity to write this thesis in cooperation with the Norwegian Public Road Administration (Statens Vegvesen) and first-on information on the mitigation system in the study area. I also want to thank the Norwegian Public Road Administration for financial support for this thesis.

I want to thank the two Czech scientists, Jiří Sedoník and Michael Bíl, for helping me through the KDE+ method used to develop the hotspot map for moose-vehicle collisions in Norway. Also, I am thankful to Olav Hjeljord for looking over my moose population estimates. I am grateful to Solveig I. Skjærvik for reading through my thesis in the end. My boyfriend, Torbjørn Dolven, deserves a thank you for keeping up with my constant complaining of too much to do and cheering me up with his good mood. Finally, I want to thank my great friends at the University; Kristin Hornset, Pernille A. E. Giske, Ingrid Verne, Espen Mikkelborg, Signe Bergum and Ida K. Nordgård for meaningful conversations over lunches and coffee breaks during the year I have been working on this thesis.

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Ås, May 12th 2017.

Abstract

Animal-vehicle collisions are a growing concern worldwide, from the perspectives of human health and animal welfare, and due to high socioeconomic costs. This has led to an intensive search for effective mitigation measures. However, underlying mechanisms increasing the collision risk is often unknown and hazardous road stretches can be difficult to detect. For the two counties Nordland and Troms in Northern Norway I have analysed the effect of an optic/acoustic mitigation measure. In order to conclude on the effect, I first looked at how temporal variation (i.e. population size, weather and traffic) correlate with the number of moose (*Alces alces*)-vehicle collisions (MVC), and whether the test sections for the mitigation measure were placed at objectively classified hotspot sections for MVCs.

A total of 3,105 MVCs were recorded in the study area during the seven years long time series from 1st of April 2009 to 31st of March 2016. A large proportion of the accidents occurred during winter and the number of MVCs were positively correlated to snow depth and population size. The predicted number of MVCs for public roads in the study area was 0.46 MVCs/10 km/year. I used the novel kernel density estimation method KDE+ to objectively detect hotspots in the area. According to the KDE+ analysis, my MVC-data formed 77 significant clusters (hotspots) with three or more MVCs in each cluster. These hotspots contained 9.8 % of all the recorded MVCs. The hotspots were ranked by significance after their cluster strength. The optic/acoustic mitigation measure were put up on four road sections of various length in the study area in 2014. Two of four sections were classified as hotspots, although all sections had a higher number of MVCs than the prediction for the area. The mitigation system is supposed to scare away the moose using high frequency sound and blinking lights when cars are present, but I found no significant reduction in the number of MVCs after installation of the instruments.

I conclude that with further improvement of the hotspot-detection method and by looking at the underlying mechanisms of variation in the number of MVCs such as snow depth and population size, the method can be used as a tool to select which road sections to mitigate. This can lead to a more cost-effective prevention of MVCs in the future. The optic/acoustic mitigation system did not show any significant reducing effect on the number of MVCs on the test sections.

Sammendrag

Dyrepåkjørsler er et økende problem på verdensbasis sett ut ifra et helse- og velferdsperspektiv både for mennesker og dyr, og i form av høye sosioøkonomiske kostander. Dette har ført til et intensivt søk etter effektive forebyggende tiltak. Årsakene til variasjon i ulykkesrisikoen er ofte usikre og det kan være vanskelig å finne de mest utsatte strekningene på en effektiv måte. For de to fylkene Nordland og Troms i Nord-Norge har jeg analysert effekten av et optisk/akustisk tiltak mot viltpåkjørsler. For å kunne konkludere om det er en effekt av tiltaket eller ikke, så jeg først på hvordan variasjon over tid (dvs. populasjonsstørrelse, vær og trafikk) korrelerer med antall elg-kjøretøy-kollisjoner (elgpåkjørsler) og om tiltaket var plassert på strekninger som objektivt sett var klassifisert som spesielt utsatte for elgpåkjørsler.

Totalt 3,105 elgpåkjørsler var registrert i studieområdet gjennom den sju år lange tidsserien fra 1. april 2009 til 31. mars 2016. En stor andel av ulykkene skjedde på vinterstid og antallet elgpåkjørsler var positivt korrelert til snødybde og populasjonsstørrelse. Det predikerte antallet elgpåkjørsler for studieområdet var 0.46 elgpåkjørsler/10 km/år. Jeg brukte den nye 'kernel density' estimeringsmetoden KDE+ for å objektivt kartlegge hotspots i studieområdet. I henhold til KDE+ analysen formet elgpåkjørselsdataene 77 signifikante hotspots med tre eller flere ulykker. Disse utsatte områdene inneholdt 9.8 % av alle de registrerte ulykkene. Hotspotene ble rangert etter signifikansnivå målt i 'cluster strength'. Det kombinerte optisk/akustiske systemet var satt opp på fire vegstrekninger av ulik lengde innenfor studieområdet i 2014. To av fire teststrekninger ble klassifisert som hotspots, selv om samtlige strekninger hadde et høyere antall elgpåkjørsler enn prediksjonen for området tilsa. Det optisk/akustiske systemet skal skremme vekk elgen ved bruk av høyfrekvent lyd og blinkende lys når biler passerer, men jeg fant ingen signifikant reduksjon i antall elgpåkjørsler etter installasjonen av instrumentene.

Jeg konkluderer med at videre utvikling av metoden for å finne hotspots og ved å se på årsaker til variasjon i antall elgpåkjørsler, slik som snødybde og populasjonsstørrelse, kan metoden bli brukt som et verktøy i utvelgelsen av vegstrekninger hvor tiltak skal iverksettes. Dette kan føre til en mer kostnadseffektiv ulykkesreduksjon i fremtiden. Det optisk/akustiske systemet viste ingen signifikant reduserende effekt på antallet elgpåkjørsler på teststrekningene

Contents

1 Introduction

Animal-vehicle collisions (AVCs) are a serious road safety issue and a growing problem worldwide (Langbein et al. 2011). In Europe, this is caused by a combination of rapid ungulate population growth and increased traffic volume and road density (Mysterud 2004; Rolandsen et al. 2011), which have led to fragmentation of the animals' habitat (Groot Bruinderink & Hazebroek 1996). These factors have contributed to an increase in negative interactions between human and wildlife on the roads (Hothorn et al. 2015; Joyce & Mahoney 2001; Seiler 2005). AVCs are the outcome of animals and vehicles being at the same spot at the same time. More AVCs are likely to occur when animals are frequently crossing roads (or rails) and when driving conditions are poor. Consequently, previous research has documented that the number of AVCs is related to factors such as crossing frequency, traffic volume (e.g. number of cars per time unit) and driving conditions (e.g. Groot Bruinderink & Hazebroek 1996).

In my thesis I will focus on collisions between vehicles and moose (*Alces alces*), which tend to cause the most serious damage and injuries of AVCs in Norway, because of the animals' high body weight and long legs (Joyce & Mahoney 2001; Seiler 2005). Moose are the largest animal in the Cervidae family, and a mature moose weighs about three times as much as a mature red deer (*Cervus elaphus*) of the same sex (Vaa et al. 2012). Estimates of the proportion of moose-vehicle collisions (MVCs) resulting in human injuries varies from less than 5 % to almost 20 % (Joyce & Mahoney 2001; Niemi et al. 2017), and some collisions even cause death to the people involved (Seiler 2005). In Scandinavia, moose are an economically important species because of hunting (Storaas et al. 2001). Moose populations have increased substantially over the past century because of low hunting quotas on adult female moose, in addition to a change in modern forestry to clear-cutting areas, which provide very good habitat for moose. In the beginning of the 20th century around 10,000 moose were harvested annually in Fennoscandia (Norway, Sweden and Finland), and hundred years later around 200,000 moose were harvested annually (Lavsund et al. 2003). Between 1970 and 2007, the number of moose killed in traffic (train and cars) in Norway increased from about 200 to 2,100, mainly because of the increasing moose density (Solberg et al. 2009). For the last ten years, approximately 1,800 moose have been killed annually in traffic collisions, where the majority (65 %) occur on roads (Solberg et al. 2009; Statistics Norway 2016b). Costs of traffic accidents involving ungulates in Norway are estimated to at least 250 million NOK/year (Direktoratet for naturforvaltning 2009).

In northern parts of Scandinavia, many moose populations are partially migratory (Bunnefeld et al. 2011; Rolandsen et al. 2016). Migrants and residents usually congregate on the same winter ranges at relatively low altitudes (Rolandsen et al. 2016). The general assumption for this pattern is that deep snow will limit the access to food and increase the cost of locomotion in the summer ranges during winter (Ball et al. 2001). As a consequence, when snow is accumulating in surrounding hills more moose will congregate in the valley bottoms where the road density is higher (Rolandsen et al. 2011). In turn, this will increase the crossing rates of animals over roads and consequently increase the number of collisions (Olson et al. 2015; Rolandsen et al. 2011). Thus, more MVCs occur in winter compared to summer, and in snow-rich compared to snow-poor winters. Moreover, the use of traditional wintering areas implies that high-risk areas of MVCs are often known. Decreasing winter temperature is also shown to increase the number of MVCs in some studies (Andersen et al. 1991; Gundersen et al. 1998; Rolandsen et al. 2011), but the mechanism leading to this pattern is not well known (Rolandsen et al. 2011). In addition, several studies have found increasing number of MVCs with increasing traffic volume (e.g. Rolandsen et al. 2011; Seiler 2005)

Road and wildlife managers are interested in methods to detect hotspots for AVCs (Bíl et al. 2016; Krisp & Durot 2007). A variety of kernel density estimations (KDE) are tried out to detect these hotspots (Bíl et al. 2016; Krisp & Durot 2007; Malo et al. 2004). If hotspots can be detected efficiently, the road authorities can focus on mitigating the most hazardous road sections, and thereby reduce the risk of AVCs more cost-effectively (Bíl et al. 2016; Malo et al. 2004). A novel and promising method for hotspot detections is the KDE+ software which locate and rank hotspots on the road network (Bíl et al. 2013; Bíl et al. 2016). This method has so far only been tested in 11 countries, excluding Norway, and never on MVCs solely (Bíl et al. 2016; Transport Research Centre 2017).

To reduce the socioeconomic costs related to ungulate-vehicle collisions (UVCs), different mitigation measures have been implemented (Andreassen et al. 2005; Huijser et al. 2009). Warning signs are probably most widely used (Putman 1997; Romin & Bissonette 1996; Sivertsen et al. 2010), but also vegetation clearing, scent marking, wildlife reflectors, supplemental feeding and wildlife fences are regularly used to prevent wildlife collisions (Andreassen et al. 2005; Huijser et al. 2009; Sivertsen et al. 2010). However, the mitigating effect of these actions have been evaluated far too seldom, especially after controlling for confounding effects of other factors affecting the number of UVCs. An important step forward is therefore to quantify the potential accident-reducing effect of the various measures after controlling for other confounding factors and continue the search for new and more efficient mitigation measures. The main aim of this thesis was to test the mitigation effect on MVCs of a novel combined optic and acoustic deer deterrent system. The system was installed at four road stretches assumed to have a relatively high risk of MVCs in Northern Norway (Wildenschild 2016). In a research work for the Austrian Road Safety Fund, Steiner (2011) found a reduction of 42 % on test sections in Austria for a previous version of an optic/acoustic mitigation system. Other analyses of systems based on reflectors and sound have not been able to document long-term effects (D'Angelo & van der Ree 2015; Ujvari et al. 1998), and a recent meta-analysis of the effectiveness of mitigation measures found that wildlife reflectors only reduced road-kills with 1 % (Rytwinski et al. 2016). However, a system combining sound and light was not examined, and has not previously been tested in Norway or on moose.

The optic/acoustic system was installed without any experimental protocol or objective assessment of MVC frequency. I wanted to control for the confounding effects of temporal variation (i.e. weather conditions, traffic volume and temperature) on MVCs before testing the effect of the optic/acoustic system. This is particularly important because the treatment effect should be evaluated in relation to natural variation in MVCs. From previous studies, I hypothesize that MVCs are a function of traffic volume, moose population size and the variation in winter temperature and snow depth. I predict that the number of MVCs will (P1) increase with traffic volume, (P2) be higher with larger moose population sizes, (P3) be higher with decreasing winter temperatures and (P4) be higher (a) in the winter than in the rest of the year and (b) particularly high in snow rich winters. Thereafter I continued to investigate if the system had been installed on sites that could objectively be classified as high-risk zones for MVCs. Based on the assumption that measures to reduce the number of MVCs are installed along stretches with initially higher probability of MVCs than average, I predict (P5) that the test sections for the optic/acoustic system would objectively be classified as hotspots. I used the KDE+ software to locate and rank hotpots on the road network (Bíl et al. 2016). Finally, based on the hypothesis that the use of sound and light can reduce the number of accidents, I predict (P6) that the number of MVCs on the test sections will be reduced after installation of the optic/acoustic system accounting for other sources of variation (P1-P4).

2 Material and methods

2.1 Study area

The study area is located in the counties Nordland and Troms in Northern Norway (figure 1). The counties constitute a large area from 65°N and 12°E to 70°N and 22°E (Kartverket 2017). I have chosen these two counties for my thesis based on where the optic/acoustic mitigation measure is installed. These devices are installed on four road sections with variable length (figure 1). There are two sections in Nordland; Kvarv (2.2 km) in Sørfold municipality and Åseli (1.5 km) in Bodø municipality. In Troms, the two sections are Karlstad (2.5 km) in Målselv municipality and the longest section, Bardu (7.5 km), in the municipality Bardu.

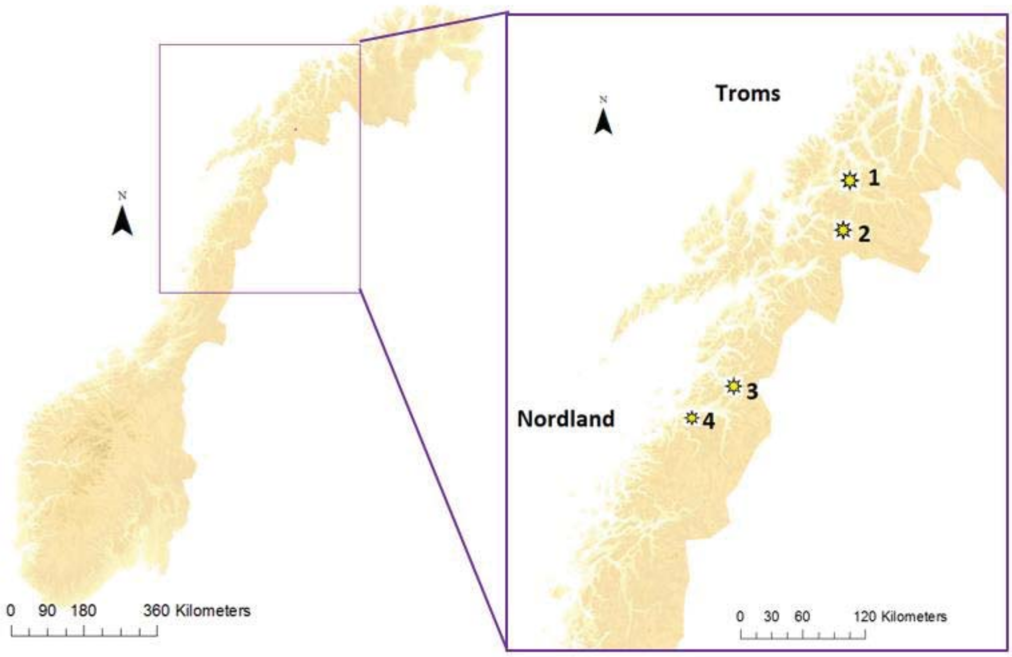

Figure 1: Norway and the counties of Nordland and Troms with the four test sections. 1) Karlstad, 2) Bardu, 3) Kvarv and 4) Åseli.

The area is situated in the boreal zone, and the further north the lower the tree limit is (around 600 meters in the northern parts of Troms). Downy birch (*Betula pubescens*) and Scots pine (*Pinus sylvestris*) dominate the forests (Sæther & Heim 1993; Ueno et al. 2014). The landscape in Northern Norway consists of a lot of mountains forming valleys. Mean temperatures for the study area vary between 8-12°C by the coast to 14-16°C in the inner parts in July, and 0 to -2°C by the coast and -8 to -12°C in the inner parts in January (Moen et al. 1999). The length of the snow cover period varies with the north-south gradient, as well as the altitude and distance from the sea. However, the mean length of the snow cover period for the whole study area is from November throughout April (Norwegian Meteorological Institute 2016). The northern parts of Nordland (above the Polar circle, 66°N) and all of Troms have no sun around solstice ± up to one month, and have an equivalent period of midnight sun around summer solstice (timeanddate.com 2017).

2.2 Study species

The moose is crepuscular, which means that it is most active during dusk and dawn, and this is reflected in the pattern of MVCs (Hothorn et al. 2015; Huseby 2013; Lavsund & Sandegren 1991; Rolandsen et al. 2010). The moose is a browser which prefers rowan (*Sorbus aucuparia*), aspen (*Populus tremula*) and willow (*Salix caprea*), but in wintertime it browses a lot on pine twigs. Other Salix-species is also favourable to the moose, but during summer birch is usually what dominates its diet (Hjeljord 2008). During the winter, the moose may be more prone to use areas near roads to feed, because of depleting food resources elsewhere (Eldegard et al. 2012). The main predator of the moose is the grey wolf (*Canis lupus*), but in Norway there are very few wolves, and they are almost absent in Northern Norway. The natural mortality for the Norwegian moose is usually lower than the hunting mortality, and most moose die due to hunting (Stubsjøen et al. 2000). Because of this, hunting is the main factor contributing to fluctuations in moose populations from one year to another (Gervasi et al. 2012).

2.3 Data collection and formatting

I have collected data from seven years, from 1st of April 2009 to 31st of March 2016. This was set as 2009-2015 because the years are expressed as hunting seasons, which in Norway is from 1st of April the given year to 31st of March the following year (henceforward year will refer to hunting year). Data starting from 2009 were chosen because data from the National Cervid Registry (NCR) had highest position precision from 2009, and this was of importance to create a precise MVC hotspot map.

Moose-vehicle collisions

The official numbers of moose killed in MVCs per municipality each year were collected in Statistics Norway's database (Statistics Norway 2016b). The input datasets of MVCs and roads to the hotspot analysis in ArcMap were provided by the Norwegian Institute of Nature Research (NINA). In the NCR MVCs were registered regardless of the outcome for the moose. The municipalities are not obligated to report the MVCs to the NCR, but it is common to do so. Here the MVCs are registered with position coordinates and date and time of the collision (Miljødirektoratet & Naturdata as 2016c), hence it is possible to see the collisions in a map. The dataset from NCR was also used in the model construction together with the official numbers. In the data from Statistics Norway the MVCs were reported as the number of accidents per hunting year per municipality (see appendix 1). To be able to compare the MVC data from Statistics Norway and NCR I had to transform the years recorded in the NCR dataset into hunting years. For some municipalities in some years the number of MVCs recorded in the NCR did not coincide with the numbers recorded in Statistics Norway. Here I used the maximum value for MVCs the given year for the given municipality, assuming that underreporting in either database is the most common error. Data and information on the optic/acoustic mitigation system were provided by the Norwegian Public Road Administration (NPRA). The numbers of MVCs on the test sections were collected by counting the accidents in the open access online map provided by the NCR (Miljødirektoratet & Naturdata as 2016c).

Moose population size

To estimate the moose population size, I collected data based on the datasets 'seen moose' (Miljødirektoratet & Naturdata as 2016b) and 'moose shot' (Miljødirektoratet & Naturdata as 2016a) during the hunting season from the NCR. I extracted data on females with calves, the total number of seen moose and the total number of moose shot during the hunting season from these two datasets. I calculated the population estimate for each municipality in the two counties using a method developed by Olav Hjeljord, professor emeritus at the Norwegian University of Life Sciences (see equation 1). I tested the correlation between the estimated population and the number of harvested moose the same year (cor=0.98, $p<0.001$). By calculating the population size, (instead of the more commonly used number of harvested moose as a proxy for moose population[1]), I was able to find the proportion of moose killed in MVC from the actual population.

Eq. 1:

[1] $\frac{\text{Total number of moose shot}}{\text{Number of calves per female with calves}} = \text{number of productive females needed}$

[2] $\frac{\text{Number of productive females needed}}{\text{Total number of moose seen}} * 100 = \text{per cent productive females in the population}$

[3] $\frac{\text{Number of productive females needed}}{\text{Per cent productive females in the population}} * 100 = \text{population before the hunting season}$

Weather data

For the weather data, I downloaded data on daily snow depths and temperature from 1st of April 2009 to 31st of March 2016 for all municipalities and weather stations with this data available. These data were collected from the Norwegian Meteorological Institute's database at eklima.met.no (Norwegian Meteorological Institute 2016). Looking at the monthly distribution of snow depth, I defined the winter to last from 1st of November to 31st of March. To find the proportion of winter MVCs I extracted the MVCs in the winter months and divided them by all the MVCs in that particular year. To estimate the snow conditions, I calculated the mean snow depth per month in the winter and summed these per municipality per year. I divided this sum on the five winter months and was left with one mean snow depth for the winter per municipality and year (See Andersen et al. 1991). For temperature data, I calculated mean winter temperature following the same procedure as for snow depth.

Traffic volume and road length

To estimate the traffic volume, I collected data on the annual number of cars per municipality and the average annual private car mileage per municipality from Statistics Norway (Statistics Norway 2016a; Statistics Norway 2016c). I multiplied the annual number of private cars per municipality with the annual average private car mileage per municipality. This number was used as an estimate for the annual traffic volume per municipality in accordance with Rolandsen et al. (2011).

[1] See f.ex. Rolandsen et al. (2011)

I contacted the NPRA to get the data concerning the length of the roads per municipality in Nordland and Troms. Municipality roads, private roads and forest roads (tertiary roads) are roads with relatively low speed limit and few MVCs. I used ArcMap and the function 'snap to line' to check how many per cent of the MVCs that occurred on tertiary roads, and only 5 % of the MVCs occurred here in the study area. Therefore, I excluded these roads from the total road length so that the predicted number of MVCs would be based upon roads with higher risk of MVCs. I was then left with State roads (Europavei + Riksvei) and county roads (Fylkesvei). In Nordland it is 5,179 km of roads in these categories, while it is 3,432 km in Troms.

2.4 The optic/acoustic mitigation instruments

The combined optic/acoustic mitigation system tested in this study is called DeerDeter. It is solar powered electronic devices that are triggered by the headlights of the approaching vehicles (Figure 2 A-B). One device is placed every 50 meters on each side of the road and the poles are placed with a 45-degree angle to the ones on the other side of the road so that the road section is covered with one pole every 25 metres (figure 2 C). The instruments send out high frequency (7.2 kHz on a 30 cm distance) sound and a blue and yellow LED-light to get the animal's attention and prevent it from crossing the road while vehicles are present. In a study of white-tailed deer's (*Odocoileus virginianus*) vision, VerCauteren and Pipas (2003) suggest that deer can see the blue and yellow colour spectrum, and this might be adaptable for moose, too. Compared to e.g. fences, the optic/acoustic system will not prevent the animals from crossing the roads when vehicles are absent, and therefore not cause a migration barrier (Wildenschild 2016, pers comm.).

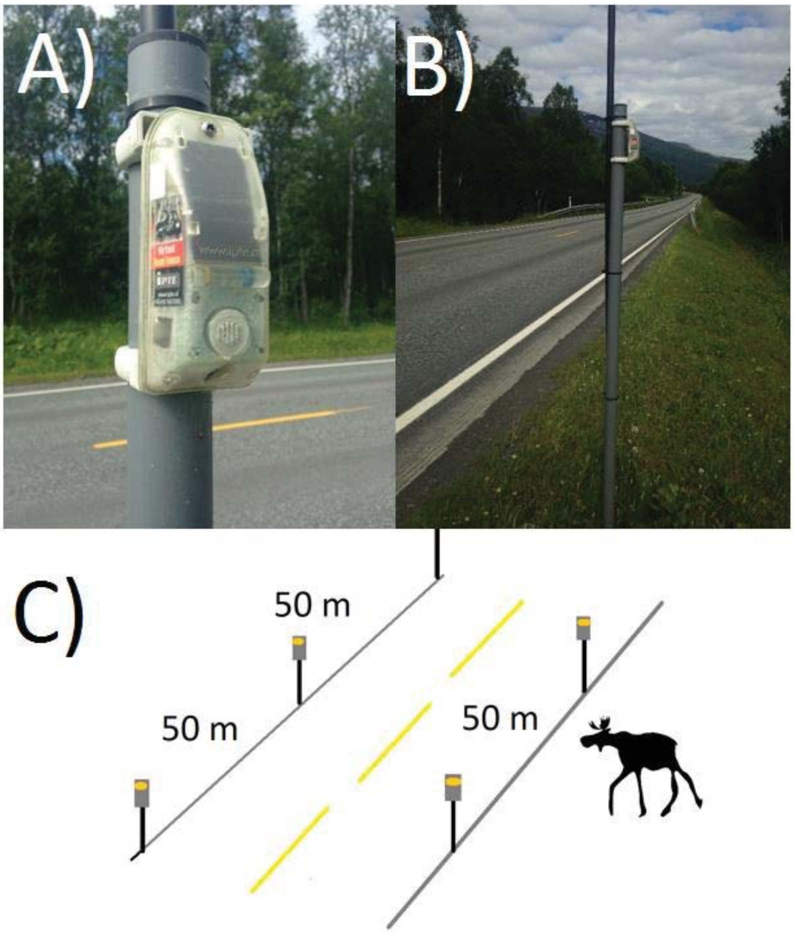

Figure 2: The optic/acoustic system to prevent moose from crossing the road while cars are present. A) Close-up of the actual device, B) the entire pole with the device, and C) illustration of the setup. Photo and ill.: Johanne B. Sørensen.

2.5 Statistical analyses

All of the data, except the hotspot map, were processed in the software R version 3.2.2 (R Development Core Team 2015). I excluded municipalities and years without recorded moose population, MVCs or snow depths, resulting in a total of 37 municipalities (see appendix 1), a total road length for both counties of 5,751 km, including primary and secondary roads, and a total of 2,560 MVCs.

Model construction

I used a generalized linear mixed-model (GLMM; Bates 2005) to model the relationship between number of MVCs per road segment and different predictor variables, and I used municipality as random effect to adjust for unexplained variation caused by differences among municipalities. My offset variable was road segment length, and the errors were assumed to follow a negative binomial distribution. The models were constructed using the glmmADMB package (Fournier et al. 2012; Skaug et al. 2016) in R, because it is the only function that can fit a mixed model with a negative binomial distribution. I tested models with moose population size, traffic volume, mean winter temperature, mean snow depth and year effects. To facilitate direct comparison of effect sizes, I standardized all these variables at mean=0 and variance=1 using the scale-function in R. I used forward stepwise regression where the variables were introduced until the ensuing new model (with one extra predictor variable) was not significantly more informative than the simpler model in likelihood ratio test (LRT) performed in R (Pinheiro & Bates 2000).

I used the selected model above to make predictions for MVCs for the test sections with the data on population size and snow depth for the actual municipality per kilometre. These model predictions were fitted in a figure together with the exact number of MVCs on the section during the period, divided by the length of the section in kilometres. For the test sections I found the yearly average number of MVCs before and after the optic/acoustic system was installed. The system was in action on all the four sections from 1st of May 2014. I included numbers on MVCs from 2009 and to March 31st 2014 (hunting year 2013) in the before installation-data. There were no MVCs on any of the sections in April 2014, hence I included the hunting years 2014 and 2015 in the after-installation data. I divided the number of MVCs after the installation by two years (hunting year 2014 and 2015). To test whether the mitigation measure significantly reduces the number of MVCs, I included a treatment-variable to my model. I used LRT to test if the treatment-variable gave a significant improvement of the model.

The KDE+ method

Kernel density estimation (KDE) is used to objectively detect spatial clusters, and is frequently used in traffic accident analyses (E.g. Bíl et al. 2013; Krisp & Durot 2007; Sabel et al. 2005; Xie & Yan 2008). Traditional KDE is planar, but the KDE+ is applied to a network (road segments) so it is one-dimensional (Bíl et al. 2013; Xie & Yan 2008). A segment is a road section between two intersections and by splitting the road into segments the annual average daily traffic (AADT) does not have to be taken into consideration because the traffic remains constant within the section. In the KDE+, Monte Carlo simulations are used to rank the clusters by level of significance (Bíl et al. 2013). The Monte Carlo simulations are repeated random simulations to objectively determine which clusters are significant and thereby ranking the clusters (Sabel et al. 2005). The clusters are ranked by a cluster strength between 0 and 1 from the least to the most critical hotspot (Bíl et al. 2016). The cluster strength quantifies how much the density estimation differs from the expected value, and hence it can be used as a quantifier for cluster significance. The strength is expressed as the ratio between the local maximum of the kernel function above the significance level and the value of the local maximum at that point (Bíl et al. 2013).

The KDE+ software is a programmed version of the KDE+ method (Bíl et al. 2016). To use the software you need the road network with lengths of each segment and the point data from the accidents with XY-coordinates as input datasets. By using data from a short time span (here: seven years), the length of the road network will remain almost unchanged (Bíl et al. 2013). I used the GIS software ArcMap version 10.4.1 (ESRI 2016) and the KDE+ toolbox to compile a map showing the hotspots (clusters) of MVCs in Norway. In this analysis, tertiary roads (municipality roads) were included too, because it was run on all of Norway. I extracted Nordland and Troms by using the 'clip'-function in ArcMap. For Nordland and Troms a total of 2,801 MVCs were analysed in the KDE+.

The KDE+ will run the analysis on your data for a chosen bandwidth and a chosen number of Monte Carlo simulations. In KDE, several shapes of kernels may be used, and in the KDE+ the Epanechnikov kernel is used. Different shapes of kernels will not affect the results substantially (Bíl et al. 2013). In my analysis, I added the following numbers for the different parameters in the software: Snapping tolerance: 50 m, bandwidth: 100 m, Monte Carlo simulations: 800, step of discretization: 1, and minimal strength: 0. A bandwidth of 100 m provide a relatively detailed map of the clustered MVCs. Xie and Yan (2008) tested different bandwidths on traffic accidents in a network-KDE analysis in Kentucky, USA. Here a bandwidth of 20 m gave a very detailed map, 100 m gave a detailed map and for bandwidths of 250 m and wider the map lost the local variation in density. By increasing the bandwidth to e.g. 1000 m, the neighbouring local hotspots will be combined and result in longer clusters, but then information on the local clusters, which is the aim to detect with the KDE+ method, will be lost.

3 Results

3.1 Patterns of MVC

The number of MVCs per municipality and year increased with moose population size and snow depth (table 1, figure 3 and 5), supporting prediction P2 and P4b. The annual traffic volume and the mean winter temperature did not give any significant improvement of the model, rejecting prediction P1 and P3 respectively. The model gave a predicted number for public rods in Nordland and Troms of 0.46 MVCs/10 km/year at mean population size (399 moose) and mean snow depth (31 cm). However, the number of MVCs were not evenly distributed along the roads, but formed hotspots at some places.

Table 1: The selected model for risk of moose-vehicle collisions per 10 km of public road in Nordland and Troms, in Northern Norway. Snow depth and population were standardized at mean=0 and variance =1 prior to analyses to facilitate direct comparison of effect sizes. Coefficients are on log scale.

Variables	**Coefficient**	**SE**	**z-value**	***p***
Intercept	-3.086	0.150	-20.6	< 0.001
Population size	0.239	0.092	2.61	0.009
Snow depth	0.253	0.058	4.40	< 0.001

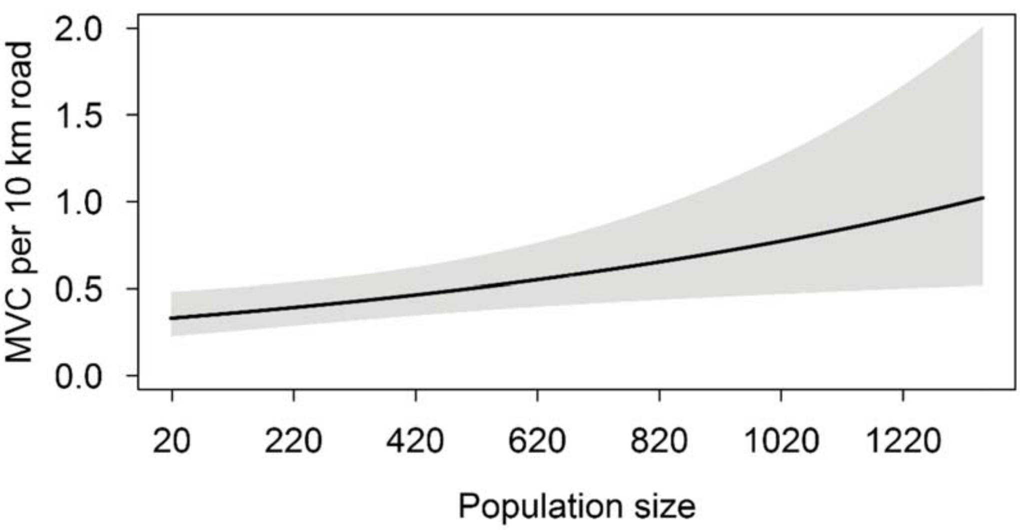

Figure 3: Predicted number of MVCs per 10 km public road in Nordland and Troms as a function of estimated moose population size ± 2 SE, after accounting for variation in mean monthly snow depth kept constant at mean value, 31 cm.

Of the municipalities included in the analysis, the estimated moose population size was lowest in Kåfjord municipality (Troms) with 18 moose in 2009 and highest in Vefsn municipality (Nordland) with 1351 moose in 2015. The average harvest rate in the study area during the study period was 26 % of the population. The mean proportion of moose killed in collisions in relation to the number of moose harvested during the hunting season was 6.1 %. The overall annual mean of traffic-killed moose was 1.5 % of the total population size.

Confirming prediction P4a, a high proportion of the MVCs occurred during the winter (figure 4). On average 78 % of the collisions occurred during the five winter months, with low variation among years. The highest proportion of winter accidents was in 2010, when as much as 80 % of the MVCs in Nordland and Troms occurred during the winter. There were no pronounced peaks in MVCs within years other than the winter in the study area. Most MVCs in the area occurred in 2010 with a total of 598 MVCs, and 2009 had fewest MVCs with 329. The average snow depth in 2010 was also the deepest during the study period with 1.9 SD above the mean, while the lowest mean snow depth was recorded in 2009 with snow depths 1 SD below the mean. Notwithstanding, the estimated population size was lowest in 2010 during the period with an average population size 1.4 SD below the mean of 399 moose.

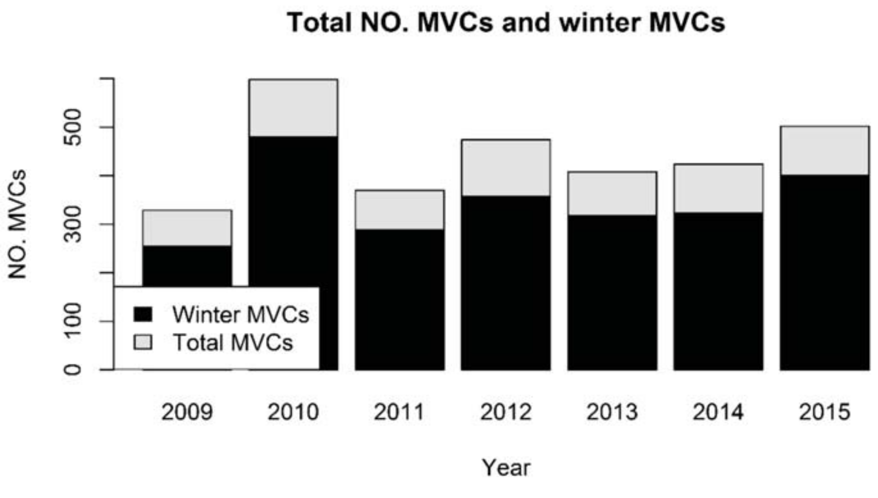

Figure 4: Total number of MVCs in Nordland and Troms per year (grey) and the number of MVCs during winter per year (black). These numbers are based on raw data.

As predicted from P4b, increasing snow depth had a significant effect on the number of MVCs ($p<0.001$; figure 5). Snow depths varied between a minimum of 0 cm in monthly mean during the winter in 2009 in Fauske (Nordland), and a maximum of 101 cm in monthly mean in 2010 in Vågan (Nordland).

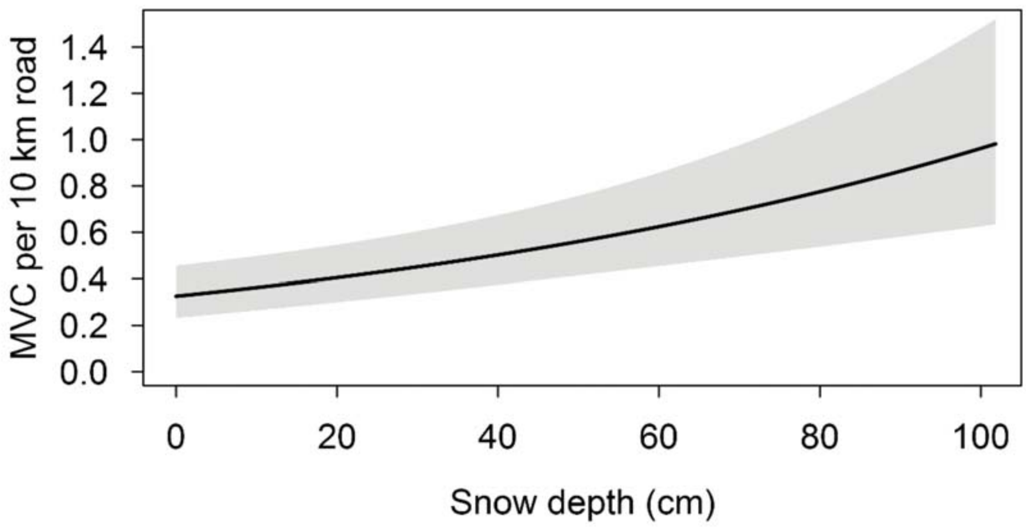

Figure 5: Predicted number of MVCs per 10 km of public road in Nordland and Troms as a function of snow depth from November to March ± 2 SE, after accounting for variation in population size kept constant at mean value, 399.

3.2 Hotspots

Of the total of 2,801 MVCs analysed for Nordland and Troms, 568 of them, or around 20 %, ended up in clusters. A total of 224 hotspots with variable lengths between 5 and 382 meters were found in the study area. I excluded all clusters with only two MVCs (147 clusters), because these were highly unstable clusters, and ended up with 77 clusters (Figure 6 A). Bíl et al. (2016) excluded clusters with less than five accidents, but I chose to keep clusters with three or more MVCs in accordance with Malo et al. (2004), as few of the clusters contained many MVCs. After excluding the unstable clusters, 274 MVCs or 9.8 % of the total MVCs in the study area ended up in clusters.

The longest cluster contained 9 MVCs and had a length of 382 meters and a strength of 0.27. The strongest cluster in the output had a strength of 0.66 and contained 3 MVCs in a total of 162 meters. Of the public road network in Nordland and Troms a total of 9.8 km was classified as hotspots including three or more MVCs according to the KDE+ method. This made up only 0.0011 % of the public road network (not including the length of municipality roads). On two of the four test sites for the optic/acoustic mitigation measure parts of the sections were classified as hotspots (figure 6 B and D), partly supporting prediction P5. Regarding the two other test sites, there was a cluster on the Bardu section (figure 6 C) containing only two MVCs, hence it was excluded. There was a highly significant cluster around 700 meters from the Åseli section, but none at the actual section (figure 6 E).

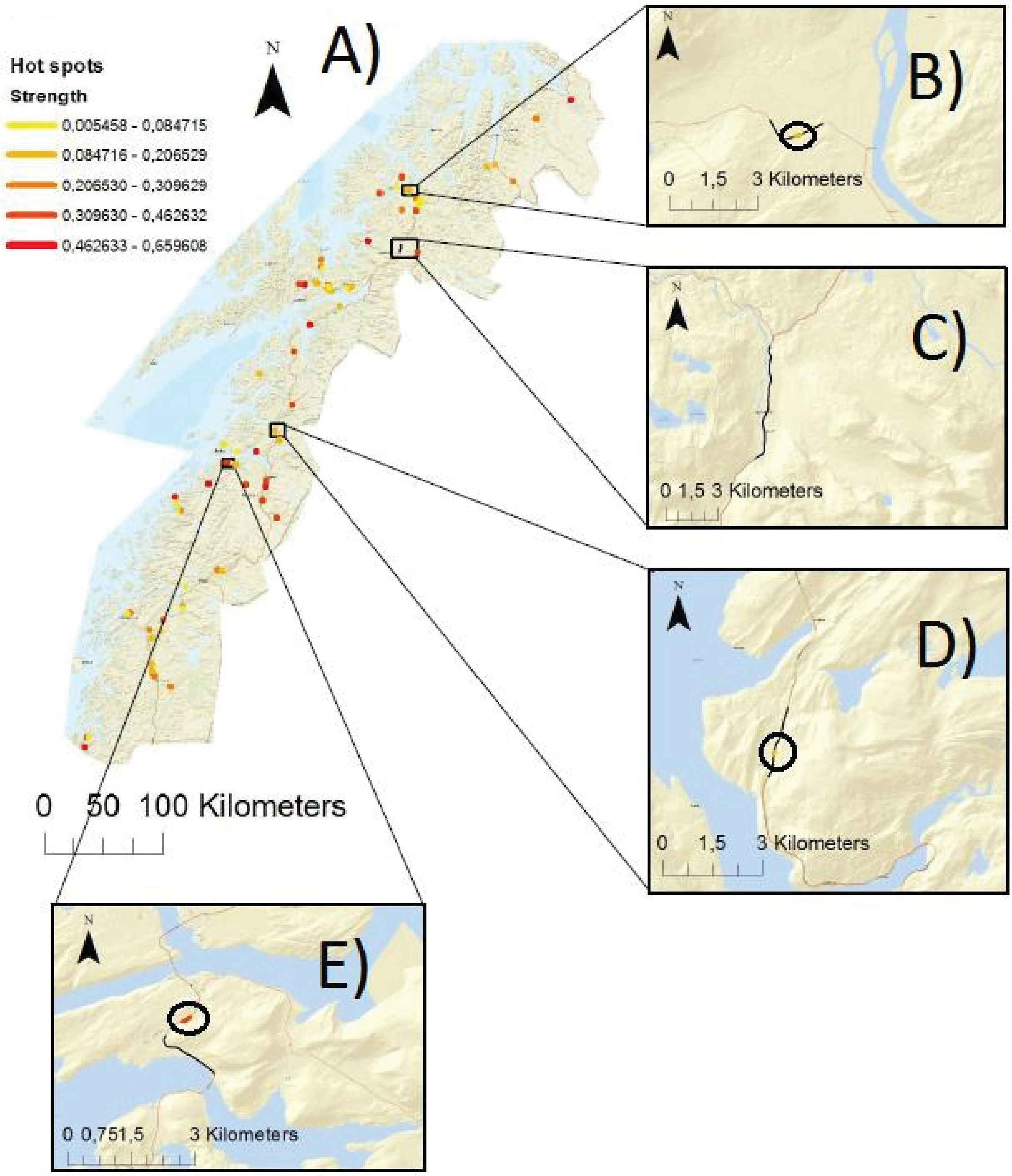

Figure 6: Map of hotspots for MVCs in the study area (A), and the test sections B) Karlstad, C) Bardu, D) Kvarv and E) Åseli. The strength indicates the significance of the clusters, the higher the number, the more significant it is. Clusters with less than three accidents are excluded.

3.3 No effect of the optic/acoustic mitigation measure

All four test sections had more MVCs than predicted by the model for the given municipality before and after the installation of the mitigation measure (figure 7). It was only the Bardu section that showed a steady decrease after the installation of the mitigation measure, but this was only based on MVC-numbers from two years. The highest prediction is 0.1 MVC per km and year (for Målselv/Karlstad 2013 and Bardu 2014), hence the prediction line look flat on this scale, but the variation is shown in appendix 1.

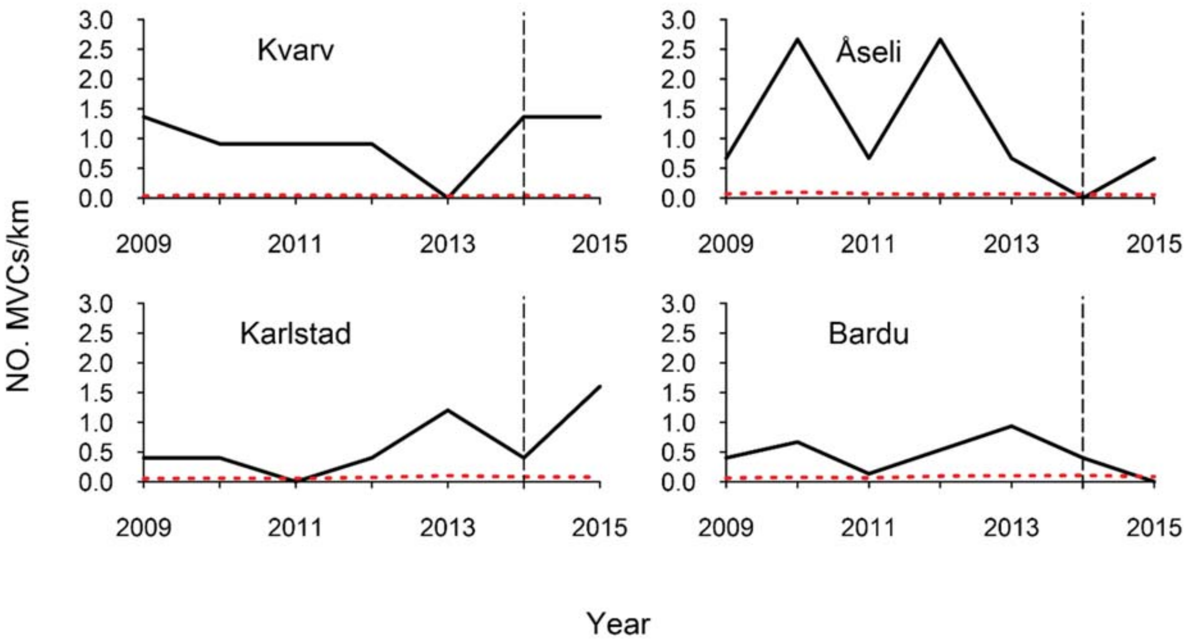

Figure 7: The predicted number (red, dashed line) vs. the actual number (black, solid line) of MVCs/km for the test sections as functions of the snow depth and moose population at the site. The vertical, dashed line indicates when the mitigation measure was put up (in May 2014). To see the year-to-year variation in the prediction line, see appendix 2.

There was no effect of the optic/acoustic mitigation measure (LRT: deviance=0.079, df=1, p=0.780), hence prediction P6 was rejected. Considering the yearly average number of MVCs/km before and after the installation of the system, the Bardu and Åseli sections show a tendency of reduction, while Kvarv and Karlstad showed an increase in the number of MVCs (figure 8), however, not significant.

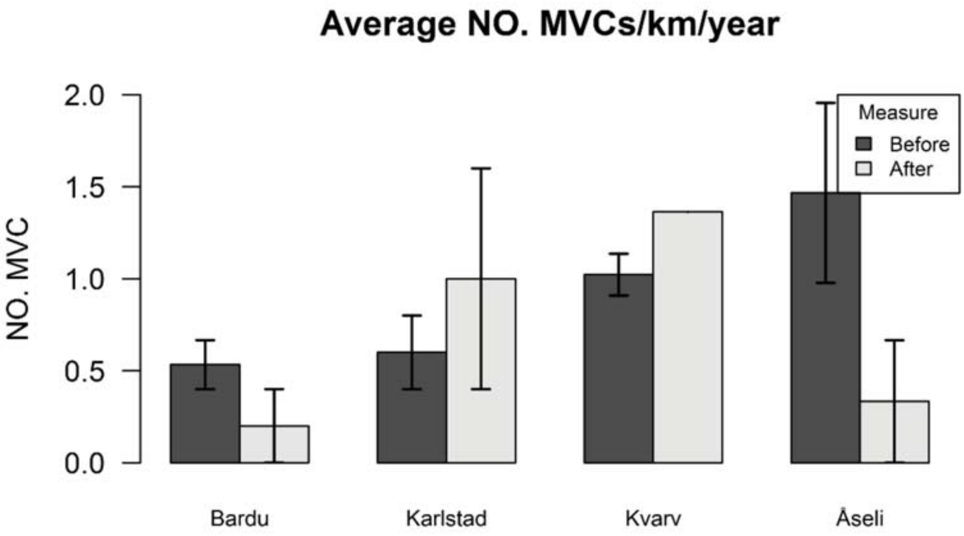

Figure 8: Average yearly number of MVCs/km ± SE on the four test sections before (black) and after (grey) the optic/acoustic measure was installed. It is the mean and SE of the raw data which is plotted.

4 Discussion

The number of MVCs was highest in the winter and increased with population size and snow depth, supporting prediction P2 and P4. However, I found no support for my predictions regarding traffic volume (P1) or winter temperature (P3). The MVCs were not randomly distributed, but formed several hotspots. I found hotspots on two of the four test sections for the optic/acoustic mitigation measure, partly supporting prediction P5. I did not find any significant decrease in the risk of MVCs on the mitigated sections, hence my hypothesized reduction in the number of MVCs using sound and light (P6) was not supported. My study confirms that annual variation in MVCs at a regional scale is driven by moose density and snow depths. It further demonstrates that hotspots for MVCs exist and that KDE+ was a suitable tool to detect short hotspots. Finally, the optic/acoustic mitigation measure showed no effect but was hampered by logistical challenges, hence the effect cannot be ruled out and warrants further testing.

4.1 The need for controlling for potential confounding effects when evaluating mitigation measures

Journals may be more willing to publish studies of successful experiments showing effects of mitigation measures rather than ineffectiveness. This trend create a publication bias and can make an unrealistic impression of the proportion of successful mitigation measures (Rytwinski et al. 2016). This thesis shows ineffectiveness of the mitigation measure evaluated, with several biases related to the accomplishment of the experiment. Rytwinski et al. (2016) found in a meta-analysis of mitigation measures that many measures were tested with a weak experimental approach only including before and after-data or control and impact-data.

My results support a number of previous studies showing a positive correlation between the number of MVCs and the moose population size (Gundersen et al. 1998; Rolandsen et al. 2011; Seiler 2005). Rolandsen et al. (2011) found an isometric relationship between moose population size and the number of MVCs. Hence, they suggested that a significant reduction of the moose population can be an efficient mitigating measure for reduction in the number of MVCs in Norway. In my study, I found that the population size was fluctuating and closely related to the number of harvested moose. I accounted for variation in the population size when evaluating the effect of the mitigation measure by including population size in the model I used. Another way of possibly eliminating the variation in population size is to conduct the study over limited time as in Clevenger et al. (2001). They used a before-after approach when studying the effect of wildlife fencing on the Trans-Canada highway. Data from a pre-fencing period of two years and a post-fencing period of the two following years were used. They continued to study the effects for 15 years to look for changes over time. However, this before-after method does not account for variation in snow depth between years, which proved to affect the number of MVCs in Northern Norway.

My data peaked in wintertime (see fig. 4), with the highest number of MVCs in the early winter from November-January. This can be related to the migratory behaviour of the moose when they congregate in the valley bottoms during winter (Andersen et al. 1991; Rolandsen et al. 2011; Steiner et al. 2014). The driving conditions may also contribute to the peak in wintertime. Roads will get slippery and the braking distance will increase considerably (Meisingset et al. 2014). The number of MVCs was positively correlated to snow depth. This effect is supported by several other studies of moose-vehicle and moose-train collisions (e.g. Andersen et al. 1991; Gundersen & Andreassen 1998; Gundersen et al. 1998; Rolandsen et al. 2011). It is suggested that the snow depth effect is most prominent in areas with mean snow depth > 50 cm (Rolandsen et al. 2011). Because of low winter temperatures in the north, a lot of winter precipitation will fall as snow in the study area, especially in the inner parts, leaving the areas with considerable snow depths (Moen et al. 1999). The snow depth is highly variable from year to year and from municipality to municipality in the study area. This indicates that snow depth should be considered in an evaluation of a mitigation measure at latitudes where snow depth usually occurs during winter. Studies with data on number of accidents before and after a measure is installed usually do not account for snow depth (E.g. Clevenger et al. 2001). Andreassen et al. (2005) found reducing effects of the three mitigation remedies scent marking, forest clearing and supplemental feeding on the number of moose-train collisions in Østerdalen valley (SE Norway). The study is an example of a control-impact study, where they account for differences between the two winters in the study by having control sites the same year instead of before and after data. However, by comparing different sites, local variations in e.g. snow depth may occur and can affect the number of MVCs.

In addition to being the snowy season, November-January is also a dark season in the study area. Several studies have shown that most MVCs occur during dusk and dawn, when the moose is the most active (Haikonen & Summala 2001; Hothorn et al. 2015; Huseby 2013; Joyce & Mahoney 2001; Lavsund & Sandegren 1991). The main mechanism for increasing MVC risk during darkness is probably that the moose is more difficult to spot for the driver (Joyce & Mahoney 2001). In the winter months in the study area the dark hours coincide with the time of day when the density of traffic is greatest, during morning and afternoon (Hothorn et al. 2015). During the summer months when it is midnight sun in the area the number of MVCs was very low, which may support this suggestion. However, I did not consider effects of different light conditions here and the only evaluated effect behind the seasonal trend which I found, was the snow depth.

Some studies have shown that less MVCs occur in winters with higher ambient temperature, and suggest that this is because the moose is adapted to cold environments and will lower its activity during warm periods to avoid overheating (Andersen et al. 1991; Gundersen et al. 1998; Rolandsen et al. 2011). I did not find any effect of temperature on the number of MVCs. In my data, I used mean temperature for the whole winter to look for between-year variation, and not the within-year variation in the number of MVCs. The mean winter temperature was very similar from year to year, so lack of variation in the data and analysing the data on too coarse temporal scale may explain this result.

The traffic volume did not give any improvement in my model predicting the number of MVCs. Positive correlation between traffic volume and the number of MVCs is found in previous studies (Rolandsen et al. 2011; Seiler 2004). Seiler (2004) revealed a significant relationship between the number of MVCs and traffic volume on a regional level. However, he found an insignificant effect of traffic volume within districts or counties. In the study conducted by Rolandsen et al. (2011), they looked at changes in traffic over 30 years, which is considerably longer time than the seven years I had collected traffic data from. The short time span and the fact that I used municipality level contributed to small variations in traffic volume between years, hence I did not find any effect of traffic in my study.

4.2 Hotspot detection

A 'hotspot' is a part of a road section where collisions occur more frequently than expected. Elvik (2008) looked at different definitions of hazardous road locations in eight European countries and he found that in half of the countries hazardous road locations are defined as locations with significantly more accidents than the normal number. In Norway it is differentiated between hazardous spots, a road section shorter than 100 meters, which contains at least four injury accidents in five years, and hazardous sections which are between 100-1000 meters and have at least ten injury accidents recorded over a period of five years (Elvik 2008). However, these numbers are for all type of accidents combined, and not MVCs alone, which in most places do not occur so frequently, and hence it would form few hotspots with these high thresholds. Joyce and Mahoney (2001) classified high-risk sections in Newfoundland as more than 3 MVCs per 10 km section. Hotspots for collisions involving moose can be caused by e.g. the local topography forming corridors leading the moose over the road in a limited area, roadside vegetation attractive to moose (Malo et al. 2004) or if wildlife fences is crossed somehow and the moose is trapped in the traffic artery (Clevenger et al. 2001; Seiler 2004). The benefit of the KDE+ method tested in this study is that it objectively detect significant hotspots and, in addition, it ranks the hotspots after their cluster strength (Bíl et al. 2013).

The KDE+ method had not been tested in Norway prior to my study. In the Czech Republic, the method was tested on both traffic accidents in general and deer-vehicle collisions in particular (Bíl et al. 2013; Bíl et al. 2016). The resulting hotspots can be used as a tool in preventing AVCs more efficiently. Given that the location of hotspots persists over time, my results suggest that by mitigating only 0.0011 % of the public road network in the study area, we can prevent almost 10 % of the MVCs. If this will work in practise, the KDE+ is an effective tool to identify very high-risk road sections which should be mitigated. Unfortunately, relatively few of the MVCs formed clusters in Northern Norway compared to the study conducted by Bíl et al. (2016) in the Czech Republic, where 33.2 % of all AVCs ended up in cluster. For all of Norway, 11.8 % of the MVCs analysed ended up in clusters, a slightly higher proportion than in Northern Norway exclusively.

It is important to evaluate at which spatial scale the hazardous sections should be defined. The KDE+ method is not able to detect hazardous sections if many collisions are evenly distributed along the section, which could be the case in my study area. Longer sections with weak clusters will not be detected in the presence of stronger clusters nearby. However, the method is meant to determine the suspicious clustering of the MVCs on a local scale, and not the long sections (Bíl et al. 2013). One could use a variogram-analysis combined with the KDE+ to evaluate if a hotspot is spatially correlated to MVCs nearby. If the spatial correlation exists on a longer section, one may assume that this is caused by the same confounding effects (such as moose density) that caused the hotspot. This should be considered before mitigation actions are implemented to prevent accident migration (Rolandsen et al. 2015). My study suggests that the KDE+ is a good tool to detect the most hazardous short road stretches that will be the first to prioritize for mitigation measures.

Considering the test sections, only two of the four sections (Kvarv and Karlstad) had parts of the sections classified as hotspot, although all the sections were located to high-risk MVC-areas and the actual number of MVCs was higher than predicted (see fig. 7 and app. 2). The fact that only two of the test sections were classified as hotspots may indicate that road authorities focus on mitigating road sections from a subjective perspective. It is highly valuable for the management authorities to be able to separate between temporary and persistent hotspots. If a peak in snow depth or population size make a temporary peak in MVCs on road sections, this may change when snow depths or population sizes decrease again. If the road authorities choose to mitigate sections based on temporary peaks in MVCs they will probably see effects of the mitigation by using pre- and post-mitigation data over few years, but this reduction in MVCs may have occurred regardless of the mitigation measure (van der Ree et al. 2015). If possible, I would have tested for hotspots on a year-to-year basis to look for a change in hotspot classification on the test sections before and after the installation of the mitigation system. If a road stretch qualified as a hotspot only for a short time before installation of the measure, one could suspect it was just a random temporary peak and that the number of MVCs would drop regardless of the mitigation measure (Lavsund & Sandegren 1991; Rytwinski et al. 2016). Unfortunately, the regression to mean phenomenon will affect the result here, and yearly hotspots will therefore be hard to detect.

4.3 No repellent effect of the combined acoustic/optic mitigation system

I did not find any significant decrease in the number of MVCs on the four test sections after installation of the optic/acoustic system, but for the Bardu and Åseli sections there were a tendency of reduction. Steiner (2011) found a reduction of 42 % for deer-vehicle collisions in Austria using a previous version of the combined optic and acoustic wildlife warning system. This study was conducted over a short period of time (2007-2011), with a total length of test sections of 34.4 km. The general trend for deer-vehicle collisions in Austria during the same period was a decrease of 2.7 %. In Austria, the system was tested on deer, and not on moose.

There have been some unfortunate complications by having the solar powered optic/acoustic system in Northern Norway. Inspections of the system to check the functionality have been done rarely and on an irregular basis. In the dark season, there has been trouble with the charging of the devices and a lot of them have had an empty battery from around January, and therefore not worked. Also, when wet snow is cleared away from the roadways it can attach to the device and block its light sensor, again preventing it from working. However, most of the devices have been operational in the autumn and the beginning of the winter during inspections. In daylight, the devices are charging and not operational. This is also the case in the summer because of the midnight sun (Wildenschild 2016), yet relatively few accidents occur during daylight (Hothorn et al. 2015).

5 Conclusions

Few studies on effects of mitigation measures on the number of AVCs include the confounding effects in the evaluation. In this study the annual variation in moose population size and snow depth affect the number of MVCs on roads in Northern Norway, and should therefore be controlled for in future evaluations of mitigation measures in the area. As the KDE+ mainly detect clusters on small scale (local clusters), I suggest that future studies of MVC hotpots may be improved by combining this with methods that can detect spatial dependence in collision risk over larger scales (e.g. variogram analysis). The road authorities can focus on mitigating the hotspots detected in such analysis to prevent MVCs more cost-effectively. I could not find reduced number of MVCs caused by the optic/acoustic deterrent system. However, I only had two years of data after the installation and technical challenges with the optic/acoustic system, hence limitations of the experimental setup limits how strongly I can conclude regarding the mitigating effect of the system. The system should therefore undergo new testing before potentially further implementation.

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Appendices

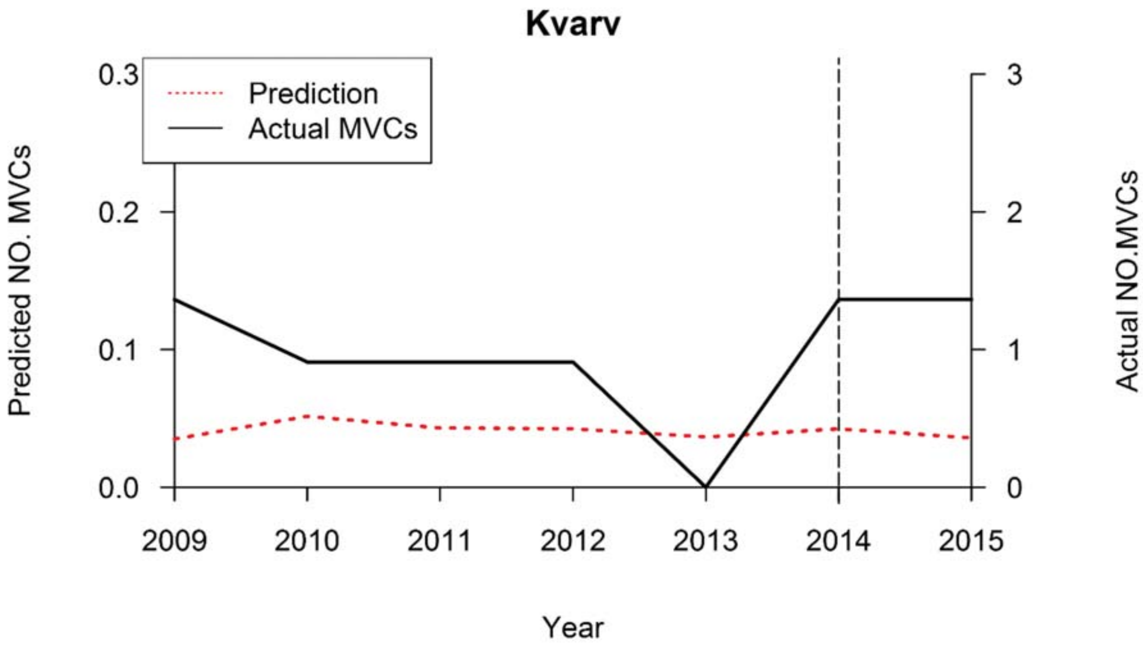
Appendix 1:

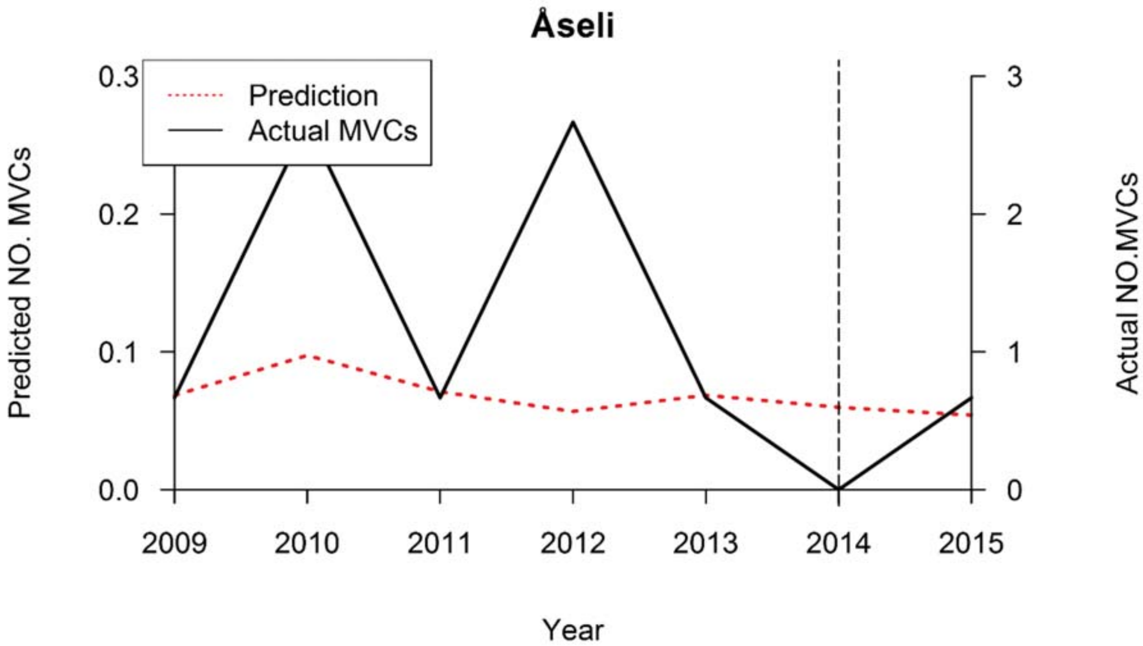
Official numbers of moose-vehicle collisions (Statistics Norway 2016b) per municipality per year for the study area. The municipalities listed are the ones that the model is based upon. Years cover hunting seasons, meaning that 2009 will be the hunting season 2009-2010.

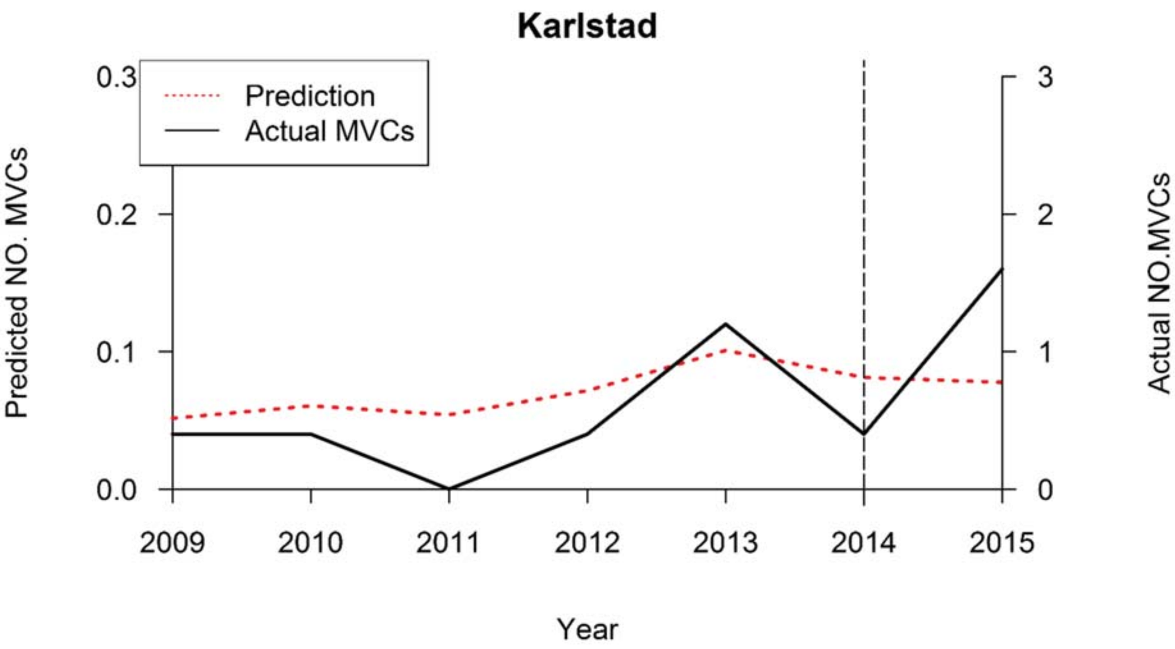
Year/ Municipality	2009	2010	2011	2012	2013	2014	2015
Alstahaug	4	9	2	0	0	1	0
Ballangen	4	9	3	8	5	4	3
Balsfjord	0	1	0	3	0	1	13
Bardu	8	12	2	8	9	2	3
Bindal	6	5	4	7	3	5	4
Bodø	13	17	13	12	8	13	6
Brønnøy	0	4	6	3	5	3	5
Fauske	5	13	1	4	8	4	2
Grane	6	9	5	8	6	4	11
Hamarøy	5	7	6	2	8	6	6
Harstad	0	0	0	0	4	7	8
Hattfjelldal	1	4	2	2	3	3	2
Hemnes	0	0	3	3	9	2	1
Karlsøy	0	0	0	0	0	0	0
Kvænangen	1	1	3	2	0	0	0
Kåfjord	0	10	2	12	5	0	7
Leirfjord	4	4	2	6	4	9	8
Lenvik	2	5	1	1	5	0	3
Lyngen	1	1	1	2	1	1	2
Målselv	8	21	3	14	14	7	12
Narvik	5	11	4	4	1	6	9
Nordreisa	4	3	0	3	6	2	2
Rana	8	14	26	4	14	12	14
Saltdal	10	9	9	11	7	3	5
Skjervøy	0	2	0	0	0	1	0
Skånland	5	3	6	12	8	8	3
Sortland	2	4	5	5	3	3	6
Steigen	4	11	3	3	2	1	3
Storfjord	5	7	0	6	5	0	9
Sømna	2	3	4	2	2	1	0
Sørfold	8	17	7	7	6	6	7
Tromsø	1	2	3	4	5	2	0
Tysfjord	0	3	0	4	4	1	5
Vefsn	7	10	11	8	5	8	9
Vevelstad	0	0	0	0	0	0	0
Vågan	1	4	0	1	0	0	0
Øksnes	1	5	0	2	0	0	0

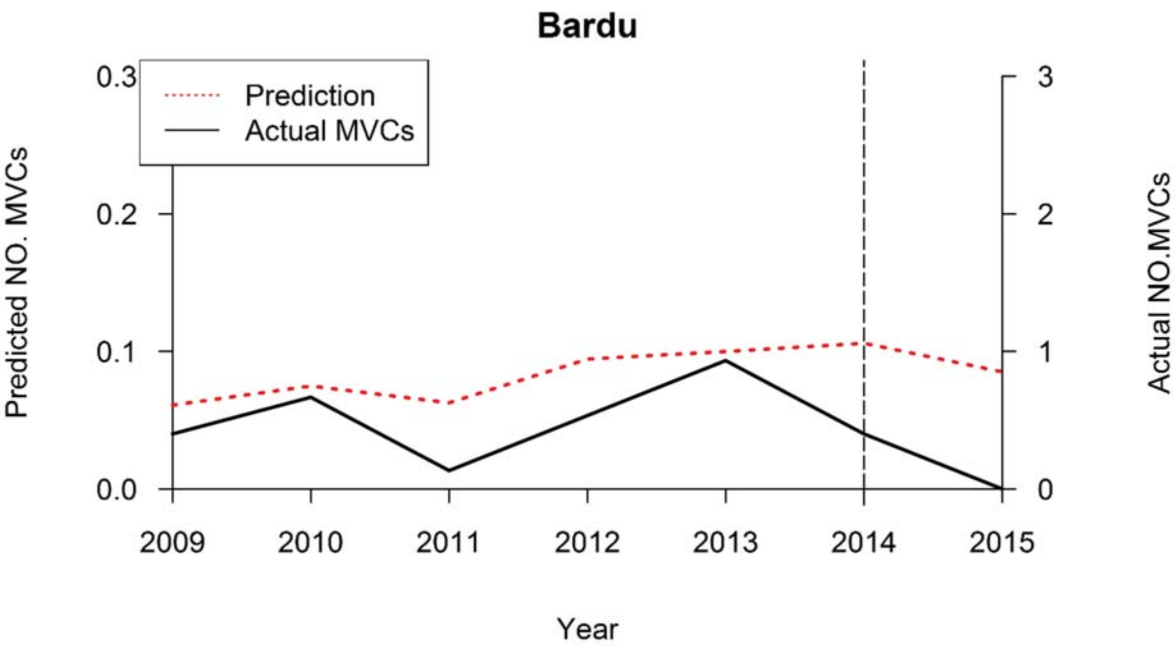
Appendix 2:

To show trends in the prediction between years, predicted and actual number of MVCs/km for the test sections are shown in one plot but with two different scales. Predicted number of MVCs/km on the left scale, red, dashed line, actual number of MVCs/km on the right scale, black, solid line. Note that the scales of actual numbers are 10 times higher than the scales of the predictions. Vertical, dashed line indicates the installation of the optic/acoustic mitigation measure.






Karlstad
Prediction
Actual MVCs
Predicted NO. MVCs
Actual NO.MVCs
0.0
0.1
0.2
0.3
0
1
2
3
2009
2010
2011
2012
2013
2014
2015
Year


Bardu
Prediction
Actual MVCs
Predicted NO. MVCs
Actual NO.MVCs
0.0
0.1
0.2
0.3
0
1
2
3
2009
2010
2011
2012
2013
2014
2015
Year

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