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Temporal patterns of moose-vehicle collisions with and without personal injuries

ABSTRACT

Collisions with wild ungulates are an increasing traffic safety issue in boreal regions. Crashes involving smaller-bodied deer species usually lead to vehicle damage only, whereas collisions with a large animal, such as the moose, increase the risk of personal injuries. It is therefore important to understand both the factors affecting the number of moose-vehicle collisions (MVCs) and the underlying causes that turn an MVC into an accident involving personal injuries or fatalities. As a basis for temporal mitigation measures, we examined the annual and monthly variation of MVCs with and without personal injuries. Using a 22-year-long (1990–2011) time series from Finland, we tested the effect of moose population density and traffic volume on the yearly number of all MVCs and those leading to personal injuries. We also examined the monthly distribution of MVCs with and without personal injuries, and contrasted the Finnish findings with collision data from Sweden (years 2008–2010) and Norway (years 2008–2011). Both moose population abundance indices and traffic volume were positively related to the yearly variation in the number of MVCs in Finland. The proportion of MVCs involving personal injuries decreased during our 22-year study period. The monthly distribution of all MVCs peaked during the autumn or winter depending on country, while MVCs involving personal injury peaked in summer. Our study indicates that efforts to reduce MVCs involving personal injuries need to address driver awareness and attitudes during summer, despite most MVCs occurring in autumn or winter.

Keywords:

Animal-vehicle collision, traffic safety, population management, mitigation measures, injury risk, deer

1 INTRODUCTION

Collisions with wild ungulates are an important traffic safety issue in North America and Europe (Groot Bruinderink and Hazebroek, 1996; Steiner et al., 2014), and ungulate-vehicle collision numbers have increased in several countries (Morelle et al., 2013, Seiler, 2004, Sullivan, 2011). Each year, approximately 1–2 million vehicle collisions with large animals, mainly deer, occur in the United States (Huijser et al., 2007), leading to notable vehicle damages, personal injuries, and even fatalities (Bissonette et al., 2008; Sullivan, 2011). In Europe, the corresponding number is approximately one million (Langbein, 2011), but is likely to increase as populations of large ungulates are increasing in many countries (e.g. Apollonio et al., 2010).

While the majority of ungulate-vehicle collisions happen with small or medium-sized ungulates, such as white-tailed deer (*Odocoileus virginianus*) or wild boar (*Sus scrofa*), the moose (*Alces alces*) as a large mammal poses greater risk for human safety during collisions. Although research on injury rates in animal-vehicle collisions is limited, some studies suggest that less than 5% of deer-vehicle collisions lead to personal injuries (reviewed by Conover et al., 1995), while the injury rate in moose-vehicle collisions (MVCs) are reported to be 10–20% or even higher (Garret and Conway, 1999; Haikonen and Summala, 2001; Joyce and Mahoney, 2001). Because of the obvious risk to human health, and its associated economic and social costs, there is a need to develop costeffective measures to reduce the number and consequences of MVCs. It is thus essential to understand both the factors explaining the variation in MVC numbers along with the factors that turn an MVC into a collision involving personal injuries or fatalities.

The most important large-scale factors related to the annual number of MVCs are moose density and traffic volume (Lavsund and Sandegren, 1991; Rolandsen et al., 2011; Seiler, 2004). Yet, on a more local scale, the number of MVCs on a certain road may decrease with increasing traffic volume due to a barrier effect (Seiler, 2005).

The number of personal injuries and fatalities caused by ungulate-vehicle collisions has increased along with a growth in the total number of these collisions (Langley et al., 2006; Sullivan, 2011). However, it is unclear whether the proportion of ungulate-vehicle collisions leading to personal injuries has been stable over time. In general, the proportion of personal injury collisions out of all traffic accidents has decreased during the last decades (e.g. Finnish Transport Agency, 2014a), probably because of improved vehicle safety and the different mitigation measures implemented.

As for other deer species, the monthly distribution of MVCs is known to differ among regions (reviewed by Steiner et al., 2014). In many areas in North America, the number of MVCs peaks in summer (Danks and Porter, 2010; Dussault et al., 2006; Joyce and Mahoney, 2001). The pattern is different in Northern Europe: Haikonen and Summala (2001) found the main MVC peak for Finland to occur in autumn, with a secondary peak during the summer. These two peaks have also been found in southern Sweden, while the number of MVCs peaks in early winter in northern Sweden (Lavsund and Sandegren, 1991) and Norway. Several factors, including seasonal migration, snow accumulation, food availability, and adverse driving conditions, have been connected with contributing to the seasonal distribution of collisions (Neumann et al., 2011; Olson et al., 2015; Rolandsen et al., 2011).

Light conditions affect the timing of ungulate-vehicle collisions, with a peak generally after sunset and at dawn (Haikonen and Summala, 2001; Hothorn et al., 2015). The circadian variation in personal injury risk is well-documented (Griktza et al., 2010; Haikonen and Summala, 2001; Sullivan, 2011), but, contrastingly, less is known of the seasonal pattern (but see Garret and Conway, 1999, who found that the greatest proportion of MVCs with personal injuries occurred in February).

In summary, while the factors affecting the number of MVCs and their seasonal and circadian distribution are identified relatively well, the temporal pattern of MVCs with personal injuries is understudied. The main aim of our study was to provide better knowledge concerning the annual and monthly variation of MVCs with and without personal injuries. In addition, we aimed to provide some basic information about the proportion of registered MVCs that lead to personal injuries. Such knowledge can be used to better inform drivers of peak MVC periods, and when implementing other temporal mitigation measures such as temporal warning signs (Huijser et al., 2015).

We tested four predictions (P1–P4), where P1 and P2 were related to the annual variation of MVCs in Finland, and P3 and P4 were related to the monthly variation of MVCs in Finland, Sweden, and Norway. Based on previous studies in Norway (Rolandsen et al., 2011) and Sweden (Seiler, 2004), we expected (P1) the number of MVCs in Finland to be higher in years with high moose population density and high traffic volume. Secondly, we examined the extent to which the proportion of MVCs involving personal injuries varied between years. Because of a constant increase in the safety measures implemented for both cars and roads (Kahane, 2015; Noland, 2003), we expected (P2) a gradual decrease in the proportion of MVCs involving injuries during the study period. Thirdly, based on previous studies (reviewed by Steiner et al., 2014), we expected (P3) the monthly number of MVCs to peak during autumn and/or winter, and to be at their lowest level in late winter and/or early spring. Fourthly, in contrast to the monthly variation of all MVCs we expected (P4) the highest proportion of personal injury collisions to occur during autumn, when less daylight is available but driving conditions are otherwise good (Garret and Conway, 1999; Griktza et al., 2010; Gunson et al., 2004; Joyce and Mahoney, 2001).

MATERIAL AND METHODS

2.1 Study area

We conducted our study in three Nordic countries: Finland (338 440 km^2), Sweden (447 435 km^2), and Norway (323 772 km^2), situated between 55° and 71° Northern Latitude (Statistics Finland, 2015a; Statistics Norway, 2015; Statistics Sweden, 2015a). Human density averaged 18 persons/km^2 in Finland (Statistics Finland, 2015b), 24 persons/km^2 in Sweden (Statistics Sweden, 2015b), and 16 persons/km^2 in Norway (Statistics Norway, 2015).

Public road density is 0.26, 0.26, and 0.29 km roads/ km^2 in Finland, Sweden, and Norway, respectively (Statistics Finland, 2015a; Statistics Norway, 2015; Statistics Sweden, 2015a). For all three countries, the most densely populated areas with the highest road densities are located in the southern and central parts, as well as along the coast.

2.2 Collision data

To test our first two hypotheses concerning the yearly trends in MVCs (see Introduction), we used a 22-year-long time series of MVC data from 1990–2011 from Finland. Each MVC was allocated a timestamp and included information on whether the MVC caused personal injuries or fatalities. With an average 6.6 per year, the annual occurrence of fatal MVCs was low. However, no additional information concerning injury severity was included. We thus pooled all MVCs leading to personal injuries or fatalities as MVCs involving personal injuries. Using this long-term Finnish data set, we calculated the annual variation of MVCs in general (P1), and calculated the annual proportion of MVCs involving personal injuries (P2).

We used the Finnish data – together with comparable data sets from Sweden (2008–2010) and Norway (2008–2011) – to test for monthly patterns of MVCs with and without personal injuries (P3, P4), and whether the monthly patterns were similar in the neighboring countries of Sweden and Norway compared to Finland.

In all three countries it is mandatory for drivers to report all MVCs. Drivers usually call the police or emergency number, after which the police contact the wildlife management authorities to assist in the removal of the carcass, or in searching for and putting down any wounded animals.

Some differences occur between the countries regarding data collection procedures. All ungulate-vehicle collisions in Finland are registered by the police, but the final database is administered by the Finnish Transport Agency (FTA). The same procedure for monitoring MVCs involving personal injuries is followed in Sweden and Norway, where the databases are administered by the Swedish Transport Administration (STA) and the Norwegian Public Roads Administration (NPRA), respectively. However, both Sweden and Norway additionally have separate databases containing all reported MVCs, which are administered by the National Council for wildlife collisions (Sweden: Nationella Viltolycksradet; Norway: Norwegian Environment Agency). To match the Swedish and Norwegian data with the Finnish collision register, we removed obvious double entries (MVCs with the same date and location) from the national databases, resulting in a single entry for each collision, marked as either an MVC with or without personal injury.

The Finnish data set we used also contains some known shortages. In Finland, changes were implemented to the ungulate-vehicle collision registering system in 2012. Unfortunately, prior to this, not all ungulate-vehicle collisions were registered in the national database because of technical reasons; only collision reports filled with all requested additional information, such as weather and driving conditions, were taken into account when creating a final database (Finnish Transport Agency, 2014b). In total, the average proportion of these dropouts was 24% between 2005 and 2010 (Ostrobothnian police, the Head of Communication and Media Relations M. Appel, personal communication). However, it is likely that most of these dropouts have been collisions with smaller deer species such as white-tailed deer, as collisions leading to major property damage, and especially collisions leading to personal injuries, are always carefully registered. Yet, as we had no reason to expect other than a random temporal distribution of these dropouts, the data were usable for our analyses.

2.3 Moose population size and traffic volume

We used two relative indices of the Finnish moose population size: the total annual number of harvested (hunted) moose (Finnish Wildlife Agency and Natural Resources Institute Finland, 2015) and the observation index. It is mandatory in Finland to report the number of harvested moose, and the statistics is assumed to be of excellent quality. The moose observation index was calculated from moose observation cards annually filled out by approximately 5000 Finnish moose-hunting teams (Lavsund et al., 2003).

Both population density indices have previously been found to closely follow the variation in moose density in the neighboring countries of Sweden (Ericsson and Wallin, 1999) and Norway (Solberg and Sæther, 1999; Ueno et al., 2014). However, the number of harvested moose has often reflected changes in moose population size with a time lag of 1–2 years (Fryxell et al., 2010; Solberg et al., 1999).

As a measure of traffic volume, we used annual estimates (billion kilometers driven) produced by the FTA (Finnish Transport Agency, 2014a). The estimate is based on measurements from approximately 440 automatic stations and the national traffic counting service, which is mainly based on sample counts. The sample count system was put into operation in the 1980s, while the network of automatic stations was built mainly during the 1990s. Certain quality criteria are set, and any possible deviations from the quality required are monitored (description of the estimation process: Saastamoinen et al., 2014).

2.4 Statistical methods

We used linear regression to examine whether the annual variation (years 1990–2011) in the number of MVCs in Finland was dependent on moose population size and traffic. The dependent variable (MVCs) and covariates (population size indices and traffic volume) were log-transformed for interpretation purposes. By doing this, a slope parameter of one indicates that a given percent increase in the covariate results in the same percentage increase in MVCs. Conversely, a slope parameter deviating from one indicates that the ratio between MVCs and the covariate changes with the size of the covariate. Model selection was based on Akaike's information criteria (AIC) corrected for small sample size (AICc). Models that differed by two or less in an absolute value were considered equally supported by the data (Burnham and Anderson, 2002).

Next, we repeated the same analysis but now only for MVCs involving personal injury. This was performed to test whether the same relationship to population size and traffic volume could be found as for all MVCs. We additionally examined whether the yearly proportion of MVCs involving personal injuries was constant or varied temporally (over years).

To examine the monthly variation of the proportion of MVCs involving personal injuries, we used generalized linear mixed models (GLMMs) with a binomial distribution (0 = no personal injuries; 1 = personal injuries) (Bolker et al., 2009; Zuur et al., 2009). Here, we used the MVC data for years 1990–2011 from Finland, 2008–2010 from Sweden, and 2008–2011 from Norway, respectively. To account for the interdependence of the data within years, we included year as a random factor. We included month, country, and the interaction between month and country as the fixed effects. Models were fitted using maximum likelihood (Laplace Approximation), and the final model was selected based on AIC values. Models were constructed using the lme4 package (Bates et al., 2015) in software R version 3.1.3 (R Development Core Team, 2015).

3 RESULTS

3.1 Yearly MVC variation in Finland

During the period of 1990–2011, the yearly number of MVCs in Finland varied between 1156 and 3041 (1829 on average). The moose observation index and the number of MVCs peaked at the same time (Figure 1; $r_s = 0.65$), while the number of harvested moose appeared to peak later than the MVCs ($r_s = 0.38$)

According to the highest ranked model (Adjusted $R^2 = 0.63$, AICc = -6.73), the annual number of MVCs increased with the moose observation index and traffic volume (Table 1A). The relationship with the observation index was higher than proportional (i.e., the log-log parameter estimate was significantly larger than 1), suggesting that a doubling of density (100% increase) results in a nearly threefold (184%) increase in MVCs. In contrast, the slope of the relationship between MVC and traffic volume was not significantly different from 1 (i.e., an isometric relationship), indicating that an increase in traffic volume returned a proportional increase in MVCs.

Models not including traffic volume (ΔAICc = >2) or models including harvest density in year t, t +1 or t + 2 (ΔAICc > 2) as an alternative to the model containing an observation index and traffic volume performed less well.

The annual number of MVCs involving personal injuries in Finland averaged 155 (75–281), resulting in an average personal injury rate of 0.09. As for MVCs in general, MVCs involving personal injuries were positively related to the moose observation index (Table 1B), which explained 47% of the yearly variation.

In addition, we found a negative trend ($\beta = -0.0015$, SE = 0.0003, $t = -4.63$, $p < 0.001$) in the proportion of MVCs involving personal injuries during the study period (Figure 2), suggesting that the probability of being injured in an MVC has decreased during our study period.

3.2 Monthly distribution of MVCs

The proportion of MVCs differed between seasons and countries (Figure 3). In Finland, MVCs peaked in September, with a secondary peak during summer. In Sweden and Norway, however, most MVCs were recorded in winter (December–February) and only a few occurred in summer. In all three countries, the number of MVCs was at its lowest level in late winter.

The monthly distribution of MVCs involving personal injuries (Figure 4) differed from the monthly distribution of all MVCs (Figure 3). The highest ranked model (Table 2) indicated that the personal injury rate differed between countries and months, while a model also including the interaction between month and country performed less well (ΔAICc >2). The personal injury rate was higher in spring, summer, and autumn (April–October) compared to winter in all three countries. Again, the injury rate was higher in Finland than Sweden, which in turn had a higher rate than Norway (Figure 4; Table 2).

DISCUSSION

Our study confirmed the positive relationship between moose population size, traffic volume, and the number of MVCs as reported in previous studies (Lavsund and Sandegren, 1991; Rolandsen et al., 2011; Seiler, 2004). Indices of moose population size and traffic volume explained approximately 60% of the yearly variation in the number of MVCs, which supported our first prediction (P1). Yet, the relationship between ungulate-vehicle collisions and the number of animals is not necessarily proportional. However, the nearly threefold (184%) increase in MVCs with a doubling (100%) of the population size index we found, does most likely not reflect the true relationship between population size and MVCs. Previous studies have shown that the moose observation index tends to underestimate population growth, probably because of a decrease in the hunters' searching efficiency with increasing moose density (Ueno et al., 2014). Hence, the true relationship is most likely closer to proportional than our result suggests, as found in a study conducted in Norway (Rolandsen et al., 2011).

From the management point of view, knowledge concerning the relationship between moose population and the number of MVCs is crucial, as it would help determine the population where the positive effects (i.e. hunting opportunities, meat production) and disadvantages (i.e. MVCs and forest damages) are balanced (see Storaas et al., 2001). However, not only size but also population structure may affect the number of collisions; male deer are killed more often in traffic than assumed based on the demographic structure of the population (Etter et al., 2002; Olson et al., 2014). We therefore suggest that future research should focus not only on the relationship between moose population size and the number of MVCs, but also on the possible effect that population structure has on collisions.

Although moose population and traffic together explained a large portion of the yearly variation in the number of MVCs in Finland, approximately 40% of the annual variations remained unknown. Yet, as our study analyzed the temporal variation of collisions across countries and between severity categories, the evaluation of the proximate cause of the observed seasonal pattern for MVCs in general was out of the scope of this study. Moreover, earlier research highlights the influence of weather conditions, and snow conditions in particular, on the annual variation in MVCs (Olson et al., 2015; Rolandsen et al., 2011). Yet, the effect of snow is likely less pronounced in

Finland, where most of the landscape is relatively flat compared to the mountainous areas in Norway.

In line with our second prediction (P2), we found that the proportion of MVCs involving personal injuries decreased over time in Finland, suggesting that safety measures in cars and along roads do indeed decrease the overall severity of moose-vehicle collisions. This explanation is supported by the fact that the overall proportion of collisions involving injuries in relation to all road accidents in Finland has decreased (Finnish Transport Agency, 2014a). In addition, implementing mitigation measures, such as wildlife fences, that not only affect the number of MVCs but may also influence their severity, has become increasingly common.

In accordance with our third hypothesis (P3), we found that MVCs peaked in autumn and winter, with some differences between the countries. Neumann et al. (2012) studied the timing of moose road-crossing activity and MVCs in northern Sweden, and suggested that the autumn/winter peak is more likely due to poorer light and road conditions than an increase in moose movements on the road area. Limited visibility due to darkness is known to influence a driver’s ability to detect ungulates crossing roads (Mastro et al., 2010), and the dark-time detection distance of moose could average as little as approximately 100 meters (Rodgers and Robins, 2006). In addition, increased moose movements during rutting season have been suggested to contribute as a collision peak in September or October (Lavsund and Sandegren, 1991). However, part of the monthly distribution of MVCs is likely explained by the intra-year population density variation: the population density is highest in summer and early autumn before the annual hunting season. In Finland, close to 40% of the pre-harvest population is shot during the autumn hunting season (Finnish Wildlife Agency and Natural Resources Institute Finland, 2015), but the effect of hunting was not tested in our study.

Opposite to Finland, a relatively large proportion of yearly MVCs occurred during the early winter in Sweden and especially in Norway. This is likely caused by the different landscape and environmental conditions. In Finland, moose apparently tend to move less when snow depth is at its highest level (Katajisto et al., unpublished data), probably to conserve energy during the time of year when forage availability is also low, thus leading to low collision numbers during the winter. In the northern part of Sweden as well as in Norway, snow accumulation forces moose to move from mountain areas to lower altitudes, where most roads are located (Rolandsen et al., 2011). During snow-rich winters animals are additionally more likely closer to roads, and hence cross them more often (Olson et al., 2015). As a consequence, the MVC peak may be closer to late autumn in Sweden and Norway in years with less snow, while the monthly distribution will be more skewed towards winter in years with more snow accumulation.

We found that the risk for being injured in an MVC increased during summer and to some degree during autumn, supporting our fourth prediction (P4) only partly. We predicted that the proportion of MVCs involving personal injuries would be highest during autumn, when driving conditions are otherwise relatively good, but darkness limits driver visibility and affects their reaction times. Indeed, the injury risk was elevated during autumn, but also in spring and summer when light conditions are much better. One explanation for our findings could be that the summer months are practically the only period of the year when driving a motorcycle is possible in Nordic countries, and motorcyclists are known to be vulnerable to the consequences of MVCs (Joyce and Mahoney, 2001; Williams and Wells, 2005). However, we found that removing moose-motorcycle collisions from the Norwegian data did not affect the results. Thus, the most feasible explanation for our findings could be the increased vehicle speed during the summer months. Finland utilizes various speed limits during the summer and winter months on certain roads; summer time limits are typically 20 km/hour higher and are implemented usually in late March or early April. However, summer time speed limits are in effect during the autumn, when the injury risk is also elevated, and as such cannot be the single factor explaining the highest injury risk in summer. If the increased risk of suffering personal injuries in MVCs during summer and autumn is mainly caused by increased driving speeds during the summertime because of better driving conditions (e.g. no snow or ice), our results are likely to be representative for other geographical regions in the Northern Hemisphere with similar seasonal variations in driving conditions such as Canada and parts of the USA.

One aspect that should always be considered when comparing collision statistics from different origins is the possible variation in data collection procedures. For example, we found a higher injury rate (the proportion of MVCs involving personal injuries) in Finland than Sweden, which in turn had a higher rate than Norway. However, this finding may be affected by differences in data collection procedures. In the Finnish data, not all reported MVCs without personal injuries necessarily ended in the final database during the period used in our analysis (see Material and methods). As a result, we may have underestimated the total number of MVCs, at least for Finland, and consequently overestimated the injury rate. Still, our study found lower yearly (Figure 2) and monthly (Figure 4) injury rates (< 10%) than the 10–20% or higher injury rates in MVCs reported by previous studies (Garret and Conway, 1999; Joyce and Mahoney, 2001). The monthly injury rates in the Swedish and Norwegian data were more similar to what has been reported from deer-vehicle collisions in North America (less than 5%, reviewed by Conover et al., 1995).

In addition to better injury rate estimates, future studies should aim to perform more detailed analyses of the severity range of personal injuries in ungulate-vehicle collisions. To actualize this, developing a collision registering system where the severity of personal injuries is recorded more precisely would help researchers to indentify the most important key variables affecting the MVC severity, and further, would help to find new prevention approaches. Again, the contrasting monthly patterns between MVCs with and without personal injuries found in all three countries in our study demonstrates that different data sources concerning ungulate-vehicle collisions from the same country results in different monthly collision distributions. Such information may be important to include in studies examining the temporal trends in ungulate-vehicle collisions (e.g. Steiner et al., 2014).

Previous research has identified several covariates (e.g., the characteristics of drivers, road conditions, weather, and vehicle speed in particular), which are known to affect the frequency and severity of traffic accidents (e.g. Koetse and Rietveld, 2009). These factors should be considered in future work, aiming to create a better understanding of the reasons affecting the number and especially the severity of MVCs. In this study, we were interested in the large-scale temporal patterns of MVCs, to target preventive measures in a more temporally adaptive manner, rather than all the variables affecting the MVC risk, and we therefore focused on the temporal explanatory variables (i.e., year and month) only. Besides, it is important to acknowledge the variation because of the differences in environmental conditions between countries and regions. It would thus be logical to conduct those analyses at a country or even a regional level, while a direct comparison across countries might be less recommended.

CONCLUSIONS

Our results confirmed the positive relationship between moose population size, traffic volume, and the number of MVCs, suggesting that management measures affecting moose population sizes influence the overall probability of MVCs. Although the annual number of MVCs involving personal injuries followed the overall trend of MVCs, the injury rate steadily decreased during our 22-year study period, proposing a positive effect on better safety measures along roads or in cars.

Interestingly, our results showed contrasting monthly patterns between MVCs with and without personal injuries: more MVCs occurred in autumn and winter than expected, but the risk of being injured in MVCs was highest in spring, summer, and autumn. This suggests that the factors affecting the number of MVCs are not necessarily the same as those affecting the severity of MVCs. This is valuable information when planning and designing temporal mitigation measures such as temporal warning signs or public awareness campaigns. Further, should these efforts be mainly targeted at reducing the total number of collisions, or those that lead to personal injuries?

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TABLES AND FIGURES

Table 1A and 1B. The highest ranked models explaining the variation in the yearly number of (log)MVCs (A) and (log)MVCs with personal injuries (B) in Finland during 1990–2011. Beta (β) is the coefficient, SE the standard error, t the test statistics, and *p*-value denotes the level of significance.

A: All MVCs

Variables included	**B**	**SE**	**t**	***p*-value**
(log)Moose observation index	1.84	0.30	6.05	< 0.001
(log)Traffic volume	0.89	0.35	2.53	0.02

B: MVCs with personal injuries

Variables included	**B**	**SE**	**t**	***p*-value**
(log)Moose observation index	1.70	0.38	4.44	< 0.001

Table 2. The highest ranked generalized linear mixed model (GLMM) with binomial distribution explaining the monthly pattern of MVCs involving personal injuries. Beta (β) is the coefficient (logit-scale), SE the standard error, and *p*-value denotes the level of significance.

	β	**SE**	***p*-value**
Fixed effects			
Intercept (January)	-2.77	0.07	< 0.001
February	-0.11	0.11	0.320
March	0.06	0.14	0.688
April	0.45	0.10	< 0.001
May	0.41	0.09	< 0.001
June	0.58	0.08	< 0.001
July	0.73	0.08	< 0.001
August	0.65	0.08	< 0.001
September	0.45	0.08	< 0.001
October	0.32	0.08	< 0.001
November	0.11	0.08	0.161
December	-0.02	0.09	0.861
Sweden	-0.32	0.06	< 0.001
Norway	-1.48	0.10	< 0.001
Random intercept	Variance	SD	
Year	0.016	0.128	

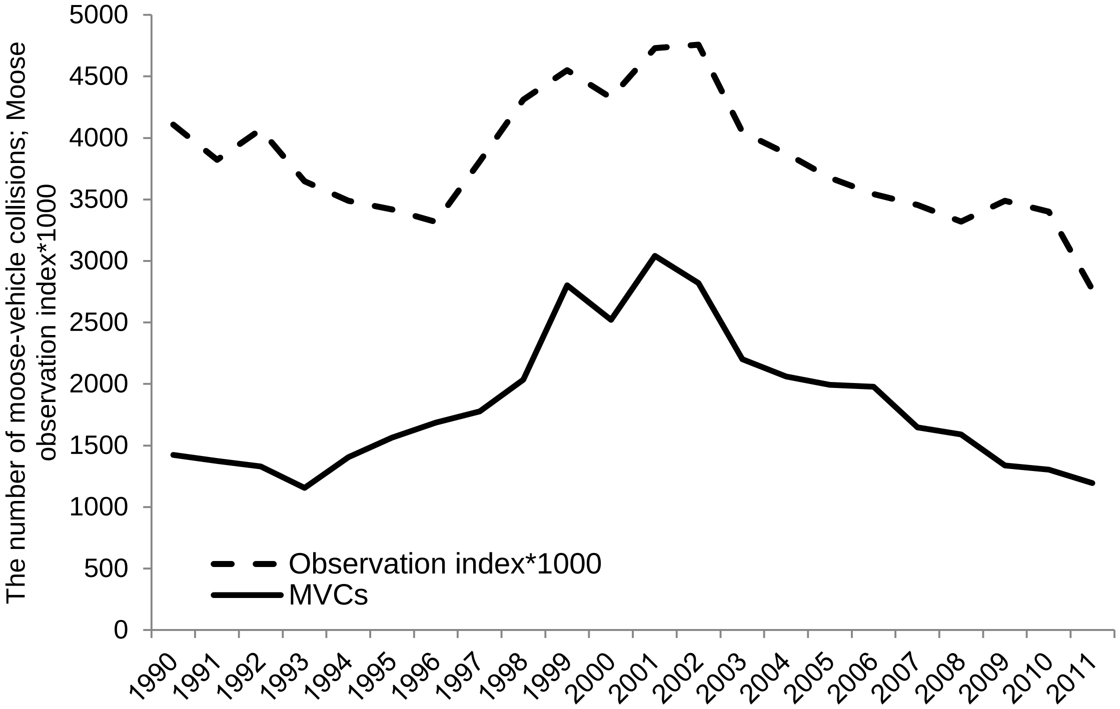

Figure 1. Variation in the yearly number of moose-vehicle collisions (MVCs) and the moose observation index*1000 in Finland during 1990–2011.

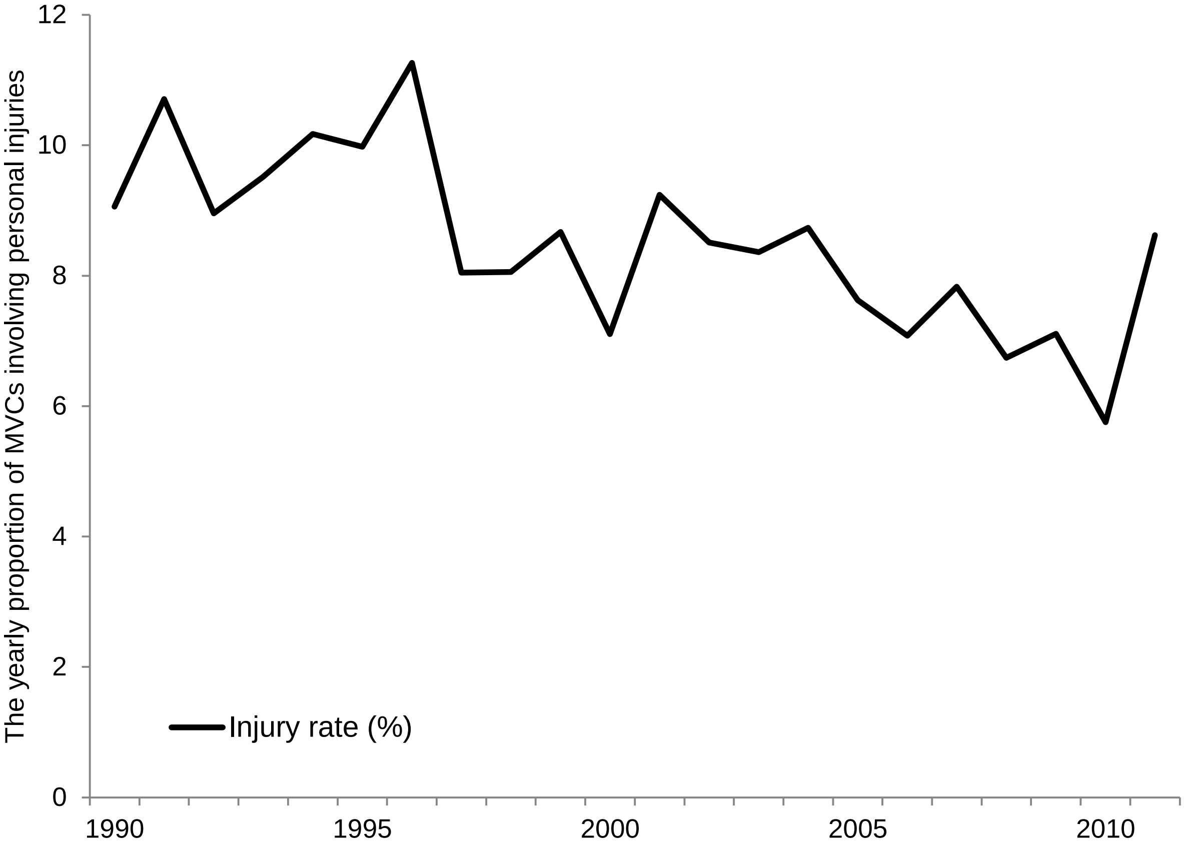

Figure 2. The yearly proportion of MVCs involving personal injuries in Finland, 1990–2011.

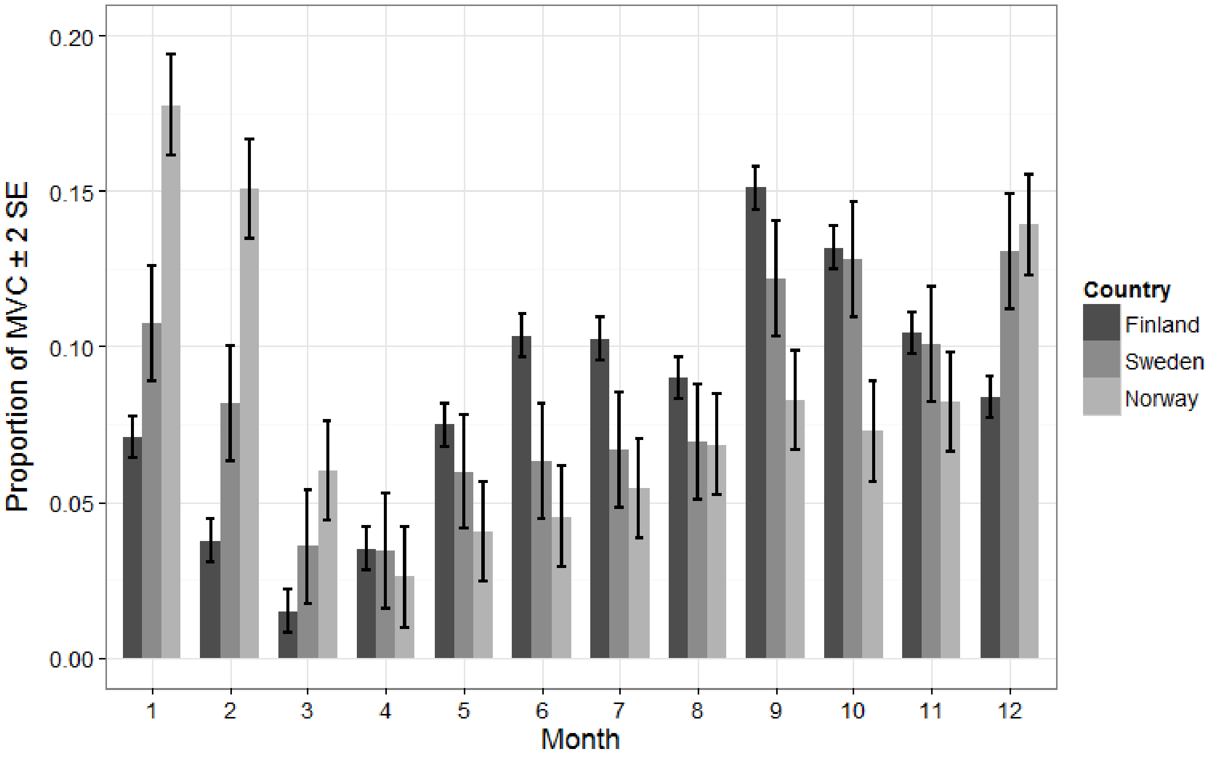

Figure 3. Predicted monthly proportion of MVCs (± 2 standard errors (SE)) in Finland (1990–2011; N = 40 238), Sweden (2008–2010; N = 17 527), and Norway (2008–2011; N = 8 214). The Norwegian data includes collisions between cars and moose only, while collisions with motorcycles are included in the Finnish and Swedish data.

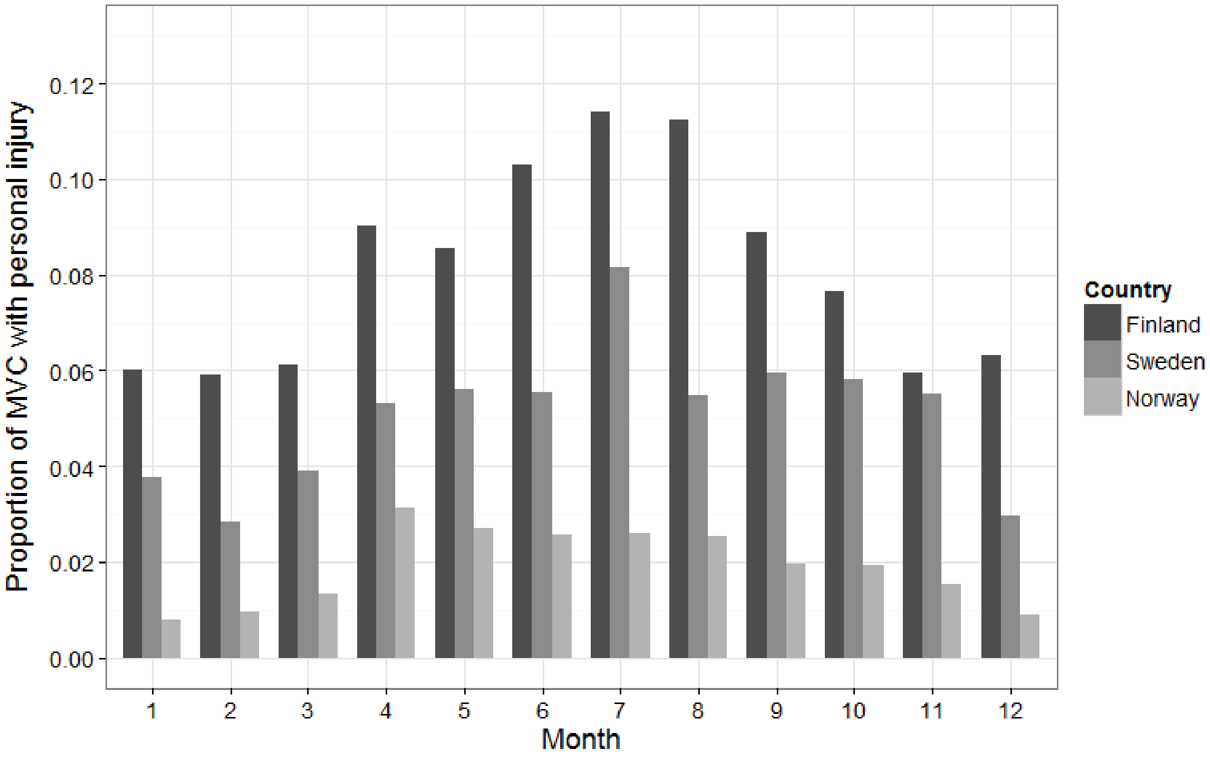

Figure 4. Monthly proportions of moose-vehicle collisions involving personal injury based on data from Finland (1990–2011; N = 40 238), Norway (2008–2011; N = 8 214), and Sweden (2008–2010; N = 17 527). The Norwegian data includes collisions between cars and moose only, while collisions with motorcycles are included in the Finnish and Swedish data.