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

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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.

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) is 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

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its associated economic and social costs, there is a need to develop cost-effective 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., 2012; 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 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 in 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 in MVCs in Finland, and P3 and P4 were related to the monthly variation in 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).

2. 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 to 2011 from Finland. Each MVC was allocated a timestamp and included information on whether the MVC caused personal injuries or fatalities. With an average of 6.6 per year, the annual occurrence of fatal MVCs was low. However, no additional information concerning injury severity was included. We thus combined 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)