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Traffic mortality of four ungulate species in southern Finland

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Abstract

Ungulate–vehicle collisions are intensively studied in many countries. However, limited knowledge exists on how many animals struck actually die due to collisions and whether differences in traffic mortality occur between species living in the same area. In this study, we estimated a kill rate (the proportion of individuals killed/struck) and, in relation to their winter population sizes, the collision and traffic mortality rates for four ungulate species (moose *Alces alces*, white-tailed deer *Odocoileus virginianus*, roe deer *Capreolus capreolus*, and fallow deer *Dama dama*). We used an unofficial collision register collected between 2001 and 2012 (a total of 12 years) by voluntary hunters from the Hyvinkää Game Management Area (323 km^2) located in southern Finland. The population estimates used were based on annual snow track censuses. A total of 497 ungulates were involved in collisions during the study period. Of these, 76% were killed directly or put down afterwards. Roe deer had the highest kill rate; 95% of struck individuals died. White-tailed deer had the highest collision and traffic mortality rates (8.0% and 6.5% of the winter population, respectively), followed by moose (6.5 % and 4.5%), roe deer (3.9% and 3.7%), and fallow deer (3.2% and 2.1%). As we found the collision and traffic mortality rates to be unequal between species, we recommend separately reporting all ungulate species when compiling collision statistics. We additionally suggest that local managers should be aware of ungulate collision and traffic mortality rates in their areas and should use this knowledge when planning annual harvest.

Keywords
Deer–vehicle collision, moose–vehicle collision, population size, collision rate, traffic mortality rate, game management

Introduction

Expanding road networks and globally increasing traffic volumes have many negative effects on the environment and animals (e.g. Forman and Alexander 1998, Fahrig and Rytwinski 2009). Road-induced mortality is one of these impacts. Road kills are the single most important cause of death e.g. for Eurasian badgers (*Meles meles*) in Britain (Clarke et al. 1998) and for Florida Key deer (*Odocoileus virgianus clavium*) in Florida (Lopez et al. 2003). The European otter (*Lutra lutra*) is also an example of a species suffering from high traffic mortality (Philcox et al. 1999, Hauer et al. 2002). Traffic can also be a significant cause of death in many common and abundant species, e.g. many ungulates, without directly threatening their population persistence (Seiler and Helldin 2006).

Ungulate–vehicle collisions (UVCs) are a notable and increasing traffic safety problem in Europe, North America, and Japan, and are therefore intensively studied in many countries (Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1998, Seiler 2004, Huijser et al. 2009, Morelle et al. 2013). Nevertheless, human injuries and fatalities (e.g. Joyce and Mahoney 2001) or the economic consequences caused by UVCs (e.g. Bissonette et al. 2008) are not the only aspects researchers have considered.

Several studies have focused on the temporal and/or spatial patterns of UVCs (Finder et al. 1999, Haikonen and Summala 2001, Danks and Porter 2010, Rolandsen et al. 2011, Niemi et al. 2013a, Rea et al. 2014, Steiner et al. 2014) and developed models for the purpose of predicting collision sites (Seiler 2005, Found and Boyce 2011). Different mitigation measures such as overpasses (Olsson et al. 2008), fencing (Clevenger et al. 2001), or warning signs (Krisp and Durot 2007) have furthermore been developed with the aim of reducing the number or severity of accidents.

Ungulate traffic mortality in relation to their population sizes is known in many countries. For example, the traffic mortality of roe deer (*Capreolus capreolus*) has varied between 13% and 16%, depending on the country (Groot Bruinderink and Hazebroek 1996, Seiler et al. 2004, Pokorny 2006). Joyce and Mahoney (2001) calculated the same ratio for moose (*Alces alces*) in Newfoundland, Canada, and found that the traffic mortality was only approximately 3% of the annual allowable harvest quota or 0.6% of the total population. In Sweden, these numbers were 10.1% and 4.0%, respectively (Seiler et al. 2004).

Although the relative importance of road kills seems low in many ungulate populations, regional variation could be notable. For Finland, Groot Bruinderink and Hazebroek (1996) reported the annual traffic mortality to be 1.2% of the total moose population, but pointed out that the portion could be 10% in the southern part of the country with denser human populations and higher traffic volumes.

Finland has three abundant ungulate game species, whose populations are mainly regulated by hunting: the moose, which is spread across the country; the introduced white-tailed deer (*Odocoileus virginianus*), which has a dense population concentrated in southwestern Finland and the roe deer, which lives in the southern half of the country (second largest distribution) at low densities (see Pulliainen 1980, Lavsund et al. 2003, Kekkonen et al. 2012, Finnish Wildlife Agency and Finnish Game and Fisheries Research Institute 2014). In addition, two small native populations of wild forest reindeer (*Rangifer tarandus fennicus*) live in central and northeastern Finland and a few small, introduced local populations of fallow deer (*Dama dama*) in southern Finland. The hunting of all these species, except for the roe deer, is based on licenses granted by wildlife authorities (Hunting Act 615/1993, Hunting Decree 666/1993).

During the 21st century, the annual country-level harvest for moose, white-tailed deer, and roe deer has varied between 38–76 000, 14–26 000, and 1–4 000 individuals, respectively. Other species are hunted only marginally; the annual hunting bag has varied between 20–130 individuals for wild forest reindeer and 50–200 individuals for fallow deer (Finnish Wildlife Agency and Finnish Game and Fisheries Research Institute 2014). At the same time, the total amount of annual collisions has varied between 1200–3000 for moose and 2600–4300 for the deer species (Finnish Traffic Agency 2014). Traffic is probably a significant cause of mortality for Finnish ungulate species, thus playing an important role when planning the annual harvest. This is particularly true for white-tailed deer, roe deer, and fallow deer, whose distributions are located near the most densely populated human settlements in southern Finland.

Study aim

The aim of our study was to estimate the traffic mortality of four ungulate species living in the same area and to discover possible inter-species differences. First, we were interested in how many percent of animals struck actually die due to collisions (later referred to as kill rate). Second, we wanted to investigate how many collisions have occurred in relation to species population sizes (later referred to as collision rate). Finally, we wanted to explore how large a proportion of the populations have died in the collisions (later referred to as traffic mortality rate). We tested the hypotheses that 1) the collision rate is equal for all species and 2) the traffic mortality rate is equal for all species.

Materials and methods

Study area

The study was conducted in the area of the Hyvinkää Game Management Association (later referred to as Hyvinkää GMA) (Fig. 1), which covers the Hyvinkää municipality

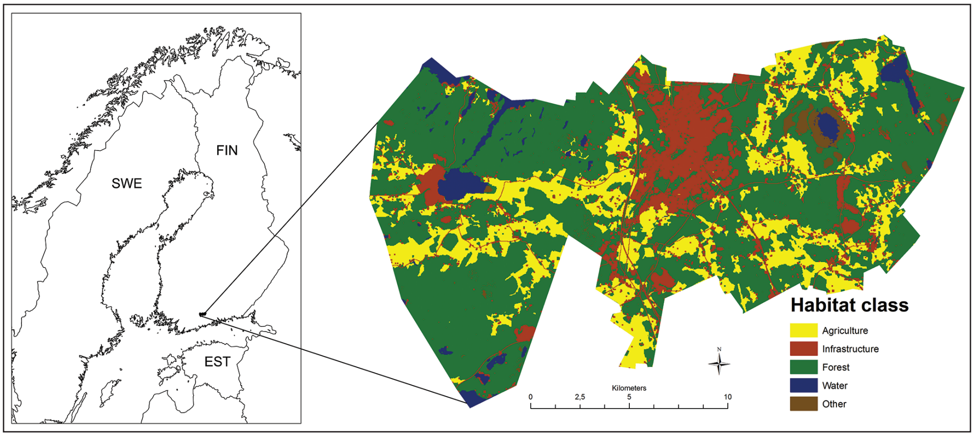

Figure 1. The map of our study area. The land use map is simplified from CORINE Land Cover 2006 data (Finnish Environment Institute 2009, CLC2006). Country borders: Eurostat.

in southern Finland, in the Uusimaa region. Hyvinkää (land area 323 km^2) is located in a densely populated part of the country with approximately 46 000 inhabitants in 2012 (Statistics Finland 2014). Most of the landscape is highly dominated by humans; the city of Hyvinkää covers the central part of the area and several smaller villages exist especially in the south. Landscape structures outside these population centers range from a mosaic of cultivated areas and settlements to more forested areas found mainly in the western parts of the municipality.

The area is divided by fenced National Highway 3 (depending on the road section, the traffic volume was approximately 20–30 000 vehicles/day in 2010; Finnish Transport Agency statistics; heavy traffic included), route 130 (running parallel to Highway 3; 3200–3500 vehicles/day) and a railway. These all run south to north, while in the east-west direction the area is limited by Highway number 25 (5–10 000 vehicles/day), which runs through the southern part of the area. Public road density is approximately 0.7 km/km^2, with an annual traffic flow approximately 330 millions of kilometers in 2010 (Finnish Transport Agency statistics). There is additionally a dense network of minor roads and forestry tracks. The speed limit on the main roads varies depending on the road section and season, being 100 or 120 km/hour on Highway 3 and 60 or 80 km/hour on the other main roads.

Ungulate data

A total of four ungulate species (moose, white-tailed deer, roe deer, and fallow deer) exist in the area of Hyvinkää GMA. All are game animals, i.e. their populations are managed by hunting. The annual maximum hunting quotas for moose, white-tailed deer, and fallow deer are defined and controlled by licenses granted by the Finnish Wildlife Agency. Roe deer harvest is not regulated by the authorities, but hunters have to report their bag (Hunting Act 615/1993, Hunting Decree 666/1993). The number of hunted individuals is thus known for each species.

The population estimate used in our study was based on an annual snow tracking census (Finnish Wildlife Agency and Finnish Game and Fisheries Research Institute 2014) coordinated by the Finnish Wildlife Agency and conducted by voluntary hunters. In the Uusimaa region, where our study area is located, each hunting club tries to assess all the ungulate individuals living in their hunting area. To avoid double counting, the census is carried out everywhere during the same weekend. Where animal populations are dense or snow conditions poor, the results of that census can be complemented with supplemental information from camera traps or other sources. The trends of an annual snow census from our study area are provided in Suppl. material 1: Annual trends in population size and collisions.

UVC data collection

Moose–vehicle accidents are registered at the species-level in the Finnish collision statistics, but crashes with other wild ungulates are treated as deer–vehicle collisions regardless of the species. Because we were interested in exploring the possible inter-species differences, the existing nation-wide collision database was not usable. We instead used a local dataset collected from the Hyvinkää GMA area by voluntary hunters who work as official assistants to the police.

UVCs in Finland have to be reported to the police, but the crash sites are usually visited by the police only in cases where personal injuries or damage to the vehicle has occurred. The collision sites are instead checked by local hunters, who work as an executive assistance to the police. These volunteers visit every UVC site, put the involved animal down if needed, and transport the carcass away from the road area. The volunteers do not have any registering duties, but will sometimes collect unofficial statistics for their own interests.

For our study, we used a specific UVC dataset collected by voluntary hunters and maintained by the chief of the Hyvinkää GMA. This register contained detailed information concerning e.g. the species and post-collision condition of an animal. The register contained UVCs from between 2001 and 2012 (12 years in total).

Data analyses

From the data collected by the voluntary hunters, we calculated a kill rate, a collision rate, and a traffic mortality rate for each species. The kill rate was simply calculated from the animals struck (how many percent of animals struck died in the collision or were fatally injured and put down afterwards). The collision rate was calculated by combining the collision data and the results of an annual snow census (i.e. how many collisions occur for each 100 individuals assessed in the snow census). The traffic mortality rate was also based on the collision and snow census data (how many individuals died in collisions for each 100 individuals assessed in the snow census). We have converted our results to percentages (e.g. a calculated rate of 0.05 = 5%) to simplify the text.

We used Fisher's exact test (e.g. Ranta et al. 1999) to test possible differences between species. Contingency tables used for the analyses are presented in Suppl. material 2: Contingency tables. We used Fisher's exact test with Bonferroni corrections for *p*-values for the post hoc analyses (MacDonald and Gardner 2000). Analyses were conducted using R software, version 3.1.3 (R Development Core Team 2015).

Results

A total of 497 ungulates were involved in 493 collisions during the 12-year study period (Table 1, Suppl. material 1). One out of two collisions ($N = 245$; 50%) was a crash involving white-tailed deer, followed by moose (118; 24%), roe deer (75; 15%), and fallow deer (40; 8%). The species was unknown in 15 cases (3%).

A total of 378 individuals (76%) were killed directly in the collisions or put down afterwards (later referred to as road-killed) (Table 1). Roe deer was the most vulnerable species: 95% of individuals involved in crashes were killed and only one was found uninjured. The lowest kill rate (65%) was recorded for fallow deer, but concurrently the number of disappeared individuals was high.

In comparison to population estimates derived from the snow track census data, white-tailed deer had the highest collision rate: 8.0% (8.0 collisions/100 individuals), followed by moose (6.5%), roe deer (3.9%), and fallow deer (3.2%) (Fig. 2). A statistically significant difference was observed between species (DF = 3, $p < 0.001$). A paired post hoc comparison showed all species pairs except white-tailed deer & moose and moose & roe deer to differ (0.05 at the α-level) after the Bonferroni correction was applied (Table 2).

Table 1. Road-killed and struck but uninjured ungulates in the Hyvinkää GMA between 2001 and 2012 (a total of 12 years). Column "Condition unknown" contains animals that have disappeared from the collision site and have not been found later by tracking, and animals whose condition has not been recorded in the database used.

	Road-killed individuals	Uninjured individuals	Condition unknown	Total number of individuals struck
White-tailed deer	198 (80%)	4 (2%)	46 (19%)	248 (50% of all)
Moose	82 (69%)	12 (10%)	24 (20%)	118 (24%)
Roe deer	72 (95%)	1 (1%)	3 (4%)	76 (15%)
Fallow deer	26 (65%)	1 (3%)	13 (33%)	40 (8%)
Unknown	0 (0%)	1 (7%)	14 (93%)	15 (3%)
Total	378 (76%)	19 (4%)	100 (20%)	497 (100%)

Figure 2. Annual variation in collision and traffic mortality rates for four ungulate species in the Hyvinkää GMA between 2001 and 2012 (a total of 12 years).

Table 2. The results of the pairwise comparisons between species' collision rates in the Hyvinkää GMA between 2001 and 2012 (a total of 12 years). Comparisons were made by using Fisher's exact test and *p*-values were adjusted using the Bonferroni correction.

Species 1	Species 2	DF	*p*-value
White-tailed deer	Moose	1	0.048
White-tailed deer	Roe deer	1	<0.001***
White-tailed deer	Fallow deer	1	<0.001***
Moose	Roe deer	1	<0.001**
Moose	Fallow deer	1	<0.001***
Roe deer	Fallow deer	1	0.332

*** p < 0.001 after Bonferroni adjustment
** p < 0.01 after Bonferroni adjustment
* p ≤ 0.05 after Bonferroni adjustment

When analyzing road-killed individuals only (i.e. excluding animals that had disappeared after the collision or were found uninjured), it became apparent that white-tailed deer had the highest traffic mortality rate (6.5% or 6.5 road-killed individuals/100 individuals) followed by moose (4.5%), roe deer (3.7%), and fallow deer (2.1%) (Fig. 2). Again, a statistically significant difference was found (DF = 3, $p < 0.001$), and in a paired comparison all species pairs except moose & roe deer differed (0.05 at the α-level) after the Bonferroni correction was applied (Table 3).

We calculated the ratio between road-killed individuals and the annual harvest for each species. The proportion of road-killed white-tailed deer was 10.3% of the annual hunting bag. The same proportions for moose, roe deer, and fallow deer were 6.9%, 30.9%, and 49.1%, respectively.

Table 3. The results of the pairwise comparisons between species' traffic mortality rates in the Hyvinkää GMA between 2001 and 2012 (a total of 12 years). Comparisons were made using Fisher's exact test and *p*-values were adjusted using the Bonferroni correction.

Species 1	Species 2	DF	*p*-value
White-tailed deer	Moose	1	0.003*
White-tailed deer	Roe deer	1	<0.001***
White-tailed deer	Fallow deer	1	<0.001***
Moose	Roe deer	1	0.249
Moose	Fallow deer	1	<0.001**
Roe deer	Fallow deer	1	0.008*

*** $p < 0.001$ after Bonferroni adjustment
** $p < 0.01$ after Bonferroni adjustment
* $p \leq 0.05$ after Bonferroni adjustment

Discussion

Collision fatality for ungulates

UVCs, especially deer–vehicle collisions, are relatively rarely fatal for humans. The opposite is true for animals. In our data, the smallest species, roe deer, was the most vulnerable: 95% of crashes lead to the death of the animal. This percentage is almost the same (94%) as that found by Almkvist et al. (1980) in Sweden. This number was lower for other species, but the number of disappeared individuals was concurrently higher. It is not known how large a proportion of these animals has been wounded and would have died later due to the consequences of the collisions. However, when ignoring these disappeared individuals, the largest ungulate species, the moose, has the best possibility of surviving a collision: 10% of individuals struck were found to be uninjured. This is similar to findings from Sweden (Almkvist et al. 1980; 8%) and Newfoundland, Canada (Joyce and Mahoney 2001; 11%). We thus note that the number of collisions with wild ungulates is more or less the same as the amount of road-killed animals. It is hence good to keep in mind that not all accidents are reported (e.g. Almkvist et al. 1980), and therefore the real number of collisions and further, the number of road-killed animals, may be larger than the number of registered accidents.

Although the size of the struck animal seemed to be an important factor affecting its possibility of surviving a collision, it is not necessarily the only one. Vehicle speed is the most important single variable that is connected to the severity of ungulate–vehicle collisions from the human point of view (Garret and Conway 1999, Joyce and Mahoney 2001), i.e. increasing speed increases the risk of human injuries or fatalities due to collisions. It is thus logical to assume that the probability that an animal struck would die in a collision is larger on highways with high speed limits than on secondary roads. Unfortunately, the data we used contained no exact spatial information of collision sites or their speed limits so we were unable to test the possible effect of speed on the kill rate of animals.

Species-specific collision and traffic mortality rates

White-tailed deer had the highest collision and traffic mortality rates: eight out of one hundred animals (in the wintering population) were involved in collisions, and the traffic mortality rate was 6.5% of the population. Etter et al. (2002) studied the survival rate of white-tailed deer in suburban Chicago and found traffic-induced mortality to be almost twice as high as our results (a rate of 0.10 for does and 0.17 for bucks compared to 6.5% or 0.065 in our data), while Dusek et al. (1989) reported traffic-related mortality of only 2% in autumn populations along the Lower Yellowstone River. We found the collision and traffic mortality rate of moose to be 6.5% and 4.5% of the population, respectively. This was similar to what Seiler et al. (2004) estimated in Sweden, but lower collision rates have been found elsewhere (Groot Bruinderink and Hazebroek 1996, Joyce and Mahoney 2001). The roe deer traffic mortality rate found by us was in concurrence with what other European countries reported in the early 1990s, while the fallow deer mortality rate was somewhat higher than reported elsewhere (Groot Bruinderink and Hazebroek 1996).

However, a straight comparison between collision or traffic mortality rates from different areas without knowledge of other explanatory factors does not necessarily illustrate the whole picture. The actual amount of collisions, and hence the amount of road-killed animals, is affected by several factors. Population size is one of the important variables explaining the number of UVCs (Lavsund et al. 2003, Seiler 2004, Rolandsen et al. 2011). In addition, though not always simple and linear, traffic volume is probably one of the key factors affecting the number of UVCs (e.g. Seiler 2004, Seiler 2005, Balčiauskas 2009). Other factors such as wildlife fences, under- and overpasses, and the distribution of feeding sites can also have an effect on the amount of collisions especially at local scales, and further, the number of road-killed animals. Thus, it is very likely that collision and traffic mortality rates vary between different areas and/or over time, even at the same population density.

In this study, we were interested in the differences concerning collision and traffic mortality rates between species concurrently living in the same area. The traffic flow and environmental variables were thus same for all species, giving us the possibility of discussing and comparing species behavior-related factors.

We found white-tailed deer to have the highest collision and traffic mortality rates, followed by the moose. However, after calculating Bonferroni corrections for *p*-values, the statistical difference between species collision rates disappeared while difference between species traffic mortality rates remained. This is likely to be due to the smaller body size of white-tailed deer, and further to the larger road kill rate found in our study. Comparing this species pair in a more detailed fashion would be interesting in the future, to investigate whether their collision rates really differ. Moose are known to have large home ranges and some of the animals implement seasonal migratory behavior (Heikkinen 2000, Singh et al. 2012). This results in moose being more likely to cross several roads during their routine movements. Laurian et al. (2008) on the other hand found that moose tend to avoid road crossings although they occasionally visit the proximity of road areas. This is not necessarily true for white-tailed deer: Feldhamer et al. (1986) observed that seasonal home ranges of some white-tailed deer individuals frequently overlapped a national highway. Although all the species we studied are adjusted to living in human-dominated landscapes, it is possible that the white-tailed deer utilizes more human-dominated areas of the landscape than the moose and is therefore more likely to cross roads during its daily routines.

In our study, roe deer and fallow deer had the lowest collision and traffic mortality rates. This could be connected with the movement behavior of these animals. Studies conducted in southern Finland found the monthly home ranges to be smaller and the daily movement distances shorter for roe deer compared to white-tailed deer (Saari 2011, Honzová 2013). In addition, apart for the home range size, landscape use could be an important factor affecting collision probability. Putman (1997) reviewed the studies concerning the daily movements of different deer species and found that although all the species regularly crossed minor roads, major roads or railways could act as a home range border, at least for the roe deer and fallow deer. The movement behavior of fallow deer in Finland has not been studied, but in general it seems that the species is relatively local and therefore might be less vulnerable to traffic than other ungulates. Groot Bruinderink and Hazebroek (1996) noted that the annual traffic mortality of an Irish fallow deer population living in a park area surrounded by a heavy traffic load was only approximately 7% of the population. On the other hand, the majority of fallow deer living in our study area were concentrated in the parts with no heavy traffic or high speed limit roads, so it is very possible that our findings could be partly explained by the animals' distribution in the field.

Ungulate–vehicle collisions cannot happen without an animal being on the road, but the temporal peak of the road crossing rate of animals and the timing of collisions are not necessarily the same. Neumann et al. (2012) combined spatiotemporal moose movement data with the Swedish collision register and found that the road-crossing probability was highest in early summer and mid-winter, while moose–vehicle collisions peaked in autumn and winter or during annual migration. They concluded that a high collision risk was related not only to animal movements, but also to light and road surface conditions. Moose–vehicle collisions in Finland are more likely to occur in autumn (Haikonen and Summala 2001), when the driving conditions are typically poor. Collisions with white-tailed deer also mainly occur during rutting season in late autumn. Contrastingly, both male roe deer movements and the roe deer collisions peak in late spring or early summer (Niemi et al. 2013b) during good light and road conditions. It may thus be possible that drivers are capable of avoiding some potential roe deer collisions because of good driving circumstances, leading overall to smaller collision and traffic mortality rates than in the case of moose and white-tailed deer.

Road kills and an annual harvest

We found notable inter-species differences when comparing the number of road-killed ungulates in relation to the annual hunting bag. The proportions of road-killed animals for the relatively abundant white-tailed deer and moose were 10.3% and 6.9% of the annual harvest, respectively. For moose, this was comparable with the ratio found in Sweden (Seiler et al. 2004). However, it is very likely that these numbers varied between areas, which should be considered by the local game authorities when planning annual harvests.

For fallow deer, the number of road-killed individuals was almost as high as the annual harvest. Although the data size was small and strong conclusions should therefore be avoided, our observation implicates the importance of taking species-specific traffic mortality into account when planning harvest quotas. Because the Finnish nationwide collision register does not differentiate between deer species, local-scale managers could benefit from their own, unofficial collision statistics.

Contrastingly to the relatively low traffic mortality rate (3.7%) of the roe deer, the species' traffic mortality in relation to the hunting bag (30.9%) was high. Roe deer hunting in Finland is free of licenses, leaving more management responsibility to local hunting clubs and even individual hunters. The past decade has been somewhat difficult for roe deer in southern Finland; the increasing Eurasian lynx (*Lynx lynx*) population and several severe winters have inhibited the population increase that began approximately two decades ago. It seems that hunters have tried to react to the changing situation by reducing their game bag; the annual amount of hunted roe deer compared to the estimated population size has decreased during the last few years in our study area (Finnish Wildlife Agency and Finnish Game and Fisheries Research Institute 2014). On the other hand, the annual amount of roe deer collisions has concurrently slightly increased (Suppl. material 1).

Conclusions

In our paper, we compared the collision statistics of four ungulate species (moose, white-tailed deer, roe deer, and fallow deer) living in the same area. Our main finding shows that both the collision (collisions in relation to population size) and traffic mortality rates (animals killed in collisions in relation to population size) of these four ungulate species differed. White-tailed deer and moose suffered the highest collision and traffic mortality rates. These rates were relatively low for roe deer and especially for fallow deer, although no strong conclusions could be drawn because of the limited amount of data especially in the case of fallow deer.

We were only able to show that the species-specific collision and mortality rates differed, but were unable to evaluate the actual reasons behind our findings. Additional work is thus needed to investigate, which factors affect the amount of collisions, and further, how traffic mortality affects ungulate populations.

However, we believe that managers responsible for defining the hunting quotas could use our results as a tool when planning the management of different ungulate species. We additionally wished to point out that combining several species under the same category in collision statistics may lead to loss of information and should therefore be avoided. Thus, in cases where the official collision register does not contain species-specific information or does not exist at all, local managers may benefit from a detailed collision registering system such as the one used in our study area.

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Supplementary material 1

Annual trends in population size and collisions

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Data type: species data

Explanation note: Annual trends in population size, harvest, and collisions.

Supplementary material 2

Contingency tables used in the analysis of collision and traffic mortality rates

Authors: Milla Niemi, Juho Matala, Markus Melin, Visa Eronen, Hannu Järvenpää

Data type: species data

Explanation note: Contingency tables.