Scale-dependent effects of landscape composition and configuration on deer-vehicle collisions and their relevance to mitigation and planning options

Stein Joar Hegland, Faculty of Engineering and Science, Western Norway University of Applied Sciences Norway, e-mail: stein.joar.hegland@hvl.no

Liv Norunn Hamre, Faculty of Engineering and Science, Western Norway University of Applied Sciences Norway, Norway, e-mail: liv.hamre@hvl.no

Corresponding author: stein.joar.hegland@hvl.no; Postal address: HVL-AIN, Røyrgata 6, N-6851 Sogndal; Tel: + 47 41501553

Highlights:

- The number of deer-vehicle collisions (DVCs) were lower when road verges contained little woody vegetation
- Landscape scale composition with high proportion of open land cover also significantly reduced DVCs
- Landscape configuration with farmland downhill and forest uphill increased DVCs
- Road verge clearance saved money and deer

Abstract

Deer-vehicle collisions (DVCs) cause animal suffering, traffic safety problems and socioeconomic costs and must be assessed in landscape planning and road management. We investigated whether landscape composition and configuration across spatial scales could predict DVCs and be used for mitigation actions and planning processes. We used data on DVCs between vehicles and red deer (*Cervus elaphus*) in Western Norway. We mapped DVCs and quantified open land cover within 10, 100 and 1000 m buffers as we expected scale-dependent effects on DVCs. A linear mixed effect model showed that DVCs was lower with higher proportion of open land on road verge scale (10 m-buffer) and ca. 50 % lower DVC frequency when proportion of open land was increased from 60 to 100 %. DVCs was generally lower in landscapes (100- and 1000 m buffers) composed of land that is more open. DVCs was 77 % higher in areas with spatial configuration of forest uphill and farmland downhill (FUFD). Landscape composition had the largest effect at fine spatial scale, whereas configuration mattered most at coarser scales, indicating scale-dependency. A case study of clearance along a 600 m road section verified the road verge effect compared to a control site, this saved four deer each year, and the payback time was less than one year providing a clear incentive to manage vegetation in road verges. In conclusion, new roads should preferably be planned in open landscapes or areas without FUFD configuration and road verge clearance is an effective mitigation measure to reduce DVCs.

Key words: collision risk; configuration; composition; landscape planning; road management; wildlife;

1. Introduction

Rising road densities, traffic volumes and vehicle speeds, combined with recent growth in the population density of various deer species, have increased the risk of deer-vehicle collisions (DVCs) across much of the world, causing a great deal of animal suffering, traffic safety problems and socio-economic costs (Bissonette et al., 2008; Bissonette and Rosa, 2012; Langbein et al., 2011). In Europe and North America, around 2 million deer are probably killed by vehicles every year, with a mean cost per DVC estimated at between USD 3500 and 6200 and around 30 000 human injuries in all (Bissonette et al., 2008; Huijser et al., 2008; Langbein et al., 2011). Such numbers are clearly a strong motivation for ecologists, wildlife scientists, road planners and authorities to seek mitigation options that can reduce some of these costs.

The risk of DVCs is known to increase with traffic volume and density of deer (Hothorn et al., 2012; Mysterud, 2004; Seiler, 2005, 2004), and a large proportion of DVCs occur during darkness (Meisingset et al., 2014; Solberg et al., 2009). However, the risk of DVCs along a specific road with a given regional traffic volume and density of deer will vary depending on additional local factors (Mysterud, 2004). Factors that increase the risk of DVCs are often habitat-specific, for example related to where deer rest and feed (Rivrud Godvik et al., 2009; Gagnon et al., 2007), where they prefer to cross roads (Meisingset et al., 2013), and how easily drivers can detect deer in the vicinity of the road as a function of visibility and traffic speed (Meisingset et al., 2014; Seiler, 2005). Several studies have found that the presence of woodland near roads may increase DVC risk (reviewed by Langbein et al., 2011), and habitat modification such as clearance of woody vegetation has been shown to decrease the risk (Meisingset et al., 2014; Seiler, 2005; Jaren et al., 1991). Moreover, animals' patterns and rates of movement influence vehicle-wildlife collision rates (Litvaitis and Tash, 2008), which highlights the importance of a landscape-extent approach. Knowledge of risk-relevant landscape factors is very valuable when designing mitigation options for use in road management or making decisions on road planning. Reviews of ways of reducing collision risk largely focus on existing roads (Langbein et al., 2011; Glista et al., 2009; Putman, 1997), and often do not consider factors that are important in planning new roads.

It is vital for planners and managers to consider scale-dependent effects of landscape composition and configuration on the risk of DVCs in order to ensure that mitigation and planning are effective. Landscape factors that have a strong influence on risk at a relatively fine scale may be important in deciding which mitigation measures to adopt (e.g. whether to use resources on road verge clearance) while factors that are important at a coarser scale may be more central in planning new roads. Landscape composition and configuration may also have different effects at different spatial scales. For example, we might expect the proportions of forest and open land, (i.e. landscape composition), to be important at a fine scale, and the location of patches, (i.e. landscape configuration), to become more important at a coarser scale. To investigate scale-dependent landscape effects on DVC frequency we formulated three hypotheses that could provide guidance for mitigation and planning processes when tested:

H1) The road-verge effect: we hypothesized a higher proportion of open land cover (grasslands and non-woody vegetation types) in road verges to reduce DVC frequency because deer are more visible to drivers and/or traffic is more visible to deer (Meisingset et al., 2014; Langbein et al., 2011). We evaluated H1 using data from DVC sites and from a case study of road verge clearance. H2) The landscape composition effect: we hypothesized that DVC frequency would be higher in areas with a higher proportion of open land cover at a coarser landscape scale, i.e. an opposite effect of H1. We expected this because red deer prefer landscapes with grassland where nutritious food resources are available (Lande et al., 2014; Rivrud Godvik et al., 2009) and have been found to cross roads more frequently close to farmland If confirmed by our results, H2 could help road planners to identify road routes that should be avoided. H3) The landscape configuration effect: we expected that the spatial configuration forest uphill-farmland downhill (FUFD) would be associated with higher DVC frequency, as red deer often prefer downhill farmland when feeding at night and uphill forest for shelter during the day (Rivrud Godvik et al., 2009). Red deer are therefore likely to cross roads on hillsides and in valleys when it is dark (Meisingset et al., 2013), which is when most DVCs occur (Mastro et al., 2010). It is also known that topography influences the risk of DVC, for example, a steeper slope may give a higher DVC risk (Meisingset et al., 2014). The overall configuration of forest and farmland in the landscape may therefore affect DVC frequency. By testing H3, we hoped to learn more about where to avoid routing new roads, which could be useful for landscape planners. We expected that the spatial configuration would be most important at the coarser landscape scales.

2. Methods

2.1. Study area

Our study focused on the county of Sogn & Fjordane which is in the core area of red deer distribution in Norway, as indicated by the largest annual harvest of red deer (*Cervus elaphus*) and the second highest number of deer-vehicle collisions (DVCs) for any county in Norway (Statistics-Norway, 2014). In Norway, officially registered data on DVCs, including data for moose (*Alces alces*), roe deer (*Capreolus capreolus*) and red deer, shows that more than 5000 animals have been killed in traffic every year since 2000 (Statistics-Norway, 2015). In addition, a large number of deer are injured and often not retrieved, but many of these are registered by the municipalities in a national open access database Hjorteviltregisteret, www.hjorteviltregisteret.no (the “Cervid Register”).

Sogn & Fjordane County has a temperate climate with a variable topography, ranging from hilly coastal landscapes with a relatively mild winter climate to mountainous areas in the inner fjord region with an oceanic to continental climate (Fig 1). This variation is reflected in the vegetation, which ranges from nemoral to high alpine, with a predominance of various types of boreal forest vegetation (Moen, 1999). Most of the county is rural. Four main highways run through the county. Rv 5 through the southern part from inland to coast (east-west). E 16 through the southeastern part south of the Sognefjord, E 39 through the central part from north to south, and Rv 15 through the northern part from inland to coast (Fig. 1). All four highways are two-lane roads with a maximum speed limit of 80 km/h and run mainly through lowland areas. Around two-thirds of the red deer in Norway migrate between distinct summer and winter ranges, and almost all deer spend the winter in the lowlands (Bischof et al., 2012). Most DVCs including red deer therefore occur in the Norwegian lowlands in winter (Mysterud, 2004; Fig. 1)

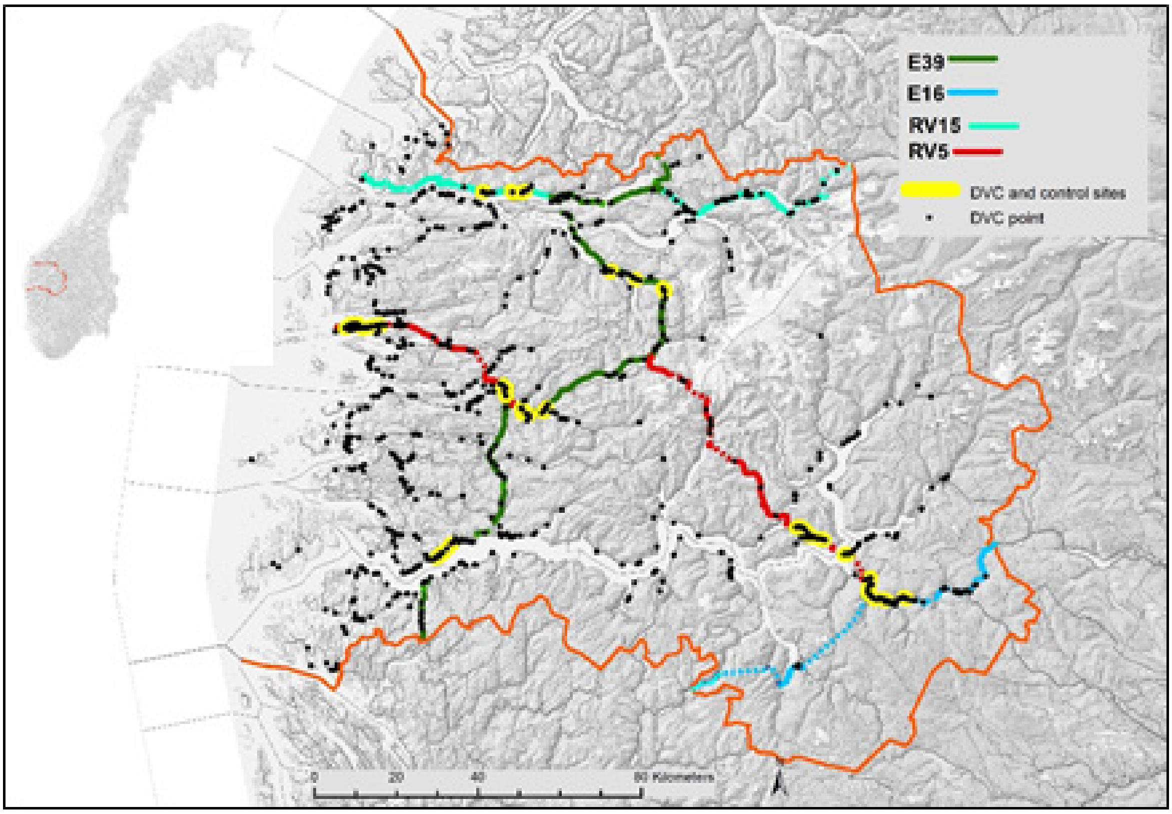

Figure 1. Map of Sogn & Fjordane county showing all registered DVCs from 2009 to 2013 as points (black) along roads (colored lines), indicating the aggregated pattern of the DVCs (yellow buffers show the study sites used).

2.2. Data collection

We obtained data from the Cervid Register (see above). In addition, we contacted the municipalities in the areas included in this study to verify that data from sources such as police and road authorities were included in the records, and received information about irregularities (e.g. missing coordinates) to ensure that the data quality was as good as possible. We made field visits to all sites and removed sites where there had been major landscape alterations within the study period (one road section with many pre-2011 collisions in Flora municipality) from the dataset. At one site in Kaupanger, Sogndal municipality, a wildlife fence was put up in 2011 and in this case we included the site but data from 2007 to 2011 only. In Gaular municipality, only collisions from 2013 and onwards have been recorded in Hjorteviltregisteret, and we excluded these potential sites. In all, 47 DVC and low-DVC sites were selected and used for further analysis.

Collision data included the location (UTM coordinates and local names), date and time of the DVC, the outcome (dead, retrieved, not found, etc.), and the age and sex of the deer. In this study, we used data from the four main highways of the county irrespective of outcome, date and sex and age of the animal. We used data from 2009-2013 as we knew from experience that older records in Hjorteviltregisteret often are less accurate. Moreover, traffic volumes and deer densities were relatively stable within this period, and the highways are of nearly identical with speed limits at 70 or 80 km/h. Such selection process is minimizing the possible confounding effects of variation in these factors during tests of our hypotheses. The data were uploaded in ArcGIS 10.2 (ESRI 2014. ArcMap 10.2. ESRI, Redlands, California).

We defined DVC sites using a hierarchical approach to account for the spatial pattern of registered DVCs, with municipalities as the highest level (see also Fig. 1). Every DVC site within a municipality was delimited in the GIS based on the position data. We defined a DVC site as a road section with a minimum mean DVC frequency of one per year (2009-2013), with a maximum distance of 300 m between the recorded collisions and a maximum total length of 1000 m. Within each municipality, we also delimited a low-DVC site, defined as a road section where collisions occurred, but less frequently (1-3 collisions/5 years). By defining DVC sites based on multiple collisions, we reduce the possible influence of imprecise coordinates, as may be a relevant problem in studies using single

DVCs for assessing landscape effects. Low-DVC sites were delimited so that their length was the same as the average length of the DVC sites in the same municipality. This resulted in a selection of sites spanning a gradient in DVC frequency from very low to rather high within each municipality. By using a gradient approach, we avoided the strong regional scale-dependent effect of traffic volume and local deer density, which is a known effect from analysis of datasets that use all data on DVCs from a given region (e.g. all road categories, winter and summer ranges of deer etc.) (Montgomery et al., 2013; Solberg et al., 2009; e.g. Mysterud, 2004). This restricted sampling was specifically targeted to test the hypotheses regarding landscape-scale effects (H2, H3). The DVC sites in our study varied in length from 94 to 994 m, a clustering pattern consistent with other studies (Bashore et al., 1985), and road length is taken into account in statistical analysis.

To test compositional effects, that is the road verge effect (H1) and the landscape composition effect (H2), we quantified open land cover, defined as grasslands (semi-natural or agricultural) and other non-woody vegetation types, around each site within 10, 100, and 1000 m buffers in ArcGIS. 10 m buffers represented the road verge scale, 100 m buffers the fine landscape scale and 1000 m buffers the coarse landscape scale (i.e. relatively large, but usually not covering high mountain areas or valleys next to the study sites etc. which would confound the test of hypotheses). Open land cover were digitized manually within each of the buffers based on ortophotos (year 2014) available from WMS orthophoto on geonorge.wms.no (UTM EUREF89) in ArcGIS. In the GIS project, map datum was WGS84 and we used transverse Mercator projection. The spatial scales were selected to represent scales that in combination could influence driver’s possibility to discover along roads (10 and 100 m) and deer choices in relation to roads (10, 100 and 1000 m) and therefore could be used in road management and planning. The minimum mapping unit of digitization was 5 meter.

To test the landscape configuration effect (H3) we categorized each site according to whether or not it had the spatial configuration forest-uphill and farmland-downhill (FUFD). On the 1000-m scale, we only included the part of the buffer that could be delimited within a rectangle placed at an angle of 90° to the DVC site (i.e. uphill and downhill). If, within this given area, there was >10 000m^2 of forest cover uphill and same amount farmland cover downhill it was classified as a FUFD-site. This is an easily detectable configuration measure that can be read from any map, in the field as well, and that indicates something about where patches of forest and farmland are located in the landscape.

2.3. Statistical analysis

We used linear mixed effects modelling (lme) to analyze the scale-dependent landscape effects on DVC frequency. The response variable was the number of DVCs (called DVC frequency) at each site between 2009 and 2013 and varied continuously from very low at the control sites to higher levels at different DVC sites. We used the proportion of open land as a fixed effect (explanatory variable) for the tests at the three different scales. The proportion of forest was almost directly inversely related to the proportion of open land, and forest effects could therefore easily be interpreted based on the results using open land as response. We could account for the hierarchical data collection and possible spatial dependence within municipalities by including municipality as random factor. For each scale we tested two different models: model 1 contained only a linear component of percentage open land, whereas model 2 also contained a quadratic component of percentage open land to test the whether the effects of landscape composition on DVC frequency peaked and then declined or increased as the proportion of open land rose. We selected between linear or quadratic models using the parsimonious principle and comparing AIC values between models (Crawley 2013) using AICc to control for sample size with a delta ≤ 2 considered as equivalent models (Burnham and Anderson 2003). Selected models were also tested against a null model. We used the program R version 3.1.1., function glmer within package lme4 and a Poisson distribution since the DVC data were count data (R Development Core Team, 2015).

2.4. Case study to evaluate road verge clearance as a mitigation measure

In Flora municipality (Brandsøy), a ca. 600 m section of road verge was cleared of all woody vegetation to a distance of ca. 10 m from each road edge in 2009. DVC-data have been registered accurately and following the same standardized procedures in this municipality since 2000 (pers. comm. M. Frøyen). We used a Before-After-Control-Impact (BACI) approach to evaluate the effect of road verge clearance. To test whether clearance had an effect on DVC frequency, we used data on DVC frequency from four years before and after clearance and compared the change in DVC frequency at the test site with the change at a control site. The control was the closest DVC site within the municipality that were not cleared. It was located 2.4 km east of the mitigation site within roughly the same type of landscape and a site used to test for the landscape effects (see Data collection) on DVC frequency. The effect of road verge clearance was calculated as the difference in DVC frequency between the control site and the mitigation site both before and after clearance. If the difference changed in a positive direction over time, this indicated that clearance had a positive effect. As we only had one test and one control site, and only few years, it was not possible to perform any statistical testing of the changes. The case study was therefore used as a qualitative comparison with the quantitative countywide part of this study. We also obtained figures for the cost of road verge clearance and the socioeconomic costs of a DVC from the road authorities (pers. comm. A. K. Nes). Clearance cost NOK 35 000 in 2009, which was ca. NOK 37 000 in 2013-kroner or ca. NOK 62/m road. The cost of a collision was set at NOK 50 000. Costs was based on a rough but conservative estimate of the kinds of costs typically associated with DVCs: call-out of search dog patrols, police and/or other officials, vehicle repairs including insurance costs, human injuries, loss of work hours, loss of harvest potential and venison use. Our estimate was similar to the mean cost of USD 6126 calculated by Huijser et al. (2008), and we used it for a simple calculation of the payback period for the mitigation measure.

3. Results

3.1. Descriptive statistics on DVCs in study area

From 2009 to 2013 a total of 1668 deer-vehicle collisions (DVCs) were registered in the Cervid Register for the county of Sogn & Fjordane. Of these, ca. 72 % occurred on the four highways included in the study (see also Fig. 1), and 70 % in the eight municipalities where our DVC and control sites were located. Most DVCs, 89%, in the county from 2009 to 2013 occurred during the non-summer months (September-May), and 68 % of them occurred in the six months from October to March. Almost all the DVCs for which a time was recorded (92 %) occurred during the relatively dark period between 17:00 hours and 09:00 hours.

3.2. The road verge effect (H1)

DVCs were lower where there was a higher proportion of open land in road verges (10 m buffer; Table 1). The best model included a quadratic component indicating a weakly declining effect of open land cover on collision frequency (Fig. 2a). DVC frequency declined with ca. 50 % as the proportion of open land in road verges increases from 60 to 100 %.

3.3. Landscape composition effect (H2)

The model on the finer landscape scale (100 m buffer) indicated a negative quadratic relationship between the proportion of open land and DVC frequency (Table 1), and the aggregated curve on municipality level showed an increasingly negative effect with a rising proportion of open land (Fig. 2b). As the proportion of land increased to > 50 %, DVC frequency dropped by ca. 50 % (Fig. 2b). On a coarser landscape scale (1000 m buffer), there was only a marginal negative effect of open land on DVC frequency (Fig. 2c; Table 1).

Table 1

Relationship between number of deer-vehicle collisions (DVCs) and proportion of open land on road verge-scale (10 m buffer) and landscape scales (100 and 1000 m buffers) as result of linear mixed effects modelling.

Scale (buffer)	Fixed effect	Coef	SE	N	P	AICc	ΔAICc	AICc$_w$
10m	Intercept	0.97	0.44	47	0.028			
	Open land	3.51	1.35	8	0.010			
	Open land^2	-2.31	1.01	8	0.022	373.41	3.01	0.18
100 m	Intercept	1.94	0.17	47	<0.001			
	Open land	1.80	0.67	8	0.007			
	Open land^2	-1.84	0.68	8	0.006	375.19	5.23	0.07
1000 m	Intercept	2.35	0.12	47				
	Open land	-0.58	0.33	8		377.56	0. 71	0.76

Note: Best models selected by AICc per scale are shown. ΔAICc is the change compared to the other tested model. AICc$_w$ gives the model weight.

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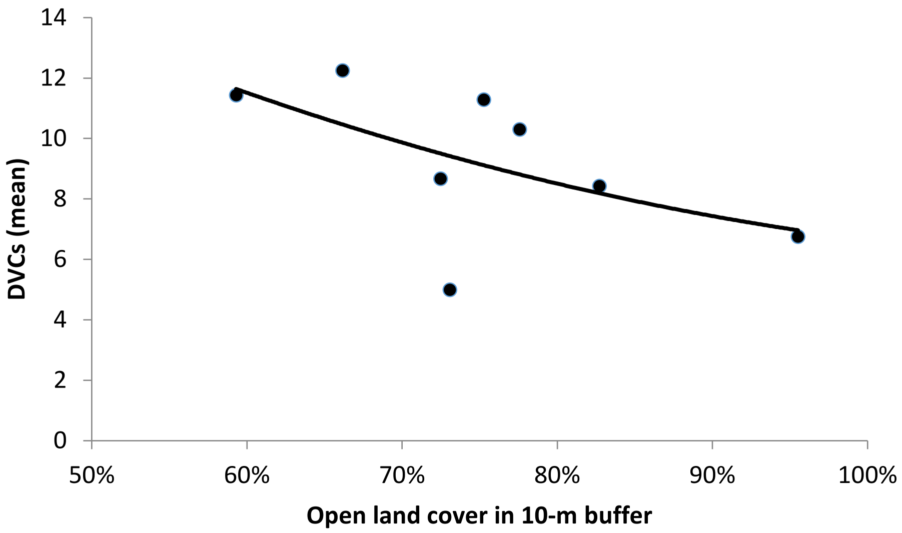

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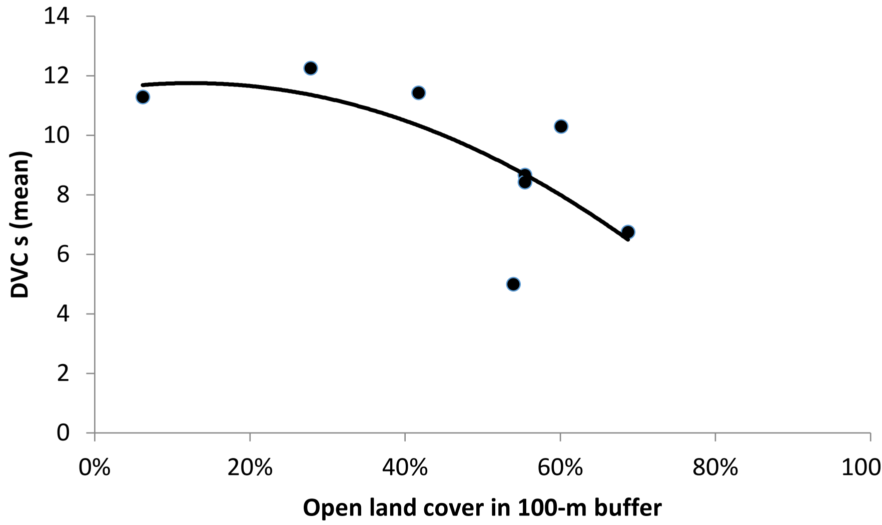

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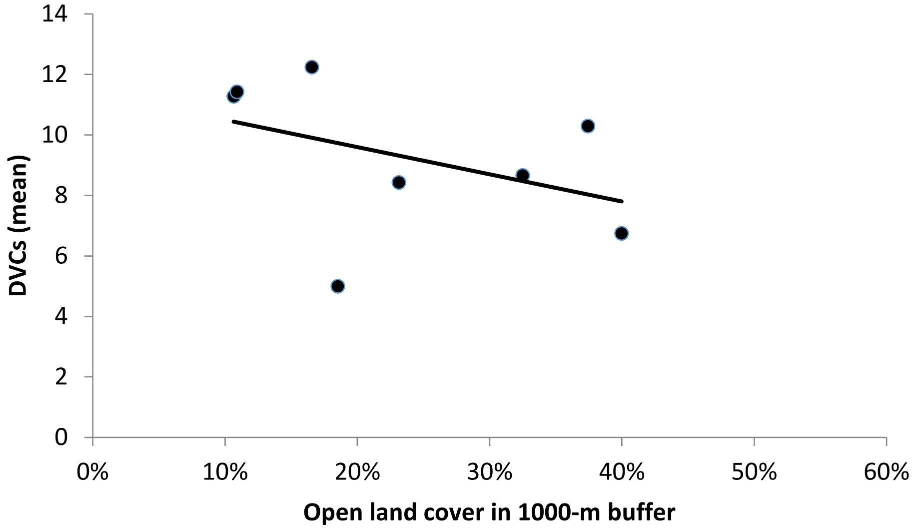

Figure 2. The relationship between the mean number of deer-vehicle collisions (DVCs) and mean proportion of open land (landscape composition) on a) road verge scale (10 m buffer) and b-c) landscape scale (100 and 1000 m buffer) on main highways in Sogn & Fjordane, Western Norway. The figures are based on mean values (5 years) on municipality level, whereas the statistical analysis was based on all data but nested on municipality level (see Statistical analysis).

3.4. Landscape configuration effect (H3)

On the finer landscape scale (100 m), the mean DVC frequency was 10.1 along road sections with the spatial configuration forest-uphill and farmland-downhill (FUFD) and 8.7 along other road sections (Coef=-0.33, SE=0.12, DF= 47, 8, P= 0.008; Fig. 3). At the coarser landscape scale (1000 m), the difference between sites with and without this spatial configuration was larger, with a mean DVC frequency of 10.6 at FUFD sites and 6 along other road sections (Coef=-1.07, SE=0.16, DF= 47, 8, P> 0.001).

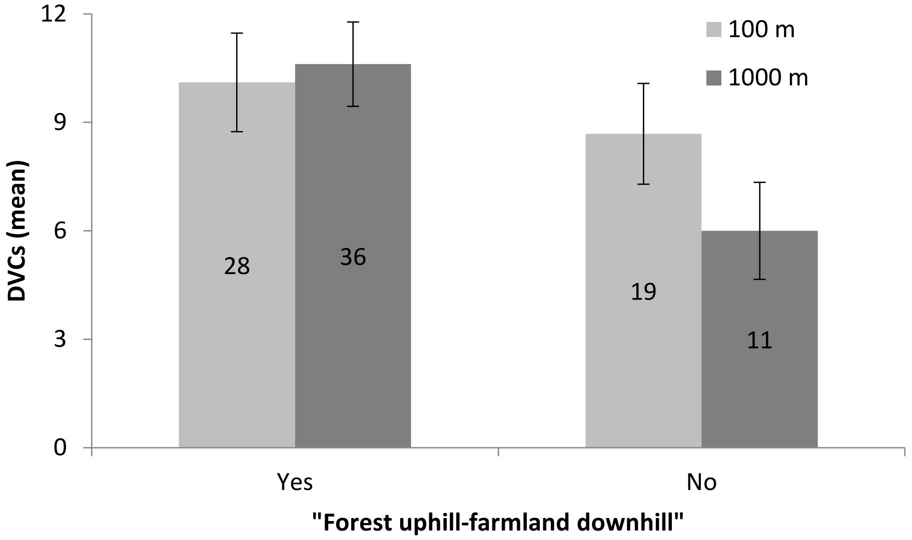

Figure 3. The difference in mean (± 1 SE) number of deer-vehicle collisions (DVCs) when the spatial configuration forest uphill-farmland downhill (FUFD) was present or not on two different landscape scales. Mean values (5 years) are from main highways in Sogn & Fjordane, Western Norway, the number of sites in each category is given within the bars.

3.5. Case study of road verge clearance

Road verge clearance showed to have a strong effect at the site in Flora municipality. Before clearance, the annual DVC frequency along the 600 m stretch of road doubled from four to eight from 2006 to 2009, whereas after road verge clearance in 2009 the DVC frequency declined most of the period (Fig. 4). The total number of DVCs was 44 % lower in the four years after clearance than in the four years before. When this was controlled against figures for the control site, where there was a generally rising trend in DVC frequency throughout period (Fig. 4), it was calculated that the mitigation measure saved ca. 4 red deer annually, resulting in savings of NOK 200 000. The payback time was less than one year, as the cost of clearance was NOK 35 000.

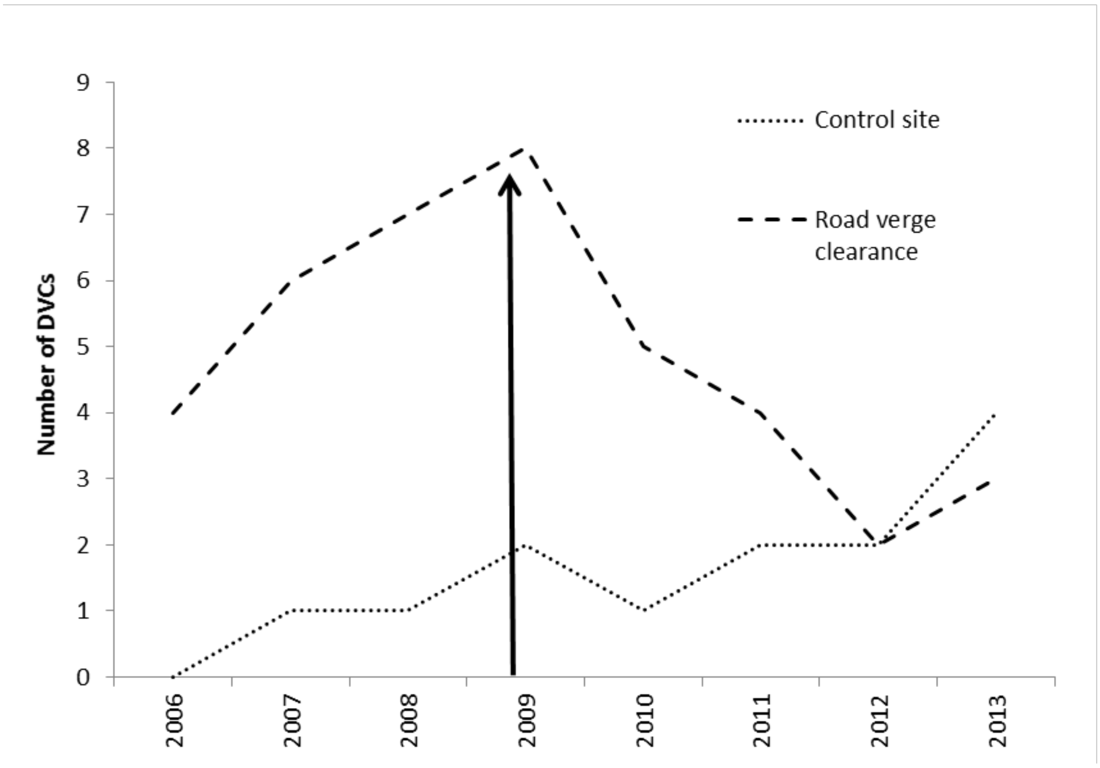

Figure 4. Annual number of DVCs from 2006 to 2013 in Flora municipality (Brandsøy), Western Norway at a road verge clearance site and the control site. The arrow indicates the timing of road verge clearance (2009).

4. Discussion

4.1. Management effect: road verge clearance

Our study of deer-vehicle collision (DVC) sites throughout the county of Sogn & Fjordane revealed that DVC frequency was up to 50 % lower when there was no forest cover in the road verge. This result was verified by a case study of road verge clearance, which showed an almost equal percentage reduction over time by comparison with a control site. These results confirmed our expectations (H1), and our findings add to a growing number of studies that highlight the importance of various forms of habitat modification to improve visibility for drivers or deer and thus reduce the risk of DVCs (Meisingset et al., 2014; Seiler, 2005; Nielsen et al., 2003; Finder et al., 1999; Jaren et al., 1991). Low visibility is generally one of the most important factors that increase collision risk between vehicles and wildlife (Gunson et al., 2011). Meisingset et al. (2014) found an almost identical reduction in DVC frequency (53 %) in a neighboring county in Western Norway using a different evaluation method including GPS-collared deer, and Andreassen et al. (2005) found comparable clearance effect for moose-train collisions, strengthens the conclusion that this is an effective mitigation measure. In both the red deer studies (Meisingset et al., 2014; present study), the road verge clearance strip was ≤ 10 m wide, indicating that the relatively wide clearance strips that have been proposed for moose (Seiler, 2005; Jaren et al., 1991) may not be required for reducing DVCs involving red deer.

Habitat modification through vegetation clearance is a nonstructural method of reducing DVCs, in contrast to structural measures such as fences and crossing structures. Nonstructural approaches are often cheaper than structural measures (Glista et al., 2009). In the case study presented here, the payback time for the mitigation measure was found to be less than one year using the actual cost of clearance (NOK 35 000) and the average estimated cost per DVC (NOK 50 000 x 4 deer saved). This makes it clear that road verge clearance may be a cost-efficient approach to mitigation. In the US, a cost-benefit analysis showed that vegetation removal on roads with 5 DVCs per km per year gave estimated savings of USD 16 000 (Huijser et al., 2008). This is probably the most cost-efficient mitigation measure along two-lane roads with relatively modest traffic volumes and in areas where DVCs occur relatively frequently but dispersed across stretches of road (Meisingset et al., 2014; present study). Where traffic volume is higher, road verge clearance may be less efficient, and other measures such as fences and crossing structures should be used (Bissonette and Rosa, 2012; Seiler, 2005).

4.2. Landscape effects and road planning

Our results show that DVC frequency is lower where there is open land cover. The results contradicts our predictions based on the expectation that red deer would be attracted to open land that would increase road crossings and hence the probability of DVCs. However, the result confirm the findings of several authors of reduced DVC frequency in open landscapes (Meisingset et al., 2014; Nielsen et al., 2003; Finder et al., 1999; Bashore et al., 1985). The constant effect of open land (or inversely, forest cover) across all three scales (10, 100 and 1000m buffers) found in the present study indicates that it should be possible to extrapolate the results to other areas. It also indicates that there are advantages in planning new roads in open landscape where visibility is higher and DVC frequency should be lower. This approach would be a way of avoiding habitat fragmentation (in forested areas), which is a key issue in landscape ecology (Turner and Gardner, 2015). Avoidance of key forest habitats, hot-spot areas and steep terrain were the main planning strategies listed in a report to the UD Congress on reduction of wildlife-vehicle collisions (Huijser et al., 2008). The authors also stressed the importance of collecting data on deer habitat use for use in planning roads and on DVC hotspots for use in planning mitigation action. However, it should be remembered that open landscapes may be valuable in many other ways, for example related to food production, biodiversity and the cultural heritage, and routing roads mainly through open landscapes to reduce DVC frequency may threaten such qualities. Clearly, a number of different approaches are needed in road planning before decisions are made on where to route new roads (Gunson et al., 2011; Huijser et al., 2008).

Landscape configuration, i.e. the spatial arrangement of patches of land cover types in the landscape, has rarely been assessed in studies of DVCs, which mainly focus on landscape composition (Bissonette and Rosa, 2012; Langbein et al., 2011; Glista et al., 2009; Romin and Bissonette, 1996). We used a simple measure of landscape configuration that can be assessed either in the field or on maps when planning roads, and that gives a straightforward indicator for planning decisions on routes for new roads. In the hilly terrain of Western Norway, DVC frequency was found to be up to

77 % higher in areas with the configuration forest uphill-farmland downhill (FUFD) than elsewhere. This result is consistent with a study from Pennsylvania, USA, which showed that DVCs were concentrated around woodland-field interfaces (Bashore et al., 1985), and a study on roe deer in Germany, which showed that up to a certain level, DVC frequency increased with increasing forest edge length (Hothorn et al., 2012) . Although the US and German landscapes are predominantly flat and relatively open, whereas the Norwegian landscapes are rugged and dominated by forest, the findings are strikingly similar. This may simply be because of the diurnal utilization of landscape by red deer, which generally involves movement between sheltering forest in the daytime and open land at night (Rivrud Godvik et al., 2009) a pattern which is particularly common in winter (Allen et al., 2014). In roe deer it has been shown that the increased possibility of DVCs after sunset and before sunrise is caused by deer behavior (Hothorn et al., 2015), which is a likely pattern in the studied red deer population as most DVCs occurred during dark hours. In the hilly landscapes of Western Norway, the FUFD configuration is relatively common, and the higher number of DVCs in these areas may be reinforced by the effects of slope and topography (Jensen et al., 2014; Meisingset et al., 2014).

It can be argued that composition and configuration are intercorrelated. In this study, both measures are based on the occurrence of open vs. forrested land cover types. However, the determination of these two measures are quite different. Composition, in our study, was a quantitative measure and the standard used in landscape ecology. Our configuration measure, however, was based on a quantifying a minimum of land cover types (see methods for details) combined with a categorization approach of where these types were found in relation to roads. The correlation between these two variables, r=0.33 and 0.28 at the 100 m and 1000 m buffer, respectively, and thus within reasonable limits. The use of both types of variables give extended possibilities for applied planning guidelines to reduce DVCs.

In general, construction of new roads in areas with the FUFD configuration should be avoided. In other types of landscapes, the specific configurations of interest may be slightly different, and roads should generally not be routed along interfaces between forest and open land (Bashore et al., 1985). The importance of the results may be more general. Landscape configuration is important, in particular on coarse spatial scales, in explaining DVC risk and may be useful in pinpointing where *not* to plan new roads to avoid the animal suffering, traffic safety issues and socioeconomic costs associated with DVCs. The results thus highlight the importance of using principles of landscape ecology in planning processes.

5. Conclusions

We detected a scale-dependent effect of landscape composition and configuration on deer-vehicle collisions (DVCs) using officially registered and publically available collision data from the county of Sogn & Fjordane in western Norway. Landscape composition had an effect on DVC frequency on all scales, and largest on road verge (10 m) and fine landscape (100 m) scale. Landscape configuration had a greater impact on the coarser landscape scale (1000 m). Such scale-dependent effects are important for efficient road management and for choosing mitigation measures to reduce DVC frequency, and provide valuable input to planning processes. On the basis of landscape composition and configuration, a DVC hotspot in Western Norway can, be defined as a road section with a high proportion of forest (i.e. low proportion of open land) where forest is located uphill and farmland downhill of the road (up to 1000 m buffer). When there is a choice between different routes for a road, sections that do not meet the FUFD-configuration or are not located in the interface between woodland and open land should be preferred, in particular in areas where there are high densities of red deer in winter.

Non-optimal design of mitigation measures tends to be the rule rather than the exception due to a lack of knowledge or funding (Glista et al., 2009). In this study, we have shown that road verge clearance can be a very cost-efficient measure. However, preconstruction planning is even more economical than mitigation action to improve existing roads (Glista et al., 2009). An assessment of landscape characteristics associated with a high risk of DVCs should therefore be a compulsory part of the environmental impact assessments required during the planning of new roads. Such assessments would ensure that landscape ecological knowledge on the influence of landscape composition and configuration on animal movement patterns is used in planning processes.

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