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Research Paper

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

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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.

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, Kassar, & Cook, 2008; Bissonette & Rosa, 2012; Langbein, Putman, & Pokorny, 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, Brandl, & Müller, 2012; Mysterud, 2004; Seiler, 2005, 2004), and a large proportion of DVCs occur during darkness (Meisingset, Loe, & Mysterud, 2014; Solberg, Rolandsen, Herfindal, & Heim, 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, Theimer, Dodd, Boe, & Schweinsburg, 2007), where they prefer to cross roads (Meisingset, Loe, Brekkum, Van Moorter, & Mysterud, 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 (Jaren, Andersen, Ulleberg, Pedersen, & Wiseth, 1991; Meisingset et al., 2014; Seiler, 2005). Moreover, animals' patterns and rates of movement influence vehicle-wildlife collision rates (Litvaitis & 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 (Glista, DeVault, & DeWoody, 2009; Langbein et al., 2011;

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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 (Langbein et al., 2011; Meisingset et al., 2014). 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, Loe, Skjærli, Meisingset, & Mysterud, 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, Conover, & Frey, 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)

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 to 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 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, Roloff, & Millspaugh, 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