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Effectiveness of short sections of wildlife fencing and crossing structures along highways in reducing wildlife–vehicle collisions and providing safe crossing opportunities for large mammals

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ABSTRACT

Wildlife fencing in combination with crossing structures is commonly regarded as the most effective and robust strategy to reduce large mammal–vehicle collisions while also maintaining wildlife connectivity across roads. However, fencing and associated measures may affect landscape esthetics and are sometimes considered costly and unpopular. Therefore fence length is often minimized. We investigated 1) whether short fenced road sections were similarly effective in reducing large mammal–vehicle collisions as long fenced road sections (literature review), and 2) whether fence length influenced large mammal use of underpasses (two field studies). We found that: 1) short fences (≤5 km road length) had lower (52.7%) and more variable (0–94%) effectiveness in reducing collisions than long fences (>5 km) (typically >80% reduction); 2) wildlife use of underpasses was highly variable, regardless of fence length (first field study); 3) most highway crossings occurred through isolated underpasses (82%) rather than at grade at fence ends (18%) (second field study); and 4) the proportional use of isolated underpasses (compared to crossings at fence ends) did not increase with longer fence lengths (up to 256 m from underpasses) (second field study). If the primary success parameter is to improve highway safety for humans by reducing collisions with large ungulates, the data suggest fence lengths of at least 5 km. While longer fence lengths do not necessarily guarantee higher wildlife use of underpasses as use varies greatly between locations, wildlife fencing can still improve wildlife use of an individual underpass.

1. Introduction

Large mammal–vehicle collisions are abundant in many parts of the world (e.g. Groot Bruinderink and Hazebroek, 1996; Conover et al., 1995). Collisions with large ungulates typically result in the injury or death of the animals involved, substantial vehicle damage, and – in some cases – human injuries and fatalities (Allen and McCullough, 1976; Bissonette et al., 2008; Conover et al., 1995). Wildlife fencing in combination with wildlife crossing structures is commonly regarded as the most effective and robust strategy to reduce these types of collisions while also maintaining connectivity across highways for wildlife (review in Huijser et al., 2009). If wildlife fencing and crossing structures are designed based on the requirements of the target species, and if they are implemented and maintained correctly, the measures can reduce large mammal–vehicle collisions by 80–97% (Clevenger et al., 2001; Gagnon et al., 2015; Sawyer et al., 2012). In addition, the number of animal movements across overpasses or through underpasses, as well as the percentage of animals out of a local population that use the structures, can be substantial (Clevenger and Waltho, 2000; Sawaya et al., 2013; Sawyer et al., 2012).

Despite the benefits described above, wildlife fences, wildlife crossing structures and associated measures can be a contentious issue. Wildlife fences for large ungulates are typically 2.4 m high and can affect landscape esthetics (Evans and Wood, 1980). In addition, some landowners may also object to associated measures such as gates, wildlife guards, or similar measures at access roads as they may be time consuming or unpleasant to drive across. Furthermore, despite the wildlife crossing structures that may be present, fences are sometimes a problem for wide ranging large mammal species such as mule deer (*Odocoileus hemionus*) and pronghorn (*Antilocapra americana*) (Coe et al., 2015; Poor et al., 2012; Seidler et al., 2015). They can even be a

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source of injury and direct mortality for the animals (Jones, 2014). Finally, transportation agencies as well as the public may perceive wildlife fencing and associated measures as relatively expensive to construct and maintain.

Because of the issues described above highway managers tend to minimize the length of wildlife fencing associated with wildlife crossing structures (Ascensão et al., 2013; Ford et al., 2011; van Manen et al., 2012). Sometimes crossing structures are not accompanied by wildlife fencing at all. This occurs especially in multifunctional landscapes where fences, mitigation at access roads, and wildlife crossing structures are more likely to conflict with other land uses. However, even with short fenced road sections, planners and designers need to know how long the mitigated zone should be in order to obtain a substantial reduction in wildlife–vehicle collisions and, as a consequence, a substantial improvement in human safety (Rytwinski et al., 2015). They also need to know if wildlife fencing is required or how long the fencing should be in order to help guide wildlife to designated crossing structures rather than have them cross at grade on the road surface (Rytwinski et al., 2015). Currently, no study exists to provide fence-length recommendations with regard to either collision reduction or wildlife use of crossing structures. Therefore we conducted a literature review to investigate whether short fenced road sections were equally effective in reducing large mammal–vehicle collisions as long fenced road sections. In addition, we conducted two field studies to investigate large mammal use of underpasses that have no or very short fences. We were specifically interested if the use of isolated underpasses with no or very short fences (up to a few hundred meters) was similar to that of underpasses with longer sections of fencing (up to several kilometers) (first field study). In the second field study we investigated whether longer fence lengths (up to a few hundred meters from an underpass) were associated with increased wildlife use of the underpasses and reduced wildlife crossings at fence ends.

2. Methods

2.1. Literature review: impact of fence length on reducing large mammal–vehicle collisions

We conducted a literature review to investigate whether short fenced road sections were equally effective in reducing large mammal–vehicle collisions as long fenced road sections. We searched for all publications (peer-reviewed and non-peer reviewed) that reported on the effectiveness of wildlife fencing designed for large mammals. We used search engines such as BIOSIS for peer-reviewed scientific articles, and we conducted internet searches (Google Scholar, Google) for gray literature. We specifically searched for effectiveness data that related to large ungulates including deer (e.g. *Odocoileus* spp.; *Capreolus capreolus*); elk (*Cervus* spp.) and moose (*Alces* spp.). Other search terms related to highways, infrastructure, mitigation measures, roads, wildlife fences, wildlife crossing structures, wildlife underpasses, and wildlife–vehicle collisions, crashes and carcasses. We only included data from road sections that had wildlife fencing on both sides of the highway. Many of the publications not only related to wildlife fences but also to crossing structures. We included data that related to fences and wildlife underpasses and overpasses. However, we excluded data from mitigated road sections with at-grade crossing opportunities (e.g. a gap in the fence on opposite sides of the highway) as these specifically allowed for the continued presence of animals on the roadway in a mitigated road section. The latter was not consistent with the objectives of our study.

The effectiveness of the fences and associated measures was sometimes based on wildlife–vehicle crash data (collected by law enforcement personnel). In other cases effectiveness was calculated based on carcass removal data (collected by road maintenance personnel or by employees of natural resource management agencies) or carcass observations (collected by researchers or the public). We included all effectiveness data, regardless of who had collected the data, unless we had reason to believe that the search and reporting effort was not constant for the road section(s) concerned (based on the description in the original publication). If multiple data sources for wildlife–vehicle collisions were reported for a road section we calculated the average of these data sources and used this value in our analyses rather than multiple values that related to the same mitigated highway section. If one overall value was reported for the effectiveness in the original publication we used this value in our analyses. However, if the wildlife–vehicle collision data (any source or combination of sources) showed an increase in collisions in the mitigated road sections rather than a decrease, the effectiveness value for the fence and associated measures was set at zero (i.e. no reduction in wildlife–vehicle collisions).

Data from studies that only reported on the combined effectiveness for different road sections of different lengths were excluded from the analyses as we could not tell what the effectiveness was of the individual fenced road sections. However, we applied one exception to this rule related to one publication (Clevenger et al., 2001). This paper reported on the combined effectiveness of three road sections, but each section was at least 10 km long. In this case we included one data point in our analyses and we assigned it to the shortest of the three road sections (10 km long).

When the data allowed, the potential reduction in wildlife–vehicle collisions was calculated based on a before–after–control–impact analysis (BACI) rather than only a before–after analysis (BA) or a control–impact analysis (CI) (Roedenbeck et al., 2007; van der Grift et al., 2013). In addition to the effectiveness data and the study design we also noted the length of the road section with wildlife fencing, fence height, target species, potential presence of fence-end and fence-gap treatments (including gates, cattle or wildlife guards, electric mats etc.), potential wildlife or multifunctional crossing structures (i.e. underpasses or overpasses), and escape opportunities from the fenced road corridor for wildlife (i.e. jump-outs, escape ramps, or one-way gates) (Appendix A). For examples of these measures see Clevenger and Huijser (2011), Huijser et al. (2015a) and Parker et al. (2008). Descriptions and characteristics of the mitigated highway sections were obtained from the original publications. In some cases additional information was obtained through communication with the authors or from satellite images.

2.2. Field studies: large mammal use of underpasses with no or very short fences

We conducted two field studies along highways in western Montana, USA to investigate if the length of wildlife fencing associated with wildlife underpasses influenced large mammal use of the underpasses. In the first field study we measured large mammal use of underpasses with no or very short fences and compared the use to that of underpasses that were associated with longer sections of wildlife fencing (up to a few kilometers). In the second field study we investigated whether longer fence lengths (up to a few hundred meters from an underpass) were associated with increased wildlife use of the underpasses and reduced wildlife crossings at fence ends.

For the first field study we selected 23 underpasses along US Hwy 93 North on the Flathead Indian Reservation (Appendix B). All underpasses had dimensions considered suitable for large mammals (Appendix B). The underpasses were constructed between 2005 and 2010 (median age at time of this research was 6 years). The fenced road length associated with the underpasses varied between 0.0 and 6.2 km (Appendix B), and fence height was 2.4 m. We placed wildlife cameras (Reconyx Hyperfire PC900) at the entrances of the 23 underpasses and kept them in operation for a full year (1 January 2013–31 December 2013) (Huijser et al., 2015b). For underpasses wider than 12 m we used multiple cameras as the maximum range of the cameras at night (with infrared flash IR flash) was about 12 m. We analyzed the images and counted the number of large mammals (deer (*Odocoileus* spp.)