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Factors Influencing Roadkill Hotspot in the Republic of Korea

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ABSTRACT

Road structures play an important role in collisions involving vehicles and wildlife. Our study aimed to determine the effect of various types of road structures on the risk associated with roadkill. We surveyed 50 previously identified roadkill hotspots, ranked from one to five according to roadkill density. We collected nine types of road structure data on each hotspot road section. Structures with similar characteristics were grouped together, resulting in five categories, namely, median barrier, high edge barrier, low edge barrier, speed, and visibility. We examined the existence of each road structure category at each hotspot rank. The cumulative link model showed that the absence of bottom blocked median barrier increased the roadkill hotspot rank. Our study concluded that a visual obstacle in the middle of roads by the median barrier decreases wildlife road crossing attempts and roadkill risk. We suggest that future roadkill mitigation plans should be established considering these characteristics.

Keywords: Korea roadkill observation system, Mammal, Roadkill hotspot, Road structure, Spatial analysis

Introduction

Since the majority of wildlife habitats are fragmented by linear structures, the occurrence of unwanted dangerous encounters that happen on roads worldwide is common. Roadkill is among the most significant threats of wildlife and humans safety. Annually, two million vertebrate and 600 thousand mammal roadkills are estimated to occur in the Republic of Korea (Choi, 2016), indicating the urgent need for roadkill mitigation plans for humans and wildlife.

Numerous factors make roads more prone to roadkills. Parameters linked to road composition, such as, road width, curvature, and structure, affect the spatial patterns of roadkills (Byun *et al*., 2016; Clevenger & Kociolek, 2013; Kim *et al*., 2019a). In particular, road structures that interfere with the behavior of wildlife, such as, road crossing, could be a critical factor in determining the spatial patterns of roadkills. For example, wildlife fencing is considered as one of the most effective roadkill mitigation measures, as it prevents wildlife from invading roads (Rytwinski *et al*., 2016). However, when fence length is not long enough, roadkill risk significantly increases at fence ends (Plante *et al*., 2019). Various types of fencing structures at the road edge, such as, rock fall fences or noise fences, have similar effects. On the other hand, obstacles with lower heights at road edges, such as, guard rails, do not significantly contribute to avoiding wildlife from invading roads (Byun *et al*., 2016).

When animals are already on the road other types of barriers can prevent them from crossing the road. For example, the median barriers reduce the permeability of roads to wildlife and the barrier effect increase roadkill risk (Clevenger & Kociolek, 2013). The median barrier may exhibit different effects depending on the body size of the animal and the structure or material of the barrier. in

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addition, visibility also influences roadkill (Collinson, 2013; Ignatavicius & Valskys, 2018; Kioko *et al*., 2015; Smith-Patten & Patten, 2008). Reduced visibility on roadways at night is considered dangerous to nocturnal wildlife (Braunstein, 1998). Therefore, understanding how these factors influence the spatial characteristics of roadkills is crucial when establishing mitigation plans (Kim *et al*., 2019a).

A total of 21,397 roadkills were collected from the Korea Roadkill Observation System (KROS) in the Republic of Korea in 2019 (Kim *et al*., 2019b). Based on these data, Song *et al*. (2020) analyzed 50 roadkill hotpots on national highways throughout the country using the kernel density estimate with 1 km search radius. Subsequently, the 50 hotspots were hierarchically divided into five categories, from rank one (low density) to five (high density) according to the z-value. In the present study, we surveyed the 50 roadkill hot spots previously identified by Song *et al*. (2020) and collected data on nine types of road structures which might influence roadkill risk. Our study aimed to identify road structures which might affect the risk of roadkills in order to suggest future roadkill mitigation plans in the Republic of Korea.

Materials and Methods

We surveyed the previously identified 50 roadkill hotspots which were ranked from one to five according to roadkill density from April to June 2020 (Fig. 1). Of the 50 hotspots, 4, 8, 8, 11, and 19 hotspots were ranked as one, two, three, four, and five, respectively. The average number of cases involving roadkill was 2.7, 4.1, 5.9, 13.2, and 23.1 cases per kilometer for rank one to five respectively (www.nie-ecobank.kr). We collected data on the presence and absence of eight types of road structures, namel y, median barrier, bottom blocked median barrier, guard rail, bottom blocked guard rail, rock fall fence, noise fence, light, and bridge. The data were classified into five categories according to their characteristics for statistical analyses (Table 1, Fig. 2).

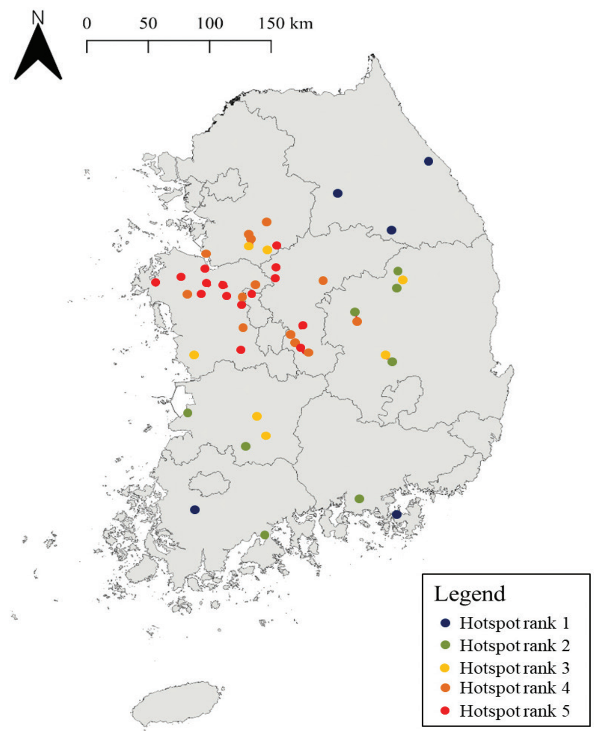

Fig. 1. Map of the study area. Five ranked road-kill hotspot are presented differently by each colour.

Table 1. Nine types of road structures and descriptions recorded from roadkill hotspot field survey

Category	Road structure	Abbreviation	Description
Median	Median barrier	MB	Longitudinal barrier that distinguish two side of traffic in the middle of roads
	Bottom blocked median barrier	MB_BB	
Edge_low	Guard rail	GR	Longitudinal barrier that keeps vehicles within the roads
	Bottom blocked guard rail	GR_BB	
Edge_high	Rock fall fence	RF	Longitudinal barrier that protects road by preventing rocks fall into road way
	Noise fence	NF	Longitudinal barrier to reduce noise produced from road way
Visibility	Light	LG	Keeps roadway bright when dark
Bridge	Bridge	BR	A structure built to span a physical obstacle without blocking the way underneath

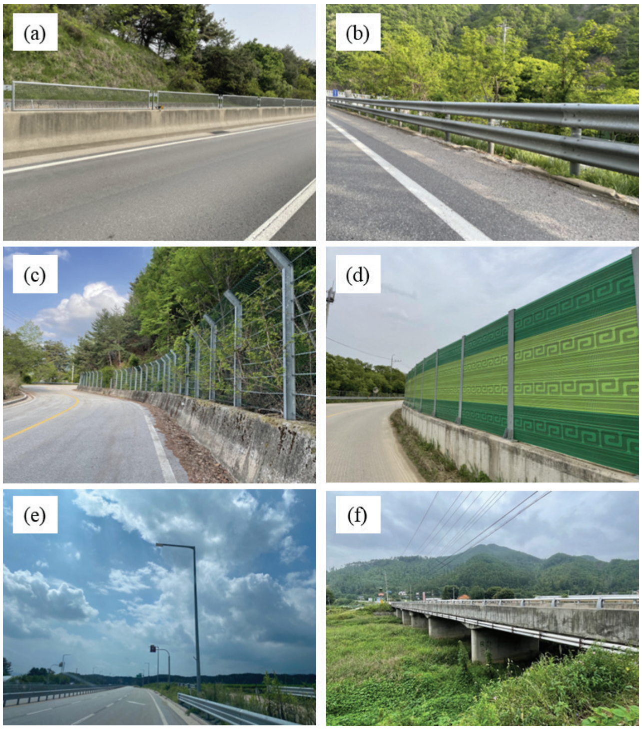

Fig. 2. Typical form of (a) bottom blocked median barrier, (b) bottom blocked guard rail, (c) rock fall fence (d) noise fence, (e) light and (f) bridge.

To investigate the effects of road structures on the probability of roadkills, we conducted a cumulative link model (CLM) using the function CLM from the ordinal package. We used the roadkill rank (one–five) as the variable response. Among the 50 roadkill hotspots, median barrier and guard rail were present in 46 and 48 sections, respectively and were therefore removed from the analysis due to low representation. To test the effects of barriers at the center and edge of the road, the presence of bottom blocked median barrier and bottom blocked guard rail were included in the model as predictors named 'median' and 'edge_low' (Table 1). We considered the presence of either noise fence or rock fall fence as a high barrier and included the presence of a high barrier (presence of noise fence or rock fall fence) in the model as the predictor named 'edge_high' (Table 1). Furthermore, we included light in the model as a predictor to test the effect of visibility-related structure named 'visibility' (Table 1). Finally, we included bridge in the model as a predictor named "bridge" to test how disconnection between road surface and surrounding landscape might influence roadkill rank (Table 1).

Results and Discussion

In general, 60 % of the roadkill hotspot rank one had bottom blocked median barrier, whereas the other ranks included a lower percentage (12.5 % in rank two, 14.3 % in rank three, 0 % in rank four, and 6.3% in rank five) (Table 2). When visually investigating the patterns between road structure sand roadkill ranks, bottom blocked guard rail was negatively correlated to roadkill hotspot rank (50 % in rank two, 28.6 % in rank three, and 14.3 % in rank four), but no bottom blocked guard rail was observed in ranks one and five (Table 2). The highest percentage of noise fence was observed in roadkill hotspot rank two (62.5 %) and the lowest percentage was found in rank three (14.3 %), without any positive or negative tendency. The percentage of rock fall fence was the highest in rank five (43.8 %) and the lowest in rank one (0 %). Light was the most frequently observed in rank three (42.9 %) and was the lowest in rank four (21.4 %). Finally, the percentage of hotspot rank with bridge was the highest in hotspot rank five (43.8 %), however, no particular tendency was observed (Table 2).

Table 2. Percentage of each road structure type on each roadkill hotspot rank. The number of each roadkill hotspot rank is 5 for rank 1, 8 for rank 2, 7 for rank 3, 14 for rank 4, and 16 for rank 5

	MB_BB (%)	GR_BB (%)	RF (%)	NF (%)	SC (%)	TL (%)	LG (%)	BR (%)
Rank 1	60.0	0.0	0.0	40.0	0.0	20.0	40.0	0.0
Rank 2	12.5	50.0	37.5	62.5	37.5	0.0	25.0	37.5
Rank 3	14.3	28.6	14.3	14.3	28.6	28.6	42.9	42.9
Rank 4	0.0	14.3	42.9	35.7	42.9	21.4	21.4	35.7
Rank 5	6.3	0.0	43.8	43.8	25.0	25.0	31.3	43.8
Average	18.6	18.6	27.7	39.3	26.8	19.0	32.1	32.0

The model for investigating the effects of road structures on roadkill rank was significant compared to the null model ($x2 = 12.416$, $df = 5$, $p = 0.029$). The roadkill rank was significantly ($p = 0.026$) higher in the absence of median category (Table 3, Fig. 3). No effect on the other parameters of the roadkill rank was observed (Table 3).

Table 3. The effects of road structures on the roadkill rank using cumulative link model

Parameter	Estimate	S.E	z value	P
Median (MB_BB)	-2.236	1.003	-2.229	0.026
Edge_low (GR_BB)	-1.112	0.742	-1.500	0.134
Edge_high (RF+NF)	-0.349	0.587	-0.594	0.552
Visibility (LG)	-0.321	0.598	-0.536	0.592
Bridge (BR)	1.095	0.608	1.800	0.072

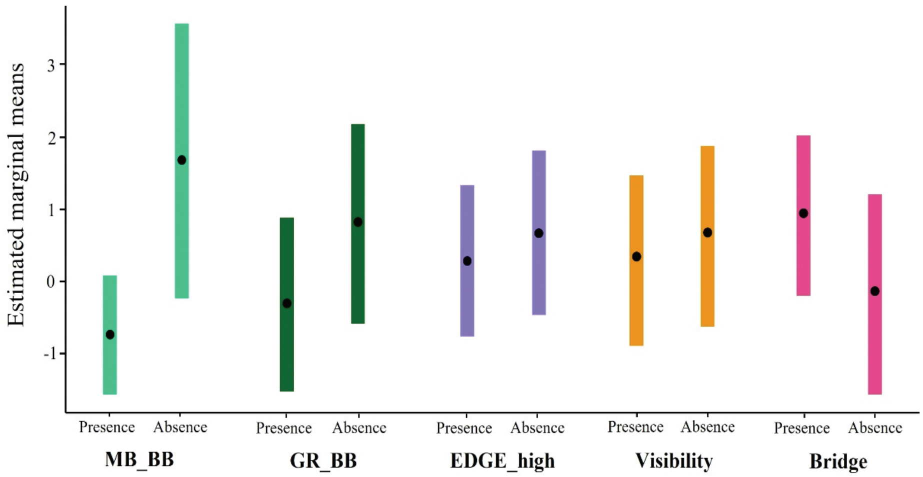

Fig. 3. Estimated marginal means depending on the absence/presence of MB_BB, GR_BB, EDGE_high, Visibility, and bridge. It indicates when the estimated marginal mean is higher, the road kill probability is higher. The bars indicate confident interval in 95%.

Although the model that contained all five road structure categories indicated significance, besides median, other parameters were not significantly affecting the roadkill rank. Similar to our result, other studies also have revealed that animals were less likely to cross roads when median barriers were present (Barnum, 2003; Gunson *et al*., 2011; Malo *et al*., 2004). In contrast, Clevenger and Kociolek (2013) concluded that low permeability due to median structures on roads increased the risk of roadkill. In the Republic of Korea, the standard size of the concrete median barrier is 140.6 cm (Kim *et al*., 2009). According to a previous study conducted by Park *et al*. (2018), the deterrence rate at a wildlife fence of 140 cm was 83.3 % with respect to water deer (Hydropotes inermis), which is the most frequent victim of roadkills in the Republic of Korea. Thus, the study concluded that median barrier decreased road crossing attempts by wildlife and roadkill risk.

Even though our result did not reveal the significant effect of bottom blocked guard rail, we reported a negative tendency of bottom blocked guard rail with respect to roadkill rank (Table 3, Fig. 3). Song *et al*. (2011) also reported that a two-layer guard rail with a height of 90 cm, referred to as bottom blocked guard rail in this study, was effective in preventing roadkills on an expressway. In contrast, Byun *et al*. (2016) concluded that the guard rail had little contribution in reducing roadkills. In addition, it was reported that, in the Republic of Korea, the deterrence rate of a fence below 100 cm was zero with respect to water deer (Park *et al*., 2018). Thus, there is need for more detailed study concerning the effect of guard rail or bottom blocked guard rail on roadkill mitigation. Furthermore, our result also showed that roadkill probability decreased in the presence of bridges (Table 3, Fig. 3). So far, many studies have been focusing on wild life crossings which connect both sides of fragmented habitats. These types of bridges help wild animals to avoid roadkills and enabled safe crossing of roads (Williams *et al*., 2019). Bridge disconnects road surface and surrounding landscape, thereby excluding wild animals from roads and lowering roadkill risk.

Our research showed that the existence of bottom blocked median barrier decreased roadkill risk. Spatial patterns of roadkill depends on various factors, such as, wildlife density, seasonality, and landscape change (Kim *et al*., 2019a; Saeki & Macdonald, 2004; Seo *et a*l., 2015). Thus, we believe that consistent monitoring and analysis are necessary to respond to the changes in roadkill hotspots. For further studies, we recommend researchers to investigate how road structures affect roadkill risk by comparing roadkill hotspots and coldspots, which refers to road sections with low roadkill density. In addition, quantitative analysis between the number of roadkills and the presence of road structures may also give an insight for management of roadkill mitigation plans.

Conflict of Interest

The authors declare that they have no competing interests.

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