Pakistan J. Zool., vol. 54(1), pp 347-352, 2022 DOI: https://dx.doi.org/10.17582/journal.pjz/20201130031155

Temporal Patterns and Hotspot Identification of Vehicle Collisions with the Roe Deer (*Capreolus pygargus*) on Jeju Island, South Korea

Seung-Yun Baek[1] and Seong-Min Lee[2]*

[1]*Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Fuchu, Tokyo, Japan*
[2]*Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul, Korea*

Article Information
Received 30 November 2020
Revised 11 December 2020
Accepted 16 December 2020
Available online 05 April 2021 (early access)
Published 16 December 2021

Authors' Contribution
S-YB and S-ML conceived this research. S-YB conducted the cluster analysis. S-ML conducted the statistical analysis. S-YB and S-ML wrote the first draft and contributed by revising the manuscript.

Key words
Deer-vehicle collisions, Hotspots, Capreolus pygargus, KDE+, Road ecology

ABSTRACT

Wildlife–vehicle collisions (WVCs) are increasing worldwide, posing a threat to both humans and wildlife in terms of human injury and loss of wildlife. Understanding the temporal and spatial non-randomness of WVCs is an essential process for effective WVC management. Roe deer (*Capreolus pygargus*) is the most prevalent wildlife species in WVCs on Jeju Island, South Korea. This study analyzed individual temporal patterns and spatial hotspots (clusters) based on roe deer–vehicle collisions (RDVC) on Jeju Island from 2014 to 2017. RDVCs occur frequently from July to October, and RDVCs are higher in male deer than with females in all seasons, except in winter. The clusters in the high-risk periods were more regionally distributed compared to the clusters in the low-risk periods. Regardless of the period, some road sections have been identified as crucial clusters that should be given priority for road fencing to mitigate human-deer conflicts. Our findings could also provide road administrators with practical options for management such as temporarily imposing vehicle speed limits and installing signboards.

INTRODUCTION

Wildlife–vehicle collisions (WVCs) are one of the most representative issues of wildlife–human conflict worldwide. WVCs lead to high socio-economic costs as they lead to vehicle damage, human injury, or death, as well as a decrease in wildlife (Putman *et al.*, 2004; Huijser *et al.*, 2008; Gren and Jägerbrand, 2019). In the United States, it is estimated that 26,000 human injuries, 200 human deaths, and a cost of more than 8 billion USD result from the 1–2 million WVCs per year (Huijser *et al.*, 2008). In Germany, approximately 200,000 the European roe deer (*Capreolus capreolus* Linnaeus, 1758) vehicle collisions result in 3,000 human injuries and 50 deaths, with a cost of 5 million euros (approximately 5.9 million USD) per year (Hothorn *et al.*, 2012). Various attempts have been made to reduce WVCs (Huijser *et al.*, 2009; Langbein *et al.*, 2011). Fencing is recognized as the most effective mitigation measure (Glista *et al.*, 2009). Fencing across the entire road acts as a physical barrier that limits wildlife movement (Jaeger and Fahrig, 2004), but it is also largely impossible due to financial constraints. Since WVCs occur non-randomly (Rodríguez-Morales *et al.*, 2013), understanding the temporal and spatial clustering of WVCs is a fundamental step in effective mitigation measures. Since WVCs are closely related to the behavior and activities of each species (Clevenger *et al.*, 2003; Pagany, 2020), there is generally an increased risk during the dispersal period and the rutting season (Haigh, 2012).

Deer–vehicle collisions (DVCs) are the most frequent type of WVC across Europe and the U.S. (Huijser *et al.*, 2008; Sjölund, 2016; Bartonička *et al.*, 2018). DVC from 2018 to 2019 and accounted for 52% of WVCs in South Korea from 2018 to 2019 (National Institute of Ecology, 2019). On Jeju Island, DVCs accounted for more than 90% of the WVCs (Jeju Special Self-Governing Province, 2018). As Jeju Island is one of South Korea's most popular tourist destinations, with more than 10 million tourists visiting each year, safety threats to tourists by DVCs have been raised to a serious level. The Siberian roe deer (*Capreolus pygargus* Pallas, 1771), the only medium-sized, herbivorous, mammalian species that currently inhabits Jeju Island, was an endangered species in the 1980s. However, its population size has increased due to consistent conservation actions, causing more than 200 crop damage cases per year on Jeju Island. Roe deer on Jeju Island has been reported to be morphologically, genetically, and ecologically different from roe deer in other regions (Oh, 2004; Park *et al.*, 2011; Lee *et al.*, 2015).

* Corresponding author: ecologist@naver.com
0030-9923/2022/0001-0347 $ 9.00/0

Therefore, it is necessary to collect field data on Jeju Island to ensure the safety of tourists and reduce roe deer–vehicle collisions (RDVCs). Thus, the purpose of this study was to identify individual temporal patterns and spatial hotspots (clusters) based on the period of RDVC occurrence risk by analyzing the RDVCs on Jeju Island, as well as to suggest efficient mitigation measures for RDVCs.

MATERIALS AND METHODS

Study area

Jeju Island (33°10′ N, 126°10′ E) is a volcanic island 85 km south of the Korean Peninsula. It is oval-shaped, with a total area of 1,850 km^2 has Mt. Halla in the center, and is 73 km east to west and 41 km north to south. Forests (35%), croplands (35%), and grasslands (19%) are the most common land cover types on the island (Fig. 1). The average annual temperature is 16.9°C, while the lowest is -1.6°C and the highest is 37.0°C. The climate varies from cold in winter to humid monsoon in summer. The average annual rainfall is 2,061 mm, with the highest (at least 200 mm) monthly precipitation in August and the lowest in December (Chang *et al*., 2019). Depending on the altitude, the vegetation there is classified as evergreen broad-leaved forest (e.g., *Quercus salicina, Q. glauca,* and *Castanopsis sieboldii*) from the coast to 600 m above sea level (a.s.l.), deciduous broadleaved forest (e.g., *Q. acutissima*, *Q. serrata*, and *Carpinus tschonoskii*) between 600 to 1,400 m a.s.l., and subalpine coniferous forest (e.g., *Abies koreana* and *Juniperus chinensis*) that accompanies scrubs (e.g., *Rhododendron mucronulatum* and *Empetrum nigrum* var. *japonicum*) between 1,400 and 1,950 m a.s.l. (Chung, 2007).

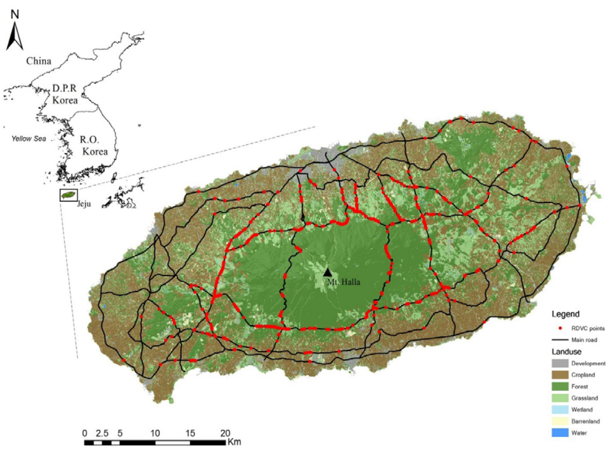

Fig. 1. Map of Jeju Island with roe deer vehicle collision (RDVC) locations (red points) on the main road (black line) between 2014 and 2017.

Roe deer vehicle collisions data

We used RDVC data recorded from January 2014 to December 2017 by the Jeju Wildlife Rescue Center and from January 2015 to December 2017 by the local government (i.e., Jeju City and Seogwipo City). The data from the Jeju Wildlife Rescue Center included collision dates, GPS coordinates, and individual information (i.e., sex of animal and age). The data of the local government included only information on the collision date and location, excluding the individual information, due to the absence of professional personnel. In the recorded data, the cases in which location information was incorrectly described were excluded from the spatial analysis.

Individual-temporal analysis

In the temporal study, a total of 1,324 RDVCs were divided by month to analyze the monthly patterns. Using data from the Jeju Wildlife Rescue Center, which included individual information (i.e., sex and age), a temporal analysis of the individuals was performed. For this, periods were defined by the four seasons: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). Individuals were assigned an age category of fawn or adult. Since the behavioral differences between the sexes of deer occur after the natal dispersal period (when the fawns become independent of the mother), fawns were excluded from the sex category (male = 70, female = 44). A two-way Chi–square test was performed to analyze the individual temporal patterns.

Identification of clusters

The KDE+ method (Bíl *et al*., 2013) was applied to identify clusters of RDVCs. The KDE+ method is a kernel density estimation method that estimates the probability density function of the underlying data using kernel functions and has been used in many studies to identify statistically significant, road cluster sections (Sjölund, 2016; Bartonička *et al*., 2018; Favilli *et al*., 2018). As the KDE+ method is affected by the length of each road, number of points on each road, and distance between points, only RDVC points (n = 720) that occurred on major roads were used for analysis, excluding points on discontinuous and short roads (Fig. 4). The clusters were identified by distinguishing between the high- and low-risk periods of RDVC occurrence.

RESULTS

Individual-temporal patterns

RDVCs occurred at an average of 118 times per month, and from July to October, they occurred higher than the average (Fig. 2). In addition, the frequency of RDVCs between the females and males in each season was different ($\chi^2 = 8.57$, df = 3, P = 0.036; Fig. 3). The frequency of RDVCs with males was the highest in autumn, with 20 cases (31%), and the lowest in winter, with 12 cases (19%). On the other hand, the frequency of RDVCs with females was the highest in winter, with 17 cases (39%), and the lowest in autumn, with 8 cases (18%). There was no difference ($\chi^2 = 5.97$, df = 3, P = 0.113) between the seasonal fawn and female RDVC frequencies, but there was a difference ($\chi^2 = 12.73$, df = 3, P = 0.005) between the seasonal fawn and male RDVC frequencies (Fig. 3).

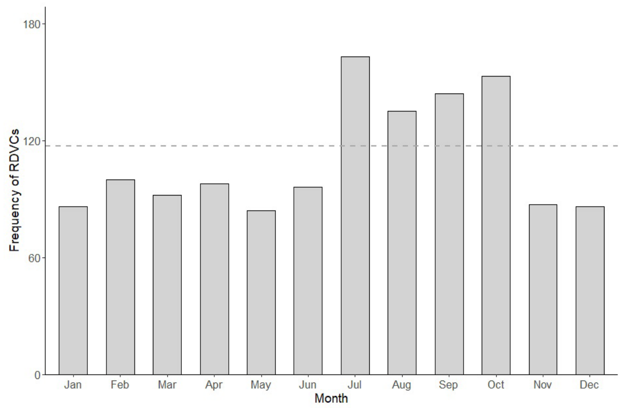

Fig. 2. Monthly pattern and annual average (dashed line) of roe deer vehicle collisions (RDVCs) on Jeju Island, South Korea between 2014 and 2017.

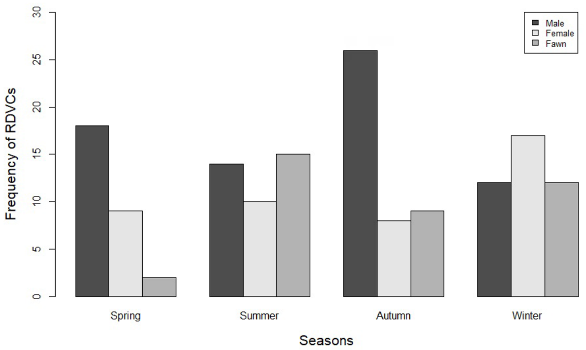

Fig. 3. Individual-temporal pattern of roe deer vehicle collisions (RDVCs) between 2014 and 2017.

Clustering of risk period

Eighty-two clusters (median: 157.8 m, range: 66 to 438 m) and 49 clusters (median: 155.1 m, range: 41 to 380 m) were identified for the high-risk period (HRP; summer–autumn) and low-risk period (LRP; winter–spring) of RDVC occurrence (Fig. 4). Although there was no difference between the size of each cluster in both the periods (Mann–Whitney test: U = 1936, P = 0.7302), the HRP had more clusters than the LRP and occurred over a wider region (Fig. 4). Some road sections had clusters in both the periods, which were mostly located around the northeast, north, and west side of Mt. Halla.

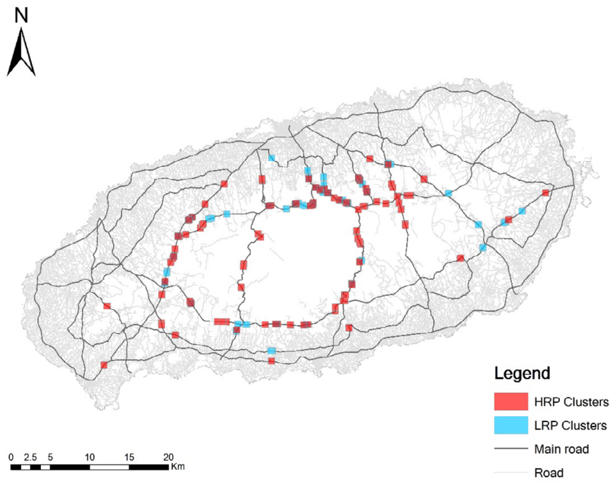

Fig. 4. Distribution of roe deer vehicle collision (RDVC) clusters generated using the KDE+ method with data from the main road. Red and blue quadrangles indicate high risk period (HRP) and low risk period (LRP), respectively.

DISCUSSION

In this study, RDVCs on Jeju Island varied based on the individuals involved and the period in which they occurred. The results also showed that spatial clusters of RDVC were generated according to risk period.

RDVC temporal pattern for individuals

RDVCs occurred most frequently between July and October, which included summer and autumn, and there were different temporal patterns, depending on sex and age. Male roe deer tend to establish and maintain their territory from spring to the rutting season, showing higher activity levels than females in the rutting season (Johansson, 1996; Oh, 2004; Pagon *et al*., 2017), as well as in other seasons, except for winter (Kämmerle *et al*., 2017). The relatively high RDVC occurrence in males appears to indicate a difference in these behaviors. In particular, RDVC occurrence was 3.25 higher in males than in females in the autumn, from September to October, when roe deer on Jeju Island were in the rutting season and males were mating while protecting their territory (Oh, 2004). These results are consistent with those shown in the vehicle collisions of European roe deer

(*Capreolus capreolus*; Vincent *et al*., 1988), white-tailed deer (*Odocoileus virginianus*; Allen and McCullough, 1976), and moose (*Alces alces*; Belant, 1995). July, the month with the highest frequency of RDVCs, is the period when fawns begin to move around with their mothers (Oh, 2004). Groot-Bruinderink and Hazbroek (1996) revealed that European roe deer had a high frequency of vehicle collisions in late spring and summer in relation to breeding and dispersion. Langbein and Putman (2006) described that the period when European roe deer mothers move with their fawns could expose them more to the threat of vehicle collisions, and according to Tufto *et al*. (1996), a lactating female travels longer distances than a non-lactating female to improve the nutrition of their milk. In addition, data from the Jeju Wildlife Rescue Center have shown that the number of RDVCs with fawns in summer is relatively high, accounting for 38% of the summer RDVCs, and that there is no significant difference between the frequency of seasonal collisions between adult females and fawns; therefore, the RDVCs during this period are likely to be affected by the activities of lactating females and fawns. Thus, our results indicate that RDVCs on Jeju may be affected by the temporal behavior of roe deer.

RDVC clusters

We identified RDVC clusters using the KDE+ method and demonstrated that clusters varied by risk period. WVCs are affected by species-specific factor (Clevenger *et al*., 2003; Gunson *et al*., 2011; Pagany, 2020) and deer behavior changes are driven by food availability, climate, and phenology (Morellet *et al*., 2009; Bischof *et al*., 2012).

We found that the RDVCs were affected by the periodic activity patterns of roe deer and were spatially clustered. The findings from our study can be used by policymakers or road administrators as a basis for cost-effective mitigation measures. As there is a temporal difference between the risk and clusters, it is expected that if preferential measures are taken for clusters during a period when the RDVCs occur at a higher frequency, the RDVCs can be effectively controlled. As some road sections have been identified as cluster sections regardless of the period, we suggest that these sections should be prioritized for road fencing. In addition, as WVCs are known to be affected by vehicle speed and volume, as well as by wildlife ecological factors (Seiler, 2005; Lao *et al*., 2011; Arevalo *et al*., 2017), the installation of temporary signs to alert drivers to risks (especially from July to October) and imposing vehicle speed limits are expected to mitigate RDVCs. Davenport and Davenport (2006) mention that WVCs are affected by complex interactions between animal ecology, transportation, and environmental factors. In the future study, more detailed and systematic approaches are needed that includes traffic and environmental factors that could not be analyzed in this study.

We conclude that spatio-temporal RDVCs and clustering related to ecological factors impact RDVCs roe deer conflict. The cluster road sections should be considered as a priority management strategy to effectively reduce RDVCs.

ACKNOWLEDGEMENTS

We are grateful to the Jeju Wildlife Rescue Center and Jeju-si City hall and Seogwipo-si City hall for their support data for this research project. We are also deeply grateful to Jirí Sedoník for his help in running the KDE+ cluster analysis.

Statement of conflict of interest

The authors have declared no conflict of interest.

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