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The Water Deer on a Road: Road-Kill Characteristics of a Nationally Abundant but Internationally Threatened Species

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Abstract

Despite numerous efforts on reducing road-kill worldwide, the collisions have been occurring continuously. Many factors are affecting road-kill occurrences and the effect is various by species. We investigated *Hydropotes inermis argyropus* road-kill characteristics on the national highway. We examined 9,099 *H. i. argyropus* road-kill points with distance to the gaps on road (interchange and intersection) and distance to six natural land-cover types as explanatory variables. We also examined the number of road-kill occurrences according to temporal variation using chi-square test with 9,658 events. In general, *H. i. argyropus* road-kill location tended to occur close to the gaps on road, agricultural lands and forests. The average distance from road-kill to the gap was 694.7 m and 78.6% of the collisions were occurred within 1 km from the gaps. In addition, Kruskal-Wallis test showed the distance between road-kill points and each land cover and the gaps was significantly different. The temporal analyses showed that the differences of the *H. i. argyropus* road-kill frequency are significant in both month and season. Our results implies *H. i. argyropus* road-kill location tended to occur close to the gaps on road, agricultural lands and forests in general, especially during May and June, according to their seasonal behavior. Thus, we suggest there is a need of concentrated management on the roads with specific characteristics for both wildlife and human safety.

Key Words: road-kill, water deer, wildlife mitigation measures, spatial analysis, road-kill observation system

Introduction

Road-kills cause critical threats to both wildlife and human safety. Many environmental factors such as distance between road and wildlife habitat, road characteristics and seasonal movement of wildlife is affecting to road-kill locations or hotspots (Clevenger et al. 2003; Hussain et al. 2007; Kim et al. 2019a). For example in the Republic of Korea, the endangered leopard cat (*Prionailurus bengalensis euptilura*) road-kill location was correlated with traffic volume, habitat connectivity, distance from ramps, elevation and distance from water (Kim et al. 2019a). However, since each species have different ecological patterns, the factors affecting to road-kill vary by species (Forman 2003; Kim et al. 2019a).

Road-kill frequency of ungulates is closely related to

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their population density in worldwide. For instance in USA, white-tailed deer (*Odocoileus virginianus*) road-kills increased with their abundance (Hubbard et al. 2000). In case of Denmark, roe deer (*Capreolus capreolus*) road-kill frequency also increased with their population abundance (Madsen et al. 2002). The water deer (*Hydropotes inermi argyropus*) is classified as vulnerable (VU) by IUCN Red List. However in the Republic of Korea, the species is designated as harmful wildlife since 1994 by the Ministry of Environment due to their large population and threats to human property such as farming. After the extinct of predators like big carnivores such as tigers, leopard, and wolves in the country, population density of *H. i. argyropus* increased rapidly. Comparing density of 0.4 individuals per 100 ha in 1971, the density has been increased more than 20 times in 2018 (8.2 individuals per 100 ha) (National Institute of Biological Resources 2018). In the Republic of Korea, *H. i. argyropus* inhabits in nationwide but most preferred habitat is agricultural lands around water source (Park and Lee 2013). According to Kim et al. (2019b), 44.8% victim of road-kill in the Republic of Korea from June 2018 to September 2019 was *H. i. argyropus*. The species is considered as one of the most dangerous species when road-kill has occurred by road management agencies because of their considerably big body size compared to other species in the Republic of Korea. Thus they are the most focal species on road-kill management or mitigation in all types of roads in the Republic of Korea.

Numerous road-kill mitigation measures have been studied worldwide, and so far, using the combination of wildlife crossing and fence alongside roads with enough length is considered the most efficient reducing road-kill frequency and connecting fragmented habitats (Rytwinski et al. 2016). Fences play an important role prohibiting wildlife to get into roads and thus prevent collision with vehicle. However, most of roads have gaps such as ramps or interchanges to be connected to other roads and forming road network. The gaps are where the fences cannot be installed due to traffic flow, and thus they can be used as entrances to wildlife to get into roads. According to road agencies where taking in charge of collecting road-kill data has argued that despite efforts to install road-kill mitigation measures such as fences, road-kills keep occurring around those gaps (Ministry of Land, Infrastructure and Transport and Korea Expressway Corporation, personal communication). Regardless of their importance, there is only handful research on the risk of gaps on roads to wildlife road-kill in the Republic of Korea. For instance, Kim et al. (2019a) resulted the road-kill risk on *Prionailurus bengalensis euptilrura* increased when ramps are farther away. Also, Byeon (2013) examined several species on expressway and concluded the mammalian road-kill frequency tends to increase around ramps. In this study, our aim is to understand spatial and temporal patterns of *H. i. argyropus* road-kills on national highway in the Republic of Korea for more efficient management plan on the most frequent and dangerous road-kill victim in the country.

Materials and Methods

Study area and data collection

We obtained *H. i. argyropus* road-kill locations by the Korea Road-kill Observation System (KROS; nie-ecobank.re.kr). The Korean government has launched the KROS in June 2018 to collect and manage national road-kill data (Kim et al. 2019b). We restricted data from Jan to Dec 2019 considering seasonal movement of *H. i. argyropus*. In addition, data analyses were conducted only for the accidents occurred on national highway due to data reliability. The total of 9,658 *H. i. argyropus* road-kill data points were collected on national highway through KROS in 2019. The national highway is considered as the most important road connecting most of cities in the country. The number of lane varies from two to above ten and annual average daily traffic (AADT) is 12,883 vehicles per day in all sections. The total length of National highway is 13,983 km in 2018 (Statistics Korea; kostat.go.kr).

The road network spatial data was provided by Ministry of Land, Infrastructure and Transport (nodelink.its.go.krm, accessed in 12th Nov, 2019). We extracted nodes (i.e. where speed of vehicles changes) and links (i.e. road between nodes) of the national highways. The node data contains intersection, start and end points of a bridge, overpass, road, underpass and tunnel, administration boundary, interchange and junction. Among them, we selected intersection (CODE=101) and interchange and junction (CODE=108), which can be used as entrances providing the "gaps" on roads for *H. i. argyropus*.

The land cover map was obtained by the Ministry of Environment (egis.me.go.kr, accessed in 10th Mar, 2020) with 30 m resolution. The land cover is categorized into seven; built-up areas, agricultural lands, forest, grasslands, wetlands, bare lands, and water (Table 1). Among them, six land covers that can provide natural habitats to *H. i. argyropus*, except built-up area, were applied for the spatial analyses.

Spatial analyses

To examine the spatial characteristics of *H. inerni* road-kill locations, we measured the Euclidean distance from each collision point to the gaps and six land cover types on the national highway using NNJoin plugin in QGIS Desktop. Among the whole dataset, 9,099 points were able to apply for spatial analyses due to the land cover map was not available for certain areas (Fig. 1). After the measurement, we used Kruskal-Wallis test in SPSS Statistic 21 to find the difference among each variable. In addition, a previous research has resulted that the daily movement of *H. i. argyropus* was 857±173 m (He et al. 2015). Thus, we divided the distance between each road-kill point and all spatial variables from 0 to 1 km by 100 m and compared the frequency that are included in each segment to find the general tendency of spatial patterns.

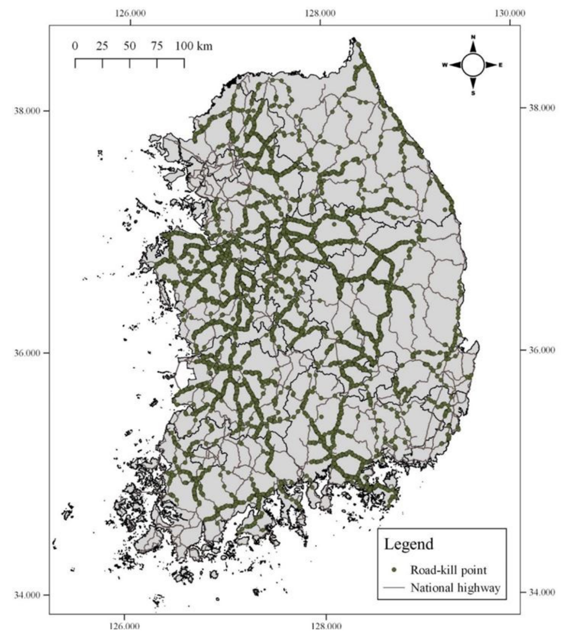

Fig. 1. Map of the study area. Green dots and black lines represent *Hydropotes Inermis* ar- gyropus road-kill points and the national highway respectively.

Table 1. Abbreviations and descriptions of six types of land cover

	Abbreviation	Description
Distance (m)	DA	Distance from agricultural lands
	DF	Distance from forest
	DG	Distance from grasslands
	DWL	Distance from wetlands
	DBL	Distance from bare lands
	DW	Distance from water

Temporal analyses

To figure out the seasonal pattern of *H. i. argyropus* road-kill, we conducted temporal analyses. Total of 9,658 road-kill events collected during Jan 1st to Dec 31st of 2019 were applied for seasonal analyses. We compared the number of road-kill events occurred in each month for understanding more specific temporal variation. Also, for comparing road-kill frequency for each season, we categorized into four seasons; spring (Mar to May), summer (Jun to Aug), fall (Sep to Nov), and winter (Dec to Feb). The road-kill frequency of each month and season were analyzed using Chi-squared test in SPSS Statistic 21.

Results

Spatial analyses

The average distance between *H. i. argyropus* road-kill point and the gap was 639.6 m and 79.6% of the collisions were occurred within 1 km from the gaps. Also, Kruskal-Wallis test showed the distance between road-kill points and each spatial variable (gaps and land covers) was sig-

Table 2. Result of the spatial analyses of *H. i. argyropus* road-kills on national highways

Variable	Mean (m)	SD
Distance from ramp	639.6	750.2
DA	24.8	102.0
DF	65.2	137.7
DG	218.2	522.1
DWL	3,039.7	4,620.6
DBL	263.5	441.1
DW	1060.9	1060.3

nificantly different (χ^2=35361.956, df=6, p < 0.01). The mean distance between each point and each land cover was the closest with agricultural land (24.8 m), followed by forest (65.2 m), grassland (218.2 m), bare land (263.5 m), water (1060.9 m) and wetland (3,039.7 m) (Table 2, Fig. 2). Also, the number of each spatial variable within 1 km in each 100 m segment around road-kill points was greatly varied (Fig. 2). Of the all 9,099 cases examined, 99.9% of agricultural lands, 99.6% of forests, 94.7% of grasslands, 46.9% of wetlands, 95.1% of bare land, and 60.9% of water were included 1 km around road-kill points.

Temporal analyses

The number of *H. i. argyropus* road-kill peaked in May (2,189 cases, 22.67%) followed by June (1,904 cases, 19.71%), whereas lowest in March (276 cases, 2.86%) and Feb (279 cases, 2.89%). By categorizing the month into season, spring was the most frequent (3,400 cases, 35.20%) followed by summer (3,338 cases, 34.56%), fall (1,754 cases, 18.16%) and winter (1,166 cases, 12.07%). The chi-squared test results showed the differences of the *H. i. argyropus* road-kill frequency are significant in both month (χ^2=5188.962, *df*=11, p < 0.001) and season (χ^2=1580.414, *df*=3, p < 0.001) (Table 3, Fig. 3)

Discussion

Our results yielded spatial and temporal patterns of *H. i. argyropus* road-kills in the Republic of Korea. The gaps on roads such as interchanges and ramps have been pointed

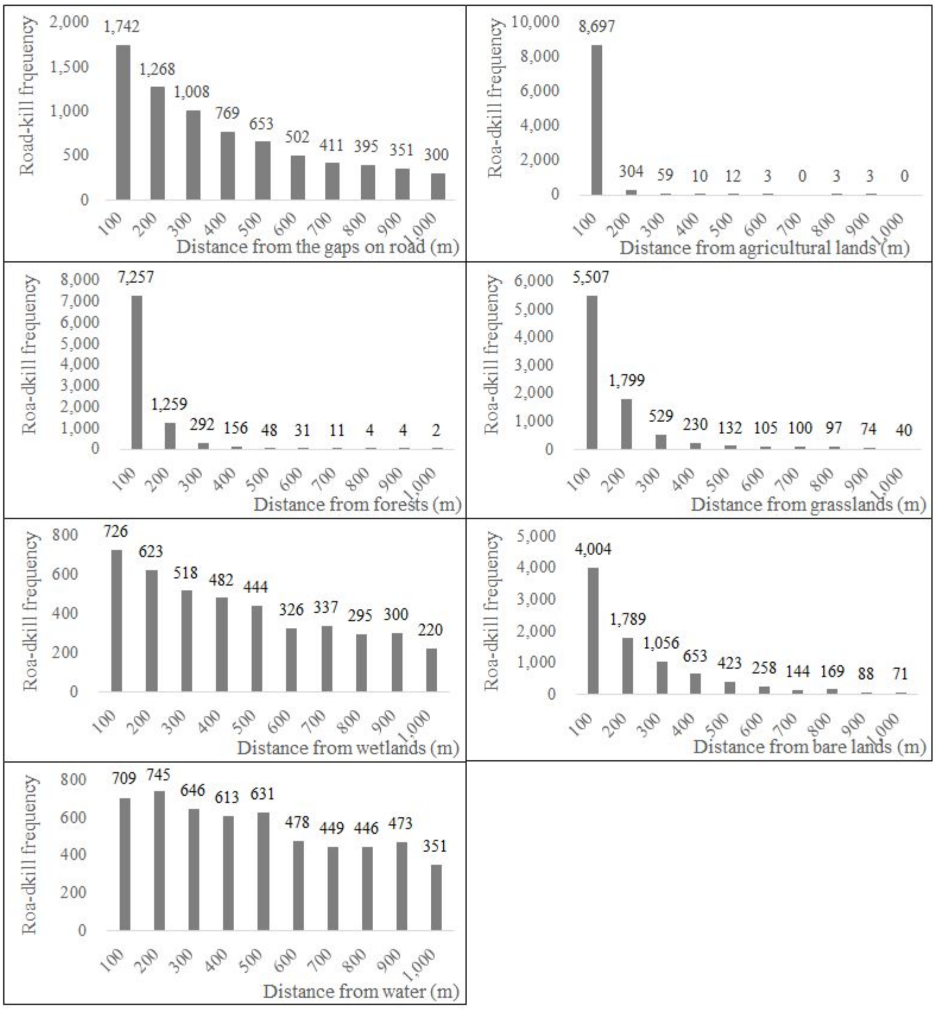

Fig. 2. The graphs shows the *H. i. argyropus* road-kill frequencies according to distance from (a) the gaps on road, (b) agricultural land, (c) forest, (d) grassland, (e) wetland, (f) bare land and (g) water for each 100-m segment (n=9,099).

out that they may play a role as entrances to get into a road for wildlife (Cserkész et al. 2013). Our result also in line with the previous argument. In this study, among the divided segments, the gaps were most frequently located within 100 m from *H. i. argyropus* road-kills compared to the other segments. This result implies that there is a need of robust management on the gaps to reduce road-kills. Deer grating (i.e. deer guard, wildlife guard and deer exclusion grates) can be a solution for managing the gaps. Previous studies have revealed that deer grating has up to 99.5% efficient to exclusion of ungulate from road (Peterson et al. 2003; Allen et al. 2013). Thus, developing a deer grating specialized for *H. i. argyropus* can be a good solution to prevent road-kill in the Republic of Korea.

Our results on land cover analyses support that *H. i. argyropus* road-kill is closely located to their most preferred habitat, agricultural lands and forests. An interesting point here is that although *H. i. argyropus* is known as a water-friendly species usually inhabiting around water source, especially within 1.6 km from water (Choi and Lee 2019), our land cover analyses result showed different pattern of their usual habitat use. The mean distance between collision points and natural water source was considerably farther then other land-cover types, containing only 60.9% water within 1 km. However, other studies on *H. i. argyropus* road-kill also showed relatively low proportion of water source around collision points (Choi 2007; Byeon 2013) although the pattern was not consistent. We suspect agricultural lands such as rice paddies supply sufficient water to *H. i. argyropus* and thus, the distance between collision point and water may not expectedly close. The farther each land cover types, except water, *H. i. argyropus* road-kill frequency tended to decrease. This pattern was more obvious in agricultural lands, forest, and grasslands, where are considered as general habitats of *H. i. argyropus*.

Road-kill frequency usually affected by seasonal move-

Table 3. Descriptive statistic result of *H. i. argyropus* road-kills on national highways (n=9,658)

Month	Frequency	Ratio (%)	Season	Frequency	Ratio (%)
Dec	449	4.65	Winter	1,166	12.07
Jan	438	4.54			
Feb	279	2.89			
Mar	276	2.86	Spring	3,400	35.20
Apr	935	9.68			
May	2,189	22.67			
Jun	1,904	19.71	Summer	3,388	34.56
July	828	8.57			
Aug	606	6.27			
Sep	445	4.61	Fall	1,754	18.16
Oct	694	7.19			
Nov	615	6.37			

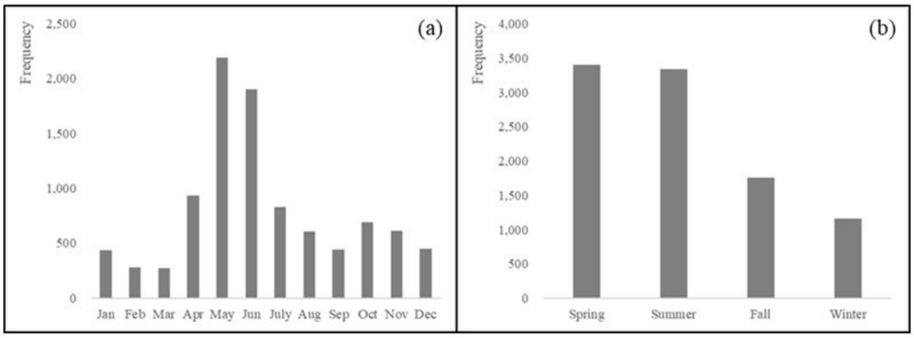

Fig. 3. Road-kill frequency by each (a) month and season.

ment of animals. The previous study conducted in the Republic of Korea on the endangered *Prionailurus bengalensis euptilrura* road-kills also have resulted the significant difference in road-kill frequency across seasons according to their dispersion and mating activity (Kim et al. 2019a). In this study, we found a significant difference in the number of *H. i. argyropus* road-kills in both month and season. The peak in May and June can be explained as their dispersion season. Other studies on *H. i. argyropus* showed similar seasonal pattern (Choi 2007; Byeon 2013; Kang et al. 2016). A study on reproduction behavior of *H. i. argyropus* suggested that they May and June in temperate region are the month of birth (Cooke and Farrell 1998). Also, in a previous research by Choi (2016b) which examined *H. i. argyropus* road-kill data collected from Chungnam Wildlife Rescue Center, showed the same pattern and resulted that 76.2% of the victims in May and June are juveniles which are inexperienced about the danger of roads.

Reducing road-kills by developing various mitigation plans and measures is not only for the wildlife, but also for human safety and social cost reduction. Although our research examined nearly 10,000 road-kill cases occurred in national highway, Choi (2016a), has resulted the annual *H. i. argyropus* road-kill in total roads is estimated 60,000 at least. Our results imply that *H. i. argyropus* road-kills have their distinctive patterns and planning on species-specialized action is necessary focused on their characteristics for both biodiversity and human.

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References

Allen TDH, Huijser MP, Willey DW. 2013. Effectiveness of wildlife guards at access roads. Wildl Soc Bull 37: 402-408.

Biological Resources Research Department, National Institute of Biological Resources. 2018. 2018 Wildlife Survey. National Institute of Biological Resources, Incheon.

Byeon Y. 2013. An Analysis of Wildlife Roadkill Based on Land Cover and Node Type in Korea Expressway. MS thesis. Ewha Womans University, Seoul, Korea. (in Korean)

Choi J, Lee S. 2019. Application of Habitat Evaluation Procedure with Quantifying the Eco-Corridor in the Process of Environmental Impact Assessment. Int J Environ Res Public Health 16: 1437.

Choi TY. 2007. Road-kill mitigation strategies for mammals in Korea: data based on surveys of road-kill, non-wildlife passage use, and home-range. Doctoral dissertation. Seoul National University, Seoul, Korea. (in Korean)

Choi TY. 2016a. Estimation of the Water deer (*Hydropotes inermis*) Roadkill Frequency in South Korea. Ecol Resil Infrastruct 3: 162-168.

Choi TY. 2016b. Wildlife on the Roads. National Institute of Ecology, Seocheon.

Clevenger AP, Chruszcz B, Gunson KE. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biol Conserv 109: 15-26.

Cooke A, Farrell L. 1998. Chinese Water Deer. Mammal Society, London.

Cserkész T, Ottlecz B, Cserkész-Nagy Á, Farkas J. 2013. Interchange as the main factor determining wildlife-vehicle collision hotspots on the fenced highways: spatial analysis and applications. Eur J Wildl Res 59: 587-597.

Forman RTT, Sperling D, Bissonette JA, Clevenger AP, Cutshall CD, Dale VH, Fahrig L, France R, Goldman CR, Heanue K, Jones JA, Swanson FJ, Turrentine T, Winter TC. 2003. Road Ecology: Science and Solutions. Island Press, Washington, DC.

He X, Chen M, Zhang E. 2015. Dispersal of reintroduced Chinese water deer after release in Nanhui East Shoal Wildlife Sanctuary of Shanghai, China. Italian J Zool 82: 582-591.

Hubbard MW, Danielson BJ, Schmitz RA. 2000. Factors Influencing the Location of Deer-Vehicle Accidents in Iowa. J Wildl Manag 64: 707-713.

Hussain A, Armstrong JB, Brown DB, Hogland J. 2007. Land-use pattern, urbanization, and deer-vehicle collisions in Alabama. Hum Wildl Confl 1: 89-96.

Kang WG, Lee JW, Jang JH, Lee JC, Oh DJ, Moon SI, Kim DS, Kwon HY, Kim HY, Kim OJ. 2016. Study on wildlife roadkills on highways in Jeollabuk-do. J Korean Assoc Anim Assist Psychother 5: 59-65.

Kim K, Serret H, Clauzel C, Andersen D, Jang Y. 2019a. Spatio-temporal characteristics and predictions of the endangered leopard cat Prionailirus bengalensis euptilura road-kills in the Republic of Korea. Glob Ecol Conserv 19: e00673.

Kim K, Woo D, Seo H, Park T, Song E, Choi T. 2019b. Korea Road-Kill Observation System: The First Case to Integrate Road-Kill Data in National Scale by Government. J For Environ Sci 35: 281-284.

Madsen AB, Strandgaard H, Prang A. 2002. Factors causing traffic killings of roe deer Capreolus capreolus in Denmark. Wildl Biol 8: 55-61.

Park H, Lee S. 2013. Habitat Use Pattern of Korean Waterdeer based on the Land Coverage Map. J Wetl Res 15: 567-572.
Peterson MN, Lopez RP, Silvy NJ, Owen CB, Frank PA, Braden AW. 2003. Evaluation of deer-exclusion grates in urban areas. Wildl Soc Bull 31: 1198-1204.
Rytwinski T, Soanes K, Jaeger JA, Fahrig L, Findlay CS, Houlahan J, van der Ree R, van der Grift EA. 2016. How Effective Is Road Mitigation at Reducing Road-Kill? A Meta-Analysis. PLoS One 11: e0166941.