Title
Wildlife Vehicle Collision be Decreased by Increasing the Number of Wildlife Passages in Korea?

Authors
Choi, Tae-Young
Park, Chong-Hwa

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Can Wildlife Vehicle Collision be Decreased by Increasing the Number of Wildlife Passages in Korea?

Tae-Young Choi (82-17-615-1277, gumiran3@snu.ac.kr), Researcher, Environmental Planning Institute, and
Chong-Hwa Park, Graduate School of Environmental Studies, Seoul National University, San 56-1, Sillimdong, Gwanakgu, Seoul 151-742 Korea

Abstract: The mitigation of fragmentation due to high density road network has been a hot topic among environmentalists and road construction engineers of South Korea. Over the last ten years 92 wildlife passages, 55 ecoducts and 37 wildlife underpasses, have been constructed on existing roads, and many more will be constructed in the future (Ministry of Environment of the Republic of Korea, 2006). We are at an early stage of data collection on wildlife vehicle collision and the role of traditionally non-wildlife-engineered passages, such as underpasses including bridges, culverts, and human underpasses, for wildlife passages.

The objective of this study was to analyze the effectiveness of the number, size, and density of non-wildlife-engineered passages. This study employed three monitoring methods: wildlife vehicle collisions, the passages use ratio (Servheen, 2003) and radio telemetry. The effectiveness of such unintended wildlife passage was evaluated by using the relationship between monthly wildlife vehicle collision data, number of usable passages, use rate of passages, and passage density.

The number of usable passages represents all crossing structures after excluding those inundated circular culverts during summer season, since they are impassable for most wildlife species. The use rates of wildlife passages were collected from 14 underpasses. They were seven circular culverts, two box culverts, and four human underpasses, and were selected from 31 structures constructed on a 6.6km segment of a four-lane highway. The landscape of study area mainly consists of rice fields on an alluvial plane and scattered forest, and the road runs along the stream. Every passage has similar surroundings. Wildlife monitoring was carried out for 12 months, from Sept. 2005 to Aug. 2006; using camera traps (an average of 239 camera operating days). The number of recorded mammals was 2,593, consisting of 13 species. We also documented 93 mammal vehicle collisions comprising 12 species by monitoring the same road daily over a period of two years (Sept. 2004-Aug. 2006).

The results of our analysis are as follows. First, the use rate of passages and the number of mammal vehicle collisions showed a positive correlation ($r=0.890$). Second, the fluctuation of the number of usable passages and collisions had no correlation ($r=0.402$). Third, the density of passages and collisions had a very weak positive correlation ($r=0.559$, $p<0.093$). Fourth, the use rate of box-type passages did not increase when pipe-type culverts were blocked by water inundation ($p=0.561>\alpha=0.05$). These results differed from following common expectations: higher numbers and use ratings of passages could cause less frequent collisions, high density areas of passage would cause fewer collisions, and the decreased number of passages would increase the use ratings of remaining passages. Fifth, most monitored mammal species with small-to-medium body sizes used all types of passage structures frequently, but water deer (Hydropotes inermis) rarely used these passage structures of under 0.7 on the openness index. Last, we found by radio telemetry that only one out of 13 radio-collared raccoon dogs was killed by vehicle `collision over a two-year period. However, a total of 12 raccoon dogs that had been killed by cars were found on the same road during the same period.

The results of our research can be summarized as follows. First, there were already enough usable passages for wildlife, in spite of seasonal blockage of some passages or the uneven spacing between passages. Second, there were many occurrences of wildlife vehicle collisions, but settlers showed relatively low collision ratio. Third, most collision victims might be wanderers or newcomers unfamiliar to existing passages or occupying settlers. Finally, water deer should be the target species for the construction of wildlife passages, and the size should be O.I of over 0.7. Vehicle collision of other mammal species can be reduced significantly by installing wildlife fences without worsening habitat fragmentation in the case of roads that have many non-wildlife-engineered passages.

Introduction

Installing wildlife passages and fences around roads in order to reduce wildlife roadkills and habitat fragmentation is the most pro-active and effective as well as most costly method in and outside of Korea. However, studies on the true extent to which roadkills and habitat fragmentation can be mitigated by installing costly wildlife passages in addition to fences, are in reality insufficient.

Meanwhile in the construction process of roads, countless culverts and passageways are created underneath roads to enable thoroughfare of water and humans, and not wildlife. In recent years, some countries have been active in their efforts to increase the potential and efficiency of the use of such structures as wildlife passages (Clevenger et al, 2001; Brudin, 2003; Lapoint et al, 2003; Donaldson, 2005; Mata et al, 2005). Especially in Korea, as a country with many mountainous areas and the world's 3rd highest population density, the structural characteristics of roads mean that crossing structures such as tunnels, viaducts, culverts, underpasses and overpasses are much more common compared to other countries. Given this context, an analysis of the potential for these structures to serve as wildlife passages will provide important foundational data for Korea's plans for building wildlife passages.

The goals of this study are therefore as follows. The first goal is to understand the potential of the crossing structures of roads, to serve as wildlife passage systems. Secondly, this study aims to analyze the changes each month, within a given area, in the number of passages that can be used, according to changes in the volume of water flow through culverts, and to analyze the resulting changes in the rate of use of passages by wildlife as well as in the number of roadkills that occur. Thirdly, this study analyzes the relationship between the concentration of passages and the frequency of roadkills. Finally, based on all of the above results, this study aims to present the factors that should be considered when establishing measures to prevent roadkills and habitat fragmentation that are suited to the realities in Korea.

Methods

Survey of Roadkills and Crossing Structures

Roadkills were examined once each day using vehicles, and after recording positional data using the GPS, and removing the carcass from the road, spray paint was used to mark the spot on the road where the body was found, to make sure that the carcass would not be accidentally recounted later on. Furthermore, roadkills were surveyed in the same areas where studies were being conducted on wildlife use of road crossing structures, in order to increase the consistency between these two sets of collected data.

For the survey of underpass structures that could potentially be used as wildlife passage systems, circular culverts about 1m in diameter were monitored by installing infra-red-operated 35mm camera in the ceilings, 1~2m into the entrances. In the case of box culverts and passageway boxes, the cameras were installed in the walls or ceilings of their central sections, and where the ranges of the sensor and of the lens did not cover the entire passageway, two cameras were installed on each opposite wall. Cameras were installed in a total of 14 structures, and the types and characteristics of the structures in which cameras were installed are as shown in [table 1].

The camera sensors were programmed so that after taking a picture, the cameras would not photograph again for the next minute at the minimum, in order to eliminate the possibility of an animal being photographed repeatedly at once. The cameras thus installed were inspected once a week on average, during which time their films were replaced.

Table 1: Types of underpass in study area

Type	Purpose	Dimension	Count of passage	Usable passage	monitored passage	Material of bottom
Box	human	2~4.3 m span by 2~4.3 m rise (6.6'~14.1×6.6'~14.1')	11	11	5	concrete
Box	culvert	2.5 m span by 2.5m rise (8.2' x 8.2')	5	2	2	concrete
Circular	culvert	0.8~1.2 m in diameter (2.6'~3.9')	19	13	7	Concrete or steel
Bridge	stream	7~260 m span (23.0'~853.0')	5	5	0	Soil and stream
Total	-	-	40	31	14	-

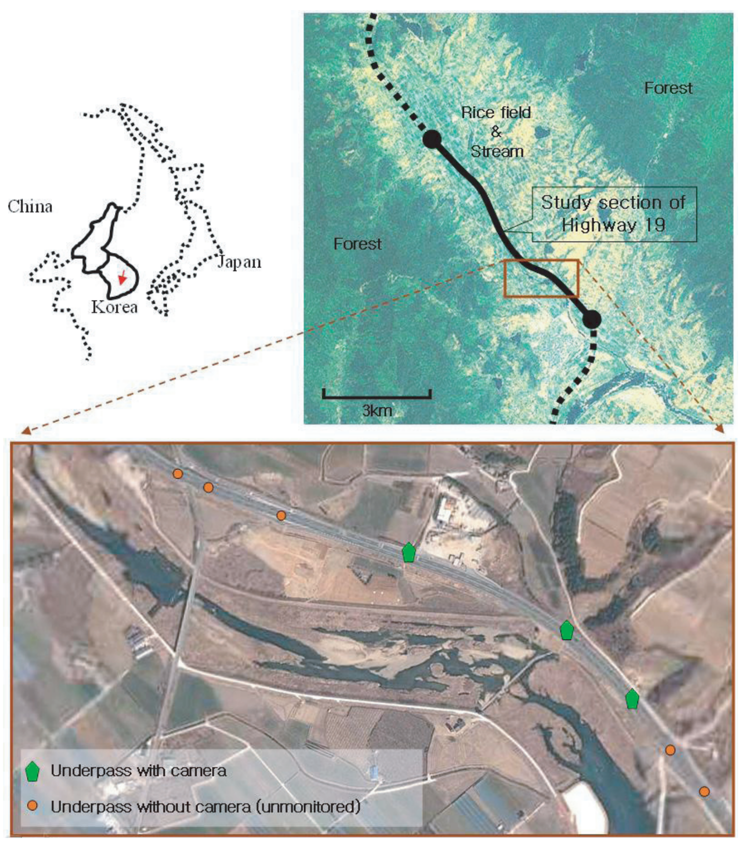

Figure 1. Location of study area and Highway 19 in Gurye county, Korea.

Figure 2. Box passageway

Figure 3. Box culvert

Figure 4. Circular culvert (waved steel pipe)

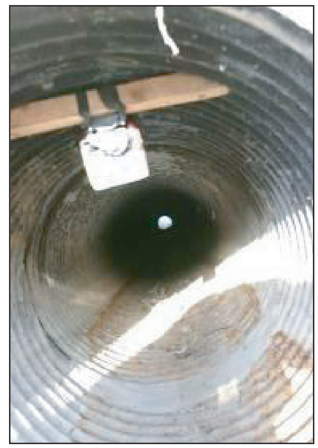

Figure 5. Installed camera in circular culvert

Study Area and Survey Period

The area surveyed was the 4-lane highway 19, in Gurye county in the Jeollanamdo province, a 6.6 km section along the Seosi stream in Gurye-eup that was completed in 1995. As part of a preliminary study, a roadkill survey was conducted on a 30 km section of the said highway for 1 year, beginning in September 2004. At the end of this period, a section was selected where roadkills occurred frequently, and where the types of habitat in the vicinity of the highway were similar. The selected 6.6 km section is adjacent to the Jirisan National Park. Most of the lands to the east of the highway are rice fields, with a few towns and forests; to the west the Seosi river flows along the highway, and in the areas between the highway and the watercourse, riparian vegetation such as reed grass predominate. Results from the on-site survey of the 6.6 km section showed that a total of 40 crossing structures existed, and that in 9 of these structures, entrances were either blocked, or deep pools of water were always present, making animal movement physically difficult. Therefore out of the 31 structures that animals could use, monitoring was carried out on 14 structures, after taking into consideration, factors such as the interval distances between structures, availability for use by wildlife, and potential for camera theft. The survey of passages using camera trap took place from September 2005 until August 2006, and the survey of roadkills was carried out from September 2004 until August 2006.

Radio-telemetry

In order to understand the effects of the roadkills that occurred within the reference survey section on wildlife populations, and to identify the characteristics of the wildlife being killed, 13 raccoon dogs were captured within 100m of the highway, between October 2004 until May 2005, and VHF radio-collars were worn on their neck. Appearances of these collared animals were recorded during surveys of camera traps and roadkills.

Methods of Analysis

The structures that served as circular culverts functioned as agricultural water channels between April and September, thus making animal movement physically impossible during those times. Therefore the counts between the usable number of crossing structures per month, and the number of roadkills occurring per month were compared to analyze the relationship between the seasonal fluctuations in the number of crossing structures and roadkill incidence.

In addition, changes in the frequency of roadkills according to fluctuations in the rate of use of crossing structures per month were examined, and analysis was also carried out on whether or not during periods when usage of some of the passages became impossible, use rates of other passages increased. Use rate here refers to the figure obtained after dividing the total number of confirmed movements, with the total number of days surveyed, and it represents how many movements take place in a given passageway per day (Servheen, 2003).

In order to analyze spatial pattern of roadkills as the density of passages increase, the point density (Silverman, 1986) module of the ArcGIS (ESRI Inc.) software was used to classify the density of passages for the given highway. Here, the buffer range for each passage was selected as 500m, and this was because the home range of the raccoon, for which the most data was collected in this study, was an average of 0.8 km^2 (Choi and Park, 2006) which in linear terms means a movement distance of about 1km.

Correlation analysis between passages-specific factors such as counts, use rate, and density, and roadkill-specific factors such as frequency and density was conducted to obtain Pearson correlation coefficients. Wilcoxon tests were performed for the investigation on whether during periods when some of the passages could not be used, use rates for other passages increased. SPSS 10.0(SPSS Inc., 2000) was used for statistical analyses.

Figure 6. Raccoon dog at dry season.

Figure 7. Inundated circular culvert.

Results

Survey Results for Crossing Structures and Wildlife Roadkills

For 1 year, surveys using infra-red-operated cameras were carried out on a total of 14 underpasses, for an average of 239 days each; in the case of mammals 2,593 movement cases were photographed for 13 species. Additionally, within the same section, over a period of 2 years, 93 mammalian roadkill incidents were discovered for 12 species (fig. 10).

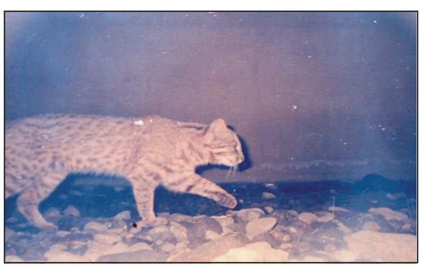

Figure 8. Leopard cat in box culvert.

Figure 9. Eurasian otter in circular culvert.

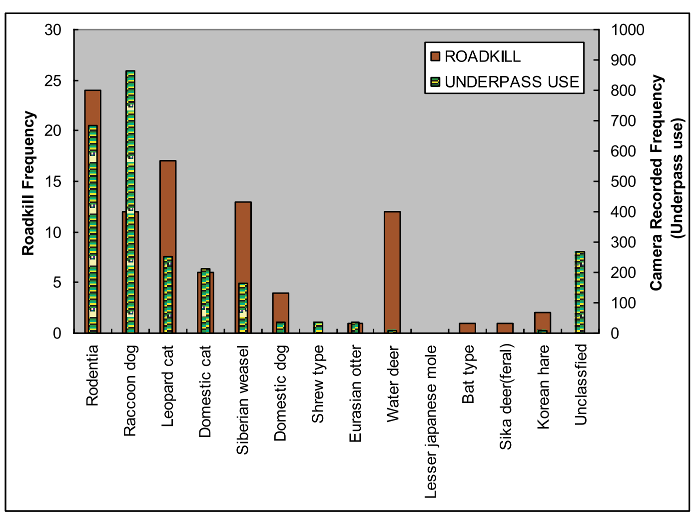

Figure 10. The frequencies of roadkill and underpass use by mammal species.

Out of total underpass movements, raccoon dogs (*Nyctereutes procyonoides*) were most frequently photographed 865 times (33.4% of total photography) and the next most frequent was the brown rat (*Rattus norvegicus*), which was photographed 455 times, accounting for 17.6% of total photography. Instances when the camera sensor detected animal movement but the flash failed to go off, or when the animal was outside of the camera's recording range and so the species could not be identified, accounted for 10.3% of total photography, or 268 photographs. Meanwhile movements of water deer (*Hydropotes inermis*) were confirmed on only 32 occasions (1.23%) and so it seemed reasonable to infer that the deer had an aversion to the crossing structures currently in place.

The species identified during roadkill surveys were: brown rats, which at 20 bodies comprised 21.5% of the total number of roadkills; wildcats, occupying 18.3% with 17 bodies; and water deer which made up 12.9% with 12 bodies (fig. 10). Therefore, compared to their highway mortalities, the water deer showed extremely low rates of use of passages, which suggests that they may be highly vulnerable to roadkills and habitat fragmentation. Leopard cats (*Prionailurus benalensis*) also showed tendencies similar to yet weaker than, those of the water deer, and therefore they were expected to be relatively vulnerable to roadkills (fig. 10).

Table 2: The results of infra-red-operated camera monitoring on 14 underpasses in study area

Structure ID	Type	Material	Measurement	Openness Index [c]	Duration Days (Functional Camera Days)	Unusable Days (Inundated Days)	Usable Days	Mammal species [a]: Rodents [b] (*Rodentia*)	Water deer (*Hydropotes inermis*)	Domestic cat (*Felis silvestris*)	Raccoon dog (*Nyctereutes procyonoides*)	Korean hare (*Lepus coreanus*)	Leopard cat (*Prionailurus benalensis*)	Eurasian otter (*Lutra lutra*)	Siberian weasel (*Mustela sibirica*)	Total	Use rate [d] of Duration days	Use rate of Usable days
3	Circular culvert	Ferroconcrete	D: 1.2m (3.9')	0.033	311	135	176	24	0	16	0	0	14	2	8	64	0.21	0.36
4	Box passageway	Ferroconcrete	3.5m span by 3.5m rise (11.5'?11.5')	0.438	69	0	69	2	0	38	30	0	2	0	0	72	1.04	1.04
11	Circular culvert	Ferroconcrete	D: 1.2m (3.9')	0.035	301	105	196	26	0	53	13	0	57	2	11	158	0.52	0.81
12	Circular culvert	Waved steel pipe	D: 0.8m (2.6')	0.018	262	165	97	16	0	36	65	0	20	7	9	153	0.58	1.58
15	Box passageway	Waved steel pipe	3.0m span by 3.0m rise (9.8'?9.8')	0.310	259	0	259	0	0	32	53	0	2	0	0	86	0.33	0.33
20	Box culvert	Ferroconcrete	2.5m span by 2.5m rise (8.2'?8.2')	0.100	184	30	154	0	0	0	52	0	24	11	2	89	0.48	0.58
21	Box culvert	Ferroconcrete	2.5m span by 2.5m rise (8.2'?8.2')	0.100	230	180	50	1	0	0	25	0	6	6	2	41	0.18	0.82
22	Circular culvert	Waved steel pipe	D: 0.8m (2.6')	0.017	253	0	253	217	0	0	52	0	13	4	49	232	0.92	0.92
23	Circular culvert	Waved steel pipe	D: 0.8m (2.6')	0.017	282	0	282	95	0	0	175	0	9	1	20	246	0.87	0.87
28	Box passageway	Ferroconcrete	3.5m span by 3.5m rise (11.5'?11.5')	0.383	189	0	189	0	7	12	34	0	5	0	0	58	0.30	0.30
31	Box passageway	Ferroconcrete	2.0m span by 2.0m rise (6.6'?6.6')	0.138	310	90	220	0	0	3	80	0	8	0	10	101	0.33	0.46
32	Circular culvert	Waved steel pipe	D: 0.8m (2.6')	0.014	288	135	153	133	0	5	87	0	66	0	41	309	1.07	2.02
34	Circular culvert	Waved steel pipe	D: 0.8m (2.6')	0.011	302	165	137	170	0	14	65	0	20	2	8	234	0.77	1.71
35	Box passageway	Ferroconcrete	4.3m span by 4.3m rise (14.1'?14.1')	0.700	111	0	111	0	25	4	134	10	8	0	6	187	1.68	1.68
SUM	-	-	-	-	3351	1005	2346	684	32	213	865	10	253	35	166	2029	9.30	13.48

[a] Rodents include 455 brown rats(*Rattus norvegicus*) and 229 striped field mice(*Apodemus agrarius*).

[b] Domestic dog(38), Shrews(38, occurred only in circular culverts), Lesser Japanese mole(1), and Bat(1) were omitted.

[c] Openness Index = (Span x Rise)/Length, (Reed & Ward, 1985), Example (6ft. x 8ft.) / 150ft. = 0.32 OI

[d] Use Rate = (? #of photographs)/(? #of functional camera days), (Servheen, 2003)

Relationship between Crossing Structures and Wildlife Roadkills

Fluctuations in the number of accessible passageways also appeared to have no correlation with roadkill incidence ($r=0.243$) (fig. 13), and this was contrary to the general belief that the greater the number of passageways, the fewer would be the number of roadkills.

Meanwhile, use rates of passages and roadkill frequencies showed a strong positive($r=0.890$) correlation (fig. 14), which was meaning that increasing movements of wildlife result in increasing roadkills.

During the April~September period, when some (max. 64%) of the passages became unusable caused by inundation, use rates for other passages showed no corresponding increase ($p=0.516>\alpha=0.05$).

Furthermore, there appeared to be a very weak but positive correlation ($r=0.559$, $p<0.093$) such that the more passages there were in an area, the higher the roadkill frequency, which again differed from the general expectation that roadkill accidents would decrease in areas where crossing structures were concentrated (fig. 15, 16).

The reason for these results may be as follows. Since 31 usable passages exist in the given 6.6km highway section, even if the number of usable passages falls to 14 during the month of July, when a lot of water accumulates in the culverts, the number of usable passages remaining is 2.2 extra structures per 1 km. Taking into consideration the fact that the home range for the raccoon dog, which is the most common wildlife in Korea, is 0.8 km^2 (Choi and Park, 2006), then as can be told from the fact that an animal would be able to use about 2 passages within its given home range, it is deemed that a sufficient number of passages exist already in the given section.

Of the 13 raccoons that were radio-collared after capture, 3 animals were caught on camera, continuously using all types of underpasses to cross roads and these animals were not observed to move to other areas to use other available passages between the months of April~September when the culverts were filled with water. This may have been due to the fact that each animal has its own home range and therefore was careful not to encroach upon the territory of other animals, or because food was available plentifully during that particular season, and thus the raccoons felt no urgent need to change their home ranges by using unfamiliar passages located in other raccoon dog's home range.

Meanwhile, it appeared that there was no correlation between number of roadkills per month and average daily fluctuation in night time traffic per month (r=0.075). This is deemed to be because, compared to the monthly changes in traffic volume in the given highway, the monthly changes in wildlife movement are much greater, and therefore, the roadkill frequencies following from changes in traffic volume are not being expressed.

Figure 11. Water deer roadkill.

Figure 12. Water deer in box passageway (Openness index 0.7).

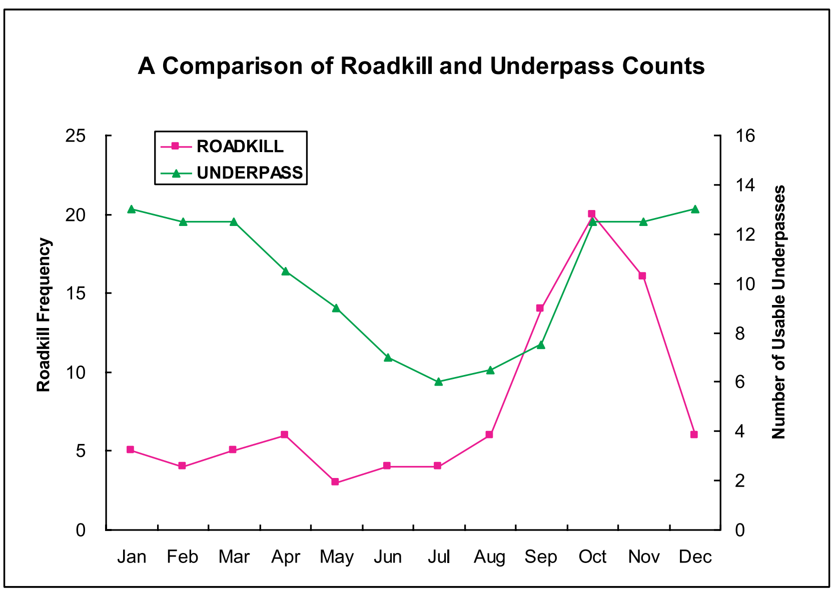

Figure 13. Fluctuations in the number of accessible passageways also appeared to have no correlation with roadkill incidence (r=0.243), and this was contrary to the general belief that the greater the number of passageways, the fewer would be the number of roadkills.

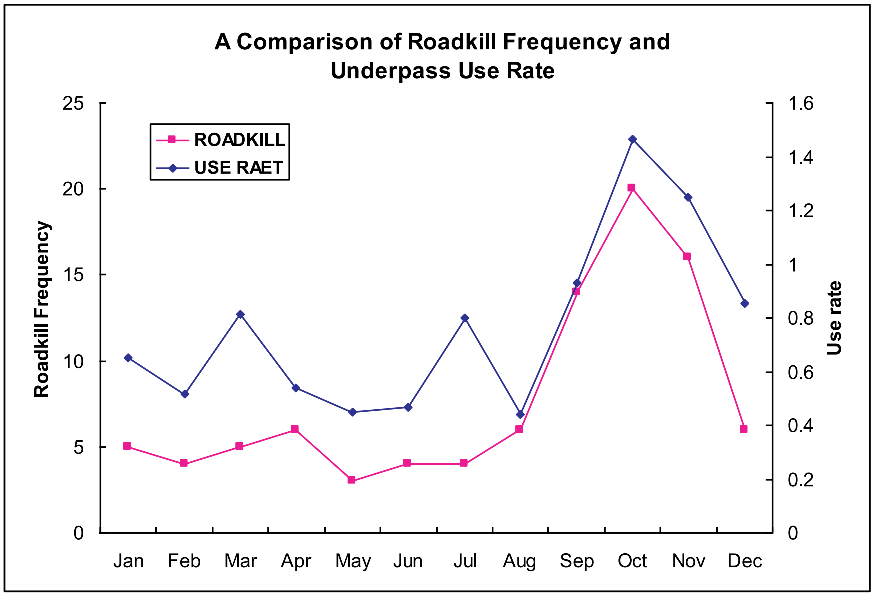

Figure 14. Use rates of passages and roadkill frequencies showed a strong positive(r=0.890) correlation, which was meaning that increasing movements of wildlife result in increasing roadkills.

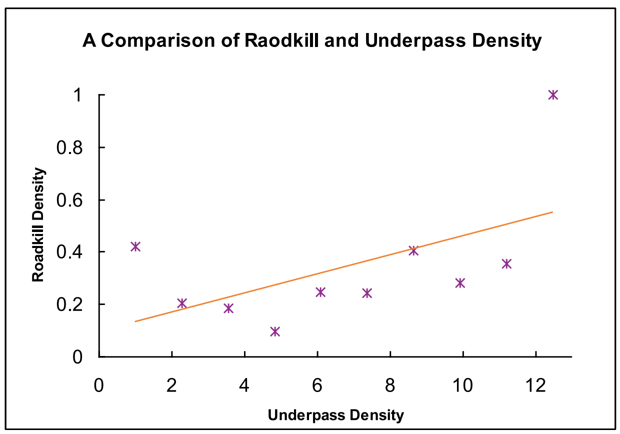

Figure 15. The more passages there were in an area, the higher the roadkill frequency, which differed from the general expectation that roadkill accidents would decrease in areas where crossing structures were concentrated (r=0.559, p<0.093). Refer to Fig. 16.

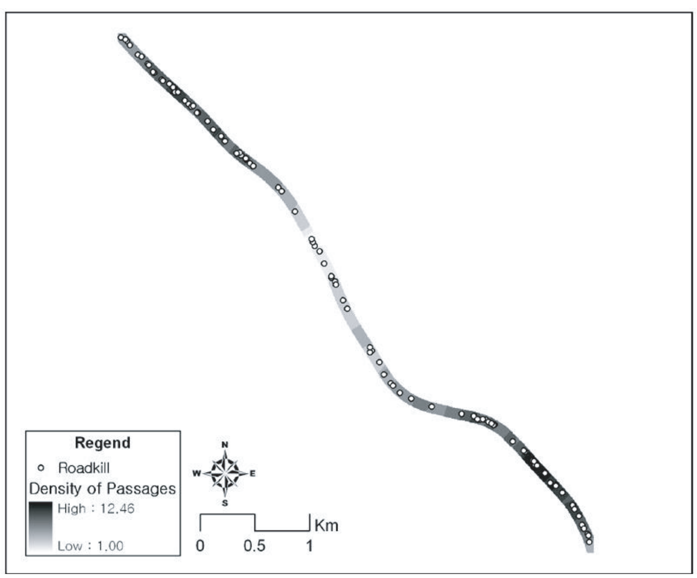

Figure 16. Spatial distribution of mammal roadkills and passage densities; 12 of density value means 12 passages are located within 1km.

Roadkills of Radio-collared Wildlife

After capturing and 13 raccoon dogs within 100m of the given highway, from October 2004 to April 2005, and releasing them after wearing radio-collars on their neck, of the total of 12 raccoon dogs that were found during the roadkill survey conducted from September 2004 until August 2006 in the reference highway, only 1 was found to be collared.

Through radio-tracking, Choi and Park (2006) discovered that the average home range of raccoon dogs that inhabited the reference area was 0.8 km^2, and considering this fact, capture of 13 raccoon dogs in a 6.6km section represents the collaring of a substantial number of the animals inhabiting that reference location, and the 12 roadkill bodies discovered similarly seem to represent a very high figure.

The fact that despite all this, only 1 out of the 12 roadkill bodies examined was collared, seems to indicate that a significant number of highway mortalities are of animals that do not inhabit the reference location, and that these animals were killed while they were on the migrations, most likely to secure new territories, either because they were not familiar with the existing passages, or because they were not allowed access to the passages by occupying settlers.

Figure 17. Radio-collared Raccoon dog.

Figure 18. Raccoon dog killed by vehicle.

Discussion

Upon examining 14 of these usable structures (non-wildlife-engineered passages), a total of 2,593 mammalian movements were confirmed during a 1 year period, which meant that these structures were functioning as crossing structures, to the extent that for each passage, an average of 0.53 mammalian movements were taking place in 1 day. These figures indicate that in the 6.6 km-long reference highway, mammalian movement using passages under the highway is taking place actively, through 31 different passage locations, at an average of 16.6 times each day.

The significance of this result is therefore that there is no reason for concern about mammalian habitat fragmentation due to highways. Given the fact that Korea has many mountainous regions and high population density, and that these conditions by definition necessitate the construction of structures such as bridges, tunnels, passageway boxes and culverts, there is a high probability that highways in other agricultural regions may have conditions quite similar to that described above. According to Choi et al.'s study (2006), after surveying 86 crossing structures in 8 highways across the nation, over a section totaling 21.5km, 1~3 days after heavy snows, 67 instances of traces of wildlife movement were found in 44 structures.

However, in the case of the water deer, only 32 instances (1.23% of total photography) of movement were confirmed over a 1-year period, so concerns are great that they may be vulnerable to habitat fragmentation and roadkills, compared to other species. 25 of 32 recorded water deer crossing occurred in the box passageway with 0.7 openness index (4.3m span by 4.3m rise (14.1'?14.1')) the largest measurement in study area. Meanwhile, out of roadkill survey, water deer made up 12.9% of total mammal roadkills. Our results showed in Choi et al.'s study (2006), it has been reported that movement of water deer does not take place through passageway boxes but that the deer only make use of bridge underpasses. Although excluded from this analysis on crossing structures, underneath some of the bridges within study area, movement tracks of water deer could be found frequently. Inter-bridge distances are however necessarily greater compared to intervals between other structures, and this increases the likelihood of habitat fragmentation for water deer, or of being forced to access roads and highways for movement.

Therefore, additional studies on the water deer's territorial ranges and movement characteristics need to be carried out in the future, to present the structure sizes that are most appropriate for water deer movement, as well as the optimal inter-structural distances.

Another obtained result was that over a 2-year period, in a 6.6 km section, 12 raccoon dog roadkills were discovered, but that out of the 13 animals that had been radio-collared, only 1 was discovered as a roadkill. This result means that most roadkill victims might be wanderers or newcomers unfamiliar to existing passages or occupying settlers. Furthermore, October when many young mammals' dispersals occurred was the seasonal peak of roadkills.

The results of this study suggest that merely increasing the number of crossing structures, or reducing the intervals between them will not lead to an increase in wildlife movement, or to a decrease in roadkills. In the case of agricultural region of Korea, where facilities that function as wildlife crossing structures are already abundant in highways, even if some of the structures become unavailable for wildlife use in certain seasons, or even if some differences do exist in the intervals between passages, sufficient numbers of passages exist such that all wildlife except water deer can make use of them as necessary.

Therefore given the unique conditions in Korea, if wildlife passages are created in agricultural region, water deer should be selected as a target species, and the optimal size for structures such that the deer will not be averse to using the passages must be considered. Additionally the home ranges and movement characteristics of water deer must be factored in when deciding upon optimal inter-structural distances. For species other than the water deer, wildlife fences that restrict access to roads and highways will be sufficient to guide wildlife to the existing passages, and that they will thereby have a huge positive impact in terms of reducing wildlife roadkills, without aggravating habitat fragmentation.

So in the end, the construction of wildlife passages, which take place under current road and highway conditions without sufficient basic research, may actually not be having any meaningful impact in terms of reducing roadkills and habitat fragmentation.

Biographical Sketches: Choi, Tae Young is a wildlife research biologist who is currently working on his Ph.D. in Graduate School of Environmental Studies, Seoul National University, Korea. His research is investigating the causes of wildlife vehicle collisions and suggests mitigation measurements. He has a master's degree in wildlife habitat modeling using geographic information system (GIS) from Seoul National University, Korea. He will work for Nature and Ecology Research Department of National Institute of Environmental Research, Korea from July 2007.

Park, Chong Hwa is an ecology research biologist and professor at the Graduate School of Environmental Studies, Seoul National University, Korea. He has been studying habitat analysis using geographic information system (GIS) and Remote Sensing (RS). Dr. Park is a graduate of the State University of New York, and has a master's degree in landscape architecture from the Seoul National University. He is currently a leader of the Korea Institute of Landscape Architecture.

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