Characteristics of forest road cut slopes affecting the movement of mammals in South Korea

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ABSTRACT

Existing forest roads that are the base infrastructure foundation for forest management have been built with a focus on structural stability rather than ecological impact. In recent, however, the concerns on the ecological and environmental impacts on the forest road construction has been increased with the emphasis of sustainable forest management and the improvement of public awareness. Especially, the cut slopes that occurred on the forest road construction are known to affect the movement and habitat of wild animals living in the forest. This study aims to establish environmental and structural standards for the cut slopes by identifying the effect of forest road cut slopes on the movement of wild animals based on a survey of national forest roads in South Korea (30 km in total). Seven factors associated with forest road cut slopes, including cut slope length, cut slope gradient, soil type, longitudinal position, crossing position, aspect, and vegetation coverage, as well as wildlife tracks were investigated. As a result of statistical analysis using cross tabulation to determine the correlation of wildlife tracks with each cut slope factor, five factors (soil type, cut slope gradient, cut slope length, vegetation coverage, and crossing position) were significantly identified. Using these five factors, a prediction model to predict whether wildlife move or not on the cut slope was developed, and the discriminant hit ratio was 76.0%. Thus, using such models, there is a need to develop the guidelines of forest road installation considering the wildlife movement and of ecological corridor installation for more eco-friendly forest road construction and design in the future.

Introduction

In South Korea, 63.2% of the land consists of forests; therefore, forest road construction is necessary for intensive forest management. The total length of forest roads was 22,457 km as of 2019, with a forest road density of 3.54 m/ha. However, this was relatively insufficient compared to the area occupied by forests compared to other major countries such as United States (9.5 m/ha), Germany (46 m/ha) and Japan (13 m/ha) (Korea Forest Service 2020a). Therefore, there have been constant efforts to increase forest road density (Korea Forest Service 2020b).

Due to the rough topographic characteristics of domestic mountains, earthwork in the forest road construction has been mainly conducted for the formation of road-bed (Han et al. 2018). In the past, for the 35° or steeper of ground slope, the road-beds were particularly formed by full-bench cut resulting in large scale of cut slopes. These cut slopes can often cause damages such as slope collapse and erosion, therefore the structural stability in forest road construction has been prioritized over ecological and environmental factors. Accordingly, forest managers have been making massive efforts to improve the quality of forest roads by advancing structure durability, strengthening maintenance, and developing standards of forest road facilities. With the recent economic developments and improvements in public welfare, however, there are growing concerns for the ecological and environmental impacts of forest road construction.

Despite the tremendous contribution of forest roads to forest management, there are also negative effects associated with forest road construction, such as environmental damage and functional degradation of the ecosystem (Tehrani et al. 2015). In particular, the movement of wildlife are revealed to be physically restricted by forest roads that act as artificial barriers within these animals’ habitat (de Maynadier and Hunter 2000; Huck et al. 2010). This can lead to serious ecological problems such as loss of habitat for wild animals, reduction in habitat area, increase in road kill probability, and changes in species diversity (Rhim et al. 2007, Choi et al. 2017). According to a related report, the movement of wild was primarily blocked by forest road cut slopes, structures used for slope stabilization, and side drainage (e.g., ditch), which led to habitat isolation (Korea Environment Institute 2012).
Habitat isolation within the forest can be prevented by establishing additional ecological corridors following the construction guideline for general roads (Ministry of Environment 2010). Ecological corridors are widely known as a critical solution to mitigate ecological fragmentation and enhance wildlife movement (Wang et al. 2017). For the forest road construction in South Korea, there is also a certain guideline for establishing ecological corridor such as ramps and natural stairs in the cut or fill slope of the forest road to ensure the movement of wildlife. However, forest managers are still struggling to find the adequate location and appropriate type and size of facilities because there is no detailed standard related to ecological corridors (Korea Forest Service 2019a).

Currently, ecological corridors for small animals (amphibians, reptiles, small mammals, etc.) such as waterway escape facilities and crossing bridges are being installed, however there have been practical difficulties in the application of ecological corridors for medium and large mammals (Kim et al. 2005, 2017; Choi et al. 2007).

Regarding the ecological and environmental impacts of forest road construction, several researches were conducted to investigate the changes of vegetation coverage, physical stability of slope, and forest landscape. (Rhim et al. 2003; Hur et al. 2005). However, there is no further research related to the characteristic of wildlife movement affected by forest road construction. Therefore, in order to establish forest roads considering the wildlife ecosystem, it is necessary to investigate the structural characteristics of the forest road, especially the cut slopes, affecting wildlife movement.

According to the ”Forest Management Infrastructure Design and Facility Standards,” the fill slope on the forest road is regulated to be constructed within the gradient of 1:1.2–2.0 (27°–40°) which is very gentle compared to that of the cut slope (Korea Forest Service 2019b). Also, by worrying about collapse or soil spill, lots of broadleaf trees are having been remained on the fill slope after the road construction (Ji et al. 2013). Based on the mentioned condition of the fill slope, it is considered to be favorable for wildlife to move around as well as crossing the road within the fill slope.

This study was conducted to investigate the environmental and structural factors of forest road cut slope influencing the movement of wildlife. Total of 300 survey points were selected at 100 m intervals on the total 30 km of forest roads constructed in Jeongseon-gun, Samcheok-si, and Taebaek-si in Gangwon-do. At each survey point, cut slope factors and wildlife tracks were investigated. Statistical analysis using cross tabulation between the cut slope factors and wildlife movement was performed, and a discriminant function formula for predicting the possibility of wildlife movement was developed. The result of our study could be contributed to forest road construction considering for the ecological and environmental aspect including wildlife ecosystem, as well as the creation of design guidelines for the effective arrangement of structures that support wildlife movement.

### Materials and methods

#### Study area

This study was conducted on a total of 30 km of forest roads, 10 km each of the Dojeon Forest Road in Jeongseon-gun, the Yookbaek Mountain Forest Road in Samcheok-si, and the Joongbong Forest Road in Taebaek-si, in Gangwon-do. A total of 300 survey points were selected at 100 m intervals by systematic sampling method (Table 1).

#### Investigation items and methods

Wildlife tracks were surveyed by tracing investigation method to identify footprints, feces, and ankertrass of wildlife within a 10 × 10 m plot of each survey point (Brown et al. 1993).

Based on the environmental and structural factors of forest road used from previous studies (Cha and Ji 2002; Baek et al. 2016; Kim et al. 2018), a total of seven forest road cut slope factors (longitudinal position, crossing position, cut slope length, cut slope gradient, aspect, soil type, and vegetation coverage) were investigated at each survey point.

The longitudinal position was classified as hill top (above the 7/10 line between the ridge and the lower end of the mountainous district), hillside (between the 3/10 to 7/10 lines), and mountain foot (below the 3/10 line) according to the altitude. Crossing position was divided into ridge, slope, and valley based on the terrain. Cut slope gradients were also classified into the interval of 10° between 20° and 50° according to the steepness presented in the forest management plan, and the aspect was also divided into four directions of east, west, south, and north. Slope length was classified into 3 m intervals based on the berm installation guideline on the forest road cut slope. Vegetation coverage was identified according to the degree of vegetation coverage within a 2 × 2 m square at an interval of 20%. Soil type was classified as hard rock, weathered rock, or soil (Table 2).

#### Statistical analysis

According to the different number of samples in each category for the seven factors of the cut slope, the relative frequency (%) for each category was calculated and the movement characteristics of wildlife were examined using the wildlife tracks rate as shown in Equation (1). Wildlife tracks rate is the relative ratio of the areas with wildlife tracks to those without wildlife.

| Item                          | Dojeon | Yookbaek mountain | Joongbong |
|------------------------------|--------|-------------------|-----------|
| Construction year            | 1991   | 1999              | 1998      |
| Elevation (m)                | 601–951| 701–1206          | 833–1045  |
| Total road length (km)       | 22     | 17.1              | 14.7      |
| Survey route (km)            | 10     | 10                | 10        |
| Survey point (No)            | 100    | 100               | 100       |

| Province                      | Jeongseon | Samcheok | Taebaek |
|-------------------------------|-----------|----------|---------|
| Construction year             | 1991      | 1999     | 1998    |
| Elevation (m)                 | 601–951   | 701–1206 | 833–1045|
| Total road length (km)        | 22        | 17.1     | 14.7    |
| Survey route (km)             | 10        | 10       | 10      |
| Survey point (No)             | 100       | 100      | 100     |
tracks. Wildlife tracks rate greater than 1 indicates a high possibility of wildlife movement while that less than 1 indicates a low possibility of wildlife movement.

$$\text{Wildlifetracksrate} (WR) = \frac{\text{Relativefrequencyofeachcategoryfortracksfound} \%}{\text{Relativefrequencyofeachcategoryfornotracksfound} \%}$$

(1)

The cross tabulation analysis was performed at a significance level of 5% ($p < 0.05$) to determine the statistically significant associations between wildlife movements and cut slope factors, and finally the cut slope factors affecting the wildlife movements were selected. To evaluate the possibility of wildlife movement, the discriminant analysis was also conducted using the influencing factors identified by the cross tabulation as predictors. Before the discriminant analysis, a homogeneity test was performed using $F$-value and Wilk’s Lambda to determine the difference between variable groups. As a result of the discriminant analysis, the discriminant function formula shown in Equation (2) was derived, and the effect of each factor on wildlife movements was compared and analyzed using the discriminant coefficient. In addition, the discriminant hit ratio was analyzed to evaluate the practical use of the discriminant function formula. The SPSS 23.0 program was used for a series of statistical analyses.

$$Z = a x_1 + b x_2 + \cdots + y x_{n-1} + z x_n$$

(2)

### Results and discussion

#### Wildlife movement characteristics

##### Longitudinal position

As a result of the wildlife tracks rate examined by different longitudinal positions, wildlife movements were shown to be most active near the hill top (1.33, Table 3). In the past studies, we found similar results that wild boars and water deer generally inhabit the hillside (between the 5/10 and 6/10 lines) and the hilltop (above the 8/10 line) in Juwangsan National Park (maximum altitude of 800 m), respectively (Chung 2006). In addition, roe deer were found to primarily inhabit the hillside (401 to 600 m) in Seorak-san National Park (maximum altitude of 1708 m) (Park and Lee 2014). However, cross tabulation demonstrated that there is no significant difference in occurrence of wildlife tracks according to the longitudinal position of forest roads ($p > 0.05$). It could be explained by the characteristic of wildlife movement that wildlife have a wide range of action for feeding activities beyond their main habitat (Choi et al. 2006). Wildlife does not generally stay in only one space but rather move from time to time to find their feeds and rests.

##### Crossing position

Analysis of wildlife tracks according to the crossing position of forest roads indicated that most wildlife tracks were found on the slope of the mountain (50.4%). However, the wildlife tracks rate was the highest in the valley (2.10), indicating that wildlife most frequently moved through the valley position ($p < 0.05$, Table 4). Accordingly, one research using unmanned sensor camera for wildlife monitoring reported the valley to be the main passageway for wildlife (Keimyung University 2015), and Park and Lee (2014) also revealed the reason for wildlife preferring valley as the abundant water and food resources formed by water system in the valley. At valley, typically where the cut slope begins or ends, forest roads are being constructed only by banking work without slope cutting which results in high suitability for wildlife moving. Our study also investigated that 69% of the cut slope on valley position had a length of less than 3 meters, and 55% had a gradient of less than 20°. These results support that the slopes of the valley provide a favorable environment for wildlife movement.

##### Cut slope length

The frequency of the wildlife movement has been different with the length of cut slope ($p < 0.05$). In particular, wildlife tracks rate was the highest at 2.18 in the category of less than 2 m, and the wildlife movement decreased dramatically with the increase of the cut slope length (Table 5). Therefore, wildlife appeared to avoid crossing over the cut slope longer than 2 m.

In general, in forest road construction, as the slope of the mountain increases, the cut slope length gets longer while the fill slope length gets shorter. Consequently, these long and steep cut slopes are capable of interrupting wildlife movement by generating barnacle-shaped erosion on the upper part of the cut slope. Therefore, the rounding work such as removing the topsoil layer and stumping on the cut slope could be helpful to enhance the wildlife movement. In addition, the cut slope where having a risk of collapse or

| Categories |
|---|
| 1 | 2 | 3 | 4 | 5 |
| Longitudinal position | Hill top | Hillside | Mountain foot |
| Crossing position | Ridge | Slope | Valley |
| Cut slope length (m) | $<2$ | 3–5 | 6–8 | $9<$ | 51≤ |
| Cut slope gradients (°) | $20$ | 21–30 | 31–40 | 41–50 | 51≤ |
| Aspect | E | W | S | N |
| Soil types | hard rock | weathered rock | soil |
| Vegetation coverage (%) | $<20$ | 21–40 | 41–60 | 61–80 | 81≤ |

Table 2. Classification of factors that influence wildlife movement.
The wildlife generally consider the gradient of slope as an essential factor for hiding or rearing their infants upon selecting their habitat, and the preferred slope gradients are varied with species (Congalton et al. 1993). The roe deer was found to inhabit areas with slope gradients of 20–30° (Park and Lee 2014), and the other study reported that ecological corridor for the movement of roe deer is most appropriate to build with slope gradients of 24–32° (Jeong 2011). In the case of boars’ habitat, there is a preference to inhabit areas with a relatively gentle slope (less than 20°) (Keimyung University 2015).

In this study, most wildlife tracks were found in areas with slope gradients under 40°, and the highest value (7.44) of the wildlife tracks rate was appeared in the area with slope gradients of 20–30°. These results show that gentle and mid slopes were more preferred for wildlife habitat and movement (Table 6). “Forest Management Infrastructure Design and Facility Standards” states that the slope gradient for the soil cut slope should be 1:0.8–1.5 (34–51°) upon building a forest road in South Korea, and our result was also included in the range of this road construction stipulation (Korea Forest Service 2019b). On the other hand, structures installed for slope stabilization are known to interrupt the movement of wildlife as acting an artificial barrier, and also accelerate the fragmentation of wildlife habitat (Korea Environment Institute 2012). In addition, Son et al. (2016) reported that medium to large mammals, such as water deer, moved along the structures installed on the forest road, and finally crossed the forest road at the end of the structures. Thus, when installing structures for slope stabilization such as braced walls, a ramp should be installed at each end of the structure to facilitate the wildlife movement.

### Table 3. Wildlife track distribution by longitudinal position of forest roads.

| Category        | Observed | Not observed | WRa | p-Valueb |
|-----------------|----------|--------------|-----|----------|
| Longitudinal position |          |              |     |          |
| Hilltop         | 29 (21.2%) | 26 (16.0%) | 1.33 | 0.28     |
| Hillside        | 106 (77.4%) | 131 (80.4%) | 0.96 |          |
| Mountain foot   | 2 (1.5%)  | 6 (3.7%)   | 0.40 |          |
| Sum             | 137 (100%) | 163 (100%) |     |          |

WRa: Wildlife tracks rate.

*Value provided by the cross tabulation analysis (p < 0.05).

### Table 4. Wildlife tracks distribution by crossing position of forest roads.

| Category       | Observed | Not observed | WRa | p-Valueb |
|----------------|----------|--------------|-----|----------|
| Crossing position |         |              |     |          |
| Ridge          | 31 (22.6%) | 40 (24.5%) | 0.92 | 0.00*    |
| Slope          | 69 (50.4%) | 102 (62.6%) | 0.80 |          |
| Valley         | 37 (27.0%) | 21 (12.9%) | 2.10 |          |
| Sum            | 137 (100%) | 163 (100%) |     |          |

WRa: Wildlife tracks rate.

*Value provided by the cross tabulation analysis (p < 0.05).

### Table 5. Wildlife tracks distribution by cut slope length of forest roads.

| Cut slope length | Observed | Not observed | WRa | p-Valueb |
|-----------------|----------|--------------|-----|----------|
| ≤2              | 77 (56.2%) | 42 (25.8%) | 2.18 | 0.00*    |
| 3–5             | 48 (35.0%) | 74 (45.4%) | 0.77 |          |
| 6–8             | 10 (7.3%)  | 38 (23.3%) | 0.31 |          |
| 9–15            | 2 (1.5%)  | 9 (5.5%)  | 0.26 |          |
| Sum             | 137 (100%) | 163 (100%) |     |          |

WRa: Wildlife tracks rate.

*Value provided by the cross tabulation analysis (p < 0.05).

### Table 6. Wildlife tracks distribution by cut slope length of forest roads.

| Cut slope gradients | Observed | Not observed | WRa | p-Valueb |
|---------------------|----------|--------------|-----|----------|
| <20                 | 28 (20.4%) | 13 (8.0%)   | 2.56 | 0.00*    |
| 20–29               | 25 (18.2%) | 4 (2.5%)    | 7.44 |          |
| 30–39               | 64 (46.7%) | 21 (12.9%)  | 3.63 |          |
| 40–49               | 19 (13.9%) | 66 (40.5%)  | 0.34 |          |
| 50≤                 | 1 (0.7%)  | 59 (36.2%)  | 0.02 |          |
| Sum                 | 137 (100%) | 163 (100%)  |     |          |

WRa: Wildlife tracks rate.

*Value provided by the cross tabulation analysis (p < 0.05).
A model was developed to predict the wildlife movement using a discriminant function analysis. The prediction model for wildlife movement on forest road cut slopes focuses on vegetation coverage and the surrounding environment. The results show that vegetation coverage (0.036) significantly influences the frequency of the use of ecological corridors by wildlife (Kim et al. 2005). The prediction model can be utilized to predict whether wildlife would move on the cut slope or not. The independent variables (five factors) are substituted in the discriminant function to calculate each discriminant score, and these scores should be compared to each other as a criterion for the prediction of wildlife movement (Table 12).
As a result of the discriminant hit ratio analysis for our developed prediction models, the 115 (83.9%) points with the wildlife tracks and the 113 (69.3%) points without the wildlife tracks were correctly assigned (Table 13). Therefore, a total hit ratio of the discriminant function was calculated as 76%, considered to be a moderate level of accuracy according to the previous study, which categorized the confidence criterion for the discriminant function as good (more than 81% of hit ratio), moderate (71-80%), and bad (less than 70%) levels (Cha and Ji 1999).

The misclassification of the points with wildlife tracks (16.1%) is contributed in underestimated discriminant scores for the wildlife tracks found on the slope of the hard and weathered rock. Also, the misclassification of the points without wildlife tracks (30.7%) was affected by the overestimated discriminant scores toward the cut slope of high vegetation coverage where the wildlife practically cannot move on.

### Conclusions

This study aimed to verify the effect of cut slope factors on the wildlife movement and to provide the basic information for the guideline of environmental management of ecological corridors and forest roads. Therefore, the wildlife tracks and the cut slope factors were investigated along the forest roads total length of 30 km located across the Baekdudaegan Mountain Range.

The cross tabulation analysis selected the five factors (soil type, cut slope gradient, cut slope length, vegetation coverage, and crossing position) that were statistically associated with wildlife tracks. The tracks of medium and large mammals were observed most frequently on the slope of the soil, length of 3 m or less, slope gradients of 20–30°, coverage of 80% or more, and the valley.

As a result of the discriminant function analysis, the cut slope factors were found to influence the wildlife movement largely in the order of soil type, slope gradient, slope length, vegetation coverage, and crossing position, and the discriminant hit ratio was evaluated moderate of 76%. In addition, the discriminant function formula can be used to predict the movement of medium and large mammals according to the cut slope factors.

In current, the full-bench cut method is being generally used for the forest road construction on the slope of gradient more than 35° producing long and steep cut slopes which cause the difficulties of wildlife movement. Therefore, despite the wide scale of alteration on the slope, a balanced design of cutting and banking work is required to facilitate the wildlife’s movement on forest road cut slopes. Thus, the regulations on the sustainable management of the forest road and the stabilization structures are also should be established to support the wildlife’s movement on the forest road cut slopes.

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### Disclosure statement

No potential conflict of interest was reported by the author(s).

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