Journal of Engineering Science and Technology
Vol. 13, No. 6 (2018) 1467 - 1475

DETERMINATION OF OPTIMAL LOCATIONS OF AMPHIBIAN ECO-DUCTS BY USING GENETIC ALGORITHMS: A CASE STUDY OF ODAESAN NATIONAL PARK IN KOREA

SUNG-YONG CHUNG, JIN-HONG KIM*

Department of Civil and Environmental Engineering, Chung-Ang University, Korea
*Corresponding Author: jinhkim@cau.ac.kr

Abstract

There are currently no systematic guidelines for placing the animal passes for wildlife to cross safely the human-made roads. This study presents a mathematical model that determines the optimal locations for amphibian eco-ducts by using a genetic algorithm. The study area is route no. 6 of Odaesan National Park in Korea, and the animals of focus are amphibians. The most crucial factor, the migration distance between amphibian road-kill sites and proposed eco-duct sites, was considered for determination of the optimal locations of amphibian eco-ducts. They were determined by calculating the minimum total distances associated with this factor near the road-kill sites. The model determined 69 optimal locations of eco-duct sites in eight sections of route no.6.

Keywords: Amphibian, Animal pass, Co-duct, Genetic algorithm, Road-kill.

1. Introduction

The increase in road installations in the modern age has brought habitat fragmentation, which in turn has led to decrease of biodiversity and increase of road-kills of wild animals [1]. Korea National Park Service records that road-kills happened at 41 roads inside 16 national parks from 2006 to 2015. 6,345 wild animals suffered road-kills and nearly 60% of these road-kills were concentrated at Woraksan, Odaesan and Deogyusan National Parks [2, 3]. Roads in these national parks were constructed very near to water sources and animal habitats, a contributing factor to road-kills.

Korean local governments are aware of this problem and built 473 eco-bridges and eco-ducts. This is the greatest number of animal passes constructed in any single country [4]. However, most of these animal passes are for large mammals

Nomenclatures

A_j	Coefficient for considering ecological, social, and economic factors of *j* proposed eco-ducts site. This is equivalent to the influence factor, which for this study we set to 1
C_{ij}	Indication of whether the amphibian at position *i* went to the proposed eco-duct site *j*. A value of 1 means the amphibian did. A value of 0 means the amphibian did not
D_{ij}	Distance between the amphibian at position *i* and proposed eco-duct site *j*
i	Numerical order of amphibian positions (from amphibian road-kill sites)
j	Numerical order of proposed eco-duct sites
M	Sum of T_{ij} values
N	Number of eco-ducts
n	Number of killed amphibians at position *i*
T_{ij}	Indication of the migration distance multiplied with coefficients

like deer or roe deer, which are animals that the public tends to care most about. Animal passes for small mammals and amphibians, which draw less attention from the public, are very few. Also, the research for such animal passes is insufficient.

There are 473 animal passes in Korea, but there are no systematic guidelines about where to place them. The only official guideline is an order from the Ministry of Environment that specifies the following: 1) to build animal passes where there are numerous road-kills, 2) to build animal passes where there are frequent animal migrations, and 3) to choose the type of animal pass according to the kind of animals that have been road-killed nearby [5, 6].

The lack of systematic guidelines means that locations of animal passes are decided by the separate know-how of different builders and the scattered advice of many experts to meet the minimum requirement of the environmental impact assessment of the Ministry of Environment at the lowest construction cost [7].

This study presents a mathematical model for optimizing numbers and locations of amphibian eco-ducts (tunnel-type animal passes) by using a genetic algorithm.

2. Model Description

A systematic and unified optimization model for deciding the locations of the amphibian eco-ducts applying a genetic algorithm was suggested. A genetic algorithm is a search algorithm imitating the natural selection. In this study, it was used for finding the locations at the road that will minimize the travel distances of the amphibians.

This study considers several factors for deciding the locations of the amphibian eco-ducts physically: factors that can draw more amphibians to the proposed eco-duct sites, or factors that make the amphibians unwilling to use the proposed eco-duct sites. Those factors considered are as follows [8].

a) Distance factor.

- The migration distance of the amphibians.

b) Influence factor.
- Accessibility to nearby streams.
- Accessibility to amphibian habitats.
- Avoidance from predators' habitats.
- Accessibility to spawning or hibernation areas.

c) Condition factor.
- Flow depth of nearby streams.
- Cost-benefit ratio.

This study focuses on the most relevant distance factor, which means the migration distance of amphibians to the eco-duct. This also follows a guideline from the Ministry of Environment to build the animal pass where there are frequent animal migrations [6]. The model assumes that road-kill sites of amphibians on a road are on the migration route of the amphibians on the road and marks the frequent positions of amphibians on that route. Out of proposed sites for construction, the model determines the number and locations of eco-ducts for which the sum of migration distance is minimized.

As an example, consider a stretch of road with 4 road-kill sites and 9 proposed eco-duct sites shown in Fig. 1(a). The red circles are the road-kill sites, which the model considers to be positioned on which amphibians can frequently be found; the black dots are the proposed sites for eco-ducts, and the black lines denote the distances between a road-kill site and a proposed eco-duct site.

The model proceeds as follows.

a) Sum the migration distances of amphibians to the proposed eco-duct sites. This is shown in Fig. 1(b), where there are four migration distances from four amphibian positions to the leftmost proposed eco-duct site.

b) For each possible number of eco-ducts, find the eco-duct location layout with the minimum summed distances from road-kill sites. This is shown in Fig. 1(c).

c) Out of these eco-duct location layouts, again find the one with the minimum total distance. This gives the optimal number and locations of eco-ducts selected from the proposed sites. This is shown in Fig. 1(d).

The optimal number and locations for eco-ducts for the given section of the road corresponding to the minimum summed migration distance.

The calculations were performed using Excel's Evolver program. Evolver program is the most accurate genetic algorithm operator in Excel. The program was used in many theses concerning optimization in the fields of the economy [9] and civil engineering [10]. However, it is not yet used for finding locations of animal passes [8].

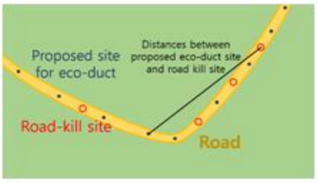
Model equations are as follows,

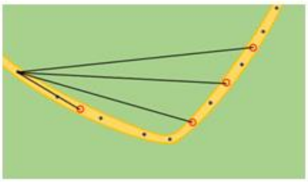
$$T = [T_{ij}] = [C_{ij}D_{ij}A_j \dots] = \begin{bmatrix} C_{11}D_{11}A_1 \cdots & C_{12}D_{12}A_2 \dots & \dots \\ C_{21}D_{21}A_1 \dots & C_{22}D_{22}A_2 \dots & \dots \\ \vdots & \vdots & \ddots \end{bmatrix} \quad (1)$$

$$M = Min\left(\sum_i^n \left(\sum_j^N (T_{ij})\right)\right) = Min\left(\sum_i^n \left(\sum_j^N (C_{ij}D_{ij}A_j)\right)\right) \quad (2)$$

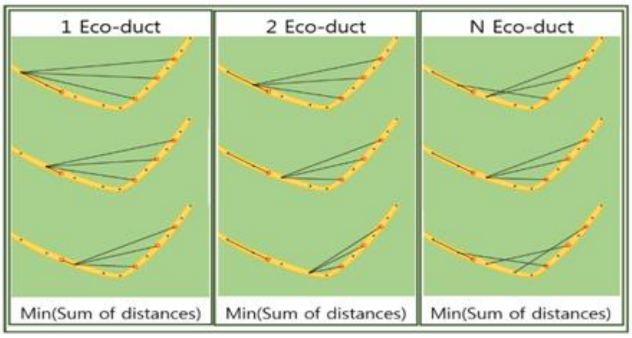
By using genetic algorithm and Excel's Evolver program, the model finds the optimized position that minimizes the travel distance of amphibians for the given number of eco-ducts. Equation (1) displays the values of $C_{ij}\ D_{ij}\ A_j$ which represents the distance between each point on the road, j and road-kill site, i. Equation (2) finds the value of M, the minimized value of the sum of $C_{ij}\ D_{ij}\ A_j$ values. The value varies according to the given number of needed eco-ducts, N. The process is done by adjusting the C_{ij} values from 0 to 1.

Thus, after the model found the value of M, the selected optimized eco-duct locations on the road are decided. The C_{ij} values of the selected locations are set to the value of 1, while others remain 0.

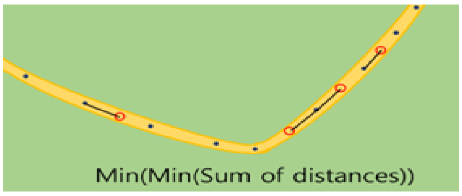




(a) Sites of road. **(b). Sum of migration distance.**



(c) Finding the minimum migration distance with 1, 2 and N eco-duct



(d) Optimal locations of eco-ducts.

Fig. 1. Method of determining the optimal locations of eco-ducts.

3. Study Area

The study area is Route No.6 within Odaesan National Park, which has seen the second most amphibian road-kills in Korea (116 road-kill sites out of a total of 666 road-kills) [11]. The location of Odaesan National Park and route no.6 are shown in Fig. 2.

It would be infeasible to compute every point on the road as possible sites for eco-duct construction. As a practical consideration, the model considers points every 100 meters as supposed eco-duct sites and located 224 supposed eco-duct sites. The total length of route no.6 is 16.0 km. Since the average scope of movement for amphibians is roughly 2 km [12], this study splits the road into eight sections.

The location of the starting and ending point of each section and number of amphibian road kill sites are shown in Table 1.

Thus, the migration distances of amphibians for given number of eco-ducts sites are calculated for the road sections 1 to 8 and the optimal position that minimizes the migration distance by using Eq. (1) and (2).

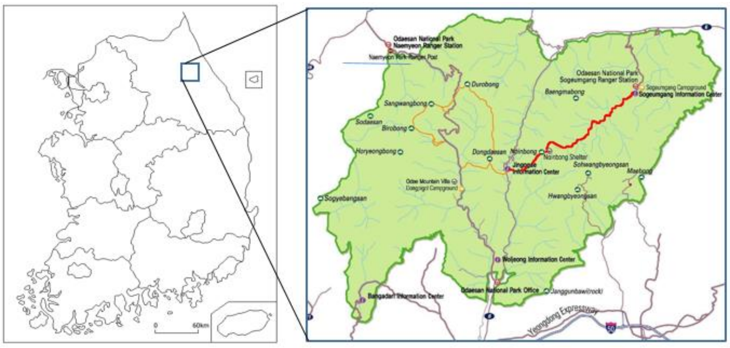


Fig. 2. Route no. 6 in Odaesan National Park.

Table 1. Starting and ending points of 8 sections

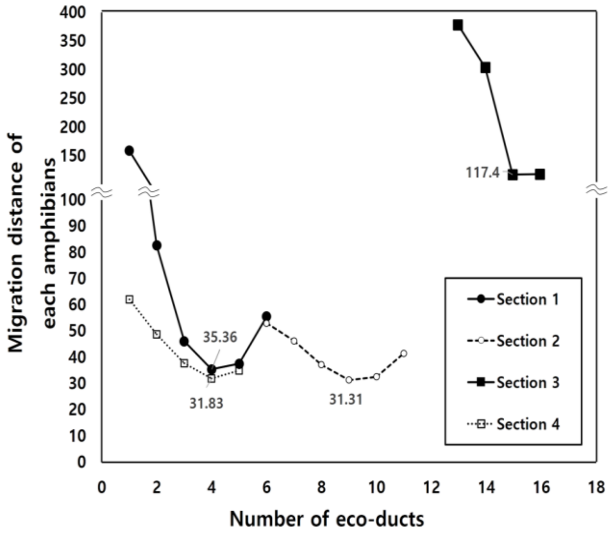
Sections	No. and latitude/longitude grid of starting point and ending point	No. of amphibian road kill sites
1	No. 1, 37.83176/128.64272 No. 17, 37.82053/128.63295	6
2	No. 18, 37.81964/128.63278 No. 42, 37.8010/128.62507	11
3	No. 43, 37.80014/128.62478 No. 90, 37.7755/128.61412	22
4	No. 91, 37.77465/128.61435 No. 131, 37.7594/128.61160	5
5	No. 132, 37.75878/128.61193 No. 156, 37.74275/128.61608	10
6	No. 157, 37.74224/128.61647 No. 167, 37.7346/128.615526	14
7	No. 168, 37.73385/128.61489 No. 184, 37.72298/128.60940	24
8	No. 185, 37.72256/128.60939 No. 224, 37.70297/128.60166	24

4. Results and Discussion

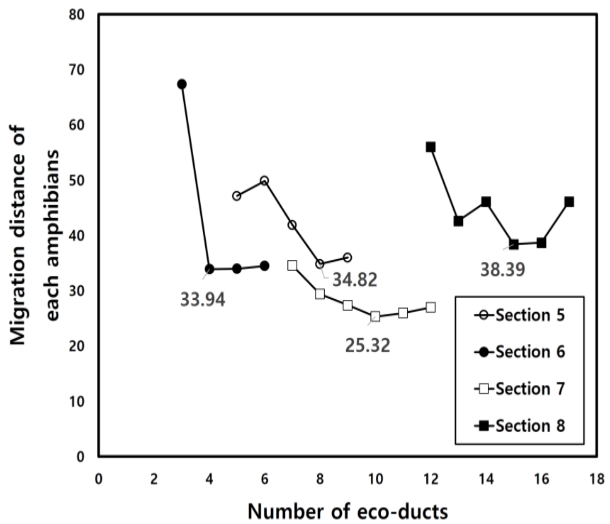
The number of eco-ducts and the corresponding sum of migration distances for the road sections 1 to 8 are shown in Fig. 3. Generally, as the number of eco-ducts increases, the migration distance decreases. This is an appropriate result considering the concept of the migration distance between a road-kill site and an eco-duct site [13]. However, if the number of eco-ducts exceeds a certain limit, the migration distance becomes larger. This is because it sets the necessary distance.

Using Fig. 3, the optimal position that minimizes the travel distance of amphibians for the road sections 1 to 8 are determined.

The given number of eco-ducts selected eco-duct sites, sum of migration distances and the minimum migration distance of amphibian are shown in Table 2. Here, selected eco-duct sites correspond to the optimal position. Thus, 69 optimal eco-duct sites in eight sections were selected and their locations are shown in Fig. 4. The ratio of a number of selected eco-duct sites to a number of the road-kill sites is the largest at sections 2 and is the smallest at section 6, which shows the straight and curved type of the road, respectively.



(a) Section 1 to 4.

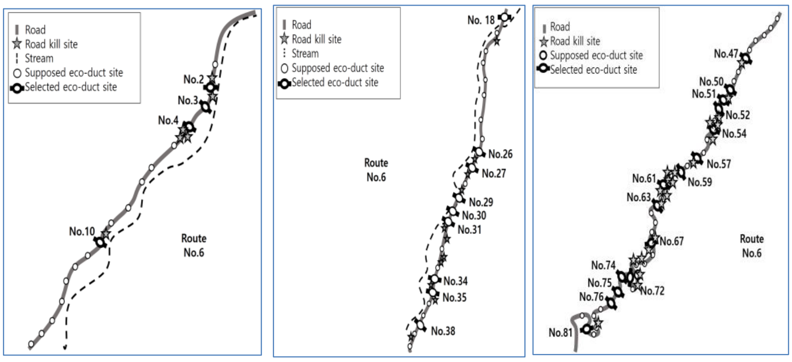


(b) Section 5 to 8.

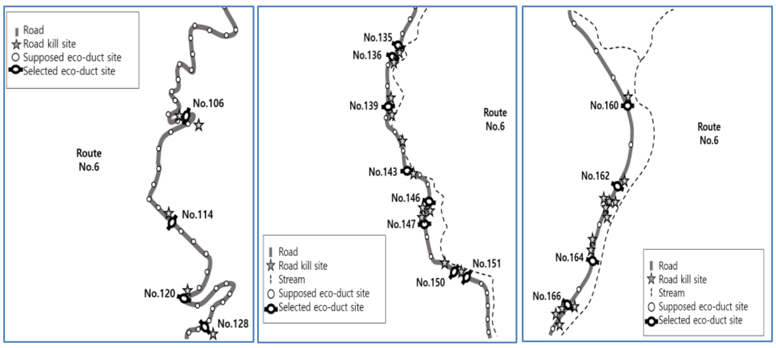
Fig. 3. Number of eco-ducts and corresponding minimum sum of migration distance.

Table 2. Number of eco-ducts, selected eco-duct site and their migration distance.

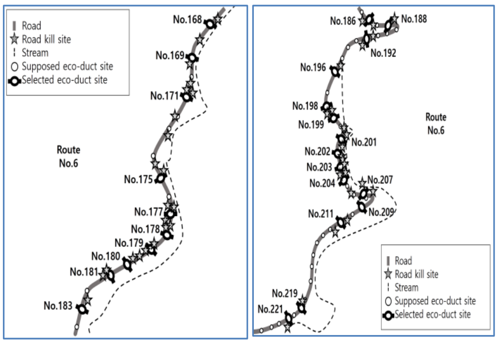
Sections	No. of eco-ducts	Selected eco-duct sites	Sum of migration distances (m)	Minimum migration distance (m)
1	4	2, 3, 4, 10	282.9	35.36
2	9	18, 26, 27, 29, 30, 31, 34, 35, 38	344.4	31.31
3	15	47, 50, 51, 52, 54, 57, 59, 61, 63, 67, 70, 74, 75, 76, 81	3890.1	117.40
4	4	106, 114, 120, 128	1444.6	32.83
5	8	135, 136, 139, 143, 146, 147, 150, 151	348.2	34.82
6	4	160, 162, 164, 166	848.6	33.94
7	10	168, 169, 171, 175, 177, 178, 179, 180, 181, 183	936.8	25.32
8	15	186, 188, 192, 196, 198, 199, 201, 202, 203, 204, 207, 209, 211, 219, 221	1597.3	38.39



(a) Section 1. **(b) Section 2.** **(c) Section 3.**



(d) Section 4. **(e) Section 5.** **(f) Section 6.**



(g) Section 7. **(h) Section 8.**

Fig. 4. Locations of selected eco-duct sites.

5. Conclusions

A mathematical model was derived to determine the optimal locations for amphibian eco-ducts based on a genetic algorithm using the implementation in Excel's Evolver program. It finds the minimum total migration distance between amphibians and supposed eco-ducts in keeping with amphibian movement. Applying the model, this study selected 69 optimal eco-duct sites in eight sections of route No.6 in Odaesan National Park where there have been many amphibian road-kills. As the number of eco-ducts increases, the migration distance decreases. However, if the number of eco-ducts exceeds a certain limit, the migration distance becomes larger. This is because it sets the necessary distance. The ratio of a number of eco-duct sites to a number of the road-kill site is the largest at sections 2 and is the smallest at section 6, which shows the straight and curved type of the road, respectively.

Acknowledgements

This research was supported by a grant (12-TI-C02) from Advanced Water Management Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

References

1. Gaston, K.J. (1994). *Rarity in population and community - Biology series 13*. London: Chapman and Hall.
2. Kim, Y.S. (2016). News on area of frequent road-kills. Retrieved May 9, 2017, from http://news.kbs.co.kr/news/view.do?ncd=3275989.
3. Korea National Park Service (2013*). Countermeasures for reduction of wildlife road-kills in national park*. Seoul: Singwangsa.
4. Lee, M.J. (2016). *Design method on ecological corridors for efficient migration of amphibians*. Seoul: Bomungak.
5. Kim, Y.S. (2016). News on road-kills of endangered species. Retrieved June 20, 2017, from http://news.kbs.co.kr/news/view.do?ncd=3298365.
6. Ministry of Environment (2011). *Guideline on management of eco-ducts*. Seoul.

7. Kim, Y.S. (2016). News on incorrect aggregate count on road-kills. Retrieved June 20, 2017, from http://media.daum.net/m/channel/view/media/20160621141750410.
8. Chung, S.Y. (2017). *A study on decision of the best location of animal passes for amphibian by using genetic algorithm.* Seoul: Chung-Ang University.
9. Hegazy, T; and Wassef, N. (2001) Cost optimization in projects with repetitive nonserial activities. *Journal of Construction Engineering and Management*, 127(3), 15-27.
10. Tam, C.M.; Tong, T.K.L.; and Wong, B.W.L. (2007). An integrated system for earthmoving planning. *Construction Management and Economics*, 25(11), 1127-1137.
11. Kim, Y.S. (2016). News on eco-pathway. Retrieved June 22, 2017, from http://news.kbs.co.kr/news/view.do?ncd=3299665.
12. Shim, J.H. (2001). *Amphibian ecology characteristics*. Korea: Expressway Corporation.
13. Sae, J.H. (2011). *Ecological guide book of herpetofauna in Korea*. National Institute of Environmental Research.