Sensors and Materials, Vol. 36, No. 9 (2024) 3881–3898
MYU Tokyo

S & M 3773

Changes in Species Richness and Rarity of Amphibians between 1997–2005 and 2014–2018 in the Central Region of the Republic of Korea

Ho Gul Kim,[1] Chan Park,[2] and Yongwon Mo[3*]

[1]Department of Landscape Architecture and Urban Planning, Cheongju University, 298, Daeseong-ro, Cheongwon-gu, Cheongju 28503, Republic of Korea
[2]Department of Landscape Architecture, University of Seoul, 163, Seoulsiripdae-ro, Dongdaemun-gu, Seoul 02504, Republic of Korea
[3]Department of Landscape Architecture, Yeungnam University, 280, Daehak-ro, Gyeongsan-si 38511, Republic of Korea

(Received May 21, 2024; accepted September 9, 2024)

Keywords: suitable habitat areas, ensemble model, conservation priority analysis, human activities

The degradation of biodiversity has been a severe problem in the Republic of Korea (ROK). Among the various wildlife, amphibians have high conservation value because of their ecological position and life cycle in both terrestrial and aquatic areas. Owing to the problems caused by the change in the habitat environment of amphibians, many studies have been conducted on the habitat characteristics and distribution changes in the ROK. However, there are only a few studies in the ROK that focused on analyzing suitable habitat areas for various amphibians and investigating species richness and rarity over time We aimed to determine the changes in species richness and rarity by identifying changes in their habitats according to temporal and spatial changes in the central region representing the ROK's temperate climate. Suitable habitat area maps for nine amphibians (*Rana huanrensis*, *Kaloula borealis*, *Rana coreana*, *Glandirana rugosa*, *Pelophylax nigromaculatus*, *Dryophytes japonicus*, *Onychodactylus fischeri*, *Bufo gargarizans*, and *Bufo stejnegeri*) at different periods were drawn. Spatial changes in species richness and rarity over time were identified using those maps. The area with high species richness decreased, whereas that with low species richness increased. In terms of species rarity, the high-altitude region had a relatively higher species rarity than the low-altitude region. Some groups were derived on the basis of the increase and decrease in the species richness and rarity of amphibians, whereas the distribution of each group was distinguished by the altitude and distance from the road. Accordingly, priority areas for conservation in the central region of the ROK were found. This study can be applied as a framework for the conservation of amphibians in temperate countries such as the ROK. It will help identify amphibians' habitats that should be protected first when a regional development is planned.

*Corresponding author: e-mail: webzin12@gmail.com
https://doi.org/10.18494/SAM5150

ISSN 0914-4935

1. Introduction

Globally, biodiversity is declining owing to human development, environmental pollution, and climate change.[1] According to the global biodiversity outlook prepared by the tenth meeting of the Conference of the Parties of the Convention on Biological Diversity (COP10), most endangered species are becoming extinct more rapidly than ever, and amphibians are chiefly at risk. The number of amphibians worldwide is declining much faster than those of other vertebrates,[2] and about 40% of them are listed as threatened by the International Union for Conservation of Nature (IUCN) (https://www.iucnredlist.org/).

The degradation of biodiversity is also a severe problem in the ROK. As of 2019, 63% of the ROK's land is composed of mountainous areas, so the amount of flat land that can be rapidly developed is less than the number of people.[3] As a result, ecological connectivity has been disrupted, and habitats have been destroyed.[4] Among the various species inhabiting the ROK, amphibians use terrestrial and aquatic ecosystems and have high conservation value because they play an essential role by their ecological niche.[5] In particular, the habitat of amphibians is prone to destruction owing to development. In the ROK, habitat loss for amphibians is often caused by the development-induced reduction in mountainous area.[6] In addition, there is a problem that road kills are most prevalent during the breeding season of amphibians owing to roads developed on hillsides.[7]

Because of the problems caused by the change in the habitat environment of amphibians, many studies on the habitat changes and characteristics of amphibians in the ROK have been conducted, such as a study that analyzed the environmental characteristics of the riparian habitat, which five species of amphibians inhabit using the habitat suitability model,[8] a study that suggested a policy for the conservation of the tree frog (*Dryophytes suweonensis*),[9] a study on methods to create a habitat for amphibians in urban forest wetlands,[10] a study on changes in the habitat of amphibians due to the construction of a debris barrier,[11] and a study analyzing the breeding habitat of *Hyla suweonensis* using a species distribution model.[12]

Several studies have also been conducted abroad to identify and preserve the habitats of amphibians. When examining the relationship between urbanization and changes in the species richness of amphibians at the spatial scales of cities, regions, and countries, the adverse effects of development, such as urbanization at smaller scales, were more pronounced.[13] As for the habitat of amphibians, the land cover structure that connects forests and wetlands is essential, and rural areas have a better connectivity structure than urban areas. Therefore, the richness of amphibians was lower in urban wetlands than in rural wetlands.[14] According to a study monitoring amphibians' diversity and species composition for five years, factors that threaten the habitat of amphibians include the destruction of natural vegetation, road construction, traffic volume, buildings, and tourists. The primary threat factors differed according to the altitude.[15] They also found significant results in species richness and rarity changes according to altitude from examining the distribution by group.[15]

On the other hand, some studies have shown that not all amphibians are declining in species richness owing to human activity. Some species may obtain ecological benefits from human activities, increasing their richness.[16] There is a study showing that the richness of 81% of species decreased, but 19% showed a tendency to increase.(17) In a study that evaluated the richness of 5,527 amphibians around the world using a species distribution model, it was found that regions with high amphibian richness had more threat factors than those with low amphibian richness.(18) Although such studies have been conducted, there are only a few studies in the ROK that focused on analyzing suitable habitat areas for various amphibians and species richness and rarity.(5,8)

In this study, we aim to identify the changes in species richness and rarity by identifying changes in the habitats of amphibians according to temporal and spatial changes in the central region representing the ROK's temperate climate. First, the habitat areas of nine amphibians were analyzed in detail, while the species richness and rarity were analyzed on the basis of their habitat areas. Second, spatial changes over time in the species richness and rarity of nine amphibians were identified. For this purpose, suitable habitat areas were analyzed at different times, using survey data obtained in 1997–2005 and 2014–2018. Third, for the application of this study, the areas with high conservation priority were explored on the basis of the increased and decreased information on the species richness and rarity of amphibians. The results of this study can be used as primary data for establishing a national land development plan considering the conservation of amphibians in the ROK.

2. Data, Materials, and Methods

2.1 Scope of study

The spatial scope of this study is the central region of the ROK and includes the administrative districts of Chungcheongbuk-do, Chungcheongnam-do, Sejong-si, Daejeon-si, Gyeongsangbuk-do, and Daegu-si (Fig. 1). The central region represents the typical climate of the ROK and was selected because it has the highest diversity of amphibians. The temporal scope of the study consists of two periods according to the duration of the National Natural Environment Survey

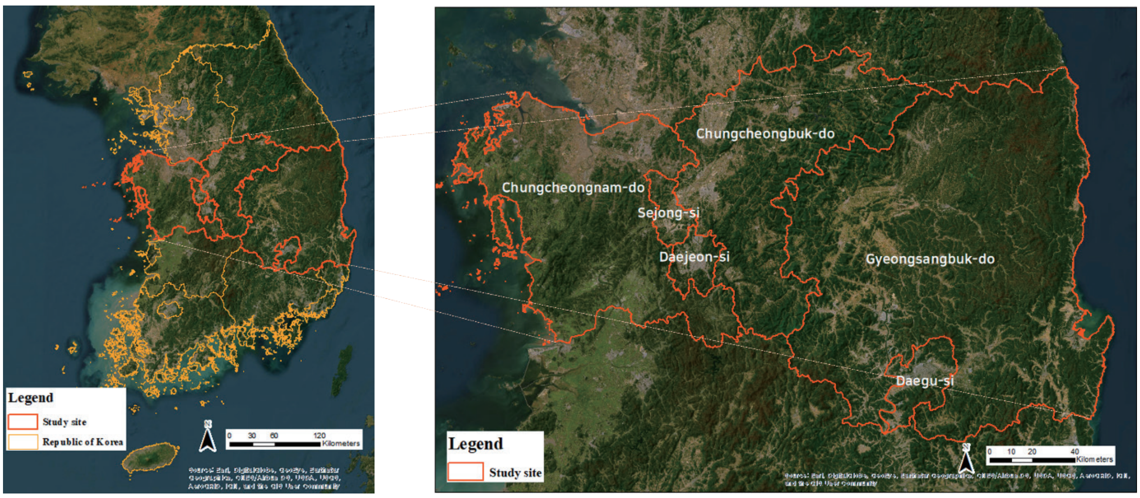


Fig. 1. (Online color) Study site.

(NNES) project. In this study, we used the second and fourth survey data to analyze suitable habitat areas (SHAs) to set the study period with sufficient time intervals. The second survey was conducted from 1997 to 2005, and the fourth survey was from 2014 to 2018 (Fig. 2). They were selected considering the period in which environmental variable data could be obtained. There were no significant differences between the two periods in terms of survey frequency, timing, location, and so forth. The NNES project is one of the first well-organized and national surveys that included amphibians.(19)

Nine amphibians were selected as the target species (Table 1). Amphibians have high biological status, have essential conservation value, and are species that require research on habitat conservation because there are many cases of habitat destruction due to development. We tried to select amphibians that could represent a variety of habitat environments. These are species that inhabit forests, grasslands, valleys, and ponds. According to the NNES, 17 species of amphibians appearing in the central region were identified. In this study, nine amphibian species were selected, and the selection criteria are as follows. First, they appeared in the two NNES survey periods. Second, more than 10 occurrence points were established. Third, only the species for which the reliability of the survey data was secured by examining the relationship between the occurrence point information and the land use map were selected. For example,

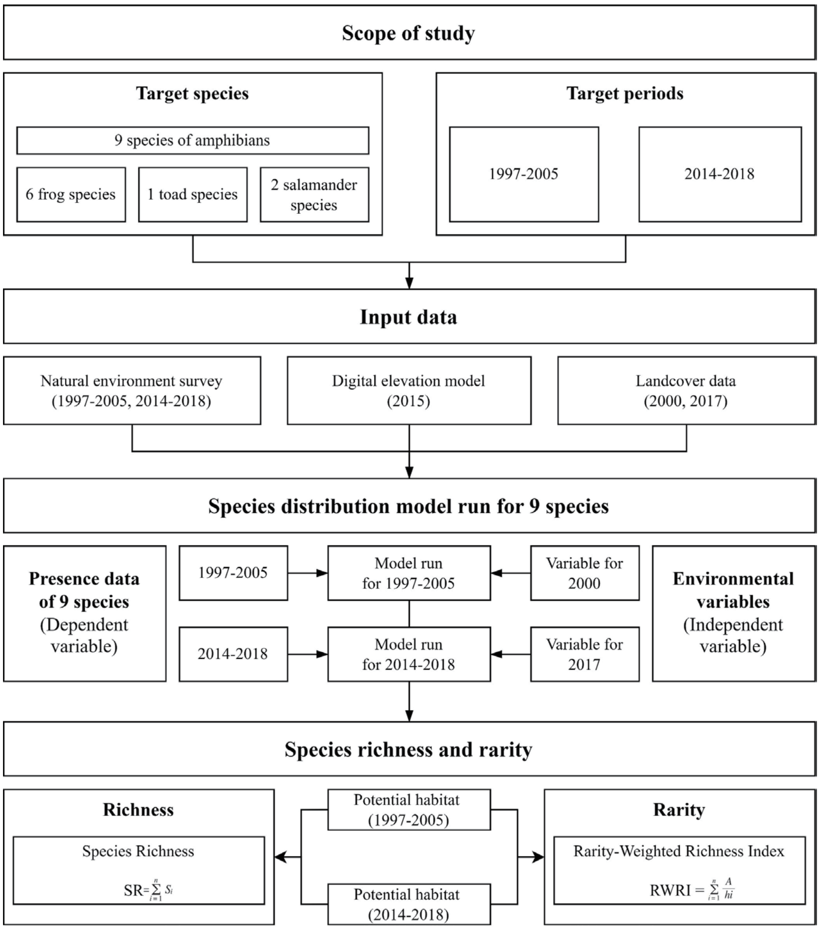


Fig. 2. Flow chart of the study.

Table 1
Target species.

No.	Common name	Scientific name	Habitat information (http://www.kbr.go.kr/index.do)
1	Huanren brown frog	*Rana huanrensis*	It inhabits mountainous valleys widely in the ROK.
2	Narrow-mouth frog	*Kaloula borealis*	It lives around villages and puddles of water at the edge of the forest, but most of them live in the ground, cannot hear, and are noticeable except during the spawning season. They come out at night to predate and gather around June to spawn at the water's edge. Spawning is usually done at night and on rainy or cloudy days. Males lure females by crying even during the day.
3	Korean red frog	*Rana coreana*	Korean endemic species. Compared with the northern mountain and valley mountain frogs that mainly inhabit alpine regions, the Korean mountain frogs inhabit low mountains and low wetlands and ponds. In the past, it was called "*Rana amurensis coreana* Okada."
4	Wrinkled frog	*Glandirana rugosa*	It lives mainly in the plain or shallow mountain areas.
5	Black-spotted pond frog	*Pelophylax nigromaculatus*	It spawns in ponds, rice paddies, and ponds from April to June. It hibernates under moist soil in rice fields or fields, then appears and spawns in April, and shows the peak of populations in May. It mainly spawns in paddy wetlands in mountains or plains.
6	Tree frog	*Dryophytes japonicus*	It lives on grass or trees in mountains or flats. Usually, it spawns on farmland with accumulated water in April and May.
7	Korean clawed salamander	*Onychodactylus fischeri*	It inhabits tall grassy grasslands, shrubs, open grass-covered areas, hillsides, and forests. Its nest is located on the ground in the forest.
8	Asian toad	*Bufo gargarizans*	It lays eggs in the standing water of the waterway around March and April. When all toads go up to the mountain, one can see them go to the mountain in groups on a rainy day.
9	Korean water toad	*Bufo stejnegeri*	It has been reported only to inhabit mountain streams in Gyeonggi-do and Gangwon-do, located in the northern part of Korea. Recently, the species has been confirmed in the valley of Mount Jirisan, located in the southern part of Korea.

survey points identified as appearing in urbanized areas were excluded. The nine selected amphibians can be classified into three subgroups, namely, frog, toad, and salamander, or six frogs, one toad, and two salamanders. There are maps of the distribution data (occurrence points) of each species in Fig. 3. For some species, the number of points decreased in the verification process after comparison with land use data.

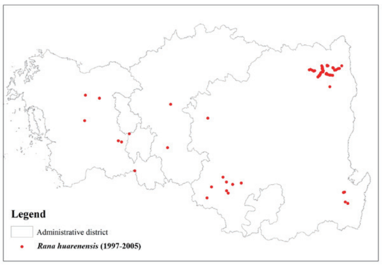
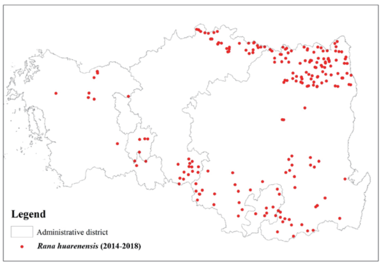
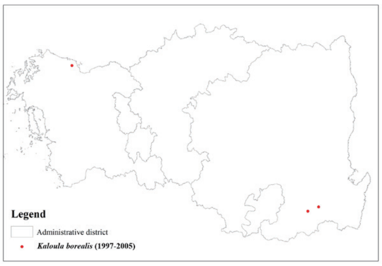
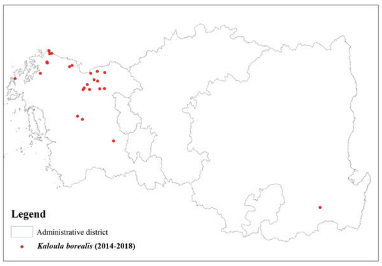
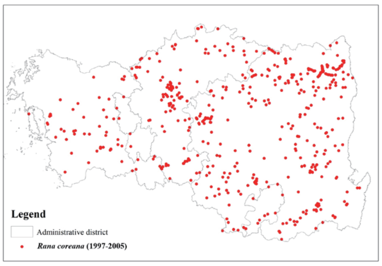
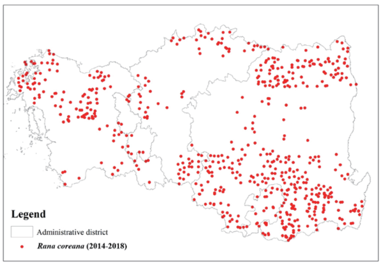
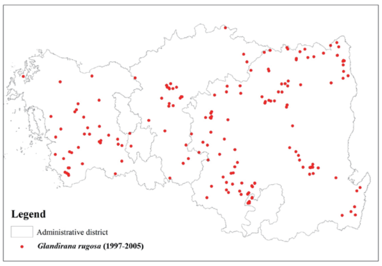
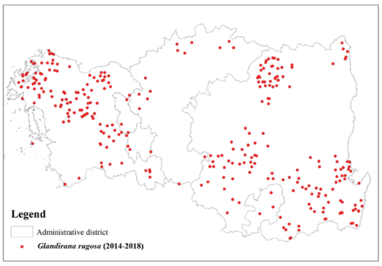
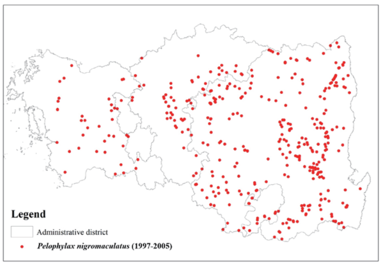
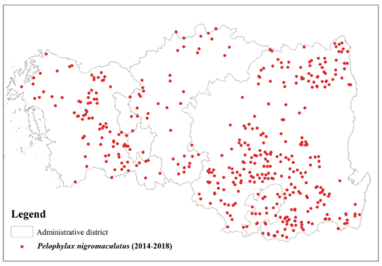
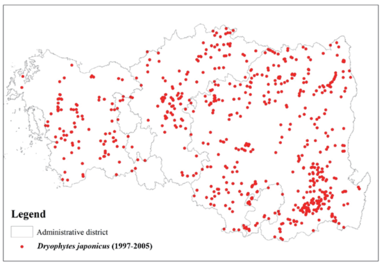
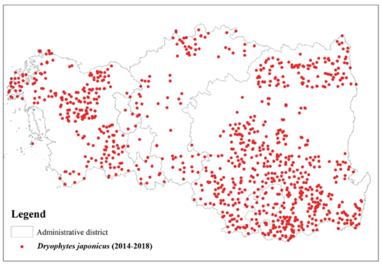
No.	Scientific name	Species distribution data of 1997–2005	Species distribution data of 2014–2018
1	*Rana huanrensis*		
2	*Kaloula borealis*		
3	*Rana coreana*		
4	*Glandirana rugosa*		
5	*Pelophylax nigromaculatus*		
6	*Dryophytes japonicus*		

Fig. 3. (Color online) Distribution data of target species.

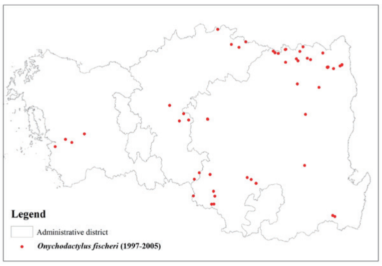
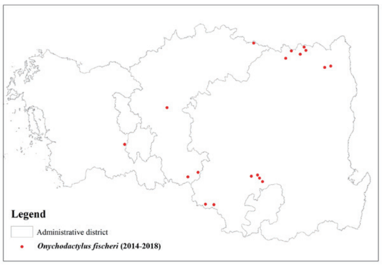
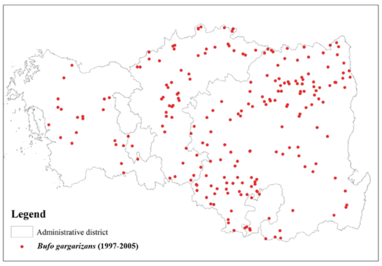
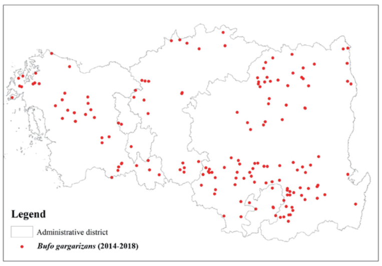
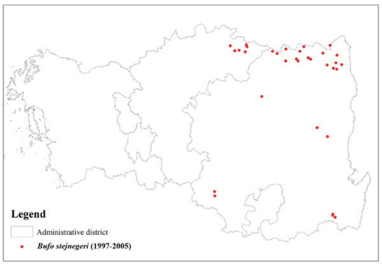
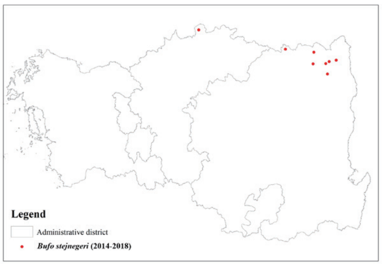
7	*Onychodactylus fischeri*		
8	*Bufo gargarizans*		
9	*Bufo stejnegeri*		

Fig. 3 (Color online) (continued) Distribution data of target species.

2.2 Species distribution model and environmental variables

In this study, we analyzed habitats using the R package Biomod2.[20] To consider the uncertainty of the results of individual models and to derive a habitat with high reliability, ensemble methods that synthesize the results of individual models were applied. Individual models include the Generalized Linear Model (GLM), Generalized Additive Model (GAM), Generalized Boosting Model (GBM) or usually called Boosted Regression Trees (CTA), Classification Tree Analysis (CTA), Artificial Neural Network (ANN), Flexible Discriminant Analysis (FDA), Random Forest (RF), and Maximum Entropy (MAXENT).

Ensemble models help compensate for the limitations of the overestimation or underestimation of individual models. Therefore, in this study, an ensemble model was applied to complement the limitations of the results of individual models and increase reliability. The commonly used ensemble methods are as follows. First is a method of averaging the species appearance probabilities of individual grids (mean of probabilities, PM). The second consists of two methods using the confidence interval of the mean appearance probability value (confidence interval for the probability of the mean, PCI upper, and PCI low). The third uses the median of individual grids in the selected model (median of probabilities, PME). The fourth makes and averages a binomial map for appearance/non-appearance (model committee averaging, CA). The fifth is a weighted mean of probabilities (PMW) method that considers the reliability of the model.[20] The weight of the model is set by considering the AUC value, which is the reliability of the individual model. High weight is given to the results of models with high reliability. Therefore, in this study, six ensemble techniques were applied, and the results of applying the most reliable ensemble technique through ROC analysis were utilized.

As environmental variables to analyze the SHAs for amphibians, 10 variables derived from previous studies were used (Table 2). Since it was confirmed that the order of the stream and the distance from the stream had a close relationship with the appearance of amphibians, these were selected as variables.[21] Considering that the distance from the road is the leading cause of road kills during the amphibian breeding season, it is judged to be a factor that has a negative effect, so it was selected as a variable.[15] Elevation, aspect, and slope were also confirmed to have a close relationship with the habitat of amphibians living in Korea and were selected as variables.[22] Forests, wetlands, and paddies were often analyzed as the main habitats preferred by amphibians, whereas residential areas were selected as variables because they were identified as non-preferred habitats.[7]

The size of the grid for analysis was set to 100×100 m^2 considering the resolution of available data. To produce environmental variables suitable for the study target period, the land cover maps of 2000 and 2017 were used according to the two NNES periods.

2.3 Species richness and rarity

Species richness is the most representative indicator of the diversity of communities and regions. The most widely used method for calculating species richness is to determine the total number of species appearing in a given area. Species richness is used as a quantitative conservation goal in conservation studies.[23,24] Therefore, species richness was used as primary data for applied conservation biology studies, protected area planning, and spatial patterns and habitat changes.[25,26] In this study, a species distribution model was constructed for all target species, and a habitat suitability map with probability values ranging from 0 to 1 was prepared. Maximum training sensitivity plus specificity in which the sum of sensitivity (prediction rate of occurrence region) and specificity (prediction rate of non-occurrence region) is maximized was used to transform the probability into binary data with 0 (non-appearance) and 1 (appearance) values.[27–30] The species richness map was analyzed by overlapping the suitable habitat area for each species, which resulted in 0 and 1.

Table 2
Environmental variables.

Variable	Abbreviation	Type
Elevation	Elevation	Continuous
Slope	Slope	Continuous
Aspect	Aspect	Continuous
Stream order of watershed	Watershed	Continuous
Distance from forest	Forest	Continuous
Distance from residential area	Resi	Continuous
Distance from river	River	Continuous
Distance from road	Road	Continuous
Distance from paddy	Paddy	Continuous
Distance from wetland	Wetland	Continuous

$$SR = \sum_{i=1}^{n} S_i \, , \tag{1}$$

where n is total number of species found in the target area and S_i is the grid in which individual species appear (grid with a value of 1).

Amphibians are a taxon with a rapid extinction rate, and how rare amphibian species are distributed is essential information.(26,30) Species richness is limited in that it can be affected by the distribution of species having an expansive and suitable habitat area. Therefore, in this study, species rarity was analyzed to overcome the limitations of species richness and to consider the distribution of rare amphibians living in a limited area. Rarity was analyzed using the Rarity-Weighted Richness Index (RWRI) after inversely calculating the number of areas in which the target species appeared (the grid in which the target species was found) for each grid and then summing the areas up.(31) In other words, rarity indicates a high probability that a species with a narrow habitat range will appear, and the higher the number of rare species, the higher its value.

$$RWRI = \sum_{i-1}^{n} \frac{A}{h_i} \, , \tag{2}$$

where h_i is the number of grids in which species i was found, n is the total number of species found in the target area, and A is the total number of grids in the target area.

2.4 Conservation priority

The priority areas that need protection and conservation efforts were found by analyzing the species richness and rarity of amphibians based on the data from the second and fourth NNES projects. Changes in species richness and rarity over time can be divided into four groups (A–D) (Table 3): Group A with decreasing species richness and increasing species rarity, Group B with increasing species richness and rarity, Group C with increasing species richness and decreasing species rarity, and Group D with decreasing species richness and rarity.

Although the species richness in Group A was small, Group A was identified as an area with the highest conservation value owing to its high species rarity. Given the characteristic of Group B, as both species richness and rarity increase, Group B can be judged as an area with a relatively high conservation value. Groups C and D had low rarities so they could be the regions with relatively low conservation values. Therefore, it could be determined that Group A had the highest conservation value and Group B had the next highest conservation value.(19)

Table 3
Classification of groups according to changes in richness and rarity.

Group	Richness	Rarity
A	–	+
B	+	+
C	+	–
D	–	–

(–: Decrease, +: Increase)

3. Results

3.1 Model evaluation

Among the ensemble models for the nine amphibians analyzed in this study, the reliability of PMW was found to be the highest. Therefore, the reliability of PMW is summarized in Table 4. When examining the reliability of the models by species, the model with the lowest reliability also showed a value close to 0.6. Most of the models show reliability close to or exceeding 0.9. Since different species show different scales of reliability, the results should be interpreted considering the limit of reliability of the habitat suitability assessment. Since this study aims to analyze the richness and rarity of all target species, an SHA map of individual species is not included. To produce the appearance probability map as an SHA map, the cut-off value suggested in the PMW ensemble model was used (Table 4).

3.2 Richness

When the species richness distribution map of amphibians for the second and fourth NNES project periods was examined, it was found that the richness was generally highly centered on water (Fig. 4). However, it was confirmed that the area of regions with high richness decreased in the fourth NNES project data analysis.

Species richness in the second NNES project period was higher than that in the fourth. In the fourth NNES project period, areas with high species richness decreased, while areas with low species richness increased.

3.3 Rarity

In the analysis based on the data of the second NNES project, species rarity was found to be high in the high-altitude areas from Wangpicheon stream to Juwang-san mountain to Gweeryeong-san mountain. In the analysis based on the data of the fourth NNES project, the rarity of the entire region showed a tendency to decrease (Fig. 5). However, the high-altitude region showed a relatively higher rarity than the low-altitude region. In particular, the species rarity was high in relatively high-altitude areas such as Danyang-gun, Jecheon-si, and

Table 4
AUC value of each species for two target periods.

Species code	AUC value of each target period		Cut-off value	
	1997–2005	2014–2018	1997–2005	2014–2018
Huanren brown frog	0.943	0.885	0.445	0.465
Narrow-mouth frog	0.771	0.965	0.345	0.605
Korean red frog	0.808	0.789	0.476	0.599
Wrinkled frog	0.855	0.724	0.479	0.565
Black-spotted pond frog	0.920	0.596	0.530	0.587
Tree frog	0.925	0.614	0.515	0.572
Korean clawed salamander	0.908	0.977	0.372	0.514
Asian toad	0.893	0.852	0.519	0.520
Korean water toad	0.964	0.979	0.507	0.731

Richness in 1997–2005

Richness in 2014–2018

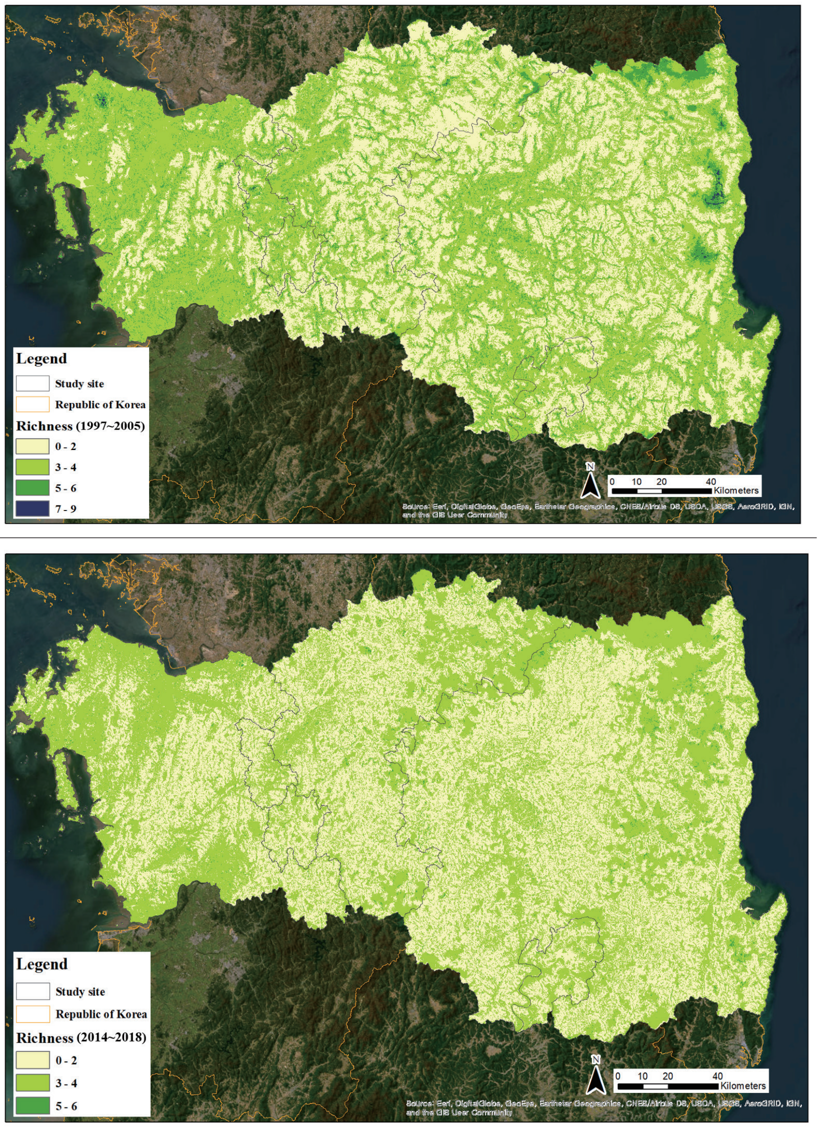


Fig. 4. (Color online) Species richness distribution by target period.

Mungyeong-si. In those regions, the suitable habitat areas of the Korean water toad and Korean clawed salamander were found to be large. On the other hand, the rarity tends to increase in the Taean Peninsula area located on the west coast of the ROK. It was identified to be the cause of the wide range of suitable habitat areas on the western coast for species such as the Huanren brown frog, narrow-mouth frog, Korean red frog, wrinkled frog, tree frog, and Korean water toad, compared with other regions.

A comparison of the rarities of the target species in the second and fourth NNES project periods showed that the rarities of the narrow-mouth frog, black-spotted pond frog, and Korean clawed salamander tended to increase. On the other hand, the rarities of the Huanren brown frog, Korean red frog, wrinkled frog, tree frog, and Korean water toad tended to decrease (Table 5).

Rarity in 1997–2005

Rarity in 2014–2018

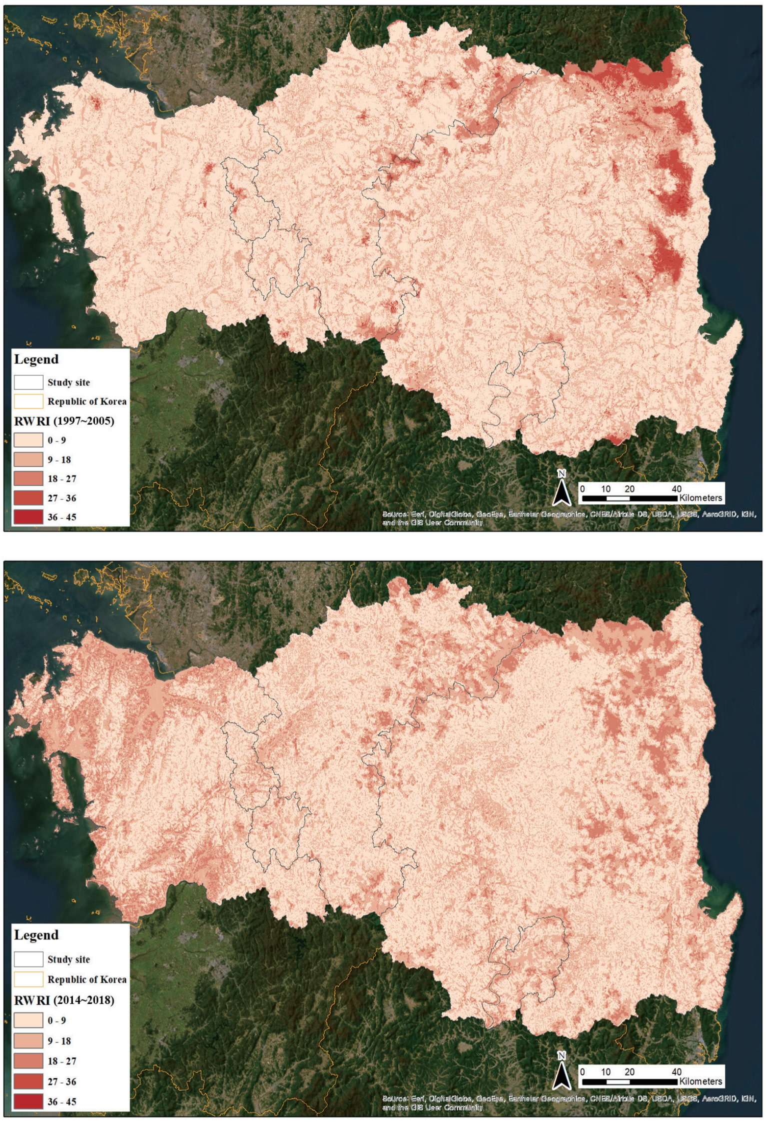


Fig. 5. (Color online) Species rarity distribution by target period.

Table 5
Changes in the rarity of target species according to the target period.

No.	Common name	1997–2005	2014–2018
1	Huanren brown frog	7.17	2.09
2	Narrow-mouth frog	1.58	7.59
3	Korean red frog	4.44	1.58
4	Wrinkled frog	3.42	2.23
5	Black-spotted pond frog	2.49	4.67
6	Tree frog	3.94	1.84
7	Korean clawed salamander	3.72	6.15
8	Asian toad	4.85	5.10
9	Korean water toad	12.67	8.83

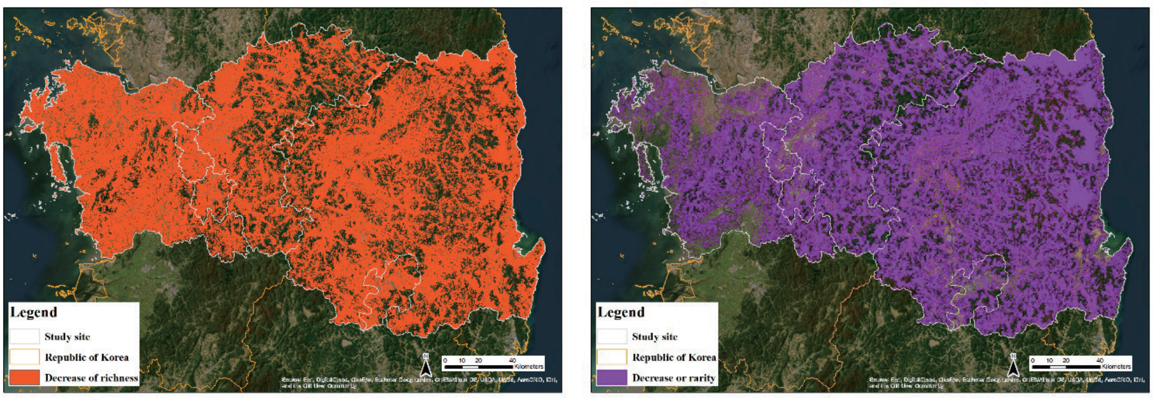
3.4 Conservation priority

A comparison of the results of amphibian richness and rarity analysis based on the second and fourth NNES project data showed that the regions where the richness and rarity decreased were as follows (Fig. 6). Species richness was confirmed to decrease in the area of 26032 km^2 out of the total area of 36537 km^2, whereas species rarity was confirmed to decrease in the area of 18373 km^2 out of the total area of the study site. Decreases in species richness and rarity were observed in fairly large areas.

The spatial distributions of the four change groups in terms of richness and rarity were as follows (Fig. 7). Group A, defined to have the highest conservation value, was found to be most widely distributed in Chungcheongnam-do, Sejong-si, and Daejeon-si, located to the west of the Central ROK. In addition, it was widely distributed in the central region of Gyeongsangbuk-do, located to the east of the Central ROK and the eastern coastal region. The area of the study site belonging to Group A was 8503 km^2. Group B, which has the next highest conservation value, was evenly distributed in the central and eastern regions of the study site. The area of the study site belonging to Group B was 9620 km^2. To efficiently manage the habitats of amphibians, it would be good to set the conservation priority focusing on the areas where Groups A and B are located.

4. Discussion

Amphibian habitats may have different significant threats due to different types of land use at different altitudes. When comparing SHAs for each type of change in species richness and rarity according to altitude, it was found that the areas of Groups A and D, which had low species richness, were larger at lower altitudes. This shows that the habitat loss or disturbance in the low-altitude area was high. Group B, which can increase the importance of conservation in the future due to both high species richness and rarity, occupied the largest area in the 200–400 m section. Considering rarity, unique spaces such as high-altitude areas can be preserved



(a) (b)

Fig. 6. (Color online) Decreases in richness and rarity based on second and fourth NNESs. (a) Decrease in richness and (b) Decrease in rarity

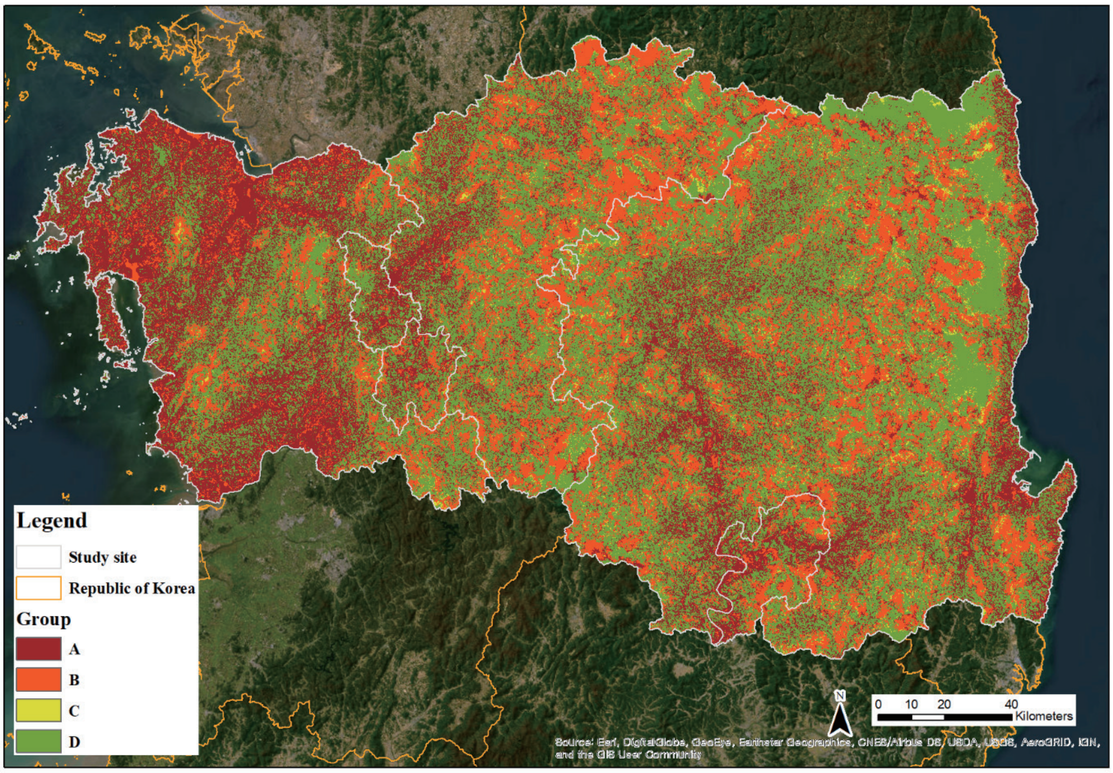


Fig. 7. (Color online) Areas are estimated to have high conservation and conservation priorities given the amphibian richness and rarity changes. Group A was an area with the highest conservation value owing to its high rarity. Group B, wherein as more species appear, rarity increases, can be judged as an area with the second highest conservation value. Groups C and D had relatively low conservation values.

preferentially. However, through this study, conservation priorities should be considered, even in the case of small hilly areas or low-altitude forests. On the other hand, the areas, including the case of Group C, which increases in richness and decreases in rarity, were found to be most widely distributed at an altitude of 200–400 m, although not relatively wide. Therefore, it can be predicted that the areas of Group C may gradually increase when habitat loss and disturbance due to development occur in natural areas at the height of 200–400 m (Table 6).

According to a study that analyzed the changes in the richness of amphibians due to urbanization at three different spatial scales—city, region, and country—the negative impact of urbanization was more severe at a small scale such as a city.[(13)] In the case of a large area such as a region or a country, the change in richness may be small because the area that amphibians can use as an alternative habitat is wide. In addition, the land cover structure that connects forests and wetlands is essential for amphibians to inhabit well. However, since such structures are difficult to find in urban areas, the richness of amphibians was lower in urban wetlands than in rural wetlands.[(14)] To conserve amphibians, it is judged that it is most important to maintain regional diversity by connecting migration routes, securing sufficient habitats that serve as buffers, and conserving regions with various hydroperiods.

Considering the impact of urbanization in previous studies, we also looked at the distribution of richness and rarity changes by group according to the distance from the road. As a result, we

Table 6
Areas of each group for distribution of richness and rarity changes (A–D) according to altitude. The unit for area is ha.

Group	Altitude (m)						
	0 –200	200–400	400–600	600–800	800–1000	1000-1200	1200-1423
A	752492	61983	20373	7730	5316	2287	199
B	242301	449385	182219	68553	18829	724	15
C	3630	48161	26897	5465	324	–	–
D	969195	493287	188386	68139	24792	7633	1369

found that all groups were more widely distributed as they were closer to the road (Fig. 8). Group D occupies the largest area close to the road, and it has a low conservation priority and a relatively low conservation value.

However, even in the case of Groups A and B, which have a high conservation priority, they showed a large area close to the road, and Group A showed more than half the area of Group D. Therefore, it is judged that a detailed investigation of the area within 500 m from the road is necessary when searching for an area that needs to be preserved in the future. In general, the closer an area's distance is from the road, the more difficult it is for amphibians to inhabit it, and the higher the possibility that it will be affected by urban development projects.[32] Therefore, it is necessary to quantitatively grasp the impact of development on Groups A and B by monitoring the areas close to the road.

On the other hand, Pyron confirmed that not all amphibians are declining in species richness owing to human activity.[16] Some species can increase their richness by acquiring ecological benefits from human activities. Nowakowski *et al.* revealed that 81% of species showed a decrease in richness, but 19% tended to increase, as mentioned earlier.[17] Therefore, some amphibians can coexist in areas with human activities, so it is judged that a different management strategy is needed depending on the characteristics of the amphibians living in those areas.

As such, it is necessary to consider the following strategies for the habitat management of amphibians. First, the areas with high richness should be managed. Second, differentiated management in consideration of altitude is required. Third, it is necessary to improve connectivity and secure buffer zones in areas close to the road or adjacent to the city. Fourth, management is necessary considering the characteristics of the target species. In particular, establishing an appropriate management strategy considering the target area and the characteristics of the target species will help in effective amphibian habitat management.

5. Conclusion

In this study, the SHAs of nine amphibians were analyzed, and species richness and species rarity were derived on their SHAs. Spatial changes in species richness and rarity over time were identified using data from different periods. Change groups were derived on the basis of the increase and decrease in the species richness and rarity of amphibians, and the distribution of each group according to the altitude and distance from the road was identified. Through this, we searched for areas that needed conservation first.

The model for some species showed low reliability. The model's reliability for biological species may be low owing to various limitations. First, it is a case where all habitat characteristics

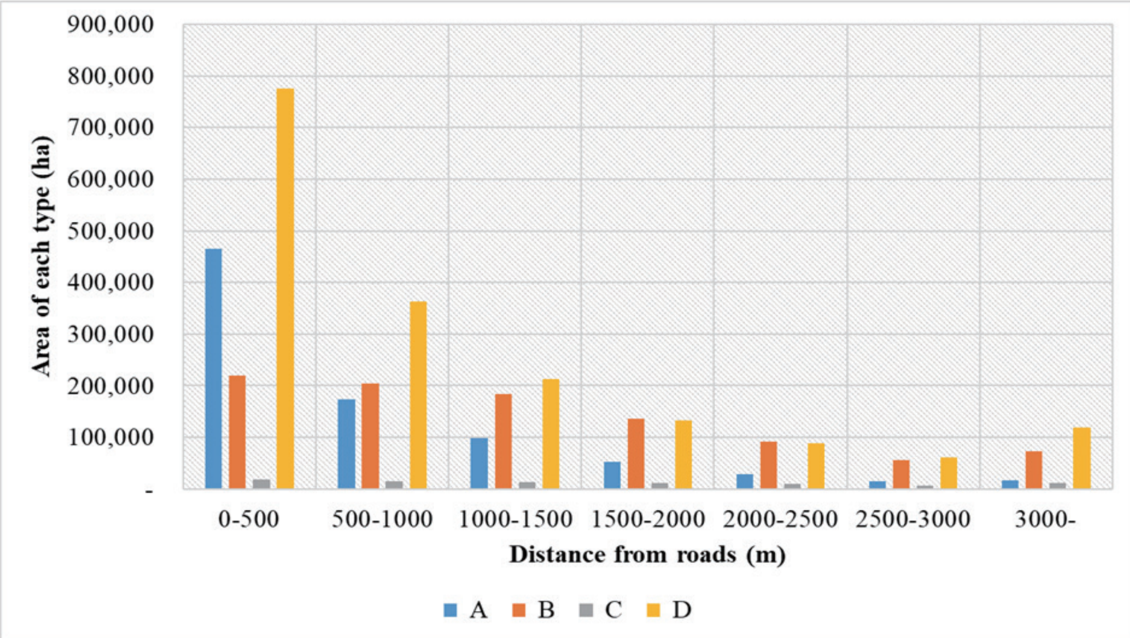


Fig. 8. (Color online) Distribution according to the distance from the road by species richness and rarity changes.

of the target species cannot be interpreted only from the point of appearance. There is a possibility that the environmental variables not applied owing to the limitations of the establishment of environmental spatial information were necessary for the model of the target species. Second, there is a limitation of the survey data. In this study, the point of appearance of amphibians was not investigated by setting a specific season, but the point of appearance of amphibians may vary by season. Therefore, to build a more reliable model, it is necessary to investigate the occurrence point by season and search for habitat characteristics considering the spawning characteristics of amphibians.

There was insufficient data on the occurrence point of species in the second survey of the narrow-mouth frog and in the fourth survey of the Korean water toad. This is because points in urbanized areas were excluded compared with land use data. Although the number of points of appearance was small, fortunately, the models for this species could obtain some degree of reliability. It is necessary to improve the model by securing additional occurrence points through field investigations in the future. If recently investigated occurrence points are added, changes in amphibian habitats can be tracked, and additional discussions on the change factors of SHAs are expected to be possible. This study is expected to be utilized as a research system for conserving amphibians in countries with a climate like the ROK's. It will help identify amphibians' habitats that should be preserved first when establishing a development plan. In addition, this study has important significance as part of efforts to conserve biodiversity.

Acknowledgments

Prof. Kim was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. RS-2022-00165578), and Prof. Mo was supported by the 2021 Yeungnam University Research Grant. We would like to thank NIE for providing the wildlife data used in the National Natural Environment Survey project.

References

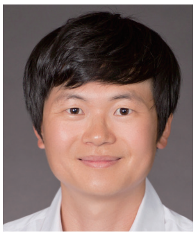
1 S. I. Zandalinas, F. B. Fritschi, and R. Mittler: Trends Plant Sci. **76** (2021) 588. https://doi.org/10.1016/j.tplants.2021.02.011
2 L. A. Rollins-Smith: Herpetologica **76** (2020) 178. https://doi.org/10.1655/0018-0831-76.2.178
3 S.-H. Park and Y.-C. Youn: Sustainability **13** (2021) 1594. https://doi.org/10.3390/su13041594
4 D. Kim, W. Shin, H. Choi, J. Kim, and Y. Song: Sustainability **12** (2020) 9529. https://doi.org/10.3390/su12229529
5 M. S. Do, J.-W. Lee, H.-J. Jang, D.-I. Kim, J. Park, and J.-C. Yoo: Korean J. Env. Eco **31** (2017) 381. https://doi.org/10.13047/KJEE.2017.31.4.381
6 J.-H. Jung, E.-J. Lee, W.-S. Lee, and C.-D. Park: J. For. Res. **24** (2019) 349. https://doi.org/10.1080/13416979.2019.1693479
7 J.-Y. Song, M.-S. Kim, I.-S. Kim, T.-H. Kim, I. Roh, S.-W. Seo, E.-K. Seo, J.-K. Seo, J.-Y. Yang, K.-D. Woo, H.-J. Won, Y.-G. Lee, Y.-H. Lim, S.-H. Han, and M.-G. Moon: Kor. J. Env. Eco. **23** (2009) 187.
8 S. Jeong, C. Seo, J. Yoon, D.K. Lee, and J. Park: J. Environ. Impact Assess **24** (2015) 175. https://doi.org/10.14249/eia.2015.24.2.175
9 B. Amaël and Y. Jang: Front. Environ. Sci. **7** (2019) 39. https://doi.org/10.3389/fenvs.2019.00039
10 M.-J. Hur, B.-H. Han, and J.-I. Kwak: J. Korean Env. Res. Tech. **20** (2017) 1. https://doi.org/10.13087/kosert.2017.20.6.1
11 S. I. Lee, J. I. Seo, S. W. Kim, and K. W. Chun: J. Korean Soc. For. Sci. **108** (2019) 241. https://doi.org/10.14578/jkfs.2019.108.2.241
12 W. Song: J. Korean Env. Res. Tech. **18** (2015) 71. https://doi.org/10.13087/kosert.2015.18.1.71
13 P. Lin, Y. Lu, and S. Zhao: Environ. Res. Commun **2** (2020) 125002. https://doiorg/10.1088/2515-7620/abd1c5
14 M. J. Rubbo and J. M. Kiesecker: Conserv. Biol. **19** (2005) 504.
15 J. Wang, Y.-H. Liu, K. Martin, and F. Luo: Global Ecol. Conserv. **20** (2019) e00694. https://doi.org/10.1016/j.gecco.2019.e00694
16 R. A. Pyron: PNAS **115** (2018) 3739. https://doi.org/10.1073/pnas.1803477115
17 A. J. Nowakowski, L. O. Frishkoff, M. E. Thompson, and B. D. Todd: PNAS **115** (2018) e3454. https://doi.org/10.1073/pnas.171489111
18 C. Hof, M. B. Araujo, W. Jetz, and C. Rahbek: Nature **480** (2011) 516. https://doi.org/10.1038/nature10650
19 H. G. Kim and Y. Mo: Korean J. Environ. Ecol. **35** (2021) 24. https://doi.org/10.13047/KJEE.2021.35.1.24
20 Package 'biomod2' Manual: https://biomodhub.github.io/biomod2/ (accessed April 2024).
21 D.-K. Lee and H.-G. Kim: J. Korean Env. Res. Tech. **13** (2010) 161.
22 J.-Y. Song, and I. Lee: Korean J. Herpetology **13** (2009) 15. https://www.earticle.net/Article/A188077
23 A. E. Magurran: Ecological Diversity and Its Measurement, (Princeton University Press, United States, 1988).
24 N. J. Gotelli and R. K. Colwell: Ecol. Lett. **4** (2001) 379. https://doi.org/10.1046/j.1461-0248.2001.00230.x
25 C. H. Graham and R. J. Hijmans: Global Ecol. Biogeogr. **15** (2006) 578. https://doi.org/10.1111/j.1466-8238.2006.00257.x
26 J. Kim, C. Seo, H. Kwon, J. Ryu, and M. Kim: J. Environ. Impact Assess **21** (2012) 593. https://doi.org/10.14249/eia.2012.21.4.593
27 J. Hu and Z. Jiang: PLoS ONE **6** (2011) e22873. https://doi:10.1371/ journal.pone.0022873
28 C. Heibl and S. S. Renner: Syst. Biol. **61** (2012) 823. https://doi.org/10.1093/sysbio/sys034
29 S. W. Jeon, J. Kim, H. Jung, W.-K. Lee, and J.-S. Kim: J. Korean Env. Res. Tech. **17** (2014) 111. https://doi.org/10.13087/kosert.2014.17.1.111
30 J. Kim, H. Kwon, C. Seo, and M. Kim: J. Environ. Impact Assess **23** (2014) 453. https://doi.org/10.14249/eia.2014.23.6.453

31 B. A. Stein, L. S. Kutner, and J. S. Adams, eds. (Oxford University Press, New York, 2000). https://doi.org/10.1093/oso/9780195125191.001.0001

32 A. J. Hamer, B. Barta, A. Bohus, B. Gal, and D. Schmera: Global Ecol. Conserv. **28** (2021) e01663. https://doi.org/10.1016/j.gecco.2021.e01663

About the Authors

Ho Gul Kim received his B.Sc., M.Sc., and Ph.D. degrees from Seoul National University, Korea, in 2010, 2012, and 2017, respectively. Since 2018, he has been a professor at Cheongju University. His research interests include climate change impact and risk, data-based disaster analysis, and habitat suitability modeling. (khgghk87@gmail.com)



Chan Park received his B.S., M.S., and Ph.D. degrees from Seoul National University, Republic of Korea, in 2007, 2009, and 2012, respectively. From 2012 to 2015, he was a research associate at the National Institute for Environmental Studies, Japan. Since 2016, he has been a professor at the University of Seoul, Republic of Korea. His research interests are in climate change, quantitative spatial economy, and spatial statistical modeling based on big data. (chaneparkmomo7@uos.ac.kr)

Yongwon Mo received his B.S., M.S., and Ph.D. degrees from Seoul National University, Republic of Korea, in 2008, 2014, and 2018, respectively. From 2018 to 2019, he was a research associate at the National Institute for Environmental Studies, Japan. Since 2019, he has been a professor at Yeungnam University, Republic of Korea. His research interests are in systematic conservation planning, landscape ecology, and sensors. (webzin12@gmail.com)