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Identifying high-priority conservation areas for endangered waterbirds using a flagship species in the Korean DMZ

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ABSTRACT

The Hangang River and Imjingang River estuaries in Korea are part of the main transit route for many migratory birds that use the East Asia-Pacific flyway. Despite the global importance of this area as a seasonal bird stopover site and resting area, conservation areas have not been established in this area based on ecological properties. This study aimed to examine the umbrella effect of the white-naped crane (*Antigone vipio*), which is one of the best-known flagship species in East Asia, and to determine the effectiveness of establishing a conservation plan in the western DMZ based on the distribution of white-naped cranes. Species distribution modeling was performed for the white-naped crane; other threatened waterbirds wintering in the western DMZ; Group 1, including species with ecological traits similar to those of the white-naped crane; and Group 2, including species with ecological traits different from those of the white-naped crane. The modeling was based on field survey data from a citizen science project, and a systematic conservation planning approach was adopted for each species group. The results showed no significant differences between the plan for the target species and the plans for the other species groups, indicating that protecting white-naped cranes habitat can also protect the habitat of other threatened waterbirds.

1. Introduction

The Imjingang River and the Hangang River estuaries in Korea are part of the main transit route for many migratory birds that use the East Asia-Pacific route and are important places for a variety of seasonal birds (Archibald and Meine, 1996). The rivers are part of the western demilitarized zone (DMZ) area of Korea, and the geographic features of the area such as the sedimentary layer of the river estuaries and the vast plains provide favorable conditions for birds (GRI, 2008). That being so, endangered birds such as cranes, eagles, vultures, and geese come to the estuary of the Hangang-Imjingang River (Kang et al., 2008). However, conservation planning in these areas has been neither clear nor based on biodiversity information (but *see* KEI, 2003). Most importantly, there is no conservation plan for the Imjingang River despite its biological importance.

Even worse, heavy development pressures that threaten the survival of a variety of wildlife exist in the Hangang-Imjingang River estuary and the western DMZ (John, 1998). The proximity to the metropolitan areas provides advantages for development activities (Koh, 2019; Sung and Cho, 2012). In addition, as inter-Korean relations improve, the sense of expectancy may encourage property speculation (Park and Paek, 2019). Currently, the trend of cultivating cash crops such as ginseng is another threat to regional biodiversity (Kim et al., 2006; Park and Nam, 2013; Sung et al., 2016). In short, despite the ecological value of the Korean DMZ, military activities, geopolitical factors, and economic feasibility make it a challenge to design conservation plans for this area.

Recently, long-term monitoring data from citizen science have emerged as an effective means for conservation planning (Coxen et al., 2017; Gouraguine et al., 2019; Parsons et al., 2018). Citizen science data can be used widely, but in general, they are inclined to focus on charismatic species that are easier to distinguish than many less recognizable species (Chase and Levine, 2016; Morelli et al., 2017; Sequeira et al., 2014). Although flagship species concept including charismatic species has been utilized regardless of the species' status or influence in the ecosystem, it is worth examining the status of the flagship species in the certain ecosystem as the effectiveness of a conservation policy may have high relevance to public awareness (Caro et al., 2004). In this study, the umbrella effect of the white-naped crane (*Antigone vipio*), a charismatic species representing the western DMZ

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ecosystem, including the Hangang-Imjingang River estuaries was investigated.

To propose a conservation plan for the Hangang-Imjingang River system from an ecological perspective, it is necessary to consider the ecosystem characteristics with species distribution and biodiversity. The species distribution modeling (SDM) and the systematic conservation planning (SCP) were applied to generate a cost-efficient conservation plan that reflects biogeographical factors as well as various interests or costs, including social and political factors (Margules and Pressey, 2000). Therefore, an optimal conservation plan of the Hangang-Imjingang River estuary could be developed.

The objectives of this study are (i) to investigate whether protecting the habitat of white-naped cranes is effective in preserving the habitats of other endangered birds regardless of their ecological characteristics, and (ii) to establish an effective and cost-efficient conservation plan for migratory birds that use these river estuaries.

2. Materials and methods

2.1. Target species

Cranes are known as one of the most ancient families of birds on earth and are now globally endangered; they are large and beautiful, with unique calls and complex behaviors (Archibald and Meine, 1996). Three crane species that are near extinction spend the winter on the Korean Peninsula: the red-crowned crane (*Grus japonensis*), the white-naped crane (WNC, *Antigone vipio*), and the hooded crane (*Grus monacha*). Of these three cranes, a number of WNCs come to the Hangang-Imjingang River estuary and the western DMZ in winter (Archibald and Meine, 1996; Lee et al., 2012; NIBR, 2019). The WNC, one of the most famous birds in Asia that uses the East Asian flyway, is a migratory bird that breeds in the Amur River basin and flies to Korea, China, and Japan in winter. The number of WNCs has been estimated at as many as 6250–6750 individuals based on recent counts; 500–1000 individuals winter in China and approximately 5750 winter in Korea and Japan (IUCN, 2019). In Korea, the wintering population of WNCs amounts to 2645–3278 (NIBR, 2019). Until the 1980s, the Hangang-Imjingang River estuary was the largest wintering site for cranes in Northeast Asia, and up to 3000 individuals were found there (Won, 1986). Currently, the population of WNCs has drastically decreased, and thus, only 200–300 stay in this region in winter. However, the Korean Peninsula is still an important habitat and stopover site for cranes because they must pass through Korea when moving from Russia and China to Japan (Higuchi et al., 1998).

Cranes are exceptional flagship species (Han et al., 2018; Senzaki et al., 2017) and are now indicators of a sound environment and symbols of ecotourism (e.g., Lee, 2004). Especially in East Asia, cranes have been beloved as a symbol of health and longevity and protected as divine creatures for thousands of years (Kim et al., 2011). Thus, public awareness of cranes is high, and as such, cranes have been used as flagship species for protecting regional natural ecosystems in East Asia (Kim et al., 2011; Senzaki et al., 2017; Wu et al., 2014). Their large size make them easy to find, they have loud cries, and they are clearly distinguished from similar species, making it easier to identify their distributions due to the low probability of misclassification. As the migratory path from breeding sites to wintering sites shows, the Korean Peninsula is a particularly important habitat for cranes (Lee et al., 2012; Won, 1986). Therefore, this study aims to determine how effective conservation planning based on WNC habitats is in terms of habitat conservation for other threatened birds that rely on wetlands.

2.2. Study site

The Hangang River is the largest river in the Republic of Korea (ROK) and has a length of 494 km (Ministry of Environment, 2020). The mainstream of the Hangang River flows through Seoul, joining the Imjingang River, which is the first branch of the Hangang River, from Paju, Gyeonggi-do Province and then entering the Yellow Sea. Therefore, the Hangang River and the Imjingang River are not separated but rather form a unified biosphere. On the border of the Democratic People's Republic of Korea (DPRK) in Kaepung-gun County, access to some areas of the Hangang River is restricted for military reasons, and the surrounding area is also designated a military reservation, which has prohibited large development projects until recently.

The Hangang-Imjingang River is an essential element of the western DMZ that has been strictly off-limits to people and protected from human disturbance for 7 decades; thus, it has unintentionally become a sanctuary for wildlife. The Hangang River estuary is an invaluable habitat for numerous migratory birds and threatened species that are protected internationally. However, due to overcrowding and overdevelopment in the Seoul metropolitan area, it has become a watershed with a high environmental pollution load. In addition, due to the military confrontations and tension sparked by the North-South division, there are many restrictions on potential adequate ecological management strategies.

2.3. Bird surveys

The total number of bird survey days was 113 and the surveys were regularly performed on weekends except a few days when the army disapproved the entrance into the civilian control zone (CCZ) from October 2014 to March 2019. The experts and citizen scientists who participated in the surveys were 96 in total and the citizen scientists were trained before the surveys. The monitoring was performed with four research teams across the study area in the Hangang-Imjingang River and the western CCZ surrounding the DMZ. Each team which consisted of one expert and several citizen scientists surveyed the avian biota along a specific route covering the whole western area of the DMZ region for 3 h in the morning. Investigators recorded the GPS location of all the regionally or internationally threatened species that are legally protected in ROK (Ministry of Environment, 2020) or are on the IUCN Red List of Threatened Species (2019).

2.4. Land use classification of the study site

The target area for determining the habitat of birds was the Hangang-Imjingang River estuary in the Paju area, and a 10 km buffer was created based on the national river boundary (Fig. 1). The buffer was established based on the activity range of the birds. The planning units (PU) were hexagonal, the length of one side of the hexagonal lattice was 500 m, and a total of 2083 hexagonal cells were arranged in a grid (Fig. 2). In addition, the study area includes the nationally protected wetland area, including the place where 1500–2000 WNCs visited in 1980. Land use and land cover (LULC) were classified as grassland, forest, artificial structure, paddy field, water, and bare land by the support vector machine method (Chang and Lin, 2011) using a satellite image from LANDSAT 8 on August 26th, 2017. For classification accuracy, the region of interest (ROI) was determined through field surveys and Google Earth images. Seventy percent of the ROI was used as training data, and 30% was used as testing data. The kappa value was 0.9, and the overall classification accuracy was 95%. LULC analyses and mapping were conducted using ENVI 5.1.

2.5. Species trait-based clustering

To investigate the umbrella effect of protecting WNC habitat, the birds were clustered into groups based on their ecological traits. The functional traits utilized were diet, foraging location, and morphological features as continuous traits (Wilman et al., 2014) and habitat location as a categorical trait (Lee et al., 2009; Takagawa et al. 2011) (Table 1). The number of clusters was determined using the NbClust package (Charrad et al., 2014), and the clustering was based on ward

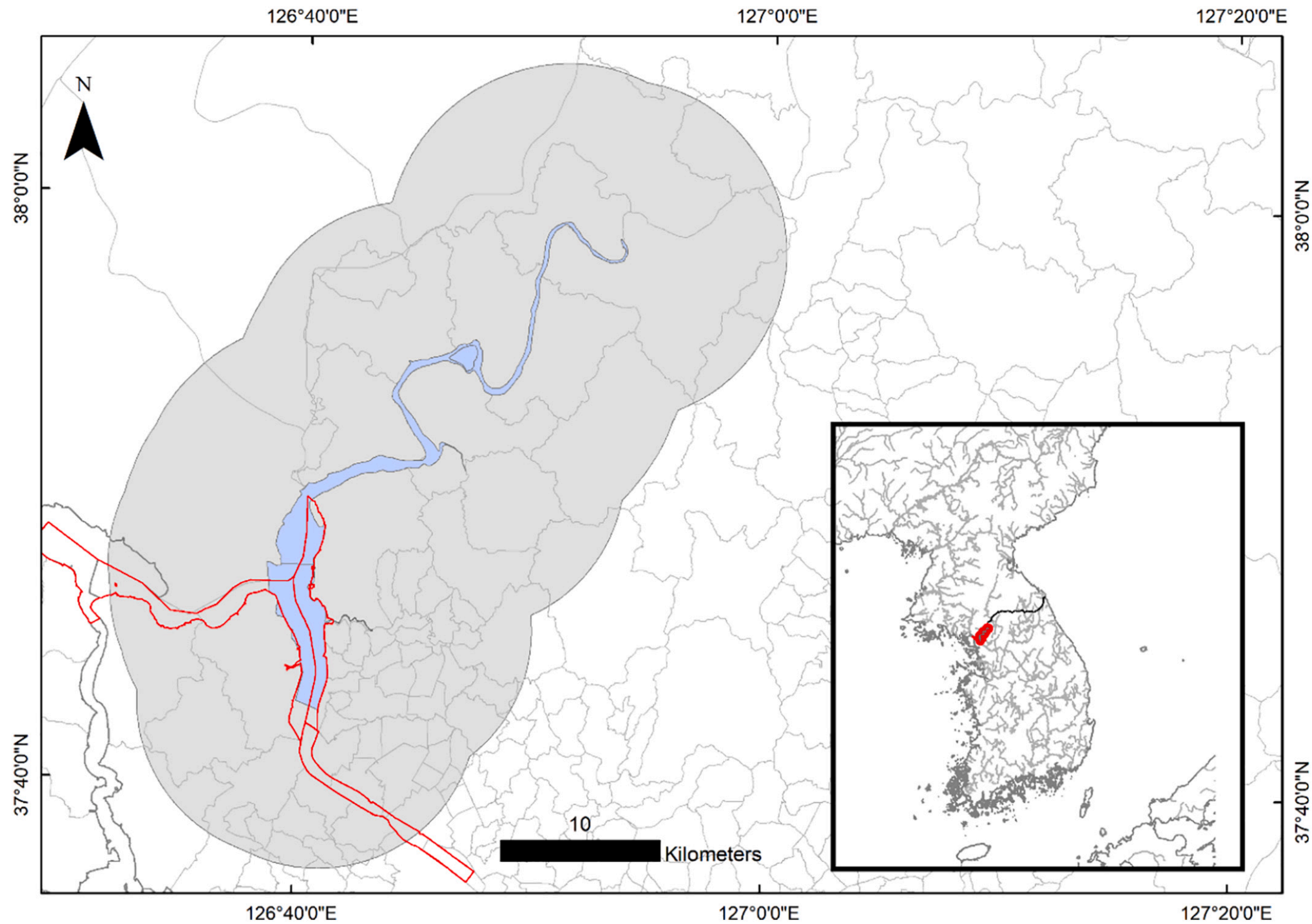

Fig. 1. Map of the study site. The blue polygon indicates the Hangang-Imjingang River. The red line indicates the nationally protected wetland area. The gray area indicates the region of interest for systematic conservation planning. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

distance and the vegan package in R. In addition, NMDS portrayed the properties of the groups. One group comprised mostly waterbirds that had traits in common with WNC, and the other group consisted of terrestrial birds that had ecological traits unlike those of WNC.

2.6. Species distribution

Based on the field survey data, species distribution models for all cases were acquired to model the distribution of the species or groups to be extended (extrapolate) to this study site. Moreover, the crane populations in the DPRK were observed, but modeling was required to overcome the limitations of distance.

Maxent ver. 3.3.3 was used to perform the SDMs. Maxent suits the purpose of this study, as it estimates the probability of distribution according to habitat properties (Liang et al., 2018). 2088 points out of 6720 points were removed that the spatially autocorrelated occurrence points with a resolution of 32.8 m to rarefy data using SDMtool box (Brown, 2014). The size of resolution was derived from the average distance nearest neighbor with ArcGIS 10.2. The environmental factors used for modeling were digital elevation model (DEM), LULC, normalized difference vegetation index (NDVI), and aspect. LULC and NDVI were analyzed using a LANDSAT 8 image, and the DEM used was the ASTER Global DEM (30 m resolution). Seventy percent of the data were used for the model training, and 30% were used as test data. Bootstrapping was performed in the replicate run 100 times, and the iterations were fixed at 1000. The jackknife method was adopted to assess the importance of variables in the final model (Phillips et al., 2006).

Six-year average abundance data for the bird species were included in the PU, and the distribution of the WNC and the species distributions of all threatened species birds, including that of WNC, were examined. Finally, the 10% threshold was established to distinguish between suitable habitat and unsuitable habitat, and the differences in the distribution of each target were confirmed. In addition, the habitats of the WNC and the places where WNC do not overlap with the habitats of other species were identified by satellite images and field surveys to determine the environmental and landscape factors. The final outputs of the model predictions were exported to ArcGIS 10.1 for further analyses.

2.7. Systematic conservation planning

SCP can be performed using Marxan software (Watts et al., 2009), which is based on a heuristic simulated annealing algorithm. Marxan is comprehensive, cost-effective, and compact, which allows multiple targets to be assessed, strategies to be identified that lower costs, and appropriate solutions to be found for SCP (Watts et al., 2009). To achieve complementarity, the most important concept of SCP, Marxan uses the following formula to construct the optimal conservation network:

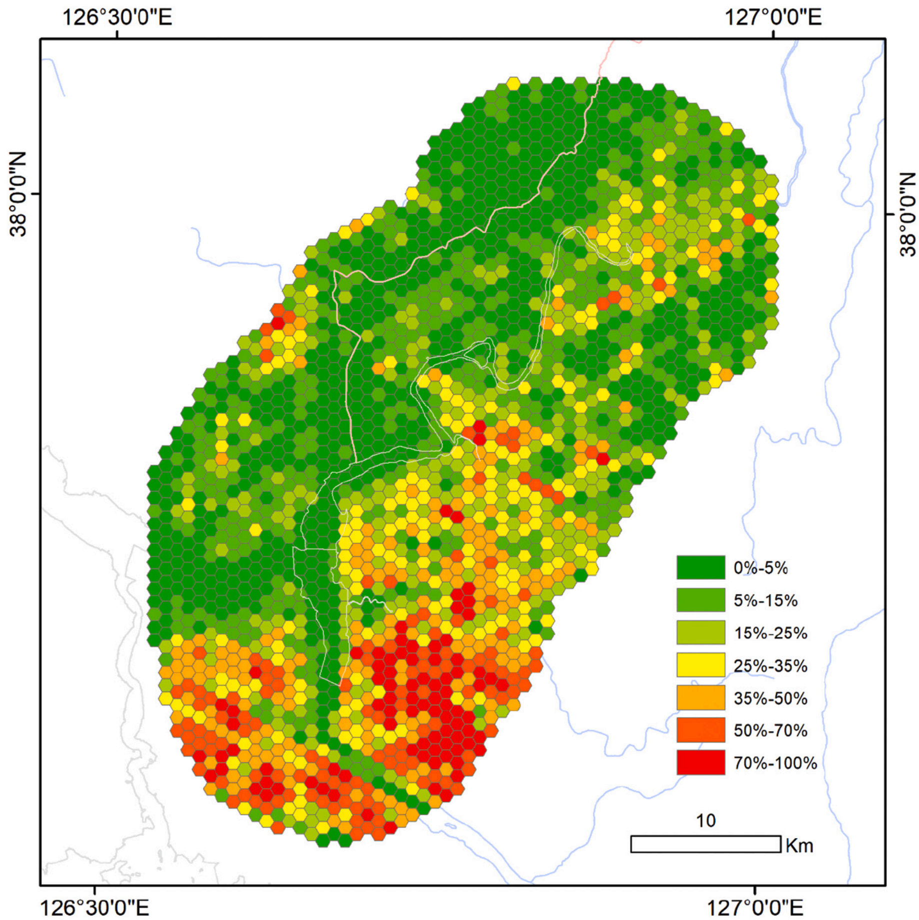

Fig. 2. Planning units showing the intensity of anthropogenic activity, which was used as cost data in the SCP model.

Objective function

$$= \sum \textit{Planning units cost} + \textit{Boundary Length Modifier}\ \mathrm{X} \sum \textit{Planning units Boundary} + \sum\nolimits_{\textit{Conservation feature}} \textit{SPF}\ \mathrm{X}\ \textit{Feature penalty}$$

The PU cost was calculated based on anthropogenic activities. For example, the urban, agricultural, and artificial structures were converted to the PU cost (Fig. 2). This is because they would be calculated into the expenses of acquiring those areas as designated protected areas. Meanwhile, since the LULC data from the DPRK were not available in the ROK, we analyzed LULC based on satellite images. In particular, the anthropogenic activities in the DPRK comprised bare land, as the forest or grassland cover in the DPRK was likely to be transformed into bare land (Park, 2014; Seo, 2008). Thus, we put the built-up areas and barren soil into the range of the PU costs in the DPRK region.

For bird species, the species penalty factor (a scaling factor) was set to 100% to make species conservation a priority and to minimize the number of missing targets. We also intended to develop conservation planning scenarios by assigning values between 40 and 100% for habitats (Table 2). Finally, the penalty that represents the shape and level of clumping of the prioritized areas was adjusted by the boundary length modifier (BLM). We set BLM 1 such that the possible simulated habitat would be clustered as closely as possible.

The model scenario was performed 200 times with the PU containing more than 95% of the conservation target, and the number of iterations in each round was 1000,000. Then, the 'best solution' was mapped accordingly. We tried to determine whether the best solution

Table 2
Summary of conservation targets for different landscape elements in SCP.

Type	Target (%)
River or Waterbody	100%
Paddy field	80%
Grassland	80%
Forest	40%
River sediments	90%

Table 1
Summary of functional traits and avian functional diversity indices.

Category	Trait	Unit and trait type
Diet	Invertebrates, Vertebrates, Herptile, Fish, Unknown, Decaying biomass,DecaDec Fruit, Nectar, Seed, Plant	Percentage (Continuous data)
Foraging location	Water (below surface, around surface), Ground, Tree (understory, mid-high, canopy), Aerial	Percentage (Continuous data)
Morphology	Body mass	Grams (Continuous data)
Migrant	Migration (migratory status in the winter)	1: Migratory, 0: Resident (Binary data)
Habitat location	Urban area, Agricultural area, Coast, Lake-river, Wetland, Grassland, Forest, Mountain	1: Yes, 0: No (Binary data)

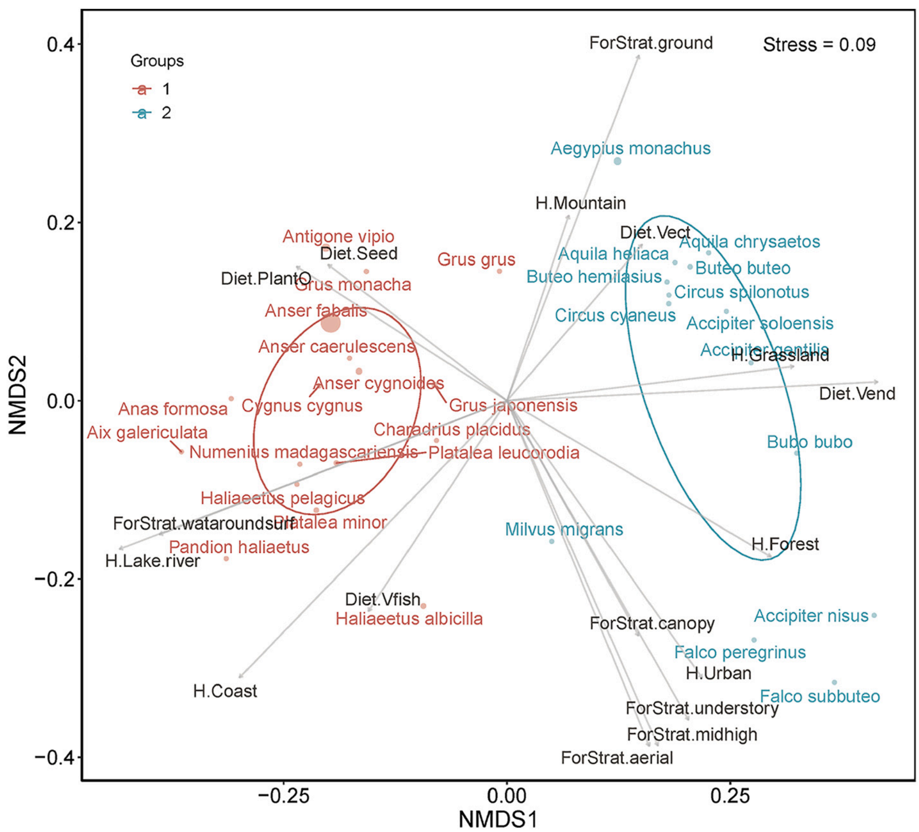

Fig. 3. Bird species clusters based on their functional traits, such as diet, foraging location, morphological features, and habitat location. White-naped crane, the focal species of the study, belongs to Group 1.

matched the habitat of WNC or of other avian species. Eventually, we identified how priority areas can be effectively defined for migratory birds using wetlands and their vicinity. SCP was performed using the Qmarxan plugin in Qgis.

3. Results

3.1. Threatened species characteristics

A total of 31 species of threatened birds were found over the last six years, with a cumulative population of 389,460 *(Supplementary data, Table S1)*. The threatened avian species were classified into two groups *(Fig. S1)*. The species in Group 1, which includes WNC, consume mostly plants and seeds and live mainly in waterbodies such as rivers, lakes, estuaries, and so on. The species that belong to Group 2 are predatory and prefer to live in forests and grasslands (Fig. 3).

3.2. Species distribution models

The average AUC for the model of all the threatened species ($n = 4623$) was 0.890. In terms of species distribution, DEM made the highest contribution to the species distribution (70%), followed by LULC (24%). The average AUC of Group 1 was 0.825, and DEM (68.9%) and LULC (30.5%) contributed strongly to the species distribution. Finally, the average AUC of Group 2 was 0.846, and DEM (80.3%) and LULC (16.2%) were notable contributing factors. The mean AUC of WNC ($n = 1263$) was 0.903, and DEM (65.8%) and LULC (26.6%) contributed greatly to the distribution. The distribution of WNC was approximately 95% consistent with the distribution of all the threatened species, 88.7% consistent with the distribution of Group 1 ($n = 3714$), and 81.9% consistent with the distribution of Group 2 ($n = 900$) (Fig. 4).

Many bird species, including the WNC, were observed to be distributed along the body of water. Moreover, it was expected that there might be many migratory birds in the agricultural lands of the DPRK.

3.3. Systematic conservation planning

As a result of applying SCP to the distribution of WNC, 1162 PUs (55.8%) were selected as the best solution for the conservation area. For all the threatened species, 1178 PUs (56.5%) were selected as the optimal conservation area. The preferences of Group 1 resulted in the selection of an optimal conservation area of 1170 PUs (56.1%). Group 2 could be preserved with the selection of 1170 PUs (56.1%) for their conservation area. The selected areas for Group 1 and Group 2 were different.

The best determined solution included the DMZ and the areas that belong to the DPRK within the study area as the prioritized conservation areas regardless of the various SCP options. Overall, the PUs selected for the conservation area designation across the Hangang-Imjingang River estuary and the DMZ area were found to be the most efficient way to conserve the habitat for a variety of bird species.

Furthermore, the similarities among the SCP results were confirmed based on the different target species for protection, i.e., WNC, all threatened species, Group 1, and Group 2. The plan targeting the WNC habitat preferences and the plan targeting Group 1 had the most similar results, with 0.7% difference. Meanwhile, the plan for all threatened species and the plan for the WNC showed the greatest differences, at 1.4%. Overall, the results indicated that the WNC-centered monitoring-based SCP result corresponded to the other wintering birds' habitat-based SCP results with high similarity (Fig. 5).

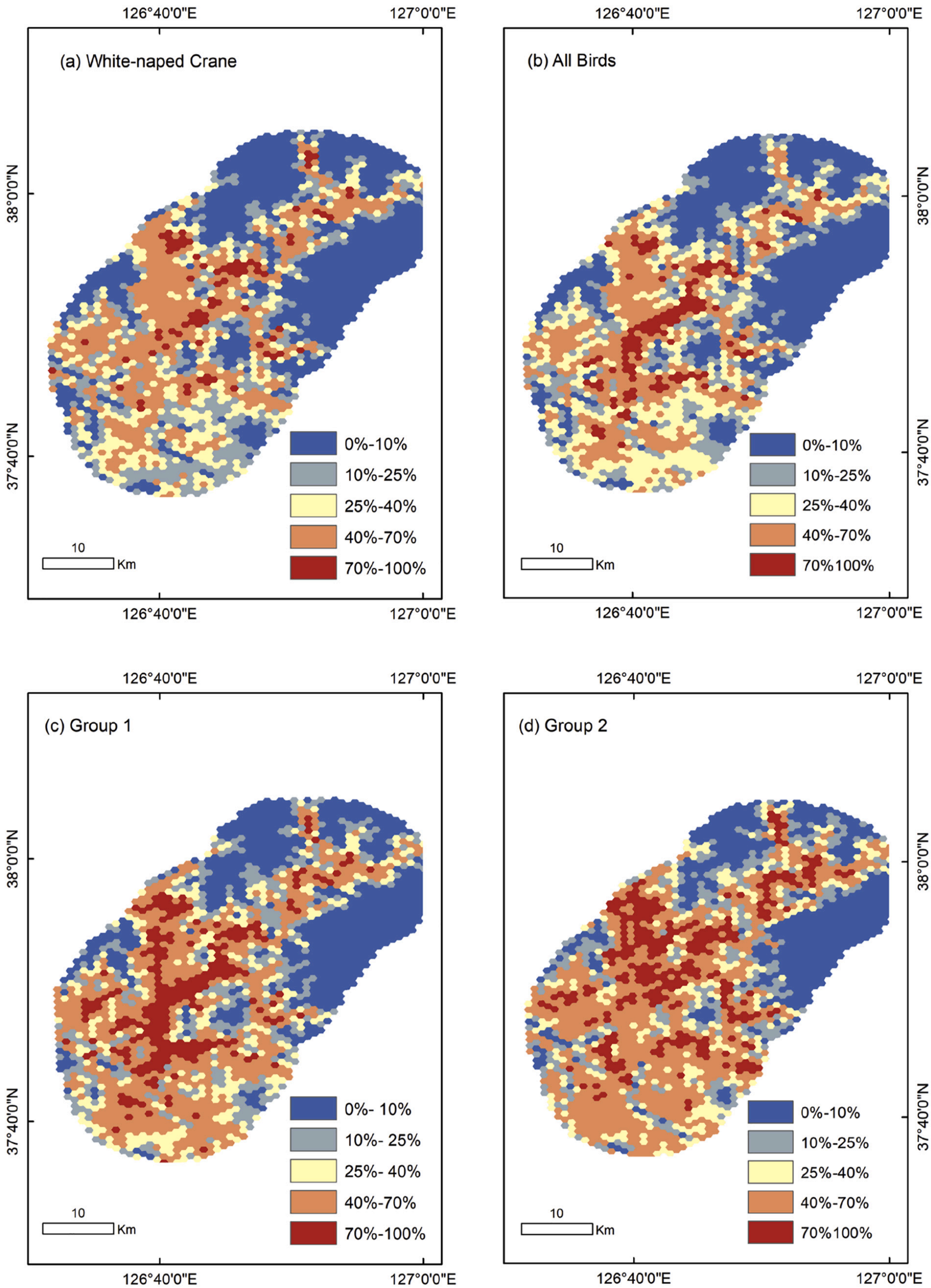

Fig. 4. Map of the species distribution models generated by MAXENT. (a) Habitat suitability for the white-naped crane, (b) habitat suitability for all threatened bird species, (c) habitat suitability for Group 1, (d) habitat suitability for Group 2.

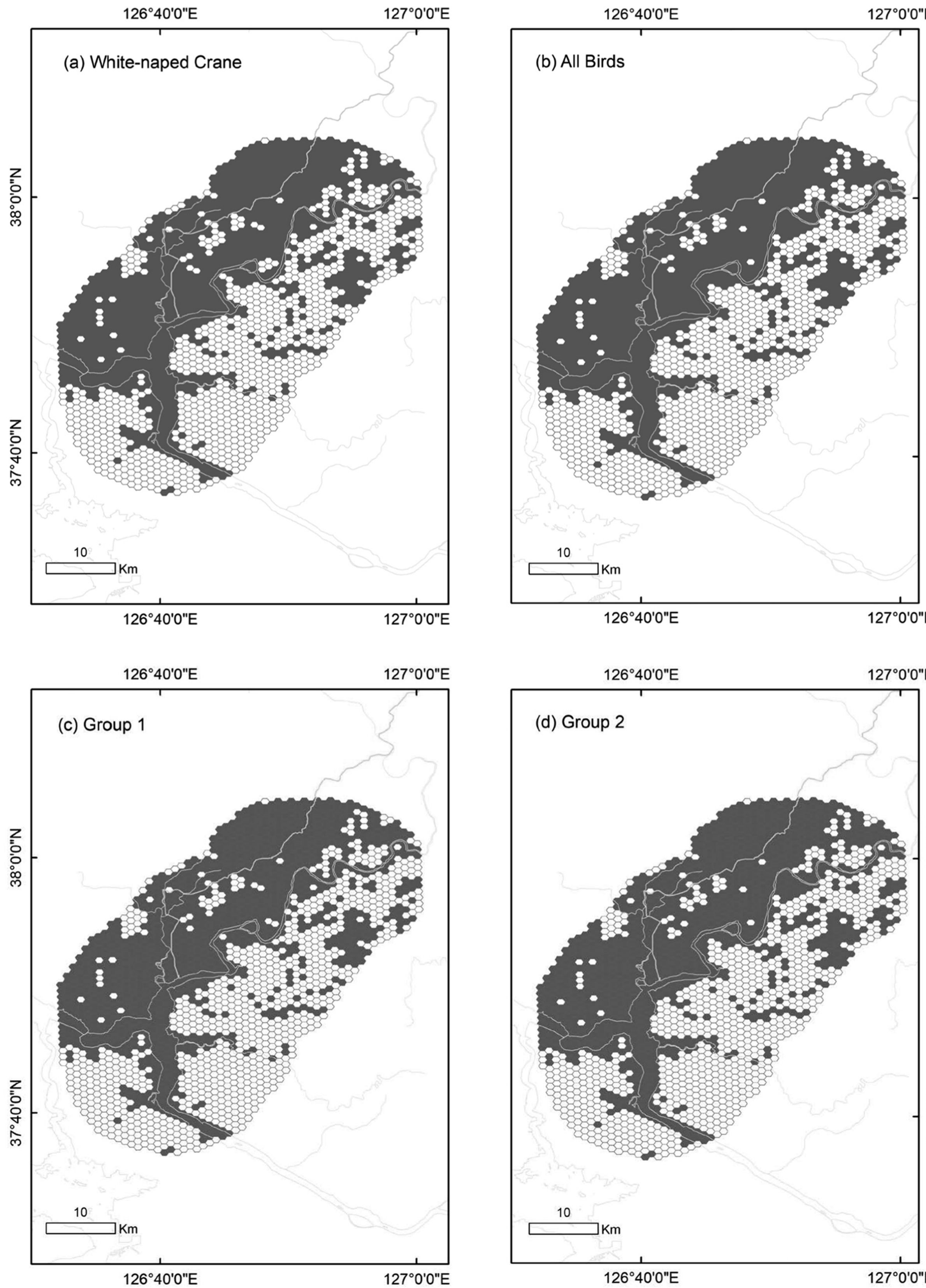

Fig. 5. The best solution for planning units determined with MARXAN. (a) The best solution determined for white-naped crane. (b) The best solution determined for all threatened species. (c) The best solution determined for Group 1. (d) The best solution determined for Group 2.

4. Discussion

This study suggested that the WNC can act as an umbrella species as well as a flagship species in the Hangang-Imjingang River estuary and the western DMZ. The ecological characteristics of the WNC and those of the other threatened birds were not identical, but the results of our analyses showed that the distribution of the WNC would include that of the other species, thus helping to preserve the habitat of the other threatened birds.

The umbrella effect of the WNC may derive from its ecological characteristics. The WNC, which winters on the Korean Peninsula, utilizes river estuaries and flat lands and requires a vast area of river and land for foraging (Lee et al., 2009; Lee, 2008). In addition, the WNC has a large body size and large home ranges (Archibald and Meine, 1996). Therefore, a large community of wildlife occupying the same habitat can be protected by preserving this umbrella species (Ozaki et al., 2006; Shen et al., 2020). Likewise, the umbrella effect of the red-crowned crane was postulated by its specialized habitat requirements and large territories in Japan (Higa et al., 2016). As such, WNC is an effective umbrella species in itself; however, our research verified its umbrella effect with field survey-based distribution data. Similarly, potential wintering sites for four cranes (*Antigone vipio*, *Grus grus*, *Grus monacha*, and *Leucogeranus leucogeranus*) were identified to protect their habitats (Shengwu et al., 2016). Meanwhile, we ascertained that the home range of WNC overlapped not only with that of conspecifics but also with that of other winter migratory birds.

Some studies have identified a problem with establishing a conservation area based on threatened species habitats: habitats for threatened species may be not appropriate for other taxa (Andelman and Fagan, 2000; Drummond et al., 2010). Likewise, the effectiveness of protecting flagship species through conservation planning has been debated (Chase and Geupel, 2005; Rodrigues and Brooks, 2007). Although we adopted a threatened species that is also a flagship species as the focal species for establishing a conservation plan, we found that the plan developed for this species would be adequate for the other species in the estuary ecosystem. Bichet et al. (2016) also suggest that the assemblage of other animals can be reliably maintained if the area is managed for one species' habitat. In addition, Drever et al. (2019) reported that a systematic conservation plan for caribou habitat could protect approximately 90% of birds and mammals. In our study, although the analyses were limited to wintering birds, with the SCP method, the differences in the selected PUs in the best solutions for the disparate groups were only slight. These findings suggest that the WNC can serve as an effective umbrella species for winter migratory birds arriving in the Hangang-Imjingang River estuary. Studies have suggested that cranes can function as umbrella species in rivers and wetlands in other countries, such as India, Cuba, Australia, and Japan (Garcia et al., 2008; Herring, 2001; Hussain et al., 2013; Higa et al., 2016).

Crane conservation supports many waterbirds and not only protects the wetlands, thereby enhancing the function of wetlands as a habitat, but also protects other threatened avian species. Currently, as North-South relations improve, economic cooperation between the two Koreas has been actively discussed (Kang et al., 2017). In the study area, preliminary plans for desilting rivers and constructing expressways have been developed. However, sedimentary deposits, especially in rivers, can be used as resting places for birds, and premature dredging plans can threaten bird habitats. The WNC, which is an indicator of wetland functioning, is suitable as a flagship species and an icon for wetland and the DMZ area conservation (Higuchi et al., 2004; Kim et al., 2011). The DMZ should also be considered an essential habitat for WNCs according to the analysis in this study. Moreover, at present, although only a small area in the Hangang River is designated as a protected area, a conservation plan for this region should include the Imjingang River and the western DMZ region in order to effectively protect the WNC. In summary, we can employ the WNC, the population of which has decreased (Lee et al., 2012; Yoo et al., 2010), to restore wildlife habitat by, e.g., instigating the proper conditions for WNC foraging, and to enhance regional and global biodiversity.

In addition, in this study, citizen science data were used to provide evidence for conservation planning. On top of the interests of the public on the WNC, identifying the umbrella effect of the species may contribute to raising awareness of the importance of the regional ecosystem (Caro et al., 2004; Senzaki et al., 2017). As we confirmed that the effectiveness of the conservation policy centered on the WNC which is easy for the public to recognize, based on these academic grounds, it is expected that the promotion of environmental awareness and establishment of conservation policies using the umbrella species will be actively progressed. In the western DMZ areas, where development projects often take precedence over ecological values, the WNC can become a symbol of the region's excellent ecosystem and an important flagship and umbrella species that will lead to ecosystem conservation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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