이학박사학위논문

Spatio-temporal approaches towards biodiversity conservation of the western DMZ in Korea

서부 DMZ 일원 경관 요소의 시공간적 변화와 생물다양성 보전 전략

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서울대학교 대학원

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Abstract

Spatio-temporal approaches towards biodiversity conservation of the western DMZ in Korea

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The Korean Demilitarized Zone (DMZ), spanning 2 km to the south and 2 km to the north of the military demarcation line at around 38°N, was established by the Korean Armistice Agreement in 1953. Access to the DMZ has been strictly restricted for decades, with the South Korean military designating the Civilian Control Zone (CCZ), a concordant area 5–10 km to the south of the DMZ, as a military buffer zone. The Korean DMZ runs east to west across the Korean Peninsula, encompassing a wide range of topographic features. As such, wildlife in the DMZ has thrived without human intervention, resulting in exceptionally high biodiversity levels. However, the high development pressure in South Korea has influenced the

DMZ and the CCZ despite their high conservation value. In particular, the western region of the DMZ, which is close to large metropolitan areas in South and North Korea, has faced very high development pressure. In this study, the ecological importance of the western DMZ was explored by analyzing various spatial and temporal dimensions of its landscape elements. In addition, the scientific basis for the conservation of the DMZ and the CCZ was outlined.

To begin with, the land use and land cover change from 1919, before the DMZ was established, to the 2010s, by which time human activity had impacted the landscape, was examined. The study area covered the western DMZ and CCZ. Most trees in DMZ and CCZ forests were originally coniferous, while the plains were employed for rice paddies. After the war, the coniferous forests were replaced with broadleaf forests. The cultivation of rice was restarted on the plains of the CCZ in the early 1990s, while the plains of the DMZ remained as grassland without general succession, such as the invasion of woody species. There have been two main reasons for the lack of succession. First, fires, which act as a disturbance in the successional process, have frequently occurred due to military action in the DMZ, particularly around Yeoncheon. Second, the grassland adjacent to the Imjingang River and small streams has experienced periodic flooding, which has prevented successional species from becoming established. In general, temperate grassland areas have become scarcer worldwide and on the Korean Peninsula because they have been exploited for agricultural use. However, grassland remains an essential habitat for a variety of wildlife in the DMZ, meaning that it is worth monitoring and conserving.

The agricultural landscape in the western CCZ consists of undeveloped land and traditional irrigation systems, such as the *dumbeong* system (the use of irrigation ponds), rather than modern reservoirs and irrigation canals. In this study, the traditional agricultural landscape (TAL) in the CCZ was explored. The agricultural landscape elements were classified, and the distribution of the bird community in response to drought in relation to these elements were analyzed. Using the functional diversity approach, which investigates the functional range and biological characteristics of a community, this study investigated the response of the avian community to landscape composition and drought events. As a result, three major elements representing the TAL in the CCZ were identified: rice paddies, forest, and fields. Under non-drought conditions, the area of the landscape with a large proportion of paddies (TAL1) had the highest species and functional richness. In areas where there was a relatively high ratio of forest (TAL2), the functional diversity index and species richness remained constant regardless of drought occurrence. In other words, forested areas are able to endure the stress of drought and act as a buffer zone for birds. Therefore, forests in TALs may help to maintain biodiversity when the regional environment faces natural disasters such as drought. Though western DMZ forests do not have high value based on standard vegetation evaluation criteria, they were shown in the present study to play an essential role in sustaining avian functional diversity by enhancing ecosystem resilience and resistance. As the signs of climate change indicate, rapid changes in weather conditions accelerate.

Therefore, restoring and maintaining forests are necessary in order to support the ecosystem function of the DMZ and conserve species diversity.

One of the distinctive geographical features of the western DMZ is the extensive river system that includes the Hangang River and Imjingang River and many smaller streams. The brackish water system of the Hangang River–Imjingang River, which flows into the West Sea, hosts an extraordinary biodiversity of waterbirds, fish, and mammals. This study suggested a conservation plan for the western DMZ ecosystem that adopts systematic conservation planning (SCP), in which an area is evaluated based on cost-effective criteria. This is an effective way to make decisions considering the many interests that are involved in setting up a conservation plan.

This study presented a conservation plan focusing on the protection of the white-naped crane (WNC), a flagship species that represents the western DMZ ecosystem. In addition, because umbrella species are an excellent management tool for protected areas, the possibility of WNC acting as an umbrella species was examined. Thus, the extent to which protecting the habitat of the WNC can protect other endangered birds was also analyzed. A species distribution map was modeled based on the GPS tracking of endangered winter migratory birds surveyed over the 2014–2019 period (using Maxent software), and a systematic conservation plan was established based on this information (using Marxan software). The endangered winter migratory birds found in the western DMZ were divided into two groups. Group 1, which includes the WNC, uses wetlands and lowlands, feeding mainly on plants, while Group 2 lives on dryland and has a carnivorous diet.

A species distribution model was then calculated for both groups and all endangered species. Under all conservation scenarios, more than 90% of the selected areas were identical to the distribution model for the WNC, meaning that it acted as an umbrella species that can be used to protect many other endangered species by preserving its habitat. The morphological characteristics of the WNC make it easy to identify, thus it is suitable for monitoring as a biological indicator for regional biodiversity management. The protected areas identified using an SCP approach included the Hangang–Imjingang River system, the western DMZ and CCZ, and a part of North Korea.

The western DMZ and CCZ have been placed under high developmental pressure and are directly affected by inter–Korean relations, but they have high value as a habitat for wildlife. Reaffirming the ecological importance of the DMZ and the CCZ, this study argued that the conservation plan for the DMZ should not be contingent on inter–Korean relations. Instead, a conservation plan that protects and maintains the current biodiversity levels on the Korean Peninsula is required.

Keywords: Demilitarized Zone, Civilian Control Zone, Biodiversity, Conservation, Hangang River, Imjingang River

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Chapter 1. General introduction

1.1 Biodiversity conservation

Biodiversity maintains the functions and structure of ecosystems, thus providing provisioning, regulating, supporting, and cultural services and protecting the intrinsic value of life. Thus, in a practical approach to conversation, the entire ecosystem, including its environmental characteristics and biodiversity, should be considered. In particular, when setting a conservation plan, various biological and environmental variables need to be carefully considered, including both temporal and spatial factors (Primack, 2010). For example, at the population level, a planner should consider species distributions, population sizes, and behavioral characteristics based on long-term monitoring data, which can be used to identify regional characteristics and describe and predict changes in an ecosystem using cumulative climatic factors (Laliberte and Ripple, 2004; Schemske et al., 1994). In fact, long-term monitoring combined with a citizen-scientific approach has been widely adopted in recent biodiversity conservation research (Johnston et al., 2020; Morelli et al., 2017).

Biodiversity can be protected by considering species populations, interactions within a community, interactions between different communities, and environmental and landscape elements that are important to the survival of those species. Establishing priority areas for conservation is usually based on the following criteria: distinctiveness (where rare and endemic species are commonly found), endangerment (the habitat of endangered species), and utility (potential value) (Primack, 2010).

To evaluate these three factors, a focal species that responds sensitively to the surrounding environment is often selected (Noss, 1990). This focal species is often an indicator species that is associated with the function of the ecosystem or that is threatened (Bani et al., 2006). Conservation areas are then often set up and managed based around the characteristics of this indicator species (Han et al., 2018). Birds and butterflies are widely used indicator species (Jew et al., 2015; Mäkeläinen et al., 2019; Morelli et al., 2017). Birds in particular are excellent indicators because they are highly differentiated, with various food sources (e.g., plants to animal carcasses) and a diverse range of habitats (e.g., from the sea to mountains). Their distinctive morphological and behavioral features also make them easily distinguishable, meaning that they are easier to track and monitor. In addition, due to their highly differentiated characteristics, changes in the function and structure of an ecosystem can be quickly recognized.

Flagship species and umbrella species are similar in concept to indicator species, and these have also been employed in conversation planning. Flagship species are usually charismatic species that are used to promote conservation awareness and ecotourism (Han et al., 2018; Senzaki et al., 2017; Shen et al., 2020). Umbrella species are employed based on the idea that it is possible to protect other species by focusing attention on a specific species. Many studies have been conducted on the selection and effects of umbrella species (Andelman and Fagan, 2000; Bani et al., 2006; Launer and Murphy, 1994).

1.2 Conservation planning

Biodiversity has intrinsic value in itself and provides numerous essential services to humans, thus it has been the focus of a significant volume of research in recent decades. However, anthropogenic land use remains the principal threat to world biodiversity and wildlife conservation (Wilson et al., 2016), leading to significant research attention on the establishment of conservation plans. Some studies have focused on conservation at the species-level (Javed et al., 2019; Mulwa et al., 2012), others have focused on ecosystem services (Chan et al., 2006), and others have looked to increase the connectivity of landscape patches (Reis et al., 2019).

The assessment of a conservation plan mostly depends on its representativeness and persistence (Margules and Pressey, 2000). Representativeness refers to the degree to which the plan represents the variety of wildlife within a region, while persistence denotes the degree to which conservation priority areas promote the long-term survival of this wildlife. In order to meet these objectives, conservation plans should take into account the size and connectivity of the priority areas and the ability to preserve wildlife habitat. Various tools have been developed for conservation planning, including Corridor Designer (Jenness et al., 2013) and Circuitscape (Anantharaman et al., 2019) for the improvement of habitat connectivity, Maxent (Phillips et al., 2006) and RAMSAS GIS (Akçakaya and Sjögren-Gulve, 2000) for species distribution modeling, and Marxan (Possingham and Watts, 2011), Zonation (Lehtomäki and Moilanen, 2013), and C-plan (Pressey et al., 2009) for the selection of reserve boundaries.

SCP provides the necessary basis to achieve conservation goals (Margules and Pressey, 2000). The science of SCP is concerned with the optimal application of spatially explicit conservation management actions to promote the persistence of biodiversity and other natural features *in situ* (Margules and Pressey, 2000). SCP was developed in the 1980s to identify the most efficient network of conservation areas (Cocks and Baird, 1989) and has been continuously explored since. Many SCP projects have employed Marxan software (Watts et al., 2009), which is based on a heuristic simulated annealing algorithm. Marxan is comprehensive, cost-effective, and compact, allowing multiple targets to be assessed, strategies that lower costs to be identified, and appropriate solutions to be found for SCP (Possingham and Watts, 2011). Marxan was originally created for the protection of marine areas, but now it is widely used in terrestrial research. In this study, Marxan was adopted for SCP in the DMZ and the CCZ. In the past, conservation planning in the DMZ and the CCZ has been neither clear nor based on biodiversity information. Most importantly, there has been no conservation plan for the DMZ and CCZ areas despite their known biological importance.

1.3 The Korean DMZ and CCZ areas

1.3.1 Overview of the Korean Demilitarized Zone

The DMZ lies between South and North Korea, across the middle of the Korean Peninsula. To the south of the DMZ, the CCZ acts as a military buffer zone. Both the DMZ and the CCZ have drawn international attention not only for the military tensions of the last remaining cold war but also for their remarkably high biodiversity and unique ecosystems. As established by the Korean Armistice Agreement in 1953, the DMZ is 4 km wide (2 km to the south and 2 km to the north of the military demarcation line) and 248 km long, running roughly along a latitude of 38°N (Figure 1-1). At the same time, the South Korean military established the CCZ, a concordant area 5-10 km to the south of the DMZ.

Access to the DMZ has been strictly prohibited for nearly seven decades since the end of the Korean War, except for certain members of the military defense force, including soldiers posted in the Panmunjom Joint Security Area, and a few authorized civilians, such as the residents of Daeseong-dong Village and Kijong-dong Village in South and North Korea, respectively. Limited agricultural activities have been permitted in the CCZ since the 1970s. Due to this limited access, this region has exceptionally high biodiversity (Kim, 1997).

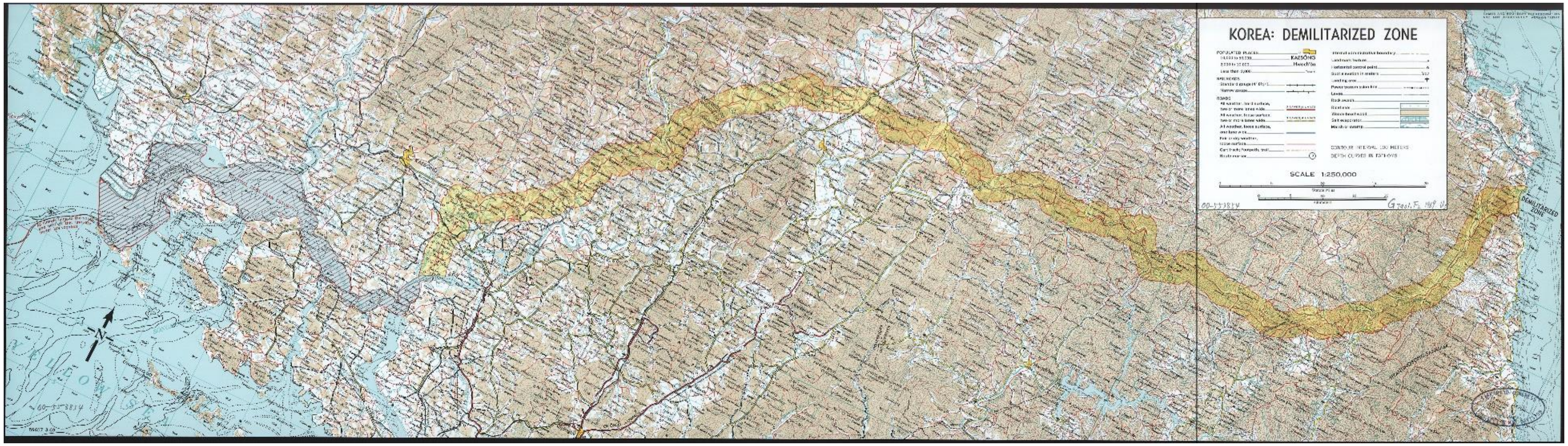


Figure 1-1. Map of the Demilitarized Zone (DMZ) of Korea published by the Central Intelligence Agency in 1969 (https://www.loc.gov/item/00553854, Accessed on Oct 24, 2020). The DMZ covers Paju to the west and Goseong to the east.

1.3.2 Biodiversity of the DMZ

The DMZ and the CCZ have high biodiversity because they have been off-limits to civilians for 70 years. In the DMZ area, 41.9% of the flora of South Korea, 19.5% of its endangered plants, 47.8% of its mammals, 55.0% of its endangered mammals, 51.0% of its birds, 70.5% of its endangered birds, 65.4% of its amphibians, 85.7% of its endangered amphibians and reptiles, 13.3% of its terrestrial insects, 13.6% of its endangered terrestrial insects, 10.8% of its fish, 44.0% of its endangered fish, and 23.0% of its benthic invertebrates are found (National Institute of Ecology, 2016). Overall, 20% of all species found in South Korea and 41% of the endangered species are found in the DMZ. Given the total area of the DMZ, about 2% of South Korea, the DMZ maintains extraordinarily high biodiversity.

In this regard, an effective strategy for biodiversity conservation in the DMZ and the CCZ could be adopting the regional biodiversity hotspot concept (Balletto et al., 2010). This concept was first proposed in relation to the proportion of endemic vascular plants, with 18 global biodiversity hotspots recognized (Myers, 1988). Since then, the concept of biodiversity hotspots has since been expanded to cover other taxa, with Myers et al. (2000) identifying hotspots using two criteria, species endemism and the threat level, and consequently suggesting 25 global biodiversity hotspots. More recently, the number of hotspots has risen to 35 (Williams et al., 2011), and other criteria for determining hotspots have been introduced, such as species richness and the presence of rare or taxonomically unusual species (Reid, 1998). However, Orme et al. (2005) demonstrated that the three common types of biodiversity hotspot (species richness, threat level, and endemism) do not show the same geographical distribution and suggested using multiple indices of diversity to identify priority areas of high conservation value. In this study, the Korean DMZ and the CCZ, which contain numerous species and endangered species, were considered biodiversity hotspots based on the threat level and species richness.

The unique biodiversity of the DMZ is primarily the result of restricting human access. However, the diverse range of ecosystems found on the Korean Peninsula should also be considered as an important factor in the high biodiversity. The eastern region of the DMZ contains coastal, lagoon, and subalpine ecosystems, while agricultural land has been developed across the wide plains of the central DMZ. In the west, lowland topographic features, including groves and river estuaries, are common. The DMZ and the CCZ also represent a vital ecological axis on the Korean Peninsula, connecting the Baekdu-daegan mountain range and regional water systems. For these reasons, the DMZ and CCZ ecosystems should be conserved.

1.3.3 Focus on the western DMZ and CCZ

The DMZ consists of three major types of landscape (National Institute of Ecology, 2016). The eastern region of the DMZ is best characterized as rugged mountains, while the central region is dominated by wide open plains and the western region of the DMZ and the CCZ has a heterogeneous landscape with a rolling topography (Figure 1-2a and c). The Han and the Imjingang Rivers provide the habitat for emergent plants (e.g., reed), *Salix* sp., mixed forest, and broadleaf forest (Figure 1-2c).

The western region of the DMZ and the CCZ has an especially high biodiversity due to the heterogeneous landscape, consisting of river estuaries, floodplains, and traditional agricultural areas (Figure 1-2). While the DMZ remains inaccessible, agriculture has been promoted in the CCZ of South Korea since the 1970s with the establishment of Tongilchon Village, just 4.5 kilometers south of the Military Demarcation Line. The inhabitants built the village from scratch, cultivating fields of beans, ginseng, and rice. Even though the agricultural system in Korea has been modernized, the traditional landscape in the CCZ has been preserved, including the *dumbeong* system, which irrigates 89% of the rice paddies in the western CCZ, thus helping to maintain its biodiversity (Kim et al., 2011; Sebastián-González et al., 2010). The Korean *dumbeong* system provides shelter for wildlife, even when conditions become extreme (Lee, 2005), and, with the increasing adoption of modern irrigation systems, there are concerns that biodiversity could plummet (Lewis-Phillips et al., 2019).

About 43% of the bird species in South Korea are found in the western DMZ, including 59% of endangered avian species, while 60% of all and 71% of endangered South Korean amphibian and reptile species also present there (National Institute of Ecology, 2016). The landscape elements that make up the western region of the DMZ and the CCZ include small hills, wide plains, non-concrete waterways, groves, forests, and streams flowing into brackish water. Notably, the western DMZ region is also a good wintering and stopover site for endangered avian species that use the nearby estuaries of the Imjingang River and the Hangang River, which flow into the West Sea (Global Interflyway Network, 2012).

However, the biodiversity of the DMZ and the CCZ has been threatened by intense demand for commercial development due to its proximity to Seoul, the metropolitan capital city of South Korea (Figure 1-3; Koh, 2019; Sung and Cho, 2012). In addition, as inter-Korean relations improve, a sense of expectancy may encourage property speculation (Paek and Park, 2019). Because Kaesong, the flagship city for inter-Korean exchanges, and Pyongyang, the capital city of North Korea, are located in the western region of the Korean Peninsula, efforts to connect the cities of North and South Korea have been growing. In addition, because Paju-si has long cultivated world-famous Korean ginseng, the cultivation of cash crops such as ginseng is another threat to regional biodiversity (Kim et al., 2006; Park and Nam, 2013; Sung et al., 2016). As such, despite the ecological value of the Korean DMZ, military activity, geopolitical factors, and economic feasibility have made it difficult to design conservation plans for the western DMZ and CCZ regions.

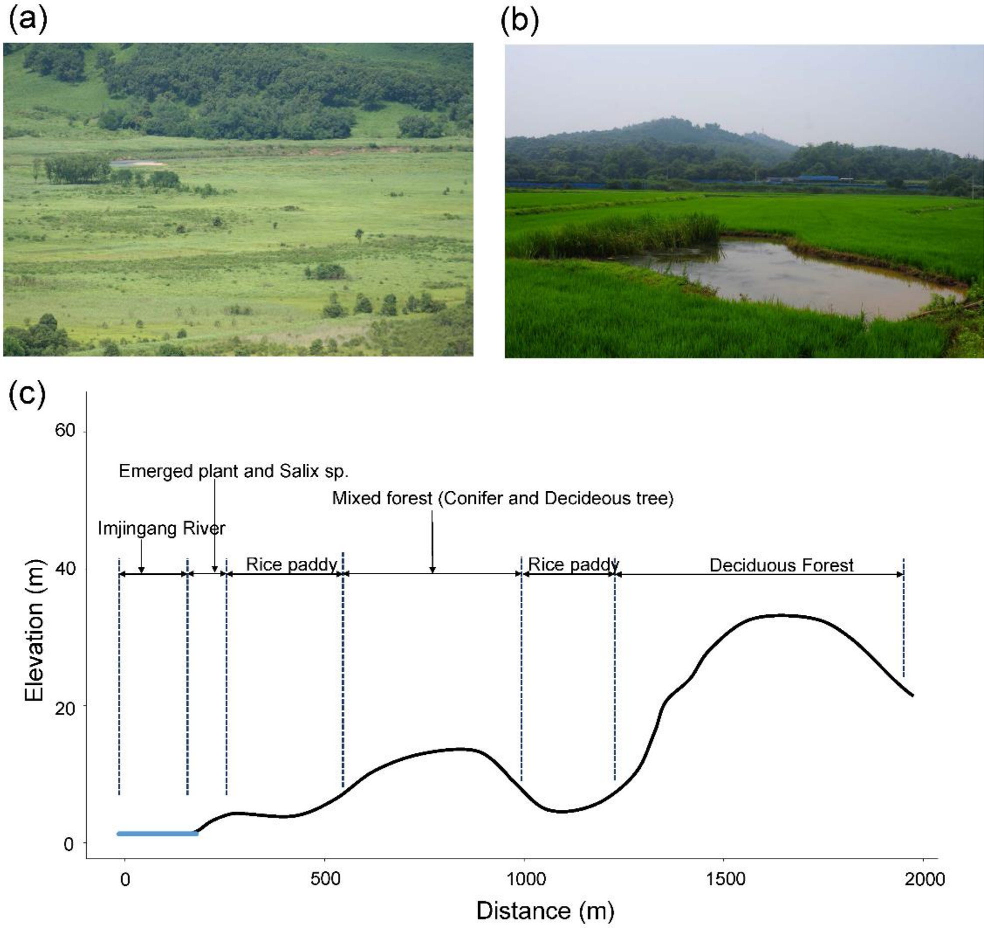


Figure 1-2. Landscape of the western DMZ and CCZ region near Paju. Typical topography and vegetation of the study site: (a) grassland and forest in the western DMZ and (b) the agricultural landscape, including *dumbeong* (traditional irrigation ponds), in the western CCZ. (c) Topographical map of the western CCZ. The landscape mainly consists of emergent plants and *Salix* species along the riverside, rice paddies, and forest

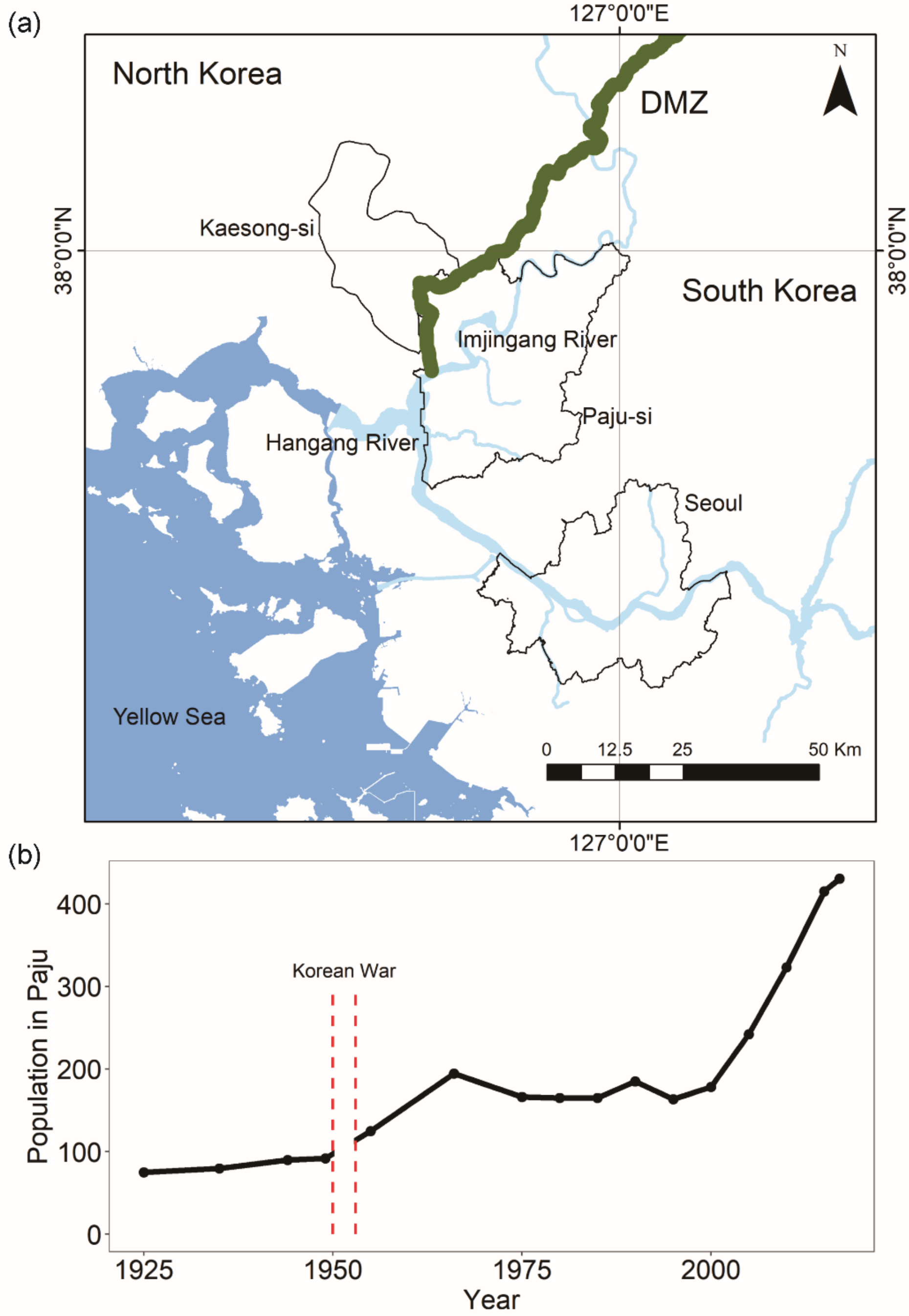


Figure 1-3. Geographical features of the western DMZ that place high development pressure on the region. (a) Western DMZ on the Korean Peninsula (study site) surrounded by big North and South Korean cities, including Seoul, Kaesong, and Paju, (b) Population of Paju (in thousands) from 1925 to 2015.

1.4 Objectives of the study

The need to conserve biodiversity rests on the perceived importance of both instrumental values, which highlight the benefits for humans, and intrinsic values, which recognize the value of life itself. However, in general, recognition of the importance of biodiversity conservation is growing. Previously established biodiversity hotspots account for only 1.4% of the global land area but contain 28–58% of all species by taxon. Similarly the DMZ and the CCZ, by-products of the Korean War, account for less than 2% of the land area of the Korean Peninsula but represent a biodiversity hotspot containing 30–60% of the species on the peninsula. As such, considering the high ecological importance of the DMZ, a conservation plan for its ecosystem is required. In this study, a plan to conserve the biodiversity of the DMZ was proposed based on the long-term monitoring of its landscape elements.

In Chapter 2, the changes in the Korean DMZ and CCZ landscape over the last 100 years are presented. The DMZ and the CCZ are considered a single ecological zone, but they have different access restrictions. For this reason, the CCZ ecosystem was examined using a direct survey of the biota, while the DMZ ecosystem had to be explored using satellite imagery and additional observations from within the CCZ. Based on a map produced during the Japanese colonial period and 2010 satellite images, the changes in the landscape elements were tracked, and the natural and artificial drivers behind these changes were identified.

In Chapter 3, the structure of the traditional Korean agricultural landscape and the response of the avian community in different types of landscape to drought events are discussed. The hypotheses were that (1) avian taxonomic and functional diversity would respond differently according to the dominant natural and anthropogenic elements, and (2) a larger *dumbeong* system (irrigation ponds) would contribute to the resilience of avian taxonomic and functional diversity in the face of drought events by replenishing the water necessary to maintain the wetland environment of rice paddies.

In Chapter 4, the extent to which protecting the habitat of the WNC is effective in protecting the habitats of other endangered birds regardless of their ecological characteristics is examined and a cost-effective conservation plan for winter migratory birds that use the Han-Imjingang River estuaries is examined.

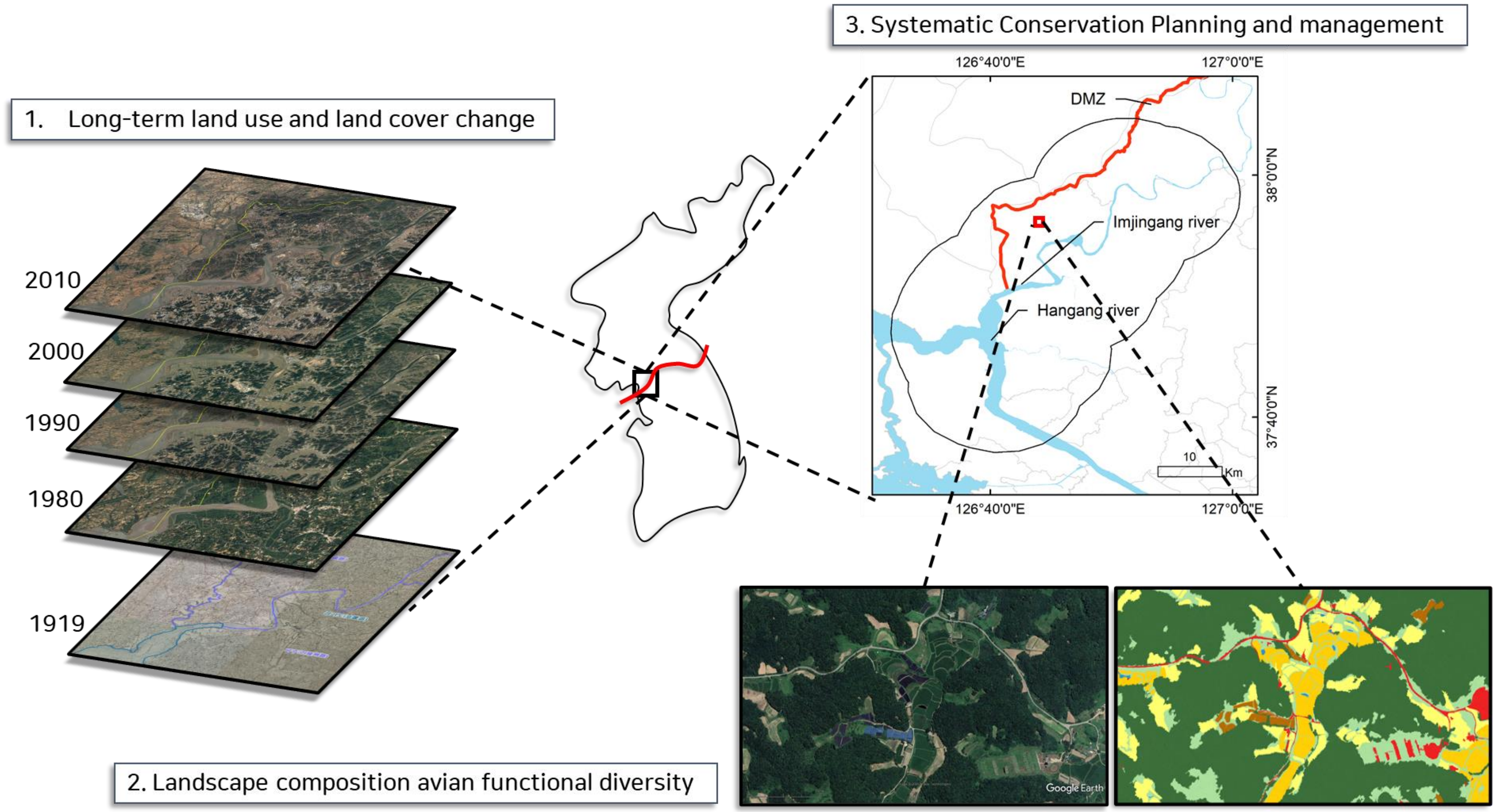


Figure 1-4 Overview of this study.

Chapter 2. Changes in Land Use and Vegetation Cover over 100 years in the Western DMZ and CCZ in South Korea

2.1 Introduction

Given the decades of access limit, the biological features of the Korean DMZ and CCZ should be explored widely. However, only flora and fauna of the Korean DMZ and CCZ have been reported (Ju et al., 2016; Kim et al., 2016; Park and Nam, 2013a), and even much of these were limited to listing species inventory and habitat descriptions. From basic studies such as genetic studies of the DMZ ecosystem to complex studies considering various biological factors, it is necessary to understand the ecosystem by multiple approaches.

Of these, long-term analysis of land cover could be a useful tool for exploring ecosystem changes. The knowledge of historical land use and land cover could contribute to identifying the driving forces affecting natural elements—e.g., forests (Wulf et al., 2010). For these reasons, long-term information on landscape change can convey important information about ecological references (Falcucci et al., 2007) and targets for restoration (Marcucci, 2000). Also, long-term tracking of landscape change is an integral part of conservation planning and biodiversity enhancement necessary for this region.

On the other hand, very little is known about the temporal and spatial changes in the landscape of the Korean DMZ and CCZ. After all, the access restrictions to the Korean DMZ have made the place flourished with all kinds of species, but ecological research had clear limitations at the same time. Even so, it is worth exploring the ecosystem that experienced natural succession for several decades, which represents the temperate biomes without human access. To figure out the Korean DMZ ecosystem, investigating landscape structures in the Korean DMZ area would be essential. Understanding the land use and land cover changes can suggest the factors affecting the Korean DMZ ecosystem changes. Considering the inability to approach the DMZ, it is best to adopt a remote sensing methodology that does not require physical access to the Korean DMZ.

In this study, changes in the landscape of the Korean DMZ and CCZ during the last 100 years were investigated. The DMZ and CCZ are in an ecological zone, but the Korean DMZ ecosystem has been exclusively off-limit to people, whereas the CCZ has partially allowed civilian activities. Thus, the CCZ ecosystem was examined by biota surveys. The DMZ ecosystem was explored with satellite imagery and estimated with supplementary observation via CCZ. From the map made in the Japanese colonial period to the 2010's satellite images, the changes in the landscape elements were tracked, and the natural and artificial drivers that led these changes were presented.

2.2 Materials and Methods

2.2.1 Study Area

The study area covered the western CCZ, which corresponds to Paju-si City and parts of Yeoncheon-gun County of Gyeonggi-do Province in South Korea (38° 00'N 126° 51'E, 37° 49'N 126° 40'E; Figure 2-1). Korean Peninsula has a typical monsoon climate: June-August is a hot season with frequent torrential rains, and November-February is mostly below zero with low precipitation (Figure 2-2).

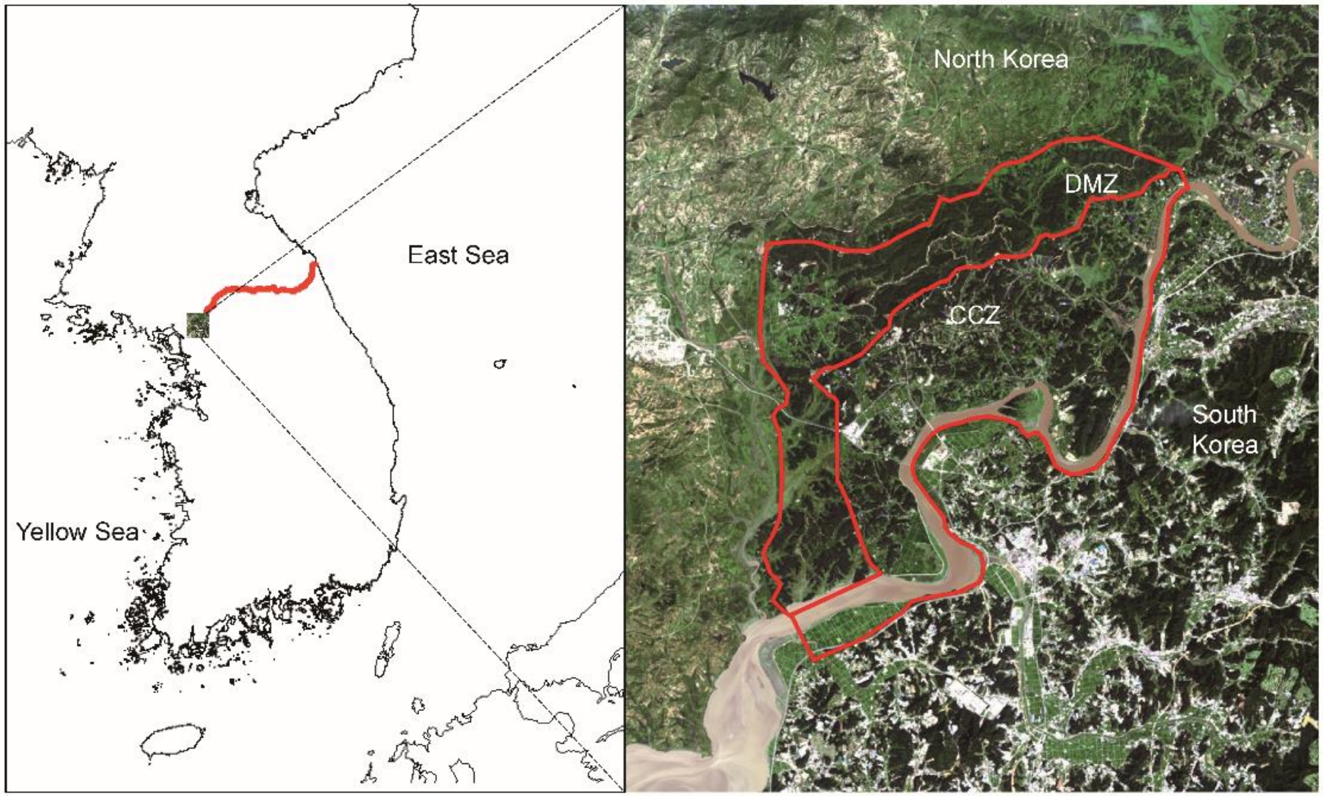


Figure 2–1. Study site in the Korean DMZ and CCZ. The solid line determines the study site in Paju and Yeoncheon.

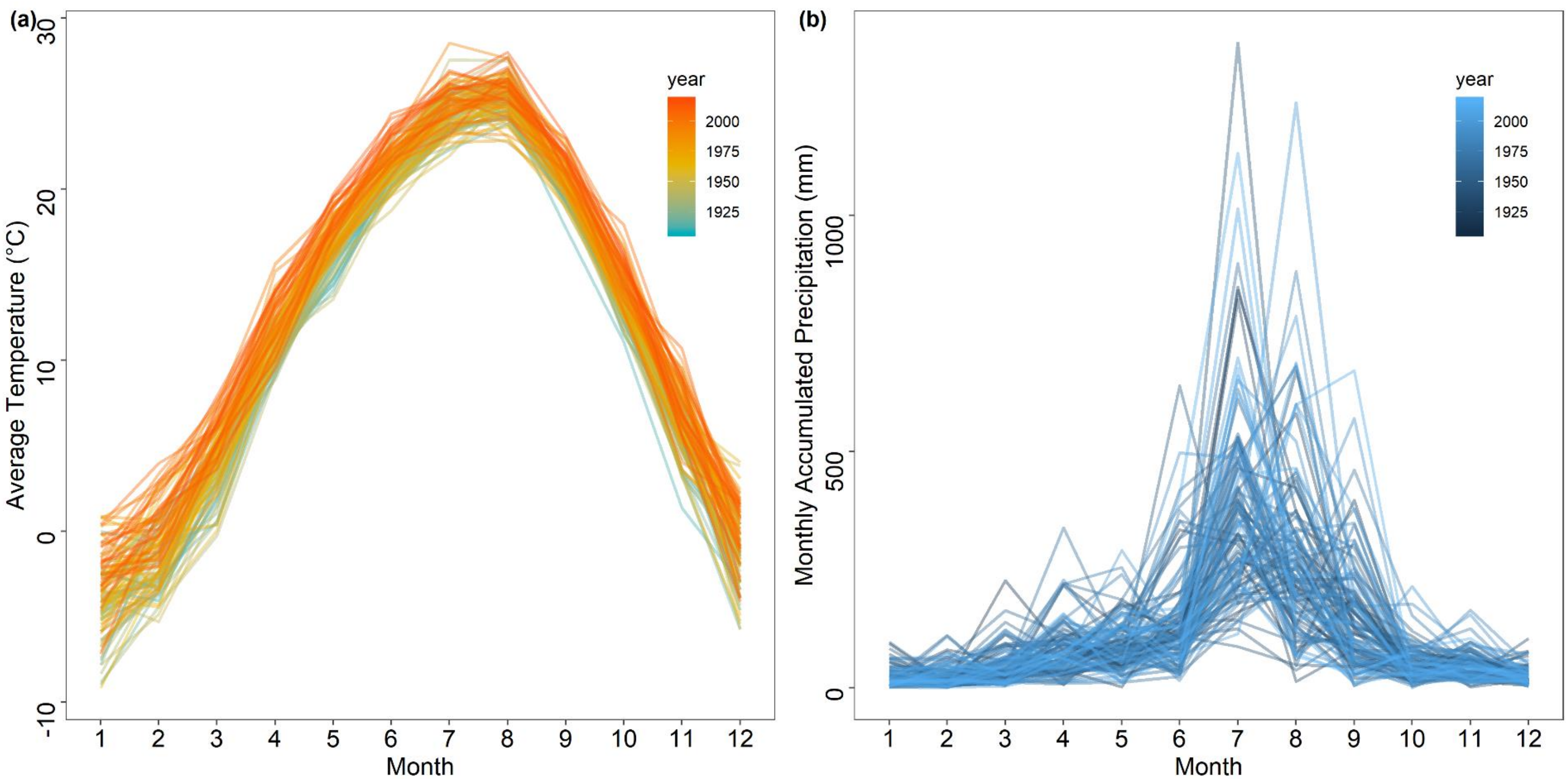


Figure 2-2. The climate characteristics of study site from 1907 to 2017. (a) The monthly average temperature, (b) The monthly accumulated precipitation.

2.2.2 Data Collection, Preprocessing, and Analysis

The landscape of 100 years ago, the map of 1919, was reconstructed from the old maps of the Japanese colonial period before the outbreak of the Korean War. The maps, from 1980 to 2017, were built with the Landsat satellite images from Thematic Mapper (TM) (1984, 1994), Enhanced Thematic Mapper (ETM+) (2006), and Operational Land Imager (OLI) (2017) (Table 2-1). The satellite images were downloaded in the orthorectified form from the Earth Explorer website (https://earthexplorer.usgs.gov/). Region of Interest (ROI) data were referenced to the high resolution of Google Earth images. In addition, radiometric correction and atmospheric correction were applied to Landsat data using ENVI Ver. 5.3.

Table 2-1. Information summary of the Landsat images.

Sensor	Date	Resolution
Landsat TM5	July 3, 1984	30 m
Landsat TM5	September 12, 1994	30 m
Landsat ETM	September 5, 2006	30 m
Landsat OLI	August 26, 2017	30 m

The prewar and postwar maps were configured with nine landscape categories – built-up structures (buildings, houses, and shelters), agricultural facilities, paddy field, coniferous forest, deciduous forest, grassland, waterbody, bare ground, and floodplain. The grassland was further divided into two classes – Veg_high and Veg_low, according to the vegetation vitality – in the postwar maps, based on the band combination of NIR (near-infrared), green, and blue. When Landsat imagery was analyzed by false color (a combination of NIR, green, blue), the grassland was identified but was clearly divided into dark and light areas, resulting in a difference in vegetation vitality. The low vitality of grassland indicated to low productivity and poor health of the vegetation. The dark areas were named Veg_low, while the bright areas were named Veg_high.

A supervised classification was conducted with the neural net method of ENVI Ver. 5.3, and an accuracy test was performed (Richards and Richards, 1999; Rumelhart et al., 1985). The overall accuracy rates and Kappa coefficients were 95% and 0.94, 85% and 0.81, and 95% and 0.92 for 1984, 1994, and 2017 maps, respectively.

Vegetation vitality was determined by calculation of NDVI (normalized difference vegetation index) (Rouse et al., 1974) and NDMI (normalized difference moisture index), following the formulae:

$$NDVI = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

$$NDMI = \frac{(\mathrm{NIR} - \mathrm{SWIR})}{(\mathrm{NIR} + \mathrm{SWIR})}$$

NDVI is relevant to plant productivity and is highly correlated to the vegetation community distribution and plant biomass (Reed et al., 1994), while NDMI is related to the amount of water that plants absorb. It provides information about the extent of the water stress of the plant. NDMI is more sensitive to moisture stress than the variance of NDVI (Wilson and Sader, 2002). Changes in the NDVI and NDMI values were tested by the Kruskal-Wallis rank sum test using 'nparcomp' package in R software Ver. 1.1.447 (Konietschke et al., 2015).

Fires were frequent in the DMZ due to landmine explosions hit by wildlife and intentional burns by the military. Landsat image was analyzed the fire frequency from 1985 to 2017 using normalized with Burn Ratio Thermal (NBRT) (Holden et al., 2005). NBRT consists of NIR and MidIR (Mid-infrared: 2215 nm) and Thermal Band (TB). The burns were inspected with a dataset of Google Earth Engine. The NBRT determination followed the formula:

$$NBRT = \frac{\mathrm{NIR} - (\mathrm{MidIR} \times \mathrm{TB})}{\mathrm{NIR} + (\mathrm{MidIR} \times \mathrm{TB})}$$

The data of population growth in Paju and the CCZ areas indicating the development pressure and anthropogenic activities were obtained from the

Korean Statistical Information Service (2019). The old maps ascertained the prewar administrative districts.

2.3 Results

2.3.1 Land Use

The landscape of the DMZ and CCZ in Paju had changed significantly since the end of the Korean War until 2017 (Figure 2-3). Before the war, according to the map of 1919, the forest amounted to approximately 51% and 45% of the DMZ and CCZ lands, respectively (Figure 2-3, Figure 2-4a). In the DMZ, the proportion of forests had increased gradually up to 60% until 2017, while the forest area of the CCZ gradually had decreased, accounting for 41% of the total land in 2017. In both the DMZ and CCZ, the forest composition changed after the war. Before the war (1919), coniferous trees were predominant in the DMZ and CCZ (conifer 52%, deciduous 1% in the CCZ; conifer 49%, deciduous 2.5% in the DMZ). After the war, deciduous forests accounted for the majority (conifer 1.6–4%, deciduous 33–49% in the CCZ; conifer 0.1–5.3%, deciduous 44–60% in the DMZ).

Rice paddy was the second-largest landscape component in 1919 (30% of the DMZ and 19% of the CCZ; Figure 2-4b). However, in the 1980s, when satellite images were available for the first time after the war, rice paddy fields were reduced, occupying 9.5% of the CCZ and 7.6% of the DMZ. Since then, the rice paddies area had gradually increased in the CCZ, holding about 17% in the 2010s (Figure 2-4b), while the rice paddies were 8% of the total area of the DMZ.

The DMZ and CCZ grassland increased from 3% and 5% in 1919 to 33% and 21% in the 1980s, respectively (Figure 2-3 and Figure 2-4b). The

CCZ grassland remained at around 20% in the 1990s, 2000s, and 2010s. Most of the rice paddies in the DMZ seemed to turn to grassland (Figure 2-3), and the proportion of Veg_low was higher than that of the CCZ region.

Bare grounds, mainly referring to residential and community yards, had no ground cover in 1919. It accounted for about 12% and 13% of the DMZ and CCZ, respectively, in 1919. However, the bare grounds had decreased to 8% until the 1980s—comprising of military yards after the war (from the 1980s to 2010s). Since then, it had shrunk to 2% of the total DMZ land until 2017, as the grassland vegetation had encroached. The CCZ bare ground had increased 12% of total areas until the 1980s but gradually decreased to 2.4% in 2017. This reduction was mostly due to agricultural cultivation expansion (Figure 2-3 and Figure 2-4).

The built-up areas occupied approximately 1% of the total lands in 1919. Due to the restrictions after the war, the number of residents in the CCZ plummeted (Figure 2-5). 0.2% of the built-up structures were in use in the 1980s. As civilian access for the agricultural purpose was permitted, the agricultural built-up, including ginseng field, rapidly increased to 2% in the 1990s and 7.9% in the 2010s (Figure 2-3 and Figure 2-4c). Compared to the 1980s, when agricultural activities were resumed, the area of artificial structures in the CCZ region increased by 46 times in 2010, and the proportion of artificial structures in 2010 was about 6.6 times higher than in 1919 when civilians lived. In the DMZ area, the built-up area had increased due to the construction of roads to the Kaesong Industrial Complex. The area of artificial structures, which was 0.03% in the 1980s, rose to 1.74% in the

2010s. It was an increase of about 58 times compared to 30 years ago, and 1.5 times compared to 100 years ago.

The water-surface area was found to shrink or expand as the Imjingang River was affected by the rise and fall of the tide. Subsequently, due to these fluctuations, the floodplain area such as riverbeds were exposed or inundated (Figure 2-3 and Figure 2-4d).

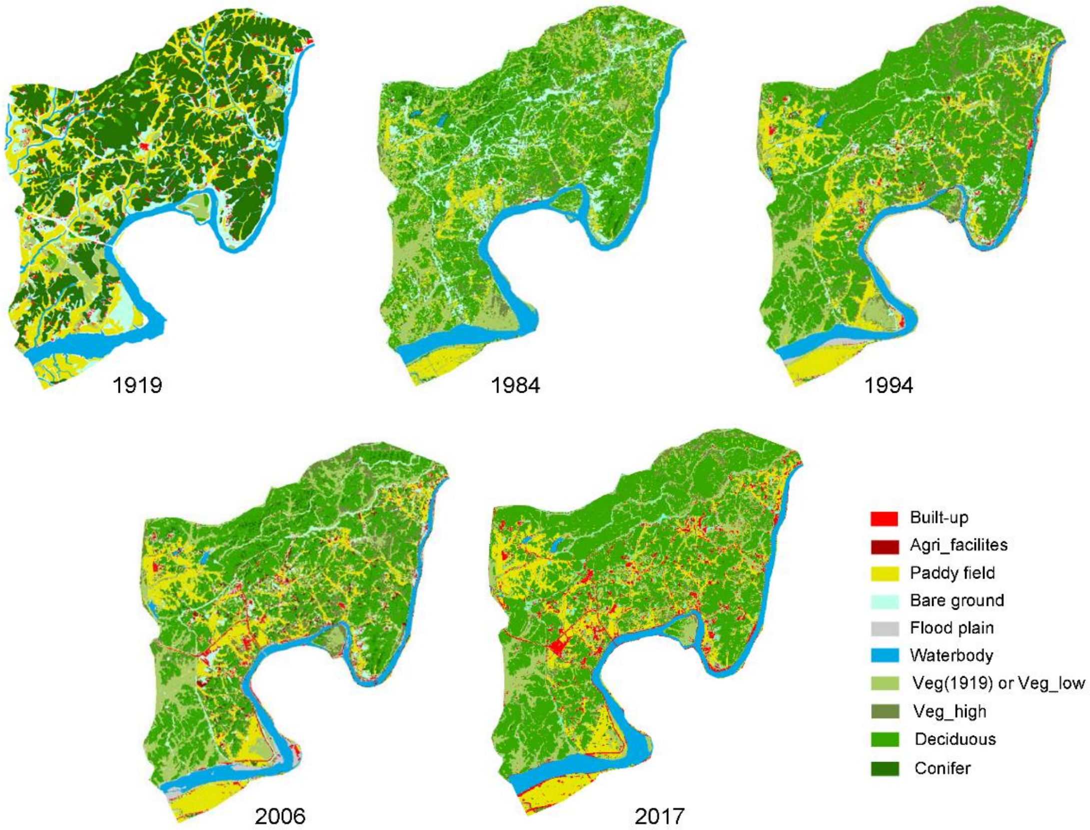
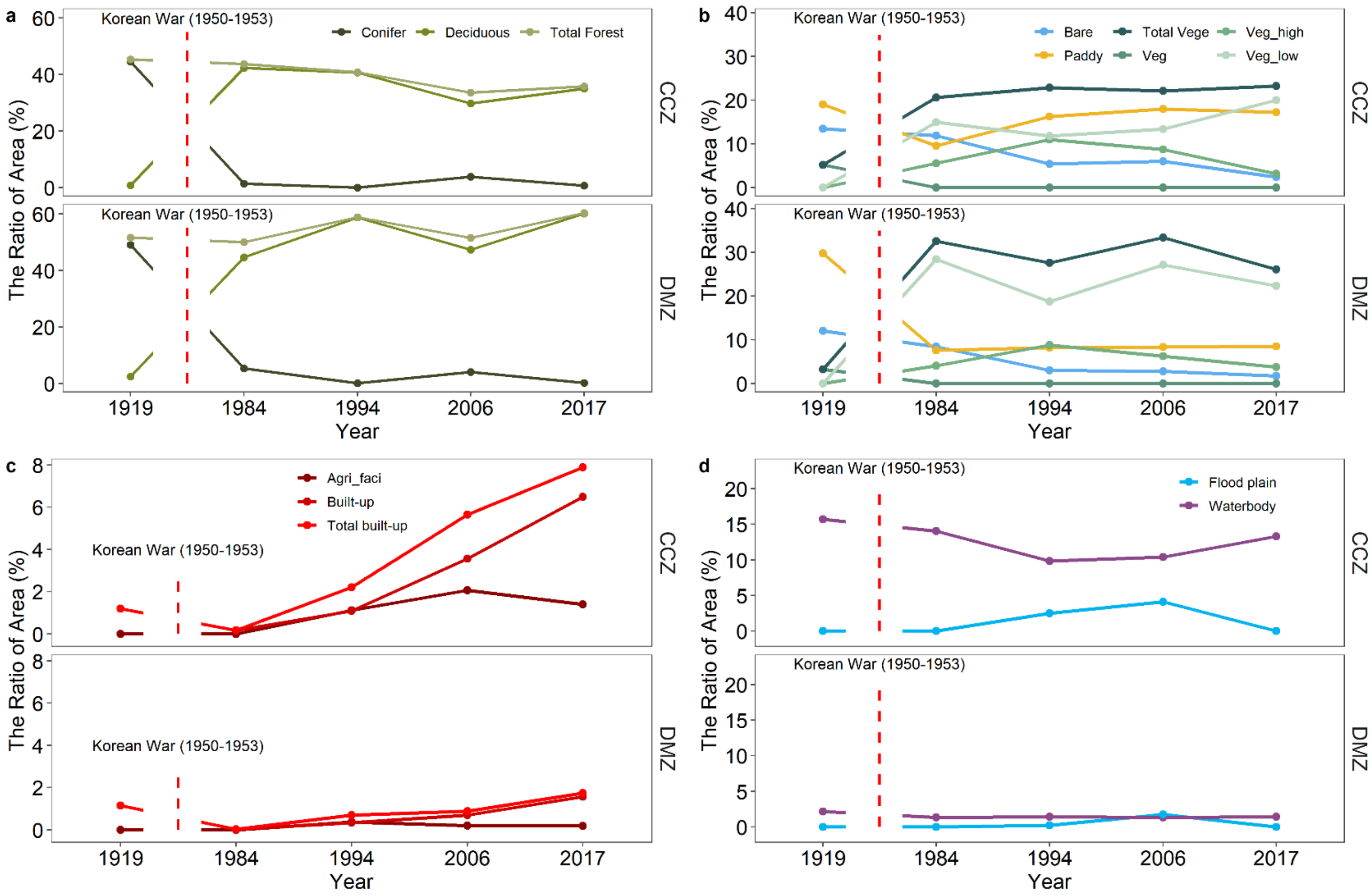


Figure 2–3. Land use maps in the western DMZ and CCZ belonging to Paju and Yeoncheon over 100 years (1919 – 2017) in Korea. Veg ; the grassland before war, Veg_high and Veg_low ; the vitality difference of grassland after war.



a
Korean War (1950-1953)
Conifer
Deciduous
Total Forest
CCZ
DMZ
The Ratio of Area (%)
Year
b
Bare
Total Vege
Veg_high
Paddy
Veg
Veg_low
c
Agri_faci
Built-up
Total built-up
d
Flood plain
Waterbody
1919
1984
1994
2006
2017

Figure 2–4. Land use changes in the western DMZ and CCZ of Paju and Yeoncheon over 100 years (1919–2017) in Korea. (a) Forest areas change. The forest was divided into coniferous and deciduous, and the relative area of the total forest was indicated, (b) Grasslands areas change (Veg, the grassland before war; Veg_high, the grassland with high vitality after war Veg_low ; the grassland with low vitality after war); rice paddies, (c) Areas of artificial structures change. The areas included roads, agricultural facilities, such as ginseng fields (Agri_facil), and the total built–up areas, (d) Waterbody and floodplain areas change. There was no vegetation developed.

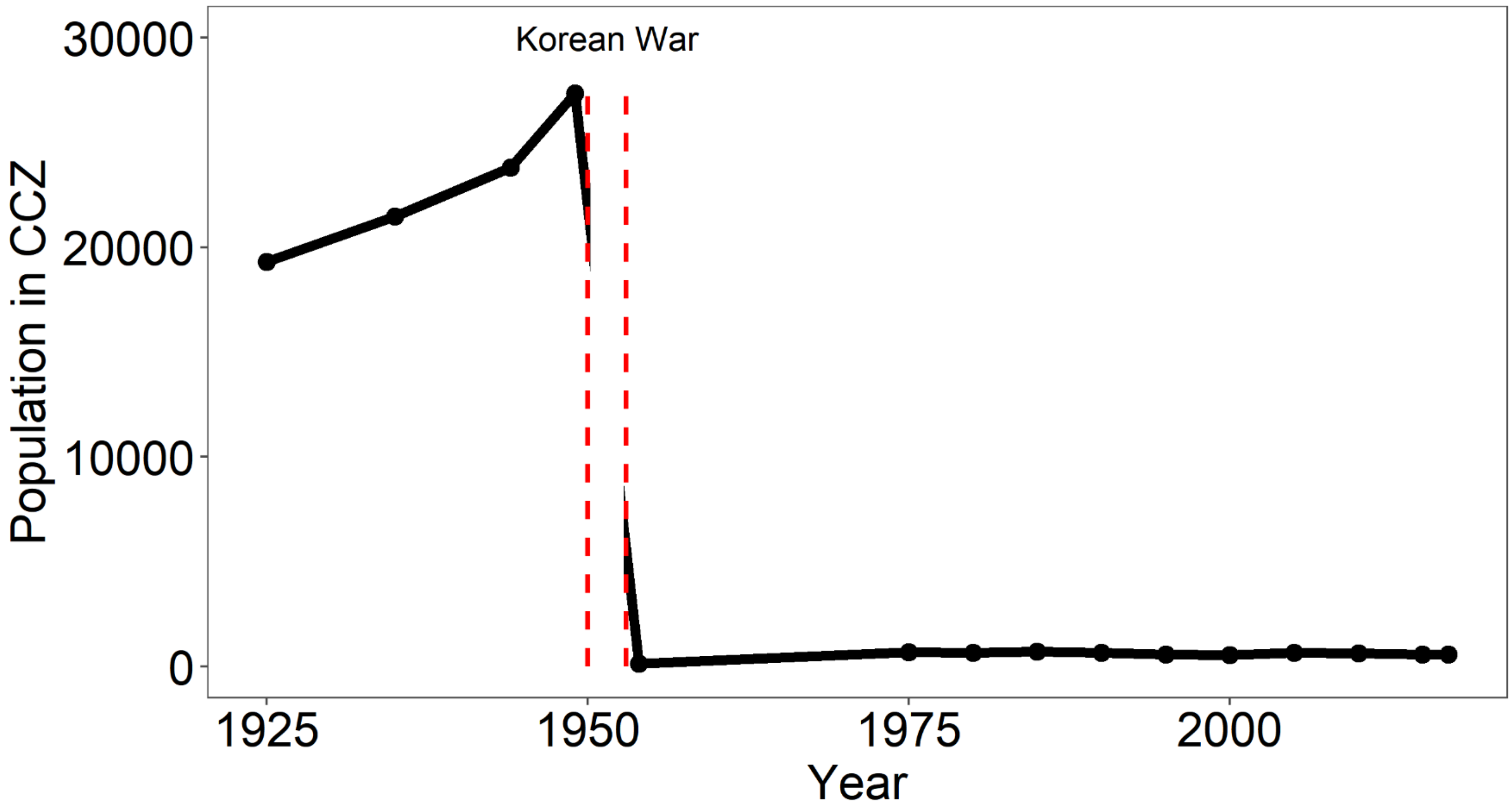


Figure 2–5. Demographic change within the western CCZ in Paju. Since the division of Korea, there have been a limited number of people living in civilian control zone.

2.3.2 Wildfire and NDVI and NDMI changes

Twenty-eight fires have been reported in the western DMZ, including the whole of Paju-si City and Yeoncheon-gun County, during the past 35 years. The fires occurred more frequently and extensively in the north side (to the direction of Yeoncheon). The southern part near Paju (Figure 2-6b) had a total of 10 fires, while the north in Yeoncheon had 15 fires. Despite the different land use compositions, the changes in NDVI and NDMI values of the DMZ and CCZ were not statistically significant ($p > 0.05$).

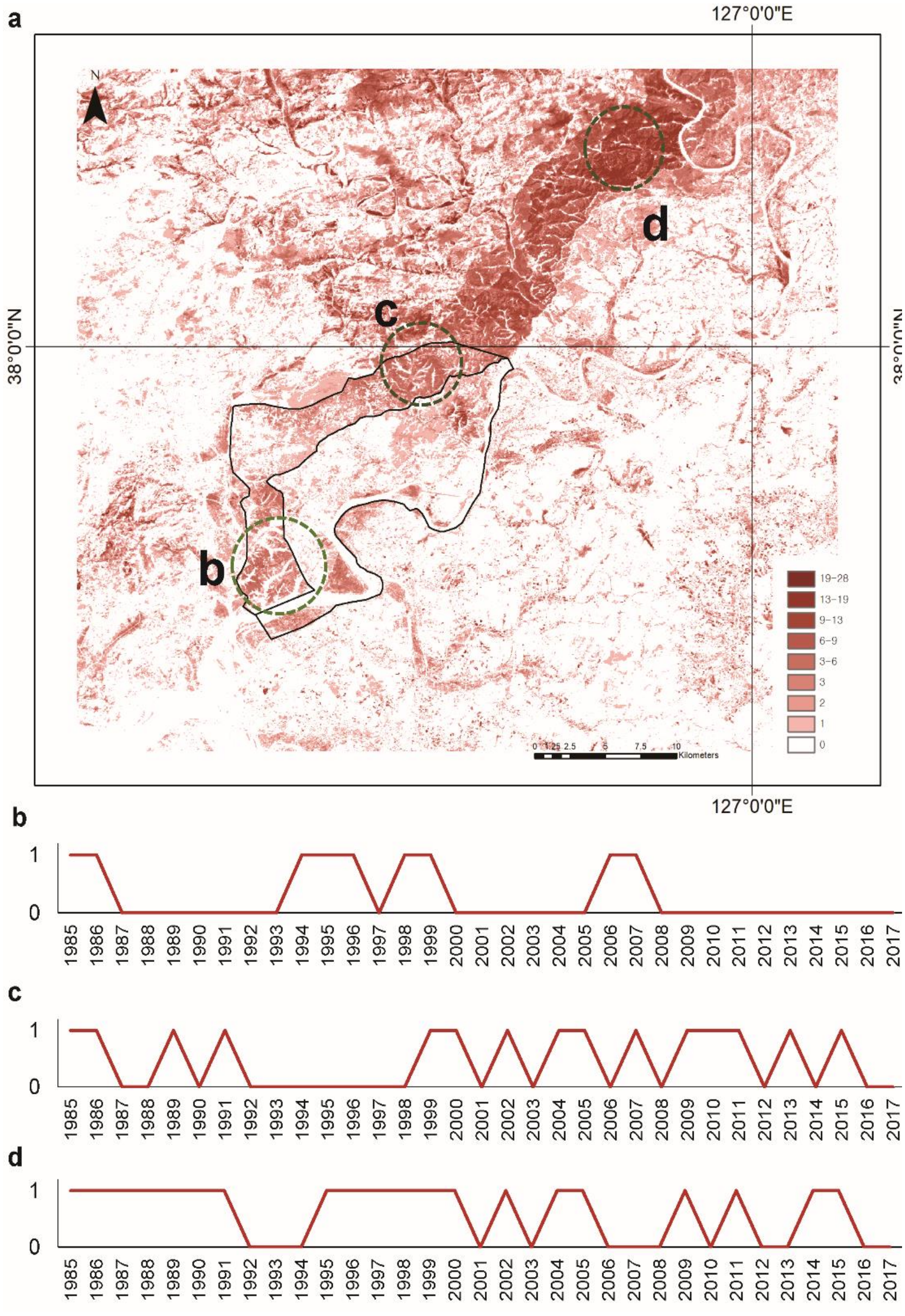


Figure 2-6. Wildfire outbreaks in the western DMZ and CCZ from 1985 to 2017. (a) Cumulative map of wildfire occurrences, (b) Wildfires occurred in area b from 1985 to 2017, and fires occurred mainly in forests among area b, (c) Wildfires occurred in area c, inland from 1985 to 2017, (d) Wildfires occurred in Yeoncheon County from 1985 to 2017, confirming that fire broke out very frequently. '1' refers outbreak of fire.

2.4 Discussion

In the western DMZ and CCZ, the most notable changes in the landscape after the Korean War were found in the forests. According to a previous study, forests diminished drastically during the war (Bae et al., 2012). The forests in the region were predominantly coniferous forests before the war, but they succeeded into broadleaf forests. The deciduous forests in the western part of the DMZ and CCZ are mostly oak trees, but the oaks' predominance may be due to their strong propagation ability by bud and seed germination (Chung et al., 2018).

Grassland was a significant element of the DMZ landscape. Inside the DMZ, the rice paddies turned into grassland after the war. This grassland area has sustained for nearly 70 years since the establishment of the DMZ (Figure 2-1a and Figure 2-5). This observation contradicts the previous studies in South Korea, which found a succession from abandoned rice paddies to grasslands and eventually to forests in a decade (Lee et al., 2002). The results indicated that two factors might arrest succession.

First, fires have prevented the establishment of trees and shrubs in the temperate region (Franklin et al., 2005; Lim et al., 2012; Liu and Ge, 2003; Odum and Barrett, 2005). Fires break out around the DMZ by anthropogenic factors such as deliberate ignition by soldiers for sight clearance or accidental fires. Due to the military confrontation between North and South Korea, it is nearly impossible to extinguish the fire instantly once it occurs. The wildfire was identified at least 28 incidents in the western DMZ and CCZ areas during the past 35 years. Fires may play a crucial role in landscape change, maintenance, and biodiversity of this region.

Second, periodic flooding could discourage grassland transit to the forest (De Jager et al., 2019; Keddy, 2010). The wetland vegetation experiences hydrological fluctuations periodically or non-periodically (Deegan et al., 2007; Wang et al., 2016; Wilcox, 2004). When the wetlands experience fluctuations like floodplains, the establishmfent of non-wetland plants or trees could be hampered by the maintenance of a certain water level and inundation in the wetlands (Garssen et al., 2015; Jian et al., 2018; Vulink and Van Eerden, 1998). The grassland areas in the southern part of DMZ are located adjacent to the stream and could have been subjected to periodic flooding (Figure 2-6b; Appendix A). Most of the Korean wetlands along rivers and estuaries have been converted into agricultural land because of their rich nutrients. The conversion of grasslands into agricultural lands has also been common worldwide (Henwood, 2010). The grassland in the DMZ region should be designated as a prioritized area considering the scarcity and wildlife habitat value (Almeida et al., 2017; Arias et al., 2018; Reis et al., 2019).

There has been a substantial increase in the built-up structures since the 1990s in Paju and Yeoncheon CCZ. It was mainly due to the conversion of rice paddy to the ginseng field. Ginseng, a valued cash crop for Asian medicine, needs shade and facilities are commonly installed for providing shades. These shading facilities are a built-up structure that reduces habitats' quality for wildlife (Park and Nam, 2013b). The reduction of rice paddies may affect the ecosystem. Rice paddies are wetlands exploited by many living animals such as birds, amphibians, reptiles, and insects. Notably, "*dumbeong*" is a traditional irrigation pond for rice cultivation in Korea, providing a refuge for local organisms (Kim et al., 2011; Lee, 2005). Conversions of rice paddies and *dumbeong* into ginseng fields in pursuit of commercial value would likely pose a threat to the regional biodiversity in the CCZ and DMZ. Conservation and revitalization of traditional agricultural landscapes, such as rice paddies, should be placed as a priority of the regional land use plan.

Moreover, in the 2000s, the pressure on the western CCZ land for commercial development was amplified as political tensions between the two Koreas loosened (Kim et al., 2018). A train station, railroads, storage buildings, power lines, and roads heading for Kaesong Industrial Complex were built in the CCZ. Current peace-dialogue, along with cooperative economic development plans between two Koreas, may only warrant further development pressure on the land of DMZ and CCZ at the expense of the region's biodiversity (Kang et al., 2017). A long-term plan for the conservation of biodiversity is needed more than ever for the land of DMZ and CCZ.

Chapter 3. Structural implications of traditional agricultural landscapes on the functional diversity of birds near the Korean DMZ

3.1 Introduction

Rice paddies comprise approximately 11% of agricultural land use worldwide, and over 90% of the world's supply of rice is produced in Asia (FAOSTAT, 2017). Rice paddies can function as alternative natural wetlands and thereby promote biodiversity (Elphick, 2000) with benefits for taxonomic groups such as aquatic plants (Luo et al., 2014), amphibians (Cunha et al., 2015), aquatic insects (Mukai et al., 2005), and birds (Ibáñez et al., 2010). Heterogeneous landscapes, such as those traditionally used in Korean agriculture, can further enhance biodiversity in rice paddies (Kim et al., 2016). Compared to modern intensive agriculture practices, traditional farming maintains greater heterogeneity in landscapes by using small fields, retaining field margins and natural land cover, and planting diverse crops – all practices that have been demonstrated to effectively promote biodiversity (Benton et al., 2003; Martin et al., 2020). Traditional Japanese agricultural landscape, including spatially mixed rice paddies and forests, similarly supports high levels of species diversity (Katoh et al., 2009; Takeuchi, 2003). However, little is known about how traditional Korean agricultural land use, comprising rice paddies and various land cover types, affects wildlife.

Birds are especially sensitive to water stress, and drought can dramatically change community structure (Smith, 1982). However, the current theory is based largely on studies of terrestrial ecosystems, not wetlands. Even though birds are inextricably subjected to influences of water stress, whether avian communities show higher diversity as alternative wetlands, such as rice paddies, increase in quantity or quality has not been well studied. Korean traditional agricultural landscapes (TAL) provide a model case in which to examine these questions. Endangered migrating birds, such as the red-crowned crane and swan goose, overwinter in the CCZ and nearby estuaries (Lee et al., 2007), but species that breed and nest in paddy fields during the summer have gone unstudied. To investigate the bird communities under specific environmental conditions, using functional diversity can be useful as well as traditional taxonomic diversity. Functional diversity is determined by the range of traits in an assemblage and is expected to be responsive to landscape composition or environmental conditions (Hooper et al., 2005; Luck et al., 2012). Therefore, functional diversity may clarify a bird community composition with the structural portrayal and may reveal the traits which are effective for surviving in a harsh drought condition. Furthermore, among a bunch of research dealing with functional diversity, few studies have considered the functional indices according to the land use and land cover (LULC) in combination with climate events (but see Weyland et al., (2019)). In this study, the resilience of avian community diversity in Korean TAL was examined when facing drought.

This study has investigated the structure of the Korean TAL and the response of the avian community in accordance with the TAL type under the drought events. The hypotheses were as follows: (1) avian taxonomic and functional diversity would respond differently according to the dominant natural elements and anthropogenic elements, (2) the higher proportion of irrigation pond would contribute to the resilience of avian taxonomic and functional diversity against drought events by replenishing water to maintain wetland environment in rice paddies.

3.2 Methods and Materials

3.2.1 Bird surveys and TAL units

Summer bird surveys were conducted in the fourth week of July and the first week of August in 2015 and 2016. This period was a break from farming, and thus the impact by anthropogenic factors was expected to be minimal. In addition, the season would be the post-breeding season, and therefore the juvenile birds could be involved in the surveys. The study site was located in the CCZ, Paju-si, Gyeonggi-do Province, South Korea (38° 00' N 126° 51' E, 37° 49' N 126° 40' E) (Figure 3-1). Thirty-six irrigation ponds were randomly chosen among 500 irrigation ponds in the study site to examine the influence on the avian community against drought. The survey was performed in the morning (5:30 – 7:30 AM), midday (11:00 AM – 1:00 PM), and afternoon (5:30 – 7:30 PM) at each site using the line transect method. During the monitoring period, investigators were divided into two teams—each team surveyed along the 500-meter monitoring line, which began at the survey point (pond). Teams then moved along either side, marking the occurrence and distribution of bird species on a map while conducting the field survey. The average transit time was approximately 30 min per site. Birds were rescored within a 100m-wide range from the monitoring line.

All the survey sites included an irrigation pond, but the composition of landscape elements around the pond differed undesigningly. The LULC type was calculated based on 1.0 × 1.5 km images along the monitoring line, which has 500-m radius-wide buffer, using Google Earth image (RGB band). The RGB image was segmented using eCognition (segmentation: shape 0.3, compact: 0.5) and classified manually. The classification results were verified on the spot. Land use type was classified into nine categories: rice paddy (RICE); ginseng field (GF); common field-cultivated soybean, adlay, et cetera (F); barren field (BF); irrigation pond (POND); freshwater, including river and stream (RIVER); forest (FOREST); artificial structures, including agricultural facilities, army camp, buildings, roads, et cetera) (AS); and mixed vegetation (MV; including weeds, ruderals on ditches and fallows).

The number of TAL types was determined using the NbClust package (Charrad et al., 2014), with the optimal number being determined according to whether they provided 30 metrics in the dataset for use in the evaluations. Clustering was based on ward distance and the vegan package. Using the prcomp package to summarize the classified LULC characteristics as a single axis, the PCA analysis was performed.

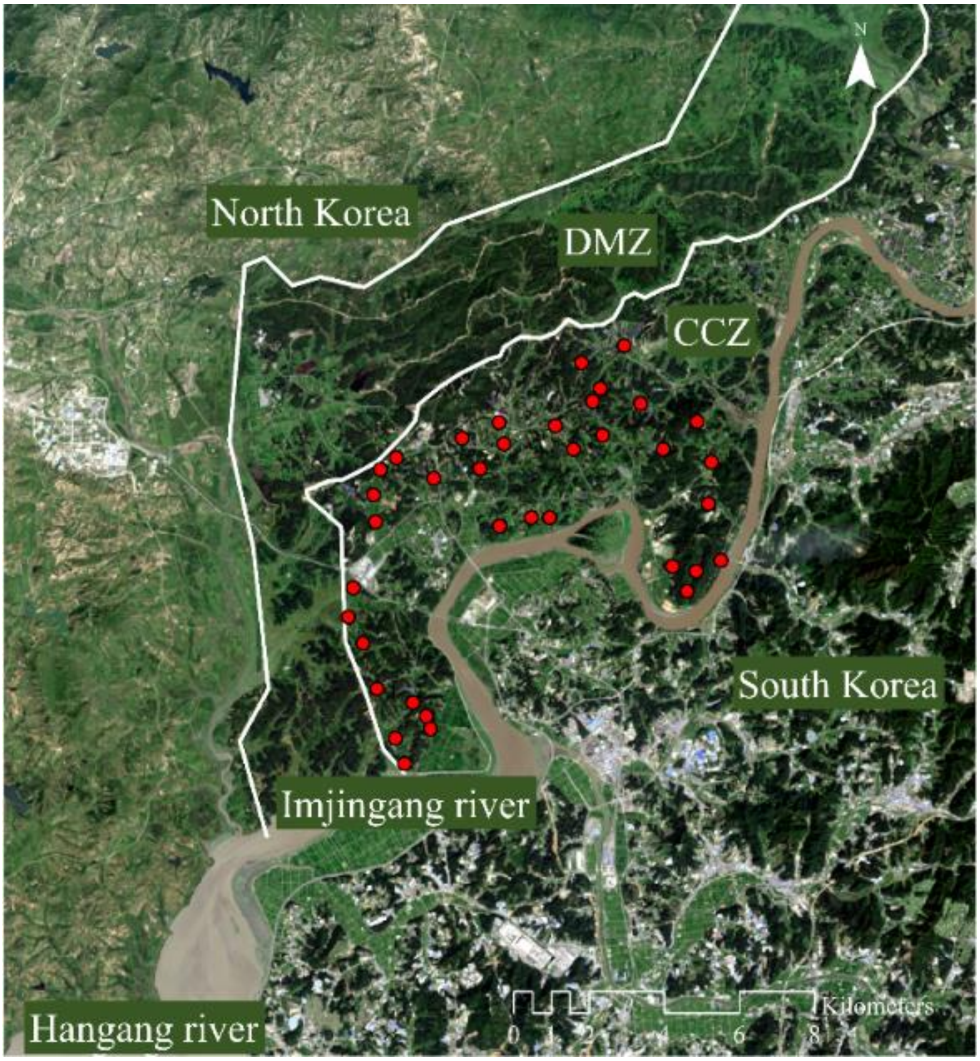


Figure 3-1. Map of the study area. Red dots indicate surveyed sites.

3.2.2 Drought index

The study sites experienced droughts in 2015 and 2016. The average annual precipitation in the region from April to July is 718 mm. However, the precipitation amounts from April to July in this area in 2015 and 2016 were 393 mm and 654 mm, respectively. When the precipitation is low from April to July, rice paddies usually would be supplied with less water, compromising their ability to function as wetlands. In 2015, precipitation was 40% lower than in 2016 and 45% lower than the average precipitation over the previous ten years.

The degree of the drought was examined using the SPEI (standardized precipitation evapotranspiration index). The SPEI, an index that improved the existing drought index to make apparent effects attributable to climate change, was first proposed by Vicente-Serrano et al. (2010). Unlike other drought indices, rather than simply calculating the precipitation (P), the SPEI uses climatic water balance. The difference between precipitation and reference evapotranspiration (P − ET0) is used as the input. This enables more precisely identifying extreme temperature rises or changes in drought caused by heatwaves (Beguería et al., 2014).

With a value for *PET* (potential evapotranspiration), the difference between the precipitation (*P*) and *PET* for the month *i* is calculated: $D_i = P_i - PET_i$ which provides a simple measure of the water surplus or deficit for the analyzed month. The calculated D_i values are aggregated at different time scales.

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3}$$

Where $W = -2\ln(P)$ for $P \leq 0.5$, P being the probability of exceeding a determined D value, $P = 1-F(x)$. If $P > 0.5$, P is replaced by $1-P$, and the sign of the resultant SPEI is reversed. The constants are: C_0 = 2.515517, C_1 = 0.802853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308. The average value of the SPEI is 0, and the standard deviation is 1. The SPEI is a standardized variable, and it can therefore, be compared with other SPEI values over time and space. An SPEI of 0 indicates a value corresponding to 50% of the cumulative probability of D, according to a Log-logistic distribution.

In this study, using the data of the monthly cumulative precipitation, average maximum temperature, and average minimum temperature (Korea Meteorological Administration, 2019), 3-month time scales were used. The period was calculated for a period of 10 years (2008-2018). The data were analyzed with the SPEI package in R Ver. 3.5 (Begueria and Vicente-Serrano, 2013)

3.2.3 Taxonomic and Functional diversity

In this study, species richness (SR) was used to measure taxonomic diversity (Magurran, 2013) for each site. The avian diversity was represented by the maximum number of species among the three surveys which were recorded on each site.

Functional diversity was calculated based on several traits (see Cagan H, 2006; Flynn et al., 2009; Luck et al., 2012): diet, foraging location, habitat location, nesting location, migration status, and morphological features (body mass), which have been commonly used in previous studies (Table 3-1). Diet, foraging location, and morphological features are continuous traits (Wilman et al., 2014), and habitat location, nesting location, and migration status are categorical traits (Lee et al., 2000; Takagawa et al., 2011). For analysis, the categorical data were converted to binary values.

Functional richness (FRic), functional evenness (FEve) (Villéger et al., 2008), and functional divergence (FDiv) (Mouchet et al., 2010) were calculated using the FD package in R (Laliberté et al., 2014). FRic refers to the amount of functional space occupied by species in a community. FEve indicates the distribution of species abundance in a community within a functional space. FDiv describes the difference in distance from the center of the functional space and is related to species abundance measures.

Table 3-1 Summary of traits and avian functional diversity indices.

Category	Trait	Unit and trait type
Diet	• Invertebrates • Vertebrates • Herptile • Fish • Unknown • Decaying biomass • 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 summer)	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)

3.2.4 Statistical analysis

Differences across the LULC types, drought event occurrence, and diversity indices were evaluated by Bayesian linear mixed models using MCMCglmm (Hadfield, 2010), running 130,000 iterations with a burn-in period of 30,000 and a thinning interval of 100. Autocorrelation was less than 0.02. Sites and months were modeled as random effects, and drought and land configuration for each functional diversity and species richness index were included as the main fixed effects.

The effect of drought on the functional diversity and taxonomic diversity for each LULC type was evaluated by paired t-test and the Wilcoxon signed-rank test. The relative ratio of the LULC in the TAL types was evaluated by ANOVA or Kruskal-Wallis test and post-hoc test Tukey HSD or Conover post hoc test. The relationship between LULC and diversity indices was tested by Kendall correlation. All statistical packages and analyses were conducted in R Ver. 3.5.

3.3 Results

3.3.1 Compositions of TALs and avian diversity

Based on the clustering, the characteristics of study sites were categorized into three types (Figure 3-2, Figure 3-3). The cumulative proportion of the first axis and the second axis of PCA was 49% (Figure 3-2, Table 3-2). The PC1 axis explained 27% of variance and showed a positive correlation with mixed vegetation (MV) ($r = 0.46$) and a negative correlation with forest (FOREST) ($r = -0.46$). The PC2 axis explained 22% of the variance and was highly correlated with the field (F) ($r = -0.57$) (Table 3-2). TAL 1 appeared to be characterized by wetlands such as rice paddies (RICE) and waterbody (RIVER), which were significantly higher than other TAL (Figure 3-2, Figure 3-3, Figure 3-4, Figure 3-5). TAL 2 had a high proportion of forest (FOR) larger than any other TAL type. TAL 3 was represented by a high proportion of field like field (F), ginseng field (GF), and barren field (BF).

FEve and FDiv did not significantly differ by TAL type. However, SR and FRic varied significantly depending on TAL types. TAL 1 was associated with the highest SR and FRic scores (pMCMC < 0.001, Figure 3-6). TAL 2 showed the lowest SR and FRic scores (pMCMC < 0.001).

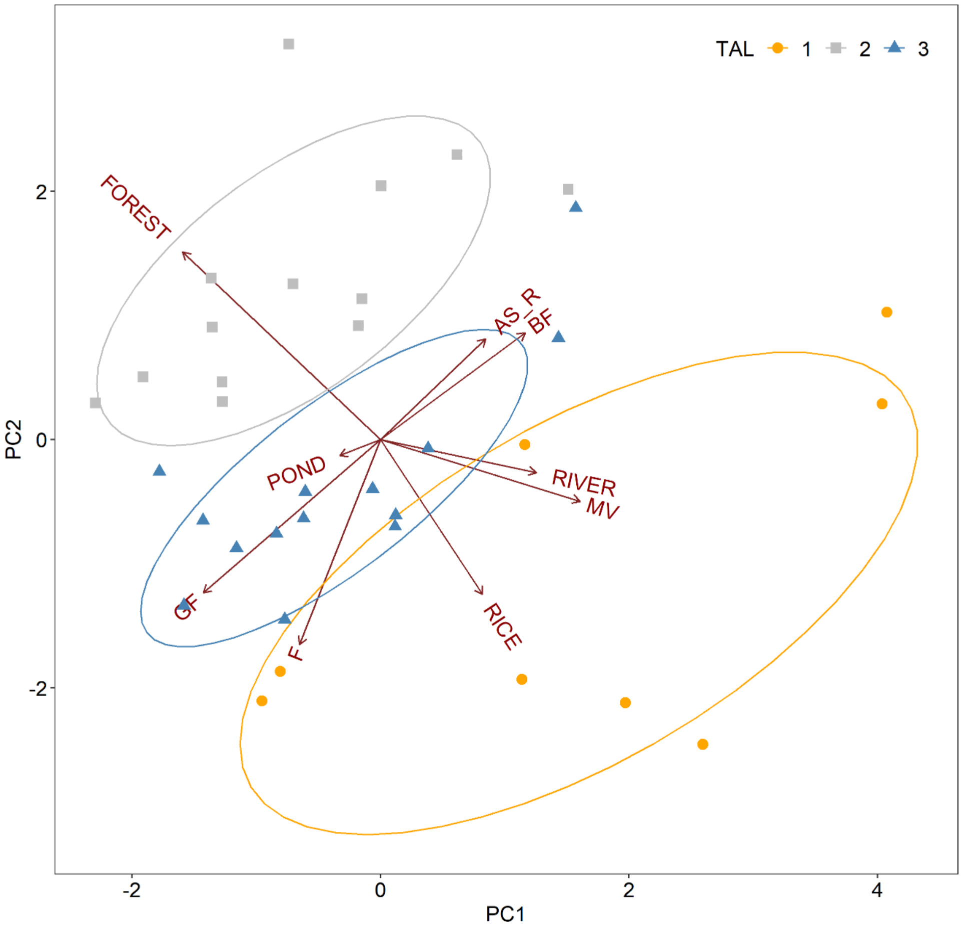


Figure 3-2. PCA results of the TAL composition. The arrows indicated the direction of the habitat composition. The first two axes explain 48.8% of the variation of the bird assemblages. PC 1 showed a very high correlation with mixed vegetation (MV) (r = 0.46), and PC 2 was highly correlated with fields (F). The round shape dot is TAL 1, and the square point is TAL 2. TAL 3 is the triangle point.

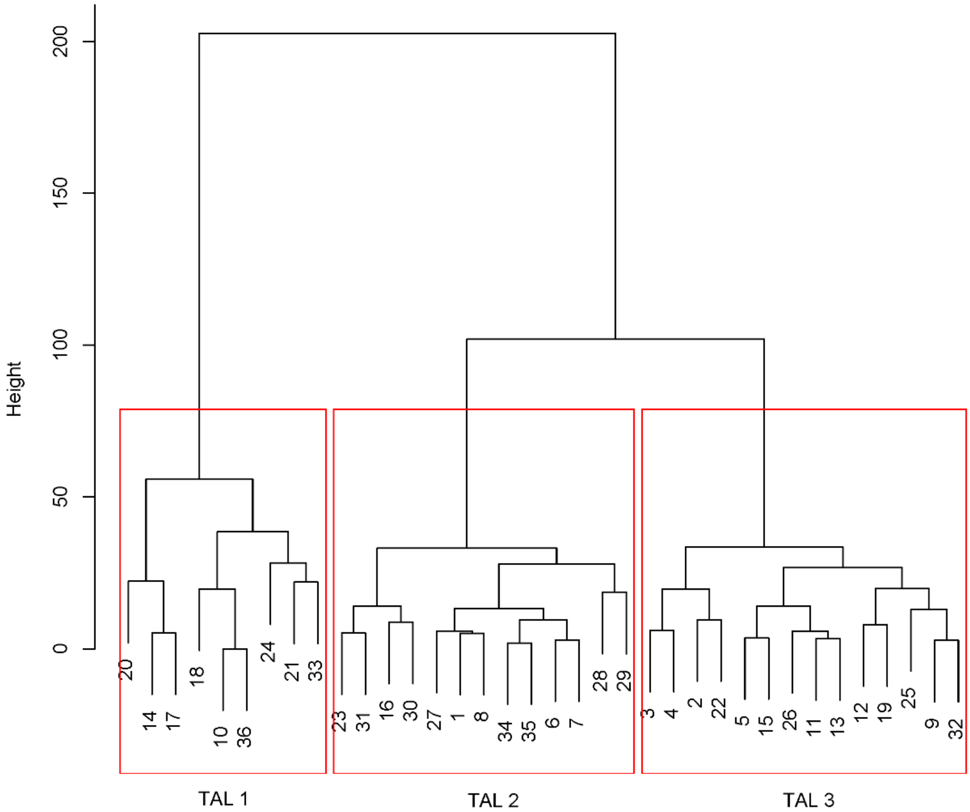


Figure 3-3. Result of the cluster analysis using ward distance.

Table 3-2. Principal Component Analysis results showing TAL variables correlated in the PC1 and PC2 ordination axis.

		PC1	PC2
The Correlation with axis and Variation	AS_R	0.24	0.26
	BF	0.34	0.27
	F	−0.19	−0.53
	FOREST	−0.46	0.48
	GF	−0.41	−0.39
	MV	0.46	−0.16
	POND	−0.10	−0.04
	RICE	0.24	−0.40
	RIVER	0.36	−0.08
Importance of components	Standard deviation	1.553	1.4058
	Proportion of Variance	0.27	0.22
	Cumulative Proportion	0.27	0.49

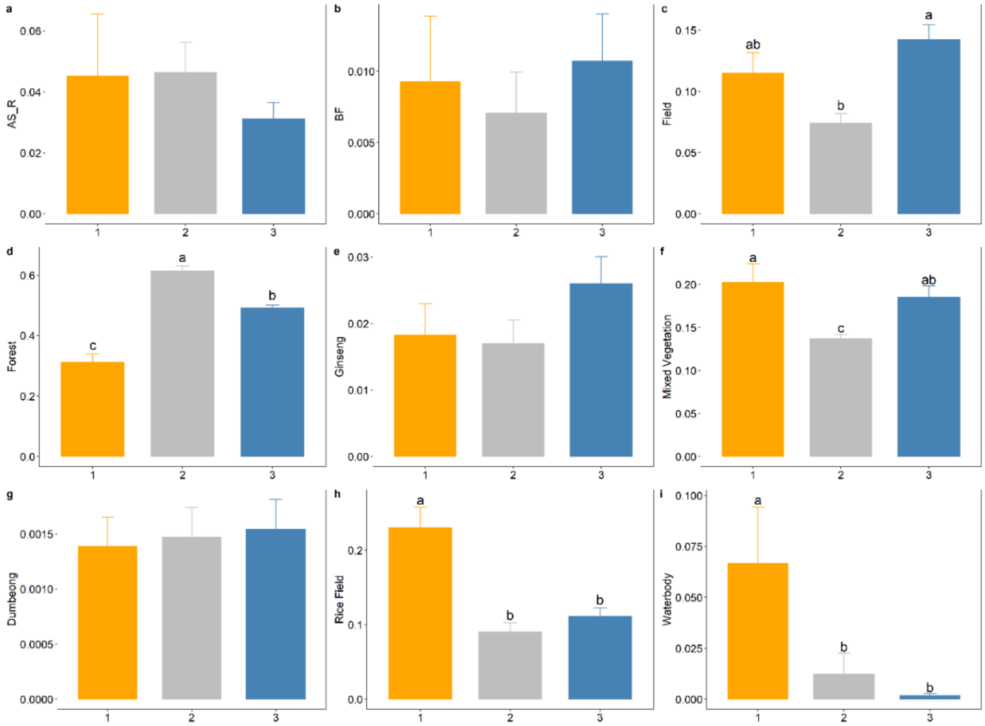


Figure 3-4. Relative ratios of the landscape units in the TAL type. Orange is the TAL 1; Grey is the TAL 2; blue is the TAL2. (Tukey HSD post hoc test or Conover post hoc test, $p < 0.05$). AS_R is an artificial structure and road; BF is a barren field.

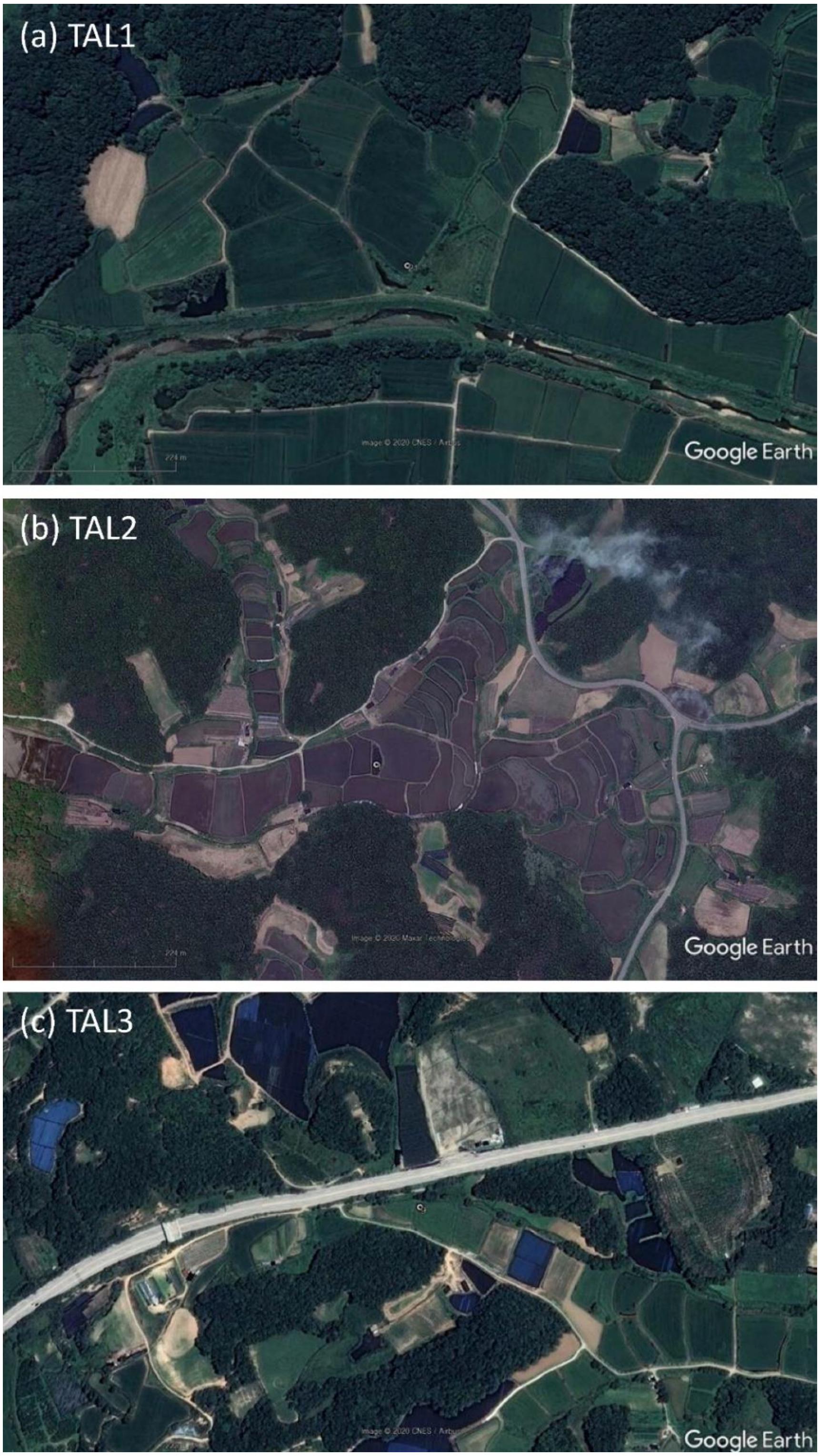


Figure 3-5. The example image of TAL types (Google Earth image).

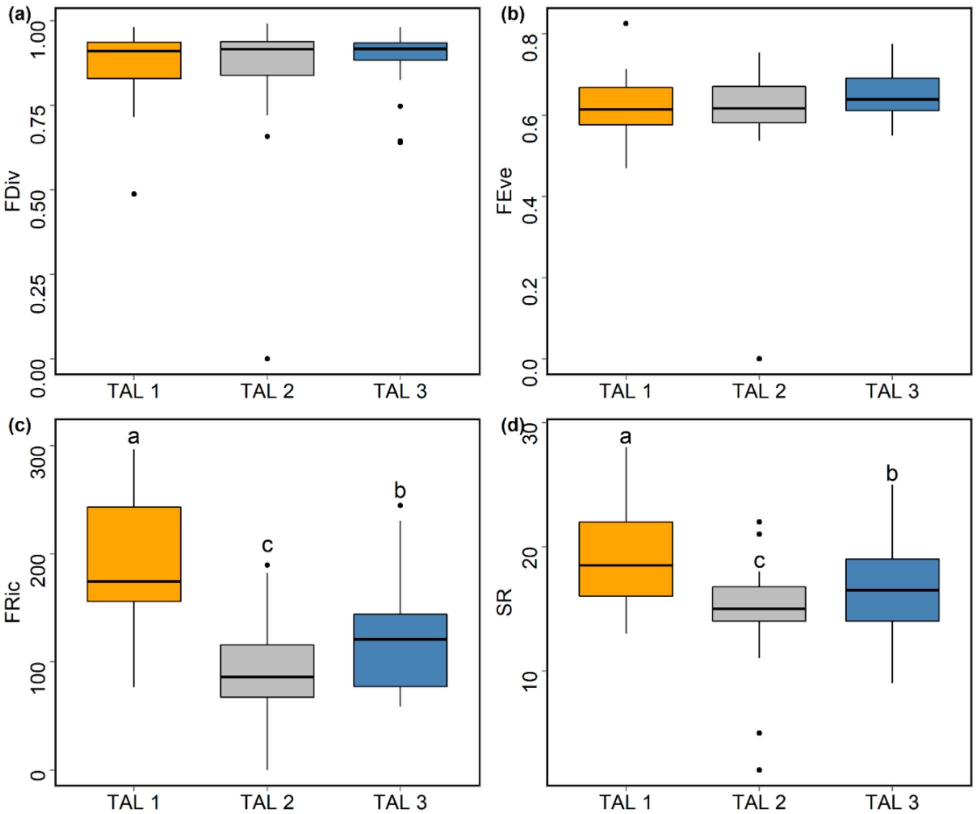


Figure 3-6. Diversity indices of the TAL types. For each type of TAL, only the FRic and SR differ statistically ($p < 0.05$, MCMCglmm). (a) The differences in FDiv by TAL types ($p > 0.05$, MCMCglmm), (b) The differences in FEve by TAL types ($p > 0.05$, MCMCglmm), (c) The differences in FRic by TAL types ($p<0.05$, MCMCglmm), (d) The differences in SR by TAL types ($p<0.05$, MCMCglmm).

3.3.2 Surveyed avian population

In this study, the results were found the legally protected species in Korea by the Ministry of Environment that is Northern Sparrow Hawk (*Accipiter nisus nisosimilis*), Grey Frog Hawk (*Accipiter soloensis*), European Hobby (*Falco subbuteo*), Water Cock (*Gallicrex cinereal*). The nature monument also protected by law in Korea by Cultural Heritage Administration that is Common Kestrel (*Falco tinnunculus interstinctus*), Brown Hawk-Owl (*Ninox scutulata japonica*), Oriental Scops Owl (*Otus sunia stictonotus*), Mandarin Duck (*Aix galericulata*), Northern Sparrow Hawk (*Accipiter nisus nisosimilis*), Grey Frog Hawk (*Accipiter soloensis*), European Hobby (*Falco subbuteo*), Water Cock (*Gallicrex cinereal*) (Table 3-3).

52 species were found in TAL 1, 54 species in TAL 2, and 50 species in TAL 3. In all TAL types, Barn Swallow (*Hirundo rustica gutturalis*) were found the most, and secondly, Vinous-throated Parrotbill (*Paradoxornis webbianus fulvicauda*) were found.

Table 3-3. Species list and average population size of avian species by TAL types. N.M is the designation number of Natural Monument by Cultural Heritage Administration; Grade is endangered species grade, legally protected by Ministry of Environment. IUCN is the international criteria of endangerment. TAL is a traditional agricultural landscape type.

Order	family	Scientific name	English name	Korean name	N.M	Grade	IUCN	TAL1	TAL2	TAL3
Anseriformes	Anatidae	*Aix galericulata*	Mandarin Duck	원앙	327		LC	2.0	4.0	2.0
		Anas poecilorhyncha zonorhyncha	Chinese Spot-billed Duck	흰뺨검둥오리			LC	11.6	2.3	2.4
Charadriiformes	Scolopacidae	*Actitis hypoleucos*	Common Sandpiper	깝작도요			LC	1.0		
		Tringa ochropus	Green Sandpiper	삑삑도요			LC	1.0	1.0	
Ciconiiformes	Ardeidae	*Ardea cinerea jouyi*	Grey Heron	왜가리			LC	1.7		
		Ardeola bacchus	Chinese Pond Heron	흰날개해오라기			LC			1.0
		Bubulcus ibis coromandus	Cattle Egret	황로			LC	2.8	3.8	4.2
		Butorides striata amurensis	Striated Heron	검은댕기해오라기			LC	1.7	1.0	1.0
		Egretta alba modesta	Great Egret	중대백로			LC	10.5	6.0	4.6
		Egretta garzetta garzetta	Little Egret	쇠백로			LC	1.7	2.5	1.2
		Nycticorax nycticorax nycticorax	Black-crowned Night Heron	해오라기			LC	1.7	1.0	2.3
Columbiformes	Columbidae	*Streptopelia orientalis orientalis*	Oriental Turtle Dove	멧비둘기			LC	8.1	6.7	5.6
Coraciiformes	Alcedinidae	*Alcedo atthis bengalensis*	Common Kingfisher	물총새			LC	1.4	1.0	1.2
		Halcyon coromanda major	Ruddy Kingfisher	호반새			LC	2.3	1.3	1.0

		Halcyon pileata	Black-capped Kingfisher	청호반새			LC	1.6	1.8	1.6
	Coraciidae	*Eurystomus orientalis*	Oriental Dollarbird	파랑새			LC	6.7	4.1	6.1
Cuculiformes	Cuculidae	*Cuculus canorus canorus*	Common Cuckoo	뻐꾸기			LC	1.3	2.4	2.4
		Cuculus saturatus horsfieldi	Oriental Cuckoo	벙어리뻐꾸기			LC			1.0
Falconiformes	Accipitridae	*Accipiter nisus nisosimilis*	Northern Sparrow Hawk	새매	323-4	Ⅱ	LC		1.0	2.0
		Accipiter soloensis	Grey Frog Hawk	붉은배새매	323-2	Ⅱ	LC	1.8	2.3	2.2
		Butastur indicus	Grey-faced Buzzard	왕새매			LC		1.0	1.0
	Falconidae	*Falco subbuteo*	European Hobby	새호리기		Ⅱ	LC	1.0	1.0	
		Falco tinnunculus interstinctus	Common Kestrel	황조롱이	323-8		LC	1.5	1.0	1.3
Galliformes	Phasianidae	*Coturnix japonica*	Japanese Quail	메추라기			NT	4.0	2.0	
		Phasianus colchicus karpowi	Ring-necked Pheasant	꿩			LC	2.7	1.9	2.2
Gruiformes	Rallidae	*Gallicrex cinerea*	Water Cock	뜸부기	446	Ⅱ	LC	1.0	1.0	1.5
		Porzana fusca erythrothorax	Ruddy-breasted Crake	쇠뜸부기사촌			LC	1.0		1.0
Passeriformes	Aegithalidae	*Aegithalos caudatus magnus*	Rong-tailed Tit	오목눈이			LC	1.0	25.0	40.0
	Corvidae	*Corvus corone orientalis*	Carrion Crow	까마귀			LC	3.3	5.1	2.4
		Corvus macrorhynchos macrorhynchos	Large-billed Crow	큰부리까마귀			LC	1.0	4.8	2.0
		Cyanopica cyana koreensis	Azure-winged Magpie	물까치			LC	2.8	4.7	1.0
		Garrulus glandarius brandtii	Eurasian Jay	어치			LC	1.5	1.4	2.0
		Pica pica sericea	Black-billed Magpie	까치			LC	11.3	20.0	10.2
	Emberizidae	*Emberiza elegans elegans*	Yellow-throated Bunting	노랑턱멧새			LC	5.0	1.0	2.0
	Fringillidae	*Carduelis sinica ussuriensis*	Grey-capped Greenfinch	방울새			LC		1.0	

	Hirundinidae	*Hirundo rustica gutturalis*	Barn Swallow	제비	LC	510.9	96.3	113.5
	Laniidae	*Lanius bucephalus bucephalus*	Bull-headed Shrike	때까치	LC	3.1	1.3	1.4
		Lanius cristatus lucionensis	Brown Shrike	노랑때까치	LC	2.0		
		Lanius tigrinus	Tiger Shrike	칡때까치	LC	2.0	2.0	
	Motacillidae	*Motacilla alba leucopsis*	White Wagtail	알락할미새	LC	1.6	1.5	
		Motacilla cinerea robusta	Grey Wagtail	노랑할미새	LC		8.0	1.0
	Muscicapidae	*Ficedula zanthopygia*	Yellow-rumped Flycatcher	흰눈썹황금새	LC	2.0	1.0	1.0
		Phoenicurus auroreus auroreus	Daurian Redstart	딱새	LC	2.1	1.7	1.7
		Saxicola torquatus stejnegeri	Eurasian Stone Chat	검은딱새	LC	6.0	1.0	1.6
	Oriolidae	*Oriolus chinensis diffusus*	Black-naped Oriole	꾀꼬리	LC	6.5	7.1	5.9
	Paridae	*Parus major mimor*	Great Tit	박새	LC	38.8	34.8	30.6
		Parus palustris hellmayri	Marsh Tit	쇠박새	LC	4.6	5.1	14.2
	Passeridae	*Passer montanus saturatus*	Eurasian Tree Sparrow	참새	LC	26.5	53.0	11.1
	Pycnonotidae	*Hypsipetes amaurotis*	Brown-eared Bulbul	직박구리	LC	10.4	7.7	7.2
	Sturnidae	*Sturnus cineraceus*	White-cheeked Starling	찌르레기	LC		1.0	
	Sylviidae	*Acrocephalus orientalis*	Oriental Reed Warbler	개개비	LC	1.3	1.0	7.0
		Cettia diphone borealis	Korean Bush Warbler	휘파람새	LC			2.0
		Phylloscopus coronatus	Eastern Crowned Willow Warbler	산솔새	LC	4.7	1.0	3.0
	Timaliidae	*Paradoxornis webbianus fulvicauda*	Vinous-throated Parrotbill	붉은머리오목눈이	LC	78.0	78.2	47.0
	Turdidae	*Turdus hortulorum*	Grey-backed Thrush	되지빠귀	LC	1.0	1.5	2.0

Pelecaniformes	Phalacrocoracidae	*Phalacrocorax carbo sinensis*	Great Cormorant	민물가마우지		LC	2.0		
Piciformes	Picidae	*Dendrocopos kizuki seebohmi*	Japanese Pygmy Woodpecker	쇠딱다구리		LC	1.3	1.4	1.3
		Dendrocopos leucotos leucotos	White-backed Woodpecker	큰오색딱다구리		LC	1.7	1.7	2.0
		Dendrocopos major japonicus	Great Spotted Woodpecker	오색딱다구리		LC	1.5	2.6	1.9
		Picus canus jessoensis	Grey-faced Woodpecker	청딱다구리		LC	1.6	1.6	1.9
Strigiformes	Strigidae	*Ninox scutulata japonica*	Brown Hawk-Owl	솔부엉이	324-3	LC		1.0	1.5
		Otus sunia stictonotus	Oriental Scops Owl	소쩍새	324-6	LC		1.0	

3.3.3 Drought and diversity indices of TAL

SPEI values showed that drought occurred periodically over the decade (Figure 3-7), but a severe drought in 2014 and 2015 followed with rainfall within a normal range. Overall, the diversity indices in a non-drought year were higher than those in a drought year (Figure 3-8). Besides, there were significant differences between drought and non-drought years on FRic and SR (MCMCglmm, Table 3-4).

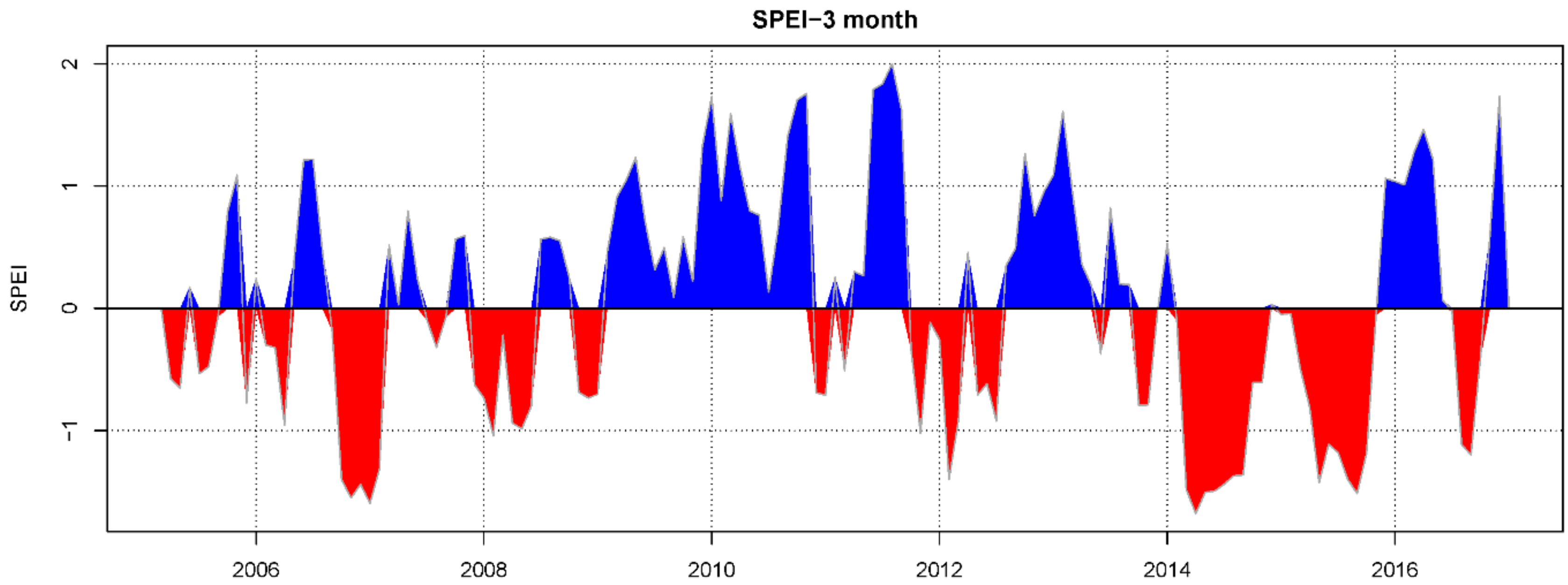


Figure 3–7. The result of the SPEI (standardized precipitation evapotranspiration index) analysis with 3–month time scale. In 2014–2015, there was a continuous drought for two years, unlike in the previous 10 years. During the past decade, droughts had occurred periodically. The red area indicates droughts.

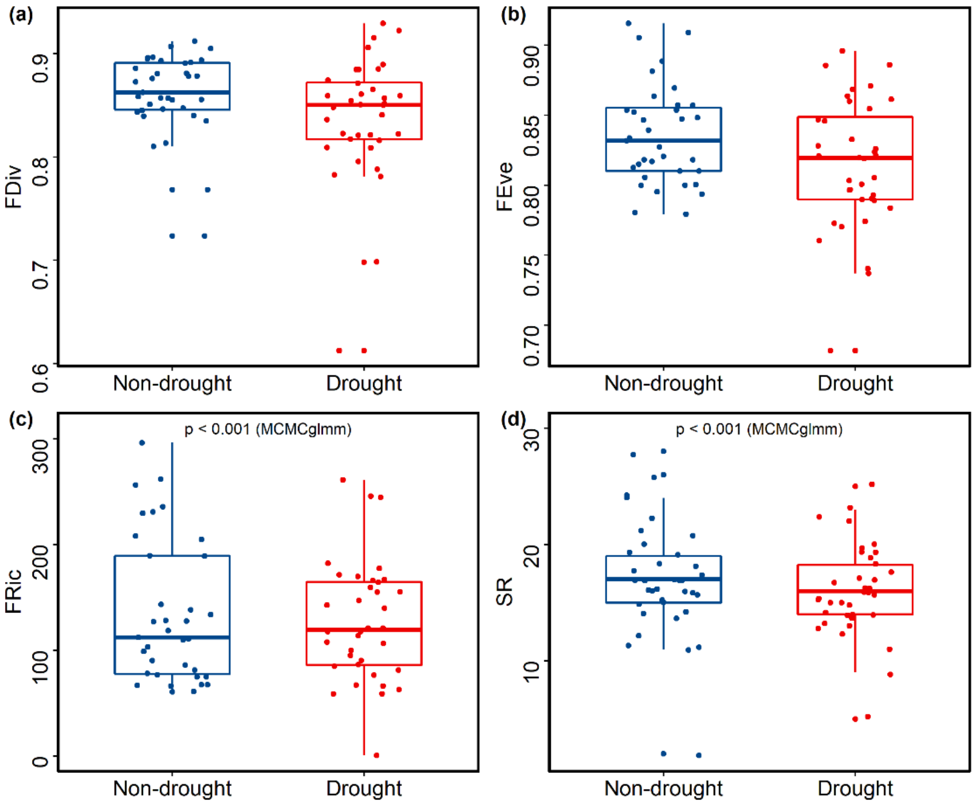


Figure 3–8. Diversity indices with drought events. For each drought condition of Diversity indices, only the FRic and SR differ statistically ($p < 0.001$, MCMCglmm). (a) The differences in FDiv by drought condition ($p > 0.05$, MCMCglmm). (b) The differences in FEve by drought condition ($p > 0.05$, MCMCglmm). (c) The differences in FRic by drought condition ($p < 0.001$, MCMCglmm). (d) The differences in SR by drought condition ($p < 0.001$, MCMCglmm).

Table 3-4. MCMC glmm including bird functional and taxonomic diversity as the dependent variables and TAL and drought condition as the independent variables. Abbreviations are as follows: post.mean = posterior mean, l-95 % = lower limit of the 95 % credible interval, u-95 % = upper limit of the 95 % credible interval, eff.samp = effective size of the sample, and *p*MCMC = posterior probability for the parameter not being different from zero. The prior was defined as follows: list(R = list(V = 1, nu = 0.002), G = list(G1 = list(V = 1, nu = 0.002), and G2 = list(V = 1, nu = 0.002))).

Factor		post.mean	l-95 %	u-95 %	eff.samp	*p*MCMC
FRic	TAL2	-124.04	-126.17	-124.09	1000	<0.001 ***
	TAL3	-85.85	-87.15	-84.61	1000	<0.001 ***
	Drought	-3.43	-3.88	-2.98	1000	<0.001 ***
FEve	TAL2	-0.017	-0.56	0.63	1000	0.918
	TAL3	0.019	-0.55	0.61	1000	0.962
	Drought	0.002	-0.47	0.45	1000	0.986
FDiv	TAL2	-0.025	-0.67	0.55	1000	0.928
	TAL3	0.005	-0.59	0.60	1000	0.980
	Drought	-0.002	-0.42	0.47	1118	0.982
SR	TAL2	-4.91	-5.89	-3.91	1000	<0.001 ***
	TAL3	-3.13	-4.33	-2.05	1000	<0.001 ***
	Drought	-0.92	-1.37	-0.47	1000	<0.001 ***

The impact of drought on bird populations differed by TAL type (Figure 3-9). In TAL 1, the diversity indices that were significantly reduced during drought were FDiv, FEve, and SR. FDiv decreased by 23.6% (Wilcoxon's signed-rank test, p = 0.01). FEve diminished by 13.1% (paired t-test, t_8=2.84, p = 0.02), and SR decreased by 22.1% (Wilcoxon's signed-rank test, p = 0.03). TAL 2 did not show a statistically significant difference in diversity indices due to drought. TAL 3 showed a significant 9% reduction in FEve during drought (paired t-test, t_{13} = 3.06, p = 0.009). Furthermore, as to the relationship between the diversity indices, LULC type, and drought event, 5 LULC elements of FOREST, RICE, GF, MV, and RIVER had negative or positive correlation ($p < 0.05$) (Figure 3-10). When the proportion of FOREST increased, the differences in diversity indices between drought and non-drought decreased. The gap of diversity indices between drought and non-drought events were increased with RICE, MV, and RIVER increased. Besides, unlike prediction, there was no significant difference in the relationship between the proportion of POND and diversity indices ($r < 0.22$).

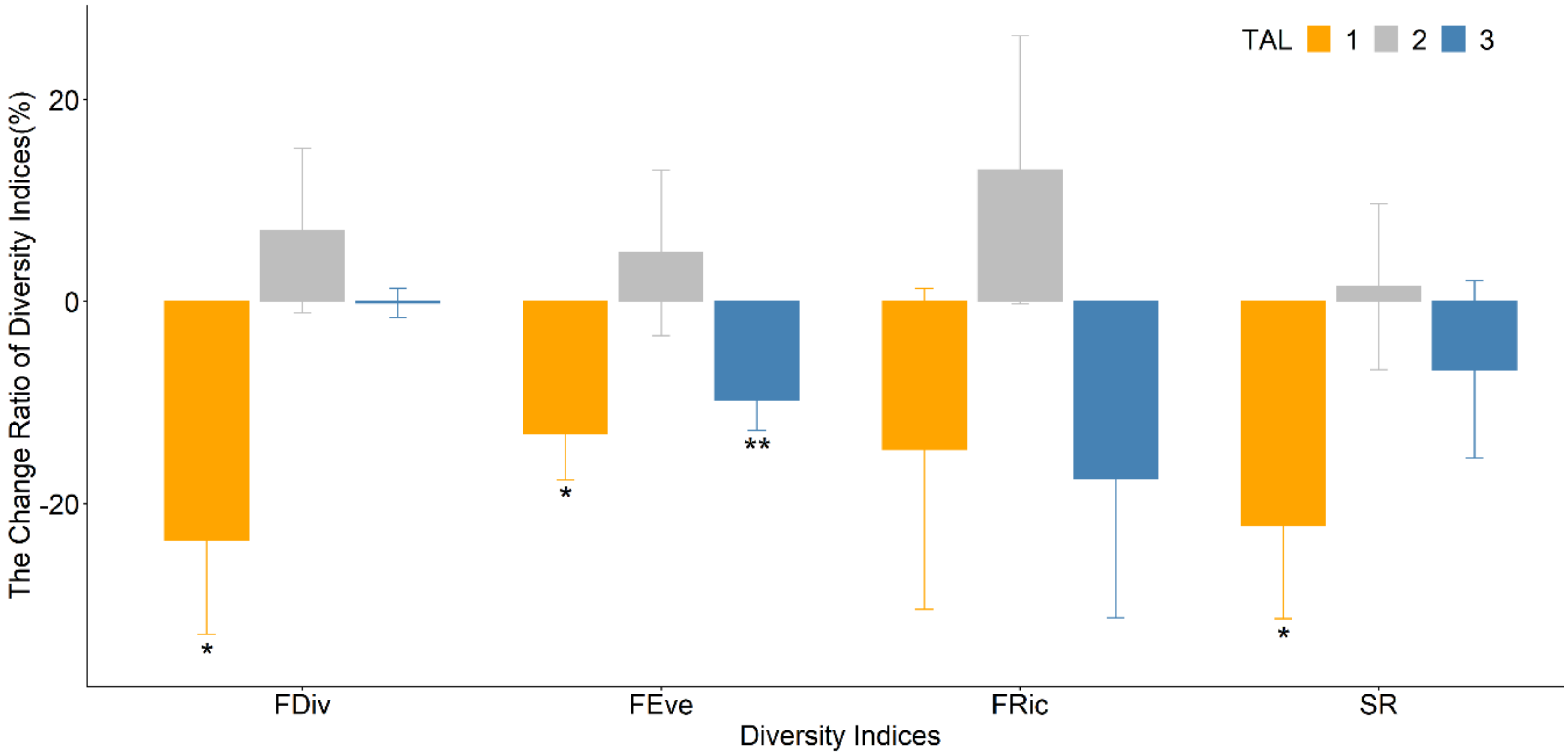


Figure 3–9. Changes in the biodiversity indices of birds with a drought event. The yellow bar is TAL 1, the grey bar is TAL 2 and the blue bar is TAL 3. (* $p < 0.05$, ** $p < 0.01$)

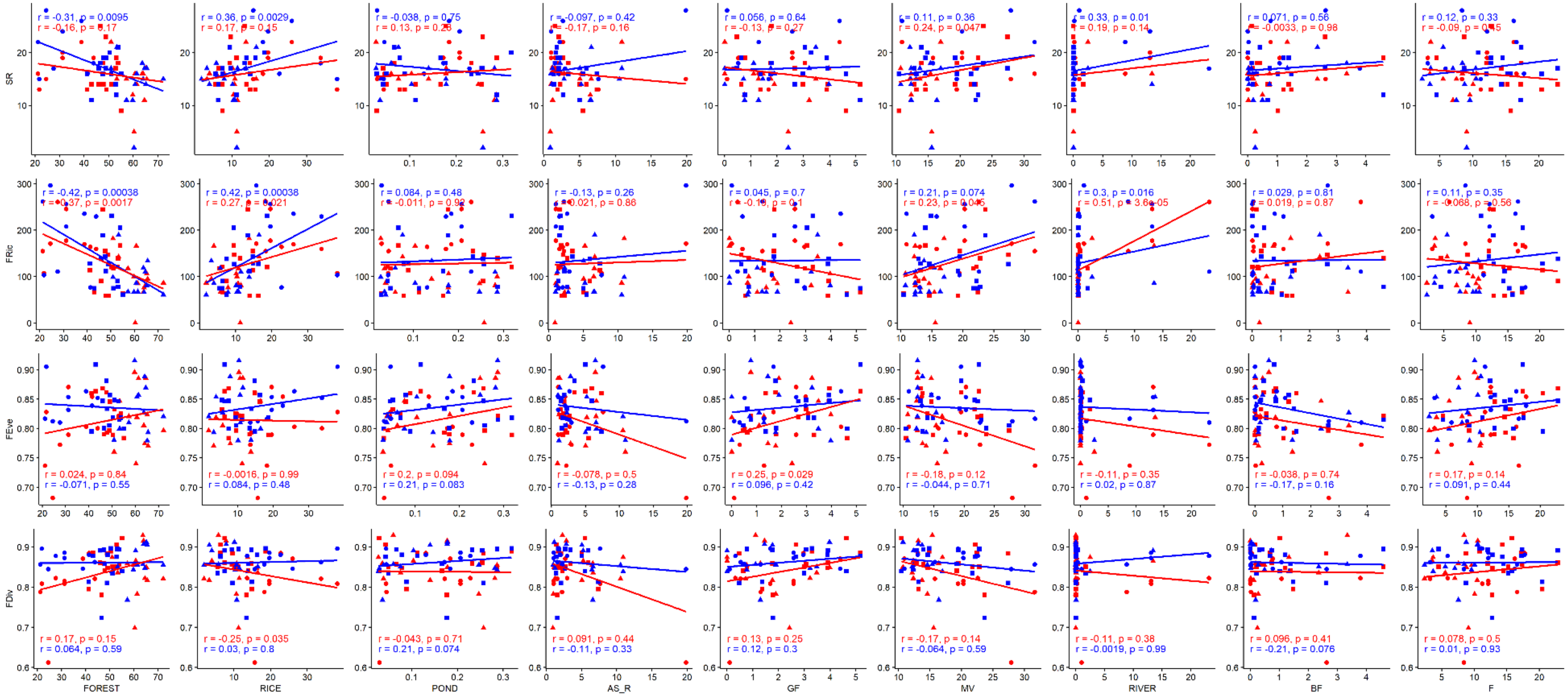


Figure 3-10. The relationship with LULC (%) and diversity indices. The red point and line showed the drought condition. The blue point and line showed the non-drought condition. The circle point is TAL 1; the triangle point is TAL 2; the square point is TAL 3. Kendall test for correlation was used.

3.4 Discussion

This study showed that the bird community responded to the drought events in the TAL. Usually, the landscape with a high proportion of rice paddies showed the highest avian SR and functional diversity, but species assemblages lack resilience to drought. In contrast, TAL with forest cover had lower average diversity but provided greater resilience to drought events. As a result, this study can suggest that forests play an essential role in the Korean TAL with *dumbeong*, and the maintenance of forests in the TAL is key to maintaining avian species diversity.

The previous studies showed that birds' functional diversity and taxonomic diversity appeared differently according to the land use type (Morelli et al., 2018). This study showed similar results that a significant difference occurred in birds' diversity according to the TAL type. In particular, rice paddies supported the highest richness, as found elsewhere (Elphick, 2000; Tourenq et al., 2001). Meanwhile, the FEve and FDiv showed no significant difference depending on TAL type in the study. It was also found in previous studies (Lee and Martin, 2017; Morelli et al., 2018). This is due to the measurement mechanisms of FEve and FDiv. FEve scribes the uniformity of species in functional space—the more regularly distributed the functional distance among species, the lower the FEve score (Mason et al., 2005; Villéger et al., 2008). In other words, the range of niche space of community would be limited to the utilization of the entire range of resources available. FDiv was calculated to which the distribution of quantities in niche space maximizes the divergence of functional properties within the community

(Mason et al., 2005; Villéger et al., 2008). The low FDiv indicates that the degree of niche differentiation was simplified, thus leading to high competition. The results suggested that, regardless of TAL types, the feed resource explored in avian assemblage could be much the same (FEve), and the degree of ecological niche differentiation in the avian assemblage was almost the same (FDiv). On the other hand, in general, functional richness increases as the species abundance increases. These study results also showed a similar trend of high correlation. It is because the formula to analyze functional richness is not independent of species richness (Mason et al., 2005).

As high as richness is, TAL1, which is not seen as having high structural stability, can be seen as instantly responding communities to droughts. TAL 1 biodiversity diminished after the drought. Even though rice paddies function as semi-natural wetlands, paddies, and *dumbeongs* differ in this respect from natural wetlands. In a previous study, functional diversity was raised in drought conditions, presumably because lower water levels expose valuable food resources for birds in natural wetlands, such as floodplains (Almeida et al., 2017). Organisms utilizing rice paddies can be more likely to be vulnerable to drought than those using natural wetlands. Thus, during a drought, resource availability becomes more depleted in rice paddies than in natural wetlands.

Meanwhile, surprisingly, there was no correlation between the relative proportion of *dumbeong* and the resilience of each TAL type. The study's hypothesis was expected *dumbeong* to act functionally like natural wetlands at drought events, but the results were unable to demonstrate this in this study.

Presumably, it seems that the water capacity of each *dumbeong* was insufficient to address the very severe drought and that the *dumbeong* did not serve as a refuge for creatures. Dry rice paddies and *dumbeongs* were easily found out during the 2015 survey. Droughts have been relatively common in Korea in recent years, but drought in 2015 occurred consecutively in 2014 and was particularly severe. During the relatively dry period, *dumbeong* helped to maintain the paddy ecosystem and protected the wildlife in itself. Still, it seems that *dumbeong* could not play a role in the severe drought. Instead, the forest may effectively contribute to maintaining avian diversity against severe drought rather than the *dumbeong* size.

The forest, rather than *dumbeong*, appears to affect the stability of the bird communities. The SR and FRic for TAL2 were lower than for the other types, but in the case of drought, the diversity of bird communities showed a positive, albeit not statistically significant change. Consistent with this, droughts positively affected bird diversity in the forest areas in a recent study (Albright et al., 2010). Bird populations exploiting forest may experience a time lag in breeding than those utilizing paddy fields, as the food resources including vegetation structure does not change immediately to cope with a drought or high temperature (Bertrand et al., 2011; Kissling et al., 2010). Thus, how bird communities respond to drought varied, at least temporarily, depending on habitat properties. Interestingly, there were similar structures based on traits between TAL type (Appendix B).

Chapter 4. Identifying high-priority conservation areas for endangered waterbirds using a flagship species in the Korean DMZ

4.1 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). However, conservation planning in these areas has been neither clear nor based on biodiversity information. Most importantly, there is no conservation plan for the Imjingang River despite its biological importance.

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

From an ecological perspective, this study had considered the ecosystem characteristics with species distribution and biodiversity to propose a conservation plan for the Hangang-Imjingang River system. 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 were (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.

4.2 Materials and Methods

4.2.1 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 6,250 – 6,750 individuals based on recent counts; 500–1,000 individuals winter in China and approximately 5,750 winter in Korea and Japan (IUCN, 2020). In Korea, the wintering population of WNCs amounts to 2,645 – 3,278 (NIBR, 2019). Until the 1980s, the Hangang-Imjingang River estuary was the largest wintering site for cranes in Northeast Asia, and up to 3,000 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 a critical habitat and stopover site for cranes because they must pass through Korea when moving from Russia and China to Japan (Higuchi et al., 2004).

Cranes are notable 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. 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 makes them easy to find. They have loud cries. 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 critical habitat for cranes (Lee et al., 2012; Won, 1986). Therefore, this study aims to determine the effect of conservation planning based on WNC habitats for securing other threatened birds' habitat that rely on wetlands.

4.2.2 Study site

The Hangang River is the largest in the Republic of Korea (ROK) and has a length of 494 km (Figure 4-1). 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 seven decades; thus, it has unintentionally become a wildlife sanctuary. The Hangang River estuary is an invaluable habitat for numerous migratory birds and threatened species protected internationally. However, due to overcrowding and overdevelopment in the Seoul metropolitan area, it has become a watershed with a high environmental pollution load. Besides, due to the military confrontations and tension sparked by the North-South division, there are many restrictions on potential adequate ecological management strategies.

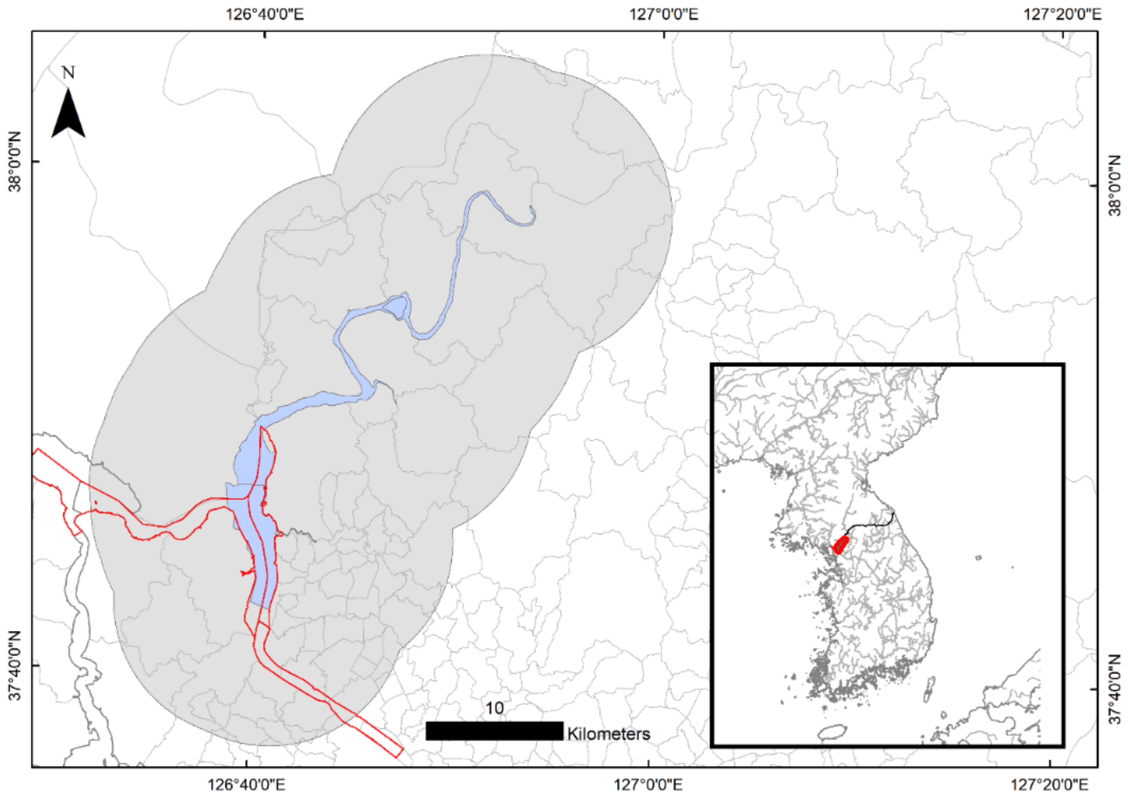


Figure 4-1. Map of the study site. The blue polygon indicates the Hangang-Imjingang River. The red line indicates the nationally protected wetland area. The gray area indicates the region of interest for systematic conservation planning

4.2.3 Bird surveys

The total number of bird survey days was 113. The surveys were regularly performed on weekends except for a few days when the army disapproved of the entrance into the 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 hours in the morning. Investigators recorded the GPS location of all the regionally or internationally threatened species that are legally protected in ROK or are on the IUCN Red List of Threatened Species (2019).

4.2.4 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 (Figure 4-1). 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 2,083 hexagonal cells were arranged in a grid. In addition, the study area includes the nationally protected wetland area, including the place where 1,500 – 2,000 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 Ver. 5.1.

4.2.5 Species trait-based clustering

In order 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., 2000; Takagawa et al., 2011) (Table 4-1). The number of clusters was determined using the NbClust package (Charrad et al., 2014), and the clustering was based on ward 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.

Table 4-1. Summary of functional traits and avian functional diversity indices.

Category	Trait	Unit and trait type
Diet	• Invertebrates • Vertebrates • Herptile • Fish • Unknown • Decaying biomass • 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)

4.2.6 Species distribution

Based on the field survey data, SDMs 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). 2,088 points out of 6,720 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 the resolution was derived from the average distance nearest neighbor with ArcGIS 10.2. The environmental factors used for modeling were the 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 1,000. 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 Ver. 10.1 for further analyses.

4.2.7 Systematic conservation planning

SCP can be performed using Marxan software (Watts et al., 2009). To achieve complementarity, the most crucial concept of SCP, Marxan uses the following formula to construct the optimal conservation network：

$$\text{Objective function} = \Sigma\, \textit{Planning units cost} + \textit{Boundary Length Modifier} \times \Sigma\, \textit{Planning units Boundary} + \Sigma_{\textit{Conservation feature}}\, \textit{SPF} \times \textit{Feature penalty}$$

The PU cost was calculated based on anthropogenic activities. For example, the urban, agricultural, and artificial structures were converted to the PU cost. 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, LULC was analyzed 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, the built-up areas and barren soil were put 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. Conservation planning scenarios were developed by assigning values between 40-100% for habitats (Table 4-2). Finally, the penalty that represents the shape and level of clumping of the prioritized areas was adjusted by the boundary length modifier (BLM). The BLM was set 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 1,000,000. Then, the 'best solution' was mapped accordingly. Whether the best solution was matched for the habitat of WNC or of other avian species was determined. Eventually, This study was identified how priority areas could be effectively defined for migratory birds using wetlands and their vicinity. SCP was performed using the Qmarxan plugin in Qgis.

Table 4-2. 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

4.3 Results

4.3.1 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 (Table 4-3). The threatened avian species were classified into two groups (Figure 4-2). The species in Group 1, which includes WNC, consume mostly plants and seeds and live mainly in water bodies such as rivers, lakes, estuaries, et cetera. The species that belong to Group 2 are predatory and prefer to live in forests and grasslands (Figure 4-3).

Table 4-3. The list of threatened species in the western DMZ area. The grades are from the list of endangered species of the Ministry of Environment in the Republic of Korea. Ⅰ refers to wildlife at risk of extinction due to a large decrease in its population caused by natural or anthropogenic threats. Ⅱ refers to wildlife for which natural or anthropogenic threats have greatly reduced the population, and if the current threatening factor is not eliminated or mitigated, there is a risk of the species becoming endangered in the near future. Ⅱ* refers to no longer endangered species since 2015. Red list grades are as follows: LC indicates least concern, NT indicates near threatened, VU indicates vulnerable, and EN indicates endangered.

Order	Family	Scientific name	Korean name	Number of Populations	Grade	Red list in Korea	IUCN red list
Anseriformes	Anatidae	*Anas formosa*	가창오리	2	Ⅱ*	LC	LC
		Anser cygnoides	개리	4089	Ⅱ	EN	VU
		Aix galericulata	원앙	5	-	LC	LC
		Cygnus cygnus	큰고니	19	Ⅱ	VU	LC
		Anser fabalis	큰기러기	356441	Ⅱ	LC	LC
		Anser caerulescens caerulescens	흰기러기	1	-	NT	LC
Charadriiformes	Charadriidae	*Charadrius placidus*	흰목물떼새	1	Ⅱ	VU	LC
	Scolopacidae	*Numenius madagascariensis*	알락꼬리마도요	3	Ⅱ	VU	EN
Ciconiiformes	Threskiornithidae	*Platalea leucorodia*	노랑부리저어새	612	Ⅱ	VU	LC
		Platalea minor	저어새	457	Ⅰ	VU	EN
Falconiformes	Accipitridae	*Accipiter soloensis*	붉은배새매	1	Ⅱ	VU	LC
		Accipiter nisus	새매	20	Ⅱ	VU	LC
		Accipiter gentilis	참매	16	Ⅱ	VU	LC

		Aegypius monachus	독수리	10647	Ⅱ	VU	NT
		Aquila heliaca	흰죽지수리	1	Ⅱ	VU	VU
		Aquila chrysaetos	검독수리	15	I	EN	LC
		Buteo buteo	말똥가리	12	Ⅱ *	LC	LC
		Buteo hemilasius	큰말똥가리	24	Ⅱ	LC	LC
		Circus spilonotus	개구리매	1	Ⅱ *	LC	LC
		Circus cyaneus	잿빛개구리매	56	Ⅱ	LC	LC
		Milvus migrans	솔개	4	Ⅱ	VU	LC
		Pandion haliaetus	물수리	14	Ⅱ	VU	LC
		Haliaeetus pelagicus	참수리	1	I	EN	VU
		Haliaeetus albicilla	흰꼬리수리	862	I	VU	LC
	Falconidae	*Falco peregrinus*	매	8	I	VU	LC
		Falco subbuteo	새호리기	1	Ⅱ	VU	LC
Gruiformes	Gruidae	*Grus grus*	검은목두루미	2	Ⅱ	LC	LC
		Grus japonensis	두루미	1550	I	EN	EN
		Antigone vipio	재두루미	14592	Ⅱ	EN	VU
		Grus monacha	흑두루미	1	Ⅱ	VU	VU
Strigiformes	Strigidae	*Bubo bubo*	수리부엉이	2	Ⅱ	VU	LC

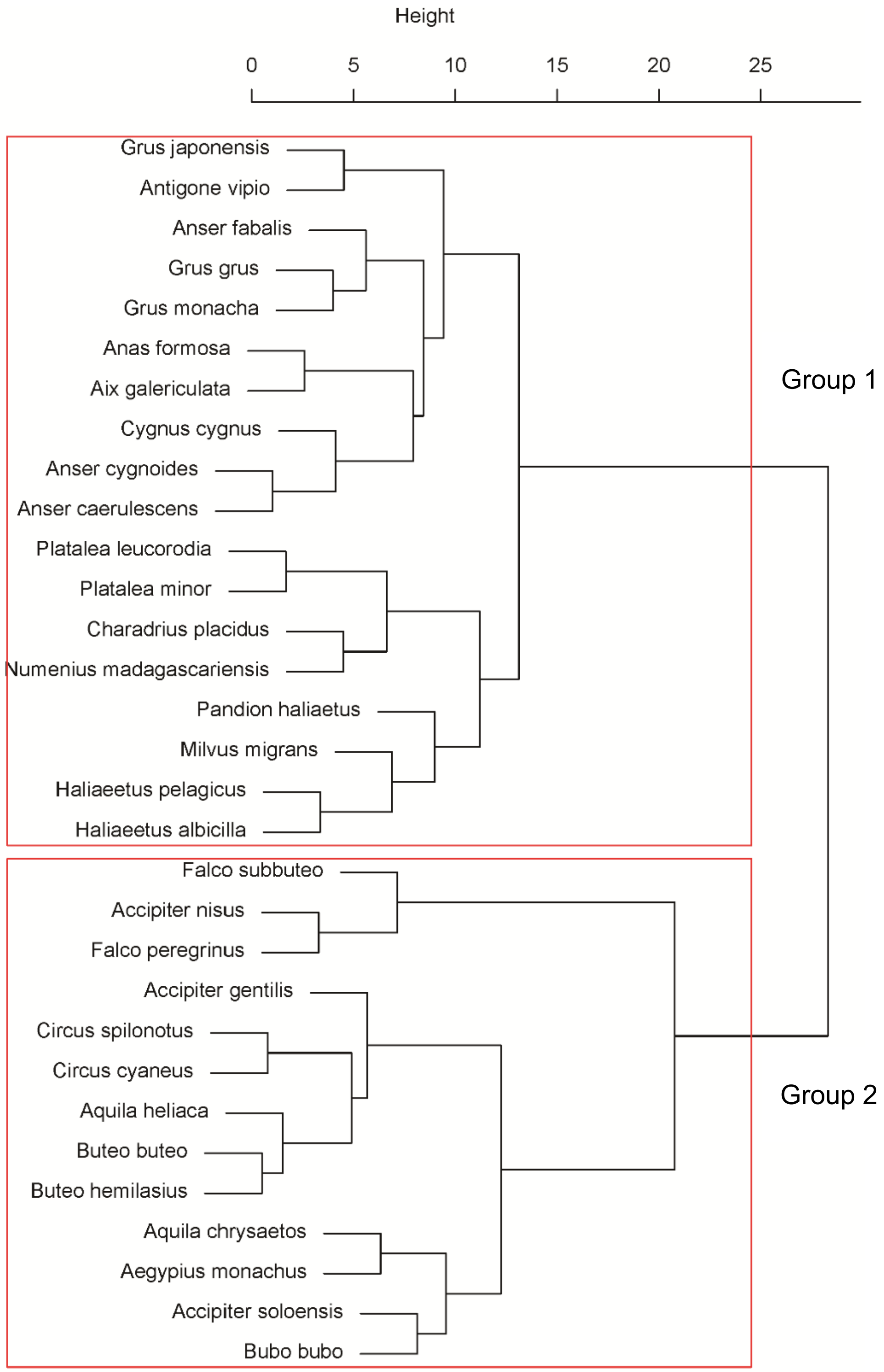


Figure 4-2. Clusters derived from functional traits of the threatened species.

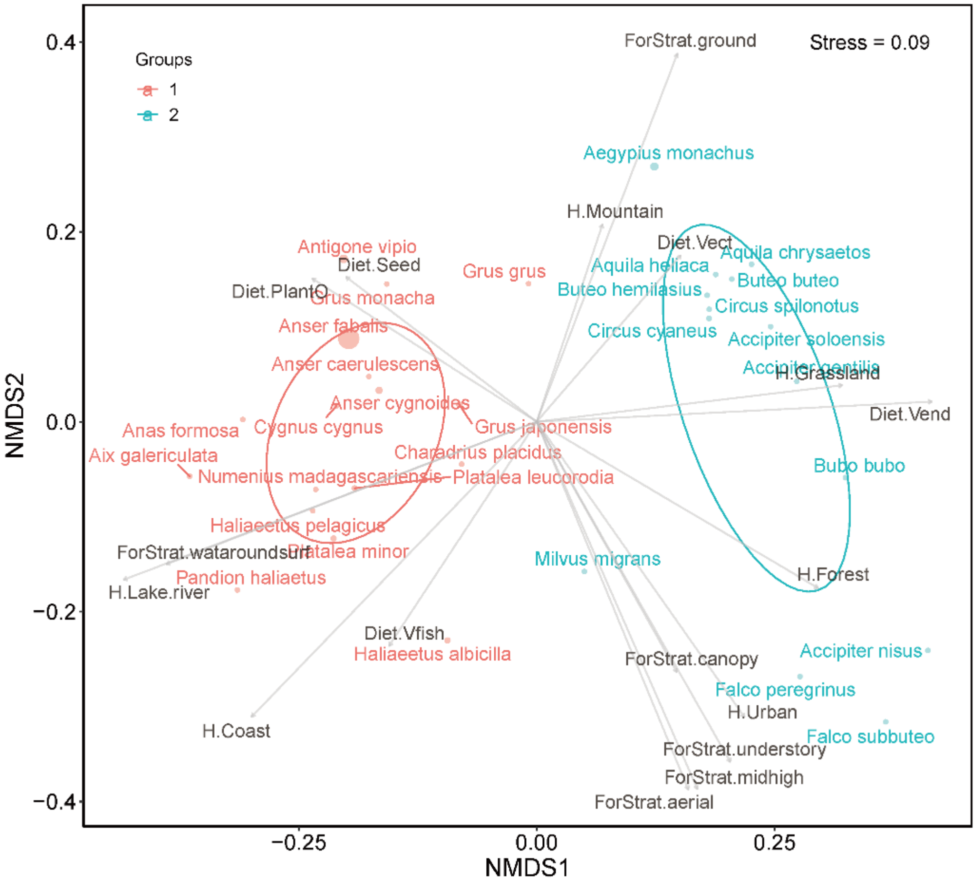


Figure 4–3. Bird species clusters based on their functional traits, such as diet, foraging location, morphological features, and habitat location. White-naped crane, the focal species of the study, belongs to Group 1.

4.3.2 Species Distribution Models

The average AUC for the model of all the threatened species (n = 4,623) was 0.890 (Figure 4-4b). 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 (Figure 4-4c). Finally, the average AUC of Group 2 was 0.846, and DEM (80.3%) and LULC (16.2%) were notable contributing factors (Figure 4-4d). The mean AUC of WNC (n = 1,263) was 0.903, and DEM (65.8%) and LULC (26.6%) contributed greatly to the distribution (Figure 4-4a). 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 = 3,714), and 81.9% consistent with the distribution of Group 2 (n = 900).

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.

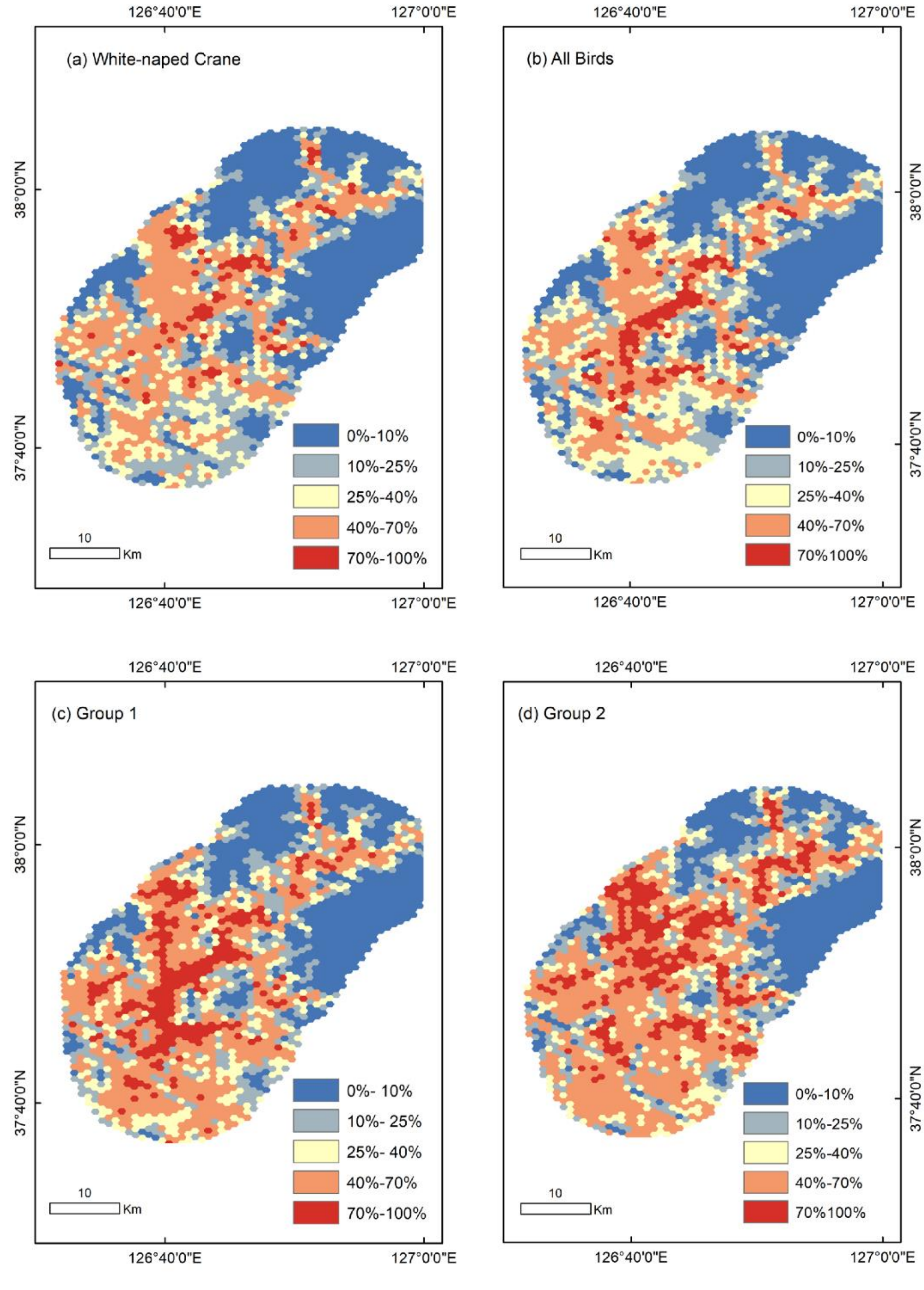


Figure 4-4. Map of the species distribution models generated by MAXENT. (a) Habitat suitability for the white-naped crane, (b) habitat suitability for all threatened bird species, (c) habitat suitability for Group 1, (d) habitat suitability for Group 2.

4.3.3 Systematic Conservation Planning

As a result of applying SCP to the distribution of WNC, 1,162 PUs (55.8%) were selected as the best solution for the conservation area (Figure 4-5a). For all the threatened species, 1,178 PUs (56.5%) were selected as the optimal conservation area (Figure 4-5b). The preferences of Group 1 resulted in the selection of an optimal conservation area of 1,170 PUs (56.1%) (Figure 4-5c). Group 2 could be preserved with the selection of 1,170 PUs (56.1%) for their conservation area (Figure 4-5d). 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 the most efficient way to conserve the habitat for various 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 a 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.

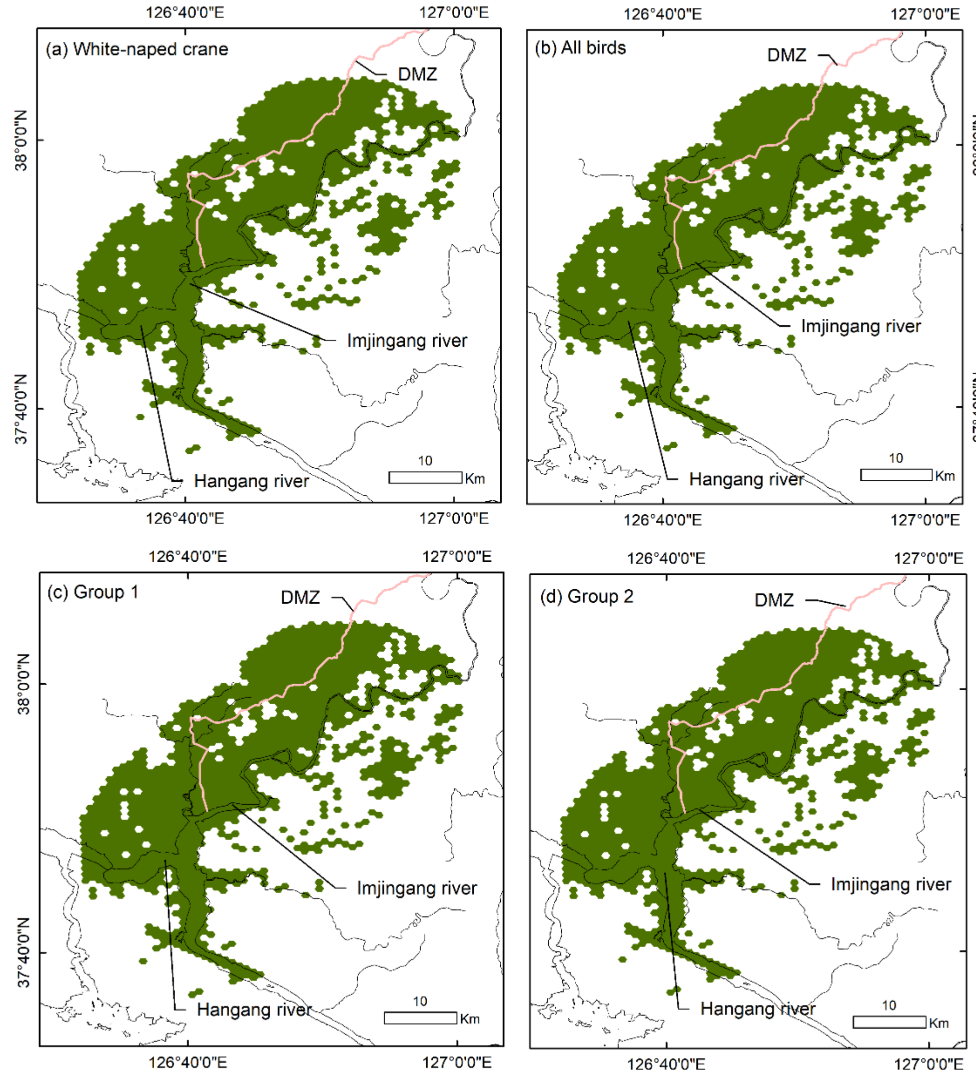


Figure 4-5. The best solution for planning units determined with MARXAN. (a) The best solution determined for the white-naped crane, (b) The best solution determined for all threatened species, (c) The best solution determined for Group 1, (d) The best solution determined for Group 2.

4.4 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 the 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 flatlands and requires a vast area of river and land for foraging (Lee et al., 2009). 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, this 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, The home range of WNC ascertained that it 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 not be 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 a threatened species were adopted that is also a flagship species as the focal species for establishing a conservation plan, This study result found that the plan developed for this species would be adequate for the other species in the estuary ecosystem. Also, Bichet et al. (2016) 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 the 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; Higa et al., 2016; Hussain et al., 2013).

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 South-North 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, 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 essential habitat for WNCs, according to the analysis in this study. Moreover, 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 to effectively safeguard the WNC. In summary, this study suggested that we could employ the WNC, the population of which has decreased (Lee et al., 2012; Yoo et al., 2010), to restore wildlife habitat and to enhance regional and global biodiversity.

Chapter 5. General conclusion

This study explored the spatial changes in the Korean DMZ over time and reaffirmed the value of the DMZ as a wildlife habitat. The strict restriction of access has allowed the DMZ vegetation to experience natural succession. The cut–and burn coniferous forest in the western DMZ region has naturally transformed into broadleaf forest. However, the grassland in the DMZ has been maintained due to both natural and artificial factors (hydrological fluctuation and wildfire, respectively). However, much of the natural CCZ vegetation has been lost or altered for human use, such as commercial development and infrastructure construction. Despite the importance of natural grassland and the DMZ, demand for this type of development, which is likely to increase in the current political climate with lower tension between South and North Korea, poses a major threat to the conservation of biodiversity in the region.

Rice paddies, which make up a large proportion of the traditional landscape of East Asia, provide water and a variety of resources for birds, leading to high biodiversity in the absence of drought. However, this study suggested that maintaining forest patches in agricultural areas may help to protect important ecological niches when drought occurs. Previous studies have highlighted the restoration and maintenance of forest areas as a key component of avian conservation programs in the face of drought (Mac Nally et al., 2009). For this reason, in order to maintain the biodiversity of the western DMZ traditional agricultural landscape, it is necessary to monitor and restrict the clearing of forest and, where forest has already been destroyed, restoration to a certain level is needed. The western DMZ region of South

Korea is threatened by increased cultivation of ginseng, the main commodity crop in the Paju area (Park and Nam, 2013b). For this reason, more forest may be converted into farmland. Furthermore, improving relations between South and North Korea may lead to the greater development of the DMZ. However, such plans would need to consider a way to safeguard the conservation of its biodiversity. As such, this study provides a potential basis for these plans.

Because abnormal meteorological events are more likely to occur due to climate change, there has been a significant volume of research on the mitigation of or adaptation to climate change. Even though CCZ forest has been undervalued, this research proved that this forest contributed to increasing the stability of bird communities in traditional agricultural landscapes in East Asia during drought events. Thus, the value of natural elements should not be underrated based on simple measurements; rather, different methods for evaluating the ecosystem should be sought.

The importance of the riverside ecosystem was also examined based on WNC habitat requirements. The river is of great importance as a shelter for numerous waterbirds, including the WNC, which is why a conservation plan for the western DMZ should be established with a focus on the riverside. In addition to the public interest in the WNC, the umbrella effect of this species may contribute to raising awareness of the importance of the regional ecosystem (Caro et al., 2004; Senzaki et al., 2017). This study thus confirmed that a conservation policy centered on the WNC, which is easy for the public to recognize, would be successful, this the promotion of environmental awareness and the management of conservation policies using the WNC as an umbrella species should be pursued. In the western DMZ region, where development projects often take precedence over ecological value, the WNC has the potential to become a symbol of the region's valuable ecosystem and an important flagship and umbrella species that will promote ecosystem conservation.

The identified priority areas for systematic conservation planning also included the Hangang-Imjingang river system and the western DMZ, CCZ, and a part of North Korea. Because the western DMZ region is under high development pressure and is directly affected by inter-Korean relations, the land-use plans for the DMZ region are frequently discarded in the absence of a solid conservation plan. Given the ecological importance of the DMZ, a strong conservation plan should not be affected by inter-Korean relations because, once disrupted, the ecosystem cannot quickly recover. If roads or buildings are constructed in the DMZ, the entire DMZ ecosystem is likely to be affected, with the damage irreversible. Therefore, a conservation plan that can protect the remaining flora and fauna and maintain the biodiversity of the Korean Peninsula is required.

For further research, conservation planning for the entire DMZ ecosystem should be pursued based on long-term monitoring and scientific evidence. The DMZ ecosystem should be handled as an important ecological axis, and consistent survey methods should be employed across the entire DMZ region. In addition, a comprehensive understanding of the DMZ ecosystem should be promoted based on ecological indicators, such as butterflies and/or amphibians, that are sensitive to changes in the environment. Finally, because the conservation of the Korean DMZ ecosystem requires cooperation between the two Koreas, it is essential to welcome an era of reconciliation and cooperation on the Korean Peninsula based on conservation.

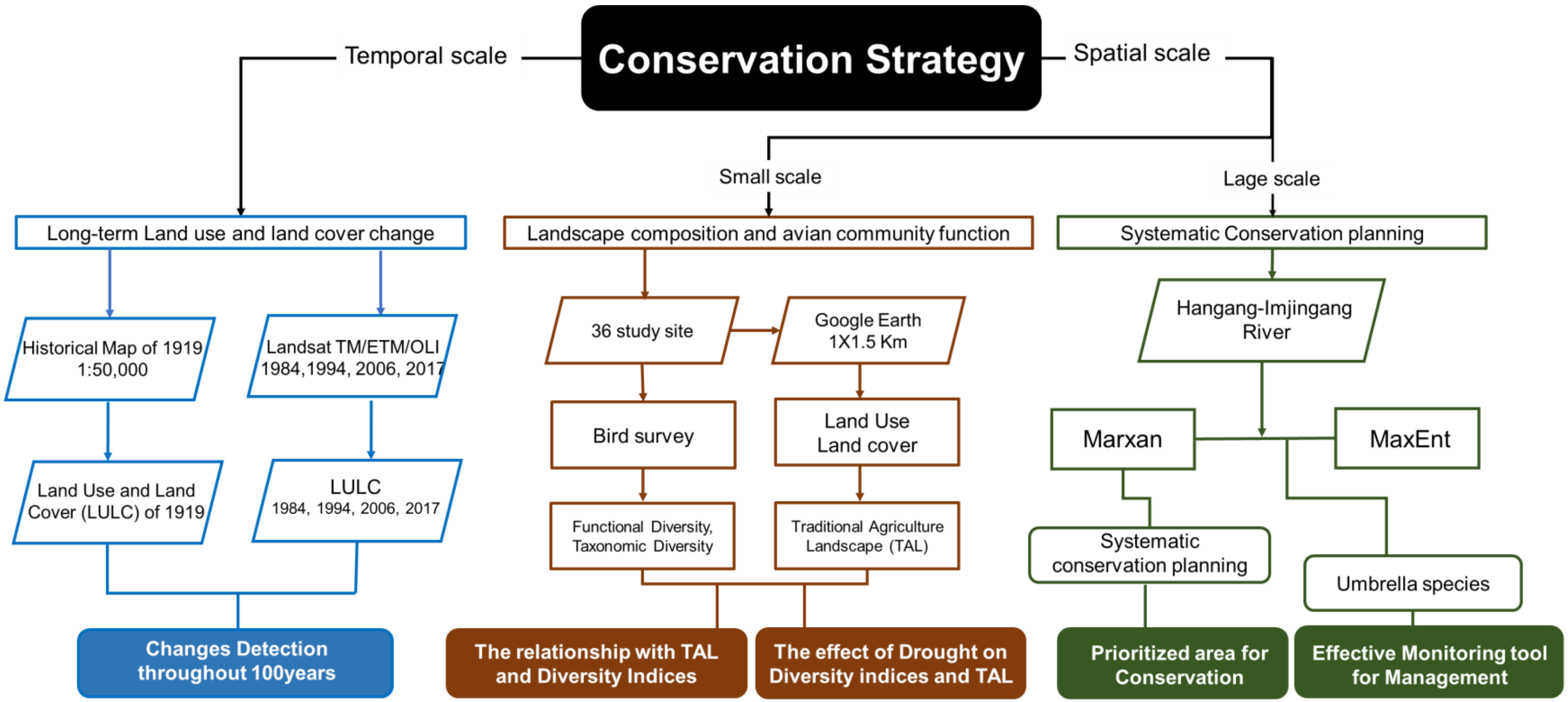


Figure 5-1. Research schematic diagram

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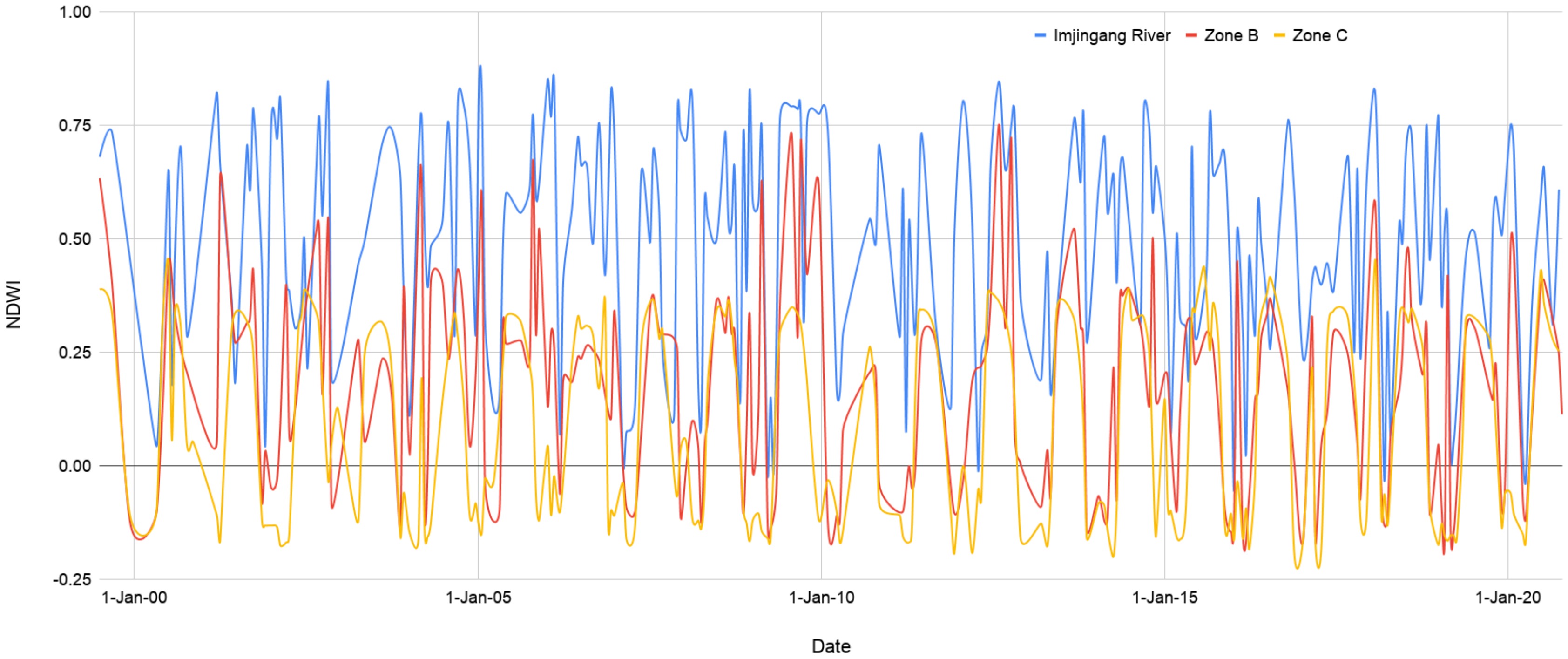
Appendix



Appendix A The time−series pattern of Normalized Difference Water Index (NDWI) in the DMZ area. The red solid line refers the NDWI of zone B in Figure 7, the wetland maintained by water fluctuation. The yellow solid line refers the NDWI of zone C in Figure 7, the frequent fires maintained the grassland. The blue solid line refers the NDWI of the Imjingang River, which is the baseline. Data analyzed from 1999 to 2020 using Landsat 7. The NDWI of wetland appears to be affected by flood as the river overflows.

Appendix B Bird species composition according to the diet types. Dark blue solid line with circle point is TAL 1 under drought event, orange solid line with triangle point is TAL 2 under drought event, Gray solid line with square point is TAL 3 under drought event, yellow dotted line with circle point is TAL 1 under non−drought event, light blue dotted line with triangle point is TAL 2 under non−drought event, green dotted line with square point is TAL 3 under non−drought event. (Diet ~ years*TAL type, ANOVA test, $p > 0.05$)

국문초록

생물 다양성 보전은 생태계서비스의 제공과 같이 인류가 직접적으로 체감하는 측면의 이익을 보존하기 위한 필요에서부터 자연의 일부인 인류가 존속하기 위해서 분리할 수 없는 것이라는 인식에 이르기까지, 관점에 차이는 있지만 중요하게 인식되고 있다. 생물 다양성 보전에 관한 개념 중 생물 다양성 중점지역은 지구 상 1.4%의 면적에 불과하지만, 분류군에 따라 28-58%가 그 안에 서식할 정도로 중요한 지역이다. 한반도 분단의 부산물인 비무장지대 일원은 한반도 면적의 2% 미만에 불과하지만 분류군에 따라 한반도 생물 종의 30-60%가 서식하고 있는, 한반도의 생물다양성 중점지역이다. 비무장지대는 한반도를 가로질러 형성되어, 한반도의 다양한 지형과 생태계들을 포함하고 있고 사람의 출입이 극도로 제한되어 수많은 생물이 서식하기에 좋은 특성을 갖추고 있다. 따라서 비무장지대 일원의 보전 가치는 매우 크다. 그러나, 남한의 높은 개발 압력은 비무장지대도 비껴가지 않아, 특히 수도권에 위치한 비무장지대 서부 일원은 남북한의 대도시인 서울, 개성과 인접해 있어 비무장지대 권역 중에도 특별히 개발 압력이 크다. 현재 비무장지대 서부 일대에는 남북한을 연결하기 위한 각종 시설이 많이 들어서 있고 예정된 개발 계획도 많다. 하지만 비무장지대의 높은 생태적 가치를 고려할 때 이 지역에는 생태계를 보전하기 위한 계획이 필요하다. 본 연구에서는 비무장지대의 경관 요소의 시공간 변화에 따른 생태계를 탐구하였다. 그리고 장기간의 모니터링 자료를 포함한 과학적 분석을 바탕으로 비무장지대 일원의 생물 다양성을 보전하기 위한 계획을 제시하였다.

먼저, 비무장지대를 규정하기 이전인 1919 년부터 2010 년대까지 토지 피복이 어떻게 변하였는지, 인간 활동으로 인한 경관 변화를 분석하였다. 전쟁이 멈추고 세월이 흐르며, 서부 비무장지대 일원의 숲은 침엽수림에서

활엽수림으로 바뀌었고 논은 초지가 되었다. 민간인출입통제지역은 1970 년대에 논농사를 재개하여, 1990 년대에는 전쟁 이전에 논이었던 지역이 거의 대부분 논으로 바뀐 반면에, 비무장지대의 논은 초지로 변한 이후 70 년 동안 목본이 유입되는 등의 후속 천이가 관찰되지 않았다. 원인은 크게 두 가지로 보이는데, 내륙의 초지에는 군사적 이유로 산불이 빈번하게 발생한다는 점과, 임진강과 소규모 하천에 인접한 초지는 주기적으로 침수를 겪는 습초원지역이라는 점이다. 이러한 온대성 습초원지역은 전 세계적으로도 희소하며, 한반도에서도 이처럼 넓은 면적이 유지되는 지역은 거의 없어 학술적 가치가 매우 크다. 비무장지대의 초지는 다양한 생물들에게 중요한 서식지일 뿐만 아니라 희소한 생태계에는 그곳에서만 서식하는 생물이 있을 가능성이 높아 비무장지대 내의 초지를 보전하고 모니터링하는 것은 매우 중요하다.

비무장지대 서부 일대의 농경지는 경지를 정리하지 않았고 현대식 저수지와 관개수로가 발달해 있지 않아 전통 농촌 경관을 유지하고 있다. 본 연구에서는 서부 민간인통제구역 내 농촌 경관을 세부 요소로 구분하여 기후변화와 함께 빈번하게 나타나는 가뭄이 조류 군집에 미치는 영향을 알아보고자 하였다. 군집 내 종의 생태적 지위의 범위와 특성을 보여주는 기능적 다양성을 지표로 채택하여 경관 구성 또는 환경 변화에 따른 반응을 탐지하였다. 서부 DMZ 인근의 농촌경관은 논습지가 상대적으로 많이 분포하는 경관, 숲이 상대적으로 많은 경관, 인삼밭, 나지가 상대적으로 많이 분포해 있는 경관, 세 가지로 구분할 수 있다. 일반적으로 논 습지가 많은 전통 농촌 경관 구조에서는 종 풍부도와 기능적 풍부도가 가장 높았지만, 숲이 많은 논습지 환경에서는 가뭄에 의한 타격이 적어 기능적 다양성 지수와 종 풍부도가 일정하게 유지되었다. 따라서 논 습지가 발달한 농촌 경관에서

숲은 가뭄 등의 갑작스러운 변화에도 생물 다양성을 유지하는 데 도움을 준다고 할 수 있다. 비무장지대 서부 권역의 숲은 식생평가기준에 따라 평가할 때 가치가 높지 않다는 해석도 있지만, 조류와 다른 분류군의 서식지로서 중요한 역할을 하고 있는 것으로 나타났다. 기후 변화가 가속화함에 따라 이상 기상 현상이 더욱 빈번하게 나타날 것으로 예상되는 만큼 비무장지대 일대의 생태계 기능을 유지하고 생물 군집의 다양성을 안정적으로 유지하기 위하여 숲을 유지하고 복원할 필요가 있다.

비무장지대 서부 권역의 두드러진 특징은 한강-임진강이라는 거대한 수계이다. 본 연구에서는 비무장지대 서부 일원의 생물 다양성을 고려한 보전 계획을 수립하기 위해 체계적인 보전 계획 방법을 활용하였다. 보전 구역 설정 시에 현실적으로 많은 이해 관계가 개입하는 점을 고려하여, 체계적인 보전 계획 방법은 비용 효율적인 방법으로 구역을 평가한다. 본 연구에서는 서부 비무장지대 일원을 상징하는 깃대종인 재두루미의 서식지를 기준으로 보전 계획을 수립하였다. 2014-2019 년에 걸쳐 조사한 비무장지대 서부 일원을 찾는 멸종 위기의 겨울 철새 위치 자료를 바탕으로 종 분포 모형을 구축하였고(Maxent) 이를 바탕으로 체계적인 보전 계획안을 수립하였다(Marxan). 조류 군집은 습지 및 저지대를 사용하며 식물체 위주의 섭식을 하는 집단(Group 1)과 육상에서 지내며 육식을 하는 집단(Group 2)으로 구분하였다. 재두루미는 Group 1 에 포함되었고 Group 2 는 재두루미와 생태 특성이 다른 집단이다. 두 집단과 전체 멸종위기종을 대상으로 종 분포 모형을 산출하여 재두루미의 분포 모형과 비교한 결과, 90% 이상의 면적이 재두루미의 서식지와 겹치는 것으로 나타났다. 또 체계적인 보전 계획 분석에서 두 조류 집단의 서식지를 각각 기준으로 예측한 시나리오와 전체 멸종위기종의 서식지를 포함한 시나리오 모두 재두루미의 서식지만을 보전 목표로

한 시나리오와 비교할 때 99% 이상의 면적이 일치하는 것으로 나타났다. 따라서 재두루미는 그 서식지를 보전할 경우 다른 많은 멸종위기종을 보호할 수 있는 우산종으로 확인되었다. 재두루미는 일반 시민들도 쉽게 식별할 수 있는 종으로, 재두루미 위주의 시민 참여 모니터링을 시행할 경우 시민 인식 증진 효과가 크고 본 지역의 생물 다양성을 관리하기 위한 모니터링 도구로 사용할 수 있다. 지속적인 모니터링은 보전 지역의 현황 파악 및 진단에 중요한데 최근에는 시민 참여 모니터링이 이러한 역할을 하고 있다. 보전 구역을 설정한 후 효과적으로 관리하기 위한 방안으로 그 지역에 확인된 우산종 위주의 시민과학을 활용할 것을 제안한다. 또한 체계적인 보전 계획법에 따른 분석 결과, 최선의 시나리오에서 제시한 보전 구역은 임진강-한강과 서부 비무장지대, 민간인출입통제구역, 그리고 북한 일부 지역을 포함하는 것으로 나타났다. 이는 서부 비무장지대 보전 계획 수립 시, 다양한 요소를 고려하여 최소한의 비용으로 이 지역의 생물 서식지를 보전하고자 하더라도, 서부 비무장지대 일원의 전체 지역을 보전 지역으로 계획하여야 함을 의미한다.

비무장지대 서부 권역은 높은 개발 압력과 남북한 관계 변화의 직접적인 영향 하에 있는 지역이지만 생물 서식지로서의 가치가 매우 크다. 본 연구에서는 목본이 이입되지 않고 초지 상태를 유지하고 있는 비무장지대의 생태적·학술적 가치를 재확인하였고, 민간인통제구역의 숲의 가치는 기후위기 시대를 맞아 재평가되어야 함을 강조하였다. 또한 최소한의 비용으로 비무장지대의 생물 다양성을 보전하기 위하여 서부 민간인통제구역, 한강-임진강 하구, 북한 지역 일부를 포함하여 보전구역으로 지정해야 함을 밝혔다. 한반도 평화의 시대를 구상하며, 남북한 관계 변화에 따라 비무장지대에 대한 계획을 변경하기 보다는, 기후위기 시대의 반성과 함께, 한반도

생태계의 보고인 비무장지대의 생물 다양성을 유지할 수 있는 안정적인 보전계획을 수립할 것을 제안한다.

주요어: 비무장지대, 민간인출입통제구역, 생물다양성, 보전방안, 멸종위기종, 한강-임진강하구

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