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Distribution of Fish Species in Wetland Protected Areas in South Korea

Yeounsu Chu, Jungdo Yoon*, Kwang-Jin Cho, Mijeong Kim, Jeongcheol Lim, Changsu Lee

Wetlands Research Team, Wetland Center, National Institute of Ecology, Seocheon, Korea

ABSTRACT

In order to secure basic data on biodiversity for wetland conservation and management used the data from Wetland Protected Area surveys conducted in South Korea (2015-2019) to analyze the distribution of fish from a total of 15 orders, 45 families, 134 species, and 12,972 individuals. The predominant species identified were *Zacco platypus* (Temminck and Schlegel) (19.47%) and *Zacco koreanus* (Kim, Oh and Hosoya) (8.16%). Of all emergent species, 52.9% (n=71 species) were freshwater species, 26.9% (n=36) were brackish species, 3.0% (n=4) were migratory species, 27% (n=36) were marine species, and 9.0% (n=12) were riffle benthic species. Overall, 5.2% (n=7 species) were endangered species, 3.0% (n=4) were exotic species, and 23.1% (n=31) were Korean endemic species. The eight identified Wetland Protected Areas (WPA) were classified based on their habitat characteristics and on the analysis of their emergent fish communities, as estuarine (n=2), coastal dune (n=1), marsh (n=2), stream (n=2), and stream-marsh (n=1) types. The environmental factors revealed to have the greatest influence on the species diversity of emergent fish were maintenance and repair, installation of reservoirs, and construction of artificial wetlands around them. The present study offers basic information on the diversity of fish species in different Wetland Protected Area types that can be used to inform conservation and management decisions for WPA.

Keywords: Biodiversity, Endangered species, Estuaries, Habitat, Ramsar convention, Rivers

Introduction

Wetlands are transition zones between terrestrial and aquatic ecosystems, and are recognized for their high biodiversity and conservation value. National reports on the roles of wetlands as habitats for migratory birds as well as their roles in preserving biodiversity are being published worldwide (Kim & Lee, 2015).

Since the Wetland Conservation Act in 1999, a total of 25 inland wetlands, including Yongneup of Mt. Daeam, have been designated as Wetland Protected Areas (WPA) by the Ministry of Environment in South Korea. Since 2006, the Ministry of Environment has been conducting intensive surveys on the WPAs under Article 4 (Wetland Investigations), Article 5 (Formulation of Master Plans for Wetland Conservation), and Article 11 (Formulation and Implementation of Conservation Plans) of the Wetland Conservations Act. Currently, the National Institute of Ecology is performing the third WPA intensive survey (2016-2020) under Article 18 (Delegation and Entrustment of Authority) of the Wetland Conservations Act.

This study identified the emergent fish species in the WPAs within inland wetlands. As the top predators of aquatic ecosystems, fish are an important group that regulates the biological structures and functions within

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***Corresponding author:** Jung-do Yoon
e-mail yjdguys1@nie.re.kr
https://orcid.org/0000-0001-9012-5621

water bodies (An *et al*., 2001; An & Kim, 2005; Lee *et al*., 2017; Shin *et al*., 2012). In wetlands, fish are not only the higher-level consumers (Choi & Byeon, 2010) but they also dominate important niches at the center of wetland food chain, acting as both consumers and producers. Inhabitation of rare and endangered species is an especially important factor when evaluating the value of domestic wetlands and their designation as protected areas. However, intensive surveys and focused research efforts are needed because the environmental preferences of fish species can result in them having narrow distributions and small populations that are hard to detect (Engler *et al*., 2004; Kim *et al*., 2018). Presently, information regarding the distribution of fish species in WPAs and the characteristics of such areas that serve as important habitats for organisms is limited.

This study, therefore, aimed to investigate the distribution of fish species that were identified during intensive surveys on the WPAs to compare and analyze their population distribution and inhabitation characteristics based on wetland patterns. Here, we provide basic reference data that can be used to develop plans for the conservation, restoration, and management of future WPAs.

Materials and Methods

Research targets and methods

Among the 22 intensive surveys of the WPAs over the last 5 years (2015-2019), we used the data for 8 wetlands in 2016, 2017 and 2019 in which fish surveys had been conducted, to understand the diversity and distribution characteristics of the fish species inhabiting the WPAs (Kim *et al*., 2016; 2017; Lim *et al*., 2019) (Fig. 1). These wetlands consisted of stream type wetlands (n=5) and marsh type wetlands (n=3) (Table 1).

Intensive surveys of the WPAs followed the monitoring guidelines of the Ministry of Environment for Korean inland wetlands (ME, 2011). In large areas where general fish investigation methods (e.g., cast net and skimming net) were not possible (e.g., the Han River estuary and Nakdong River estuary), we enlisted the help of fishermen to capture individuals using fixed shore nets, gill nets, dredge nets, and other methods. Species of captured individuals were either identified in the field and released after recording the required data, or were fixed with 10% formalin and identified in lab if identification in the field was not possible. Fish species were identified with reference to Chae *et al*. (2019), Choi *et al*. (2002), Kim *et al*. (2005), and Kim and Park (2002), and the taxonomic sequencing was based on the National Species List of Korea (NIBR, 2019).

Data analysis

We compiled a list of the fish species based on the reports of the intensive surveys conducted for the WPAs to analyze the diversity and distribution of the emergent fish in the WPAs. We analyzed the fish community characteristics and similarities using the diversity and population data of emergent fish, as well as the richness index (Margalef, 1958), dominance index (McNaughton, 1967), evenness index (Pielou, 1975), and species diversity index (Shannon & Weaver, 1963).

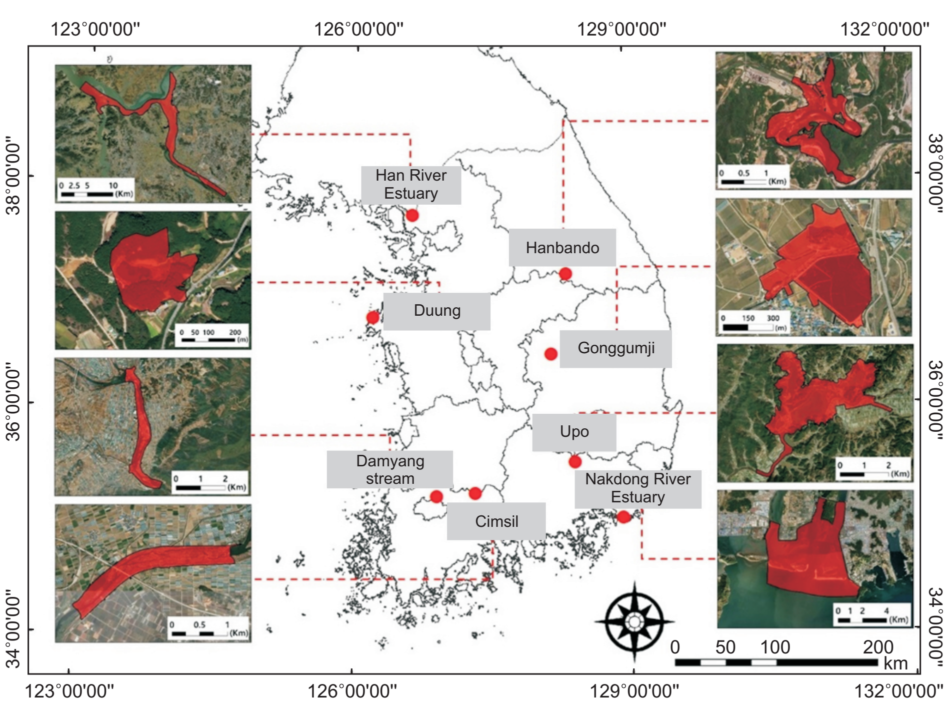

Fig. 1. Map showing the Wetland Protected Areas in which intensive surveys were conducted in South Korea during 2015-2019.

Table 1. Details of the WPA fish surveyed in South Korea 2016, 2017, 2019

Wetland name	Date designated as a WPA	Area (km^2)	Survey year
Nakdong River Estuary	Aug 9, 1999	37.718	2017
Upo	Aug 9, 1999	8.609	2016
Duung	Nov 1, 2002	0.067	2019
Damyang Stream	July 8, 2004	0.981	2019
Han River Estuary	Apr 17, 2006	60.668	2016
Gonggumji	June 29, 2011	0.264	2019
Hanbando	Jan 13, 2012	2.772	2019
Cimsil	Nov 7, 2016	2.037	2019

WPA, Wetland Protected Area.

All statistical analyses were performed using R (R version 3.5.2, R Core Team 2020). First, we performed a hierarchical cluster analysis using the 'hclust' (method='ward. D2') function in the Vegan package to understand the relationship between wetland types (Bang *et al*., 2006) and the fish community structure (Oksanen *et al*., 2020). The total species population of the collected individuals (S) was converted to log(S+1) to be used as the input data, and the species that emerged in only one wetland were excluded from the analysis to eliminate regional specificity.

Second, we applied non-metric multidimensional scaling (NMDS) using the 'metaMDS' function in the Vegan package (Oksanen *et al*., 2020), and analyzed the fish community structure and relationship in the investigated sites using ordination methods. Again, we converted the species population data to log(S+1) to produce the input data for the analysis. We calculated the distance between the investigation sites using the Bray-Curtis method (Bray & Curtis, 1957). In addition, we determined the correlation coefficients and levels of significance using the 'envfit' function in the Vegan package (Oksanen *et al*., 2020) to analyze the eating behaviors of fish and other correlations in the 2-dimensional visualization of the NMDS results. We referred to the "Biomonitoring Survey and Assessment Manual" (ME, 2016a) and "Biomonitoring Survey and Assessment Manual: Estuary Ecosystem (fish)" (ME, 2017a) to determine the ecological characteristics of the fish species.

Results and Discussion

Emergent fish fauna in the WPAs

A total of 15 orders, 45 families, and 134 fish species were identified from the 12,972 individuals collected from the 8 WPAs. Specifically, 28 species were identified in the Han River estuary, 21 species in the Upo wetland, 60 species in the Nakdong River estuary, 17 species in the Gonggumji reservoir, 18 species in the Damyang stream, 9 species in the Duung wetland, 46 species in the Cimsil wetland, and 36 species in the Hanbando wetland. The most species appeared in the mouth of the Nakdong River estuary, and the proportion of marine fish species was high. Next, the second most abundant species appeared in the Cimsil wetland (Table 2).

The Nakdong River estuary, a partially-mixed estuary, has an estuary bank and coastal or bay characteristics that have enabled the high occurrence of marine fish species as well as the largest overall number of species. Blockage of the freshwater inflow by the estuary bank had gradually transformed the brackish water zone into a marine environment; which is consistent with the observations of previous studies (Kang *et al*., 2012).

On the other hand, the Han River estuary does not have an estuary bank, and the brackish water zone is extended due to the direct influence of the tides. The Han River estuary is a well-mixed estuary that maintains the typical ecosystem structure of estuaries along the Korean western coast (Hwang & Rhow, 2010), therefore, estuarine fish species were observed to be the dominant species. The species diversity of the Han River and Nakdong River estuaries differed greatly, with the latter estuary having a relatively higher occurrence of marine fish species.

The Cimsil wetland, which was found to support the second highest number of species, has a widely spread out brackish water zone due to the lack of an estuary bank, and the water quality is relatively high due to the lack of a source of atmospheric pollution. The diverse endemic species in the Cimsil wetland may largely influence the high proportion of endemic species in this area (Baek *et al*., 2013; Jang *et al*., 2009). Among the collected fish, 45 species (33.58%) of Cyprinidae, 12 species (8.96%) of Gobiidae, and 8 species (5.97%) of Cobitidae (Fig. 2A) were identified. In the observed population, the emergent fish species and their associated rates (from highest to lowest) were *Zacco platypus* (19.5%), *Zacco koreanus* (8.2%), *Lepomis macrochirus* (6.3%), and *Carassius auratus* (5.4%) (Fig. 2B). Among the emergent fish, there

Table 2. Fish species identified in the Wetland Protected Area s in South Korea during 2016, 2017, 2019

Species	Han River	Upo	Nakdong River	Gonggumji	Damyang	Duung	Cimsil	Han bando	Remarks
Anguilla japonica			●						
Conger myriaster			●						
Muraenesox cinereus			●						
Oryzias sinensis						●			
Strongylura anastomella			●						
Hyporhamphus intermedius	●		●						
Hyporhamphus sajori	●		●						
Clupea pallasii			●						
Konosirus punctatus			●						
Sardinella zunasi			●						
Sardinops melanostictus			●						
Coilia mystus	●								
Coilia nasus	●		●						
Engraulis japonicus			●						
Thryssa adelae			●						
Thryssa hamiltonii			●						
Thryssa kammalensis			●						
Cobitis hankugensis				●					Ke
Cobitis tetralineata							●		Ke
Iksookimia koreensis								●	Ke
Koreocobitis rotundicaudata								●	Ke
Misgurnus anguillicaudatus		●		●	●	●	●	●	
Misgurnus mizolepis		●		●			●	●	
Iksookimia longicorpa							●		
Orthrias nudus								●	
Abbottina rivularis	●						●		
Acanthorhodeus chankaensis	●						●		
Acheilognathus koreensis							●		Ke
Acheilognathus lanceolata intermedia		●		●			●	●	
Acheilognathus macropterus		●							
Acheilognathus majusculus							●		Ke, En
Acheilognathus rhombeus							●		
Acheilognathus signifer								●	Ke, En
Acheilognathus yamatsutae								●	Ke
Aphyocypris chinensis				●					
Carassius auratus	●	●	●	●	●	●	●	●	
Carassius cuvieri		●						●	Ex
Coreoleuciscus aeruginos							●		Ke
Coreoleuciscus splendidus								●	Ke
Culter brevicauda		●							En
Cyprinus carpio	●	●	●	●	●	●	●	●	

Table 2. Continued

Species	Han River	Upo	Nakdong River	Gonggumji	Damyang	Duung	Cimsil	Han bando	Remarks
*Cyprinus carpio**								●	Ex
Erythroculter erythropterus	●								
Gnathopogon strigatus							●		
Gobiobotia brevibarba								●	Ke, En
Hemibarbus labeo	●		●		●		●	●	
Hemibarbus longirostris							●	●	
Hemibarbus mylodon								●	Ke, En
Hemiculter eigenmanni		●			●				
Hemiculter leucisculus	●								
Microphysogobio longidorsalis								●	Ke
Microphysogobio yaluensis					●		●	●	Ke
Opsariichthys uncirostris amurensis		●	●		●		●		
Pseudogobio esocinus				●	●		●	●	
Pseudopungtungia tenuicorpa								●	Ke, En
Pseudorasbora parva		●		●	●	●	●	●	
Pungtungia herzi							●	●	
Rhodeus ocellatus	●								
Rhodeus uyekii		●		●			●		Ke
Rhodeus notatus							●		Ke
Rhynchocypris oxycephalus							●		
Sarcocheilichthys nigripinnis morii							●		Ke
Sarcocheilichthys variegatus wakiyae							●	●	Ke
Squalidus chankaensis tsuchigae		●			●		●		Ke
Squalidus gracilis majimae	●	●					●	●	Ke
Squalidus japonicus coreanus		●							Ke
Squaliobarbus curriculus	●								
Zacco koreanus							●	●	Ke
Zacco platypus		●		●	●		●	●	
Zacco temminckii							●		
Chelon haematocheilus	●		●						
Mugil cephalus	●		●						
Eptatretus burgeri			●						
Neobythites sivicola			●						
Plecoglossus altivelis							●		
Repomucenus beniteguri			●						
Repomucenus lunatus			●						
Repomucenus olidus	●		●						
Trachurus japonicus			●						
Lepomis macrochirus		●		●	●		●		Ex
Micropterus salmoides		●		●	●		●	●	Ex
Psenopsis anomala			●						

Table 2. Continued

Species	Han River	Upo	Nakdong River	Gonggumji	Damyang	Duung	Cimsil	Han bando	Remarks
Coreoperca herzi							●	●	Ke
Siniperca scherzeri								●	
Channa argus		●		●		●	●	●	
Acanthogobius flavimanus			●						
Acentrogobius pellidebilis			●						Ke
Amblychaeturichthys hexanema			●						
Favonigobius gymnauchen			●						
Gymnogobius urotaenia	●		●			●			
Odontamblyopus lacepedii	●								
Rhinogobius brunneus					●	●	●	●	
Rhinogobius giurinus	●						●		
Synechogobius hasta	●		●						
Tridentiger bifasciatus	●		●						
Tridentiger brevispinis	●								
Tridentiger obscurus			●						
Nuchequula nuchalis			●						
Lateolabrax japonicus	●		●						
Lateolabrax maculatus	●		●						
Macropodus ocellatus				●			●		
Odontobutis interrupta					●		●	●	Ke
Odontobutis platycephala					●		●		Ke
Pholis fangi			●						
Pholis nebulosa			●						
Acanthopagrus schlegelii			●						
Argyrosomus argentatus			●						
Johnius belengerii			●						
Sillago japonica			●						
Sillago sihama			●						
Zoarchias uchidai			●						Ke
Pampus argenteus			●						
Zoarces gillii			●						
Lethenteron reissneri							●		En
Cynoglossus joyneri			●						
Cynoglossus semilaevis	●								
Paralichthys olivaceus			●						
Kareius bicoloratus			●						
Pleuronectes yokohamae			●						
Pleuronichthys cornutus			●						
Zebrias fasciatus			●						
Trachidermus fasciatus	●								
Hemitripterus villosus			●						

Table 2. Continued

Species	Han River	Upo	Nakdong River	Gonggumji	Damyang	Duung	Cimsil	Han bando	Remarks
Platycephalus indicus			●						
Liobagrus andersoni								●	Ke
Leiocassis nitidus			●						
Pseudobagrus fulvidraco		●		●		●	●		
Pseudobagrus koreanus					●		●	●	Ke
Silurus asotus		●		●	●		●		
Silurus microdorsalis								●	Ke
Monopterus albus							●		
Takifugu niphobles			●						
Takifugu obscurus	●								
Takifugu xanthopterus			●						
Total									
No. of species	28	21	60	17	18	9	46	36	134
No. of individuals	521	1,439	1,980	919	818	118	3,147	4,030	12,972

Ke, Korean endemic species; En, endangered species; Ex, exotic species.
*Translocation species.

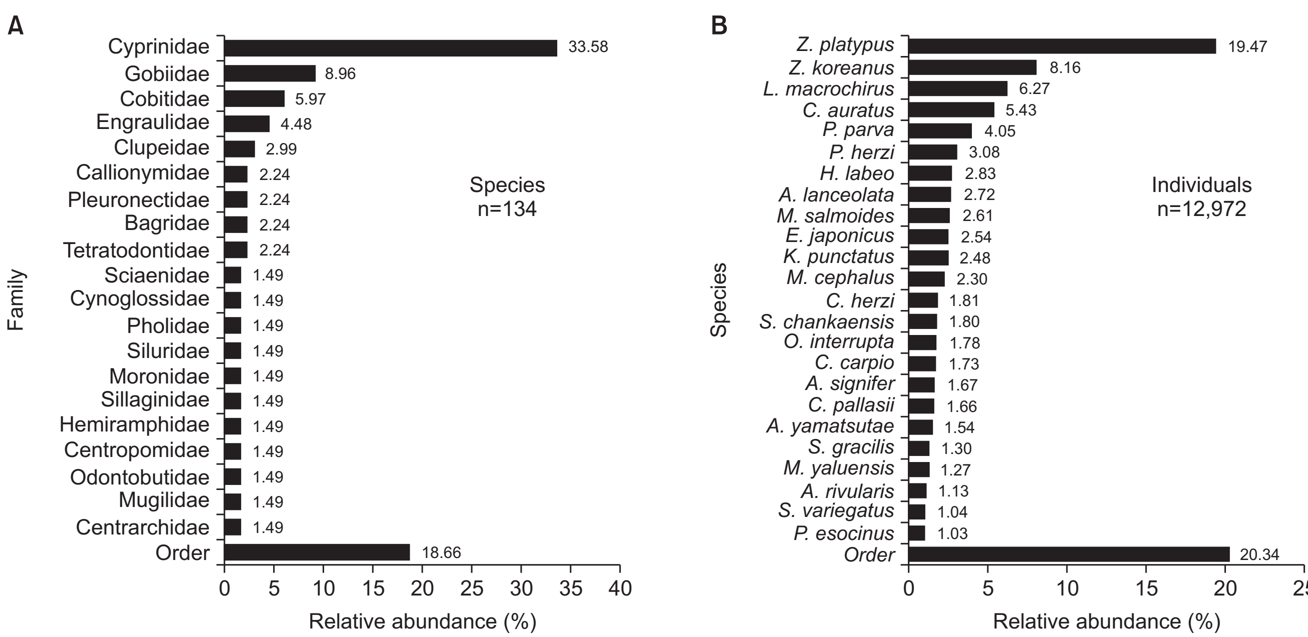

Fig. 2. Comparison of fish species and individuals collected in the Wetland Protected Areas in South Korea during 2015-2019. (A) Species. (B) Individuals.

were 7 legally protected species: *Acheilognathus signifer*, *Acheilognathus majusculus*, *Culter brevicauda*, *Gobiobotia brevibarba*, *Hemibarbus mylodon*, *Pseudopungtungia tenuicorpa*, and *Lethenteron reissneri*, that made up 5.2% of the total emergent species; 4 exotic species: *Carassius cuvieri*, *Cyprinus carpio*, *L. macrochirus*, and *Micropterus salmoides*, that made up 3.0% of the total emergent species; and 31 Korean endemic species: including *Z. koreanus*, *Coreoperca herzi*, *Squalidus chankaensis tsuchigae*, *Odontobutis interrupta*, *A. signifer*, and *Acheilognathus yamatsutae*, that made up 23.1% of the total emergent species (Fig. 3A). There were 36 brackish water species: including *Hyporhamphus intermedius*, *Hyporhamphus sajori*, *Konosirus punctatus*, and *Thryssa kammalensis*, that

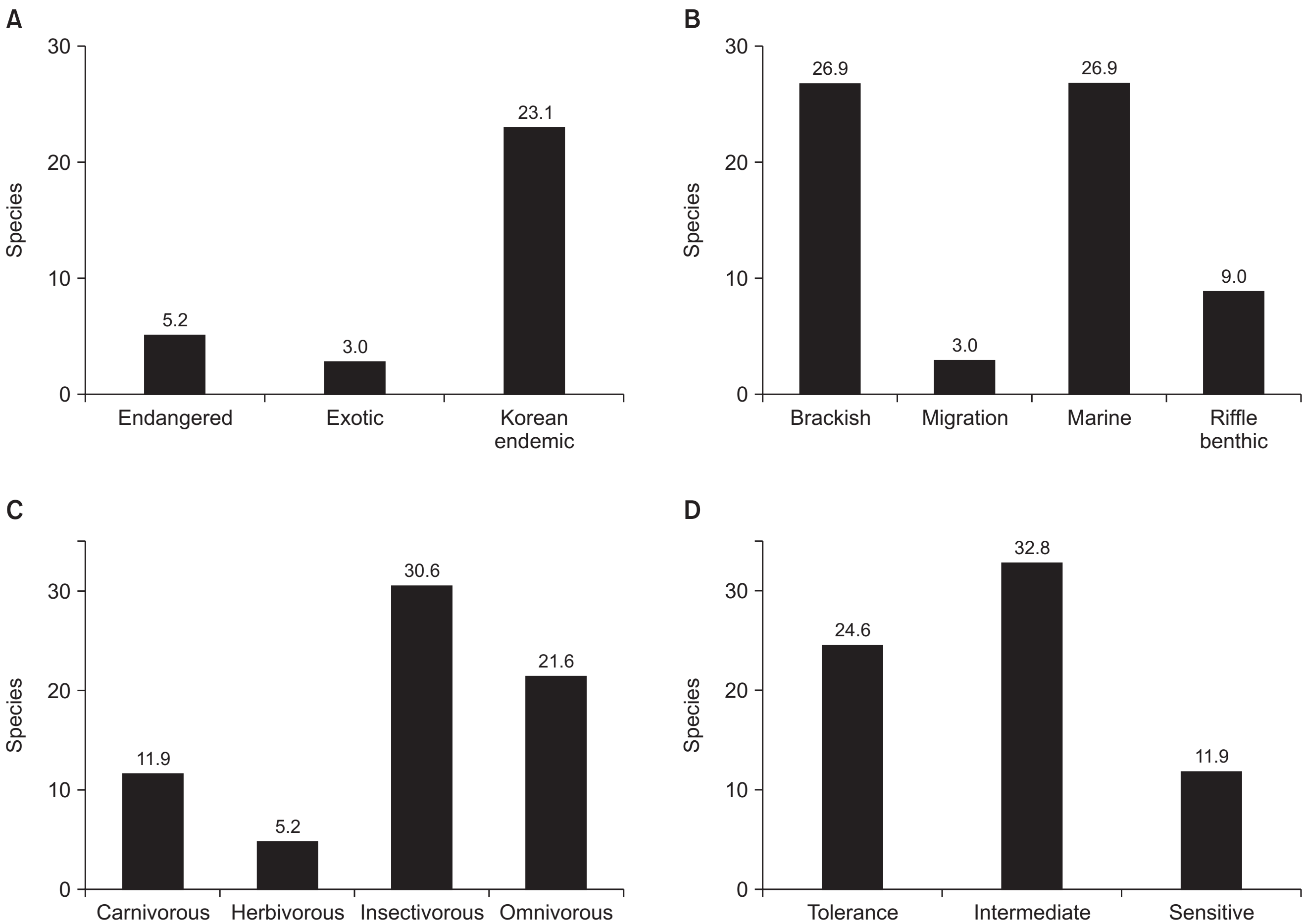

Fig. 3. Appearance rate of emergent fish species collected in the Wetland Protected Areas in South Korea during 2015-2019. (A) Specific. (B) Inhabit. (C) Feeding. (D) Tolerance.

made up 26.9% of the total emergent species; 4 migratory species: *Anguilla japonica*, *Coilia mystus*, *Coilia nasus*, and *Plecoglossus altivelis*, that made up 3.0% of the total emergent species, 36 species of marine species: including *Conger myriaster*, *Muraenesox cinereus*, and *Strongylura anastomella*, that made up 26.9% of the total emergent species; and 12 species of riffle-benthic species, including *Coreoleuciscus splendidus*, *G. brevibarba*, and *Koreocobitis rotundicaudata*, that made up 9.0% of the total emergent species (Fig. 3B).

After analyzing the eating behavior and tolerance characteristics using the National Institute of Environmental Research (2017). Biomonitering Survey and Assessment Manual, Incheon: National Institute of Environmental Research. We identified 16 carnivorous: including *A. japonica*, *C. brevicauda*, *Erythroculter erythropterus*, and *Channa argus*, that made up 11.9% of the total emergent species; 7 herbivorous: including *H. intermedius*, *H. sajori*, and *K. punctatus*, that made up 5.2% of the total emergent species; 41 insectivorous: including *Cobitis hankugensis*, *C. splendidus*, and *Repomucenus olidus*, that made up 30.6% of the total emergent species; and 29 Omnivorous: including *Oryzias sinensis*, *Abbottina rivularis*, and *Acheilognathus koreensis*, that made up 21.6% of the total emergent species (Fig. 3C). In addition, there were 33 tolerant species: including *O. sinensis*, *A. rivularis*, and *C. auratus*, that made up 24.6% of the total emergent species; 44 species with intermediate tolerance: including *A. japonica*, *H. intermedius*, and *C. nasus*, that made up 32.8% of the total emergent species; and 16 sensitive species: including *A. signifer*, *C. splendidus*, and *P. tenuicorpa*, that made up 11.9% of the total emergent species (Fig. 3D).

Fish community indexes and similarity analysis

Among the investigated WPAs, the Nakdong River estuary and Duung wetland had the highest and lowest Diversity and Richness indexes of 3.0 and 7.77 and 1.45 and 1.68, respectively. The Han River estuary, Upo wetland, and Cimsil wetland had similar Evenness indexes of 0.75, 0.75, and 0.74, respectively, and the Duung wetland had the lowest Richness index of 1.68. On the other hand, the

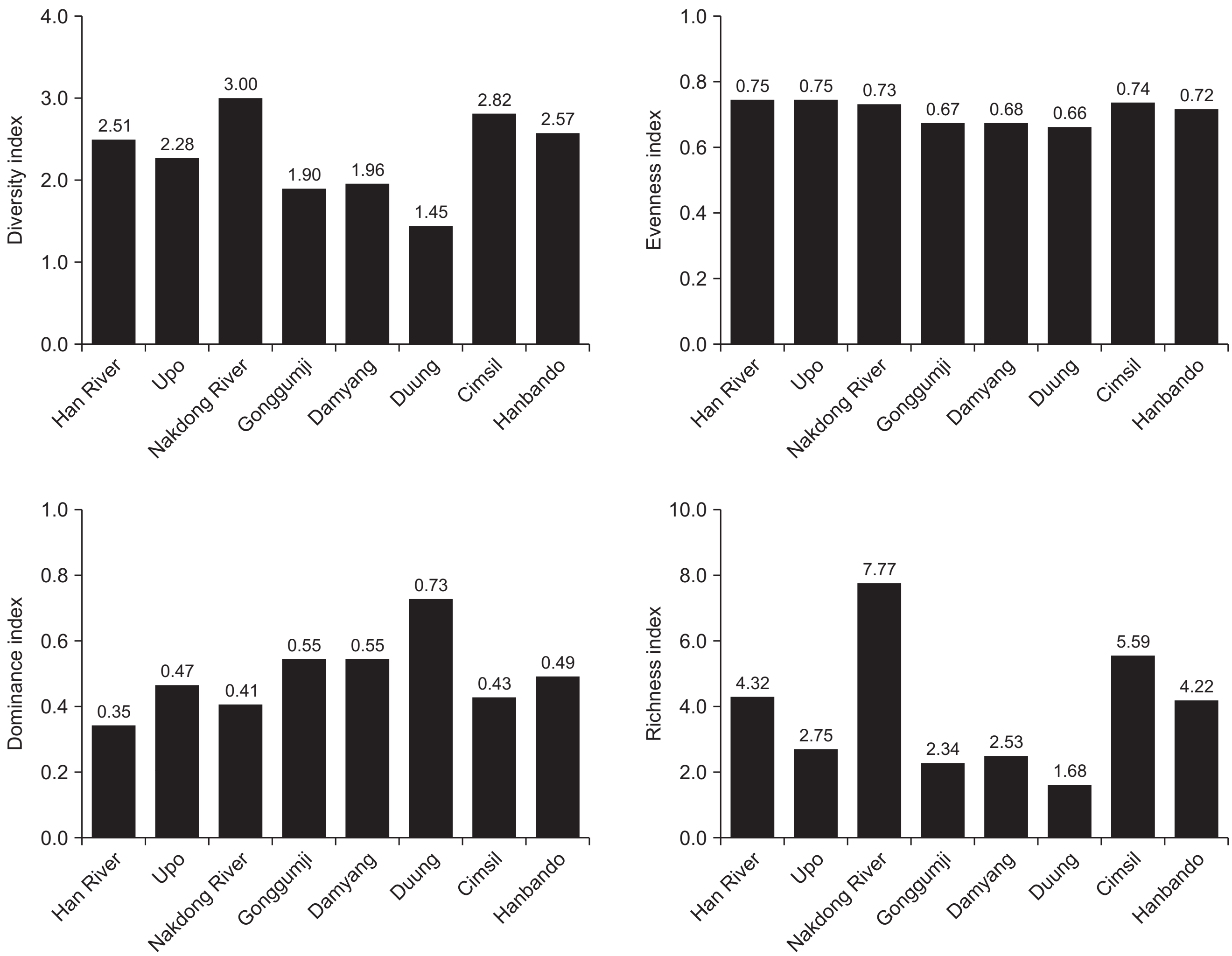

Fig. 4. Fish community index in each Wetland Protected Area in South Korea during 2015-2019.

Duung wetland had the highest Dominance index of 0.73 because its small area and lack of water inflow resulted in the domination of *C. auratus* (Fig. 4).

The NMDS and hierarchical cluster analysis of fish communities in the eight WPAs showed that the wetlands can be classified into four categories: estuary-type, stream-type, lake-type, and coastal dune-type (Figs. 5, 6). The Han River and Nakdong River estuary-type wetlands were placed on the left side of the first axis, and were found to have a high incidence of marine fish species and brackish water species, such as *H. intermedius*, *Chelon haematocheilus*, and *Synechogobius hasta* (Fig. 6). It is noteworthy that herbivorous fish species dominated the estuary-type wetlands. The Cimsil and Hanbando wetlands (i.e., typical stream-type wetlands) were placed on the upper-right side of the first axis, and were found to have a high incidence of endemic species and riffle-benthic species, such as *Z. koreanus*, *Sarcocheilichthys variegatus wakiyae*, and *C. herzi*. The Upo and Gonggumji lake-type wetlands that are created by floodplains, were placed on the lower-right side of the first axis, and found to be dominated by exotic species, such as *M. salmoides* and *L. macrochirus*.

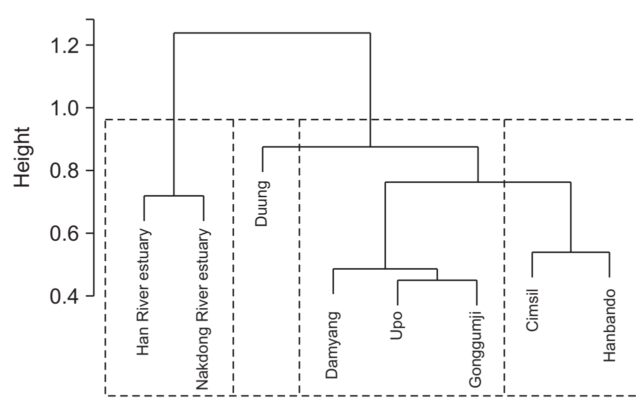

Fig. 5. Dendrogram of the similarities among the Wetland Protected Areas.

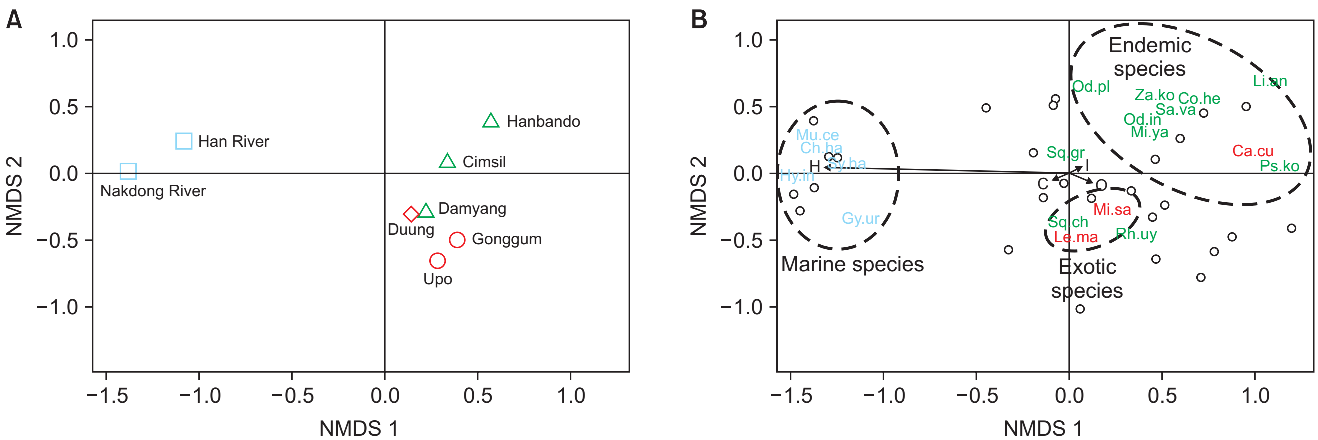

Fig. 6. Biplots of NMDS using fish community data in Wetland Protected Areas. (A) Wetland sites by habitat type (circle, lake; triangle, river; square, estuary). (B) Distribution of fish species. The length and angle of arrows indicate the contribution of a feeding characteristic to the NMDS axes. NMDS, nonmetric multidimensional scaling; C, carnivorous; I, insectivorous, H, herbivorous; O, omnivorous.

On the other hand, the Damyang stream wetland was considered to be better characterized as a stream-lake-type wetland (e.g., the Upo and Gonggumji wetlands) than a stream-type wetland because a significant amount of this stream wetland has been lost by development activities, such as the renovation of a dammed pool for irrigation, installation of a detention pond, construction of artificial wetlands, and large-scale engineering works. The loss of this stream wetland has resulted in water pollution and eutrophication, and parts of the retained wetland are undergoing various geomorphic changes and rapid successional changes that are driving a change in the wetland type.

In conclusion, this study was based on the results of fish-related investigations for 11 sites included in the intensive surveys on WPAs in South Korea. Currently, 44 sites (1,553.13 km^2) are designated as WPAs; however, studies that focus on emergent fish and their distributions despite the variations in shape, area, and type of WPAs are seriously limited

Analysis of the fish investigation data from the intensive surveys on WPAs revealed that there are four wetland types and one combined wetland type, and that the wetland types differed in species composition. Additionally, the predominant species *Z. koreanus* and *Z. platypus* contributed the most to the similarity of the fish communities, and are reportedly dominant species in domestic streams (Yoon *et al.*, 2011). Tolerant or exotic species had high incidences in lakes, which is similar to the findings of a previous study where the proportion of omnivorous and tolerant species increased with the increase in stagnant water (Han & An, 2013).

Such environmental changes in wetlands have direct influences on fish communities; thus, it is high possible that they will be used as the main indexes in the management of wetland types. However, fish communities are influenced by a combination of waterfront vegetation, differences in water quality, and physical characteristics of river beds. It is, therefore, difficult to use limited data for fish communities to develop a comprehensive management plan for wetlands. This is especially relevant regarding estuarine WPAs, in which fish communities vary depending on the geomorphic characteristics of habitats and the salinity of the water source (e.g., freshwater, brackish water, saltwater) (Baek *et al.*, 2013; Kim *et al.*, 2018; Park *et al.*, 2013). Data supplementation and an improvement of our understanding through the classification of geomorphological environment types and analysis of biota including fish communities within inland wetlands is necessary for the overall management of wetlands.

Conflict of Interest

The authors declare that they have no competing interests.

Acknowledgments

The concept setting and drafting was done by Jung-do Yoon, and all authors participated in the methodology and analysis, manuscript revising and editing, and the final version to be published was reviewed and agreed. In addition, please be advised that all authors included in the thesis do not have any conflict of interest in the academic publication of the research content.

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