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Fish Community and Habitat Environmental Characteristics in the Gudam Wetland

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ABSTRACT

In this study, we investigated the water quality and fish community of the Gudam Wetland, a riverine wetland in the middle-upper reaches of the Nakdong River, during March-October 2020. The main results were as follows: average annual flow rate: 45.0±23.7 m^3/s, flow velocity: 0.4±0.3 m/s, water depth: 1.4±0.4 m, water temperature: 17.5±0.8°C, pH: 7.8±0.2, electrical conductivity: 121.6±19.0 μs/cm, dissolved oxygen concentration: 11.4±0.9 mg/L, suspended solids concentration: 3.8±2.0 mg/L, and the water quality was classified as Ia (very good). A total of 754 individual fish belonging to 4 orders, 7 families, and 19 species were investigated. Cyprinidae was the dominant group, with 13 species. The dominant species was *Zacco platypus* (39.3%), followed by *Pseudogobio esocinus* (17.5%). There were 8 (42.1%) endemic Korean species and 1 exotic species, *Micropterus salmoides*. Four species were carnivores, six were insectivores, and nine were omnivores. Regarding tolerance to environmental changes, 6 species were tolerant, 11 had intermediate tolerance, and 2 were sensitive. Fish community analysis revealed dominance of 0.57, diversity of 2.04, evenness of 0.69, and richness of 2.72, indicating a diverse and stable fish community. The fish assessment index showed that the assessment class was B (average 62.5), which was higher than that of major streams of the Nakdong River (class C). For sustainable conservation of the Gudam Wetland, management strategies such as minimizing aggregate collection and preventing inflow of non-point pollutants are required.

Keywords: Fish community, Gudam Wetland, Ichthyofauna, Riverine wetland

Introduction

The Gudam Wetland (2,269,611.42 m^2) is a riverine wetland located in the middle and upper reaches of the Nakdong River. With the decrease in the flow velocity due to the construction of the Andong Dam and Gudam weir, bed sediments accumulated, the appearance of a braided channel disappeared, and the vegetation settled in the alluvial island, resulting in the formation of the current wetland (Kang, 2011). In terms of the vegetation environment, riparian vegetation such as perennial wet grasslands and willow communities have developed (Lee & Kim, 2021), serving as an area of high species diversity and an important habitat for endangered wildlife. In addition, the sandbar formed in the wetland is used as a resting and breeding ground for water birds, and the lentic system and alluvial island near the Gudam weir have high ecological value as a winter resting ground for ducks (National Institute of Ecology, 2020). Despite various social and ecological functions and roles of riverine wetlands, the Gudam Wetland is recognized as a target for development and utilization, and is threatened by

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continuous disturbances and losses such as land formation, eutrophication, hydrological disturbance, habitat destruction, and reduced biodiversity (Brinson & Malvárez, 2002; Davidson, 2014; Mitsch & Gosselink, 2000; Zedler & Kercher, 2004).

For riverine wetlands with high environmental value, efficient conservation measures and systematic management are required through monitoring and field surveys to obtain various data, such as that of topography, water quality, and biological species (National Institute of Ecology, 2020). In this regard, the Wetlands Center of the National Institute of Ecology has conducted an intensive, time-series survey by area to propose designation of wetland protected areas, targeting wetlands with ecological excellence. The results of the survey were utilized to evaluate the ecological value of the wetland biodiversity for eight areas, including vegetation, terrestrial insects, birds, mammals, and fish (Ministry of Environment & National Institute of Ecology, 2020). Among these areas, fish require various habitat conditions depending on changes in the physical aquatic environment; thus, it is a useful biological indicator for evaluating the aquatic ecosystem (Chae & Yoon, 2011; Dolédec & Statzner, 2008; Ward, 1992; Yang & Chae, 1993). As apex predators, fish are also one of the key factors in determining aquatic ecosystem biodiversity (Moyle & Cech, 2000). Ichthyofauna surveys were conducted in the Gudam Wetland in a previous study on the Nakdong River ecosystem as a part of the National Ecosystem Survey (Ministry of Environment & National Institute of Ecology, 2015). These surveys showed that endemic fish communities are well maintained in the Gudam Wetland, with a high ratio of endemic species and a low rate of introduced species (Kang, 2011). For quantitative analysis of aquatic ecosystem health, the fish assessment index (FAI), which has been established with eight metrics, was derived considering the characteristics of rivers in Korea (National Institute of Environmental Research, 2019).

In this study, as part of a nationwide intensive inland wetland survey, an intensive survey on the ichthyofauna distribution in the Gudam Wetland was conducted to investigate the characteristics of ichthyofauna and fish communities. Based on the results, this study aimed to confirm the ecological value and importance of the Gudam Wetland as a fish habitat and obtain basic reference biological data for the establishment of efficient conservation and management measures for the wetland.

Materials and Methods

Water quality survey

The Gudam Wetland is a representative S-shaped meandering river section among the channel sections of the Nakdong River. A stable flow regime was confirmed because of the Andong and Imha dams in the upstream area of the wetland. The Gudam weir is installed in the downstream area of the wetland, which enables river bed stabilization and water level retention (Table 1).

To investigate the water quality of the Gudam Wetland, measurements of eight elements (flow rate, mean flow velocity, mean water depth, water temperature, pH, electrical conductivity [EC], dissolved oxygen [DO], and suspended solids [SS]) were conducted in the Gudam weir, Gwangdeok Bridge, Hahoe Village, in the main stream of the Nakdong River on six occasions from April-October 2020 (April 30, May 31, June 29, August 29, September 22, and October 12). pH, EC, and water temperature were measured using a waterproof tester (HI-98130; HANNA Instrument, Nusfalau, Romania), DO was measured using a portable DO meter (PDO-520; HANNA Instrument), SS was measured using a portable turbidity meter (TB-31; TOADKK, Tokyo, Japan), and flow velocity was measured using a portable flowmeter (FLOWATCH; JDC, Yverdon-les-Bains, Switzerland). Values were calculated by averaging three measurements at each site.

Survey method and community analysis method

Ichthyofauna community surveys were conducted from March-October 2020. For survey sites, four points were selected in the Gudam Wetland, located in the middle and upper reaches of the Nakdong River near Andong-si, Gyeongsangbuk Province, and the survey was conducted

Table 1. Results of the hydrological and water quality survey of Gudam Wetland

Survey station	Flow rate (m^3/s)	Flow velocity (m/s)	Water depth (m)	Water temperature (°C)	pH	EC (μs/cm)	DO (mg/L)	SS (mg/L)
St. A	45.0±23.7	0.4±0.1	1.0±0.3	17.4±0.8	7.9±0.3	114.0±16.7	11.5±0.9	3.4±2.1
St. B	45.0±23.7	0.7±0.2	1.5±0.2	17.5±0.9	7.7±0.1	118.3±16.7	11.4±0.8	3.4±2.0
St. C	45.0±23.7	0.1±0.1	1.8±0.1	17.7±0.7	7.7±0.2	132.3±18.3	11.3±1.0	4.5±1.6
Total	45.0±23.7	0.4±0.3	1.4±0.4	17.5±0.8	7.8±0.2	121.6±19.0	11.4±0.9	3.8±2.0

Values are presented as mean±standard deviation.
EC, electrical conductivity; DO, dissolved oxygen; SS, suspended solids.

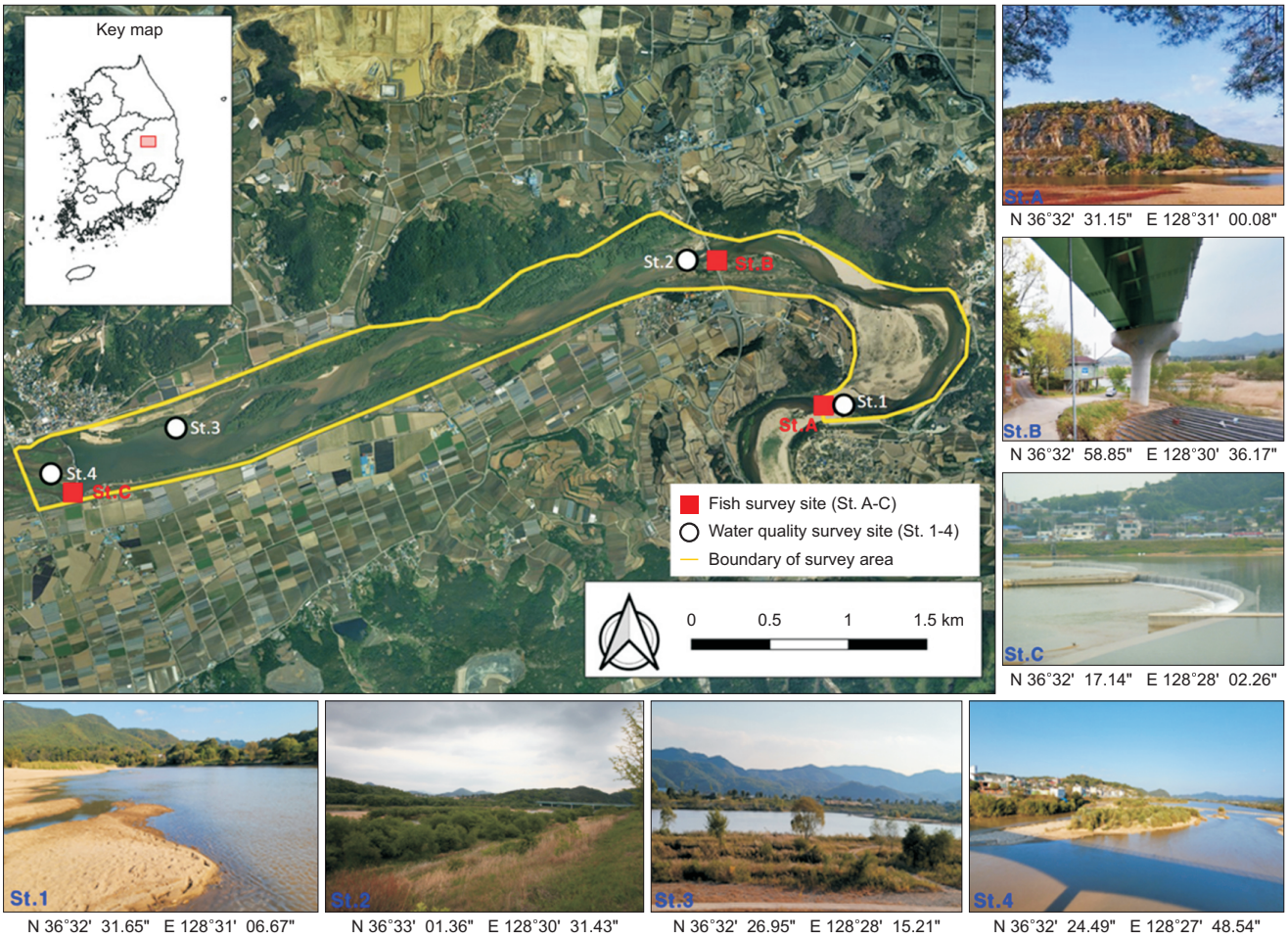

Fig. 1. Survey sites.

twice, i.e., before and after the flood (Fig. 1).

For fish collection, a cast net (7×7 mm mesh), stake net (5×5 mm mesh), and fyke net (7×7 mm mesh) were used. Identification and classification of the collected fish were performed on-site to determine the species and number of individuals, and then immediately discharged. A small number of individuals that were difficult to identify or for which photographs and sample preparation were required were fixed in neutral buffered 10% formalin solution (Sigma-Aldrich Corp., St. Louis, MO, USA) or stored in a cooler and transported to the laboratory for identification and measurement. For identification and classification, Kim (1997) and Kim and Park (2002) were used as references, and the classification system was arranged based on Nelson (2006). For structural analysis of fish communities, dominance, diversity, evenness, and richness were calculated based on the number of fish collected at the survey sites (Margalef, 1958; McNaughton, 1967; Pielou, 1966; 1975).

Aquatic ecosystem health assessment

The FAI was calculated using an ecological health metric model, and an analysis of the ecological health model of fish was performed based on the eight evaluation metrics, which have been improved and modified by the Ministry of Environment to reflect the circumstances in Korea based on the original standards of the Klemm *et al*. (1993) (National Institute of Environmental Research, 2019). According to the FAI, the health evaluation result of the river is classified into five levels, with 80-100 as "very good (Grade A)," 60-80 as "good (Grade B)," 40-60 as "normal (Grade C)," 20-40 were classified as "bad (Grade D)," and 0-20 as "very bad (Grade E)" (National Institute of Environmental Research, 2019).

Results and Discussion

Physico-chemical environment

The flow regime of the channel section in the Gudas Wetland showed a very good flow due to the discharge from Andong and Imha dams, with annual average flow

rate of 45.0±23.7 m^3, flow velocity of 0.4±0.3 m/s, water depth of 1.4±0.4 m, and water temperature of 17.5±0.8°C.

The water quality survey showed that the Gudam Wetland had a pH of 7.8±0.2, EC of 121.6±19.0 μS/cm, DO concentration of 11.4±0.9 mg/L, and SS concentration of 3.8±2.0 mg/L. The EC and SS values were higher at Station (st.) C than at other sites, which was determined to be due to the reduced flow velocity by the installation of the Gudam weir in the lower reach, which led to an increase in sediments such as organic matter and nutrients. According to the environmental standards in accordance with the Annexed Table 1 of Article 2 of the Enforcement Decree of the Framework Act on Environmental Policy, water quality of the river in the Gudam Wetland was very good (Ia Grade), and it was classified as an ecosystem rich in DO and free from pollutants. In addition, considering the water quality data for the last 5 years in the areas adjacent to the Gudam Wetland (Ministry of Environment, 2021; Regional Office: Andong 4, Table 2), in general, the Gudam Wetland water quality showed grades from very good (Ia) to good (Ib); therefore, it is considered that the Gudam Wetland satisfied the requirements of conservation as a riverine wetland (Table 2).

Current status of fish species composition and distribution in the Gudam Wetland

In terms of fish species composition and distribution of the four survey sites in the Gudam Wetland, there were 4 orders, 7 families, 19 species, and 754 individuals (Table 3). Among the fish that were present, 13 species of Cyprinidae accounted for the majority, and only one species appeared in each of six families, including Adrianichthyoidae, Cobitidae, and Centrarchidae. Examination of the number of individuals by family showed that there were 697 individuals of Cyprinidae (92.4%), 29 individuals of Cobitidae (3.9%), and 15 individuals of Odontobutidae (2.0%). The diversity of distribution of family Cyprinidae compared to other taxa was consistent with the characteristics of freshwater ichthyofauna flowing into the Southwest Sea of Korea.

Analysis of 19 species collected from the Gudam Wetland showed that the dominant species was *Zacco platypus*, with a total of 296 individuals (39.3%) and that the subdominant species was *Pseudogobio esocinus* with a total of 132 individuals (17.5%). This pattern was identical at all survey sites. In terms of the distribution of the fish species at each survey site, 10 species and 156 individuals appeared at St. 1, 15 species and 279 individuals appeared at St. 2, 13 species and 195 individuals appeared at St. 3, and 18 species and 195 individuals appeared at St. 4. The reason for the similar number of fish species appearing at each survey site is that the aquatic environment of the Gudam Wetland does not differ significantly across the study area.

Among the fish collected in the present survey, there were eight species endemic to the Korean peninsula, including *Cobitis hankugensis*, *Acheilognathus koreenis*, *Microphysogobio yaluensis*, *Rhodeus uyekii*, *Squalidus chankaensis tsuchigae*, *Squalidus gracilis majimae*, *Coreoperca herzi*, and *Odontobutis platycephala*. This accounted for 42.1% of the total number of species that appeared in the Gudam Wetland, indicating high endemism of the area. The ratio of endemic species was higher than 28.8% (Kim *et al*., 2005), which is the endemic species ratio for freshwater fish in the entire Korean Peninsula, and was slightly higher than 38.6% which was reported in the upper reach of the Nakdong River (Chae *et al*., 2015). The three endangered species, *Koreocobitis naktongensis*, *Lethenteron reissneri*, and *Brachymystax lenok tsinlingensis*, which are endangered species that have been reported in previous studies, were not identified in this survey. However, among the two exotic species that have been reported, i.e., *Micropterus salmoides* and *Lepomis macrochirus*, *M. salmoides* appeared in this survey; therefore, measures for removing the exotic species in the Gudam Wetland are required for the protection of endan-

Table 2. Water quality survey results near (Point: Andong 4) Gudam Wetland (Ministry of Environment, 2021)

Survey year	pH	DO (mg/L)	BOD (mg/L)	COD (mg/L)	SS (mg/L)	T-N (mg/L)	T-P (mg/L)	TOC (mg/L)	Water temperature (°C)	SS (μS/cm)
2019	7.7±0.3	10.6±2.5	1.0±0.3	5.2±1.8	7.2±10.8	1.930±0.458	0.017±0.013	2.9±0.7	14.2±6.6	198.2±19.9
2018	7.4±0.2	11.4±3.4	1.2±0.3	5.4±1.7	6.8±5.0	2.367±0.538	0.022±0.021	3.5±0.9	14.5±8.0	196.1±22.7
2017	7.8±0.3	11.7±3.5	1.3±0.3	5.1±1.2	8.1±13.9	1.934±0.443	0.025±0.023	2.5±0.3	14.7±7.8	203.3±41.3
2016	8.0±0.2	10.8±2.4	1.3±0.3	5.2±1.2	4.4±3.3	2.751±0.999	0.021±0.013	3.2±0.9	15.4±7.2	234±70.2
2015	8.1±0.3	10.3±2.1	1.0±0.2	4.2±0.6	3.4±2.0	2.040±0.586	0.018±0.008	2.5±0.4	17.2±7.1	234.8±48.3
Total	7.8±0.4	11.0±2.9	1.2±0.3	5.1±1.5	6.1±8.7	2.211±0.716	0.021±0.017	2.9±0.8	15.1±7.4	212.4±47.5

Values are presented as mean±standard deviation.
DO, dissolved oxygen; BOD, biochemical oxygen demand; COD, chemical oxygen demand; SS, suspended solids; T-N, total nitrogen; T-P, total phosphors; TOC, total organic carbon.

Table 3. Details of fishes collected from Gudam Wetland

Family and species	To	Tr	Ha	Station				Total	RA (%)	Re
				1	2	3	4			
Family Adrianichthyoidae										
Oryzias latipes	TS	O			2	4	3	9	1.19	
Family Cobitidae										
Cobitis hankugensis	IS	I		7	11	6	5	29	3.85	
Family Cyprinidae										
Acheilognathus koreenis	IS	O			5	1	3	9	1.19	E
Acheilognathus lanceolata intermedia	IS	O			26	7	21	54	7.16	
Carassius auratus	TS	O					4	4	0.53	
Cyprinus carpio	TS	O					1	1	0.13	
Hemibarbus labeo	TS	I		3	4	5	10	22	2.92	
Hemibarbus longirostris	IS	I		3	1		2	6	0.80	
Microphysogobio yaluensis	IS	O	RB	14	30	15	18	77	10.21	E
Pseudogobio esocinus	IS	I		21	44	30	37	132	17.51	
Pungtungia herzi	IS	I		12	13	7	10	42	5.57	E
Rhodeus uyekii	IS	O			2	4	7	13	1.72	
Squalidus chankaensis tsuchigae	IS	O		4	7	5	11	27	3.58	E
Squalidus gracilis majimae	IS	I		4	2	5	3	14	1.86	E
Zacco platypus	IS	O		87	126	31	52	296	39.26	
Family Centrachidae										
Micropterus salmoides	TS	C					2	2	0.27	X
Family Centropomidae										
Coreoperca herzi	SS	C			1			1	0.13	E
Family Odontobutidae										
Odontobutis platycephala	SS	C		1	5	4	5	15	1.99	E
Family Siluridae										
Silurus asotus	TS	C					1	1	0.13	
No. of individuals				156	279	124	195	754		
No. of species				10	15	13	18	56		
No. of families				3	5	5	6	19		

To, tolerance guild; Tr, trophic guild; Ha, habitat guild; RA, relative abundance; Re, remark; TS, tolerant species; IS, intermediate species; SS, sensitive species; O, omnivore; I, insectivore; C, carnivore; RB, Riffle-benthic species; E, Korea endemic species; X, exotic species.

gered species, including endemic Korean species.

Analyses of the characteristics of each survey site showed that St. 1, located at the uppermost reach of Gudam Wetland, had well-developed sandy bars on both river banks. In the survey, the dominant species was identified as the *Z. platypus* (87 individuals, 55.8%), the subdominant species was *P. esocinus* (21 individuals, 13.5%), and 5 endemic species and 30 individuals were identified, showing an endemic species ratio of 19.2%. St. 2 is the downstream site of Gwangdeok bridge, and rapids occur over a distance of approximately 30 m due to the concrete structure downstream of the bridge; at this site, the flow velocity is rapid and the substrate structure is characterized by the presence of a large amount of gravel and boulders compared to other survey sites. In addition, during the survey, it was found that heavy equipment was used to collect sand on sandbars in the river; therefore, it is necessary to guide to villagers regarding the conservation of the Gudam Wetland. In the survey, the dominant species was identified as the *Z. platypus* (126 individuals,

45.2%), the subdominant species was *P. esocinus* (44 individuals, 15.8%), and 8 endemic species and 63 individuals were identified, showing an endemic species ratio of 22.6%. St. 3 is located between Gwangdeok and Gudam bridges, and there is a weir downstream of the survey site; therefore, the site maintained the lowest flow velocity among the survey sites. In the survey, the dominant species was identified as *Z. platypus* (31 individuals, 25.0%), the subdominant species was *P. esocinus* (37 individuals, 19.0%), and 7 endemic species and 40 individuals were identified, showing an highest endemic species ratio of 32.3%. St. 4 is upstream of the Gudam bridge, where the weir is present, and an alluvial island had developed at this site. In the survey, the dominant species was identified as *Z. platypus* (52 individuals, 26.7%), the subdominant species was *P. esocinus* (37 individuals, 19.0%), and 7 endemic species and 52 individuals were identified, showing the endemic species ratio of 26.7%. One exotic species, bass (two individuals; 0.3%), was identified in the survey site, and it is suggested that measures are required for reducing the number of exotic species.

Feeding and tolerance analysis

Analyses of the feeding and tolerance characteristics of the fish species by referring to the River Section of the Guidelines on Aquatic Ecosystem Survey and Health Assessment Methods (National Institute of Environmental Research, 2019) showed that the feeding characteristics were classified as follows: 4 carnivorous species, including *C. herzi*, *O. platycephala*, and *Silurus asotus* (21.1% in appearance rate), six insectivorous species, including *C. hankugensis*, *Hemibarbus labeo*, and *Hemibarbus longirostris* (31.58% in appearance rate), and 9 omnivorous species including *Oryzias latipes*, *A. koreenis*, and *Acheilognathus lanceolata intermedia* (47.4% in appearance rate) (Fig. 2A). In terms of tolerance characteristics to environmental changes, there were 6 tolerant species, including *O. latipes*, *Carassius auratus*, and *Cyprinus carpio* (31.6% in appearance rate), 11 species with intermediate tolerance, including *C. hankugensis* and *Acheilognathus lanceolata intermedia* (57.9% in appearance rate), and 2 sensitive species, including *C. herzi* and *O. platycephala* (10.5% in appearance rate) (Fig. 2B).

Fish community analysis

Table 4 shows the ecological characteristics representing the community structure, including the dominance index, diversity index, evenness index, and richness. The diversity index was the highest at St. 4 (2.32) and lowest at St. 1 (1.52); notably, it was >1.5 in all survey sites, indicating relatively high diversity. The evenness index was the highest at St. 3 (0.85), and was low at St. 1 and St. 2 (0.66 and 0.67, respectively). Contrary to the evenness and diversity, the dominance index was the highest at St. 1 (0.69), and was relatively low at St. 3 and St. 4 (0.49 and 0.46, respectively). The richness was the highest at St (43.22), which is the most downstream site among the survey sites, and was the lowest at St. 1 (1.78), i.e., the site where the lowest number of species were present. Overall, the dominance index was 0.57, indicating that the dominant and subdominant species accounted

Table 4. Fish community indices in Gudam Wetland

Index	Station				Total
	1	2	3	4	
Dominance	0.69	0.61	0.49	0.46	0.57
Diversity	1.52	1.83	2.18	2.32	2.04
Evenness	0.66	0.67	0.85	0.80	0.69
Richness	1.78	2.49	2.49	3.22	2.72

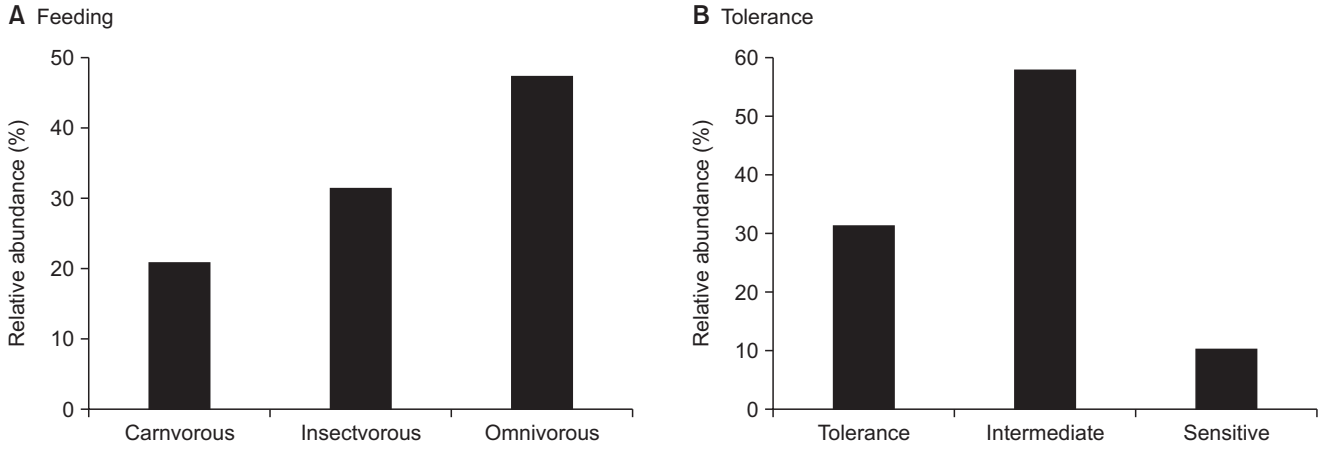

Fig. 2. Relative abundances of surveyed fish with different (A) feeding and (B) tolerance to environmental conditions in Gudam Wetland.

Table 5. Comparison of fish species in Gudam Wetland

Families and species	Byeon (2000)	Kang (2011)	Ministry of Envirionment and National Institute of Ecology (2015)	Present study
Family Adrianichthyoidae				
Oryzias latipes				●
Family Cobitidae				
Misgurnus anguilicaudatus	●	●		
*Cobitis hankugensis**	●	●	●	●
Family Cyprinidae				
*Abbottina springeri**	●			
*Acheilognathus koreenis**	●	●		●
*Acheilognathus yamatsutae**	●			
Acheilognathus rhombeus	●	●		
Acheilognathus macropterus	●	●		
*Acheilognathus gracilis**	●			
Acheilognathus lanceolata intermedia	●	●		●
Carassius auratus	●	●		●
Cyprinus carpio		●		●
*Coreoleuciscus splendidus**	●			
*Gobiobotia naktongensis**	●	●		
*Microphysogobio jeoni**	●			
Hemibarbus labeo	●	●	●	●
Hemibarbus longirostris	●		●	●
*Microphysogobio yaluensis**	●	●		●
Nipponocypris koreensis	●			
Opsariichthys uncirostris amurensis	●	●	●	
Pseudogobio esocinus	●	●	●	●
Pseudorasbora parva		●		
Pungtungia herzi	●	●	●	●
Rhodeus ocellatus	●			
*Rhodeus uyekii**	●	●		●
*Squalidus chankaensis tsuchigae**	●		●	●
*Squalidus gracilis majimae**	●	●	●	●
*Squalidus japonicus coreanus**	●			
Zacco platypus	●	●	●	●
Family Centrachidae				
Micropterus salmoides†				●
Family Centropomidae				
*Coreoperca herzi**			●	●
Family Osmeridae				
Hypomesus nipponensis	●			
Family Rhinogobius				
Rhinogobius giurinus	●	●		
Rhinogobius brunneus	●	●	●	
Tridentiger brevispinis	●	●	●	
Family Odontobutidae				
*Odontobutis platycephala**	●	●	●	●
Family Siluridae				
Silurus asotus		●		●
No. of species	31	23	13	19

*Korean endemic species; †Exotic species.

for approximately 50%, and the diversity index was generally high at 2.04. The evenness index was low at 0.69; however, richness was high at 2.72, indicating the maintenance of a relatively stable fish community in the wetland. Compared to the results from the 4th National Ecosystem Survey (Ministry of Environment & National Institute of Ecology, 2015), in the latest survey, diversity, evenness, and richness were higher and dominance was lower, which appeared to be related to the total number of species appearing at each site.

To examine the change in ichthyofauna in the Gudam Wetland, survey data from Byeon (2000), Kang (2011), and Ministry of Envirionment and National Institute of Ecology (2015) were used (Table 5). Byeon (2000) reported 6 families and 31 species, Kang (2011) reported 5 families and 23 species, and 5 families and 13 species were reported in the recent 4th National Ecosystem Survey. In the present study, the survey results recorded 7 families and 19 species. Among all the results, *Z. platypus* was the dominant species, and there was no change in the dominant species. In the surveys of Byeon (2000) and Ministry of Envirionment and National Institute of Ecology (2015), *C. hankugensis* was the subdominant species, whereas the results of Kang (2011) showed that *Opsariichthys uncirostris amurensis* was the subdominant species and *P. esocinus* appeared as a subdominant species, showing a difference between the results. In a previous survey, 15 endemic species were identified in Korea, including *C. hankugensis*, *A. koreenis*, *C. herzi*, and *O. platycephala*; however, in the present study, out of the 15 species, 7 species including *Abbottina springeri*, *Coreoleuciscus splendidus*, and *Gobiobotia naktongensis* were not recorded. *G. naktongensis* (an endangered species) was recorded in by Byeon (2000) and Kang (2011); however, its appearance was not confirmed in the Ministry of Envirionment and National Institute of Ecology (2015) nor in the present study. In addition, no exotic species were identified in Byeon (2000), Kang (2011), or Ministry of Envirionment and National Institute of Ecology (2015) surveys; whereas one exotic species, *M. salmoides*, was recorded in the present study. Homogenization of biota due to introduced species is a global trend (Elvira *et al*., 1996; Gratwicke & Marshall, 2001; Lövei, 1997). Because the fish community in Gudan Wetland may be homogenized due to *M. salmoides* (i.e., a carnivorous species), continuous research is necessary to understand the relationship between the status of the introduced species and the endemic species population.

There were 17 species that were recorded in the past surveys but were not confirmed during this survey, including *Opsariichthys uncirostris amurensis* and *Rhinogobius brunneus*. In contrast, there were two species (*O. latipes* and *M. salmoides*) that did not appear in previous surveys but were identified in the present survey. Evidently, the difference in the species composition and number of individuals for subdominant and endemic species is thought to have been due to the following reasons: With the completion of the Gudam weir in 2011, water stagnation increased, which led to a decrease in the flow velocity and the deposition of a large amount of sediment. This resulted in changes in the substrate structure which led to changes in the fish species composition. In addition, the variety of survey sites and differences in the tools used in the different surveys may also have contributed to the difference in the results.

Aquatic ecosystem health assessment

The aquatic ecosystem health assessment using the FAI for the Gudam Wetland showed that in terms of the river health state of the wetland, there were three survey sites classified as grade B (good) (75%) and one site classified as grade C (normal) (25%). St. 1 showed the lowest assessment value (56.6), and St. 2 showed the highest value (68.8) with a mean value of 62.5% (grade B; good). This grade is higher than the result of the aquatic ecosystem evaluation including fish in the main streams of the Nakdong River, i.e., grade C (normal) (Noh *et al*., 2015), indicating a good health state of the Gudam Wetland aquatic ecosystem. It is thought that the flow rate is controlled in the Imha and Andong dams, and that the water level is controlled by the Gudam weir, but that these have not had adverse effects on fish, such as that due to water pollution or habitat disturbance (Fig. 3).

Unlike other types of wetlands, riverine wetlands have the inherent characteristics of rivers and perform various ecological functions, such as removing externally introduced pollutants and providing habitat for animals and plants (Ann *et al*., 2014). In this study, the current status of biodiversity and ecosystems was surveyed and analyzed in the Gudam Wetland, located in the middle reach of the Nakdong River and lower reaches of Andong Lake.

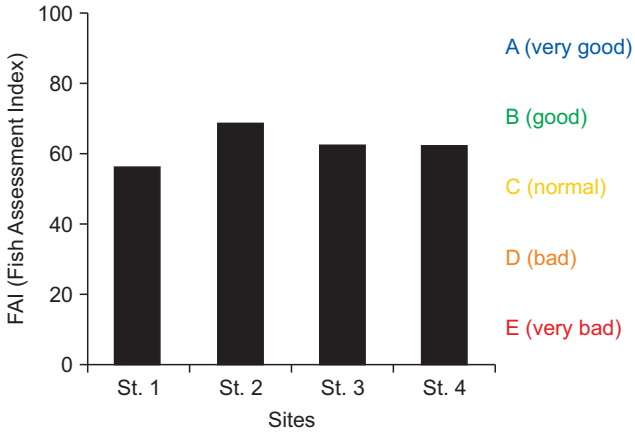

Fig. 3. Fish assessment index (FAI) results at four sites in Gudam Wetland.

The number of species that were reported in the survey of the Gudam Wetland was 7 families and 19 species. Of these species, 8 were endemic, accounting for 42.1% of the total number of species, which is higher than the endemic freshwater fish species rate in the Korean Peninsula (28.8%) and in the upper reach of the Nakdong River (38.6%), indicating a stable community structure. However, an exotic species of bass was confirmed at St. 4, and there has been a report on *G. naktongensis* (i.e., a Class I endangered species) habitation around the Nakdong River, the same water; therefore, it is highly probable that this species may be present in the Gudam Wetland, which provides a favorable habitat. Therefore, active measures are required to prevent ecosystem disturbance, as strong predation and diffusion of the exotic species may cause a reduction in the endemic species. In addition, non-point pollution sources (such as arable land) are distributed along the Nakdong River embankment, indicating a high possibility of influxes of chemical and organic matter. Because wetlands are characteristically in close proximity to residential areas, they are also exposed to development pressures such as damage to the vegetation and landforms due to waste dumping by visitors and tourists in summer and sand collection in the riparian area of the wetland. Therefore, in order to maintain ecosystem health of the Gudam Wetland, it is necessary to restrict indiscriminate development and utilization in the watershed and to establish an institutional foundation for continuous conservation and management of wetlands.

This study was conducted to investigate the current status of fish in the Gudam Wetland and to determine its ecosystem value. It is expected that ecological characteristics, such as the ichthyofauna communities that were identified in the present study, will serve as the basis for designating the Gudam Wetland as a protected area and provide basic data for establishing conservation measures.

Conflict of Interest

The authors declare that they have no competing interests.

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