Journal of Environmental Science International
27(11); 1105~1115; November 2018
pISSN: 1225-4517 eISSN: 2287-3503
https://doi.org/10.5322/JESI.2018.27.11.1105

ORIGINAL ARTICLE

Characteristics of Aquatic Ecosystem Environment in Seosan Reservoir, Korea

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Abstract

The aim of this study was to collect crucial data for the improvement of water quality and ecosystem conservation by analyzing water samples, sediments, benthic macroinvertebrates, and fish in the Seosan reservoir. The average values of water quality parameters from 2001 to 2016 were a chemical oxygen demand of 10 mg/L, total nitrogen of 1.22 mg/L, and total phosphorus of 0.074 mg/L. Cadmium was detected in the range of 0.531–0.748 mg/kg in the reservoir sediment. Fish belonging to 6 families and 9 species were identified in the reservoir. The dominant species were *Carassius auratus* and *Micropterus salmoides*. Benthic macroinvertebrates belonging to 22 families and 28 species were identified. The ecological score of the benthic macroinvertebrate community was 15 inside the reservoir (St. 2). *Micropterus salmoides*, an invasive alien species, was determined to be the subdominant fish species based on the number of captures, and the presence of the invasive species, *Sicyos angulatus L.* and *Paspalum distichum L.* was confirmed among the land flora.

Key words : Nutrient release, Agricultural reservoir, Reservoir management, Eutrophication

1. Introduction

Many agricultural reservoirs were constructed in the 1970s and over 60% of the water used for agriculture is currently supplied by these reservoirs. Reservoirs exhibit ecosystem disturbances because of eutrophication arising from increased phytoplankton populations. Nutrient salts and organic matter from point pollution sources, such as stock breeding facilities, or nonpoint pollution sources, such as farmland, in the surrounding areas accumulate in the reservoir, contributing to ecosystem deterioration and the occurrence of offensive smells owing to algal blooming. Water quality in the reservoir can be affected by various factors such as the lake scale, flow in the water body, climate, pollutant sources in the watershed, and water circulation (Kim and Hwang, 2004, Youn et al., 2008).

In Korea, rain mainly occurs during the summer, and massive pollutant inflows from nonpoint pollution sources occur during the rainy season. Reservoirs located in rural or mountainous territories have long storage times until the water is utilized for irrigation. Thus, pollutants that flow in to the reservoir with the rain water accumulate and adversely affect the water quality via excessive nutrient concentrations.

Received 4 October, 2018; **Revised** 22 October, 2018;
Accepted 24 October, 2018
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Deteriorated reservoirs are vulnerable to drought, localized heavy rain, and serious effects of leakage.

Small- or medium-scale reservoirs are often used for various purposes, such as swimming pools, aquatic sport facilities, camping facilities, and theme parks. Additionally, it has been suggested that fresh water resources can be used to improve biological diversity, develop inland fisheries, provide energy, and enable flood control of downtown areas (Kim 2004, Lee and Seo, 2009, Choi, 2014).

Fish are located at the top of the food chain and have longer life cycles than other biota. Identification of different species is facilitated, and the tolerance and trophic guilds differ between species (Jones et al., 2005). Changes in the food chain structure of domestic fishes can be caused by the deterioration of water quality or domination by invasive alien species (Pikitch et al., 2004). Benthic macroinvertebrates provide a source of food and are important members of lake ecosystems. They are considered as biological indicators because of their sensitivity to the organic content and toxic matter in the water (Hynes, 1963; Kehde and Wihm, 1972). The possibility of biota extinction owing to habitat simplification and water quality deterioration in fresh water stagnated by dams and reservoirs has increased. Changes in the characteristics and populations of benthic macroinvertebrates occur because of changes in the surrounding ecological system, including changes in the food webs of aquatic organisms, species composition, and growth of fishes, which may result from water pollution and environmental disturbances (Lee et al., 2009). In this study, various components and parameters of the aquatic ecosystem in the Seo-san reservoir in Korea, such as water quality, sediments, benthic macroinvertebrates, and fishes, were analyzed to collect crucial information to develop an effective water management plan.

2. Materials and Methods

2.1. Target area of investigation

The target area is in the southern part of Jeon-nam, South Korea. The inlet stream is Yeonjicheon River, which starts on Cheongwan Mountain and flows into Seosan reservoir. In six drainages, the water levels are so low that nearly the entire bed is exposed, except during the rainy season when there are inflows into the

Fig. 1. Map of Seosan reservoir watershed with sampling sites.

reservoir. The total areas of the water shed and benefitted area were 3.57 and 1.69 km^2, respectively. Water samples were collected on four days, July 14, August 16, September 1, and September 22. The sampling sites SS-1, SS-2, and SS-3 were located in the northern, middle, and southern parts of the reservoir (Fig. 1).

2.2. Analytical methods

Physicochemical factors, such as temperature, dissolved oxygen (DO), pH, and conductivity, were measured using a YSI 556MPS (Yellow Springs, OH, USA) multiparameter water quality meter. Two-liter samples were collected to measure the Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total Phosphorus (TP), and chlorophyll-*a* (Chl-*a*). The analytical methods used were in accordance with the standard methods for the measurement of water pollution adopted in Korea.

Fish and benthic macroinvertebrates were collected from three points: St. 1 (inlet of the reservoir, St. 2 (inside the reservoir), and St. 3 (outlet of the reservoir). Fish samples were collected using a cast net (mesh size 6 × 6 mm) and skimming net (mesh size 4 ×4 mm), and the lengths and weights of the sampled fishes were measured. The samples were fixed with 10% formalin solution and transferred to the laboratory for identification based on taxonomy as described by Nelson(2006) and based on studies by Kim and Park (2002) and Lee and Noh(2006). Fishes under 20 mm in length and fry were excluded from analysis.

Benthic macroinvertebrates were sampled three times with a dredge net (30 × 50 cm, mesh size 0.2 mm) and surber net (30 × 30 cm, mesh size 0.2 mm). Identification of benthic macroinvertebrates was based on Yoon(1995) and Won et al.(2005).

Triplicate samples were collected at each sampling location. The reservoir sediment was analyzed for Cd, Cu, As, Cr^{6+}, Hg, Pb, Ni, F, Zn, polychlorinated biphenyls (PCBs), cyanide (CN), benzene, toluene, ethylbenzene and xylenes (BTEX), total petroleum hydrocarbons (TPH), trichloroethylene (TCE), and tetrachloroethylene or perchloroethylene (PCE) using standard methods for the measurement of soil pollution in Korea.

3. Results and Discussion

3.1. Water quality

In the tested samples, DO ranged between 5.6 and

Table 1. Analysis of water quality in Seosan reservoir from July 14 to September 23, 2016

Time	Site	pH	DO (㎎/L)	BOD (㎎/L)	COD (㎎/L)	SS (㎎/L)	T-N (㎎/L)	T-P (㎎/L)	TOC (㎎/L)	Conductivity (µS/㎝)	Chl-*a* (㎍/L)
July 14th	SS-1	7.7	7.5	8.1	14.3	8.8	0.723	0.056	6.07	193	26.6
	SS-2	7.8	7.7	5.8	13.8	10.0	0.819	0.101	6.69	172	27.0
	SS-3	8.0	7.8	6.2	10.4	7.2	0.675	0.082	4.89	154	22.7
August 17th	SS-1	7.8	6.2	9.3	12.7	10.0	0.807	0.069	7.15	200	30.7
	SS-2	7.7	6.4	6.0	14.1	9.4	0.872	0.123	7.53	184	27.4
	SS-3	8.2	6.2	6.5	11.1	6.8	0.736	0.077	6.48	161	31.6
Sep. 2nd	SS-1	8.0	5.9	8.2	10.6	9.4	0.777	0.060	7.24	197	30.7
	SS-2	7.8	5.6	5.6	12.3	8.6	0.854	0.108	7.49	180	26.7
	SS-3	8.1	6.0	6.2	9.9	6.2	0.722	0.064	6.51	156	27.1
Sep. 23th	SS-1	8.1	6.0	8.8	10.7	10.0	0.794	0.052	7.34	209	30.8
	SS-2	8.1	6.2	5.9	12.1	9.0	0.865	0.095	7.55	188	27.3
	SS-3	8.2	5.9	6.7	10.3	6.8	0.706	0.073	6.57	163	29.7

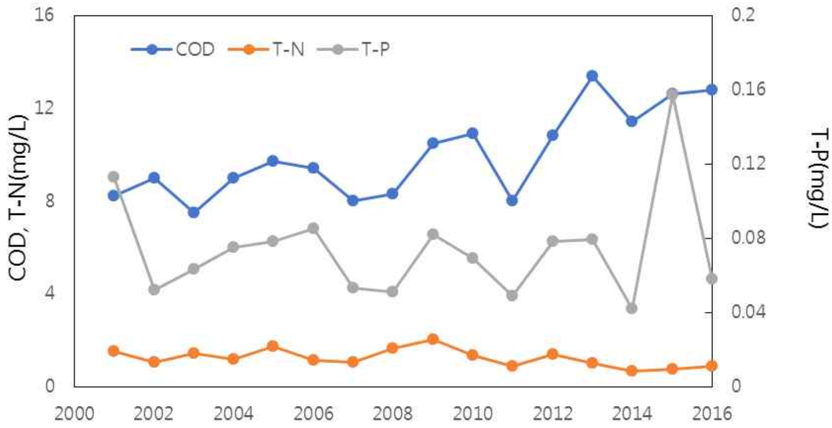

Fig. 2. Annual variations in T-N, T-P, and COD from 2001 to 2016.

7.8 mg/L (Table 1). The COD, T-N, and T-P levels were 9.9~14.3, 0.675~0.872, and 0.052~0.123 mg/L, respectively. Based on the investigation of 22 domestic medium and small-scale reservoirs, Lim et al.(2015) reported that water quality was worse during winter than during summer, which was attributed to the decrease in the quantity of water during winter. Medium- or small-scale reservoirs are more vulnerable to the influence of pollutants and amount of rainfall than large reservoirs.

The highest T-N and T-P content was observed at SS-2. The average COD, TOC, T-N, and T-P levels were 11.9, 6.79, 0.78, and 0.08 mg/L, respectively. The measured Chl-*a* was 28.2 μg/L. The mean value of COD during the 16 years from 2001 to 2016 was 10.0 mg/L, with the value showing an increasing trend (Fig. 2).

3.2. Sediment

The quantities of chemical elements in the sediments analyzed were as follows: Cd (0.53~0.75 mg/kg), Cu (15.33~23.46 mg/kg), As (1.49~2.92 mg/kg), Hg (0.078~0.081 mg/kg), Pb (43.90~51.47 mg/kg), Zn (166.84~190.61 mg/kg), Ni (30.86~32.47 mg/kg), and F (93~104 mg/kg). Hexavalent chromium, organic phosphorus compounds, PCBs, phenols, BTEX, TCE, PCE, and benzopyrene were not detected in any of the samples. Cd was present at SS-2 (0.626 mg/kg) and SS-3 (0.748 mg/kg). Accordingly, the Cd content in the sediments was classified as grade II based on the pollution assessment standards for lake sediments in Korea. The levels detected are potentially toxic to benthic organisms.

The composition of the sediment layer in the Seo-san reservoir was 56.4% silt and 43.6% clay (Table 2). No sand was found in this sample. The sediment at SS-1, SS-2, and SS-3 all contained silt. The highest levels of organic matter and T-N were detected at SS-1. The highest value for T-P was detected at SS-3. T-N contents ranged from 1124.1 to 1811.6 mg/kg and T-P contents ranged from 225.19 to 537.04 mg/kg. Higher total phosphorus content was observed under aerobic conditions than under anaerobic conditions. Total phosphorous levels released from the sediment under aerobic and anaerobic conditions were 0.745 and 0.310 $mg/m^3/day$, respectively, and total nitrogen levels released from the sediment were 16.30 and 16.54 $mg/m^3/day$, respectively. This result is useful for making decisions regarding dredging of the sediment for water quality improvement in the Seosan reservoir.

Table 2. Physical characteristics of bed sediments in Seosan reservoir

Items		SS-1	SS-2	SS-3
Particle Distribution	Gravel (%)	-	-	-
	Sand (%)	-	-	-
	Silt (%)	55.0	55.5	58.7
	clay (%)	45.0	44.5	41.3
Organics (%)		3.08	2.40	2.06
Ignition Loss (%)		8.2	8.5	8.5

3.3. Benthic macroinvertebrates

Benthic macroinvertebrates belonging to 22 families and 28 species were identified in the reservoir. Non-insect species and insect species accounted for 32.13% and 67.87%, respectively, of the total order count (Table 4). A total of 60 specimens were identified at St. 1 and the dominant and subdominant species at St. 1 were *Micronecta sedula* and Chironomidae sp. Thirty-five specimens were identified at St. 2; because the levee is composed of concrete, vegetation levels were low. Species at St. 2 were identified as *Physa acuta, Cloeon dipterum, Cercion calamorum, M. sedula,* and *Enochrus simulans*. A total of 140 populations were found at St. 3 at the outlet of the reservoir, including *M. sedula, E. simulans, C. dipterum,* and *Agabus browni*.

Plecoptera, and Trichoptera of the EPT groups (Ephemeroptera, Plecoptera, Trichoptera) which are sensitive (Lenat,1988) to the pollutants in this investigation were not observed. GOLD groups (Gastropoda, Oligochaeta, Diptera), which have the tendency to proliferate in rich area of organic matter (Lawrence et al., 2014) was found 1, 4, and 4 at St. 1, St. 2, and St. 3.

The ESB counts for St. 1, St. 2, and St. 3 were 32, 15, and 41, respectively, suggesting that this area can be classified as moderate to bad. St. 2 is found to be an α-polysaprobic area, and thus this area should be prioritized for quality improvement.

3.4. Fish distribution

Sixty-three fish specimens were found in the reservoir in this study, including 6 families and 9 species. Species belonging to the families Cyprinidae,

Table 3. Analysis of bed sediments in Seosan reservoir

Items	SS-1(mg/kg)	SS-2(mg/kg)	SS-3(mg/kg)
T-N(㎎/㎏)	1,811.56	1,347.17	1,124.14
T-P(㎎/㎏)	230.44	225.19	537.04
Cd(㎎/㎏)	0.531	0.626	0.748
Cu(㎎/㎏)	15.334	23.459	20.222
As(㎎/㎏)	1.49	2.43	2.92
Hg(㎎/㎏)	0.078	0.081	0.080
Pb(㎎/㎏)	43.904	50.467	51.469
Zn(㎎/㎏)	166.843	190.606	172.704
Ni(㎎/㎏)	32.470	30.858	31.887
F(㎎/㎏)	98	104	93

*PCBs, phenols, benzene, toluene, ethylbenzene, xylene, trichloroethylene, Tetrachloroethylene and benzopyrene were not detected

Table 4. Benthic macroinvertebrates in Seosan reservoir

Scientific Name	St.1	St.2	St.3
Viviparidae			
Cipangopaludina chinensis			2
Bithyniidae			
Parafossarulus manchouricus			2
Lymnaeidae			
Radix auricularia	1		2
Physidae			
Physa acuta	3	2	5
Planorbidae			
Gyraulus chinensis	2	1	4
Ampullariidae			
Pomacea canaliculata	4		13
Erpobdellidae			
Erpobdella lineata			1
Tubificidae			
Limnodrilus gotoi	1	4	2
Asellidae			
Asellidae sp.			7
Baetidae			
Cloeon dipterum	5	2	12
Coenagrionoidae			
Cercion calamorum	3	3	7
Ischnura asiatica	2	6	4
Platycnemididae			
Copera tokyoensis	2		5
Aeshnidae			
Aeschnophlebia longistigma	1		
Anax parthenope julius	3		6
Corixidae			
Micronecta sedula	15	8	35
Sigara substriata	1		2
Belostomatidae			
Diplonychus esakii	1		
Nepidae			
Ranatra chinensis			1
Dytiscidae			
Agabus browni			6
Rhantus pulverosus			5
Noteridae			
Noterus japonicus	2		
Hydrophilidae			
Enochrus simulans	2	2	8
Sternolophusrufipes	2		3
Chironomidae			
Chironomidae sp.	6	7	5
Tabanidae			
Tabanus amaenus			1
Culicidae			
Anopheles sp.	4		
Culicini sp.			2

Table 5. Fish fauna in Seosan reservoir

Scientific Name	St.1	St.2	St.3
Cyprinidae			
Zacco temminckii			2
Cyprinus carpio	2	1	
Carassius auratus	4	12	4
Pseudorasbora parva	3	5	3
Cobitidae			
Misgurnus anguillicaudatus		3	2
Bagridae			
Pseudobagrus koreanus		1	
Centrarchidae			
Micropterus salmoides	7	6	5
Gobiidae			
Rhinogobius brunneus			1
Channidae			
Channa argus		2	

Cobitidae, Bagridae, Centrarchidae, Gobiidae, and Channidae were found, among which 57.1% belonged to Cyprinidae (Table 5 and Fig. 3). A previous study identified 9 families and 28 species (Ministry of Environment in Korea, 2011). However, the Mugilidae, Osmeriformes, Beloniformes, and Hemiramphidae families were not found in this study. Species such as *Mugil cephalus, Chelon haematocheilus, Pseudobagrus fulvidraco, Plecoglossus altivelis, Oryzias latipes, Hyporhamphus intermedius, Synechogobius hasta, Gymnogobius urotaenia, Tridentiger brevispinis,* and *Tridentiger trigonocephalus*, which were recorded in the previous report, were not found in this study (2011). However, *Pseudobagrus koreanus* were newly identified at St. 2. The species with the largest number of specimens was *Carassius auratus*, followed by *Micropterus salmoides, Pseudorasbora parva, Misgurnus anguillicaudatus*, and *Cyprinus carpio*.

Especially, the number of *M. salmoides* was 18 in this investigation, which were not found previously report(2011). *M. salmoides* has been designated as an invasive alien species by the Ministry of Environment in Korea. *M. salmoides* are currently distributed throughout streams and lakes in Korea since they were first adopted from the US in 1973(Lee et al., 2008). They are already the dominant or subdominant fish species at St. 1, St. 2, and St. 3. Extermination should be continued for ecosystem conservation because overpopulation may result in the extinction of indigenous fishes.

3.5. Other major ecological groups of animals and plants

Seven families and 12 species of mammals were identified around the Seosan reservoir. The presence of *Lutra lutra* (Eurasian otter) and *Prionailurus bengalensis* (leopard cat), which are listed as endangered species in the list of fauna and flora by the Ministry of Environ -ment in Korea, were observed in the area.

Twenty-one families and 38 species of birds were observed around the reservoir. Bird species identified included *Falco tinnunculus* and *Accipiter gentilis*, which are designated as natural monument species in Korea. The dominant species of birds was *Fulica atra*. A total of 63.16% were resident birds, while winter visitors, summer visitors, and passing migrant birds accounted for 26.32%, 5.26%, and 5.26%, respectively.

Sixteen species of naturalized plants, including *Rumex crispus* L. and *Sicyos angulatus* L. were identified. Additionally, invasive alien plants such as *Sicyos angulatus* L. and *Paspalum distichum* L. were found. The over-abundance of *Trapa japonica*

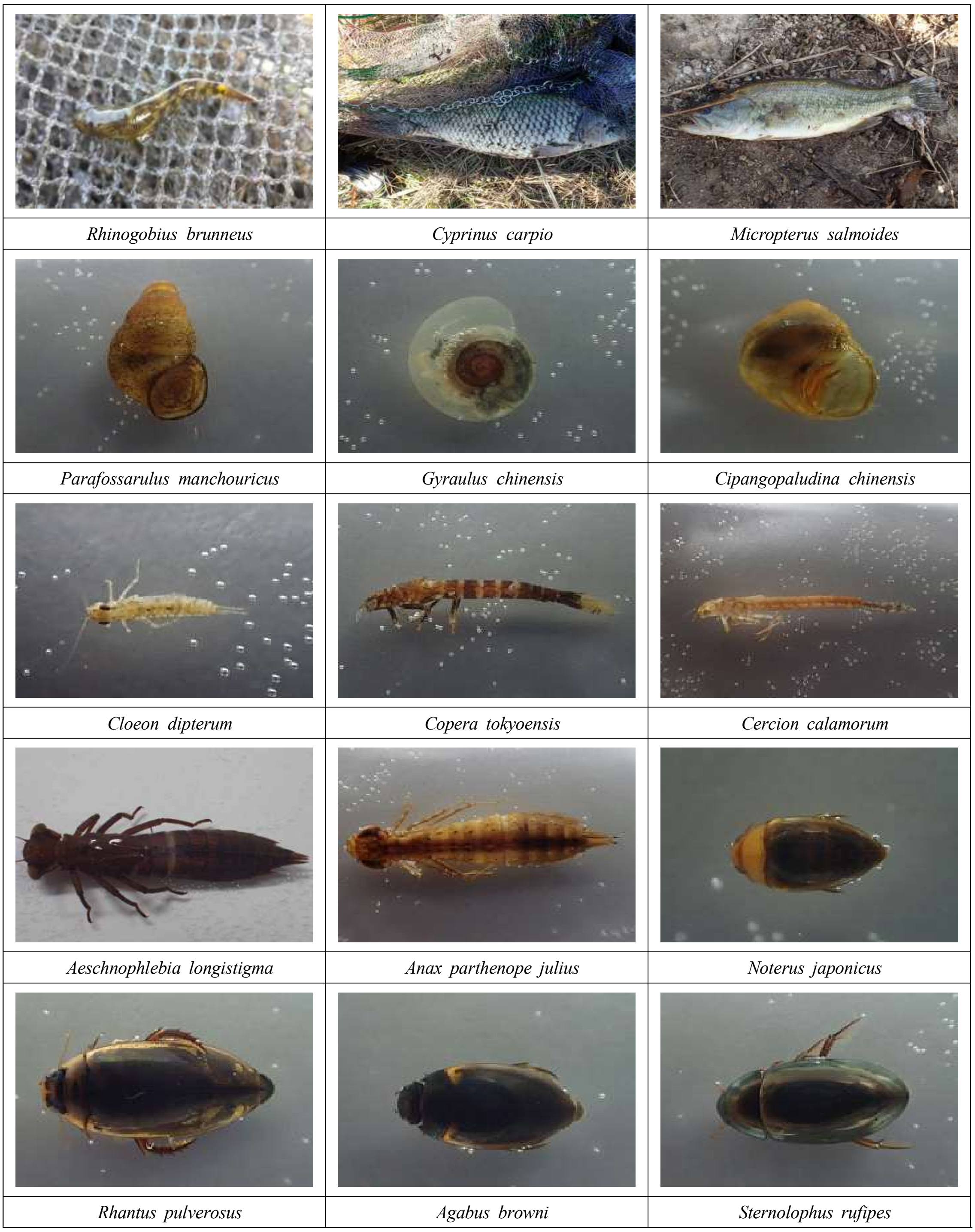

Fig. 3. Photographs of fishes and benthic macroinvertebrates in Seosan reservoir.

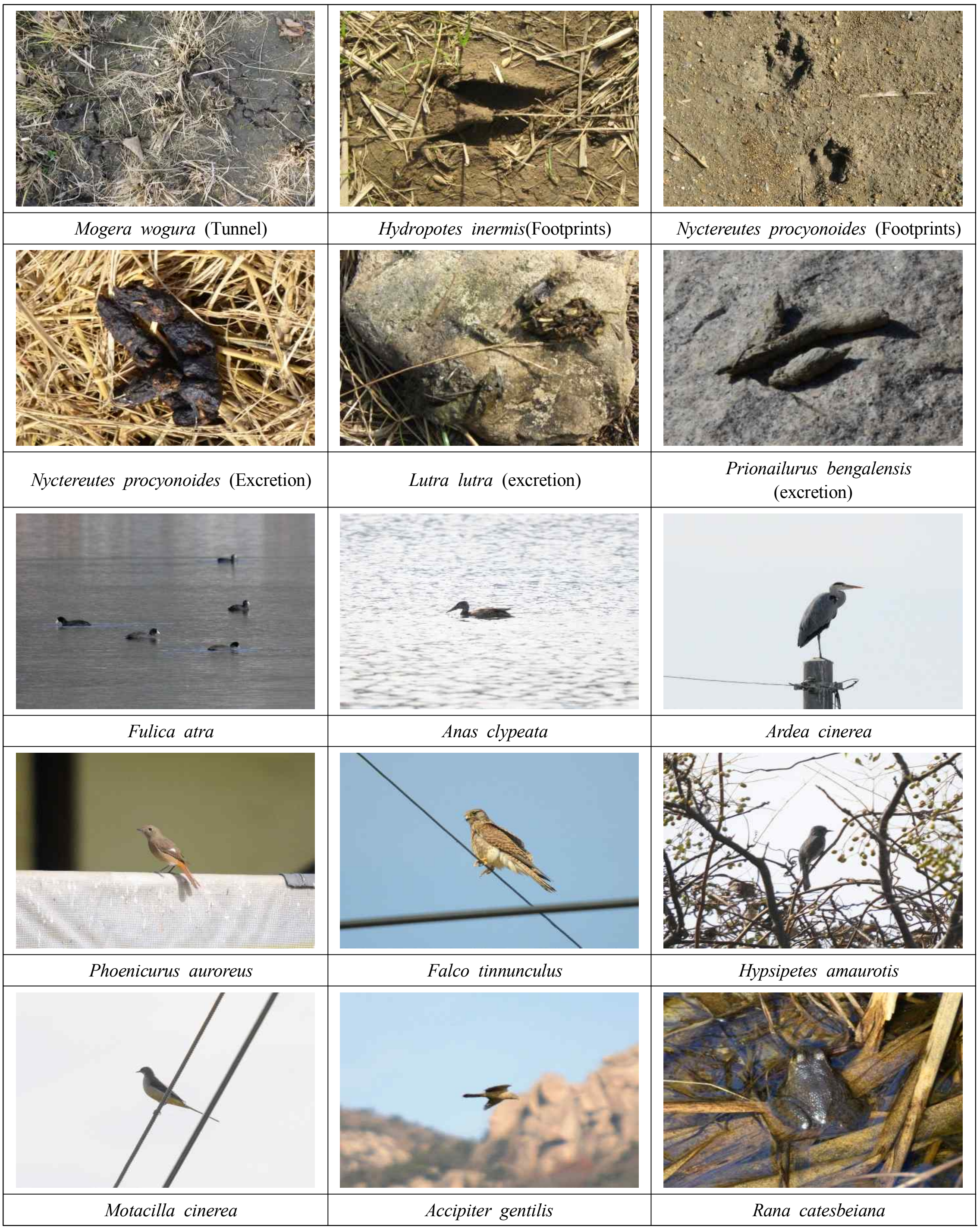

Fig. 4. Status of terrestrial creatures from the research (Detailed list of birds and mammals were not reported herein).

Fig. 5. View of *Trapa japonica* on the surface of Seosan reservoir.

presents a serious problem in the Seosan reservoir, and most of the water surface is covered by this plant (Fig. 5). Increases in TOC, T-N, and T-P were attributed to the growth of *T. japonica* (Choi et al., 2016). Aquatic plants play a role in trapping nitrogen and phosphorus absolving from the water body during their growth phase. However, the absolved nutrients are released during the withering phase. This affects the environment of the reservoir by increasing water pollution. Additionally, the appearance of the reservoir is affected, and water movement is prevented because of the excessive growth of this plant. Thus, the influence of internal factors, such as vegetation, should be considered in addition to the cessation of pollutant inflow in the management of reservoir water quality. Therefore, further studies on the effect of internal factors such as the growth and distribution of *T. japonica* are needed.

4. Conclusion

The aim of this study was to evaluate the Seosan Reservoir, which was built in 1945 to provide water for irrigation. We examined the parameters and components in the ecosystem, including water quality, sediments, fishes, and benthic macroinvertebrates. The mean value of COD in the last five years of the water was 13.9 mg/L, with the value showing an increasing trend.

Fish belonging to 6 families and 9 species were found; the dominant and subdominant species were *C. auratus* and *M. salmoides. Micropterus salmoides* is listed as an invasive species by the Korean Ministry of the Environment. The family Cyprinidae accounted for 57.1% of all fishes found. The ESB was assessed as 15 for St. 2, indicating that this area should be prioritized for improvement of water quality.

The proliferation of *T. japonica* was considerable, and this plant covered the water surface of the reservoir, necessitating a plan for its removal. Stock breeding facilities did not exist in the watershed, and untreated sewage and nutrient salts from farmland were responsible for the deterioration of the water quality of the reservoir.

Acknowledgments

This study was supported by grant from the Korea Rural Community Corporation.

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