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Distribution characteristics of freshwater fish in Jeju-do, Korea

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ABSTRACT

In order to examine distribution characteristics of freshwater fish in Jeju-do, freshwater fish were examined at 17 stations including three reservoirs, 13 stations in six streams, and one estuary wetland. A total of 396 fish individuals of seven species in four families were collected at the three reservoir stations and *Lepomis macrochirus*, an introduced species that disturbs the ecosystem, was the dominant species (71.7%). There were 770 fish individuals of 22 species in 15 families collected from the six streams. The dominant species was *Chaenogobius urotaenius* (22.6%). A total of 26 fish of four species in three families were found at the Hadori wetland and the dominant species was *Tridentiger obscurus*. There were five species of fish found for the first time in Jeju-do during this study; *Micropterus salmoides*, *Eleotris* sp., *Tridentiger brevispinis*, *Redigobius bikolanus*, and *Scatophagus argus*. In particular, *Eleotris* sp. of Eleotridae had not so far been recorded in Korea.

Introduction

There are many islands in the southwestern seas of Korea. Each island has small independent streams and various freshwater fish live there. Because freshwater fish are distributed separately among islands, and also among streams, fish fauna of each island, and the geographical distribution of fish provide valuable data for research of the natural history of the island (Son and Song 1998). All streams in Jeju-do have steeper slopes towards the upstream, so there is severe erosion during heavy rainfall. In addition, most stream beds consist of volcanic rock formed by volcanic activities. Most streams are normally ephemeral streams and when it rains, most rainwater permeates through the ground so the environment is extremely poor for freshwater fish, excluding a few streams (Moon et al 2005).

There are several studies on distribution of freshwater fish in islands of Korea; Choi and Jeon (1980), Song et al (1987), Jeon (1992), and Son (1995).There are also studies on distribution of freshwater fish in Jeju-do, Korea including the list of fish in the freshwater and seawater by Uchida and Yabe (1939), and various studies by the Fisheries Agency (1970), Kim (1970), Jo (1980), Yang (1994), Kim and Lee (1994), Lee et al (1999), and Kim (2006), but a comprehensive study on freshwater fish had not yet been conducted.

This study examined distribution status and community characteristics of freshwater fish inhabiting reservoirs, streams, and wetlands of Jeju-do, to identify distribution of freshwater fish in Jeju-do and to compare it with other islands of Korea. Furthermore, this study identified the distribution of *Micropterus salmoides* and *Lepomis macrochirus*, which are introduced species that can damage the ecosystem, to provide conservation strategy of the freshwater fish in Jeju-do.

Materials and methods

Environment study of streams

For the environmental study of streams, the stream width was measured using the monocle distance measuring device (Newcon

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Figure 1. Survey methods: A, B, environmental measurement; C, casting net; D, scoop net. environmental measurement, casting net, and scoop net.

LRM 1500; Newcon Internation Ltd., Toronto, ON, Canada). Water temperature (WT), dissolved oxygen (DO), pH, electrical conductivity (EC), and salinity (SAL) were measured using the mobile multi-item water quality measuring device (YSI 556 MPS; YSI Inc., Yellow Springs, OH, USA), and stream velocity was measured using a current meter (Flowatch; JDC Electronic SA, Yverdon-les-Bains, Switzerland). The stream bed was composed by the percentage (%) of boulder (diameter > 256 mm), cobble (256.64 mm), pebble (64∼16 mm), gravel (16∼2 mm), and sand (<2 mm) according to the classification method by Cummins (1962).

Collection and categorization of freshwater fish

Literary studies were conducted to identify characteristics of the fish and were compared with actual field investigations. Fish was collected using a casting net (net size 7 mm × 7 mm, 15 times) and a scoop net (net size 6 mm × 6 mm, 30 minutes). The collected fish were measured on site and then released or fastened with formalin and transported to the lab to measure the total length, body length, and weight after species identification (Figure 1). The collected fish were identified in accordance to the search keys of Kim and Park (2002), Kim et al (2005), and Lee and

Table 1. Location of sampling stations and coordinates in the Jeju-do, Korea.

Stations			Location	Coordinates	
			Jeju-do	N	E
Reservoirs	Gwangnyeongji	St. 1	Aewol-eup, Jeju	33° 28' 17.79	126° 25' 35.68
	Susanji	St. 2	Aewol-eup, Jeju	33° 28' 15.57	126° 23' 13.36
	Yeanhwaji	St. 3	Aewol-eup, Jeju	33° 27' 16.65	126° 20' 50.08
Streams	Musucheon	St. 4-1	Oedoi-dong, Jeju	33° 29' 32.50	126° 26' 08.92
		St. 4-2	Oedoi-dong, Jeju	33° 29' 34.56	126° 26' 12.64
	Ongpocheon	St. 5	Hallim-eup, Jeju	33° 24' 25.88	126° 15' 27.41
	Changgocheon	St. 6-1	Andeok-myeon, Seogwipo	33° 15' 22.69	126° 21' 13.52
		St. 6-2	Andeok-myeon, Seogwipo	33° 14' 38.93	126° 20' 30.27
		St. 6-3	Andeok-myeon, Seogwipo	33° 14' 19.27	126° 20' 39.50
	Jungmuncheon	St. 7-1	Saekdal-dong, Seogwipo	33° 15' 33.26	126° 25' 23.83
		St. 7-2	Jungmun-dong, Seogwipo	33° 14' 59.35	126° 24' 59.47
		St. 7-3	Saekdal-dong, Seogwipo	33° 14' 50.31	126° 25' 07.42
		St. 7-4	Saekdal-dong, Seogwipo	33° 14' 43.85	126° 25' 06.79
	Hyodoncheon	St. 8-1	Sanghyo-dong, Seogwipo	33° 18' 03.57	126° 34' 51.86
		St. 8-2	Hahyo-dong, Seogwipo	33° 15' 07.59	126° 37' 27.27
	Euigwicheon	St. 9	Namwon-eup, Seogwipo	33° 16' 52.44	126° 44' 22.64
Wetland	Hadori wetland	St. 10	Guiwa-eup, Jeju	33° 30' 29.26	126° 53' 34.74

St. = Site.

Rho (2006) and were organized according to the categorization system of Nelson (2006). In order to identify the ecological index of the observed fish, the dominance index (McNaughton 1967), diversity index (Shannon and Weaver 1963), species richness index (Margalef 1958), and evenness index (Pielou 1966) were examined and the ecosystem status per survey station and per species analyzed.

Survey period and stations

Survey period

The survey was conducted during the 5-day joint survey of Korean Biodiversity Consortium from September 2, 2013 to September 6, 2013.

Table 2. Water environmental factors in the reservoirs of Jeju-do, Korea.

Stations		WT (°C)	EC (μs/cm)	SAL (‰)	DO (mg/L)	pH	ORP (mV)
Gwangnyeongji	St.1	25.29	115	0.05	3.85	8.96	−51.9
Susanji	St.2	26.47	117	0.05	3.68	7.16	−51.9
Yeanhwaji	St.3	24.26	222	0.10	3.82	6.77	−30.6

DO = dissolved oxygen; EC = conductivity; ORP = oxidation reduction potential; SAL = salinity; St. = Site; WT = water temperature.

Survey stations

The surveys were conducted on three reservoir sites (Gwangnyeongji, Susanji, Yeanhwaji), six stream sites (Musucheon, Ongpocheon, Changgocheon, Jungmuncheon, Hyodoncheon, and

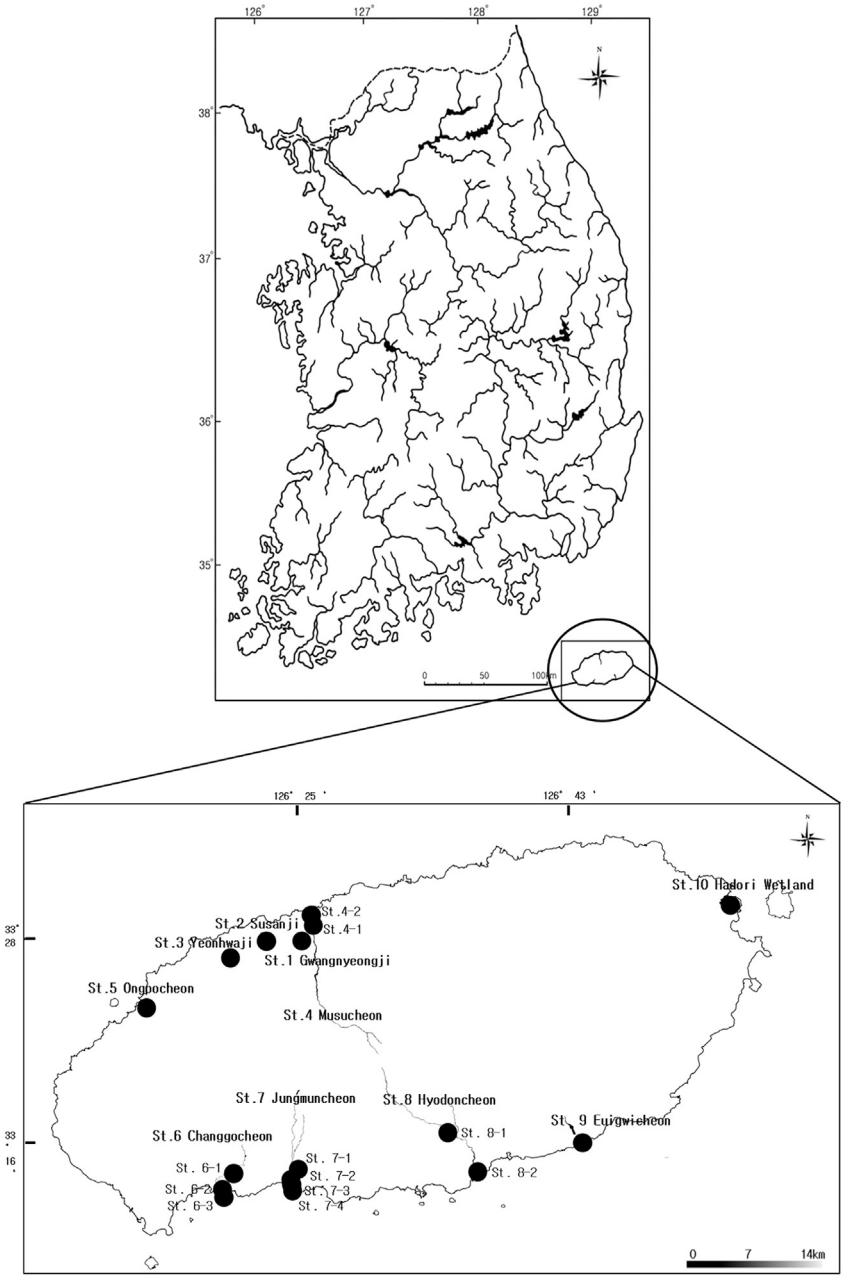

Figure 2. Map showing the study stations in Jeju-do, Korea (St. 1 Gwangnyeongji, St. 2 Susanji, St. 3 Yeanhwaji, St. 4 Musucheon, St. 5 Ongpocheon, St. 6 Changgocheon, St. 7 Jungmuncheon, St. 8 Hyodoncheon, St. 9 Euigwicheon, and St. 10 Hadori wetland).

Table 3. Water environmental factors in the stream of Jeju-do, Korea.

Stations		WT (°C)	EC (μs/cm)	SAL (‰)	DO (mg/L)	pH	ORP (mV)
Musucheon	St. 4-1	17.63	120	0.06	5.46	7.57	−73.6
	St. 4-2	25.86	30,785	19.13	3.13	7.3	−71.4
Ongpocheon	St. 5	16.82	249	0.12	6.44	7.22	−54.8
Changgocheon	St. 6-1	21.81	148	0.07	3.94	7.32	−60.9
	St. 6-2	26.34	168	0.08	3.67	7.69	−81.5
	St. 6-3	28.78	17,998	10.79	3.46	7.79	−87.4
Jungmuncheon	St. 7-1	23.39	36	0.01	2.78	7.28	−57.3
	St. 7-2	17.14	124	0.06	5.38	7.66	−74.8
	St. 7-3	17.23	122	0.06	4.73	7.54	−7.21
	St. 7-4	17.3	121	0.06	5.23	7.44	−66.9
Hyodoncheon	St. 8-1	15.53	53	0.02	4.76	7.46	−65.3
	St. 8-2	24.89	25,400	15.56	3.13	8.02	−98.8
Euigwicheon	St. 9	24.77	17,500	11.72	3.84	7.31	−71.8

DO = dissolved oxygen; EC = conductivity; ORP = oxidation reduction potential; SAL = salinity; St. = Site; WT = water temperature.

Table 4. Water environmental factors in Hadori wetland of Jeju-do, Korea.

Station		WT (°C)	EC (μs/cm)	SAL (‰)	DO (mg/L)	pH	ORP (mV)
Hadori wetland	St.10	16.11	3947	2.1	10.54	7.88	−90.7

DO = dissolved oxygen; EC = conductivity; ORP = oxidation reduction potential; SAL = salinity; St. = Site; WT = water temperature.

Table 5. Physical environmental factors in the reservoirs of Jeju-do, Korea.

Stations		Basin (m^2)	Effective storage (ton)	Water depth (m)	Built (y)
Gwangnyeongji	St.1	66,115	51,000	1.2	1956
Susanji	St.2	127,169	681,000	1.5	1960
Yeanhwaji	St.3	12,495	–	1.3	1950

St. = Site.

Euigwicheon), and one estuary wetland (Hadori wetlands). Various habitats such as retarding basins and lentic were included in the stream survey and the administrative region and GPS per survey site are as follows (Table 1, Figure 2).

Table 7. Physical environmental factor in Hadori wetland of Jeju-do, Korea.

Station		Area (m^2)	Water current (m/s)	Water depth (m)	Bottom structure (%)[a]				
					B	C	P	G	S
Hadori wetland	St. 10	770,000	0.05	1	10	10	30	30	20

St. = Site.
[a] Bottom structure: B (boulder), > 256 mm; C (cobble), 256 ~ 64 mm; P (pebble), 64 ~ 16 mm; G (gravel), 16 ~ 2 mm; S (sand), > 2 mm (Cummins 1962).

Table 8. The fish fauna and individual numbers collected in reservoirs of Jeju-do, Korea.

Scientific name	Korean name	Stations			
		St. 1	St. 2	St. 3	Total
Order Cypriniformes	잉어목				
Family Cyprinidae	잉어과				
Cyprinus carpio	잉어		8		8
Carassius auratus	붕어		1	1	2
Pseudorasbora parva	참붕어			85	85
Order Synbranchiformes	드렁허리목				
Family Synbranchidae	드렁허리과				
Monopterus albus	드렁허리	2			2
Order Perciformes	농어목				
Family Gobiidae	망둑어과				
Chaenogobius urotaenius	꾹저구		1		1
Family Centrarchidae	검정우럭과				
Lepomis macrochirus	블루길	105	128	51	284
Micropterus salmoides	배스	11	3		14
No. of individuals		118	141	137	396
No. of species		3	5	3	7

St. = Site.

Results

Water quality environment factors

Reservoirs

The water environments of the reservoirs were similar to each other for the most part, as shown in Table 2, which shows low DO and SAL, and high WT. The pH was different from each reservoir so it could restrict survival of certain fish species (Table 2).

Table 6. Physical environmental factors in the stream of Jeju-do, Korea.

Stations		Stream width (m)	Water current (m/s)	Water depth (m)	Stream type[a]	Bottom structure (%)[b]				
						B	C	P	G	S
Musucheon	St. 4-1	37	0.15	0.7	Bb	20	30	30	10	10
	St. 4-2	28	0.1	1.4	C	60	30	–	–	10
Ongpocheon	St. 5	14	0.15	0.8	Bb	–	–	20	20	60
Changgocheon	St. 6-1	3	0.3	0.7	Aa	40	30	–	20	10
	St. 6-2	20	0.1	0.6	Aa–Bb	10	30	40	10	10
	St. 6-3	31	0.05	0.8	C	50	30	–	–	20
Jungmuncheon	St. 7-1	24	0	2	Aa	20	–	–	–	80
	St. 7-2	20	1.5	0.8	Aa	50	30	10	–	10
	St. 7-3	25	0.3	1.3	Bb	10	20	20	20	30
	St. 7-4	38	0.5	1.5	C	10	–	–	–	90
Hyodoncheon	St. 8-1	5	0.6	1	Aa	50	20	10	10	10
	St. 8-2	56	0.2	2.5	C	–	30	–	10	60
Euigwicheon	St. 9	2.5	0.05	1.2	C	60	10	10	10	10

St. = Site.
[a] Stream type: Aa = upstream; Aa-Bb = upstream and middle-stream; Bb = middle-stream; C = downstream (Kani 1944).
[b] Bottom structure: B (boulder), > 256 mm; C (cobble), 256 ~ 64 mm; P (pebble), 64 ~ 16 mm; G (gravel), 16.2 mm; S (sand), > 2 mm (Cummins 1962).

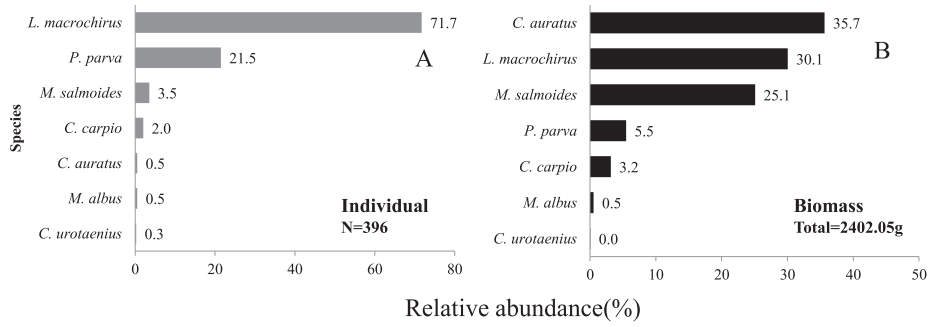

Figure 3. Relative abundance of (A) the individual number and (B) the biomass in the reservoirs of Jeju-do, Korea.

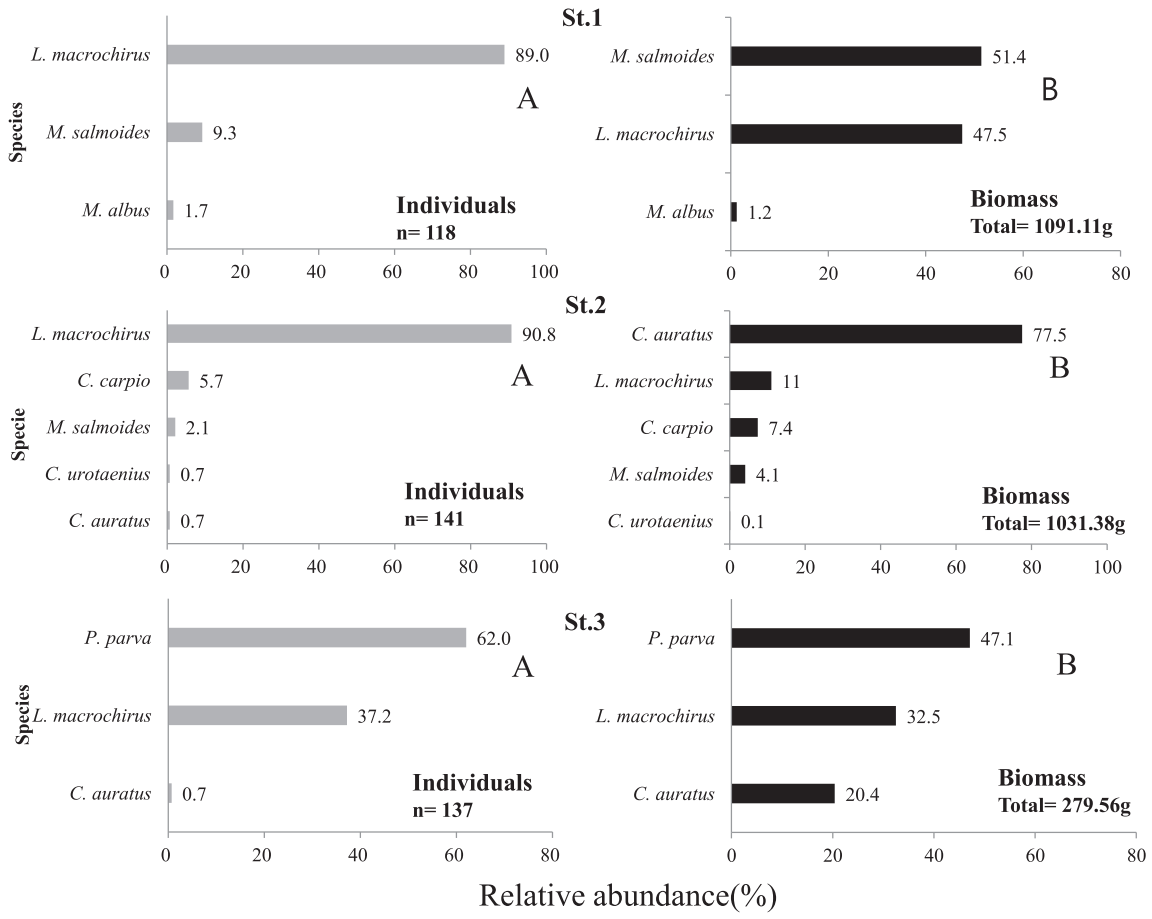

Figure 4. Relative abundance of (A) the individual number and (B) the biomass at each reservoir in the Jeju-do, Korea (St. 1 Gwangnyeongji, St. 2 Susanji, and St. 3 Yeanhwaji).

Streams

The surveyed streams showed considerable changes in SAL depending on inflow of seawater to the estuary, and therefore, there was a big difference in conductivity. The water quality was relatively stable in the upstream and the WT was low. In the midstream, however, the WT rose and the downstream was affected by seawater, thus having a direct influence on habitation of primary freshwater fish. In brackish zones, which were far-most downstream survey areas of the streams like that of Euigwicheon, due to the difference of tides, the quantity of water changed greatly and there was also a big difference in water quality environment (Table 3).

Table 9. Community indices in the reservoirs of Jeju-do, Korea.

Stations		H'	E	RI
Gwangnyeongji	St. 1	0.39	0.36	0.42
Susanji	St. 2	0.40	0.25	0.81
Yeanhwaji	St. 3	0.70	0.64	0.71

E = evenness index; H' = diversity index; RI = species richness index; St. = Site.

Wetland

As a result of the Hadori wetland that was developed on the coastline of Jeju-do, the WT was low and conductivity (EC) was high, while the SAL and DO were also high (Table 4).

Table 10. The fish fauna and individual numbers collected in stream of Jeju-do, Korea.

Scientific name	Korean name	Musucheon		Ongpocheon	Changgocheon			Jungmuncheon				Hyodoncheon		Euigwicheon	Total
		St. 4-1	St. 4-2	St. 5	St. 6-1	St. 6-2	St. 6-3	St. 7-1	St. 7-2	St. 7-3	St. 7-4	St. 8-1	St. 8-2	St. 9	
Order Anguilliformes	뱀장어목														
Family Anguillidae	뱀장어과														
Anguilla japonica	뱀장어			1			1								2
Order Cypriniformes	잉어목														
Family Cyprinidae	잉어과														
Carassius auratus	붕어			1		24									25
Pseudorasbora parva	참붕어			7											7
Rhynchocypris oxycephalus	버들치				21	7			18	89	16				151
Family Cobitidae	미꾸리과														
Misgurnus anguillicaudatus	미꾸리			1		4		3							8
Order Osmeriformes	바다빙어목														
Family Osmeridae	바다빙어과														
Plecoglossus altivelis	은어	46	12	7		7				19	12				103
Order Mugiliformes	숭어목														
Family Mugilidae	숭어과														
Mugil cephalus	숭어		5				9						13		27
Order Perciformes	농어목														
Family Moronidae	농어과														
Lateolabrax japonicus	농어												1		1
Family Gerreidae	게레치과														
Gerres oyena	게레치												1		1
Family Kyphosidae	황줄깜정이과														
Microcanthus strigatus	범돔												13		13
Family Oplegnathidae	돌돔과														
Oplegnathus fasciatus	돌돔												1		1
Family Eleotridae	구굴무치과														
Eleotris sp.	제주구굴무치(가칭)													2	2
Family Gobiidae	망둑어과														
Chaenogobius urotaenius	꼭저구	40		134											174
Redigobius bikolanus	점박이망둑													14	14
Rhinogobius giurinus	갈문망둑	3				3	5		1	15	38			4	69
Rhinogobius brunneus	밀어	2	1		2	23			8	4	3				43
Tridentiger obscurus	검정망둑		20				7						10	50	87
Tridentiger brevispinis	민물검정망둑						21								21
Family Microdesmidae	청황문절과														
Parioglossus dotui	꼬마청황													3	3
Family Scatophagidae	납작돔과														
Scatophagus argus	납작돔													13	13
Family Siganidae	독가시치과														
Siganus fuscescens	독가시치												1		1
Order Tetraodontiformes	복어목														
Family Tetraodontidae	참복과														
Takifugu niphobles	복섬												1	3	4
No. of individuals		91	38	151	23	68	43	3	27	127	69	0	41	89	770
No. of species		4	4	6	2	6	5	1	3	4	4	0	8	7	22

St. = Site.

Table 11. List of dominant and subdominant species at each station in the streams of Jeju-do, Korea.

Stations		Dominant species (%)	Subdominant species (%)
Musucheon	St. 4-1	*Plecoglossus altivelis* (50.6)	*Chaenogobius urotaenius* (44.0)
	St. 4-2	*Tridentiger obscurus* (50.0)	*Plecoglossus altivelis* (30.)
Ongpocheon	St. 5	*Chaenogobius urotaenius* (88.7)	*Pseudorasbora parva* (4.6)
			Plecoglossus altivelis (4.6)
Changgocheon	St. 6-1	*Rhynchocypris oxycephalus* (91.3)	*Rhinogobius brunneus* (8.7)
	St. 6-2	*Carassius auratus* (34.3)	*Rhinogobius brunneus* (32.9)
	St. 6-3	*Tridentiger brevispinis* (48.8)	*Mugil cephalus* (20.9)
Jungmuncheon	St. 7-1	*Misgurnus anguillicaudatus* (100)	–
	St. 7-2	*Rhynchocypris oxycephalus* (62.1)	*Rhinogobius brunneus* (27.6)
	St. 7-3	*Rhynchocypris oxycephalus* (70.1)	*Rhinogobius giurinus* (11.8)
	St. 7-4	*Rhinogobius giurinus* (55.1)	*Rhynchocypris oxycephalus* (23.1)
Hyodoncheon	St. 8-1	–	–
	St. 8-2	*Mugil cephalus* (31.7) *Microcanthus strigatus* (31.7)	*Tridentiger obscurus* (24.4)
Euigwicheon	St. 9	*Tridentiger obscurus* (56.2)	*Redigobius bikolanus* (15.7)

St. = Site.

Table 12. Community indices in the streams of Jeju-do, Korea.

Stations		H'	E	RI
Musucheon	St. 4-1	0.90	0.65	0.67
	St. 4-2	1.06	0.77	0.82
Ongpocheon	St. 5	0.49	0.27	1.00
Changgocheon	St. 6-1	0.30	0.43	0.32
	St. 6-2	1.61	0.78	1.65
	St. 6-3	1.31	0.81	1.06
Jungmuncheon	St. 7-1	–	–	–
	St. 7-2	1.00	0.62	1.19
	St.7-3	0.89	0.65	0.62
	St. 7-4	1.11	0.80	0.71
Hyodoncheon	St. 8-1	–	–	–
	St. 8-2	1.53	0.73	1.88
Euigwicheon	St. 9	1.35	0.69	1.34

E = evenness index; H' = diversity index; RI = species richness index; St. = Site.

Physical environment factors

Reservoirs

Gwangnyeongji is a small reservoir with effective storage of 51,000 tons. Susanji is a mid-sized reservoir with effective storage of 681,000 tons built to supply agricultural water and it is the largest reservoir in Jeju-do. Yeanhwaji is a small reservoir constructed in 1950 and was used for drinking water, water for livestock, and for laundry. Currently, most of the reservoir is covered by lotus flowers and thus it has formed a large lotus pond (Table 5).

Streams

The result of the physical environmental factors of the streams is as shown in Table 6. The upstream is usually composed of boulders and cobbles and the downstream consists of pebble, gravel, and sand. However, there were differences depending on the stream and there was great difference in species that inhabited the stream bed. Excluding Station 8-2, which is the Hyodoncheon estuary, the stream width did not exceed 40 m and depth was also no deeper than 2 m.

Wetland

The Hadori wetland that was formed by reclamation has a wide area of 770,000 m^2, but it is a lentic with 1 m of depth (Table 7).

Fish fauna of Jeju-do

Reservoirs

A total of 396 fish of seven species of four families were observed at the three reservoirs (Table 8). Three species are members of the family Cyprinidae, two species are the family Centrachidae, one species is a member of the family Flutidae, and one species is a member of the family Gobiidae. Any endangered species or native species to Korea were not observed, while many numbers of introduced species, *L. macrochirus* and *M. salmoides* appeared frequently. The dominant species was *L. macrochirus* (71.7%) and the subdominant species was *Pseudorasbora parva* (21.5%). For biomass, *Carassius auratus* was the dominant species (35.7%) followed by *L. macrochirus* (30.1%), *M. salmoides* (25.1%), and *P. parva* (5.5%) (Figures 3 and 4).

Compared to fish fauna characteristics of each reservoir, a total of three species appeared at the Gwangnyeongji reservoir; the dominant species was *L. macrochirus* (88.9%) and the subdominant species was *M. salmoides* (9.3%). In terms of biomass, it was in the order of *M. salmoides* (51.4%) and *L. macrochirus* (47.5%). Results of community analysis showed species diversity of 0.39, evenness of 0.36, and richness of 0.42 (Table 9). A total of three species appeared at the Yeanhwaji reservoir; the dominant species was *P. parva* (62.0%) and the subdominant species was *L. macrochirus* (37.2%). For biomass, it was in the order of *P. parva* (47.1%), *L. macrochirus* (32.5%), and *C. auratus* (20.4%). Results of community analysis showed species diversity of 0.70, evenness of 0.64, and richness of 0.71 (Table 9).

Upon investigating Gwangnyeonji, Susanji, and Yeanhwaji, which are major reservoirs of Jeju-do, *L. macrochirus*, which are foreign introduced species, are the most dominant species with 284 fish (71.7%) and 14 (3.5%) *M. salmoides* were found at Gwangnyeongji and Susanji. Thus, two species which were designated as invasive species by the Ministry of Environment were distributed in the reservoirs. It is therefore necessary to develop comprehensive management plans.

Streams

A total of 770 freshwater fish of 22 species of 15 families were collected in the six streams of Jeju-do (Tables 10 and 11). Six species (27.3%) were members of the family Gobiidae and three (13.6%) were of the family Cyprinidae. One species each appeared of other families (Tables 10 and 11). Unlike in reservoirs, the introduced species of *L. macrochirus* and *M. salmoides* were not found in the streams. The dominant species was *Chaenogobius urotaenius* (22.6%) and the subdominant species was *Rhynchocypris oxycephalus* (19.6%). For biomass, it was in the order of *Plecoglossus altivelis* (36.5%), *C. urotaenius* (16.5%), *Mugil cephalus* (13.1%), and *Tridentiger obscurus* (10.0%) (Figures 5 and 6)

Four species appeared at Station 4-1 of Musucheon. The dominant species was *P. altivelis* (50.6%) and the subdominant species was *C. urotaenius* (44.0%) (Table 12). This survey site is a water

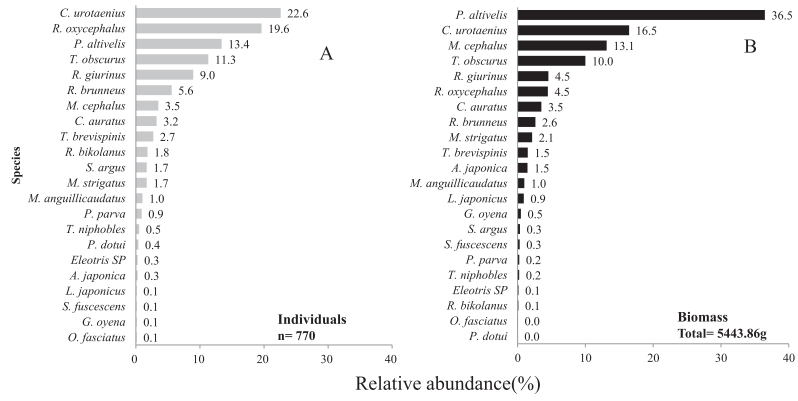

Figure 5. Relative abundance of (A) the individual number and (B) the biomass in the streams of Jeju-do, Korea.

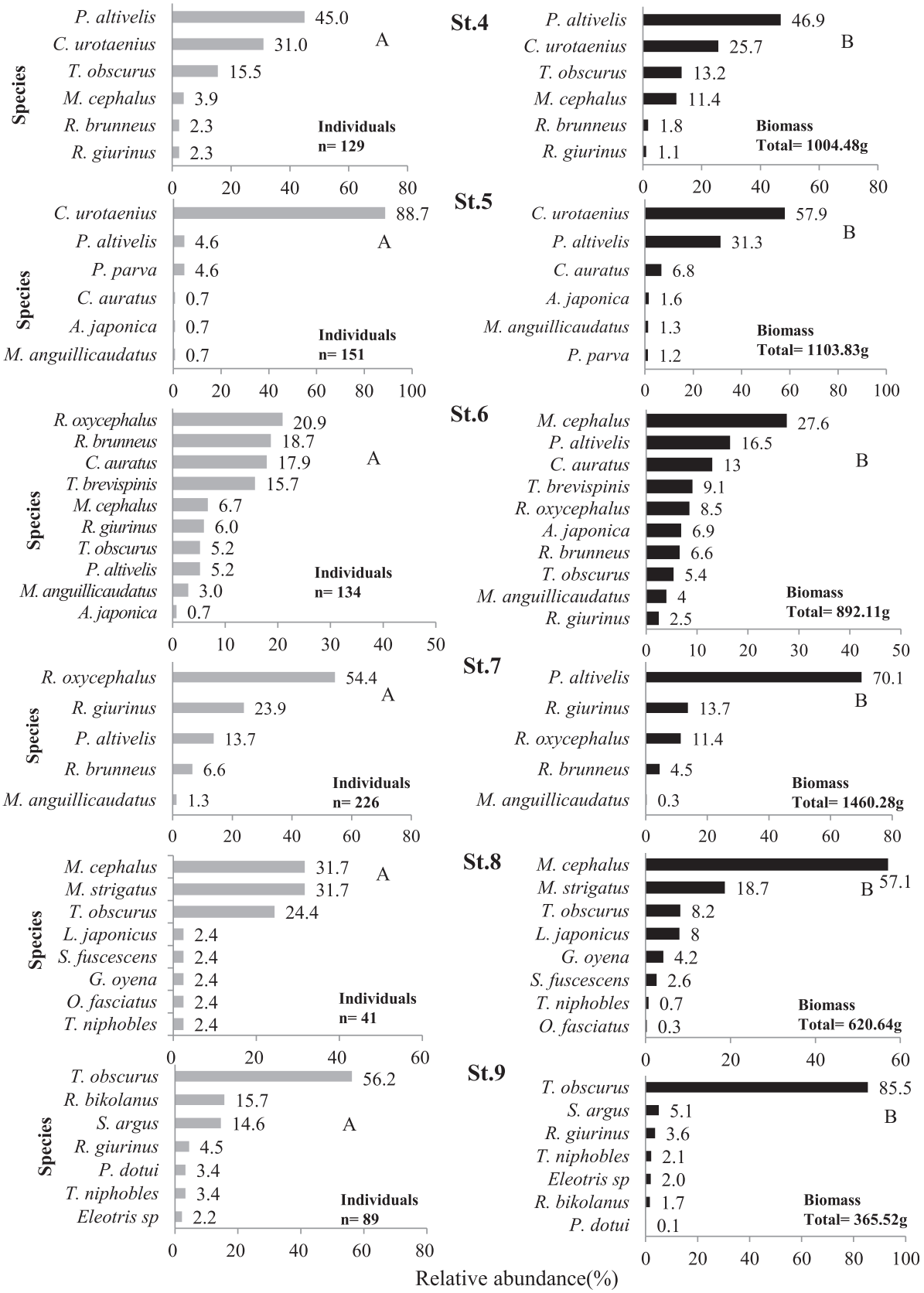

Figure 6. Relative abundance of (A) the individual number and (B) the biomass at each stream in the Jeju-do, Korea (St. 4 Musucheon, St. 5 Ongpocheon, St. 6 Changgocheon, St. 7 Jungmuncheon, St. 8 Hyodoncheon, St. 9 Euigwicheon).

Table 13. The fish fauna and individual numbers collected in Hadori wetland of Jeju-do, Korea.

Scientific name	Korean name	Hadori wetland
		St. 10
Order Perciformes	농어목	
Family Gobiidae	망둑어과	
Tridentiger obscurus	검정망둑	1
Tridentiger brevispinis	민물검정망둑	20
Order Pleuronectiformes	가자미목	
Family Paralichthyidae	넙치과	
Paralichthys olivaceus	넙치	2
Order Tetraodontiformes	복어목	
Family Tetraodontidae	참복과	
Takifugu niphobles	복섬	4
No. of individuals		27
No. of species		4

St. = Site.

Table 14. Community indices in Hadori wetland of Jeju-do, Korea.

Station		H'	E	RI
Hadori wetland	St. 10	0.82	0.59	0.91

E = evenness index; H' = diversity index; RI = species richness index; St. = Site.

supply point and a number of *P. altivelis* inhabited inside a weir which was constructed in the reservoir. In Station 4-2, four species appeared and it was the brackish zone on the downstream from the weir. The dominant species was *T. obscurus* (52.6%) and the subdominant species was *P. altivelis* (31.6%); five *M. cephalus* were also found.

At Ungpocheon (St. 5), six species appeared and the dominant species was *C. urotaenius* (88.7%) and the subdominant species were *P. altivelis* and *P. parva* (4.6%). For biomass, it was in the order of *C. urotaenius* (57.9%), *P. altivelis* (31.3%), and *C. auratus* (6.8%).

At Changgocheon, 10 species were collected and the dominant species was *R. oxycephalus* (20.9%), followed by *Rhinogobius brunneus* (18.7%), *C. auratus* (17.9%), and *Tridentiger brevispinis* (15.7%). For biomass, *M. cephalus* (27.6%) was the dominant species, followed by *P. altivelis* (16.5%), *C. auratus* (13.0%), and *T. brevispinis* (9.1%). At Station 6-1, two species appeared and the dominant species was *R. oxycephalus* (91.3%). This survey point was in the midstream and it was stagnant water due to the lack of water in the stream and mostly being blocked by large stones. The flow was slow and the stream bed was composed of cobble and pebbles. Its dominant species was *C. auratus* (34.3%) and the subdominant species was *R. brunneus* (32.9%). Five species appeared in Station 6-3; it was the brackish zone of the downstream, and during the survey it was in the ebb tide state. The dominant species was *T. brevispinis* (48.4%) and the subdominant species was *M. cephalus* (20.9%).

Six species appeared at Jungmuncheon. The dominant species was *R. oxycephalus* (54.4%) and the subdominant species was *Rhinogobius giurinus* (23.9%) followed by *P. altivelis* (13.7%) and *R. brunneus* (6.6%). For biomass, it was in the order of *P. altivelis* (76.4%), *R. giurinus* (13.7%), and *R. oxycephalus* (11.4%). In Station 7-1, one species of the family Cobitidae was found. This was a lentic where there was little water flowing and was in the form of a pond with no stream flow. There was a big stone at the edge of the stream and the stream bed was composed of sand. There were large amounts of green algae and it was a difficult environment for fish to inhabit; only one species of the family Cobitidae was found here. Three species appeared in Station 7-2. *R. oxycephalus* (66.7%) inhabited the stream that flowed next to the waterfall and *R. brunneus* (29.7%) was found between the large stones under the waterfall. A total of four species were collected at Station 7-3; the dominant species was *R. oxycephalus* (70.1%) and the subdominant species was *R. giurinus* (14.9%). Five species were collected at Station 7-4 and *M. cephalus* that moved against the tide from the seas was found at this site. The dominant species was *R. giurinus* (55.1%) and the subdominant species was *R. oxycephalus* (17.4%), but there were also a large number of *P. altivelis*. At Station 8-1, the upstream of Hyodoncheon, there were no fish. At Station 8-2, which was the estuary area, eight species were collected and the dominant species were *M. cephalus* (31.7%) and *Microcanthus strigatus* (31.7%), followed by *T. obscurus* (24.4%). For biomass, it was in the order of *M. cephalus* (57.1%), *M. strigatus* (18.7%), *T. obscurus* (8.2%), and *Lateolabrax japonicus* (8%).

At Euigwicheon, seven species were collected at the estuary; the dominant species was *T. obscurus* (56.2%) and the subdominant species was *Redigobius bikolanus* (15.7%). For biomass, it was in the order of *T. obscurus* (85.5%) and *R. bikolanus* (5.1%). One species that was never found in Korea, a fish of the family Eleotridae, was found, so more detailed studies are necessary.

Wetlands

Freshwater fish that appeared at the Hadori wetland counted were 26 of four species of three families; two species of the family Gobiidae (50.0%), and one species each of the Paralichthyidae (25.0%) and Tetraodontidae (25.0%) families (Table 13). The dominant species was *T. brevispinis* (74.1%) and the subdominant species was *Takifugu niphobles* (14.8%). For biomass, *T. brevispinis* (61.2%) was the highest, followed by *Paralichthys olivaceus* (20.3%), *T. niphobles* (12.5%), and *T. obscurus* (6.1%) (Figure 7). Results of the community analysis showed

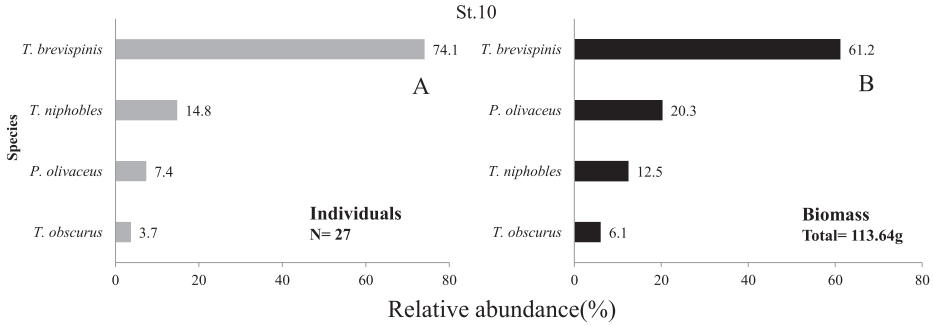

Figure 7. Relative abundance of (A) the individual number (B) and the biomass in Hadori wetland of Jeju-do, Korea. St. = Site.

Table 15. The comparison of fish fauna in Jeju-do Island from 1980 to 2013.

Scientific name	Korean name	Jo (1980)	Choi and Jeon (1980)	Jo (1990)	Son (1995)	Lee et al (1999)	Kim (2006)	Hwang et al (2008)	Present study (2013)
Order Anguilliformes	뱀장어목								
Family Anguillidae	뱀장어과								
Anguilla japonica	뱀장어	●	●	●		●	●	●	◎
Anguilla marmorata	무태장어	●	●						
Order Clupeiformes	청어목								
Family Engraulidae	멸치과								
Engraulis japonicus	멸치							●	
Order Cypriniformes	잉어목								
Family Cyprinidae	잉어과								
Cyprinus Carassius auratusio	이스라엘잉어						●		
Cyprinus Carassius auratusio	잉어	●			●	●			◎
Carassius cuvieri	떡붕어					●	●		
Carassius auratus	붕어	●		●	●	●	●		◎
Pseudorasbora parva	참붕어			●		●	●		◎
Rhynchocypris oxycephalus	버들치	●	●	●	●	●	●	●	
Family Balitoridae	종개과								
Lefua costata	쌀미꾸리	●		●	●	●	●		
Family Cobitidae	미꾸리과								
Misgurnus anguillicaudatus	미꾸리	●	●	●	●		●	●	◎
Misgurnus mizolepis	미꾸라지					●			
Cobitis hankugensis	기름종개	●							
Order Siluriformes	메기목								
Family Plotosidae	쏠종개과								
Plotosus lineatus	쏠종개							●	
Order Osmeriformes	바다빙어목								
Family Osmeridae	바다빙어과								
Plecoglossus altivelis	은어	●	●	●		●	●	●	◎
Order Salmoniformes	연어목								
Family Salmonidae	연어과								
Oncorhynchus mykiss	무지개송어	●				●			
Order Mugiliformes	숭어목								
Family Mugilidae	숭어과								
Mugil cephalus	숭어	●	●	●		●	●	●	◎
Order Beloniformes	동갈치목								
Family Hemiramphidae	학공치과								
Hyporhamphus sajori	학공치	●				●	●		
Order Synbranchiformes	드렁허리목								
Family Synbranchidae	드렁허리과								
Monopterus albus	드렁허리	●	●	●	●	●	●		◎
Order Perciformes	농어목								
Family Moronidae	농어과								
Lateolabrax japonicus	농어	●					●		◎
Family Centrarchidae	검정우럭과								
Lepomis macrochirus	블루길	●		●			●		◎
Micropterus salmoides	배스								◎
Family Carangidae	전갱이과								
Caranx sexfasciatus	줄전갱이					●			
Trachurus japonicus	전갱이					●			
Family Gerrdidae	게레치과								
Gerres oyena	게레치								◎
Family Sparidae	도미과								
Acanthopagrus schlegeli	감성돔					●	●		
Family Pempheridae	주걱치과								
Pempheris japonica	주걱치							●	
Family Kyphosidae	황줄깜정이과								
Microcanthus strigatus	범돔					●	●		◎
Family Terapontidae	살벤자리과								
Terapon jarbua	살벤자리	●				●	●	●	
Family Kuhliidae	알롱잉어과								
Kuhlia marginata	알롱잉어	●					●		
Family Oplegnathidae	돌돔과								
Oplegnathus fasciatus	돌돔								◎
Family Eleotridae	구굴무치과								
Eleotris oxycephala	구굴무치		●						
Eleotris sp.	제주구굴무치(가칭)								◎
Family Gobiidae	망둑어과								
Cryptocentrus filifer	실망둑			●					
Gymnogobius heptacanthus	살망둑	●					●		
Chaenogobius castaneus	날망둑			●					
Chaenogobius urotaenius	꼭저구	●		●		●	●	●	◎
Acanthogobius flavimanus	문절망둑						●		
Sicyopterus japonicus	열동갈문절						●	●	
Rhinogobius giurinus	갈문망둑			●		●	●	●	◎
Rhinogobius brunneus	밀어	●	●	●	●		●		◎

Table 15. (*continued*)

Scientific name	Korean name	Jo (1980)	Choi and Jeon (1980)	Jo (1990)	Son (1995)	Lee et al (1999)	Kim (2006)	Hwang et al (2008)	Present study (2013)
Tridentiger obscurus	검정망둑	●	●			●	●	●	◎
Tridentiger brevispinis	민물검정망둑								◎
Favonigobius gymnauchen	날개망둑					●	●		
Mugilogobius abei	모치망둑					●			
Luciogobius guttatus	미끈망둑	●	●				●		
Redigobius bikolanus	점박이망둑								◎
Family Microdesmidae	청황문절과								
Parioglossus dotui	꼬마청황					●			◎
Family Scatophagidae	납작돔과								
Scatophagus argus	납작돔								◎
Family Siganidae	독가시치과								
Siganus fuscescens	독가시치								◎
Order Pleuronectiformes	가자미목								
Family Paralichthyidae	넙치과								
Paralichthys olivaceus	넙치								
Order Tetraodontiformes	복어목								
Family Tetraodontidae	참복과								
Takifugu niphobles	복섬	●	●	●		●	●	●	◎
Takifugu poecilonotus	흰점복					●			
No. of species		23	12	16	7	26	28	14	25

species diversity of 0.82, evenness of 0.59, and richness of 0.91 (Table 14).

Discussion

The fish collected from the three reservoirs, six streams including brackish zones, and one wetland in the Jeju-do, were 25 species of 17 families. There were 52 species of 27 families that were spotted at least once in the island, including this survey. A bigger diversity of species was collected in this study compared to the previous records by Jo (1980) of 23 species, Choi and Jeon (1980) of 12 species, Jo (1990) of 16 species, Son (1995) of 7 species, and Hwang et al (2008) of 14 species, but were fewer than 26 species of Lee et al (1999) and 28 species of Kim (2006). Species that appeared in all surveys starting from Jo (1980) were the five species of *Anguilla japonica*, *R. oxycephalus*, *P. altivelis*, *M. cephalus,* and *Takifugu niphobles*. Fish discovered for the first time through this survey were *M. salmoides*, *Eleotris* sp., *T. brevispinis*, *R. bikolanus*, and *Scatophagus argus* (Table 15).

Korean native species were not found in Jeju-do, while introduced species such as *L. macrochirus* and *M. salmoides* were found in all three reservoirs. *L. macrochirus* and *M. salmoides* inhabit dams and reservoirs of the mainland of Korea. However, this was the first study to discover *M. salmoides* in the Jeju-do and *L. macrochirus* was also distributed in all of the surveyed reservoirs. *L. macrochirus* was first introduced by being mixed with *Cyprinus carpio* and *C. auratus* that were introduced to the Haga reservoir (Jo 1980; Yang 1994). Afterwards, they were found in the Susanji reservoir and Gwangnyeongji reservoir, as well as small ponds adjacent to the reservoirs (Kim 2006). However, there is no record on the introduction of *M. salmoides* and this was the first time they were discovered, so it is believed that recently they were introduced artificially. Unlike the original habitat of introduced species, Jeju-do has no natural predator and interspecies competition among their species is not fierce, making it easy for its breeding and growth. They cause reductions of fish resources in reservoirs within the Jeju-do and affect the ecosystem (Azuma 1992; Byon and Jeon 1997).

The most common freshwater fish in Jeju-do are *R. oxycephalus* and *P. altivelis*, and these species can inhabit environments that maintain clean water quality. *P. altivelis* is a conciliation species and important to marine resources. Sufficient quantities must be maintained and allowed to grow sufficiently and they have been found in the mid and down streams of most streams within the Jeju-do. Furthermore, the sizes of *R. giurinus* and *R. brunneus* are larger than those found in different stream bodies in the mainland of Korea. *M. cephalus* can inhabit both seawater and the brackish zones of streams and inhabit most of estuaries of Jeju-do (Jo 1980; Kim 2006; Lee et al 1999).

Figure 8. Eleotrid fish (*Eleotris* sp.) collected from Euigwicheon, Korea (Photograph by Dr. S.H. Choi).

Compared to other streams of similar sizes that flow into the sea in mainland of Korea, there were few species found in Jeju-do. Compared to small streams that flow to the sea in the mainland such as the Ungcheon stream that showed 29 species, the Baek stream of the Byeonsan peninsula that showed 22 species, the Sora stream of Yeosu that showed 21 species, and the Daecheon stream that showed 42 species, the fish fauna was comparatively weak (Choi et al 1992; Hong et al 1999; Lee et al 2004; Song et al 2013). This is consistent with the report that the number of species that appear are inversely proportional to the distance between the mainland and island for the number of freshwater fish that live in the island (Gorman 1979). Characteristics of streams in Jeju-do are that the waterways are short and the stream beds are made up of porous volcanic rocks and volcanic ash soil. Also, the slopes are steep and most rainwater permeates through the ground, the amount of water scarcity in the streams and it is a poor environment as habitat for fish (Moon et al 2005).

R. bikolanus is a species first recorded in the brackish zone of Changgocheon in Jeju-do and 14 of them were collected in the brackish zones of Euigwicheon in this study (Table 10). These species were found only in the brackish zones of streams in the southern part of Jeju-do (Kim et al 2010). Also, *Eleotris oxycephala* of the family Eleotridae is a rare species that was recorded in Jeju-do by Choi and Jeon (1980), but was never discovered in later surveys by other researchers (Jo 1990; Son 1995; Lee et al 1999; Kim 2006; Hwang et al 2008). In this study, fish of the family Eleotridae were found at the Euigwicheon estuary, and while it is a member of the same genus of *E. oxycephala* that was recorded previously, it showed clear differences. Also, while it was similar to the subtropical species of *Eleotris acanthopoma*, it was classified as *Eleotris* sp. and further taxonomical review was requested (Figure 8).

In conclusion, it was difficult to collect fish distributed in the brackish zones of streams and in reservoirs, and most of the streams were ephemeral streams, resulting in little distribution of fish. While there were many species in this study compared to previous research, through seasonal surveys by increasing frequency of surveys and thorough surveys in the brackish zones of streams, it is expected that more species would be observed.

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