

Long-term changes in fish community and the impact of exotic fish, between the Nakdong River and Upo Wetlands

Hyunbin Jo¹, Min-Ho Jang², Kwang-Seuk Jeong¹, Yuno Do¹, Gea-Jae Joo¹ and Ju-Duk Yoon^{1,*}

¹Department of Biological Sciences, Pusan National University, Busan 609-735, Korea

²Department of Biology Education, Kongju National University, Gongju 314-701, Korea

Abstract

To evaluate fish community changes and the impact of exotic fish between the Nakdong River (lotic) and Upo Wetlands (lentic) using long-term ecological monitoring results, we conducted seasonal surveys of the fish community from 2005 to 2010. A fixed shore net (mesh 15 × 15 mm), cast net (7 × 7 mm), and scoop-net (5 × 5 mm) were used to collect fish specimens. Changes in the fish community were not significantly different in the Nakdong River and Upo Wetlands, respectively ($R_s > 0.322$, $N = 44$, $P < 0.05$). Changes in the fish community between the Nakdong River and Upo Wetlands were identified as significant according to the results of cluster analysis. The relative abundance of exotic species increased steadily during the study period, and reached 34.2% and 89.7% in the Nakdong River and Upo Wetlands, respectively, in 2010. The bluegill (*Lepomis macrochirus*) was used to evaluate the level of health according to prevalence around all study sites. The length-weight relationship for bluegill in the Upo Wetlands was shown to have the highest values, via the formula ($W = aL^b$), with an average of 3.26 for the 'b' variable. According to the results of this study, lentic and lotic systems differed significantly; exotic species had an impact on both the lentic and lotic systems, but the impact of exotic species in lentic systems was greater than in the lotic systems. Additionally, the exotic species tested herein (bluegill) adapted well in the lentic system.

Key words: exotic species, fish community, lentic system, long-term ecological monitoring, lotic system

INTRODUCTION

Recently, an increasing amount of research based on long-term ecological research (LTER) has been conducted. LTER is an important survey method which can detect temporal changes in ecosystem structure and function, using accumulated long-term data, regardless of ecosystem type (Turner et al. 2003). Biological long-term research has become common practice for rivers and wetlands. Accumulated data can be employed to predict changes in ecosystems resulting from global warming. LTER can also provide us with important information regarding the long-term effects of exotic species on eco-

systems. The freshwater ecosystem is more vulnerable to exotic species than other ecosystems (Sala et al. 2000). Therefore, LTER-based evaluations of exotic species in freshwater ecosystems are both important and necessary.

The effect of exotic species on freshwater ecosystems varies, but we focused specifically on changes in the food-web structure caused by the presence of exotic fish. Exotic fish can cause the collapse and homogenization of the food-web or its structure (Power et al. 1996). Additionally, exotic fish introduced into a new habitat are

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***Corresponding Author**

E-mail: zmszmsqkek@pusan.ac.kr

Tel: +82-51-510-2258

www.kci.go.kr

frequently more competitive than native species (Pascual et al. 2002). With competitive exclusion, competition between species is not a limiting factor, and the increasing population of exotic fish causes a reduction in the numbers of endemic species (Angermeier 1982). The majority of introduced fish species are top predators in the food chain (Jang et al. 2006). Therefore, when introduced, these species can affect the structure of the existing fish community. Introduced or exotic species are defined as successfully reproducing organisms transported by humans into regions where they did not previously exist; this introduction of exotic species has occurred in many areas of the world, for many centuries (Baker and Stebbins 1965). The establishment of exotic species and the loss of native species ameliorates regional differences among fauna and flora, a process referred to as biotic homogenization (McKinney and Lockwood 1999); however, there are highs and lows in this effect, which depend on the environment.

The Freshwater system is divided into lotic systems and lentic systems based on environmental differences; the fish community composition in each system can differ considerably. The lotic system, because of its characteristics flow, is a dynamic environment in which fish community changes are affected by both spatial and seasonal differences (Agostinho and Zalewski 1995). Comparatively, fish adapted to a eutrophic environment dominate lentic systems. Fish communities in lentic systems appear to be generally more temporally stable than those in lotic systems (Merona 1987) because of their high habitat diversity and more stable environment. We are empirically aware of the differences in aquatic biota and of the impact of exotic species between lotic and lentic systems. However, only a relatively few studies have been conducted to evaluate the effects of exotic fish between lotic and lentic systems. Even though a large number of studies have been conducted on either native or exotic species, no long-term studies have been performed specifically addressing the effects of exotic fish between the two systems.

In this study, we evaluated the change in the annual lotic and lentic fish communities in the Nakdong River and Upo Wetlands. We also compared the impact of exotic species in the lotic and lentic systems based on the fish community. Finally, we estimated the length-weight relationship of bluegill (*Lepomis macrochirus*) in the Upo Wetlands to determine how well exotic species adapt in lentic systems.

MATERIALS AND METHODS

Sampling sites

The Korean Peninsula is located in far-eastern Asia, and the Nakdong River lies within the southeastern region of Korea (35-37°N, 127-129°E). The length of the river is approximately 520 km, making it the second largest river system in South Korea. Four multi-purpose dams and one estuarine barrage regulate the water flow of this river, resulting in the eutrophication observed in the Nakdong River (Ha et al. 1998). The riparian zone evidences low vegetative diversity. The river bed is composed primarily of sands. The Upo Wetlands are connected to the main channel of the Nakdong River and have been designated as a Ramsar site since 1998. In the Upo Wetlands, the riparian zone evidences high vegetative diversity (Fig. 1) (Kim et al. 2004). We conducted seasonal surveys of the fish community between 2005 and 2010. The river kilometer from estuary barrage (RK) value is calculated below.

St. 1: 35°52'53.32"N, 128°23'18.00"E (RK 190) - Nakdong River main channel

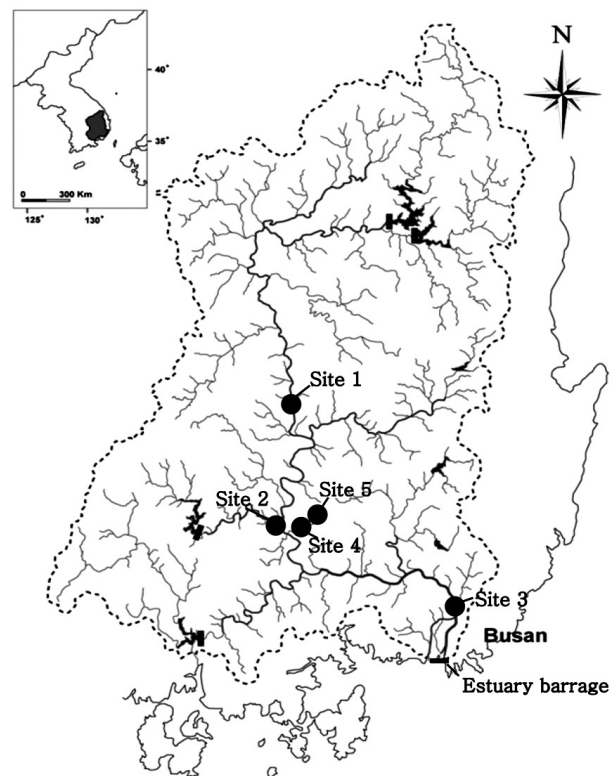


Fig. 1. Map of study sites.

St. 2: 35°31'45.42"N, 128°21'42.04"E (RK 120) - Nakdong River main channel

St. 3: 35°19'52.83"N, 128°57'29.58"E (RK 19) - Nakdong River main channel

St. 4: 35°31'45.99"N, 128°23'13.64"E (added 2.5 Km from St. 2) - Upo Wetlands (It is stream connected between Nakdong River and Upo Wetlands)

St. 5: 35°33'45.74"N, 128°24'15.62"E (added 7.5 Km from St. 2) - Upo Wetlands (Mokpo Wetland)

Fish collection

A fixed shore net (mesh 15 × 15 mm), cast net (7 × 7 mm), and scoop-net (5 × 5 mm) were used to collect fish specimens. The fixed shore nets were set for 24 h, and the cast nets were cast 20 times per site. Approximately 100 m of river length was sampled at each site. In the Nakdong River, the cast and scoop-nets were used to collect fish specimens. In the Upo Wetlands, the fixed shore, cast, and scoop-nets were used to collect fish specimens. The collected specimens were identified and released at the study site. In cases in which exact identification was not possible, we preserved specimens in 10% formalin solution until counting, after which they were stored in 5% formalin solution. All specimens were identified according to the methods of Choi et al. (1990), Kim and Park (2002), and the classification system of Nelson (1994).

Analysis

To evaluate the fish community at the study sites, the species diversity (Simpson 1949), dominance (Shannon and Weaver 1949), richness (Pielou 1966), and evenness (Margalef 1958) were calculated from the density data for various species. The Bray-Curtis dissimilarity (Bray and Curtis 1957) was used for cluster analysis. To compare the annual occurrence of fish species, we used Spearman's correlation. The Length-weight relationship of the bluegill was calculated according to the following formula:

$$W = aL^b$$

W = total weight (g), L = total length (mm), a = a constant parameter and b = an exponent parameter usually lying between 2.5 and 4.0 (Hile 1936, Martin 1949). For an ideal fish species that maintains the same shape, $b = 3$; however this has only occasionally been observed (Allen 1935). Generally, if parameter b is greater than 3, the fish is considered to be adapted well to its environment. The condition factor K is used to evaluate the health of fish

and the fish community. The condition factor K for Bluegill was calculated using the following formula:

$$K = W/L^3 \times 10^5$$

RESULTS

Fish fauna in Nakdong River

Thirty five species of fish from 11 families were collected from the Nakdong River (site1, 2, and 3) from 2005 to 2010. Cyprinidae (relative abundance [RA] 60.1%, 21 species) was the dominant family. Centrarchidae (RA 23.0%, 2 species) was the sub-dominant family (Table 1). *Opsariichthys uncirostris amurensis* (RA 20.6%), *Hemibarbus labeo* (RA 8.9%), *Pseudogobio esocinus* (RA 7.6%) and *Squalidus chankaensis tsuchigae* (RA 5.4%), which favor a lotic system, were dominant in the Nakdong River (Fig. 2). *Microphysogobio jeoni*, which is especially adapted to lentic systems, was not collected during the research period, but was collected in 2010. The dominant and sub-dominant species changed from 2005 to 2010. The dominant species were *O. u. amurensis* (2006, RA 27.0%; 2007, 26.0%; 2009, 29.1%), *S. c. tsuchigae* (2005, RA 23.3%) and *Micropterus salmoides* (2008, RA 18.8%; 2010, RA 33.5%). The sub-dominant species differed each year. Dominance decreased from 0.17 (2005) to 0.10 (2008) and then increased from 0.16 (2009) to 0.17 (2010). The

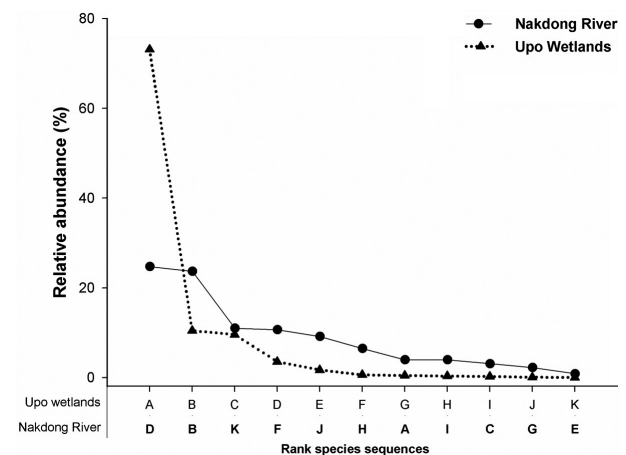


Fig. 2. Comparison between Upo Wetlands and Nakdong River. Normal initials are Upo Wetland species and bold lettering initials are Nakdong River species (dotted line, Upo Wetlands; solid line, Nakdong River). A, *Lepomis macrochirus*; B, *Micropterus salmoides*; C, *Carassius auratus*; D, *Opsariichthys uncirostris amurensis*; E, *Pseudorasbora parva*; F, *Hemibarbus labeo*; G, *Acanthorhodeus macropterus*; H, *Squalidus chankaensis tsuchigae*; I, *Zacco platypus*; J, *Pseudogobio esocinus*; K, *Tridentiger brevispinis*.

Table 1. List of fish fauna collected during the survey

Family	Species	Nakdong River							Upo Wetlands							
		05	06	07	08	09	10	Ag.	05	06	07	08	09	10	Ag.	
Engraulidae	<i>Coilia nasus</i>			13.6				2.8								
Cyprinidae	<i>Cyprinus carpio</i>			0.2	0.2	0.2	0.2	0.2	3.1	2.2	0.9	0.6	0.6	1.9	1.5	
	<i>Carassius auratus</i>			0.2	8.4			3.8	2.6	28.3	14.5	1.8	3.0	2.1	0.1	8.7
	<i>Carassius cuvieri</i> *									4.0				0.5	3.4	1.6
	<i>Rhodeus ocellatus</i>			0.8				0.2								
	<i>Rhodeus uyekii</i> †							15.8	3.5							
	<i>Acheilognathus lanceolatus</i>			0.4	4.0			0.9	1.1	2.2		0.1	0.1			0.4
	<i>Acheilognathus yamatsutae</i> †	0.6				0.2	0.5	0.2								
	<i>Acanthorhodeus macropterus</i>	1.1	3.5	1.6	3.2	1.3	1.3	1.9								
	<i>Pseudorasbora parva</i>			0.8	0.8			1.8	0.7	2.2	6.1	4.5	0.1	0.3	0.1	1.5
	<i>Pungtungia herzi</i>	1.7	2.1	0.2	0.8			0.4								
	<i>Sarcocheilichthys variegatus</i> ‡			1.0	2.0	1.3		0.9								
	<i>Squalidus gracilis majimae</i> †					0.2	5.5	1.3	0.7							0.2
	<i>Squalidus chankaensis tsuchigae</i> †	23.3	9.9	4.5	8.0	1.9	0.7	5.4						1.0	0.2	0.3
	<i>Hemibarbus labeo</i>	15.6	15.6	5.0	10.8	8.1	7.7	8.9				0.2	0.6	0.3	2.0	0.5
	<i>Hemibarbus longirostris</i>								0.6							0.2
	<i>Pseudogobio esocinus</i>	19.4	5.0	8.1	6.4	9.6	2.9	7.6							0.4	0.1
	<i>Gobiobotia nakdongensis</i> †	0.6						0.1								
	<i>Microphysogobio yaluensis</i> †				0.2	0.7		0.2								
	<i>Microphysogobio jeoni</i> †							0.4	0.1							
	<i>Zacco platypus</i>	14.4	5.7	0.6	6.2	2.4		3.3	0.4					0.1	0.6	0.2
<i>Opsariichthys uncirostris</i> ‡ <i>amurensis</i>	19.4	27.0	26.0	13.6	29.2	11.3	20.6	2.1	5.9	1.8	0.5	6.8	2.4	3.2		
<i>Erythroculter erythropterus</i> ‡			4.1	0.4			1.5	1.3	0.1	1.4	0.2	4.6	1.1	0.2	1.1	
<i>Culter brevicauda</i>									0.8		1.1	0.3			0.4	
<i>Hemiculter eigenmanni</i> †,‡							0.2	0.1	2.6	3.6	2.0	3.1	0.4	1.0	1.8	
<i>Hemiculter leucisculus</i>									0.4						0.1	
Cobitidae	<i>Misgurnus anguillicaudatus</i>	0.6				0.8	0.5	0.4	2.7		1.4	0.9	0.2	0.3	1.1	
	<i>Misgurnus mizolepis</i>								0.2	1.4		0.1		0.1	0.1	
	<i>Cobitis cf. sinensis</i> †	0.6		1.6	0.8			0.5								
Bagridae	<i>Pseudobagrus fulvidraco</i> ‡								1.0	0.8	0.4	0.1	0.1	0.1	0.4	
	<i>Leiocassis ussuriensis</i> ‡			0.2		0.3		0.1								
Siluridae	<i>Silurus asotus</i>								0.4	1.4	0.2		0.1	0.2	0.2	
Osmeridae	<i>Plecoglossus altivelis</i>	0.6						0.1								
Salangidae	<i>Neosalanx andersoni</i>			0.2				0.1								
Mugilidae	<i>Mugil cephalus</i>			0.4	0.2			0.1								
Synbranchidae	<i>Monopterus albus</i>								0.2	0.6		0.1	0.1	0.1	0.1	
Centropomidae	<i>Siniperca scherzeri</i>			0.4	0.2			0.1								
Centrarchidae	<i>Lepomis macrochirus</i> *			2.3	5.8	6.2	0.7	3.3	41.1	36.0	77.3	73.6	76.8	77.6	66.3	
	<i>Micropterus salmoides</i> *	1.7	7.8	20.7	18.8	15.0	33.5	19.7	7.0	22.9	8.0	12.3	9.2	8.8	9.5	
Odontobutidae	<i>Odontobutis atycephala</i> †		2.8	0.6				0.3								
Gobiidae	<i>Rhinogobius giurinus</i>	0.6				2.7	1.1	0.9								
	<i>Rhinogobius brunneus</i>		9.9	1.7	4.2	1.9	0.9	2.4					0.1	0.1	0.1	
	<i>Tridentiger bifasciatus</i>		10.6	5.0	5.2	18.0	9.7	9.2								
Channidae	<i>Channa argus</i>								0.9	0.8	0.2	0.1	0.1	0.3	0.4	
	No. of species	14	11	25	21	18	20	35	21	14	14	16	19	20	25	

Ag., aggregate.

*Exotic species.

†Korean endemic species.

‡Introduced species.

Table 2. Changes of dominance species, sub-dominance species, dominance, diversity, evenness and richness between Upo Wetlands and Nakdong River

	Nakdong River					Upo Wetlands						
	05	06	07	08	09	10	05	06	07	08	09	10
Dominant species	<i>Squalidus chankaensis tsuchigae</i> (RA 23.3%)	<i>Opsariichthys uncirostris amurensis</i> (RA 27.0%)	<i>O. uncirostris amurensis</i> (RA 26.0%)	<i>Micropterus salmoides</i> (RA 18.8%)	<i>O. uncirostris amurensis</i> (RA 29.2%)	<i>Rhodeus uyekii</i> (RA 15.8%)	<i>Lepomis macrochirus</i> (RA 41.1%)	<i>L. macrochirus</i> (RA 36.0%)	<i>L. macrochirus</i> (RA 77.3%)	<i>L. macrochirus</i> (RA 73.6%)	<i>L. macrochirus</i> (RA 76.8%)	<i>L. macrochirus</i> (RA 77.6%)
Sub-dominant species	<i>Pseudogobio esocinus</i> (RA 19.4%)/ <i>O. uncirostris amurensis</i> (RA 19.4%)	<i>Hemibarbus labeo</i> (RA 15.6%)	<i>M. salmoides</i> (RA 20.7%)	<i>O. uncirostris amurensis</i> (RA 13.6%)	<i>Tridentiger brevispinis</i> (RA 18.0%)	<i>M. salmoides</i> (RA 33.5%)	<i>Carassius auratus</i> (RA 28.3%)	<i>M. salmoides</i> (RA 22.9%)	<i>M. salmoides</i> (RA 8.0%)	<i>M. salmoides</i> (RA 12.3%)	<i>M. salmoides</i> (RA 9.2%)	<i>M. salmoides</i> (RA 8.8%)
Dominance	0.17	0.14	0.14	0.10	0.16	0.17	0.44	0.21	0.61	0.56	0.60	0.62
Diversity	1.90	2.15	1.96	2.19	2.11	1.71	1.31	1.90	0.98	1.02	0.95	1.03
Evenness	0.37	0.43	0.31	0.35	0.33	0.27	0.16	0.32	0.14	0.14	0.12	0.14
Richness	2.50	2.02	3.84	3.22	2.66	3.01	2.40	2.21	1.81	2.06	2.32	2.89

RA, relative abundance.

diversity index was between 1.90 and 2.19 without any marked tendencies towards increase. Evenness and richness evidenced no marked tendencies (Table 2).

Fish fauna in Upo Wetlands

In Upo Wetlands (sites 4 and 5) 25 species of fish from 8 families were collected from 2005 to 2010. Centrarchidae (RA 75.8%, 2 species) was the dominant family. Cyprinidae (RA 21.9%, 16 species) was the sub-dominant family (Table 1). *L. macrochirus* (RA 66.3%), *M. salmoides* (RA 9.5%), *Cyprinus auratus* (RA 8.7%) and *Pseudorasbora parva* (RA 1.5%), which favor lentic systems, were dominant in the Upo Wetlands (Fig. 2). The dominant species was *L. macrochirus* from 2005 to 2010. The RA (*L. macrochirus*) exceeded 70% except for 2005 (41.1%) and 2006 (36.0%). The sub-dominant species was *M. salmoides*, except in 2005 (*C. auratus*, RA 38.6%). Dominance decreased from 0.44 (2005) to 0.21 (2006) and remained steady between 0.56 and 0.62 (2007-2010). Diversity and evenness were also stable, except in 2006. Richness decreased from 2.4 (2005) to 1.81 (2007) and then increased steadily to 2.89 (2010) (Table 2).

Fish assemblage differences between lentic and lotic system

To evaluate annual changes in fish species, we used Spearman's correlation with the relative abundance of occurrence of fish species between the Nakdong River and Upo Wetlands. Annual changes in the fish species of the Nakdong River evidenced a positive correlation

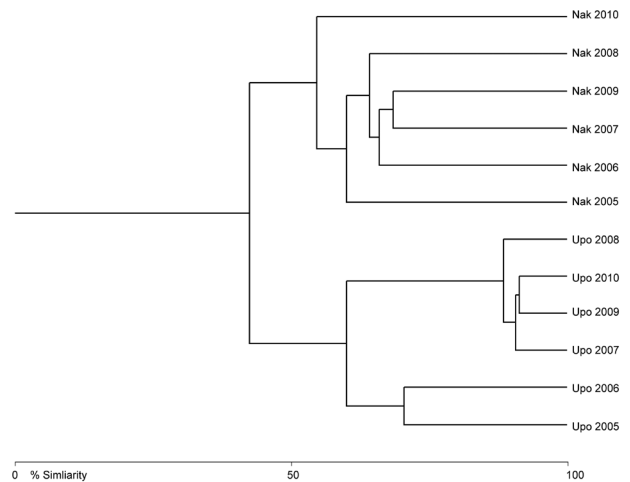


Fig. 3. Cluster analysis of fish collected from the Nakdong River and Upo Wetlands (2005-2010).

between study years from 2005 to 2010 ($R_s > 0.322$, $N = 44$, $P < 0.05$). In the Upo Wetlands, we also observed the same results ($R_s > 0.604$, $N = 44$, $P < 0.05$). Fig. 3 shows the results of the cluster analysis of the Nakdong River and Upo Wetlands. The lentic and lotic sites clustered out independently of one another. The next cut level split the lentic and lotic sites up according to year, with the years being clustered according to environmental responses. For the Nakdong River, 2005 and 2010 both separate out individually, with 2006-2009 being clustered together. By way of contrast, in the cluster analysis for the Upo Wetlands, the years 2005 and 2006 clustered out independently and 2007-2009 were clustered together (Fig. 3).

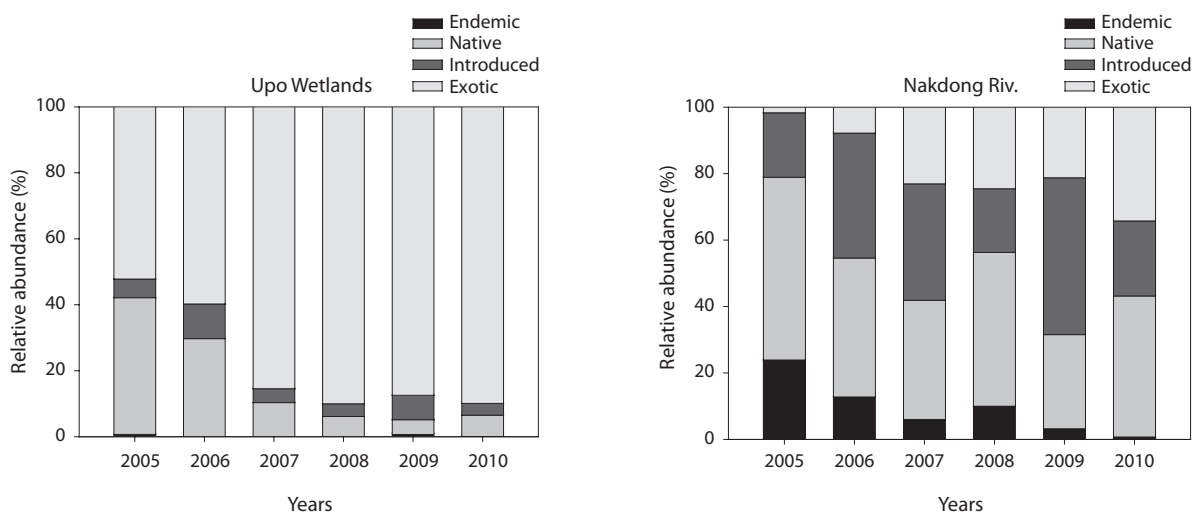


Fig. 4. Changes of relative abundance during research periods.

Effect of exotic fish

The exotic species assessed herein included *Carassius cuvieri*, *L. macrochirus* and *M. salmoides*. *C. cuvieri* were collected only in the Upo Wetlands and the RA value was 1.6%. Comparatively, *M. salmoides* evidenced a steady increase, with the RA in 2010 more than double that of the previous year. *L. macrochirus* (RA 45.1%) was the dominant species in all study sites. Especially in the Upo Wetlands, the total RA was 66.3% and the annual mean RA was over 70% except in 2005 and 2006 when *C. auratus* was dominant. We classified the fish species into endemic, native, introduced, and exotic species. The endemic species decreased and exotic species increased in the Nakdong River. In the Upo Wetlands, native species decreased and the exotic species evidenced a steady increase (Fig. 4).

As a result of the length-weight relationship for *L. macrochirus* collected from 2007 to 2010, this species had the highest RA for exotic species. Length and weight ranged from 36 to 235 mm and from 0.5 to 292.5 g, respectively. The annual changes of parameter 'b' in 2007, 2008, 2009, and 2010 were 3.260, 3.144, 3.530, and 3.099, respectively.

Every year's parameter b exceeded 3 (Fig. 5). According to the length of *L. macrochirus*, the condition factors ranged from 0.57 to 5.91. The average for the condition factor was 1.96, whereas the average of the gradient was positive at 0.0067. The annual value of condition factors decreased from 1.97 (2007) to 1.70 (2009) and then increased to 2.42 (2010). Annual gradients evidenced a steady increase from 0.0051 (2007) to 0.0093 (2010) (Fig 6).

DISCUSSION

Cluster analysis results were used to classify and compare the fish communities in a lotic (Nakdong River) and a lentic (Upo Wetlands) environments, which are connected environments. Species richness was relatively high in the lentic system because of the addition of pool species and an increase in habitat diversity (Kuehne 1962). Annual changes in the fish community did not differ significantly between the river and wetlands. Fish communities in lentic systems appear more temporally stable relative to lotic systems (Merona 1987). However, the results of

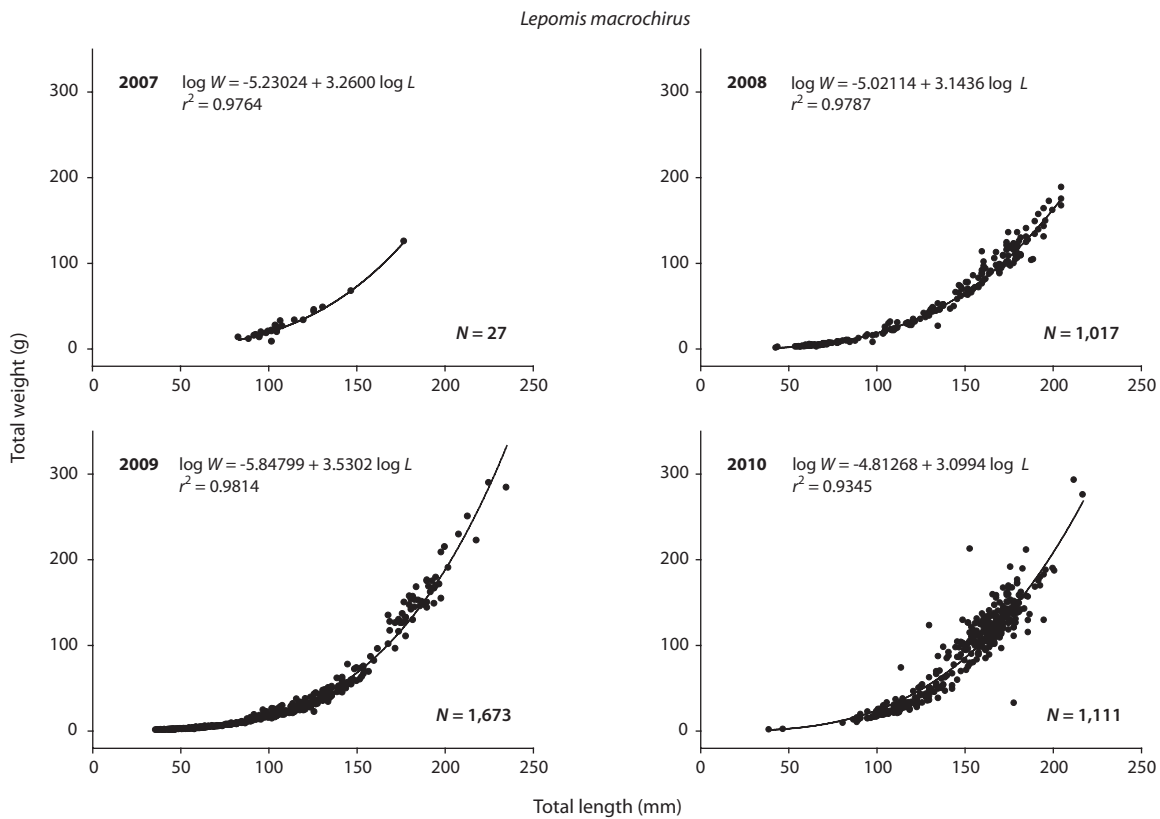


Fig. 5. Length-weight relationship for *L. macrochirus*.

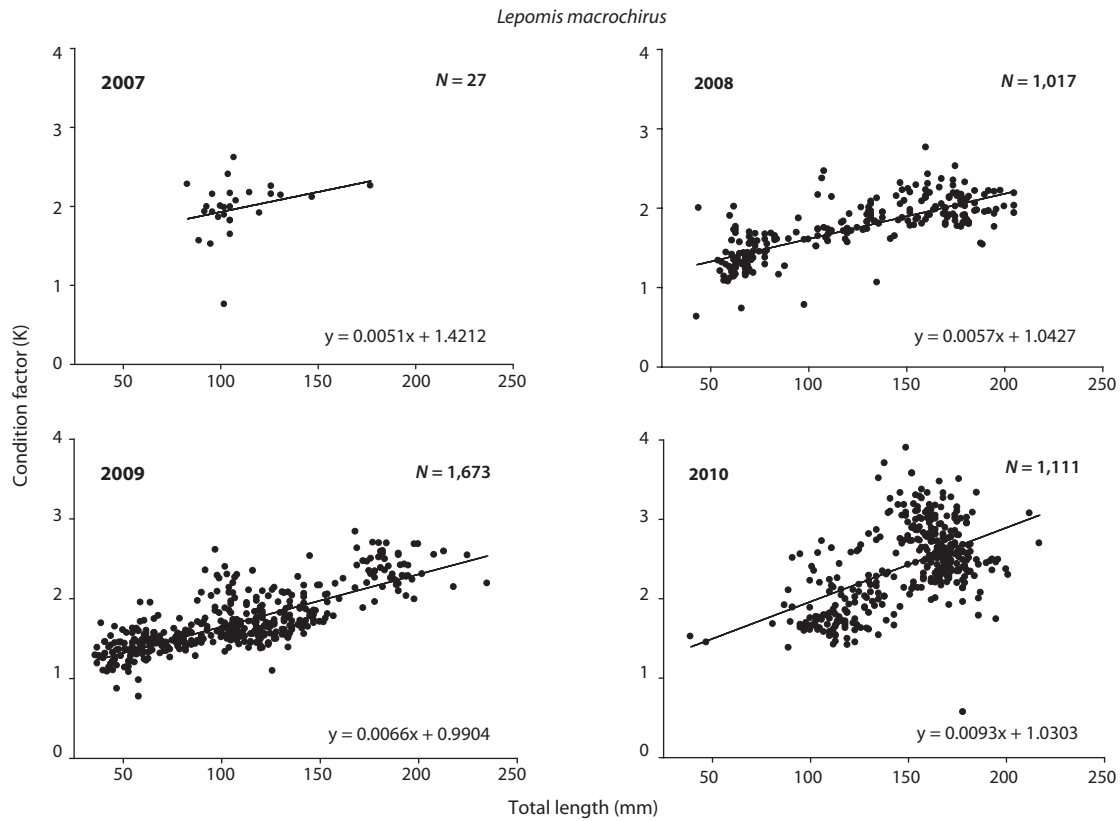


Fig. 6. Condition factor (K) for *L. macrochirus*.

this study showed that this stability was more vulnerable to the introduction of exotic fish. *L. macrochirus* and *M. salmoides*, which are exotic species, were higher in relative abundance in the Upo Wetlands than in the Nakdong River. In 2010, the combined relative abundance increased to 34.2% and to 89.7% (2010) in the Nakdong River and Upo Wetlands, respectively. Moreover, endemic and native species decreased rapidly and died out subsequent to the introduction of exotic fish.

M. salmoides was the sub-dominant species in the Nakdong River. In the Upo Wetlands, even though *M. salmoides* evidenced low relative abundance, it was a sub-dominant species. The young of *M. salmoides* primarily eat zooplankton, but adult *M. salmoides* is a typical piscivore and profoundly affects the surrounding fish community (Jang et al. 2006). These species preferred a lentic environment or low flooding river. *M. salmoides* is not only a serious problem in South Korea, but also in other countries. This shows the decreasing diversity of the fish community and an accelerating spread of exotic species in both the lentic and lotic systems.

L. macrochirus evidenced the highest relative abundance in the Upo Wetlands. This species, which has an

extensive food niche, eats phyto-zooplankton, aquatic insects, molluscs, fish eggs, and fry. Therefore, it profoundly affects freshwater systems (Byeon et al. 1997). The length-weight relationship for *L. macrochirus* collected in the Upo Wetlands (a lentic system) from 2007 to 2010 was calculated. It showed that *L. macrochirus* was healthy in the Upo Wetlands. The total average of parameter b was 3.26. This value is higher than the 3.2 total average in the USA (FishBase 2010) and is less than 3.29, which is the average for Lake Biwa in Japan (Yamamoto et al. 2010). Generally, if parameter b is greater than 3, the fish is considered well adapted to its environment. The condition factor K, is used to evaluate the health of fish and the fish community. Generally, if condition factor K is high, the fish have abundant food sources (Le Cren 1951). The average of condition factor K was 1.96, and thus the Upo Wetlands provide an appropriate habitat for *L. macrochirus*. The Centrarchidae are adapted to eutrophicated freshwater and have substantially higher growth rates than Cyprinidae during their early life stages (Schlosser 1982).

According to the results of this study, the exotic species impact of both lentic and lotic systems but the impact

of exotic species in lentic systems was greater than that of lotic systems. Unfortunately, our river channels are undergoing a general transformation from lotic to lentic systems. S. Korea is an industrialized nation with increasing economic growth and accelerating production. These changes are accompanied by the channelization of rivers, the construction of levees that play a role in the disconnection of wetlands from the rivers, and the reclamation of wetlands for land development purposes. As a consequence, the river and wetlands have been modified physically, chemically, and biologically (Joo et al. 1997), and this is an ongoing modification. One example of this is the current Four Rivers project, which involves the modification of rivers by altering their substrate, morphology, and composition via the construction of 9 large dikes in the Nakdong River channel.

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