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Population biology of largemouth bass, *Micropterus salmoides*, in Goe-san Lake, Korea

by

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괴산호 베스의 개체군 생태학적 연구

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괴산호 베스의 개체군 생태학적 연구

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요약

생태계에서 어류 개체군과 침입종인 큰입베스의 효과를 조사하기 위하여, 2010 년 3 월부터 2012 년 11 월까지 어류 다양성과 큰입베스의 개체군 생물학을 연구하였다. 어류의 다양성은 담수 생태계에서 매우 중요한 지표이다. 큰입베스는 한국으로 수입되었고 한국에 살기 적합했고 정착하였다. 개체군 생태학은 그들이 이 환경에 어떻게 적응하였는지, 그들이 이 지역에서 어떤 중요한 역할을 하는 종인지, 또한 지역종과의 상호작용은 어떻게 하는지에 대한 좋은 정보를 제공할 수 있다. 주요한 결과는 다음과 같다.

제 1 장: 한국 괴산호의 어류의 구성과 다양성

(1) 괴산호에서 채집된 총 2744 마리의 어류는 10 개의 과로 구성되어 있고, 그 중 2402 마리는 잉어과, 157 마리는 꺽지과, 그리고 144 마리는 나머지 8 개의 과의 어종이다. 이는 어류 종의 다양성이 낮음을 보여주었다.

(2) 주 우점종의 구성은 3 년간 비슷한 경향을 보였다. 계절 간의 어류 우점종의 변화는 크게 나타나지 않았다. 이곳은 강물 흐름의 큰 변화에 영향을 받았다.

(3) 가장 높은 유사성이 나타난 곳은 봄과 여름이고, 또한 가을과 다른 계절 간에도 높은 유사성이 나타내었다. 지역적으로는 상류와 중류간에서 가장 높은 유사성이 나타나였고, 상류와 하류간에는 낮은 유사성이 나타내었다

(4) 각 계절간의 다양성 지수는 여름에는 종풍부도가 가장 높게 나타나였고, 가을에는 가장 낮게 나타내었다. 다양도지수는 가을에 가장 높게 나타나였고, 여름에는 가장 낮게 나타내었다. 균등도는 가을에 높게 나타나였고, 여름에 낮게 나타내었다. 다양도 지수의 변동의 범위는 여름에 크게 나타내였고, 가을에 낮게 나타나었다. 구간 별로 보면 상류에서는 풍부도가 높고, 중류에서는 낮다. 다양도 지수는 하류에서 높게 나타내었고, 중류에서 낮게 나타내였다. 균등도 지수는 중류에서 높게 나타내었고, 상류에서 낮게 나타내었다. 다양도 지수의 변동 범위는 하루에서 가장 크고, 중류에서 가장 작다.

(5) 어류의 풍부도와 균등도, 상대적인 풍부에 영향을 주는 요인을 조사하였다. 풍부도와 균등도는 수온 및 강우량과 큰 상관관계가 있었다. 풍부도는 여름에 가장 좋다.

제 2 장 : 대한민국 괴산호에서의 큰입베스의 개체군 생물학

(1) 연령과 성장, 그리고 자연 사망: 큰입 베스의 연령 조성과 성장 매개 변수는 대한민국 괴산호에서 2010 년 3 월부터 2012 년 11 월까지 채집한 큰입베스의 이석을 사용하였으며 측정하였다. 수컷과 암컷은 각 47.9 와 52.1 퍼센트로 나타내였다. 수컷의 전장 범위는 98.8 mm 에서 347.2 mm 이고 암컷의 전장 범위는 104.4 mm 부터 413.8 mm 이다. 전체의 전장과 전중의 상관 관계는 $TW = 0.000007L^{3.099}$ 이다. 이석(sagittae - 화살무늬)의 고리수는 계수하였고, 이석의 반지름과 고리의 반지름을 측정하였다. 매달 변화하는 증가한계률은 두 성별에서 모두 1 년에 하나의 고리가 생기는 것과 그 고리가 4 월에 형성된다는 것을 나타내었다. 큰입베스의 연령범위는 0 에서 8 세까지로 조사되었다. 반버틀란피 성장식을 사용하여 나타낸 역산체장 식은 $L_t = 448.76(1-e^{-0.234(t+0.527)})$이다. 성장성과는 4.67 이다. 큰입베스의 생리학적인 생활기간은 12.3 년으로 추정되었다. 자연사망률은 사용된 방법에 따라 조금 다양하게 추정되었다. 괴산호의 큰입베스 자연사망률은 $0.32\ yr^{-1}$ 이다. 이는 상대적으로 낮다.

(2) 생식: 기준에 따라 난소와 정소를 단계에 따라 5 개의 기로 나누었다. 수컷에 대한 암컷의 비율은 전장이 증가할수록 증가하였다. 암컷은 약간 크고, 조금 더 많은 수가 채집되었다. 평균크기와 연령은 암컷(전장 255 mm, 2.03 년)이 수컷(전장 227 mm, 2.44 년)보다 더 큰 것으로 나타내었다. 큰입베스의 산란 시기는 4 월에서 6 월까지이고, 5 월에 생식소 숙도지수와 수컷과 암컷의 생식소 단계가 최고치를 나타내었다. 성숙한 암컷은 산란기에만 채집되었다. 평균 포란수는 27656 ± 1424 이다. 포란수는 전장과 양의 상관관계를 나타내었고, 이는 평균 포란수 = 202.4 전장 - 38188 로 나타낼 수 있었다. 높은 포란수는 큰입베스가 유동적인 산란전략과 괴산호에 잘 적응할 수 있다는 것을 알려준다.

(3) 섭식 생태: 227 마리의 큰입베스 위 내용물의 범위는 84 mm 에서 412 mm 이다. 위가 비어있는 큰입베스의 비율은 개체의 크기가 증가할수록 늘어났다. 부유생물, 벌레, 갑각류, 어류 이 4 가지의 먹이 구성의 용적률을 구하였다. 큰입베스의 주된 먹이는 크기와 상관없이 검정망둑과, 갈문망둑 이 2 개의 우점종으로 구성되어 있다. 어린 베스의 경우에는 어린 갈문망둑을 선택적으로 섭이한다. 이들이 자라게 되면, 베스는 적지만 큰 검정망둑도 같이 섭이 하였다. 모든 크기의 큰입베스는 봄과 가을에 이 망둑어들을 선호하는 경향이 있다. 큰입베스는 전장 30 ~ 40 mm 때 부유생물 섭이자에서 어류섭이자로 바꾼다.

General introduction

Fresh water makes up only 0.01% of the world's water and approximately 0.8% of the Earth's surface, yet this tiny fraction of global water supports at least 100,000 species out of approximately 1.8 million - almost 6% of all described species. Freshwater ecosystems provide vital resources for humans and are the sole habitat for an extraordinarily rich, endemic, and sensitive biota. Human demands on freshwater ecosystems have risen steeply over the past century (Strayer and Dudgeon, 2010).

This is a critical time for organisms living in continental waters. Quite literally, the hydrological regime of the Earth is being drastically altered to meet the needs of rapidly expanding societies or in response to alterations of the land and the atmosphere. Water regimes that helped shape the evolution of freshwater diversity and the life history adaptations of individual species will be different from now on.

From year 1970 to 2002, a mere 30 years, freshwater biodiversity declined 55%, while that of terrestrial systems and marine systems, each declined 32%. One must suspect that the actual value for continental waters was considerably higher considering the incompleteness of the taxonomic database on freshwater biodiversity. The global freshwater biodiversity is being threatened under five headings: overexploitation; water pollution; flow modification; destruction or degradation of habitat; and invasion by exotic species. Their combined and interacting influences have resulted in population declines and range reduction of freshwater biodiversity worldwide. Conservation of biodiversity is complicated by the landscape position of rivers (Dudgeon et al., 2005). River conservation and management activities in most countries including Korea suffer from inadequate knowledge of the constituent biota. Therefore, research is being pursued globally to develop conservation planning to protect freshwater biodiversity (Pusey et al., 2010; Lipsey and Child, 2007).

Fish is the most important community in a freshwater ecosystem. Fish is sensitive to changes in water chemistry due to different anthropogenic activities from their catchment. Fish responses to environmental disturbances, including hydro-morphological factors are different in time and space in comparison. Therefore, the fish diversity is critical for a freshwater ecosystem.

Invasive species often cause rapid population declines and the extinction of native species. Our ability to minimize the effects of invasive species depends on understanding the mechanisms underlying their interactions with native populations. Many invasive species are successful because they are released from natural controls (e.g., competitors, predators) that regulate population growth within their native range (Brown, 1989; Simberloff, 1989). Invasive species also tend to be superior competitors, with a high reproductive potential and predation strategies that were absent during the evolution of isolated native populations (Ogutu-Ohwayo, 1993; Townsend, 1996; Sakai, 2001). Recent research has revealed complex interactions between invasive and native species because of size structured competition and predation (Wissinger, 1992; Belk et al., 2001).

Largemouth bass is one widely introduced species of fish prized for their angling potential. The introductions of this species, although commonly done by management agencies and the public, typically involve little or no consideration of the impacts this species may have on other species of fish and the aquatic ecosystems. Field studies and review of literature are used to document various direct and indirect effects of bass occurrence in reducing diversity of small-bodied fish species (Whittier et al. 1997), creating more homogeneous fish communities (Radomski and Goeman, 1995; Rahel, 2000), increasing competition among small-bodied fish (He and Wright, 1992; MacRae and Jackson, 2001), reducing energy flow to other game fishes, alternating planktonic and benthic communities (Jackson and Harvey, 1993), and potentially changing habitat complexity. There appears limited interest regarding the negative impacts that bass may have on aquatic ecosystems.

Largemouth bass was imported to Korea from Louisiana (USA) in June, 1973 into three lakes located around the Korea. It has settled in and suited to live in Korea very well. Most of the exotic fish species were characterized by large size, long longevity, late maturity, high fecundity, few spawning per year, and short reproductive span (Anna et al., 2005). In order to make the more useful knowledge of largemouth bass in Korea, Goe-san Lake was chosen as the target area, and fish diversity was studied firstly. Then, the invaded species, largemouth bass were collected to be researched its population biology, which will supply good information to show their adaptations to this environment, how important the role of this species in this area, and how the interaction is with the native species (Fig. 1).

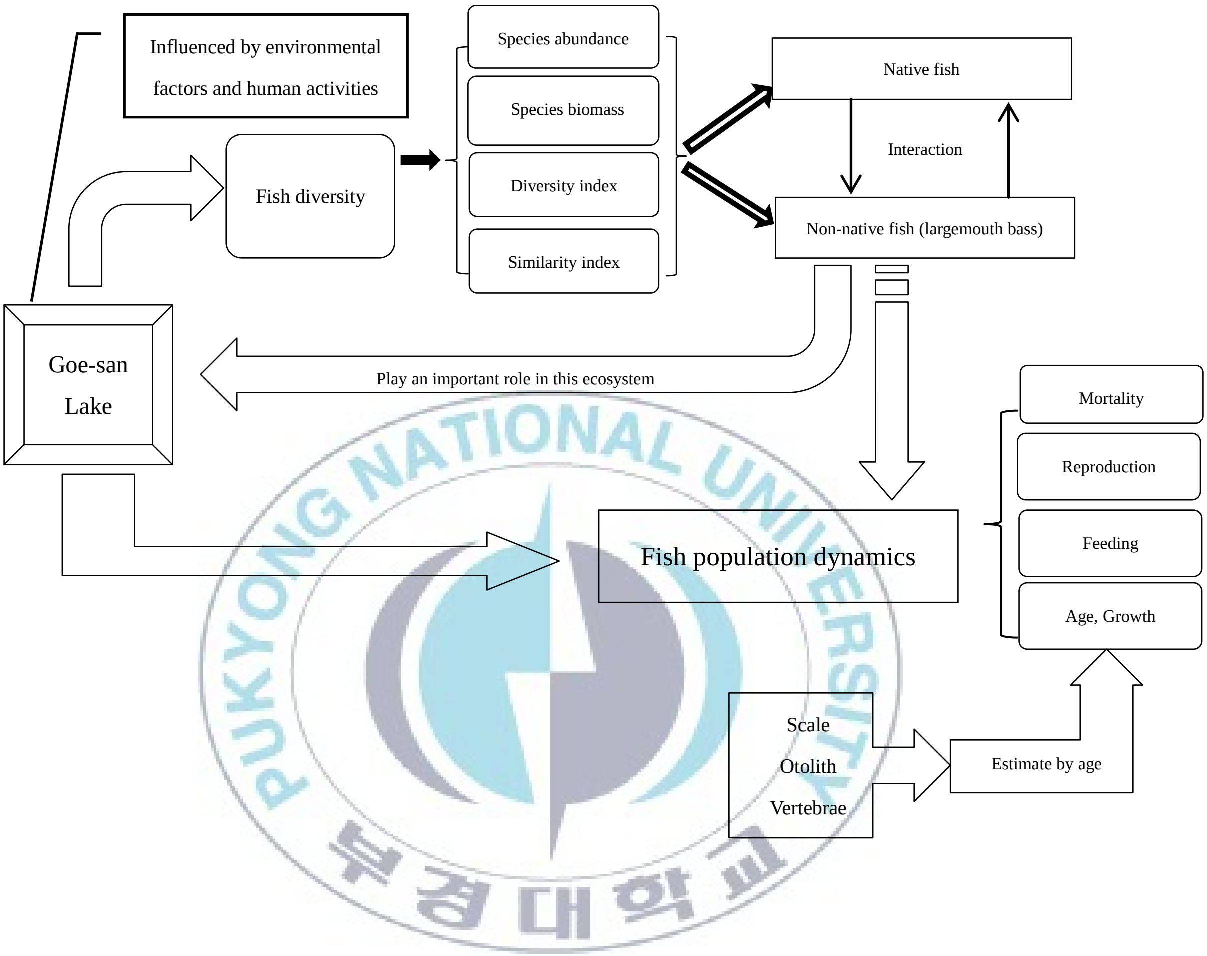


Fig. 1. Flow diagram of this study

Chapter I. Composition and diversity of fish in Goe-san Lake, Korea

1. Introduction

Inland waters and freshwater biodiversity constitute a valuable natural resource, in economic, cultural, aesthetic, scientific and educational terms. Their conservation and management are critical to the interests of all humans, nations and governments. Yet this precious heritage is in crisis. Fresh waters are experiencing declines in biodiversity far greater than those in the most affected terrestrial ecosystems in past 30 years (Jenkins, 2003), and if trends in human demands for water remain unaltered and species losses continue at current rates, the opportunity to conserve much of the remaining biodiversity in fresh water will vanish. The global freshwater biodiversity is being threaten under five headings: overexploitation; water pollution; flow modification; destruction or degradation of habitat; and invasion by exotic species. Their combined and interacting influences have resulted in population declines and range reduction of freshwater biodiversity worldwide. Conservation of biodiversity is complicated by the landscape position of rivers (Dudgeon et al., 2005).

Here we focused the freshwater fish biodiversity in the Goe-san Lake. Fish have been regarded as an effective biological indicator of environmental quality and anthropogenic stress in aquatic ecosystems (Fausch et al., 1990; Simon, 1995) not only because of its iconic value, but also because of sensitivity to subtle environmental changes (Karr, 1981) and represents a wide range of tolerance at community level. Fish is sensitive to changes in water chemistry due to different anthropogenic activities from their catchment. Fish responses to environmental disturbances, including hydro morphological factors are different in time and space in comparison to simpler organisms, as they tend to be integrated over larger intervals. Fish has been identified as suitable for biological assessment due to its easy identification and economic value (Siligato and Bohmer, 2001; Smith et al., 1999)

The total surface area of Goe-san Lake is about 17.5 km^2, the length is 15 km, and the total storage capacity is about 15,329,000 m^3. It formed being a tributary of the Namhan River because of dam construction. The storage capacity is less for the Geographical characteristics of narrow canyon. Although the water level fluctuation is frequency in the rainy season, it differs a little. Extreme variation in flow exists within the downstream area controlled by the dam. The total water resources and a big amount of sediment are transported downstream by the river and distributed across the fringing floodplains during the monsoon.

Fish assemblages have widely been used as ecological indicators to assess and evaluate the level of degradation and health of rivers and streams at various spatial scales (Zampella et al., 2006). Fish assemblages may differ on longitudinal gradient in streams according to various biological aspects such as species diversity, stress tolerance, habitat preferences, feeding behaviors and origin of species (Ganasan and Hughes, 1998). These variations depict the level and severity of degradation in stream health. Many fish species have become highly endangered, particularly in rivers where heavy demand is placed on freshwater.

Therefore, exploration and conservation of river have become vital for the overall development and nutritional livelihood security of the Goe-san region, but no study on the fish fauna of Goe-san Lake has been done so far. In this connection, this study was carried out (1) to determine the current pattern of freshwater fish biodiversity, distribution and abundance; (2) to review the threats to fish diversity; and (3) to make recommendations for fish biodiversity conservation and management.

2. Materials and methods

2.1. Sampling time and sites

Samples were taken from Goe-san lake (Fig. 2), divided into upstream (6 stations), midstream (8 stations) and downstream (10 stations), respectively. The downstream was the deepest and close to a dam. From July to August, it was the rainy season (Fig. 3b) in Goe-san. The water level and flow can be adjusted by the dam. Different threats faced by the fish biodiversity of Goe-san lake in each sampling area and season were also observed.

In addition to primary data on fish distribution and abundance, monthly samples were collected from March to November in 2010-2012, since water in the lake was mostly frozen during January and February. In December and March, it was difficult to fish for the low activities at lower temperature.

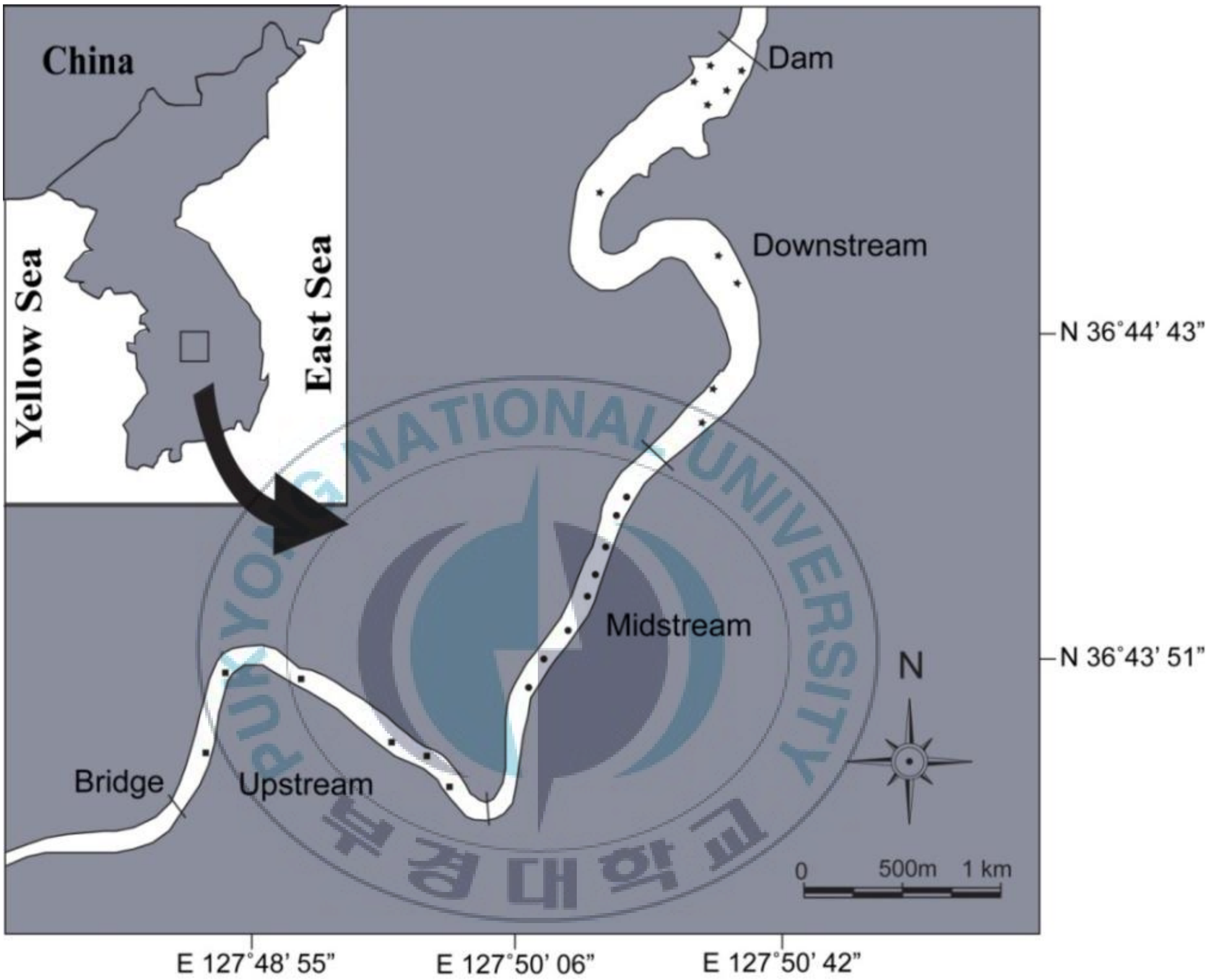


Fig. 2. Map showing the sampling area in Goe-san Lake, Korea

(■ , ●, ★, stand for sampling stations in upstream, midstream and downstream)

2.2. Sampling procedure

Experimental fishing was carried out in all sampling points with help of locally hired professional fishermen. Fishes were collected by fishing, gill nets (length: 20m, width: 1m, mesh size: 3.0 cm and 3.5 cm) and trap nets (mesh size: 1.5 cm) in Goe-san lake (Fig. 4). Fishing was only used to collect largemouth bass, and trap net was only set in the upstream because of lower water level. In the field, the water quality (pH, DO, temperature and rainfall) was measured. The samples were kept in insulation can with ice bags to move back. In the laboratory, total length (TL) was measured to the nearest 1 mm for all fish sampled. Total weight, body weight and gonad weight was recorded with an electronic analytical balance to the nearest 0.01 g.

All specimens were identified based on the classification system of Nelson (2006) and scientific names were verified using http://www.fishbase.org. The color, spots if any, maximum size and other characters of the fishes caught were recorded in a format developed for this purpose. Representative specimen (n = 10) of all fishes were preserved in 10% formaldehyde and transferred to the laboratory and stored in glass jars. Fishes were also collected from nearby fish market and landing center associated with the river system which was not collected during experimental sampling. Taxonomy discrepancies were resolved with the latest database.

The abundance (percentage of catch) of fish across different sites was calculated by the following formula.

Number of samples of particular species x 100/Total number of samples

2.3. Diversity index and the similarity index

Fish species diversity was subjected to diversity analysis using different indices, and they were calculated following formula.

(1) **Margalef's** richness index (Margalef, 1957)

$$D=(S\text{-}1)/\ln N$$

(2) **Shannon-Wiener's** diversity index (Shannon and Wiener, 1963)

$$H'=-\sum P_i \ln P_i$$

$$P_i=n_i/N$$

(3) **Pielou's** evenness index (Pielou, 1975)

$$J_{sw}=H'/\ln S$$

Where S is the number of species, n_i is the total numbers of individuals of each species in the sample, N is the total number of individuals in the sample.

Analysis of variance was conducted to test the presence of fish species in the different sites in river protected and unprotected area. Comparisons of mean data of diversity index were done using Tukey's Multiple Comparison Test. Statistical calculations were performed using SPSS 17.0.

(4) Similarity index

Similarity of the species in all sampling area and season was calculated using **Jacquard's** index (Rodger, 1991)

$$S_j = j/(x+y-j)$$

where Sj is the similarity between any two zones X and Y, j the number of species common to both the areas (seasons) X and Y, x the total number of species in zone (season) X and y total number of species in zone (season) Y. Similarity within the sites was generated by using the Estimates S (version 8) software.

3. Results

3.1. Environmental factors

The temperature and rainfall is recorded in Figure. 3. There was no significant difference of temperature among month from 2010 to 2012, but there was significant difference of rainfall among month in these three years (Fig. 3a). The rainfall of 2011 from April to July was significantly higher than that of 2010 and 2012 (LSD, $P < 0.05$). The peak of 2010 and 2011 attained in July, and 2012's attained the peak in August (Fig. 3b).

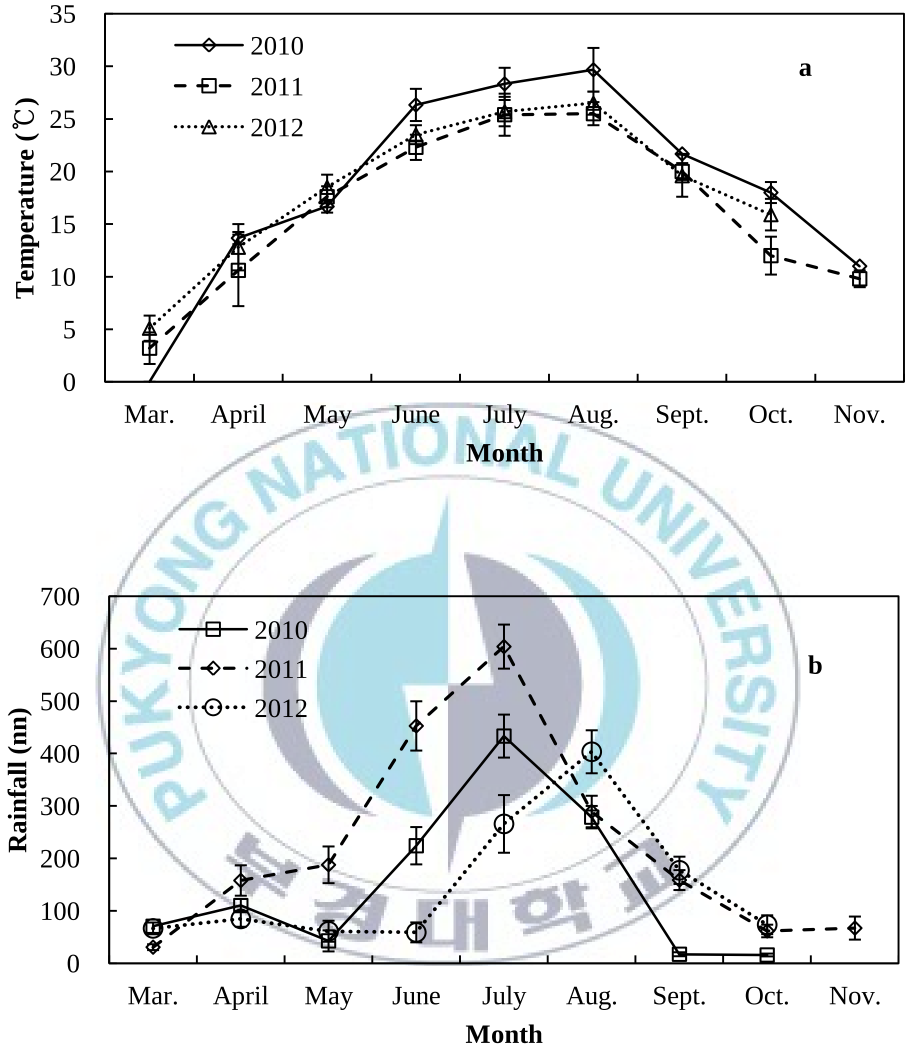


Fig. 3. Distributions of temperature (a) and rainfall (b) from March to November in 2010-2012 in Goe-san Lake. (a: temperature; b: rainfall)

Fig. 4. Sampling tools. a, trap net; b, gill net

3.2. Faunal composition

In Korea, 135 indigenous freshwater finfishes had been described of which belongs to 29 families. A total of 2875 fish belongs to 12 families, 32 species (Fig. 5) in of Goe-san Lake, of which 2572 belonging to family cypinidae, 87 to centrachidae, 70 to centropomidae and 146 to the remaining to 9 families. It was shown that fish species diversity was low. The list of fish species is shown in Table 1.

The total numbers of fish species were 32, 18 and 13 in the upstreams, midstreams and downstreams, respectively (Fig. 6). The number of species that were collected in every stream is 13. The total numbers of fish species were 21, 27 and 19 in spring, summer and autumn, respectively (Fig. 7). The number of species that were collected in every season was 14.

The distribution of fish species is quite variable depending on geographical and geological conditions. The fish species abundance, biomass and distribution were shown in Figures 6 and 7. It showed that the composition of season and area by the abundance and biomass of family. Cyprinidae, centrachidae, and centropomidae were three predominant families. The Cyprinidae family was found to be the most dominant group, and the percentage of cypinidae by both abundance and biomass were higher than 80%. The number of family is the highest in upstream and downstream’s was the smallest. In different areas, there were the most family in spring, and least in autumn.

Table 1. List of fish species collected from the Goe-san Lake in 2010-2012

Order	Fish species	Distribution								
		2010			2011			2012		
		Up-stream	Mid-stream	Down-stream	Up-stream	Mid-stream	Down-stream	Up-stream	Mid-stream	Down-stream
1	*Acheilognathus lanceolata*	+	+		+			+		
2	*Acheilognathus yamatsutae*				+			+		
3	*Anguilla japonica*	+			+			+		
4	*Carassius auratus*	+	+	+	+	+	+	+	+	+
5	*Carassius cuvieri*	+	+	+	+	+	+	+	+	+
6	*Coreoperca herzi*	+			+			+	+	
7	*Cyprinus carpio*	+	+	+	+	+	+	+	+	+
8	*Hemibarbus labeo*	+	+	+	+	+	+	+	+	+
9	*Hemibarbus longirostris*	+	+		+	+		+		+
10	*Iksookimia koreensis*	+		+	+					
11	*Leiocassis ussuriensis*							+	+	
12	*Liobagrus andersoni*	+	+							
13	*Microphysogobio yaluensis*	+								
14	*Micropterus salmodies*	+	+	+	+	+	+	+	+	+
15	*Misgurnus anguillicaudatus*	+								
16	*Odontobutis intereupta*	+	+	+	+	+		+	+	+
17	*Opsariichthys uncirostris amurensis*	+	+	+	+	+	+	+	+	+
18	*Plecoglossus altivelis*	+								
19	*Pseudirasbora parva*	+								
20	*Pseudobagrus esocinus*	+	+		+			+		+
21	*Pseudobagrus fulvidraco*	+	+	+		+	+	+	+	+
22	*Pungtungia herzi*	+			+			+		
23	*Rhinogobius brunneus*	+								
24	*Sarcocheilichthys nigripinis morii*				+			+		
25	*Sarcocheilichthys variegatus wakiyae*	+	+					+		
26	*Sarcochelichthys czerskii*							+		
27	*Silurus asotus*				+				+	
28	*Siniperca scherzeri*	+	+	+	+	+	+	+	+	+
29	*Siniperca scherzeri (Albino type)*							+		
30	*Squalidus gracilis majimae*							+		
31	*Zacco platypus*	+	+		+			+		+
32	*Zacco temminckii*	+			+			+		

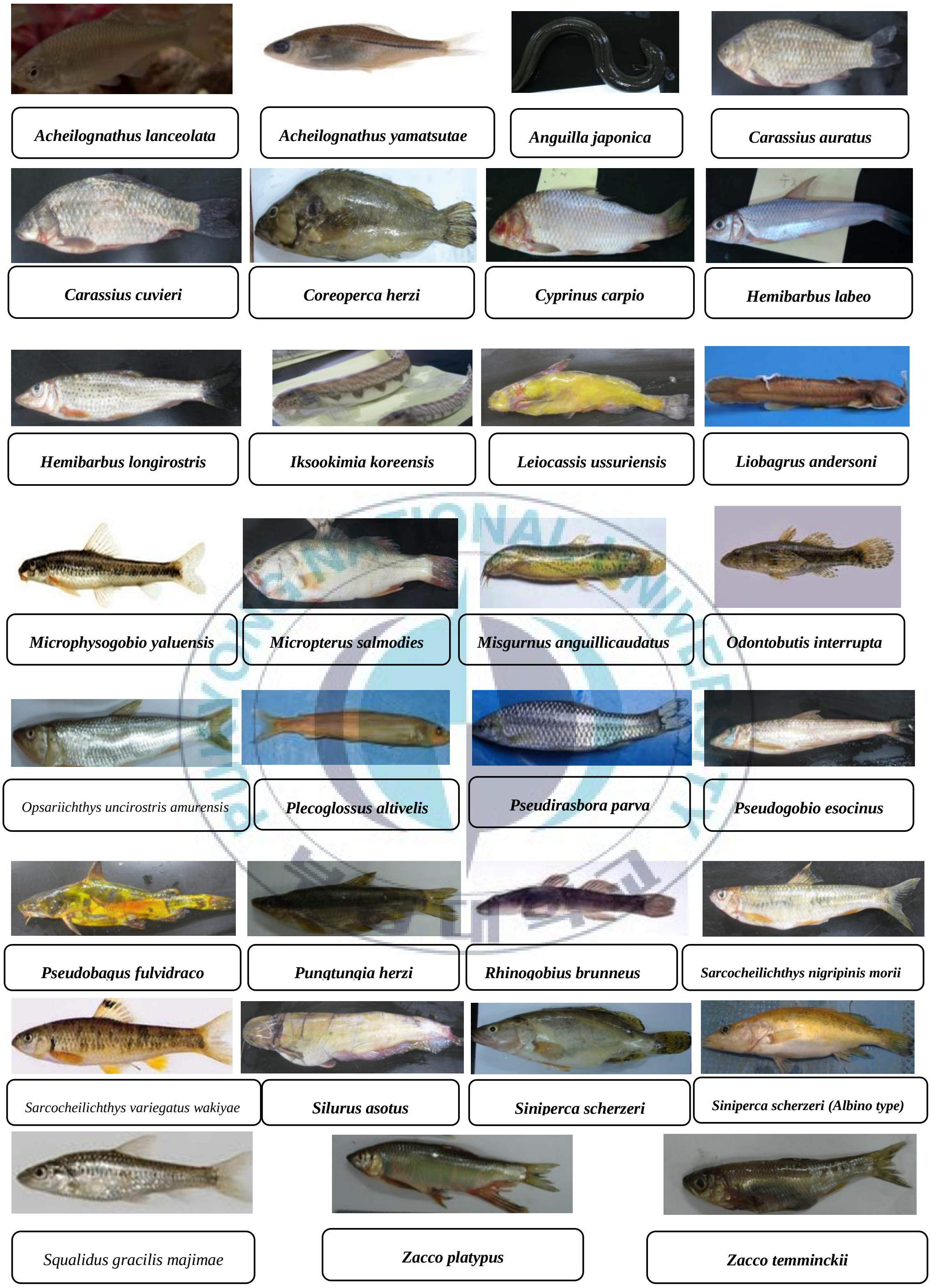


Fig. 5. Composition of fish species in Goe-san Lake

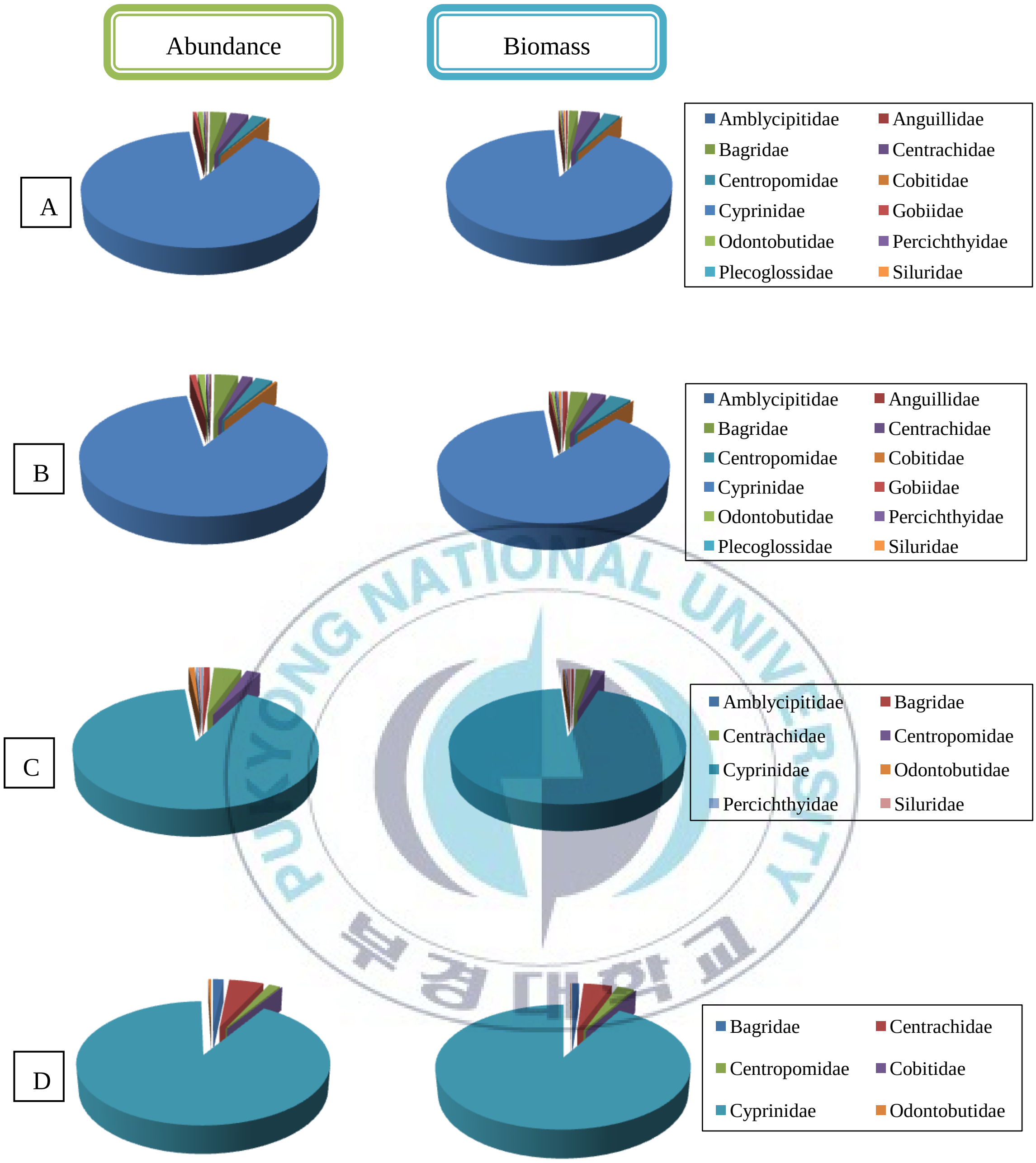


Fig. 6. Representation of family and biomass in three streams in Goe-san Lake from 2010-2012. A: verall, B: upstream, C: midsream and D: downstream

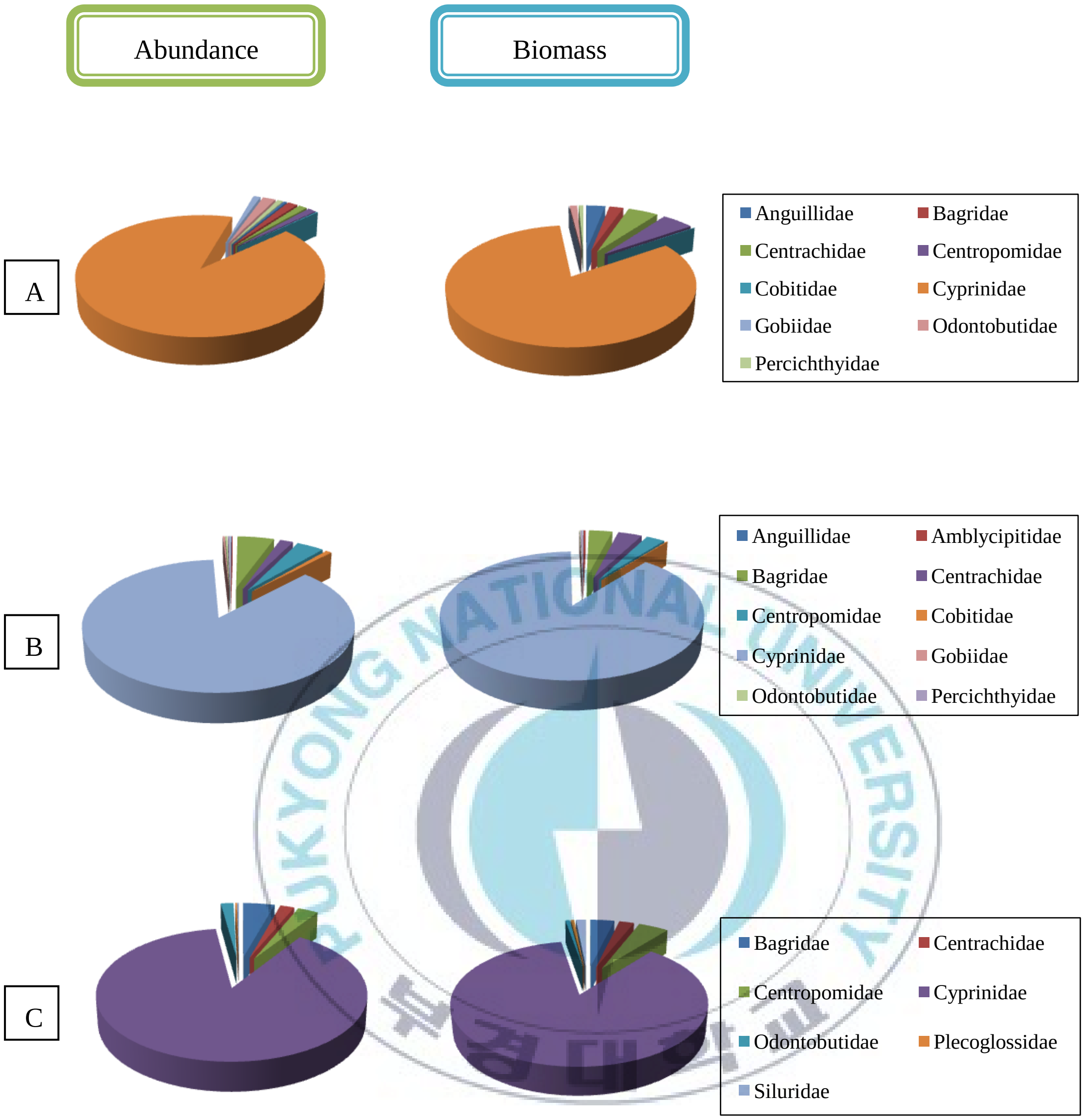


Fig. 7. Representation of family and biomass in three seasons in Goe-san Lake from 2010 to 2012.

A: spring, B: summer, C: autumn

3.3. Relationship between abundance and biomass

The relationship between abundance (ind./h) and biomass (kg/h) are shown in Figure 8. For the samples collected by gill nets, the abundance was the largest in the upstream, but the biomass was in the downstream. Both of them were the least in the midstream. The abundance and biomass were the least in spring, and summer’s were the largest. For the samples collected by trap nets, the abundance was the largest in spring, and the autumn’s was least. The biomass was largest in the summer, and that of summer was the least. For the samples collected by fishing, both abundance and biomass was largest in spring, and both of them were the least in autumn.

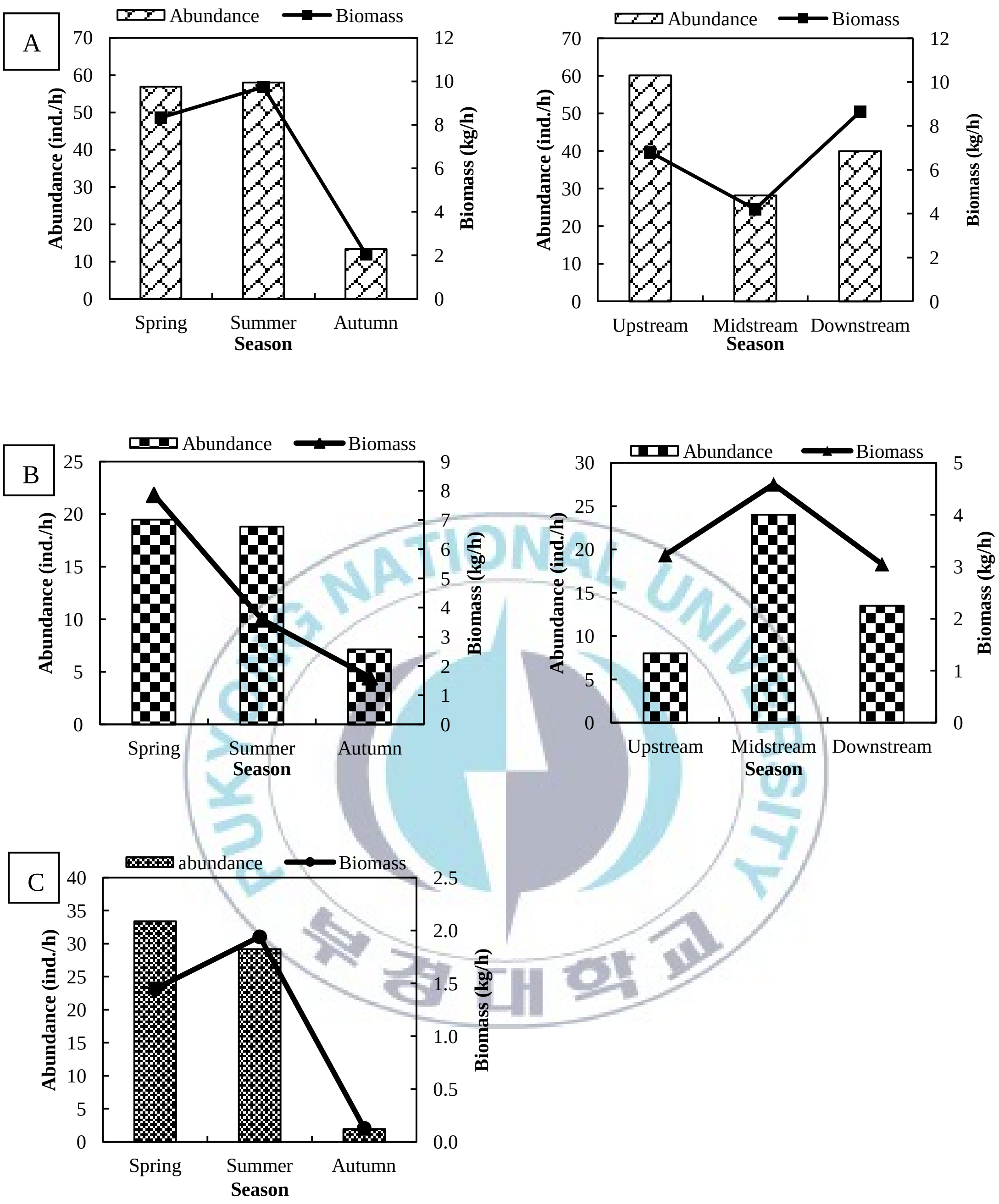


Fig. 8. Relationship between abundance/biomass and area/season. (A: Gill net; B: Trap net; C: Fishing)

3.4. Dominant species

The overall dominant species composition from 2010 to 2012 is shown in Table 2a. According to the order of number percentage from the biggest to the smallest, In 2010, the dominant species are *Hemibarbus labeo*, *Opsariichthys uncirostris amurensis, Carassius auratus, Hemibarbus longirostris* and *Pseudogobio esocinus;* In 2011, the dominant species were *Hemibarbus labeo, Carassius auratus, Hemibarbus longirostris, Opsariichthys uncirostris amurensis and Pseudogobio esocinus;* In 2012, the dominant species were *Hemibarbus labeo, Hemibarbus longirostris, Pseudogobio esocinus, Carassius cuvieri* and *Opsariichthys uncirostris amurensis.* The change among years was not too much. During these three years, there were almost the same dominant species except for the *Carassius cuvieri* in 2012. *Hemibarbus labeo* was the first dominant species.

The dominant fish species composition of every season is shown in Table 2b in 2010. According to the order of number percentage from the biggest to the smallest, in spring (from March to May), the dominant species were *Zacco platypus, Opsariichthys uncirostris amurensis, Acheilognathus lanceolata, Carassius cuvieri* and *Micropterus salmodies;* In summer, the dominant species were *Hemibarbus labeo, Micropterus salmodies, Opsariichthys uncirostris amurensis, Hemibarbus longirostris* and *Carassius cuvieri; In autumn, Pseudogobio esocinus, Hemibarbus labeo, Carassius cuvieri, Hemibarbus longirostris* and *Opsariichthys uncirostris amurensis.* The common dominant species were *Carassius cuvieri* and *Opsariichthys uncirostris amurensis.*

The fish dominant species composition of every season in 2011 is shown in Table 2c. According to the order of number percentage from the biggest to the smallest, in spring (from March to May), the dominant species were *Zacco platypus, Opsariichthys uncirostris amurensis, Acheilognathus lanceolata, Carassius cuvieri* and *Micropterus salmodies;* In summer, the dominant species were *Hemibarbus labeo, Micropterus salmodies, Opsariichthys uncirostris amurensis, Hemibarbus longirostris* and *Carassius cuvieri; In autumn, Pseudogobio esocinus, Hemibarbus labeo, Carassius cuvieri, Hemibarbus longirostris* and *Opsariichthys uncirostris amurensis.* The common dominant species were *Carassius cuvieri* and *Opsariichthys uncirostris amurensis.*

The fish dominant species composition of every season in 2012 is shown in Table 2d. According to the order of number percentage from the biggest to the smallest, in spring, the dominant species were *Hemibarbus labeo, Pseudogobio esocinus, Hemibarbus longirostris, Hypomesus nipponensis* and *Zacco platypus;* In summer, the dominant species were *Hemibarbus labeo, Hemibarbus longirostris, Pseudogobio esocinus, Pseudobagrus emarginatus* and *Leiocassis ussuriensis;* In autumn, *Hemibarbus longirostris, Cyprinus carpio* and *Siniperca scherzeri.* The composition of dominant species differed significantly, and the common species were *Hemibarbus labeo* and *Hemibarbus longirostris.*

Table 2. Dominant fish species composition in Goe-san Lake after collected by gill nets and trap nets. (a: overall, b: 2010, c: 2011 and d: 2012) Note: *Micropterus salmoides*, which is very important species, wasn't list in the table, because they were caught by fishing.

(a)

Dominant species	Year (%)		
	2010	2011	2012
Hemibarbus labeo	30.83	31.68	29.00
Opsariichthys uncirostris amurensis	12.12	9.32	5.71
Carassius auratus	11.28	25.84	
Hemibarbus longirostris	11.28	9.69	16.32
Pseudogobio esocinus	8.46	4.84	14.73
Carassius cuvieri			5.82

(b)

Dominant species	Season (%)		
	Spring	Summer	Autumn
Zacco platypus	27.87		
Opsariichthys uncirostris amurensis	14.75	13.62	6.60
Acheilognathus lanceolata	12.57		
Carassius cuvieri	7.65	4.69	14.93
Micropterus salmodies	6.56	14.55	
Hemibarbus labeo		36.15	15.97
Hemibarbus longirostris		12.68	13.54
Pseudogobio esocinus			24.31

(c)

Dominant species	Season (%)		
	Spring	Summer	Autumn
Hemibarbus labeo	37.80	25.25	31.22
Carassius cuvieri	17.16	23.28	
Opsariichthys uncirostris amurensis	16.09		
Hemibarbus longirostris	7.77	8.52	10.41
Carassius auratus	6.70	9.18	9.50
Pseudobagrus fulvidraco		9.84	
Pseudogobio esocinus			13.57
Zacco platypus			8.60

Table 2. (d)

Dominant species	Season (%)		
	Spring	Summer	Autumn
Hemibarbus labeo	41.78	19.14	15.06
Pseudogobio esocinus	14.04		
Hemibarbus longirostris	10.62	15.74	35.54
Hypomesus nipponensis	7.19		
Zacco platypus	6.16		
Pseudogobio esocinus		12.52	11.45
Pseudobagrus emarginatus		10.38	
Leiocassis ussuriensis		10.20	
Cyprinus carpio			9.64
Siniperca scherzeri			8.43

3.5. Species' dominance analysis

In a stable ecosystem, the abundance of communities dominated by one or a few large species. Species dominance show that the dispersion degree of dominant species within the community. Species dominance curve was used to test the number of dominant species in the fish composition. The less the number of dominant species is, the more stable the community is. According to the number percentage of species from the biggest to the smallest in different areas, the dominance curves of midstream and downstream are similar during the total three years, and they were higher than upstream's. The cumulative percentage of first 8 species is more than 95% in midstream and downstream, and the first 15 species made up the 95% composition in upstream. In 2010, the three dominance curves were different in upstream, midstream and downstream. The cumulative percentage of first 13, 8, 5 species were more than 95%, respectively. The dominance of downstream was highest (Fig. 9a). In 2011, the dominance of midstream and downstream are very similar, and they are significantly higher than that of upstream. The cumulative percentage of first 11, 5, 5 species were more than 95%, respectively (Fig. 9b). In 2012, the dominance curves of upstream and downstream were very similar. The cumulative percentage of first 11, 8, 8 species are more than 95%, respectively (Fig. 9c) The dominance of upstream was lowest among areas from 2010 to 2012, and the dominance of upstream in 2011 was lowest (Fig. 9d) .

The dominance of upstream was the lowest among areas from 2010 to 2012, and the dominance of upstream in 2011 was lowest. In 2010, the dominance curves were very similar in three seasons, and the dominance of autumn was a little higher. In 2011, the dominance curves were very similar in summer and autumn, and they were lower than that of spring. In 2012, the dominance curves were very similar in spring and autumn, and higher than that of summer (Fig. 10a, b, c, d).

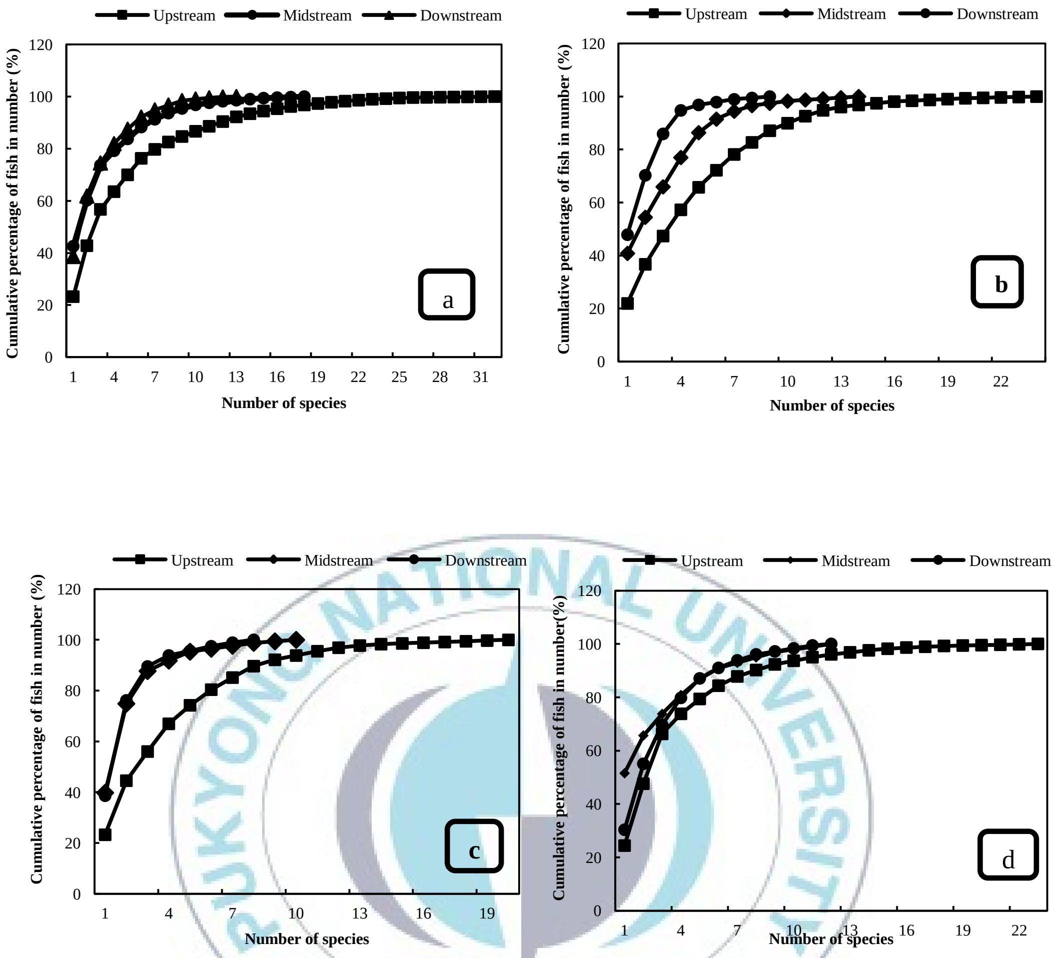


Fig. 9. Dominance-diversity curves calculated from seed bank data collected in three streams in Goe-san Lake. (a: overall, b: 2010, c: 2011 and d: 2012).

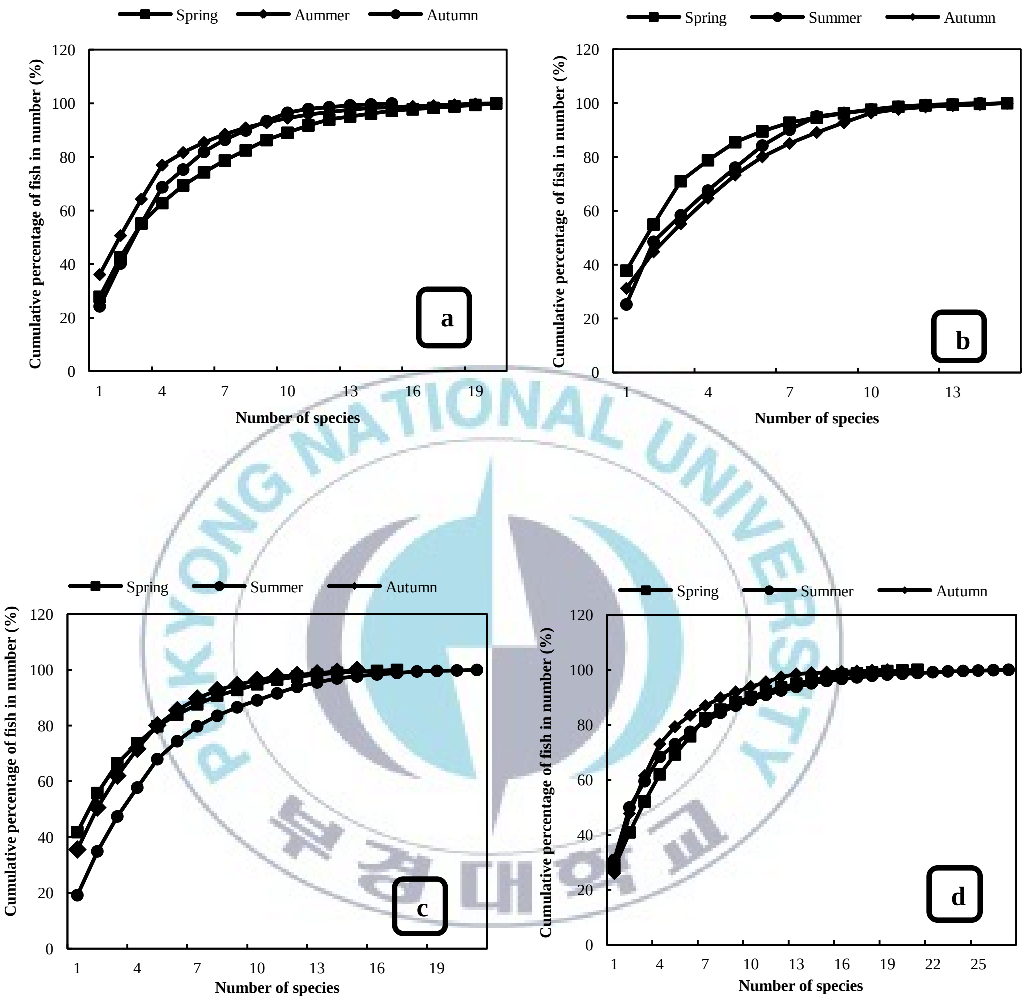


Fig. 10. Dominance-diversity curves calculated from seed bank data collected in three seasons in Goe-san Lake. (a: 2010, b: 2011, c: 2012 and d: overall).

3.6. Fish diversity

The diversity indices of each season as well as the total index value are shown in Table 3. The highest richness and diversity index was recorded in spring of 2010, autumn of 2011 and summer in 2012. The highest evenness index was in autumn of 2010 and 2011, summer of 2012. The fluctuations of diversity index range were most in summer and the autumn’s range least. The diversity of fish samples collected by trap nets was higher than that collected by gill nets in every season.

The diversity indices of each stream as well as the total index value are shown in Table 4. The upstream richness index was the highest and downstream’s was lowest from 2010 to 2012. The diversity index was highest in upstream from 2010 to 2012, and smallest in the downstream in 2010 and 2011, and that of midstream in 2012. The evenness index was highest in upstream in 2010 and 2011, and in downstream in 2012. The highest was in downstream, and the lowest was in midstream in 2012. The fluctuation of diversity index range was most in midstream and the upstream’s range least. The diversity of fish samples collected by trap nets was higher than that collected by gill nets in every area.

Annual diversity index was shown in Figure 11. The richness index (D) and diversity index (H’) were the least in the samples collected by gill nets and trap nets in 2011. The evenness index decreased in the samples collected by gill nets from 2010 to 2012, but increased in the samples collected by trap nets.

Table 3. Seasonal diversity indexes of fishes collected by gill nets (a) and trap nets (b) in Goe-san Lake from 2010 to 2012

(a)

Year	Index	Season		
		Spring	Summer	Autumn
2010	D	2.12	1.31	0.75
	H'	1.18	0.76	1.07
	Jsw	0.59	0.49	0.61
2011	D	0.72	0.63	0.93
	H'	0.81	0.99	1.08
	Jsw	0.51	0.59	0.61
2012	D	1.21	1.36	1.11
	H'	0.90	1.36	0.96
	Jsw	0.51	0.61	0.56

(b)

Year	Index	Season		
		Spring	Summer	Autumn
2010	D	2.23	1.48	1.19
	H'	1.53	1.17	1.24
	J_{sw}	0.79	0.69	0.81
2011	D	1.18	1.08	1.40
	H'	1.02	1.17	1.18
	J_{sw}	0.71	0.79	0.81
2012	D	1.59	1.86	1.52
	H'	1.05	1.57	1.12
	J_{sw}	0.56	0.66	0.61

Table 4. Area-diversity indexes of fishes collected by gill nets (a) and trap nets (b) in Goe-san Lake from 2010 to 2012

(a)

Year	Index	Seson		
		Spring	Summer	Autumn
2010	D	2.05	1.34	0.87
	H'	1.28	0.96	1.10
	J_{sw}	0.59	0.69	0.81
2011	D	1.16	1.07	1.39
	H'	0.81	0.99	1.08
	J_{sw}	0.54	0.62	0.64
2012	D	1.22	1.56	1.13
	H'	0.90	2.46	2.06
	J_{sw}	0.53	0.63	0.58

(b)

Year	Index	Seson		
		Spring	Summer	Autumn
2010	D	2.50	1.79	1.32
	H'	1.52	1.20	1.34
	J_{sw}	0.57	0.47	0.59
2011	D	1.15	1.06	1.38
	H'	1.07	1.25	1.34
	J_{sw}	0.51	0.59	0.61
2012	D	1.59	1.93	1.50
	H'	1.09	1.55	1.15
	J_{sw}	0.53	0.63	0.58

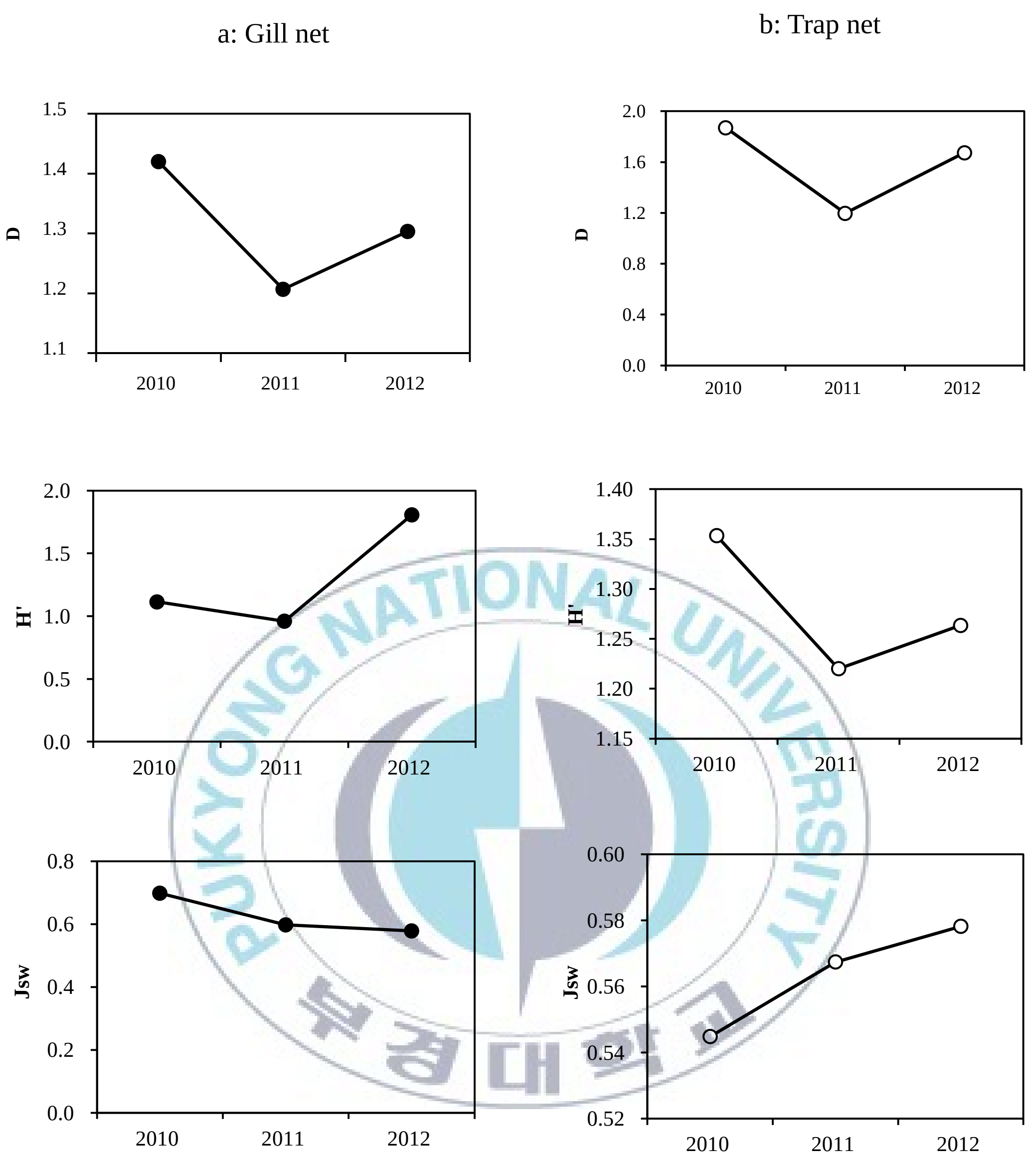


Fig. 11. Annual diversity indexes of fishes collected by gill nets (a) and trap net (b) from 2010 to 2012

3.7. Relationship between biomass and species diversity indices

In this study, the diversity and relative biomass of fish was negatively correlated (Fig. 12). D, H' and J decreased along with relative biomass increasing. High biomass doesn't mean high diversity index. The reason of higher biomass area or season is normally that the ratio of some species increase, and make their dominance increase, then result in lower diversity index. This result is consisted to that of Fujita (Fujita, 1993).

3.8. Fish similarity

Similarity of the species in all sampling area and season was calculated based on their shared species (Table 5). The similarity was highest between 2011 and 2012. The similarity was highest between summers and autumn, and lowest between spring and summer from 2010 to 2012. The highest similarity was recorded between upstream and downstream, and lowest between midstream and downstream from 2010 to 2012.

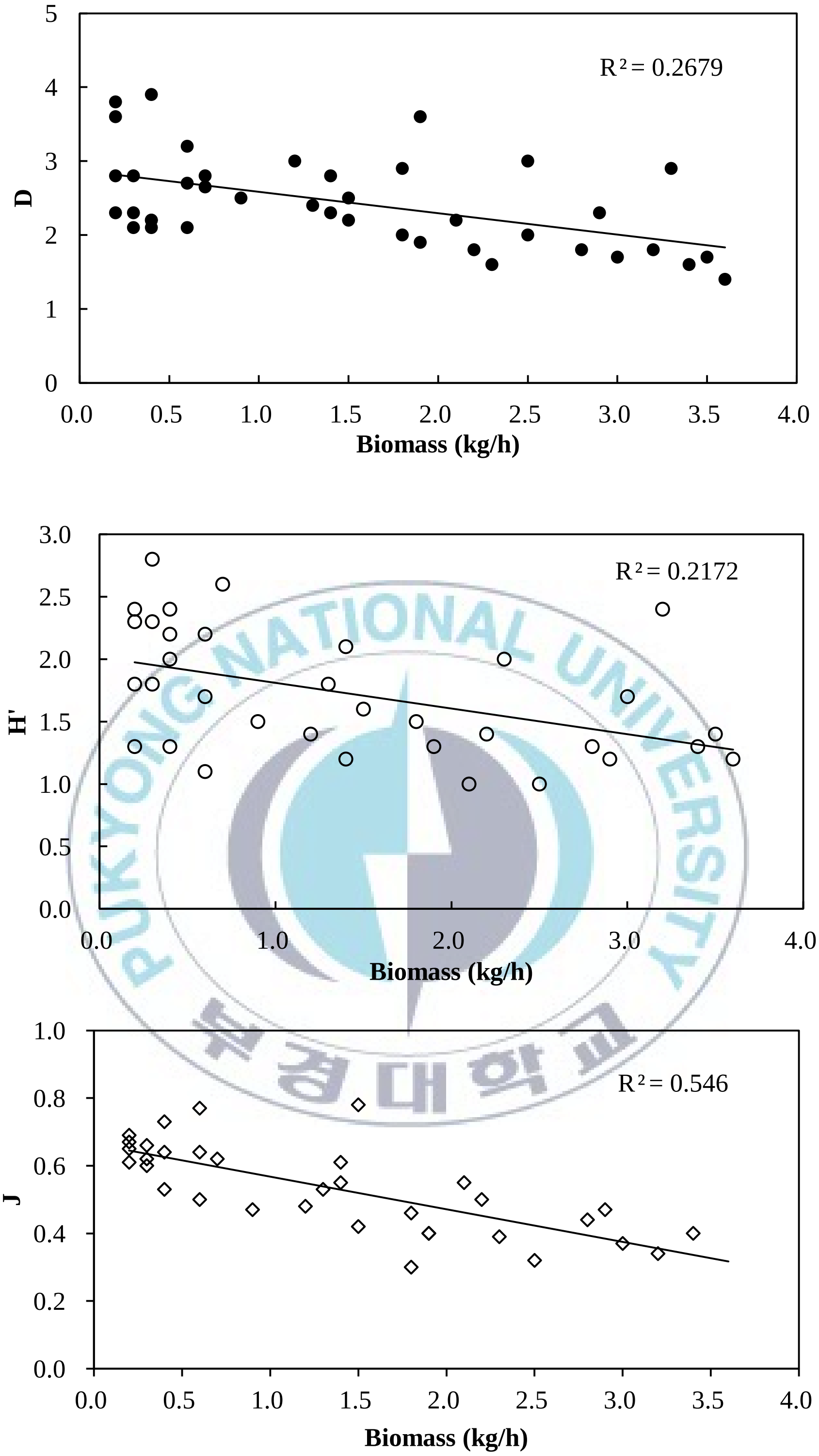


Fig. 12. Relationship between relative biomass and species-diversity indices in the Goe-san lake (a: D, b: H' and c: J)

Table 5. Shared species among years, seasons and areas in Goe-san Lake. (a: year, b: season and c: stream).

(a)

Year	2010	2011	2012
2010			
2011	16		
2012	16	19	

(b)

Year	Seasons	Spring	Summer	Autumn
2010	Spring			
	Summer	10		
	Autumn	11	14	
2011	Spring			
	Summer	10		
	Autumn	11	11	
2012	Spring			
	Summer	12		
	Autumn	13	13	

(c)

Year	Areas	Upstream	Midstream	Downstream
2010	Upstream			
	Midstream	14		
	Downstream	9	9	
2011	Upstream			
	Midstream	9		
	Downstream	8	7	
2012	Upstream			
	Midstream	11		
	Downstream	12	9	

4. Discussion

The present study was conducted firstly on fish diversity and conservation priority in Goe-san Lake. *Micropterus salmoides*, an exotic species, settled in and suited to live in Korea very well. They will devour anything in the way, from small bait fish, freshwater shrimps and other animals, and some species are considered to be rare. It can affect the community composition and diversity very much. These values of diversity indices investigated that also the degree of the structural stability was relatively bad, so the environmental conditions from this area of the river are not good to allow a sufficient number of species to live and develop normally. Due to lack of previous information on fish diversity from this river, it is not possible to quantify the rate of decline in fish diversity but the present study would be useful as baseline data for any future assessment after interlinking. Most importantly, our study indicate considerable share in supporting fish biodiversity in the region despite alterations like damming and habitat degradations.

Our study explored the patterns and environmental drivers of fish community composition and diversity in different areas and seasons from 2010 to 2012. Our results suggest that natural and human-related environmental factors have differentially shaped fish communities at the watershed scale. Richness of the summer community was greater in watersheds characterized by more precipitation regimes and more stable food composition because of the more rainfall (Fig. 3b) and optional temperature, which is fit for adult fish to spawn and feed (Brown and Ford 2002).

Moreover, fluctuating summer flows provide juveniles access to critical backwater habitats (Minckley et al. 2003). There is a dam near the downstream, which can be control the water level. A rainy season happened in July. When the rainfall is higher, the dam has to be open to drain (Fig. 13). At the same time, the flow fluctuates during this period. The similar report had been done by Graff in 1999.

The richness of upstream is higher than that of midstream and downstream. It is consider to be related to the position character of upstream. It is shown that there are three tributaries join at the upstream. Therefore, a lot of precipitation occurred in the upstream (Fig. 14), which can provide stable food. At the same time, a lot of small fish prefer to live this area for the low water level and higher flow.

Fig. 13. Some condition of dam with high water level in the rainy season (July)

Fig. 14. Distinct characters of upstream in the Goe-san Lake

Shannon-Weiner index (H') affects both number of species and evenness of their population, diversity increases as both increases. Diversity is maximum when all species that made up the community are equally abundant (i.e. have a similar population sizes). The diversity is partly a function of the variety of habitats; the more varied habitats tend to be inhabited by a large number of species than less variable ones. Secondly the older habitats usually contain more species than younger ones. Warmer temperatures, availability and stability of food result in high level of diversity, others include latitudes and longitudes.

A striking result of our study was that natural and human related factors explained substantially more variation in functional trait composition of community. External factors affecting populations of freshwater species include: simple habitat loss resulting from withdrawal of water for human use such as irrigation, domestic and industrial use; impact of anthropogenic factors; and direct exploitation such as impoundment, wetland drainage and flood control causing the load of inorganic and organic pollutants in flowing waters to increase (Fig. 15). The major challenge is to address the increasing volume of polluted waste water from industrial and agricultural processes. Dam construction and channelization strongly disrupt natural production cycles, including migration of fishes that ascend rivers from downstream areas or the sea in order to spawn. Fish production can be maintained or increased in some circumstances, although natural aquatic biodiversity is expected to decrease.

In conclusion, increased fishing pressure exerted from overfishing activity of the artisanal fishermen that operating in this water body; and couple with the downstream migration of fish in search for food, shelter and spawning; industrialization, urbanization and farming activities around the river as factors that were probably responsible for low fish composition and diversity in Korea. This study could serve as baseline data in assisting relevant bodies in the management and conservation of fisheries resources of this water body where there are dearth of information relating to its fish and fisheries. Government must take immediate action through public awareness and education to regulate fishing, industrialization, urbanization and farming activities within and around this water body as preclude to conserving its resources that are fast depleting. Enactment and enforcement of laws and orders by regulating agencies in the management and conservation of the resources of our natural waters should be considered a top priority. For example, we should forbid fishing during the spawning season of most fish, and avoid draining too much for some constructions done normally.

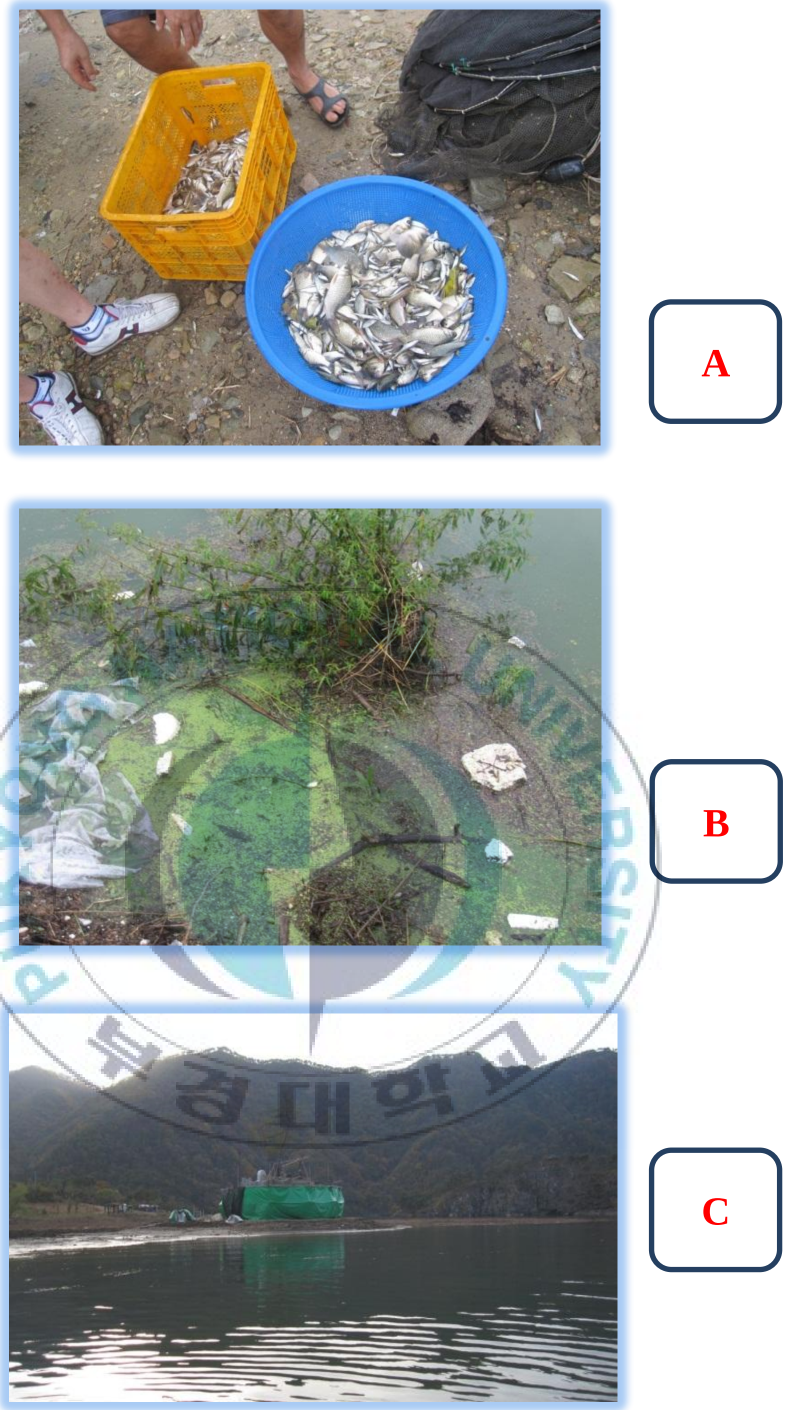


Fig. 15. Some factors affecting the fish diversity in Goe-san Lake. (A: overfsihing; B: pollutions; C: human activity).

Chapter II. Age, growth, reproduction and feeding ecology of largemouth bass, *Micropterus salmoides*, from Goe-san Lake in South Korea

1. Introduction

Largemouth bass (Fig. 16), *Micropterus salmoides*, is one of the most important freshwater game fish belonging to the family Sunfish (Scarola, 1987). It is native to the Midwestern and southeastern United States, and northeastern Mexico, which prefers marshy environments and the shallow waters of larger lakes (Hickley et al., 1994). Because it is a premium sport fish, it has been introduced, although not always successfully, into several countries in temperate and tropical climates (Heidinger, 1976). It was imported to Korea from Louisiana in June, 1973 into three lakes located around the Korea.

It has settled in and suited to live in Korea very well. Therefore, it's very important to do a research on its' population biology, as understanding the population biology is critical for guiding and evaluating management activities. Obtaining information of population is often dependent on identifying hard structures, which can provide precise estimates on age.

Several procedures are used routinely to provide estimates of age. Routine age determination of individual fish from the natural environment usually involves a detailed interpretation of their hard or calcified structures, including scales, fin rays, otoliths, cleithra, opercular bones and vertebrates (Devries and Fire, 1996; Michael and Zachary, 2007). Tests of accuracy have frequently been relegated to low priority.

Validation should be an essential and routine part of every study that involves the extraction of age data from calcified structures of fish (Carlander, 1982; Beamish and McFarlane, 1983). Because a specific type of interpretation and prodcedure has been demonstrated as valid for a particular species under certain conditions, it should be valid for other species and conditions.

There are some records on the age and growth on largemouth bass by different methods (Maraldo and MacCrimmon, 1979; Stone and Modde, 1982; David, 1990; Mundahl et al., 1998; Olaf, 1999; Boxrucker, 2002; Mesing et al., 2008). During it's over 30 years in Korea, there wasn't any report on these. In order to make a good understanding on the characters of age and growth, and make a comparison with other geographical areas, Goe-san Lake was chosen to be the target area, and the present research mainly focused on the age and growth of the largemouth bass, which is the basic of stock assessment.

Determining the timing, location and mode of spawning as well as potential fecundity is important in building a thorough knowledge of a species' general biology and its management requirements (King, 1995). Information on the reproductive biology of freshwater bass and few comparative data are available. Another aspect, as the introduced areas were different and the environmental factors varied schoolings of the freshwater bass mature earlier or later and have evolved in varying spawning strategies.

A few studies on the reproduction of *M. salmoides* have been done (Martin et al., 1999; Lorenzoni et al., 2002; Beamish et al., 2005; Victoria et al., 2009). Lorenzoni

(2002) and Victoria (2009) paid their attention on the spawning time and the maturation size and age. Martin (1999) reported the comparison of inhibiting effects of low water temperature and high stocking density on reproduction. So far, because the information on their life history is still lack, the exploitation status and assessment of appropriate management measures remain confusing in South Korea. In this study, the reproductive biology of *M. salmoides* was investigated in Goe-san lake, South Korea. We also examined the factors potentially responsible for their spawning strategies and compared with those reported in other geographic populations. Predation plays a very important role in population regulation. Many studies have been made on feeding ecology of largemouth bass in their native range in America (Adams et al., 1982; Storck, 1986; Hoyle and Keast, 1987; Hambright, 1991) and in non-native environment of Japan (Mikio and Motomura, 1998). The feeding habits of bass will be reported in the Goe-san Lake, which it's a new non-native environment. In order to understand the character of this species and the interaction with native species, the following works were conducted. (1) to determine the age by comparing different calcified structures (scale, sagittae, vertebrae and opercula bone); (2) the abundance and mortality; (3) estimate the growth by the optimal structure; (4) to investigate population sex ratio, spawning seasonality, fecundity and length/age at sexual maturity; (5) characters of feeding ecology.

Fig. 16. Photography of largemouth bass, *Micropterus salmoides*, collected from Goe-san Lake

2. Materials and methods

2.1. Field sampling

Goe-san lake has optimal conditions including extensive shallow areas (<6 m depth) around the upstream that support submerging vegetations as well as areas deep enough (3-15 m depth). See'2.1 sampling time and sites' for sampling in detail. In the field, the water environmental factors (pH, DO, temperature and rainfall) were measured.

2.2. Relationship between length and weight

The samples were kept in insulation can with ice bags to move back. In the laboratory, total length (TL), standard length (SL) and fork length (FL) were measured to the nearest 1 mm for all fish sampled (Standard length was measured from the anterior tip of the upper jaw to the tip of the hypural bone (urostyle). Fork length was measured from the anterior tip of the longest jaw to the median point of the caudal fin and the total length was measured from the anterior tip of the longest jaw to the most posterior part of the tail (Laevastu, 1965)). Conversions among length measurements can generally be accomplished with simple linear regressions models. Therefore, length-length relationships were determined by the method of least squares to fit a simple linear regression model. Linear regressions were run on all combinations of the length measurements. The following relationships were established using linear regression analysis; (a) TL vs. FL; (b) TL vs. SL; (c) FL vs. SL. Total weight, body weight and gonads weight were recorded with an electronic digital balance to the nearest 0.01 g. The relationship between total length (TL), fork length (FL) or standard length (SL) and total weight (TW) was determined by fitting the data to a potential relationship for males and females in the equation:

$$TW = aTL^b$$

To confirm whether b values obtained in the exponential regression was significantly different ($\alpha = 0.05$) from the isometric value of 3.0, this equation according to Sokal and Rohlf (1981) was applied: $t_s = (b-3) / s_b$, where t_s is the two-tailed t-test value, b the slope, and s_b the standard error of the slope (b). The comparison between t_s and the respective critical table values allowed me to determine whether b values were in the isometric ($b = 3$) or allometric range (negative allometric as $b < 3$ or positive allometric as $b > 3$) (Tesch, 1971; Somers, 1991).

2.3. Comparison of calcified structures

Scale, sagittae and vertebrae (Fig. 17) were used for age estimation. Six to twelve non-regenerated scales were extracted from the left flank, near the tip of the pectoral fin and below the lateral line. Scales were washed with nylon for fat elimination and immersed in 5% potassium hydroxide for 24 h. Rinsed in water and bound tightly between two glass slides. Sagittae and first two trunk vertebrae were removed and stored in glycerin and ethanol respectively. The distal surfaces of the sagittae and vertebrae still immersed in pure glycerin were immersed in pure glycerin, and the centra were examined on a background using reflected light by an image processing system consisting of a computer, a video camera microscope (Zeiss DV8), and the Optical Pattern Recognition System software package of Image-Pro Plus Version 4.1. (Fig. 18)

Scale annuli were distinguished by criteria used by Jearld (1983). Annuli on sagittae and vertebrae were defined by Casselman (1974). There is linear relationship between structure radius and total length. The structure is chosen, which has a highest correlation coefficients.

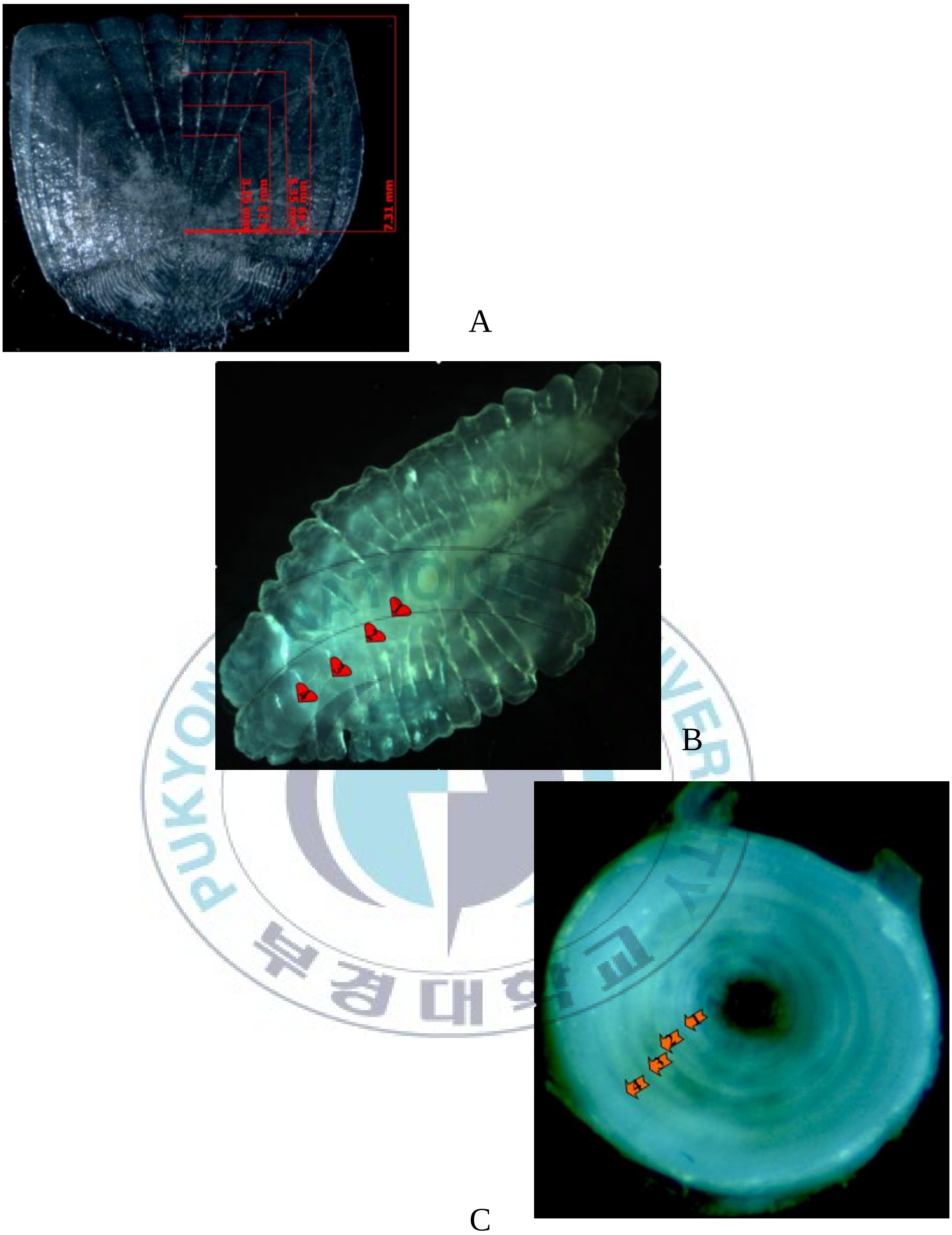


Fig. 17. Calcified structures photograph of *Micropterus salmoides* collected for ageing by reflected light. (A: scale, B: sagittae, C: vertebrae)

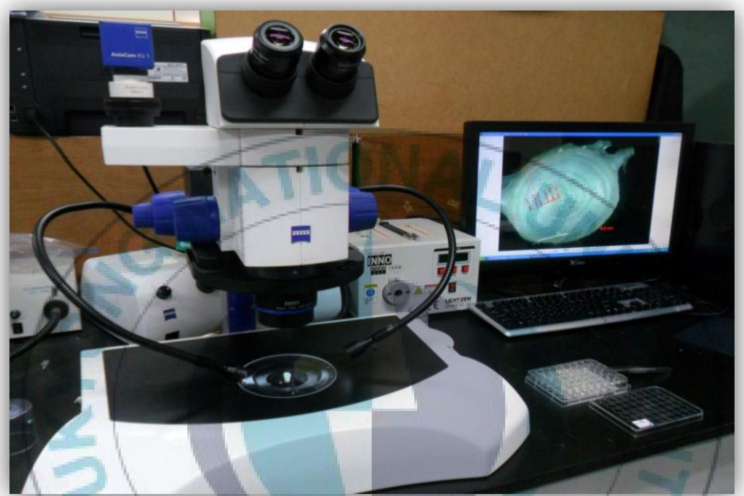


Fig. 18. Aging analysis using microscope of Carl zeiss Discovery v.8 video camera

2.4. Validation of age and the annuli formation periodicity

Structures were read twice by the author at an interval of 20 days. They were read randomly to avoid bias in assigning ages. The average percentage error (*APE*) and coefficient of variation (*CV*) were was used to compare age readings (Beamish and Fournier, 1981),

$$APE_j(\%) = 100 \times \frac{1}{\mathrm{R}} \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j}$$

$$CV(\%) = \frac{1}{N} \sum_{j=1}^{N} \frac{\sqrt{\sum_{i=1}^{R} (X_{ij} - X_j)^2 / R - 1}}{X_j} \times 100\%$$

Where R is the number of times each fish is aged, X_{ij} is the i (th) age determination of the j (th) fish, X_j is the mean age calculated for the j (th) fish.

To validate the rings as indicators of the fish's age, rings were counted and radii were measured. The number of rings must show a directly proportional relation to structures' size and fish length for being considered a growth indicator. This relationship was done by linear regression using the Fraser-Lee equation (Francis, 1990),

$$TL = a + bR$$

Where SL is standard length, R is scale radius, a and b are the parameters to be estimated.

Marginal increment (*MI*) analysis was used to validate the periodicity of growth (Lai et al., 1996),

$$MI = \frac{R - r_i}{r_i - r_{i-1}}$$

Where R represents structure radius, ri and ri-1 are annular radii of the last and penultimate annuli, respectively. The period of annuli formation was considered as the one for which the MI displayed the smallest value.

2.5. Growth back-calculation

Based on the linear regression between fish length and structure radius, lengths at growth mark formation were back calculated using the Fraser-Lee equation (Francis, 1990),

$$L_i = c + (TL - c)(\frac{S_i}{S})$$

Where Li is the total length of fish when growth mark i was formed, TL is the total length at time of capture, Si is the distance from scale centre to growth mark I, S is scale radius and c is the intercept on length axis of linear regression between total length and scale radius.

The growth curve was modeled using the von Bertalanffy growth equation,

$$L_t = L_\infty(1 - e^{-k(t-t_0)})$$

The growth performance (φ') of a species can be captured by the growth index (Munro and Pauly, 1983), which can be used to compare growth rates between species and to evaluate growth performance potential under various environmental stresses (Pauly, 1994).

$$\varphi' = \log_{10} K + 2\log_{10} L_\infty$$

where Lt is the total length at age t, L_∞ is asymptotic length, K is the coefficient of growth, t_0 is the theoretical age when predicted mean length is zero.

Longevity was calculated from Taylor's equation (Taylor 1958):

$$A_{0.95} = t_0 + 2.996/K$$

where $A_{0.95}$ is the lifespan or age required to reach 95% of the final length (L_∞), and t_0 and K are von Bertalanffy growth parameters.

Natural mortality was computed by the method of Pauly (1980), assuming a mean annual water temperature (T) for the lake of Goe-san of 17.5 ℃:

$$\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T$$

where L_∞ and K are VBG parameters, and T is the annual average temperature of the habitat (℃).

Length-weight relationships were tested for differences between sexes using the ANCOVA. The MI differences during the months were evaluated by one-way ANOVA. When ANOVA was significant, differences in means of the variables were tested by the posterior Tukey-HSD method. The parametric paired t-test was used to compare assigned ages between twice readings of one reader.

2.6. Reproduction

2.6.1. Sex ratio and gonad stages

Gonad samples of each identifiable sex and stage of development were preserved for histological inspection and fecundity estimation. We examined macroscopically the gonads of both sexes of *M. salmoides* from Goe-san Lake and assigned reproductive stages according to the development criteria based on color, size and visibility of oocytes (Fig. 19). Stage I, juvenile stage; Stage II, resting stage; stage III, developing stage; Stage IV, ripe stage and Stage V, spent stage (Table 6).

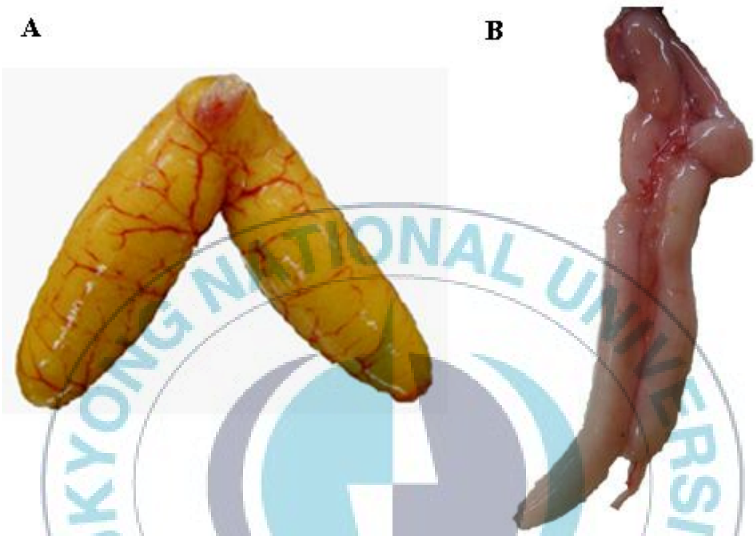


Fig. 19. Ovary and oocyte photograph of *Micropterus salmoides*. (A. Ovary: stage V; B. Oocyte: stage IV).

Table 6. Macroscopic characteristics of the maturity stages of the ovary and testis of *Micropterus salmoides*

Macroscopic stage	**Description**
Juvenile	Gonads not fully formed but present as two small sacs.
Resting	Ovary slightly yellowish. Oocytes macroscopically distinguishable. Testis small and opaque.
Developing	Ovary enlarged, oocytes readily visible and yellow. Testis broadened, distended and cream in color.
Ripe	Oocytes of maximum size, yellow and hydrated. Testis swollen to maximum size.
Spent	Ovary partly empty and flaccid with irregular oocyte size. Testis flaccid.

2.6.2. Gonadosomatic index (GSI) and hepatosomatic index (HSI)

The gonadosomatic index (GSI) was calculated by the equation (Chris et al., 2011):

$$GSI = \text{gonads weight} / (\text{somatic total weight} - \text{gonads weight}) \times 100$$

Monthly change in the hepatosomatic index (HSI) was also analyzed as a clue of the energy budget during the reproductive cycle. HSI index was determined as follows:

$$HSI = (\text{liver weight}/\text{somatic gonad weight}) \times 100$$

2.6.3. Fecundity and the relationship with body size

We used ovaries of 172 ripe specimens with III and IV maturity stage, from females caught in March in order to estimate absolute and relative fecundities. The gonads were removed, weighed and then placed in Gilson's fluid for 3–4 weeks to harden eggs and dissolve ovarian membranes. The peritoneum was removed and individual eggs were released from the egg mass. The number of eggs was estimated by gravimetric method, using three pieces removed from the ovary.

$$\text{Fecundity } (F) = W \cdot P \cdot N / W_s$$

Where W is total weight of gonad, P is weight of sample after Gilsons/weight of sample before Gilson's, N is mean number of ovary from 3 subsamples, Ws is the mean weight of ovary from 3 subsamples. (Bagenal and Tesch, 1978).

2.6.4. Egg size

Eggs volume was measured from 10 eggs sub samples and directly counted to minimize bias. The eggs were measured along the major and minor axes using light microscope to the nearest 0.01 mm. The eggs were treated as ellipsoids, and the volume (*V*) of eggs was calculated by using the following equation,

$$V = \frac{4}{3}\pi r_1 r_2^{\,2}$$

where r_1 is the half the major axis and r_2 is half the minor axis. The chorionic membrane that tightly adhering to eggs surface was also included in axis measurement.

2.6.5. Length at sexual maturity

The total length and age at sexual maturity of *M. salmoides* from Goe-san lake were estimated using macroscopic staging of gonads as described. During the spawning season, collected fish were classified as immature if the gonads were estimated to belong to stage 1 and 2, and as mature if belong to stage 3 or 4. By calculating the proportions of mature fish in each 10 mm TL class and each year class, it was known that logistic curves was fitted to the data. Sizes at maturity (L_{50}) were determined separately for each sex. If there was no significant difference between sexes, data were pooled to use. The proportion (P) of sexual mature individuals by length (L) adapting a logistic equation (King, 1995):

$$P = 1 / (1 + \exp[-r (L - L_m)])$$

Where r is the slope of the curve, and Lm is the mean length at sexual maturity, or the length which corresponds to a proportion of 0.5 in reproductive condition.

This equation can be transformed to linear form as:

$$Ln[(1-p)/p] = rL_m - rL$$

which can be treated as a linear regression and solved analytically. From this equation, the intercept (a) is rL_m and the mean length at sexual maturity, $L_m = a/r$.

A Chi-squared (χ^2) test was chosen to analyze the difference in sex ratio. One-way analysis of variance (ANOVA) was used to test difference in mean GSI and HSI between sexes. Prior to ANOVA, assumption of ANOVA were examined by Bartlett's test. Multiple comparisons were made with Least-significant difference (LSD) test. Statistical were carried out using SPSS Version 17.0 and SYSTAT Version 9.0.

2.7. Feeding ecology

2.7.1. The sampling procedures of stomach content

All samples for gut content analysis (GCA) were preserved on site. Small bass

(<150 mm TL) were preserved whole, while only the stomachs were retained from larger fish. All samples were fixed in the field in 10% buffered formaldehyde and later transferred to 70% ethanol for storage. In order to examine the food items, the fish abdomen was split with scissors from anus to the throat, and the digestive system was removed with forceps. The stomach was then taken out by cutting of the elementary tract flash between the end of esophagus and the pylorus. The volume of the contents of each stomach was then measured and 4% formaldehyde was added for conservation. The contents were then identified and counted under a microscope in petri dishes.

2.7.2. The criterion of stomach fullness

Gut contents were analyzed according to recommendations in Hyslop (1980). First, stomach fullness was recorded as empty, 25%, 50%, 75% or 100% full. This five different fullness conditions were identified and they were rated as: (1) completely filled and swollen; (2) just filled over full length, but not swollen; (3) content divided in different patches; (4) very few feed particles and (5) completely empty.

2.7.3. Diet composition

The diet was quantified in three ways: (1) prey abundance (%N), the number of individuals as a proportion of all prey items; (2) frequency of occurrence (%F), the number of stomachs containing a specific prey item as a percentage of all sampled stomachs; and (3) the volume of each prey item as a percentage of the total volume of all stomach contents (%V). An index of relative importance (IRI) was calculated for each prey item by IRI= (%N + %V) × (%F) (Pinkas et al., 1971) and then expressed as a proportion of the sum of IRI values for all prey items (%IRI).

Using the statistical software package R, the log-linear G statistic was used to assess whether or not diet was dependent on size class using a 2 size-classes × 29 prey-item contingency table (Quinn and Keough, 2002). The same test, using a 2 size-classes × 5 stomach-fullness categories contingency table was used to assess differences in stomach fullness between large and small sized bass. Similarly, for each of the dominant food groups, the Kolmolgorov-Smirnoff two-sample test was used to detect differences in numerical (N) contribution between the two size groups.

3. Results

3.1. Age, growth and mortality

3.1.1. Compositions of length and weight

The largemouth bass caught in size ranged from 98.8 to 413.8 mm in total length (TL) and from 11.68 to 1,500.05 g in total weight. Out of the 211 specimens collected, 101 (47.86%) were identified as males, ranging from 98.8 to 347.2 mm and 11.68 to 1,017.54 g, while the other 110 (52.13%) individuals were females from 104.4 to 413.8 mm and 21.90 to 1,500.05 g. Mean total length (± SD) for males and females were 255.10 (± 51.66) mm and 262.58 (± 46.92), respectively. The size-distribution showed that both males and females were not normally distributed (Anderson-Darling normally test: $P > 0.05$) (Fig. 20). There was no significant difference in size composition structure between males and females (Kolmogorov-Smirnov two-sample test; $d_{max} = 0.204$, $P = 0.652$).

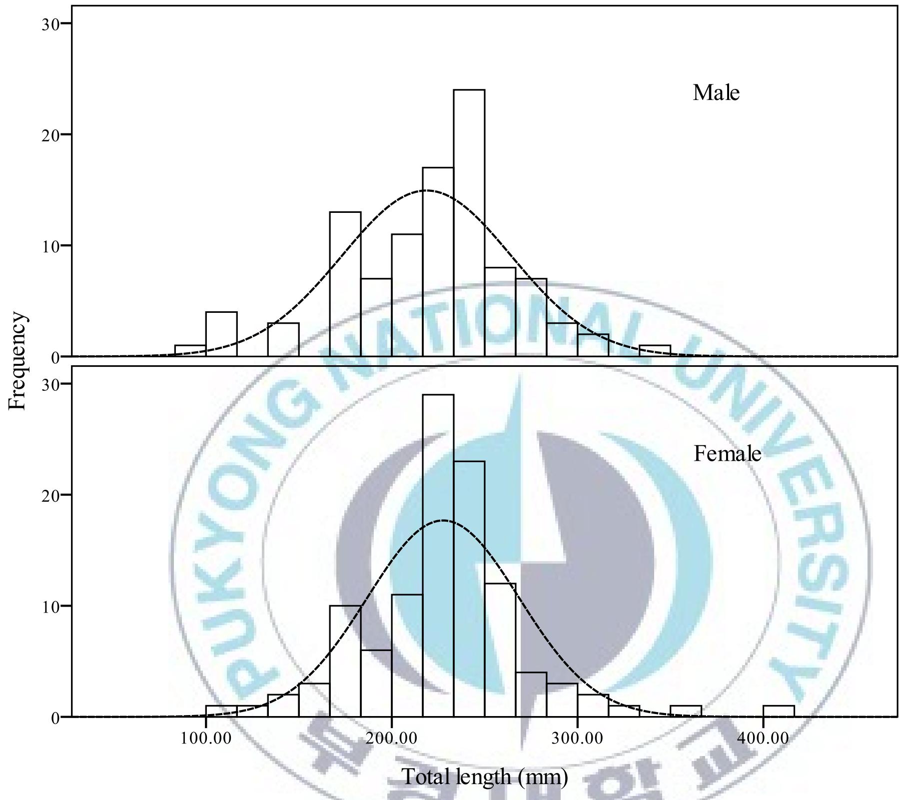


Fig. 20. Total length distribution in both sexes samples of *Micropterus salmoides*.

3.1.2. L-W relationship

The total weight-total length relationship was separately evaluated for all individuals and grouped by sexes (females and males). Slopes of BW-TL regressions did not differ significantly between sexes (ANCOVA test for equal slopes: F = 0.991, P > 0.05; ANCOVA test for intercepts: F = 15.68, P > 0.05). Therefore, sexes were modeled together, and the equation for all individuals was given as follows:

$$W = 0.000007 \cdot L^{3.099}$$

The b-values of the relationships implied that body shape of combined sexes display algometric form, with 95% confidence interval for b-value of 3.041-3.116 (Fig. 21).

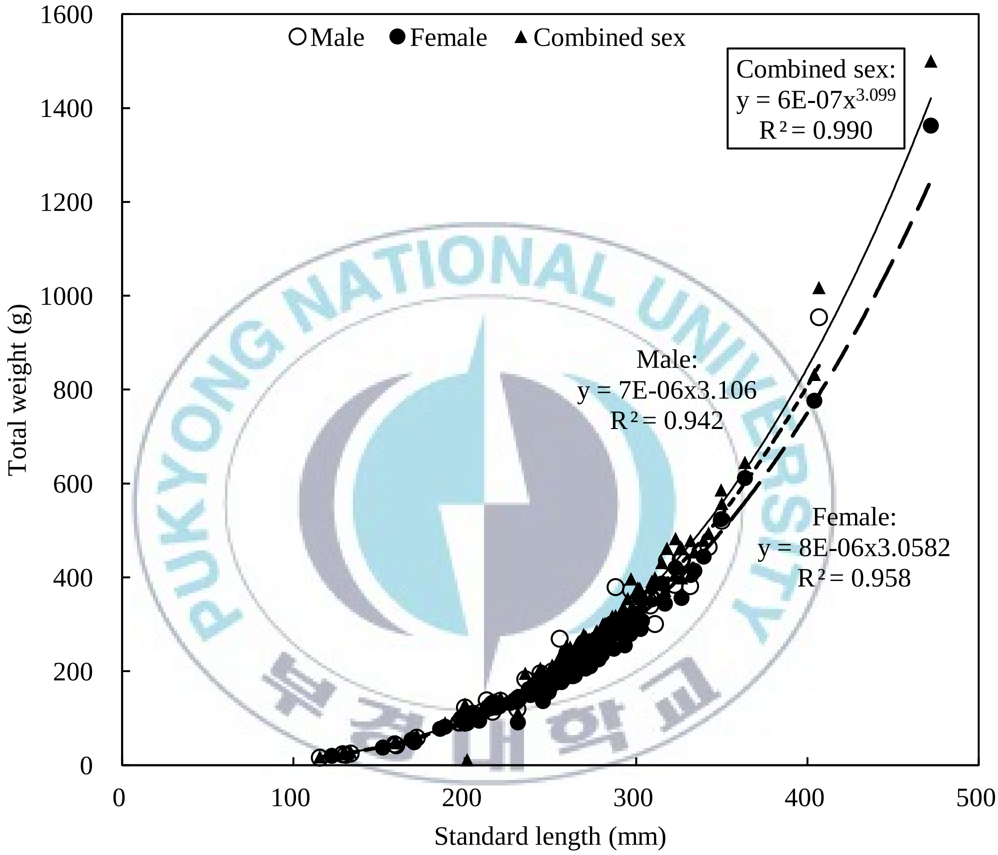


Fig. 21. Relationship between total length and total weight in the samples of *Micropterus salmoides*..

3.1.3. Comparison of calcified structures and decision

The relationship between structure radius and total length was analyzed by linear regression (Table 7). The regression coefficient of sagittae is the highest. Therefore, the sagittae has been chosen as the calcified structure to determine the age and estimate the growth. The relationship between sagittae radius and total length was: L = 65.64R+22.45 (Fig. 22).

3.1.4. Ring formation

The relationship between the sagittae radius and the annulus radii was examined for the otolith taken from the specimen. There were linear relationship between them, and they were shown in Fig. 23.

Table 7. Linear regression of structure radius (R) and total length (L) by combined sex of *Micropterus salmodies* in Goe-san Lake.

Structure	Linear regression	Regression coefficient (r^2)
Scale	L = 52.18R + 18.95	0.706 *
Sagittae	L = 65.64R + 22.45	0.923 * *
Vertebrae	L = 63.43R + 26.49	0.852 * *

^{ns} = P>0.05 * = 0.05>P>0.01 * * = P<0.01

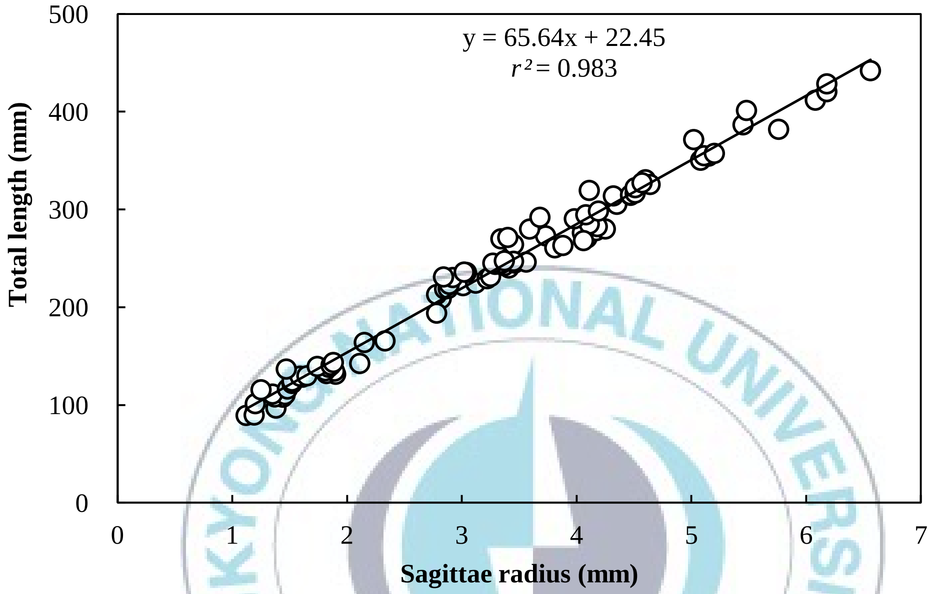


Fig. 22. Relationship between total length and sagittae in the samples of *Micropterus salmoides*.

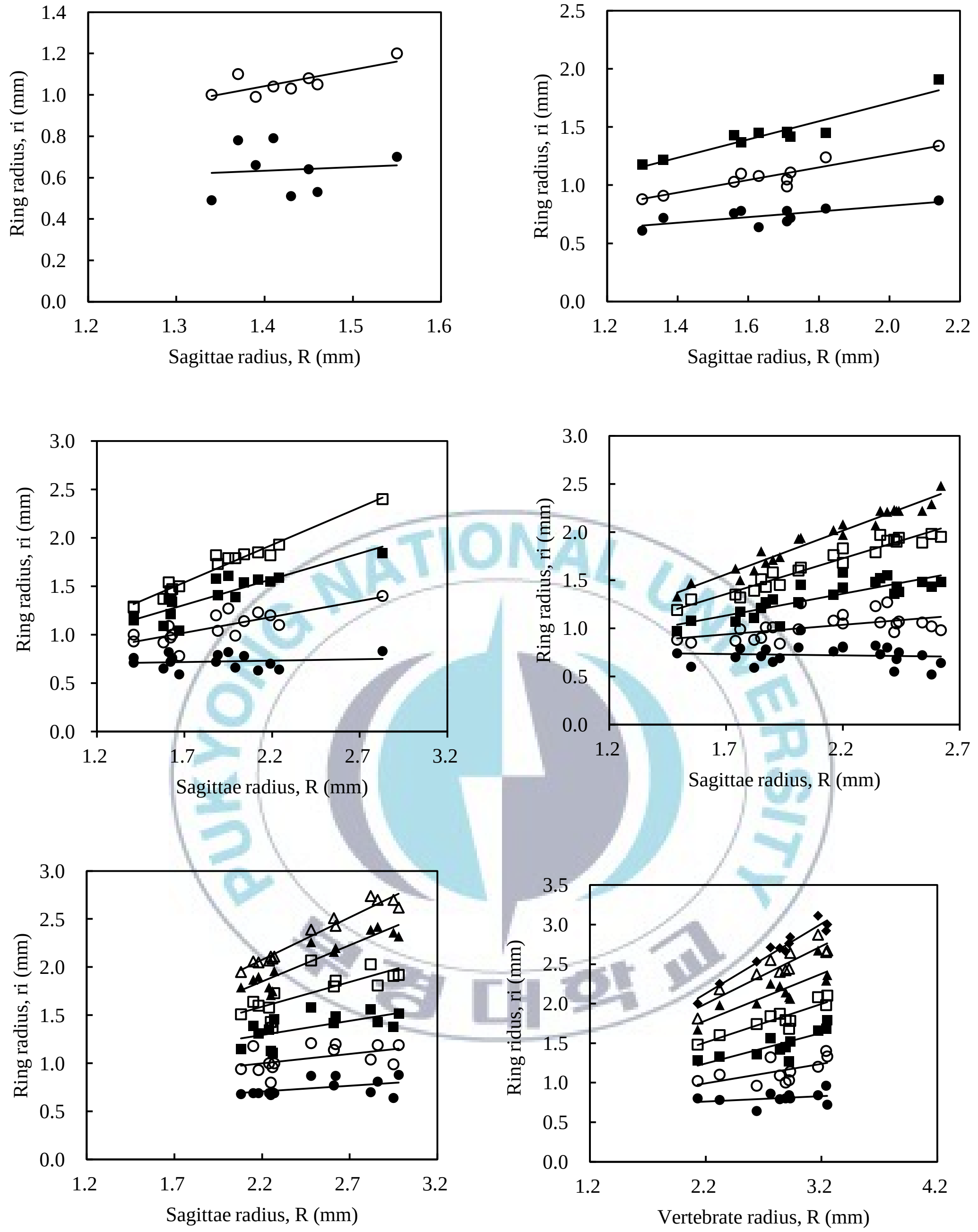


Fig. 23. Relationship between sagittae radius and annulus radii in the otolith of *Micropterus salmoides*

3.1.5. Validation of age by sagittae

The weight of both left and right sagittae was recorded with an accuracy of 0.1 mg and compared using a *t*-test for paired comparison. As no significance was found (Student's *t*-test, df = 100, t = 1.532, P > 0.05).

Sagittae was immersed in ethanol with distal face up and the annulus was counted using a microscope under reflected light against a dark background. The nucleus and the opaque zones of otolith appeared as light rings translucent or hyaline zones as dark rings. The combination of each opaque and subsequent translucent zone was considered to be an annulus.

3.1.6. Period of annuli formation

The monthly changes of marginal growth index (MI) differed significantly (ANOVA, $F = 101.69$, $P < 0.05$), which expressed the relative growth patterns of the scale in a year, are shown in Fig. 24. The index showed the minimum value in April, increased gradually from May to October and attained the maximum value in October. The value in November was slightly lower than that in October.

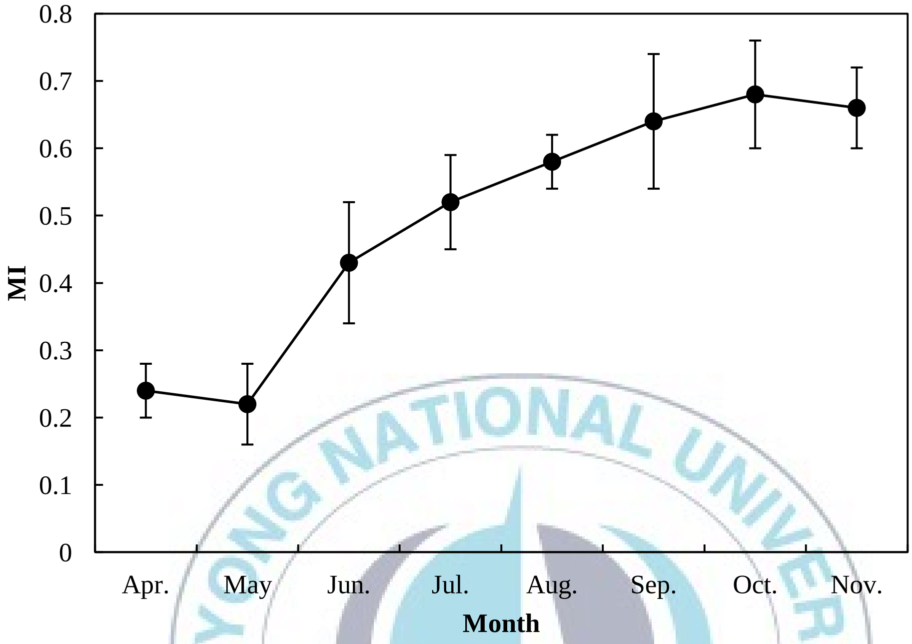


Fig. 24. Monthly change of marginal growth index (MI) of *Micropterus salmoides* in Goe-san Lake in 2011

3.1.7. Age composition

The age of the largemouth bass studied ranged from 0 to 8 years, and the age groups 0, 2 and 3 were the dominant groups (Table 8). By the twice observation, the first reading assigned ages between 0 and 8 years, and the second reading was between 0 and 7 years. APE was used to determine age precision and agreement, first and second age readings agreed for 63% of the used fish. The paired *t-test* applied to compare age assigned by two time readings revealed significant differences ($P < 0.05$) (Fig. 25).

3.1.8. Back-calculation of total length

The back-calculated total length (Table 9) was obtained from the corrected ring radius using the equation $L_i = c + (TL-c) \times (S_i/S)$, which gives the standard length at the time of the ring formation.

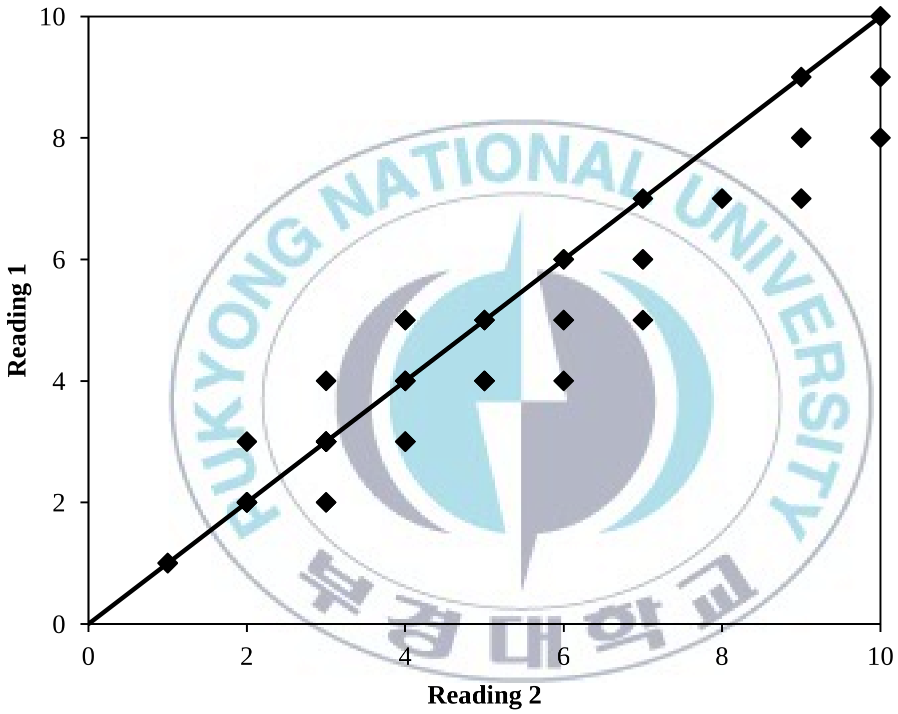


Fig. 25. Agreement plot for comparisons between ages assigned twice reading by the same reader.

Table 8. Composition for age, total length and total weight of *Micropterus salmoides*

Age (year)	Sample (ind.)	Percentage (%)	Total length (mm)	Total weight (g)
			Mean ± SD	Mean ± SD
0^+-1	24	26.37	121.45 ± 16.36	23.76 ± 9.10
1^+-2	4	4.40	170.23 ± 27.79	71.56 ± 33.80
2^+-3	26	28.57	241.16 ± 22.78	200.72 ± 69.19
3^+-4	18	19.78	275.53 ± 21.59	273.62 ± 74.86
4^+-5	6	6.59	318.82 ± 6.45	569.65 ± 64.54
5^+-6	6	6.59	345.05 ± 14.59	1 559.27 ± 221.32
6^+-7	4	4.40	385.35 ± 12.37	899.11 ± 52.41
7^+-8	2	2.20	426.00 ± 7.78	1 158.57 ± 172.49
8^+-	1	1.10	472.00 ± 0.00	1 500.05 ± 0.00

Table 9. Back-calculated standard length of *Micropterus salmoides* by pooled data in Goe-san Lake

Age (year)	Sample	Standard length (mm)	Back-calculated standard length (mm)							
			L1	L2	L3	L4	L5	L6	L7	L8
1	4	121.4	138.5							
2	26	170.2	135.6	202.3						
3	18	241.2	136.2	198.6	253.4					
4	6	275.5	136.4	203.2	260.3	302.8				
5	6	318.8	133.8	203.1	254.9	303.5	328.5			
6	4	345.1	129.5	200.3	244.5	305.8	343.2	364.3		
7	2	385.4	130.3	199.7	253.2	297.3	336.9	381.4	401.2	
8	1	424.5	139.7	198.9	246.8	298.1	321.5	374.3	403.4	434.6
Measured mean			135.6	200.8	250.4	299.2	329.5	374.8	398.9	432.6

3.1.9. Growth equation

The Bertalanffy growth equation was determined from the back-calculated standard length at age for combined sex of largemouth bass (Fig. 26). The equation is

$$L_t = 448.76\ (1 - e^{-0.234(t+0.527)}).$$

The growth performance index was 4.67 calculated by the growth parameters.

3.1.10. Growth rate and growth acceleration

The first derivative and second derivative were calculated on the growth equation, and the equations of growth rate and growth acceleration were described as follow,

$$dl/dt = L_{\infty}Ke^{-k(t-to)} = 105.01\ e^{-0.234(t-0.527)}$$

$$dl^2/dt^2 = -105.01\ e^{-0.234(t-0.527)}$$

In Figures 26 and 27, it was shown that the growth rate decreased with time, and growth acceleration increased with time.

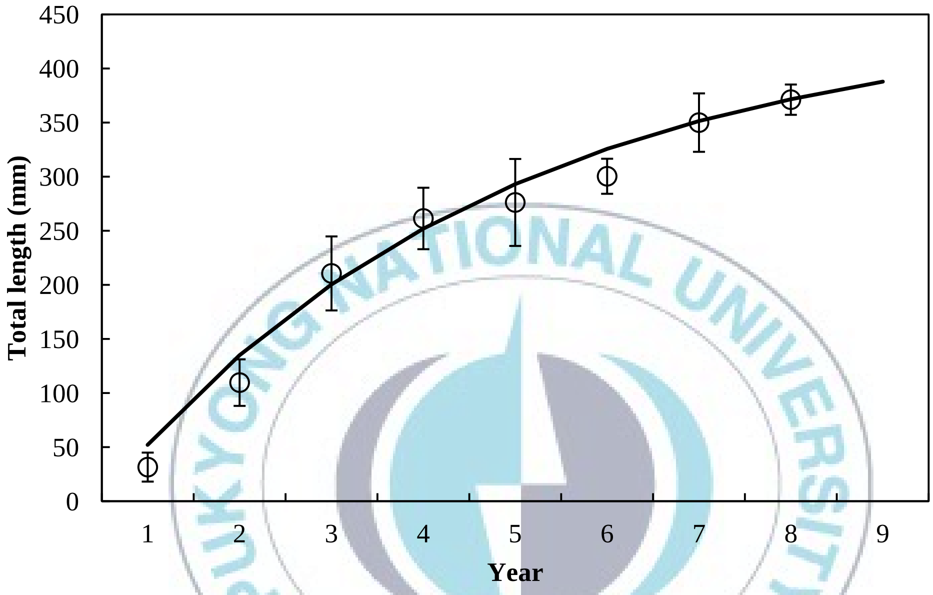


Fig. 26. Growth curve of *Micropterus salmoides* in Goe-san Lake in 2010

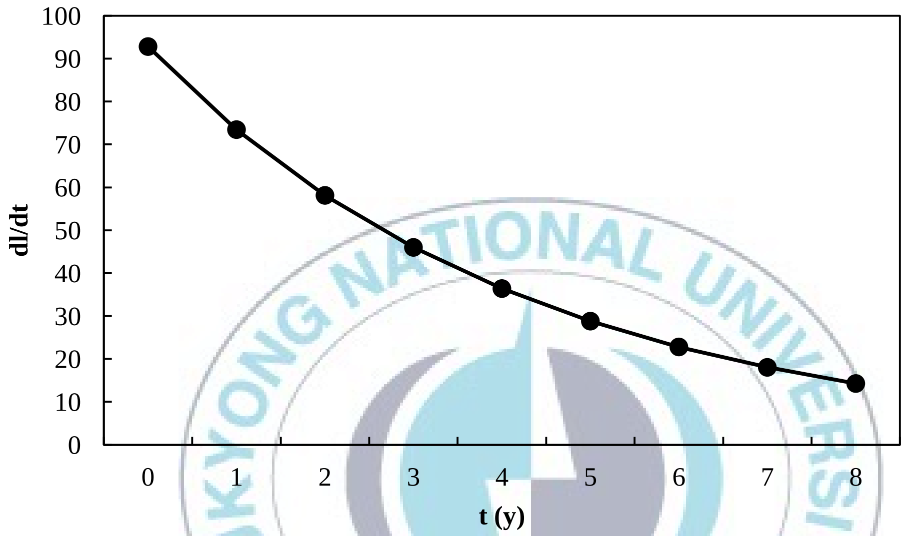


Fig. 27. The growth rate curve of body length of *Micropterus salmoides*

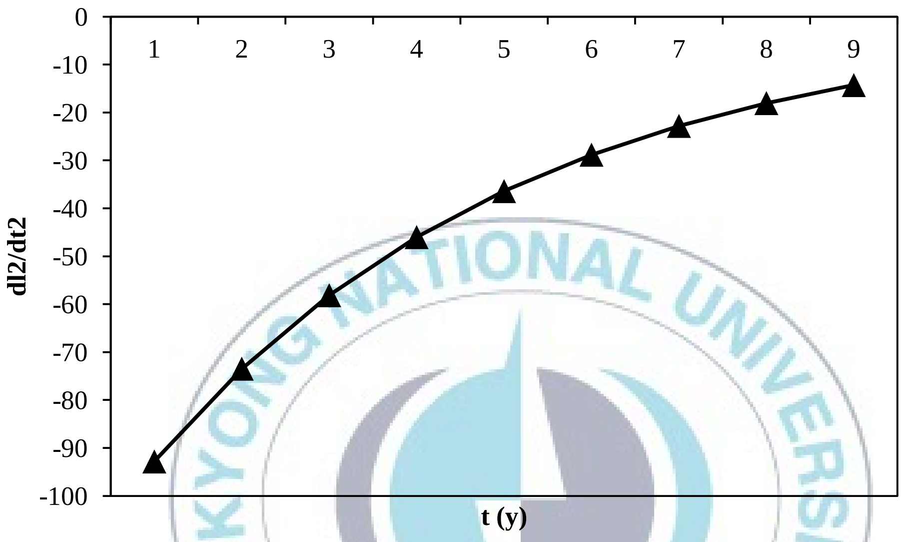


Fig. 28. The growth acceleration curve of body length of *Micropterus salmoides*

3.1.11. Longevity and natural mortality

The estimated physiological life span of *M. salmoides* was 12.3 years. Estimates for natural mortality (M) varied slightly depending on the method used. Based on the model of Pauly, natural mortality of *M. salmoides* was 0.32 yr^{-1} in Goe-san Lake. It was relatively low.

3.2. Reproduction

3.2.1. Sex ratio

The total 211 gonads (male, n = 101; female, n = 110) of *M. salmoides* were macroscopically examined to assess their reproductive stage of development. The sex ratio of female to male was 1.12:1. There was no significant difference (χ^2 = 0.07, df = 1, P > 0.05). Sex ratios differed between months (Fig. 29). It ranged from 0.63-1.95, with the peak in May. Sex ratios differed significantly with size (χ^2 = 35.44 , df = 3, P < 0.01), with the ratio of females to males increasing steadily from an 1:1 ratio less than 200 mm total length (Table 10).

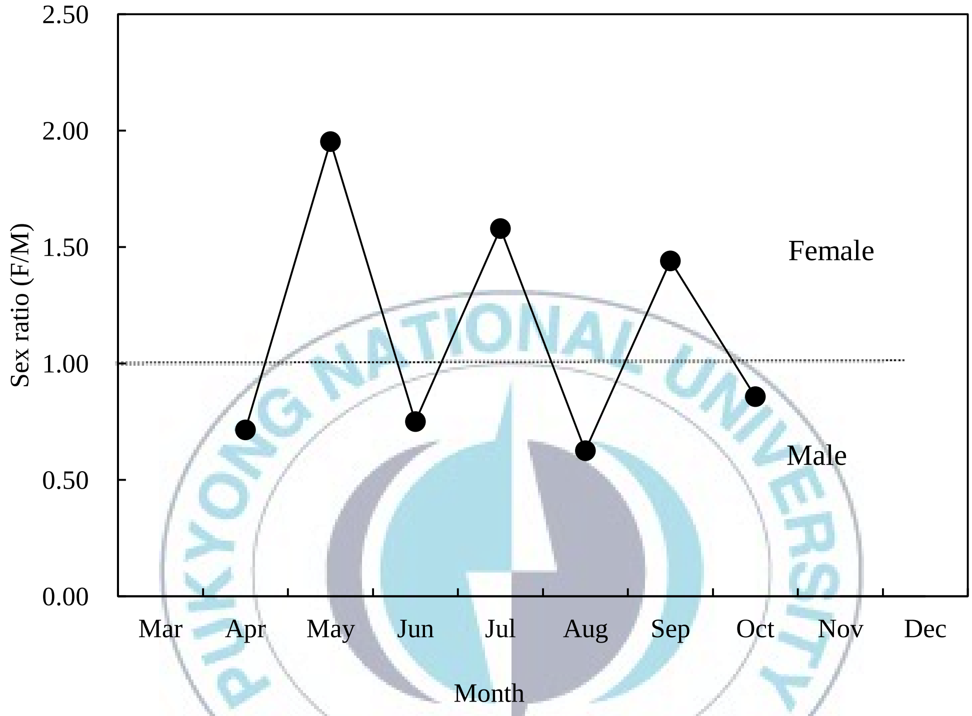


Fig. 29. Sex ratios of *Micropterus salmoides* from April to October in 2010 in Goe-san Lake, Korea

Table 10. Ratio of female to male of *M. salmoides* in relation to the size in Goe-san Lake

TL (mm)	♀	♂	n	♀:♂
≤ 200	7	7	14	1:1
200-300	101	92	193	1.09:1
300-400	19	15	34	1.27:1
≥ 400	2	1	3	2:1

3.2.2. Spawning period

GSI and HSI were examined to determine the spawning season. In female, GSI was 4.63 in April, reached the peak 5.60 in May, and decreased greatly until July. The GSI of male had a similar pattern curve. The female HSI was greatly higher than that of male from April to July, and slightly higher from July to October. The spawning period was also determined between April and June, and main spawning time was May. There was a significant difference in the mean GSI of both sexes between months (ANOVA, Female: $F = 39.65$, $df = 1, 6$, $P < 0.01$; Male: $F = 17.28$, $df = 1, 6$, $P < 0.01$) (Fig. 30a). The pattern of HSI was similar with that of GSI (Fig. 30b). The peaks also occurred in May. The female HSI was greatly higher than that of male from April to July, and similar from July to October. The spawning season was also determined in May. Significant differences between testis stages (ANOVA, $F = 214.8$, $df = 4, 100$, $P < 0.01$) and ovary stages (ANOVA, $F = 187.6$, $df = 4, 109$, $P < 0.01$) were found, respectively. There was a significant difference in the mean HSI among months (ANOVA, Female: $F = 17.6$, $df = 1, 6$, $P < 0.01$; Male: $F = 30.4$, $df = 1, 6$, $P < 0.01$). The monthly variation of GSI was significantly correlated with HSI for both sexes (Female: $r = 0.882$, $P < 0.01$; Male: $r = 0.669$, $P < 0.01$).

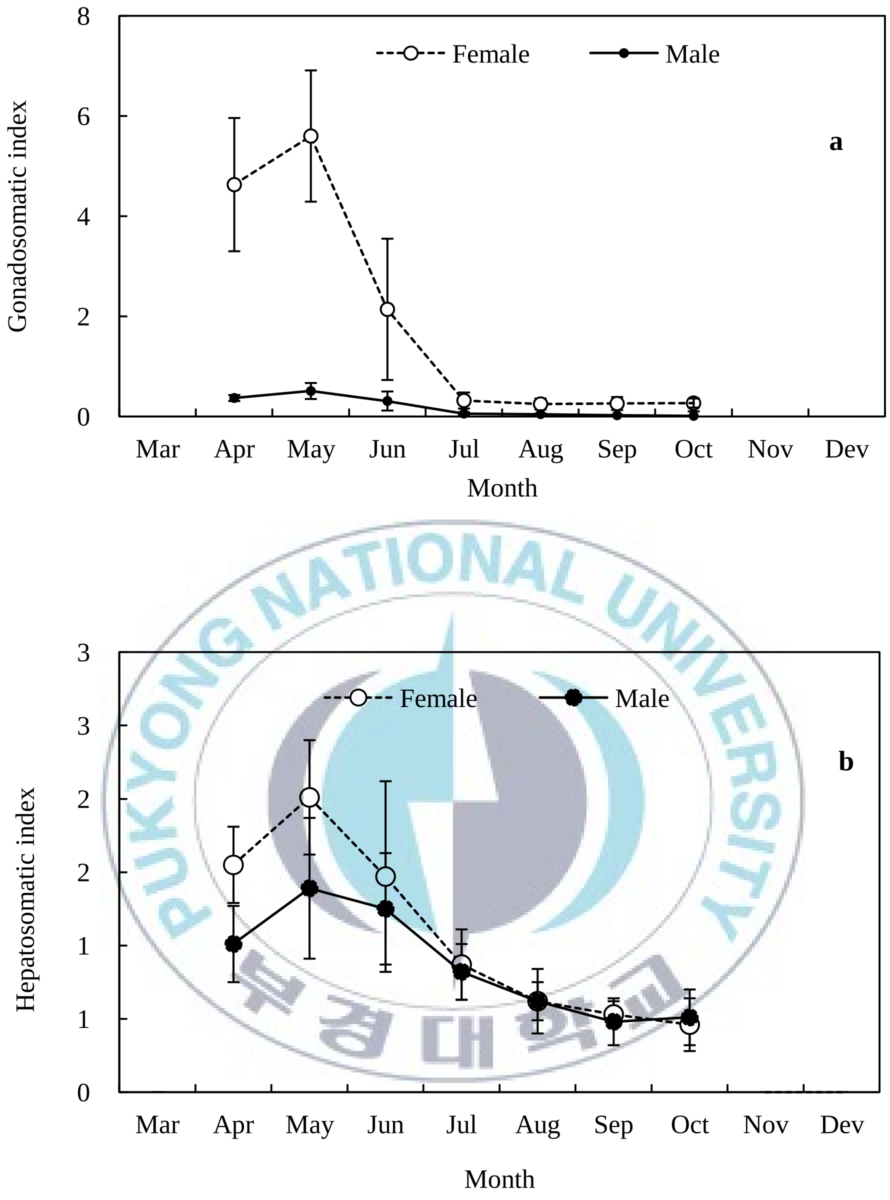


Fig. 30. Gonadosomatic index (mean % GSI ± SE) and hepatosomatic index (mean % HSI ± SE) for female and male *Micropterus salmoides* in Goe-san lake, Korea. (a, GSI; b, HSI)

3.2.3. Length and age at maturity

The age of the largemouth bass studied ranged from 0 to 8 years, and the age groups 2 and 3 were the dominant groups. The von Bertalanffy growth equation was determined from the back-calculated standard length at age for combined sex of largemouth bass. The estimated parameters of L_∞, K, t_0 were 459.1, 0.126 and - 0.416. Logistic curves for length at maturity were separated by sex. The estimated L_{50} of female *M. salmoides* (253 mm TL) was larger than males (227 mm TL) The relationship between the proportion of sexual mature and total length by sexes was calculated by fitting a logistic function (Fig. 31):

$$\text{Female: } P = 1 / (1 + \exp[-0.23 (L-252)])$$

$$\text{Male: } P = 1 / (1 + \exp[-0.98 (L-227)])$$

Males began to mature at smaller sizes and approach 100% maturity over a larger range of size classes than females. However, both females and males were estimated to reach 100% maturity at similar sizes (475 mm TL). The estimated age at 50% maturity of female and male was 2.44 and 2.03 years, respectively. By calculation, the age at sexual mature was 2.03 years for male and 2.44 years for female, respectively.

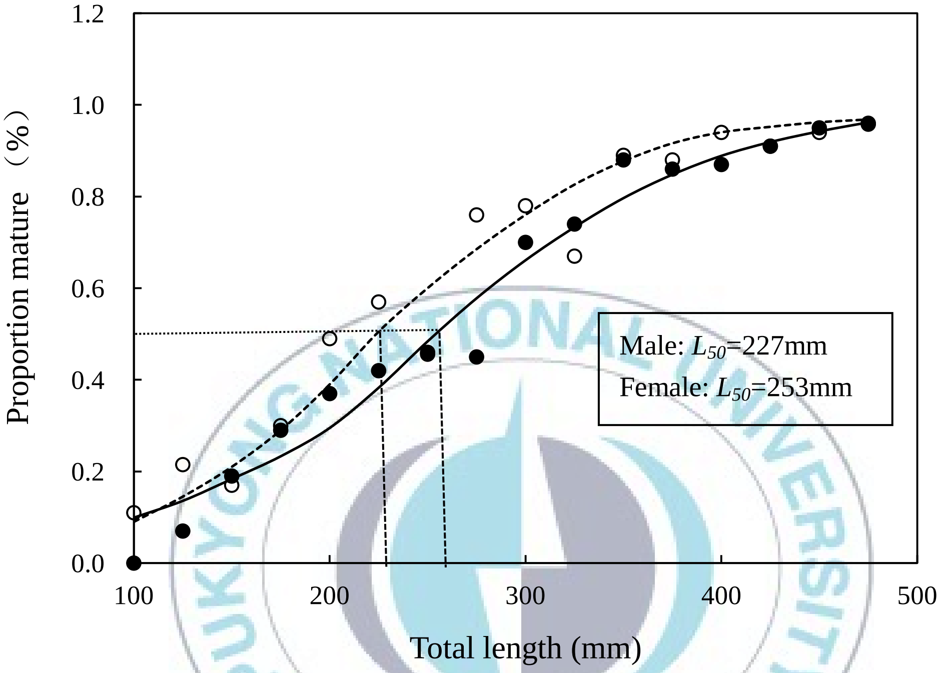


Fig. 31. Reproductive maturity total length with fitted logistic curves for male and female *Micropterus salmoides*. The logistic curve for males is represented by a dashed line and for female by a solid line.

3.2.4. Fecundity

The fecundity of *M. salmoides* was examined in maturing and ripe fish sampled between April and July. The observed fecundity varied between 7,568 eggs at 239 mm total length and 44,226 eggs at 324 mm total length. There were significantly positive relationships between fecundity and total length ($n = 51$, $r^2 = 0.736$, $p < 0.01$) (Fig. 32).

Fecundity is potentially affected by changes in abundance (Cushing, 1995). Although direct estimates of fecundity as a function of population size are comparatively rare, there is substantial information on changes in body size of fish as a function of abundance. In many exploited stocks, the spawning stock has become progressive more male-biased through the loss of large, old spawners that are disproportionately female (Marshall et al., 2006). In this study, the spawning stock was female-biased. It may be the large loss of male during the past exploited activities or the gear selective for more females. The highly fecundity of *M. salmoides* fecundity also well indicated that the largemouth bass has a flexible spawning strategy and has acclimatized well to Goe-san lake. The mean egg volume ranged from 4.32 to 5.64 mm^3. There was no regression relationship with total length and total weight ($p > 0.05$).

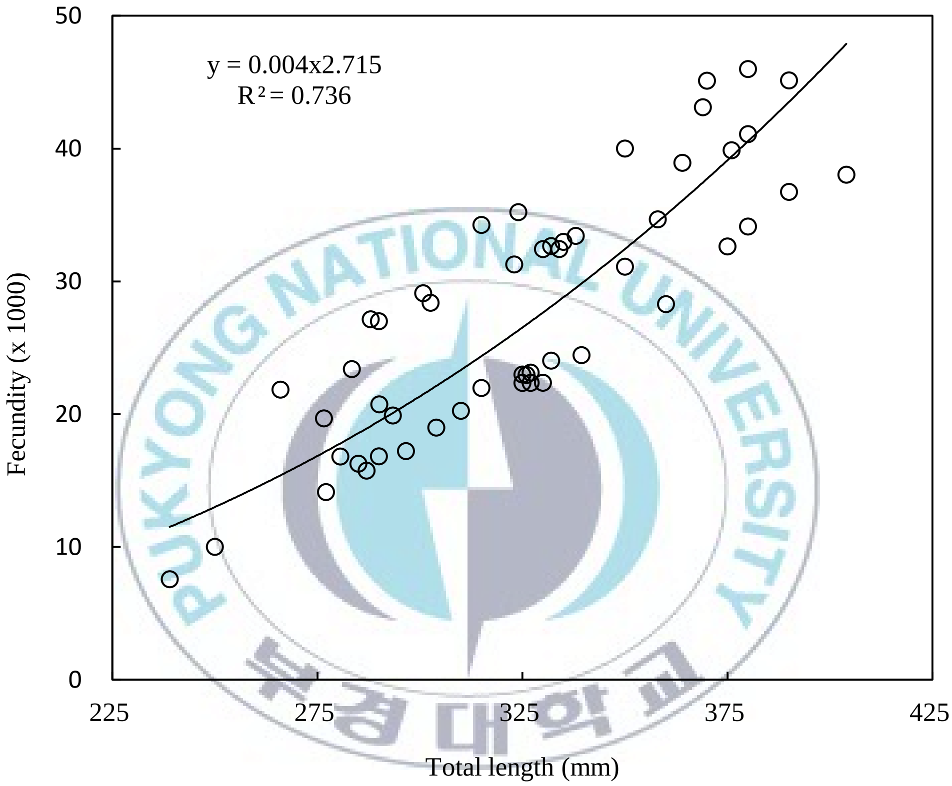


Fig. 32. Relationship between fecundity and total length (mm) for stage III and IV female *Micropterus salmoides* in Goe-san lake, Korea.

3.3. Feeding ecology

3.3.1. Stomach fullness composition

A total of 129 largemouth bass of two distinct size groups [small fish: 66–138 mm TL (n = 62) and large fish: 152–448 mm (n = 84)] were collected. Bass size differed with sampling locality and almost of the large fish was caught in the downstream near the dam, while the small fish were mostly sampled near upstream. Stomach fullness differed between size groups ($G = 10.37$, $df = 4$, $P < 0.05$) with those of small fish being emptier than those of the large fish (Fig. 33).

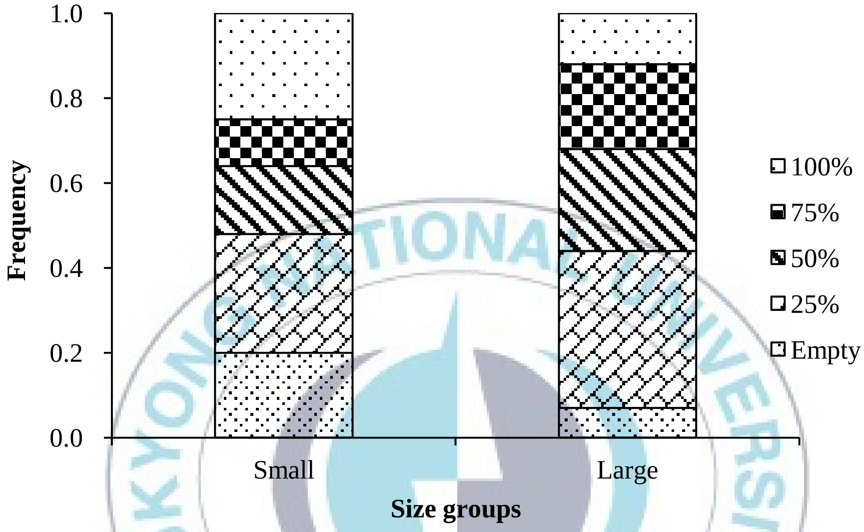


Fig. 33. Stomach fullness index, showing percentage contribution of each fullness category for large and small sized largemouth bass, *Micropterus salmoides*, in Goe-san Lake. (Small: 66-138 mm; large: 152-448 mm)

3.3.2. Diet composition

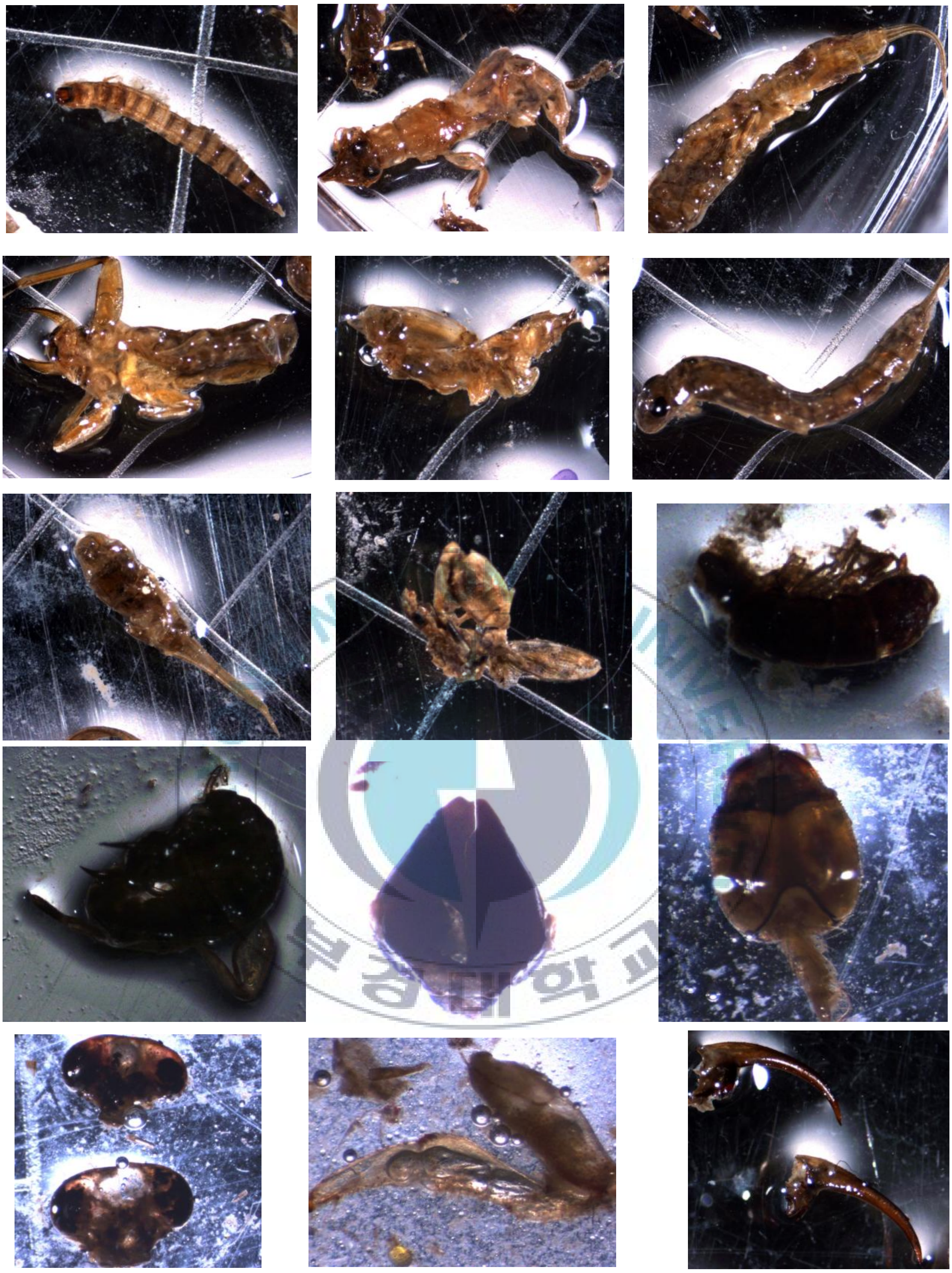
A total of 15 and 16 taxa were present in the stomachs of small and large bass, respectively, but only 8 taxa were found in stomachs of both size categories (Fig. 34, Table 11). *Leptocerus* sp. and *Amphipoda* sp. were the most important food items eaten by smaller fish. *Potamonautes sidneyi* and *Anax* sp. were the most important prey items for large largemouth bass.

Table 11. Results of gut content analysis. Prey abundance, occurrence and importance in small size class and large size class largemouth bass, *Micropterus salmoides*, in the Goe-san Lake, Korea

Prey taxa	Small					Large				
	N	N%	F%	V%	IRI%	N	N%	F%	V%	IRI%
Arachnida										
Hynobidae										
Hynobius sp.	0	0	0	0		9	3.8	2.5	0.1	0.12
Bufonidae										
Bufo sp.	0	0	0	0		0				
Arachnida										
Araneae										
Ambanus cochlea sp.	4	1.2	1	0.6	1.78	2	0.9	2.2	1.2	0.05
Arari										
Acari sp.	36	10.5	6.3			0				
Insecta										
Ephemeroptera										
Cloeon sp.	4	1.2	3.6	1.5	2.86	0				
Hemiptera										
Notonectid sp.	2	0.6	2.3	1.1	1.38	0				
Appasus sp.	0					2	0.9	2	0.7	
Trichoptera										
Leptocerus sp.	59	17.2	21.6	5.6	4.92	0				
Diptera										
Chiromonid sp.	73	21.2	27.2	3.6	1.85	0				
Odonata										
Trithemus sp.	1	0.3	0.6	1.7	1.05	27	11.5	8.5	4.1	2.04
Anax sp.	2	0.6	0.4	1.6	0.36	59	25.2	16.8	7.5	4.81
Leste sp.	2	0.6	1.2	0.5	0.13	18	7.7	4.2	2.3	1.42
Ischnura sp.	0	0.0				24	10.3	6.1	1.5	
Malacostraca										
Amphipoda										
Amphipoda sp.	148	43.0	30.4	1.1	3.41	4	1.7	0.9	0.4	0.18
Decapoda										
Palaemon capensis	1	0.3	0.5	0.9	0.59	1	0.4	0.6	0.2	0.07
Potamonautes sidneyi	0					75	32.1	21.8	8.6	6.6
Isopoda										
Isopod sp.	5	1.5	0.8	0.3	0.14	0				
Maxillopoda										
Calanoida										
Copepod sp.	4	1.2	2.5	0.6	0.45	0				

Table 11 (continued)

Prey taxa	Small					Large				
	N	N%	F%	V%	IRI%	N	N%	F%	V%	IRI%
Teleostei										
Centrarchidae										
Micropterus sp.	0					0				
Clupeidae										
Gilchristella aestuaria	0					6	2.6	1.12	0.4	0.38
Gobiidae										
Glossogobius callidus	3	0.9	1.6	1.1	0.32	5	2.1	2.04	0.7	0.06
Mugilidae										
Myxus capensi	0					2	0.9	0.5	0.3	0.04
Unidentified organic material				62.4					51.6	



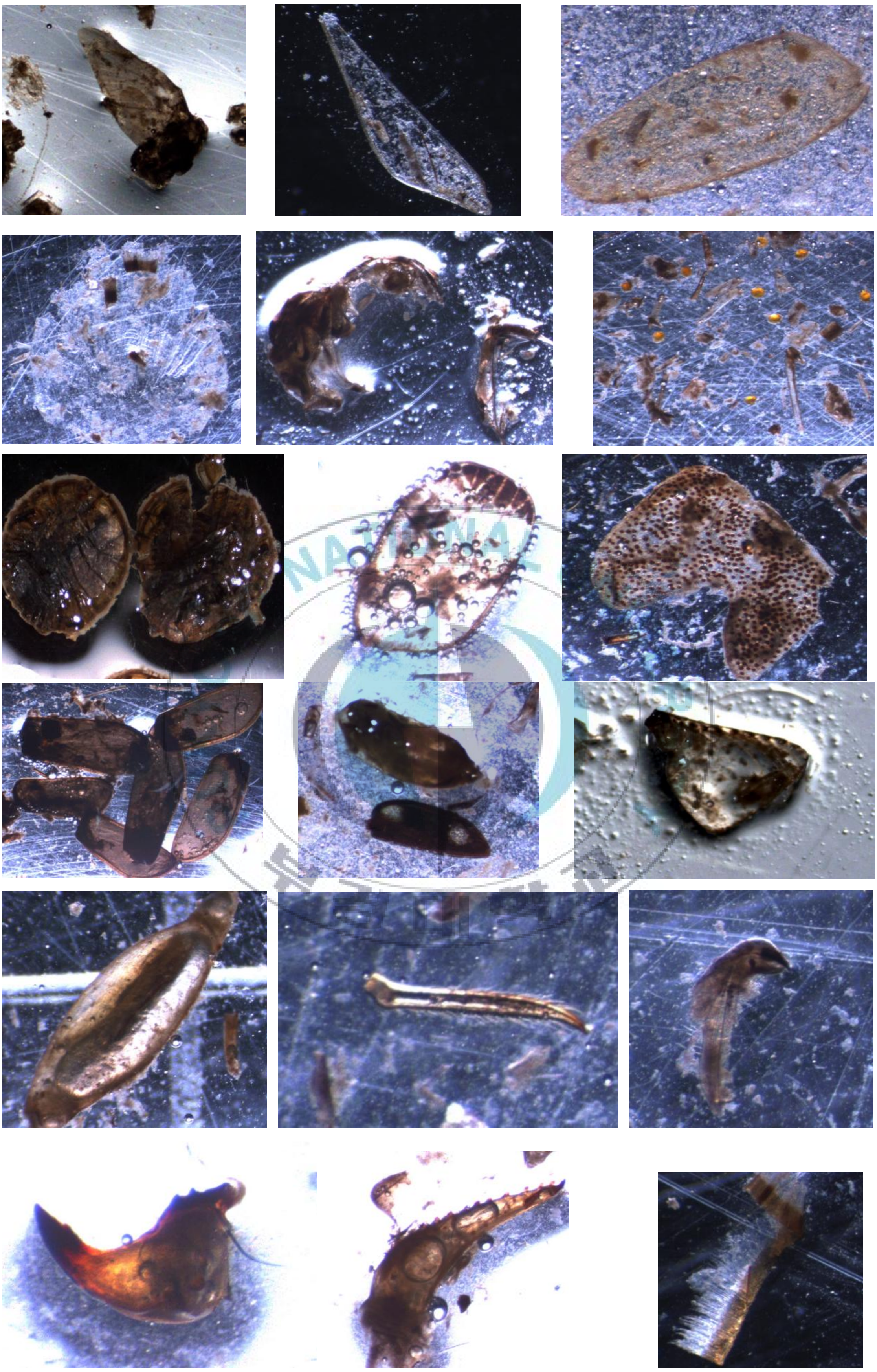


Fig. 34. Pictures of prey items collected from *Micropterus salmoides* in Goe-san Lake.

4. Discussion

4.1. Age and growth

4.1.1. Marginal increment

In teleosts, many calcified structures have been used for aging (Yole, 1989). There are different growth zones on them, which may be formed annually. How to validate it ? The marginal increment analysis on scales has frequently been used, but it is more useful in short-lived species (Campana, 2001). For largemouth bass, some research has showed that this method in old fish can underestimate the fish age because of the slow growth rate and the overlap growth at the margin in older fish, as reported by Maraldo and MacCrimmon (1979). Many factors (Fig. 3) can affect the formation of annuli, whereas the most important factor is temperature. There is evidence that the formation of growth marks in scales requires seasonal changes in water temperature of 4-5 ℃ (Longhurst and Pauly, 1987). Indeed, in this study, the seasonal mean water column temperature difference area was 8.67 ℃.

4.1.2. Relative growth

Length and weight data are standard results of fish sampling. Length-weight relationship gives information on the condition and growth pattern fish (Bagenal and Tesch, 1978). For this species, the growth was found to be allometric in combined sexes since the b value was 3.099, suggesting that the weight increased faster than the cube of their standard lengths. The value of “b” in the present study is in accordance with that estimated by Godinho (1993) working on the same species in the P.do-Altar Lake and Deep Greek Lake (Carlander, 1977). However, it differs from the other three lakes in the same study (Carlander, 1977). It also differes from the Pontiac, Whitmore, Kent and Michigan average Lakes by Goudy (1981) (Table 12). This variation in the exponents could be attributed to different stages in ontogenetic development as well as the differences in age, maturity and sex. Geographic location and associated environmental conditions, such as season (date and time of capture), disease and parasite can also affect the value of “b”.

Table 12. List of *b* values of length-weight relationship on *Micropterus salmoides*

Lake	Author	Year	*b*
Goe-San	Present	2010	3.099
P.do Altar	Godinho	1993	2.926
S. Clara	Godinho	1993	2.419
Magos	Godinho	1993	2.586
V. Cobrao	Godinho	1993	2.336
Pontiac	Goudy	1980	3.469
Whitmore	Goudy	1980	3.651
Kent	Goudy	1980	3.351
Michigan Average	Goudy	1980	3.127
Deep Greek	Carlander	1977	3.080

4.1.3. Growth performance

The growth performance of a fish reflects the ability of a species to meet nutritional requirements and its adaption to prevailing abiotic conditions such as the temperature regime (Beamesderfer and North, 1995). There is no data on the growth of largemouth bass in Korea. Comparison of the parameters of the von Bertalanffy growth equation in the literature (Table 13) showed that largemouth bass in Goe-san Lake had lower $L\infty$ than most other study populations, and that growth was normal with rather intermediate K values. Growth can be judged by the φ' value which was lower in Goe-san Lake than other data reported.

Table 13. Parameters of the von Bertalanffy equation of *Micropterus salmoides* from other lakes' populations in literature

Location	L_∞	K (y r^{-1})	φ'
Goe-san	448	0.234	4.67
Alabama	625	0.28	5.04
Arkansas	543	0.29	4.93
British Coulumbia	592	0.16	4.75
Connecticut	565	0.22	4.85
Delaware	542	0.29	4.93
Florida	619	0.26	5.00
Georgia	563	0.23	4.86
Idaho	638	0.16	4.81
Illinois	573	0.3	4.99
Iowa	661	0.19	4.92
Kentucky	604	0.36	5.12
New Mexico	911	0.08	4.82
Ohio	698	0.14	4.83
Oklahoma	566	0.31	5.00
South Dakota	716	0.11	4.75
Virginia	635	0.26	5.02

4.1.4. Back-calculated length at age

The back-calculated techniques involved in this study should be concerned, because the use of several back-calculated techniques (i.e. Fraser-Lee, direct proportion) may increase variation in a data set. When length is calculated, the Fraser modification takes the intercept value “a” of a regression line. Resultantly, it is more accurate than the simple direct proportion method, which the regression line doesn’t pass through the origin. The value of “a” is the length of the fish at the time of scale formation. Intercept values for largemouth bass had been reported by Carlander (1977) to range from 0 to 64 mm. Scale formation generally occurs at 18 to 26 mm (Heidinger, 1976). In this study, the value of “a” is 22.45 fell within the range (Table 14). The similar result was reported by Goudy (1981). The intercepts of 42.9 mm and 30.1 mm obtained at Pontiac and Kent lakes fell within the range given in the literature and they were used in the back-calculations of length at age for the respective lakes. However, the 93.0-mm intercept for bass from the Whitmore Lake was considered to be unusually high as it lay beyond the previously reported intercept range. A second regression analysis of length on radius was conducted.

The intercept was also somewhat suspect, because most of the sample was collected by fishing in this study. Therefore, the number of small size samples by fishing is less than that by electrofishing. The accuracy with which the intercept can be calculated is affected by the range of sizes in the sample as well as the number of specimens (Carlander, 1977).

In this study, Table 8 and 9 showed that the back-calculated age was older than the observed age. It was also testified that the age by scale was under-estimated. Other more accurate methods to age the fish should be employed in order to make a good knowledge on its growth.

4.1.5. Aging error

In order to avoid the bias in assigning ages, scales were read twice at an interval of 20 days. The significant difference of ages between the twice reading was presented in Fig. 25. The second reading did relative lower age estimation than that from the first reading. In the present study, the collected scales were immersed in 5% potassium hydroxide (KOH) for 24 h, and then rinsed in water. If some scales were not washed clearly, some part of it could appear as vague rings or broken part because of the serious causticity of KOH. Also the other concentration of KOH (3%) had been reported (Maraldo and MacCrimmon, 1979; Zymonas, 2009). All the studies suggest that an optimal concentration should be adjust to the fish species and scale type.

4.2. Reproduction

4.2.1. Sex ratio and size distributions

Freshwater fishes were found generally to exhibit a 1:1 ratio of females to males, with some exceptions, particularly among larger species where "females were either more abundant or larger than males" (Carlander, 1977). In the present study, a positive bias in the ratio of females to males and an increase in the proportion of males with increasing size were showed in Table 11. The factors such as species size, depth distribution and different collecting tools and methods may account for the bias toward females in this study. It is consistent to the result in Escambia Rive (Orlando et al., 1999) and Tohopekaliga in Florida (Lange et al., 1994). However, opposite bias was reported (Orlando et al., 1999) in Blackwater River in Florida. The possible reasons may be related with the sampling time and the geographic difference of species.

Sex ratio (F/M) showed a smaller and smaller hackle change with the time passing. From April, temperature became high, and may be possibly for *M. salmoides* to act and feed, especially for male. At the same time, we knew that males matured earlier than male, therefore, males tried their best to feed more to save enough energy for reproductive and spawning. So the sex ratio was male-biased in April. In May, females started to do the similar things, and males mostly matured, so the sex ratio skewed to female. After males matured and spawned in May, they began to feed again in June, as more males were collected. Following males, females also finished some spawning and started to feed again, that was why females was higher than males collected. The spawning season was determined from April to June, mainly in May (Fig. 30). At the same time, because the fishing sporting was more and more, the stock size was smaller and smaller. Therefore, a smaller and smaller hackle curve was done.

Males *M. salmoides* of male had a smaller size than female in Goe-san Lake. The predominance of larger sized females is common amongst Centrarchidae. It is consistent to the reports on *M. salmoides*, which is likely the result of different growth and longevity of the sexes (Porak et al., 1988; Orlando et al.,1999; Lange et al., 1994). Porak (1988) reported largemouth bass in peninsular Florida experience sexual dimorphic growth and females grow faster than males after approximately 200 mm in length.

4.2.2. Spawning period

Most of the fish living in the temperate zone exhibit an annual reproductive cycle. Reproduction, or more precisely hatching, occurs when food is available for the fry in the wild. Therefore, reproduction is closely related to environment. Harris (1986) also postulated that falling water temperatures and decreasing photoperiod were main cues in the onset of spermatogenesis and oocyte maturation in *M. novemaculeata*, with flooding acting as the proximal factor. In this study, *M. salmoides* spawned mainly from April to June, mainly in May determined by GSI and HSI. According to the investigation of the environment factors, during this period, the temperature increased and it is possibly temperate for photoplanktons and zooplanktons to grow. The fry and larval of *M. salmoides* can get enough food. The biomass of zooplankton increased significantly during this period. Carlander (1977) postulated that reproductive cycles in mid-water fishes were timed to coincide with the spring bloom (and the consequent increase in zooplankton abundance).

4.2.3. Length and age at maturity

Female *M. salmoides* reached sexual maturity at size of 255 mm, and was larger than male at size of 227 mm. The maturation of males at smaller sizes than that of females is consistent with findings of other studies (Orlando et al., 1999; Olaf and Thomas, 1999) and has been suggested to be likely due to different growth rates between the sexes. Male and female *M. salmoides* 50% sexual maturity was at 2.03 and 2.44 years. It was similar to the result done by Olaf (1999), which is age with males spawning as early as the second winter following birth, whereas females were more likely to commence spawning in the third winter. Typical of many teleosts, the onset of sexual maturity in male and female *M. salmoides* coincided with an overall decrease in growth rates and is likely due to energy being invested in reproduction other than somatic growth. Further studies are required to definitively determine the causal mechanisms influencing spawning and recruitment in *M. salmoides* populations, including the effects of environmental flows.

This research demonstrated that *M. salmoides* exhibited a relatively higher fecundity and longer spawning period. Therefore, its spawning strategy is highly flexible. The variation in the timing and periodicity was shown to be related with the latitude location, environmental factors including mainly temperature and rainfalls as well as the age and size structure of the population. Nonetheless, the data of fecundity is also limited, and the climate is changing. Therefore, more systematic investigations should be done in more areas.

4.3. Feeding ecology

4.3.1. Stomach fullness composition

Largemouth bass are predatory fish that prey mainly on invertebrates when small and as they grow, shift their diet increasingly to fish (Olson, 1996; Weyl and Hecht, 1999; Garcia-Berthou, 2002; Post, 2003; Jang et al., 2006). Where they have become established, they have been shown to alter invertebrate communities (Weyl et al., 2010) and reduce the abundance of native fishes (Cambray and Stuart, 1985; Gratwicke and Marshall, 2001; Shelton et al., 2008; Tweddle et al., 2009; Ellender et al., 2011). In this study, we also know that the length at maturity is 251 mm (female) and 227mm (male), which belongs to the small group. Before the fish mature, they feed more only to support body growth. They will use most energy from feeding to support gonad growth. This is in accordance with the result, which the percentage of full stomach of small fish is bigger than that of big fish.

4.3.2. Diet composition

In this study, *Leptocerus* sp. and *Amphipoda* sp. were the most important food items eaten by smaller fish smaller than 135 mm TL. *Potamonautes sidneyi* and *Anax sp.* were the most important prey items for large largemouth bass. The dominance of invertebrates in the diet of juvenile largemouth bass has been observed by numerous authors (Olson, 1996; Dibble and Harrel, 1997; Weyl and Hecht, 1999; Garcia-Berthou, 2002; Post, 2003) and it is likely that the small bass may not have attained a size at which they become primarily piscivorous in the Goe-san Lake. A similar result was found by Garcia-Berthou (2002) in a Spanish lake where small bass (25–75 mm) fed mainly on amphipods and insects, while Olson (1996) also found that zooplankton along with insect larvae dominated the diet of the smaller size classes.

General conclusion

In order to investigate the condition of fish community and the effect of invaded species, *Micropterus salmoides*, on the ecosystem, the fish diversity and the population biology of *M. salmoides* were studied from March, 2010 to November, 2012. Fish diversity is a very important indicator in a freshwater ecosystem. *M. salmoides* was imported to Korea. It has settled in and suited to live in Korea very well. Population biology can provide good information to show their adaption to this environment, how important the role of this species in this area, and how the interaction is with the native species. Main results were as follows:

Chapter 1: Composition and diversity of fishes in Goe-san lake, Korea

(1) A total of 2744 fish was recorded across all sites of Goe-san Lake and belonged to 10 families. Among them, 2402 fish belonged to family Cypinidae, 157 fish to family Centropomidae and 144 to the remaining other 8 families. It suggested that fish species diversity is low.

(2) The dominant species were similar during the three years investigated. The changes of dominant fish species composition among seasons were not too much. However, there was a relatively large change at different streams.

(3) The highest similarity occurred between spring and summer, and there were higher similarities among autumn and other seasons. The highest similarity occurred between the upstream and midstream, and there were lowest similarities between the upstream and downstream.

(4) The diversity indices of each season as well as the total index value showed that

summer richness index was biggest, and autumn's was smallest. The diversity index was biggest in autumn, and the summer's was smallest. The evenness index was biggest in autumn, and the summer's was smallest. The fluctuations of diversity index ranged most in summer and the autumn's range least. In different streams, the upstream richness index was biggest, and midstream's was smallest. The diversity index was biggest in downstream, and the midstream's was smallest. The evenness index was biggest in midstream, and the upstream's was smallest. The fluctuations of diversity index ranged most in downstream and the midstream's range least.

(5) The factors effecting fish species richness, evenness and relative abundance were examined. Richness and evenness were strongly correlated with the temperature and rainfall. The abundance was most in summer.

Chapter 2: Population biology of the largemouth bass, *Micropterus salmonides* from Goe-san Lake, Korea

(1) Age, growth and natural mortality: The age composition and growth parameters of *M. salmoides* caught from Goe-san Lake in South Korea were investigated by otolith from March to November in 2010 - 2011. Males and females made up of 47.9% and 52.1%, respectively. The standard length of males ranged from 98.8 to 347.2 mm, and females from 104.4 to 413.8 mm. The relationship between standard length and total weight for both sexes was estimated as $TW = 0.000007L^{3.099}$. The number of otolith (sagittae) rings was counted, otolith radii and annual radii measured. Monthly changes of the marginal increment rate

indicated that a single ring was formed yearly for both sexes and the rings formed in April. The age of *M. salmoides* studied ranged from 0 to 8 years. Back-calculated standard length was expressed using the von Bertalanffy growth equation as: $L_t = 448.76(1 - e^{-0.234(t+0.527)})$. The growth performance (φ') was 4.67. The estimated physiological life span of *M. salmoides* was 12.3 years. Estimates for natural mortality (M) varied slightly depending on the method used. Natural mortality of *M. salmoides* was relative low with $0.32 yr^{-1}$ in Goe-san Lake.

(2) Reproductive: The development of ovary and testis was graded into 5 stages by the criteria. The ratio of females to males increased with total length. Females were sampled in slightly larger size and greater number. Mean size and age were greater for females (255 mm total length and 2.03 years, respectively) than males (227 mm and 2.44 years, respectively). The spawning season of *M. salmoides* was from April to June, with a peak in May by the gonadosomatic indices and the monthly proportions of female and male gonad stages. Ripe females were collected during the spawning period. Mean fecundity was 27656 ± 1424 oocytes every female. Fecundity was positively correlated with total length, and it was described by: mean fecundity = 202.4 total length - 38188. Higher fecundity well indicated that *M. salmoides* has a flexible spawning strategy and has acclimatized well to Goe-san Lake.

(3) Feeding ecology: The stomach contents of a total of 227 *M. salmoides* ranged from 84 to 412 mm. The proportion of *M. salmoides* with empty stomachs increased in larger fish. Percent volumetric contributions of four functional prey

categories are plankton, insect, crustacean, and fish. The principal foods of *M. salmoides* regardless of size consisted of two numerically dominant species, the trident goby and paradise goby. The young *M. salmoides* of the year fed exclusively and selectively on the abundant young of paradise goby. As *M. salmoides* grew, they also consumed fewer but larger trident goby. All size of *M. salmoides* preferred these gobies from spring to autumn. *M. salmoides* switched from zooplanktivory to piscivory at standard length of 30−40 mm.

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