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THE IMPACTS OF EXOTIC SPECIES AND STREAM IMPOUNDMENT ON A FRESHWATER LAKE FISH COMMUNITY: LAKE SOYANG, KOREA.

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ABSTRACT

Freshwater lake systems are often subject to invasion, deliberate stocking of exotic species, and habitat alterations. Most studies of such impacts have been done in Europe and North America. We investigated the species composition and dynamics of the fish community in Lake Soyang, an artificial reservoir in Korea, to assess the magnitude of such disturbances on a native fish community in Asia. We collected 37 species from 11 families, including 15 endemic Korean species and 13 exotic species. The species composition has changed significantly from the condition before the reservoir was created by construction of a dam. The community is dominated numerically and in biomass by a combination of native cyprinids and the exotic bluegill sunfish, *Lepomis macrochirus.* We attribute the loss of several native species from the original fish community to changes from a lotic to lentic aquatic system by construction of the dam. The presence of so many exotic species appears to be the result of the disruption of the original stream habitat by damming of the river, and deliberate introductions of exotic species.

Keywords: Exotic invaders, species diversity, biomass, introduced fish, native, reservoir, lake.

INTRODUCTION

There is increasing concern about invasive freshwater fishes and the integrity of native fish communities (Moyle and Light, 1996; Moyle et al., 2003), as part of more general concerns about biological diversity (Poos et al., 2009). In addition to the invasion of exotic species, one of the most pervasive impacts on freshwater fishes is the construction of dams and other barriers to fish passage (McLaughlin et al., 2001; 2005). Although these are recognized as a general phenomenon in freshwater systems, most of the empirical research and management theory has focused on North American or European examples. We directed our attention to what appears to be a comparable situation in Korea, where the exotic invading fishes are North American species, and where there has been no systematic study of these impacts on the native fish community. Soyang Dam was constructed

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in 1973 with in a watershed of 2,703 km^2 on the Naerincheon River about 13 km northeast of Chuncheon City. The impoundment is 64 km long and 0.5 km wide, with a maximum depth of 118 m, and a storage duration of about 300 days. The stored water is maintained well above 4°C in winter, and so there is no ice formation. The surrounding area remains as a mixture of deciduous forest and small farms. The human population of the catchment area is approximately 40,000 (Lake Soyang Dam Support Periodical, 2002).

The Lake Soyang dam was constructed on the mid - and upper regions of the river, thus the riverine habitat changed to a lacustrine system. We predicted that fishes native to the high current habitats in the original river system would either migrate to the upper reaches of the river above the lake or became extinct. We also predicted that fishes adapted to lentic habitats that would be formed by the impoundment would increase their populations. Thus we predicted that the dam construction would result in an overall reduction in fish species diversity. We tested these predictions by measuring the composition of the fish community about 30 years after construction of the dam, when it should have been approaching a stable state (Gido et al., 2000). We compared our results to data on the fish community collected prior to construction of the dam to estimate any significant changes. Previous studies of the fish fauna in the Naerincheon drainage, which was the incoming river to Lake Soyang, include Choi (1973), Cho et al. (1991), Cho and Byeon (1993), Jeon and Hwang (1995), Jeon (1994), and Nam et al. (1998).

Our study was also intended to provide baseline data for the lake ecosystem for better management of the fish resources in the lake. Byeon et al. (1997a) and Lee et al. (1997) have previously described the fish fauna in Lake Soyang. We extended their studies by including quantitative estimates of the numbers and biomass of fish species present, and with detailed analysis of the origins of the fish species present in the lake.

MATERIALS AND METHODS

We selected two sampling stations near the incoming river and three within the lake itself (Figure 1). We designated the sampling stations as follows:

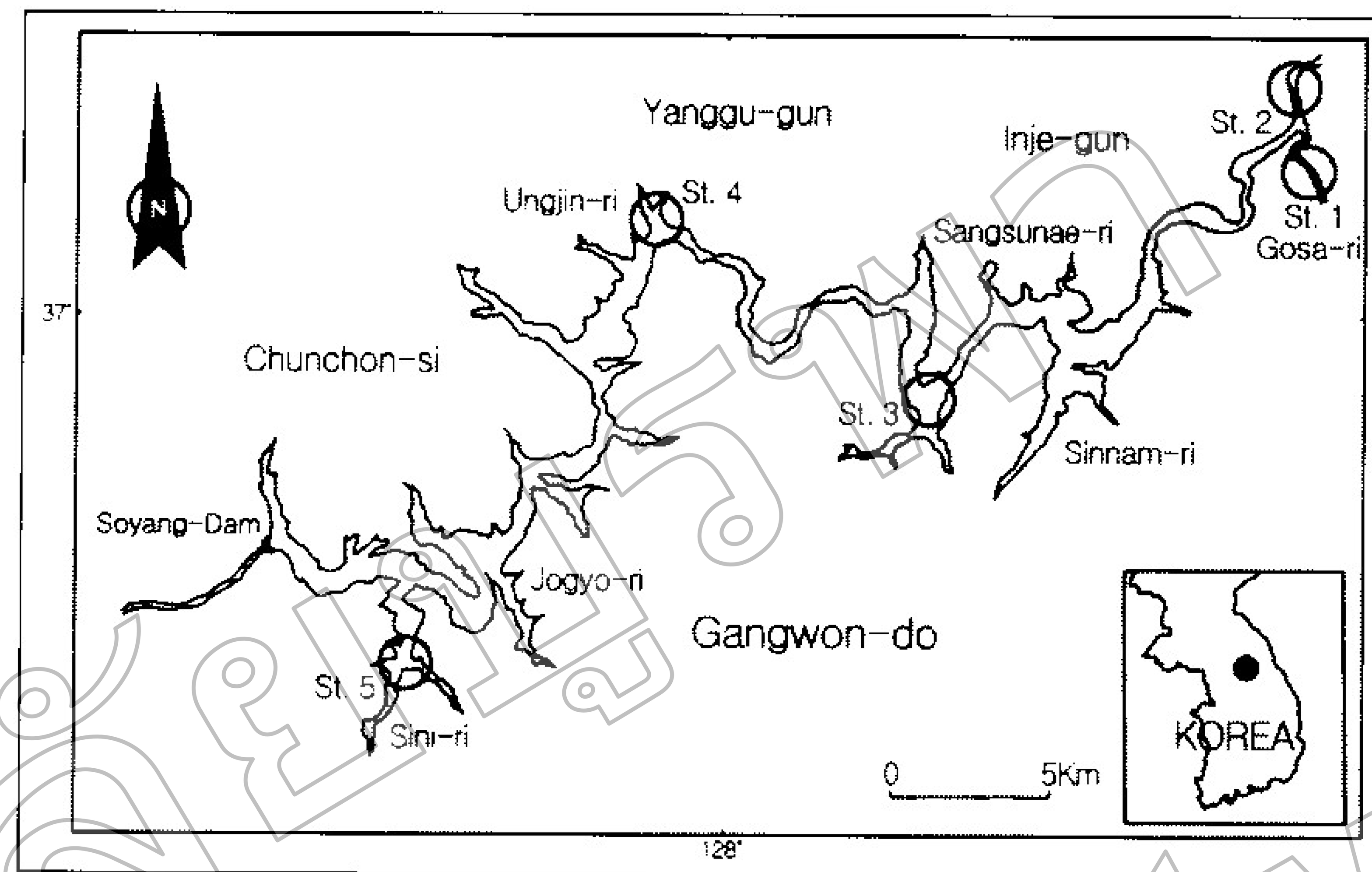

Figure 1. Map showing the study area in Korea.

Station 1: Kangwondo Injekun Injeup Kosari Sungae (Naerincheon)

Station 2: Kangwondo Injekun Injeup Duksanri Livingston Bridge

Station 3: Kangwondo Injekun Nammyeon Sangsunaeri (Yang Gu Bridge)

Station 4: Kangwondo Yangjukun Yangguup Woongjinri (Yang Gu Port)

Station 5: Kangwondo Choonchеonsi Dongmyeon Siniiri

We collected samples from April 2001 to September 2002:

First Investigation: 27-29 April 2001
Second Investigation: 27 -29 June 2001
Third Investigation: 1-3 December 2001
Fourth Investigation: 15-17 February 2002
Fifth Investigation: 29-30 May 2002
Sixth Investigation: 12-14 September 2002

We collected fishes by gill nets (mesh size 5x5 mm and 20x20 mm) set at each station for 48 hours. For near shore stations we used a cast-net (7x7 mm mesh) and scoop-net (3x3 mm mesh). We fixed all fishes in 10% formalin and then transferred them to the laboratory where we identified them as to species and measured the wet mass (± 0.1 g) and length (± 1 mm) of each specimen.

We took our species identifications and definitions of habitat preferences for each species from numerous previous publications (Uchida, 1939; Jeong, 1977; Kim, 1984, 1988, 1997; Kim et al., 1985; Lee, 1998; Son, 1987; Jeon, 1980, 1983, 1984, 1989, 1994; Choi et al., 1997, Kim and Kang, 1993). We followed the major classification system of Nelson (1994). Our analyses of the fish community data included diversity, dominance, and evenness (Simpson, 1949; Shannon and Weaver, 1963; Pielou, 1966).

We used a PVC Van Dorn vegetation device weekly to measure the total phosphorus and chlorophyll a around the lake, and to measure the vegetation at depths of 0, 2, 5, 19, 20, 30, 40, 50, 60, 70, 80, 90, and 100 m from January 1986 to December 2000. We prepared the TP test solution by adding 0.5 ml of 20N sulfuric acid to 500 ml of sample water. The content was examined by applying persulfate digestion and ascorbic acid methods derived from Standard Methods (APHA, 1992). We filtered chlorophyll a through a GF/C glass filter, and then stored the filter paper (- 20°C) for later analysis. We placed the cold filter paper in a tissue homogenizer, dissociated the sample with 90% acetone, and then centrifuged it. We measured the supernatant for absorption in a spectrophotometer, and calculated chlorophyll a concentration using the Lorenzen (1967) method.

RESULTS AND DISCUSSION

1. Fish species and composition of the community

Table 1. Species list and numbers of fishes collected from Lake Soyang and inlet streams. See text for details of collecting procedures.

Species	Stations					Total	RA	Remarks
	1	2	3	4	5			
Anguillidae								
Anguilla japonica (Temminck and Schlegel, 1846)			8	7	1	16	0.09	Ph
Cyprinidae								
Cyprinus carpio (Linnaeus, 1758)			88	20	4	112	0.66	Pr
Cyprinus carpio (Israeli type; Linnaeus, 1758)				4		4	0.02	Pr
Carassius auratus (Linnaeus, 1758)			33	10		43	0.25	Pr
Carassius cuvieri (Temminck and Schlegel, 1846)			189	3	2	194	1.15	Pr
Pungtungia herzi (Herzenstein, 1872)	22	24	5		4	55	0.33	Pr
Pseudopungtungia tenuicorpus (Jeon and Choi, 1980)	5	3				8	0.05	Pr, E
Coreoleuciscus splendidus (Mori, 1935)	28	28				56	0.33	Pr, E
Squalidus gracilis majimae (Jordan and Hubbs, 1925)	43	18	725	249	1031	2066	12.24	Pr, E
Squalidus japonicus coreanus (Berg, 1906)				356		356	2.11	Pr, E
Hemibarbus labeo (Pallas, 1707)	5	5	91	37	44	182	1.08	Pr
Hemibarbus longirostris (Regan, 1908)	14	14	27	4	37	96	0.57	Pr
Hemibarbus mylodon (Berg, 1907)	1	1	2	5		9	0.05	Pr, E, NM
Pseudogobio esocinus (Temminck and Schlegel, 1846)	12	13	6		8	39	0.23	Pr
Gobiobotia brevibarba (Mori, 1935)	32	20				52	0.31	Pr, E
Microphysogobio yaluensis (Mori, 1928)				2	20	22	0.13	Pr, E
Microphysogobio longidorsalis (Mori, 1935)	47	12		1		60	0.36	Pr, E

Species	Stations					Total	RA	Remarks
	1	2	3	4	5			
Zacco temmincki (Temminck and Schlegel, 1846)	71	56	26	11	34	198	1.17	Pr
Zacco platypus (Temminck and Schlegel, 1902)	237	365	628	5071	382	6683	39.60	Pr
Opsariichthys unirostris amurensis (Berg, 1940)	3	3	13	34	40	93	0.55	Pr
Hemiculter eigenmanni (Jordan and Metz, 1913)		1	4	45	51	101	0.60	Pr
Cobitidae								
Misgurnus anguillicaudatus (Cantor, 1842)			14	2		16	0.09	Pr
Iksookimia koreensis (Kim, 1975)	5	3	2	1	2	13	0.08	Pr, E
Iksookimia rotundicaudata (Wakiya and Mori 1929)	6	14	15	1		36	0.21	Pr, E
Siluridae								
Silurus asotus (Linnaeus, 1758)			1		8	9	0.05	Pr
Silurus microdorsalis (Mori, 1936)		1		4		5	0.03	Pr, E
Bagridae								
Pseudobagrus fulvidraco (Richardson, 1846)			35	4	210	249	1.48	Pr
Pseudobagrus koreanus (Uchida, 1990)	2			2		4	0.02	Pr, E
Amblycipitidae								
Liobagrus andersoni (Regan, 1908)	25	20				45	0.27	Pr, E
Osmeridae								
Hypomesus olidus (Pallas, 1814)			3768	1582	1	5351	31.70	Ph
Plecoglossus altivelis (Temminck and Schlegel, 1846)					2	2	0.01	Ph
Centropomidae								
Coreoperca herzi (Herzenstein, 1986)	7	5	2			14	0.08	Ph, E
Siniperca scherzeri (Steindachner, 1892)	1		66	23	16	106	0.63	Ph
Siniperca scherzeri (Albino type; Steindachner, 1892)					2	2	0.01	Ph, NM
Odontobutidae								
Odontobutis platycephala (Iwata and Jeon, 1985)		1	1			2	0.01	Ph, E
Gobiidae								
Rhinogobius giurinus (Rutter, 1987)			124	49		173	1.03	Ph
Rhinogobius brunneus (Temminck and Schlegel, 1845)	30	36	59	2	32	159	0.94	Ph
Tridentiger brevispinis (Katsuyama, Arai and Nakamura, 1972)				9	2	11	0.07	Ph
Centrarchidae								
Lepomis macrochirus (Rafinesque, 1819)				49	188	237	1.40	Ph
Family	6	7	9	9	9	11		
Species	20	21	25 2	7	23	37		
Number of individuals	596	643	5932	7587	2121	16879		

Table 1 shows the results of our fish sampling in Lake Soyang and the neighboring river. We collected 37 species of 11 genera. We did not include the largemouth bass, *Micropterus salmoides*, since we did not collect it ourselves, but fishermen have reported this species in the lake. We collected 20 species belonging to six families from the incoming river (Station 1) at Naelincheon. There were 21 species belonging to seven families at Livingston Bridge (Station 2), 25 species belonging to nine families within Lake Soyang (Station 3), 27 species belonging to nine families from Station 4, and 23 species belonging to nine families from Station 5. Overall there was a high frequency of 15 indigenous Korean species (39.5% of all fishes). However, there were only 10 endemic Korean species within the lake itself, which indicates that the lake contains a relatively low proportion of the original species compared to other Korean rivers (Cho et al., 1991; Yang et al., 1991; Yang and Chae, 1993; Byeon et al., 1994; Nam et al., 1998). This is as we predicted since the lacustrine area located within the dam would more likely contain smaller numbers of indigenous species than corresponding riverine areas (Yang et al., 1997).

Among the 37 species we collected, cyprinids were most frequent (19 species, ~ 50% of the total). The next most abundant families were three species (~ 8% of all species) from each of the Cobitidae and the Gobiidae. There were two species (~ 5% of all species) each from the Siluridae, the Bagridae, the Osmeridae, and the Centropomidae, and a single species (~ 3% of all species) from each of the Anguillidae, Amblycipitidae, Odontobutidae, and Centrarchidae. The predominance of the Cyprinidae and the Cobitidae is typical of the freshwater fish fauna of rivers in southwest Korea (Jeon, 1980). There were 26 species (~ 70%) of primary freshwater fishes, and 11 species (~ 30%) of peripheral freshwater fishes. The endemic Korean species were *H. mylodon and S. scherzeri* (albino type). We collected a single specimen of *H. mylodon* from each of Station1 and Station 2, and two and five specimens from Station 3 and Station 4, respectively. More specifically, at the Yanggu wharf at Woongjinri, we collected the same numbers of species continuously and even though the presence of juvenile fish was a minor component, this suggests the possibility of spawning within the lake. Further studies are needed to resolve this question. In addition, we collected two specimens of *S. scherzeri* (albino type) at Siniiri (Station 5).

In contrast, the comparison of fish species collected from the incoming river and the lake shows that there were 4 species (~ 10%) captured only from the river. There were 14 fish species (~ 40 %) captured only within the lake. There were 19 fish species (~ 50%) captured at both river and lake locations (Table 1). The dominant species we collected was *Z. platypus* (6,683 individuals, ~ 40% of all specimens). The next most abundant species was *H. olidus* (5,351 individuals, ~ 30%). The other species we captured are listed, from the most to the least abundant, in Table 1. We categorized the 14 species that constituted less than 0.10% of the total catch as scarce species.

2. Biomass

The total mass of fishes collected from the study sites was 85.3kg (Figure 2). *Z. platypus* comprised the greatest biomass (19.5 kg), followed by *H. olidus* (8.8 kg), and lesser amounts of the remaining species (Figure 3). There was a greater total biomass from stations within the lake than from the river location. The biomass totals of Sangsunaeri (Station 3) and Siniiri (Station 5) were the highest. From Sangsunaeri (Station 3), we collected the largest quantity (15.8 kg) and the greatest number of fishes, including *C. carpio, C. cuvieri* and *H. labeo*

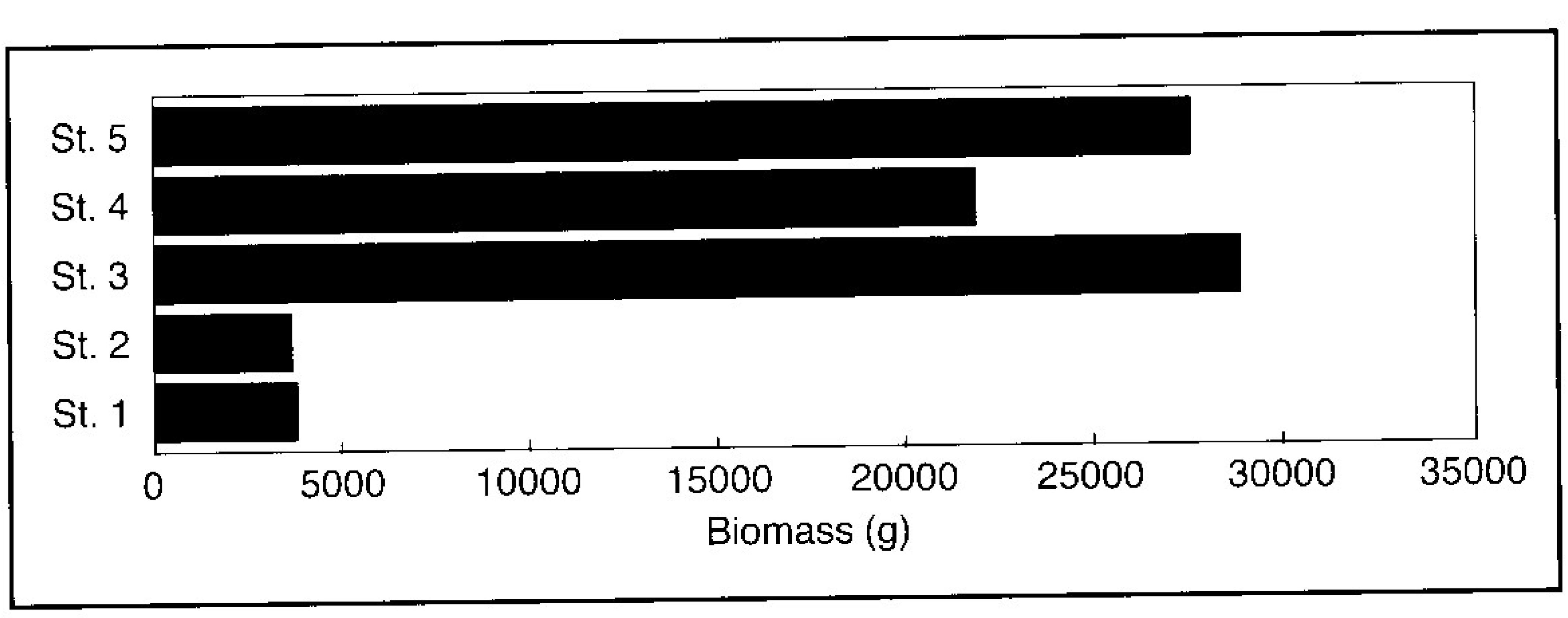

Figure 2. Fish biomass at sites in Lake Soyang.

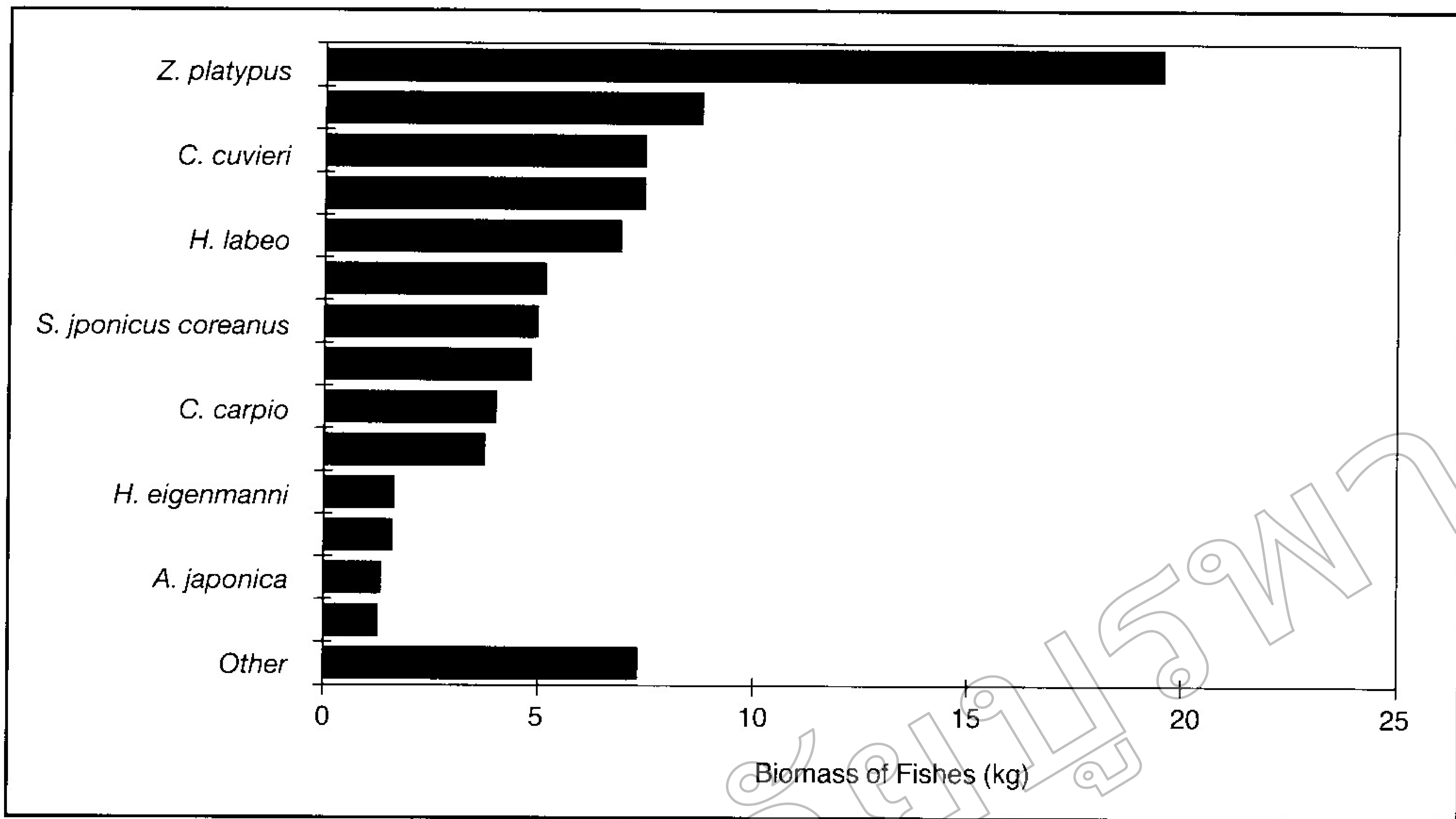

Figure 3. Biomass of collected fishes in Lake Soyang.

during our sixth collection of 2002. At that time massive amounts of summer rain had increased the water level, which induced the migration of those species to Sangsunaeri and Sinnamri regions. In addition, Sinnamri which was close to the study site, consisted of a large floodplain region with flourishing aquatic plants that provided specific habitat for fish species like *C. carpio* and *C. cuvieri.*

3. Biological indices

Our analyses of these included the diversity, dominance and evenness indices (Table 2). Stations 1 and 2 had relatively higher values for the diversity index than Stations 3, 4, and 5. Stations 1 and 2, which were the tributary river locations, had relatively higher values of evenness index, compared to Stations 3, 4, and 5, which were located within the lake. The locations within the lake, stations 3, 4, and 5 generally had higher values of dominance index compared to the tributary locations at stations 1 and 2. The higher dominance index values within the lake combined with relatively low diversity and evenness indices are the consequence of the abundance of *S. gracilis majimae, Z. platypus,* and *H. olidus* in the lake.

Table 2. Biological indices of the fish community in Lake Soyang.

Stations / Indices	1	2	3	4	5
Diversity	2.17	1.78	1.38	1.10	1.73
Evenness	0.72	0.59	0.43	0.33	0.55
Dominance	0.52	0.65	0.76	0.88	0.67

4. Changes in Fish Fauna

Unfortunately there were no studies of the fish fauna within the Lake Soyang area before the dam construction in 1973. Byeon et al. (1997a) examined the overall fish fauna status of Lake Soyang and Lee et al. (1997) carried out a limited study as well. Table 3 compares our results to those reports. In total, 42 species from 13 families have been reported. Byeon et al. (1997a) reported 33 species from 13 families. Lee (1998) suggested that there were 13 species from eight families. We observed 38 species from11 families. The species that were previously found but were absent in our study were *Onchorhynchus mykiss, O. obscura, Ictalurus punctatus,* and *Chaenogobius urotaenius.* Byeon et al. (1997a) collected a single specimen each of *O. mykiss* and *I. punctatus*, and Lee (1998) collected four specimens and one specimen of those two species, respectively. Given these small numbers, it is possible that those two species still live within Lake Soyang. Byeon et al. (1997a) reported two specimens of *O. obscura* caught in Sangsuri, thus there is also a possibility that this species could still live in some areas. Moreover, Lee (1998) observed that 19 specimens of *C. utotaenius* were caught in Mulnori and Naepyungri, thus it is probable that this species occurs in Lake Soyang. There was a total of eight species (from the total of 42) not collected in 1997 but found in our study. This suggests that either some species have migrated into the area during disturbances or else there has been stocking of juvenile fish in the area. The fact that *P. tenuicorpus* and *G. brevibarba* were collected in our study could be a consequence of our sample site in the upper inlet river. *O. platycephala* and *S. gracilis* majimae were minor species in the area, but their populations were so low that they would not likely have been collected in the earlier studies. Since these two species lived in the mid - and upper river, as the water level increased above the Soyang dam it would change the lotic habitat to a lentic state, which caused these two species to move up into the Hap River. Fishermen were probably responsible for introducing M. salmoides to the Lake. In summary, the 13 species that have moved into this area are probably: *A. japonica, H. eigenmanni, H. olidus, L. macrochirus, C. cuvieri, C. carpio* (Israeli type), *R. giurinus, C. urotaenius, T. brevispinis, I. punctatus, P. altivelis, O. mykiss, and M. salmoides.*

Table 3. Changes of the ichthyofauna in Lake Soyang from 1997 to 2002.

Species	Byeon et al., 1997a	Lee et al., 1997	Present study 2002
Anguillidae			
Anguilla japonica (Temminck and Schlegel, 1846)	31		16
Cyprinidae			
Cyprinus carpio (Linnaeus, 1758)	220	74	112
Cyprinus carpio (Israeli type; Linnaeus, 1758)	68	2	4
Carassius auratus (Linnaeus, 1758)	25		43
Carassius cuvieri (Temminck and Schlegel, 1846)	73		194
Pungtungia herzi (Herzenstein, 1872)	114		55
Pseudopungtungia tenuicorpus (Jeon and Choi, 1980)			8
Coreoleuciscus splendidus (Mori, 1935)	11		56
Squalidus gracilis majimae (Jordan and Hubbs, 1925)			2066
Squalidus japonicus coreanus (Berg, 1906)	2123		356
Hemibarbus labeo (Pallas, 1707)	256	25	182
Hemibarbus longirostris (Regan, 1908)	54		96
Hemibarbus mylodon (Berg, 1907)	1		9
Pseudogobio esocinus (Temminck and Schlegel, 1846)	100	6	39
Gobiobotia brevibarba (Mori, 1935)			52

Species	Byeon et al., 1997a	Lee et al., 1997	Present study 2002
Microphysogobio yaluensis (Mori, 1928)	26		22
Microphysogobio longidorsalis (Mori, 1935)	8		60
Zacco temmincki (Temminck and Schlegel, 1846)	103		198
Zacco platypus (Temminck and Schlegel, 1902)	2126		6683
Opsariichthys uncirostris amurensis (Berg, 1940)	393	69(248)	93
Hemiculter eigenmanni (Jordan and Metz, 1913)	80		101
Cobitidae			
Misgurnus anguillicaudatus (Cantor, 1842)	1		16
Iksookimia koreensis (Kim, 1975)	16		13
Iksookimia rotundicaudata (Wakiya and Mori 1929)	3		36
Siluridae			
Silurus asotus (Linnaeus, 1758)	33	1	9
Silurus microdorsalis (Mori, 1936)	2	1	5
Bagridae			
Pseudobagrus fulvidraco (Richardson, 1846)	34	2	249
Pseudobagrus koreanus (Uchida, 1990)	3		4
Salmonidae			
Onchorhynchus mykiss (Walbaum)	1	4	
Amblycipitidae			
Liobagrus andersoni (Regan, 1908)	6		45
Osmeridae			
Hypomesus olidus (Pallas, 1814)	5119		5351
Plecoglossus altivelis (Temminck and Schlegel, 1846)			2
Centropomidae			
Siniperca scherzeri (Steindachner, 1892)	5	111(1)	14
Siniperca scherzeri (Albino type; Steindachner, 1892)	2		2
Coreoperca herzi (Herzenstein, 1986)	320		106
Odontobutidae			
Odontobutis platycephala (Iwata and Jeon, 1985)			2
Odontobutis interrupta (Iwata and Jeon, 1985)	2		
Gobiidae			
Chaenogobius urotaenius (Hilgendorf, 1879)		(19)	
Rhinogobius giurinus (Rutter, 1987)			173
Rhinogobius brunneus (Temminck and Schlegel, 1845)	156	(64)	159
Tridentiger brevispinis (Katsuyama, Arai and Nakamura, 1972)			11
Centrarchidae			
Lepomis macrochirus (Rafinesque, 1819)	1912	17(70)	237
Micropterus salmoides (Lacepede)			●
Ictaluridae			
Ictalurus puntatus (Rafinesque)	1	1	
Family	13	8	11
Species	33	13	38
Number of individuals	13,428	313(402)	16,879

( ) : Juvenile ● : con—rmed species

The list of dominant species from the three studies of the Lake appears not to have changed significantly (Figure 4). However, the noticeable changes were the decrease in number of *S. japonicus coreanus*, the increase in number of *S. gracilis majimae* and the dramatic decrease of exotic species such as *L. macrochirus*. There is no obvious explanation for the decrease of *S. japonicus coreanus* and the increase of *S. gracilis majimae*, but this might result from environmental changes during the extensive drought in 2001. The number of *L. macrochirus* increased explosively in 1997 (Byeon et al., 1997b), but fishermen claim that this increase has now either stopped or decreased. When *L. macrochirus* was introduced to Korea, it had carnivorous feeding habits (Water Resources Corporation, 1996; Byeon et al., 1997b) and its numbers increased exponentially (Byeon et al., 1997b; Choi et al., 1997). Its population fluctuations appear to have stopped except near the Andong Dam. At the Andong Dam, the decrease in numbers of *L. macrochirus* could be due to competition with other species such as *H. eigenmanni* (Yang and Chae, 1993). However, fishermen have claimed that the decrease of *L. macrochirus* in Lake Soyang could be related to the removal of a fish farm in 1999. The influence of alien species from aquaculture is well known (De Silva et al., 2009). We found that *L. macrochirus* in Lake Soyang longer than 70 mm consumed mainly zooplankton and fish prey. Bluegills under 70 mm length consumed a greater variety of organisms, including phytoplankton, zooplankton, and chironomids. It has previously been reported that small bluegills consumed phytoplankton most intensively (Water Resources Corporation, 1996). Therefore, juvenile *L. macrochirus* in Lake Soyang appeared to be largely influenced by changes in the phytoplankton.

The amount of phytoplankton in Lake Soyang increased as the production from the aquaculture operation increased and reached maximal levels from 1990 to 1995 (Kim et al., 1995). The aquaculture operation was introduced in the 1970's and was most active in 1986 (Ahn and Kong, 2007). The aquaculture operation was reduced in 1998 and completely removed by1999. As a consequence, the concentration of T-P and the phytoplankton decreased significantly. In 1990 when phytoplankton density was at its highest, the concentration of T-P was 0.014 mg/m^3 but it decreased to 0.009 mg/m^3 in 1999 (Figure 5). As the T-P concentration decreased, the phytoplankton also decreased, which caused the chlorophyll-a concentration to decrease from 8.5 µg/l in 1990's to 1 µg/l in 2000 (Figure 6). We predict that it will continue to decrease further (see also, Khim et al.,

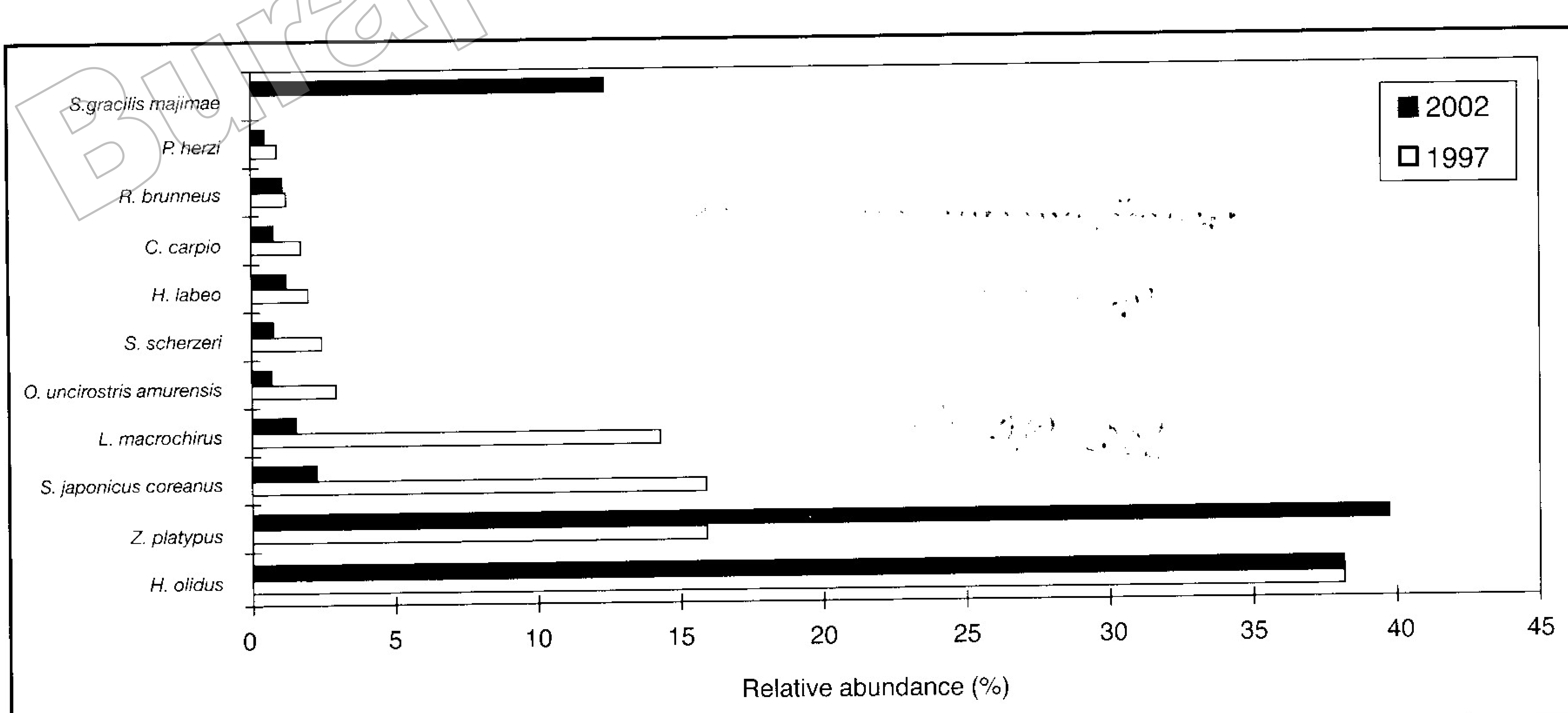

Figure 4. Relative abundance of the collected species in Lake Soyang.

2005). As shown above, fluctuations of the T-P and phytoplankton showed a pattern similar to the fluctuations in fish production. The decrease in numbers of *L. macrochirus* could be due to the same reason. According to studies of the feeding habitats of *Siniperca scherzeri* from Lake Soyang (Lee et al., 1997), individuals less than 10 mm in length consumed only fish prey. Individuals greater than 150 mm in length relied on *Z. platypus*, *L. macrochius*, and shrimp. Therefore, the decrease in numbers of *L. macrochirus* was probably the result of the phytoplankton decrease and competition with *Siniperca scherzeri*. However, these fluctuations in numbers could have been affected by various factors, and those relationships will require further study.

It has been confirmed that pelecypods of the *Unio douglasiae* group were present within Lake Soyang, so the absence of the Acheilognathinae and the *Sarcosheilichthys* species that spawn in mussels

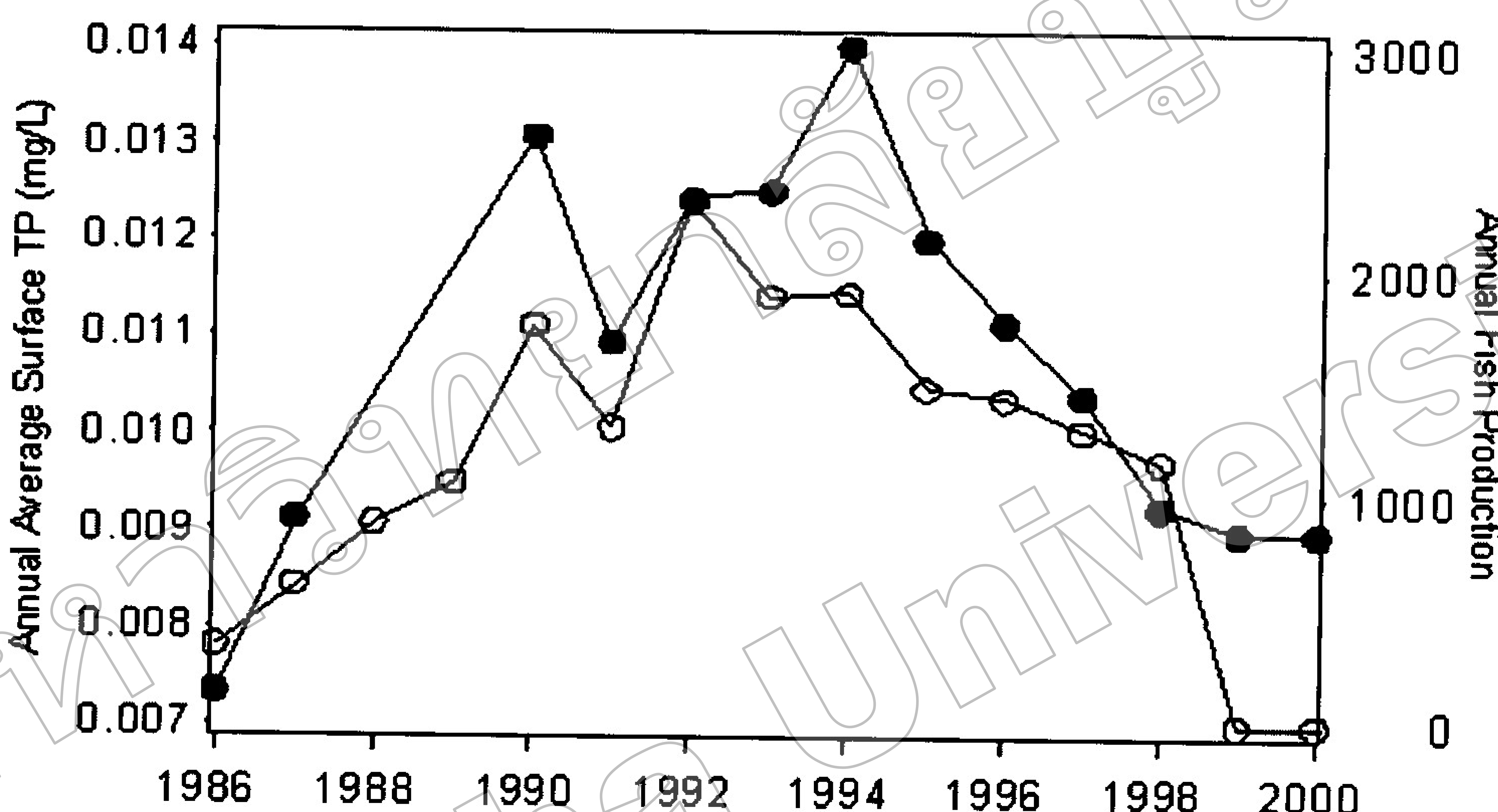

Figure 5. Annual fish production (tonnes yr^{-1})and surface TP (mg L^{-1}) in Lake Soyang. (○ fish production, ● TP)

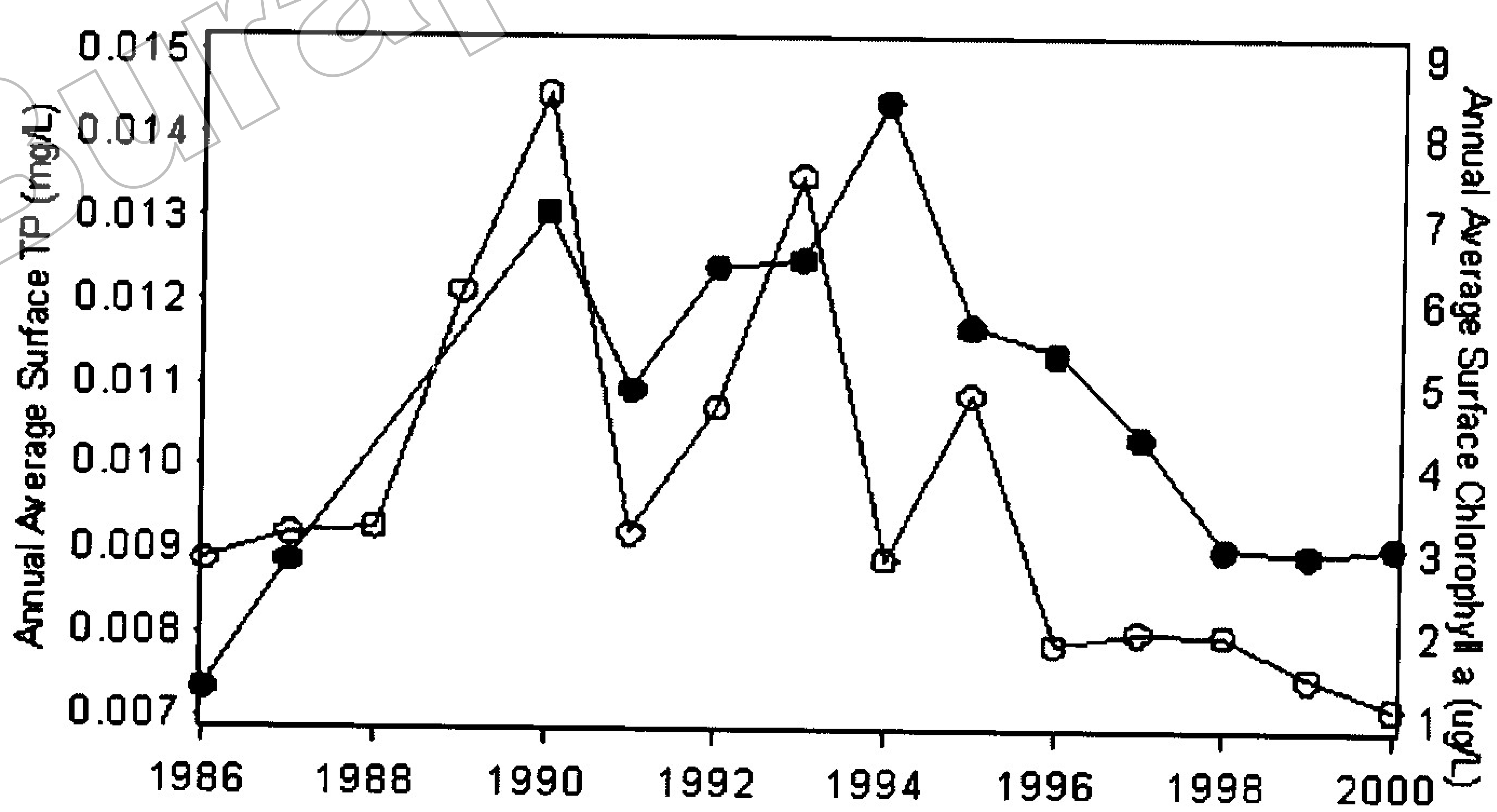

Figure 6. Annual average TP and chlorophyll-a in Lake Soyang (○ chlorophyll-a (mg m^{-3}), ● TP (mg L^{-1})

seems puzzling. Studies from Paldang and Euiam dams (Son et al., 1997; Song and Kwon, 1994) indicated that there were significant numbers of Acheilognathinae and *Sarcosheilichthys* species present along with other pelecypods. *Acheilognathus yamatsutae* selected 30 ~ 80 cm deep water as its main habitat. Moreover, the larger individuals tended to inhabit deeper areas and they relocated into water up to 2 - 3.5 m deep in the winter seasons (Song, 1994). Since the water in Lake Soyang tends to be deep and the pelecypods inhabit areas exceeding 10 m depth, it is likely that these fishes were unable to use the mussels as hosts for their spawning.

5. The status of exotic species

Overall 13 exotic species from seven families have been reported from the Lake (Table 4). According to Byeon et al. (1997a), juveniles and fertilized eggs of *A. japonica* and *H. olidus* were introduced by the author ities to the area in order to increase the income for fishermen. *H. eigenmanni* was reportedly stocked into the area at the same time as juvenile *C. carpio* (Israeli type). Moreover, Lee et al. (1997) reported the fertilized eggs and early stages of the mandarin fish as well as the larval plankton collection of *C. urotaenius* were stocked in a small numbers. Fertilized eggs and juveniles of *P. altivelis* were supplied to the area from the year 1997 to increase the income for the fishermen. *R. giurinus* and *T. brevispinis* were collected for the first time, and were stocked annually along with the other species. There were six species from countries other than Korea, including *C. carpio* (Israeli type), *C. cuvieri*, *Onchorhynchus mykiss*, *L. macrochirus*, *M. salmoides*, and *I. punctatus* introduced to support the aquatic resources. The population of *L. macrochirus* first increased and then dramatically decreased and is now only observed at certain sites. This pattern of population change appears to fit the pattern for many invading species (Moyle and Light, 1996). *M. salmoides* was collected or observed in small numbers around the Mulnori area in recent years, and the fishermen claim that the species was introduced by the public. The population of *C. carpio* (Israeli type) is decreasing after the removal of the aquaculture operation in 1999, and the local fishermen indicated that very few *O. mykiss* and *I. punctatus* are now collected.

Table 4. List of introduced fish species in Lake Soyang.

Anguillidae	
Anguilla japonica	K
Cyprinidae	
Cyprinus carpio (Israeli type)	I
Carassius cuvieri	I
Hemiculter eigenmanni	K
Salmonidae	
Onchorhynchus mykiss	I
Osmeridae	
Hypomesus olidus	K
Plecoglossus altivelis	K
Gobiidae	
Chaenogobius urotaenius	K
Rhinogobius giurinus	K
Tridentiger brevispinis	K
Centrarchidae	
Lepomis macrochirus	I
Micropterus salmoides	I
Ictaluridae	
Ictalurus puntatus	I

I : Introduced species from country outside Korea
K : Introduced species from other native river system within Korea

Thus, as we predicted, there has been a loss of several native species from the original fish community as a result of the change from a lotic to lentic aquatic system by construction of the dam. The presence of so many exotic species appears to be the result of the disruption of the original stream habitat by damming of the river, and deliberate introductions of exotic species. All of these effects are likely to be common throughout Asian reservoirs created by dam construction, and so they should be considered by those responsible for management of such systems (Jang et al., 2003).

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