Changes in Fish Community after Invasion and during Control of Alien Fish Populations in Mizoro-ga-ike, Kyoto City

Kan ABEKURA[1], Michio HORI[2] and Yasuhiro TAKEMON[3]

[1]*Laboratory of Animal Ecology, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan*
e-mail: abekura@terra.zool.kyoto-u.ac.jp
[2]*Laboratory of Animal Ecology, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan*
e-mail: hori@terra.zool.kyoto-u.ac.jp
[3]*Laboratory of Global Hydrology, Water Resources Research Center, Disaster Prevention Research Institute, Kyoto University, Kyoto 611-0011, Japan*
e-mail: takemon@wrcs.dpri.kyoto-u.ac.jp

Abstract

Information was obtained on changes over a 30-year period in a fish community after invasion of alien fish species in Mizoro-ga-ike, a natural pond of nine hectares in area located in Kyoto City, and then an investigation done on changes over five years in populations of two alien fishes, largemouth bass (*Micropterus salmoides*) and bluegill sunfish (*Lepomis macrochirus*) while the local government took measures to control their populations. The species richness of the native fish community of the pond decreased from 14 species in the 1970s to six species in the 2000s: i.e., more than half of the native species became extinct during those 30 years. On the other hand, the percentage of alien species increased from 7.7% in 1972 to 50.0% in 2002. A population control program using net fishing and spawning redd destruction was implemented by Kyoto City in 1998. This resulted in an effective decrease in population estimates for *M. salmoides* from 84 in 1998 to several in 2002. Those for *L. macrochirus*, on the other hand, showed only a gradual decrease from 9,500 in 1999 to 5,400 in 2002 after the start of population control. Although the population of 1+ cohorts (one year old) of the species did not decrease distinctively after 1999, those of 2+ and 3+ cohorts decreased constantly. Population estimates of *Channa argus* based on a mark and recapture method resulted in a decrease from 540 in 1998 to 220 in 2002 in spite of no efforts to control on species. Causal relationships of alien fish invasion to changes in the fish community in Mizoro-ga-ike and the effects of the control measures on alien fish populations were examined.

Key words: alien fish, fish community, *L. macrochirus*, Mizoro-ga-ike, *M. salmoides*, population control

1. Introduction

Severe impacts of alien predatory fish on native biotic communities have been reported in a lot of freshwater ecosystems in various countries of the world, including extinction of native populations and reduction in biodiversity (*e.g.*, Myers, 1965; McDowall, 1968a, b, 1984; Ogutu-Ohwayo, 1990). The predatory fishes, largemouth bass (*Micropterus salmoides*) and bluegill sunfish (*Lepomis macrochirus*), which are native to North America, are two distinctive representatives of such invasive alien species (Keast & Webb, 1966; Azuma, 1998). The piscivorous *M. salmoides* has been introduced to 52 countries (Lever, 1996) and is listed as one of the world's 100 worst invasive alien species for its strong impacts on native biotic communities (ISSG, 1999). The omnivorous *L. macrochirus* is also known for its strong impacts on species compositions of native biotic communities through predation on a wide range of prey species, including eggs and brood or fry of fishes (Bain & Helfrich, 1983; Hall *et al*., 1970; Minckley, 1973, Gilinsky, 1984; Hambright *et al*., 1986; Mittelbach, 1988). Impacts of the two predatory fishes on prey species or on competitive species have been well documented in the United States (Power *et al*., 1985; Carpenter *et al*., 1985; Hambright *et al*., 1986; Werner & Hall, 1988; Carpenter & Kitchell, 1993; Hill & Lodge, 1994; Baca & Drenner, 1995).

In Japan, *M. salmoides* and *L. macrochirus* were introduced from the United States in 1925 and 1960, respectively (National Federation of Inlandwater Fisheries Cooperatives, 1991), and both have become representative of invasive alien freshwater fishes listed in Japan (Murakami & Washitani, 2002). Intentional release of the two species resulted in the rapid spread of their distributions throughout Japan except in Hokkaido and Okinawa Prefectures (Azuma, 1992). Reductions in stocks of native fish species after their invasion were reported in various regions in Japan (Hamada, 2000; Takahashi *et al*., 2000; Minobe & Kuwamura, 2001). In addition, changes in benthos communities caused by their invasion have also been reported in a number of irrigation ponds in Japan (Maezono & Miyashita, 2003). Such ecosystem degeneration caused by *M. salmoides* and *L. macrochirus* is now one of the most important issues for biodiversity conservation in a wide range of freshwaters in Japan. Most ponds and lakes, however, lack data on past biological communities before the introduction of alien fishes, and this hinders effective planning of restoration programs.

In Mizoro-ga-ike Pond in Kyoto City, the biological community has been designated as a national treasure because of the unusual richness of rare species in the pond, and thus quantitative data on its flora and fauna in the past are available (Kyoto City Tourist Bureau, 1981). In spite of considerable conservation efforts by citizens and the local government, however, *M. salmoides* and *L. macrochirus* were released by someone into the pond some time since the late 1970s, resulting in the extinction of eight native fish species in total and drastic changes in the benthic fauna of the community (Takemon, 2000; Takemon *et al*., 2002). Kyoto City decided to start work on controlling *M. salmoides* and *L. macrochirus* populations in Mizoro-ga-ike in 1998. The City consigned the work to 'The NGO for Mizoro-ga-ike Freshwater Animals and Plants,' composed of volunteer members, including academic scientists, students and citizens. Among them, in particular, retired seniors played an important role in fieldwork such as net fishing and fish measurement.

The present study aims to describe changes in fauna and species composition in the fish community of Mizoro-ga-ike during these thirty years based on a review of past surveys and on monitoring data obtained in the course of the work to control the two alien fish populations. We also present annual changes in the total number of fish removed and estimates of each alien population for the five years in relation to the fishing efforts and we evaluate the effects of the control work on the alien fish populations.

2. Methods

2.1 Study site

Mizoro-ga-ike (35º03'N, 135º50'E, 75m a.s.l.) is a small natural pond of nine hectares in area and one kilometer in circumference, located in the north of Kyoto City. Mizoro-ga-ike has no river flowing in or out but it has a floodgate and an irrigation gage (Fig.1). The age of the pond as a wetland has been estimated at more than 20,000 years based on a pollen analysis of sediment core samples (Nasu, 1981). This may be a reason for the unusual richness of flora and fauna species in the pond, where a set of relic species of the cold-temperate and subtropical zones coexist within such a small pond. The former include *Menyanthes trifoliata*, Menyanthaceae; *Argyroneta aquatica,* Argyronetidae; and a syrphid fly, *Eurinomyia lineata*, in the high moorland and floating islands in the middle of the pond; and the latter include *Phragmites communis*, *Zizania latifolia*, Gramineae; *Neohydrocoptus bivittis*,

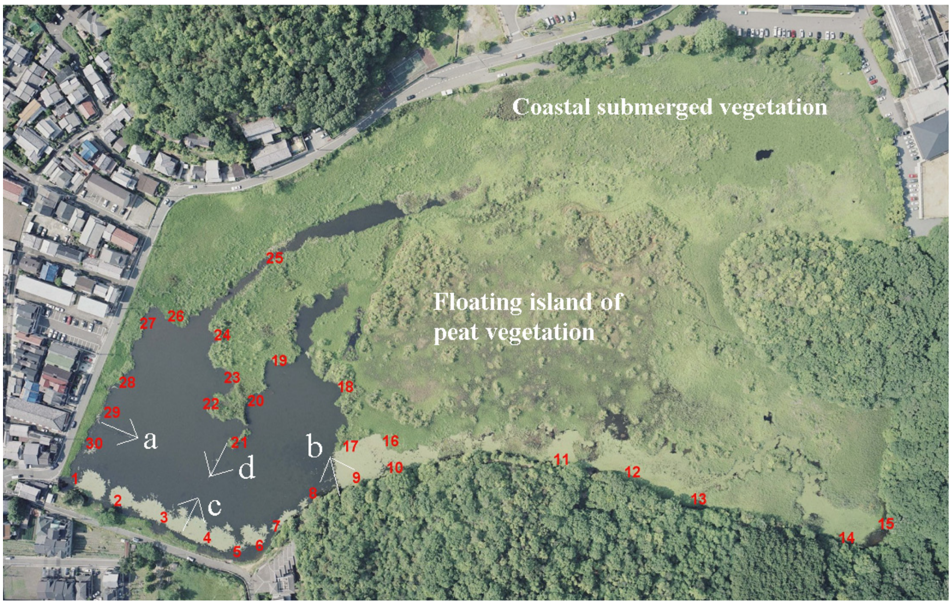

Fig. 1 Map of Mizoro-ga-ike. Arrows a-d and numerical numbers 1-30 represent the sites of 'Eri-ami' fishing and 'Mondori' trap fishing, respectively. Net sites a and b were used in 1998, all four sites in 1999, and c and d in 2000, 2001 and 2002. 'Mondori' trap fishing was carried out at the sites 1-30 in 2001 and 2002. The aerial photograph was taken in June 2003.

Phreatodytidae; and *Hydrovatus bonvouloiri*, Dytiscidae, in the littoral zone of the pond. Based on such unique natural properties of the pond, the plant community of Mizoro-ga-ike was designated as a natural treasure by the Japanese government in 1927 and the whole biological community was designated likewise in 1988.

2.2 Fish collection for faunal survey and alien population control

Kyoto City consigned the alien fish control work at Mizoro-ga-ike to 'The NGO for Mizoro-ga-ike Freshwater Animals and Plants' in 1998. The NGO group was established by one of the authors, Yasuhiro Takemon, who contacted citizens using online mailing lists. A total of 40 volunteers have participated as members, including academic scientists, students and citizens. Among them, in particular, the first author, Kan Abekura, and retired seniors took the initiative in activities such as net fishing and surveys to monitor the biological community and water quality. Fish collection methods have been selected and improved through discussion among the authors and citizens at a meeting held beside the pond every month. We decided to remove the two alien populations of *M. salmoides* and *L. macrochirus* first. There were other alien species such as snakehead (*Channa argus*) and topminnow (*Gambusia affinis affinis*) at the start of the work in 1998. When snakehead was collected, however, it was released alive after tagging for population estimation, because we assumed that snakehead had less of an impact on the community compared with the former two species. As to for the topminnow, we have never found any effective methods for their removal, and its control will be a subject for future discussion. Consequently, we have conducted fishing surveys and population control work at Mizoro-ga-ike using the series of methods listed in Table 1. All native fishes caught were released except for a small number of samples for research purposes.

Although gill nets, electro fishing and trawling are often adopted for fish collection to control fish populations (Berg *et al*., 1997; Parker *et al*., 2001; Raborn *et al*., 2002; Hamrin, 1999), they are unsuitable in Mizoro-ga-ike because it has a lot of endangered species of aquatic plants, submerged macrophytes and benthic animals, which could be damaged by the trawling. Gill nets have been reported to be one of the most effective fishing methods for removal of large-sized *M. salmoides* bass and *L. macrochirus* (National Federation of Inland Water Fisheries Cooperatives, 1991). Traditional gill-net fishing, however, causes an estimated 35%-70% mortality rate among incidentally caught fish (Buchanan & Farrell, 2002) and thus native fish apt to be killed by such fishing. Electro fishing was also rejected for the same reason. Thereby, we selected three methods, 'cast net fishing,' fixed net fishing using traditional Japanese 'Eri-ami,' and 'Mondori' traps for our purpose (Table 1, Fig. 2). We destroyed the spawning redd of the two alien fishes during April to July. 'Cast net fishing' using a net of 2 m in diameter with an 8 mm mesh-size was conducted 1-4 times per month during May to December every year from 1998-2002.

Two or four sets of 'Eri-ami' 20 m long and 1.5 m deep, with 5 mm mesh size were set in the ponds to draw fish into a central net (tsubo-ami)(Fig. 1, Fig. 2). The 'Mondori trap' is a basket type with two holes on both sides, 60 by 90 cm and 60 cm in height, made of net with 1 cm mesh size (Fig. 2). Having entered the 'Mondori trap,' fish can't find the exit easily and will stay for a while. To conserve water quality, no bait was used. Trap fishing was performed 2-3 times per week for the purpose of population estimates and control of *L. macrochirus* in 2001 and 2002 (Table 1).

Age classes were judged by examining scales and the total body length (TL) for *M. salmoides* and *L. macrochirus* (National Federation of Inland Water Fisheries Cooperatives, 1991). For *M. salmoides*, a body length of not less than 10 cm in TL was defined as the 1+ (one year old) stage or higher. Age classes for *L. macrochirus* were identified using Cassie's length-frequency example (Cassie, 1954) on samples captured by 'Eri-ami' fishing in April, May and June.

2.3 Population estimates

M. salmoides and *L. macrochirus* were trapped for population estimates using a marking and recapture method in 1998 and 1999. Then they were removed without marking or release in 2000, 2001 and 2002. The populations were estimated in 2001 and 2002 by removal methods. Petersen's marking and recapture method (Chapman, 1951) using fin cutting was adopted for estimating 1+ or higher age populations of *L. macrochirus* in 1999. Population estimates in 1999 were based on samples from four 'Eri-ami' fishing nets, a, b, c and d. The population in 1998 was

Table 1 Fishing efforts invested for alien species control work in Mizoro-ga-ike for five years since 1998.

	Eri-ami net fishing (No. of nets) (total man power days)		Casting net fishing (total man power days)		Mondori trap fishing (No. of traps) (total man power days)		Removal of spawning beds
1998	March - July, September - November	(2) (112)	April - June	(3)			
1999	March - July	(4) (49)	March - November	(28)			April - July
2000	May- July, September - November	(2) (39)	April - December	(29)			April - July
2001	May - July, September - November	(2) (23)	April - November	(17)	May - November	(10) (35)	April - July
2002	May - July, September - November	(2) (30)	April - October	(11)	April - November	(30) (52)	April - July

Fig. 2 Fishing nets used for population control of largemouth bass and bluegill sunfish in Mizoro-ga-ike.
a) 'Eri-ami' fishing net and b) 'Mondori' trap.

estimated from the catch per unit effort (CPUE) based on 'Eri-ami' fishing carried out at sites a and b in 1998 and 1999. A removal method (Delury, 1947, 1951) for population estimation was used in August 2001 using samples from ten 'Mondori' traps, 1-10, and samples from 30 traps, 1-30, in June and July 2002 (Fig. 1). In 2000 the population was estimated using the CPUE method, based on net casting carried out at the same points in 2000 and 2001. Petersen's marking and recapture method, attaching tags, was adopted to estimate 1+ or higher age populations of *M. salmoides* bass and *C. argus* every year.

3. Results

3.1 Changes in the fish community

The fish fauna of Mizoro-ga-ike changed drastically, during 20 years since the 1970s (Table 2). In 1972 twelve native species were listed, with snakehead, *C. argus*, as the only introduced species. A continental alien species, *Rhodeus ocellatus ocellatus*, invaded before 1977 and as a result, related native species, *R. ocellatus kurumeus*, disappeared during the same period. The *M. salmoides* bass and *L. macrochirus* invaded in the latter half of the 1970s and *G. affinis affinis* invaded before 1985. During the several years between 1977 and 1985, a total of six native species and even the established intruder, *R. ocellatus ocellatus*, disappeared. Consequently, in the 2000s, only six native fish species in total were surviving. The ratio of introduced species of fish fauna in Mizoro-ga-ike showed a constant increase from 7.7% to 54.5% during those thirty years. Among the introduced species, however, three species, *Carassius carassius buergeri*, *Cichlidae* sp. and *Glyptoperichthes gibbiceps*, were captured only once and were presumably temporal dwellers without successful colonization.

The relative abundance of alien species, *Rhodeus ocellatus ocellatus,* in the fish community was only 23.9% in 1979, with the rest, 76.1%, composed of five native species (*Carassius* sp. 25.2%, *Pseudorasbora parva* 17.7%, *Oryzias latipes* 12.3%, *Rhinogobius* sp. 12.3%, *Cyprinus carpio* 8.6%) in 1979 (Fig 3). Contrastingly, the relative abundance of introduced species had increased to 98% (*L. macrochirus* 97%, *M. salmoides* 1%) in 2000. In 2002, five years after the start of population control of the two alien species, their relative abundance had decreased to 87% (*L. macrochirus* 84%, *M. salmoides* 3%) and that of native species composition increased to 13% (*Pseudorasbora parva* 8%, *Carassius* sp 5%).

3.2 Effects of population control of alien fishes

Annual changes in population estimates of *L. macrochirus* after the start of population control are shown in Table 3. The estimated population decreased in 1998 just after starting population control, from 9,545 in 1998 to 5,744 in 2000. 'Mondori' traps were used in addition to 'Eri-ami' and net casting from 2001 and removed three times as many fish as in 2000, but the populations have shown no significant decrease since 2000. In 2002, the mean catch number by all fishing methods decreased significantly from 30.8 in 2001, to 15.9 in 2002 by 'Eri-ami' fishing, from 3.8 to 0.9 by net casting, from 13.0 to 4.2 by 'Mondori' trapping and the CPUE of all fishing decreased. Annual changes in population estimates for each age class of *L. macrochirus* are shown in Table 4. Fish of the 1+ class decreased to 3,984 in 2000 from 6,093 in 1998 but increased to 4,205 in 2002. The composition of the 1+ class increased to 78.0% in 2002 from 63.7% in 1998. Fish of the 2+ and 3+ classes or higher decreased from 2,726 and 736 in 1999, to 1,014 and 168 in 2000, respectively.

Population estimates of *M. salmoides* decreased from 84±23 in 1998 to 33±24 in 2000 (Table 5). Quantitative estimates were not possible in 2001 and 2002 because no *M. salmoides* were captured in spite of fishing efforts. The capture efficiency (ratios of catches to population estimates) of the *M. salmoides* bass was 2-3 times higher than that of *L. macrochirus* by 'Eri-ami' fishing. As for *C. argus*, population estimates decreased significantly from 498±109 in 1999 and 224±126 in 2002, though they were not subject to population control (Table 6).

Table 2 Changes in the fish fauna of Mizoro-ga-ike after introduction of alien species.
○ : Native species, ● : Introduced domestic species, ▲ : Introduced exotic species.
* : Temporal dwellers without successful colonization

Family	Species	72	77	79	85	98	99	2000	01	2
Cyprinidae	*Zacco temmincki*	○								
	Zacco platypus	○		○						
	Aphyocypris rasborella	○	○	○						
	Gnathopogon elongatus elongatus	○	○	○						
	Gnathopogon elongatus caerulescens		●							
	Pseudorasbora parva	○	○	○	○	○	○	○	○	○
	Cyprinus carpio	○	○	○	○	○	○	○	○	○
	Carassius auratus cuvieri		●		●	●	●	●	●	●
	Carassius auratus langsdorfii		○	○	○	○	○	○	○	○
	Carassius carassius buergeri					●*				
	Carassius auratus					●*	●*	●*		
	Pseudogobio esocinus								●*	
	Rhodeus ocellatus ocellatus		▲	▲						
	Rhodeus ocellatus kurumeus	○								
	Acheilognathus tabira tabira		○							
Cobitididae	*Misgurnus anguillicaudatus*	○	○	○	○	○	○	○	○	○
Loricaria	*Glyptoperichthes gibbiceps*							▲*		
Siluridae	*Silurus asotus*	○	○			○	○	○		
Oryziatidae	*Oryzias latipes*	○	○	○						
Poeciliidae	*Gambusia affinis affinis*				▲	▲	▲	▲	▲	▲
Channidae	*Channa argus*	▲	▲	▲		▲	▲	▲	▲	▲
Centrarchidae	*Micropterus salmoides salmoides*			▲	▲	▲	▲	▲	▲	▲
	Lepomis macrochirus			▲	▲	▲	▲	▲	▲	▲
Cichlidae	*Cichlidae* sp.							▲*		
Gobiidae	*Odontobutis obscura*	○	○							
	Rhinogobius sp.	○	○	○	○	○	○	○	○	○
	Number of native species	12	11	9	5	6	6	6	5	5
	Number of introduced species	1	4	4	4	7	6	8	6	5
	Percentage of introduced species	7.7%	26.7%	30.8%	44.4%	53.8%	50.0%	57.1%	54.5%	50.0%
Reference		1)	1)	2)	1)	3)	3)	3)	3)	3)

1) Hosoya (2001), 2) Nagata and Hosomichi (1981) , 3) Present study

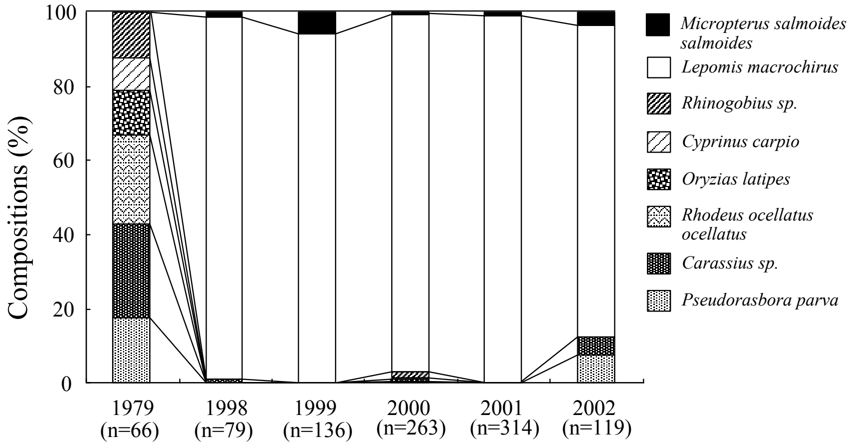

Fig. 3 Changes in species composition of the fish community in Mizoro-ga-ike from 1979 to 2002, based on fish with ages of more than 1+ captured in May to July by net casting. Data for 1979 from Nagata and Hosomichi (1981).

Table 3 Annual changes in the total catch and the population estimates of bluegill sunfish (*Lepomis macrochirus*). Petersen's marking and recapture method (Chapman, 1951) was adopted in 1999. A removal method (Delury, 1947,1951) was used in 2001 and 2002. The population in 1998 was estimated from CPUE based on 'Eri-ami' fishing carried out at a and b in 1998 and 1999.The population in 2000 was estimated from CPUE based on net casting between 2000 and 2001. The mean number of captures of the 1+ or higher age classes is based on data in May to July. That of the 0+ age class in September to October.

Year	1998	1999	2000	2001	2002
Total days of Eri-ami fishing	112	49	39	23	30
Number of Eri-ami nets per day	2	4	2	2	2
Total days of net casting	3	28	29	17	11
Number of net casting per day	10	5 - 10	14	14	14
Total days of mondori trap fishing	—	—	—	35	52
Number of net casting per day	—	—	—	10	30
1+ and higher					
Estimated population	9,545	7,477	5,744	5,775	5,387
Max 95% confidence limit	—	9,713	—	7,069	6,586
Minimum 95% confidence limit	—	5,241	—	4,481	4,188
Marking	—	254	—	—	—
Recapture	—	33	—	—	—
Total catch by Eri-ami fishing	1,214	1,900	666	574	325
Mean number of catch/net/week	21.7	20.4	32.1	30.8	15.9
Total catch by net casting	77	758	786	715	180
Mean number of catch/net	2.4	3.5	3.7	3.8	0.9
Total catch by Mondori trap fishing	—	—	—	3,601	4,353
Mean number of catch/trap	—	—	—	13.0	4.2
Total removal	771	2,404	1,452	4,796	4,858
0+					
Total catch by Eri-ami fishing	3,759	0*	12,679	4,707	2,792
Mean number of catch/net/week	207	—	756	315	248
Total catch by net casting	19	494	222	97	76
Mean number of catch/net	—	2.8	2.4	1.1	0.8
Total catch by Mondori trap fishing	—	—	—	119	1,329
Mean number of catch/trap	—	—	—	2.8	2.8
Removal	3,778	494	12,901	4,923	4,197
Remaval of spawning beds	—	0	0	2	1
Total capture	5,069	3,152	14,353	9,813	9,055
Total removal	4,549	2,898	14,353	9,719	9,055

* Eri-ami wasn't used in July to December in 1999 and no fish of the 0+ age class were caught.

Table 4 Annual changes in population estimates for each age lass of bluegill sunfish (*Lepomis macrochirus*) in Mizoro-ga-ike. Estimation methods in 1998-2002 are as mentioned in Table 2 (a). Age classes were identified from the frequency distribution of body length of fish captured by 'Eri-ami' fishing in April, May and June ('98 n=506, '99 n=401, '00 n=163, '01 n=231,'02=99). Relations of body length to age were judged from scale examination of subsamples in 2000 and 2001 ('00 n=11, '01 n=86, '02 n=60).

Year / Age group	1998	1999	2000	2001	2002
Number of 1+ and higher	9,545	7,477	5,744	5,775	5,387
(Max 95% confidence limit)	-	9,713	-	7,069	6,586
(Minimum 95% confidence limit)	-	5,241	-	4,481	4,188
1+ (%)	6093(63.7)	5145(68.8)	3984(69.3)	4198(72.6)	4205(78.0)
2+ (%)	2726(28.5)	1940(25.9)	1334(23.2)	1192(20.6)	1014(18.8)
3+ or higher (%)	736(7.7)	392(5.2)	426(7.4)	385(6.6)	168(3.1)
Removal of 1+ and higher	771	2,404	1,452	4,796	4,858
Removal of 0+	3,778	494	12,901	4,923	4,197

Table 5 Annual changes in the total catch and population estimates of largemouth bass (*Micropterus salmoides salmoides*). Petersen's marking and recapture method (Chapman, 1951) was adopted in 1998,1999 and 2000. The population in 2001 could not be estimated because there was no capture by Eri-ami fishing. See Table 2 for the total annual effort of each fishing method. Mean number of captures of the 1+ and higher age classes was based on data from May to July.

Year	1998	1999	2000	2001	2002
Total days of Eri-ami fishing	112	49	39	23	30
Total days of net casting	3	28	29	17	11
Total days of mondori trap fishing	—	—	—	35	52
1+ and more					
Estimated population	84	48	34	—	—
Max 95% confidence limit	109	75	57	—	—
Minimum 95% confidence limit	58	22	10	—	—
Marking	24	12	7	0	0
Recapture	12	4	2	0	0
Total catch by Eri-ami fishing	45	19	12	0	1
Mean number of catch/net/week	0.7	0.3	0.5	0.0	0.1
Total catch by net casting	1	21	2	3	6
Mean number of catch/net	0.03	0.20	0.03	0.04	0.04
Total catch by Mondori trap fishing	—	—	—	0	4
Mean number of catch/trap	—	—	—	0	0.004
Total removal	12	24	7	3	11
0+					
Total catch by Eri-ami fishing	1,290	591	616	285	36
Mean number of catch/net/week	54	16.4	26.9	15.8	1.8
Total catch by net casting	7	14	59	33	39
Mean number of catch/net	0.22	0.35	0.22	0.33	0.14
Total catch by Mondori trap fishing	—	—	—	19	37
Mean number of catch/trap	—	—	—	0.1	0.03
Removal	1,297	605	675	337	112
Removal of spawning beds	—	several	2	5	4
Total capture	1,343	645	689	340	123
Total removal	1,309	629	682	340	123

Table 6 Annual changes in the total catch and the population estimates of snakehead (*Channa argus*). Petersen's marking and recapture method (Chapman, 1951) was adopted every year. See Table 2 for the annual total effort of each fishing method.

Year	1998	1999	2000	2001	2002
Total days of Eri-ami fishing	112	49	39	23	30
Total days of net casting	3	28	29	17	11
Total days of Mondori trap fishing	—	—	—	35	52
1+ or more					
Estimated population	539	498	366	235	224
Max 95% confidence limit	751	607	535	376	350
Minimum 95% confidence limit	327	389	196	93	98
Marking	82	123	47	22	14
Recapture	15	39	10	3	1
Total catch by Eri-ami fishing	104	161	83	33	17
Total catch by net casting	0	0	0	0	0
Total catch by Mondori trap fishing	—	—	—	15	3
Total removal	8	2	5	7	3
0+					
Total catch by Eri-ami fishing	1	2	309	0	0
Total catch by net casting	0	0	0	0	0
Total catch by Mondori trap fishing	—	—	—	—	
Removal	1	0	0	0	8
Total capture	105	184	392	48	28
Total removal	9	2	5	7	11

4. Discussion

4.1 Impacts of alien fishes on the fish community in Mizoro-ga-ike

Out of twelve native Japanese fishes inhabiting Mizoro-ga-ike in the 1970s, a total of six disappeared, and in their place, introduced alien species, particularly *M. salmoides* and *L. macrochirus*, increased in abundance in the pond during these twenty years. It is fairly difficult in general to prove that such missing species are really extinct. The past records on fish fauna in the period between 1972 and 1985, in particular, were based only on sampling by net casting (Hosoya, 2001; Nagata & Hosomichi, 1981), and thus the absence of species (Table 2) does not necessarily mean extinction of the populations. The faunal list of the present study after 1998, however, was based on much greater efforts at fish collection (Table 1), thus it seems highly probable that these fish became extinct during the twenty years. Although faunal changes in freshwater ecosystems may be attributable to various environmental changes, including water pollution, embankment, vegetation removal, etc., inter-specific interactions within the community are plausible in the case of Mizoro-ga-ike, since the pond has been reserved as a national treasure and development of its catchment area was avoided during the twenty years. In addition, the present situation of the fish species composition (Fig. 3) being overwhelmingly occupied by the two alien species of *M. salmoides* and *L. macrochirus* indicates that these two invaders had serious impacts on the native community in the pond. Strictly speaking, however, the impact of each alien species is difficult to judge separately because they invaded the pond within a comparatively short period in the 1970s-1980s, except for *C. argus*, which established a population in the 1960s. We will discuss, hereafter, possible reasons for the changes in each native fish population in relation to the timing of invasion of the alien species.

When we investigate in detail the fish faunal changes shown in Table 2, those of *R. ocellatus kurumeus* and *O. latipes* may be explained as follows. Since *R. ocellatus kurumeus* disappeared in 1977 before the invasion of *L. macrochirus* and *M. salmoides*, the related continental species, *R. ocellatus ocellatus*, could have threatened its congenic native species with gene degradation by hybridization (Kawamura *et al*., 2001). In the case of *O. latipes*, its disappearance in 1985 coincided with the invasion of *G. affinis affinis.* Since *G. affinis affinis* is an egg predator (Komak & Crossland, 2000) and has a similar habitat to *Oryzias latipes* (Sahara & Kouchi, 1980), the invasion of *G. affinis affinis* may be a principle cause of *O. latipes*' extinction.

As for *C. argus*, another predatory alien fish, its impacts on the biological community are not clear enough. Since *C. argus* had been introduced to Mizoro-ga-ike in the 1960s, it coexisted at least with the twelve native species recorded during 1972-1979.

In 1979, the percentage of *R. ocellatus ocellatus* was 23.9% and five native species were coexisted with it (Fig 3). In contrast, *L. macrochirus* accounted for more than 94% of the fish in Mizoro-ga-ike in 1998-2001. Only three native species, *Pseudorasbora parva*, *Rhinogobius* sp. and *Carassius* sp., constituted a mere 0% -5% of the fish fauna in these years, except 2002.

As for the other cyprinids and *Rhinogobius* sp., their extinction or reduction in abundance may be attributed to the invasion of *M. salmoides* and *L. macrochirus.* Since the two alien predators were introduced in the same period in the latter 1970s, it is difficult to determine their individual impacts on Mizoro-ga-ike.

4.2 Effects of control on the *L. macrochirus* population

Population estimates of *L. macrochirus* decreased from 9,545 in 1998 to 5,744 in 2000 but didn't decrease appreciably from 2000 to 2002 (Table 3). The populations in 1998 and 1999 were estimated based on 'Eri-ami' fishing samples, and those in 2000, 2001 and 2002 were based on 'Mondori' trap fishing. Since the difference in fishing methods might influence population estimates, we compared the CPUEs of net casting among these years, and this resulted in somewhat of an increase during the first four years. Thus, the decrease in population from 1998 to 2000 may have been less significant than the estimates in Table 3. Population estimates in 2001 were based on ten 'Mondori' traps, and in 2002, on 30 traps. Since the population in 2002 was estimated based on samples from a wider area than of 2001, the population in 2002 may have been overestimated in comparison with those in 2000 and 2001. In conclusion, the population of *L. macrochirus* decreased rapidly in the first two years, but it did not decrease appreciably, at least in the following three years, in spite of increased control efforts.

Reasons for the slow decrease in the population may be related to changes in its population structure. The population estimates of the 2+ and 3+ age classes or higher decreased distinctly from 2000 to 2002. This means that the population of these age classes can be controlled by a combination of 'Eri-ami,' net casting, and 'Mondori' trap fishing. Since population estimates of the 3+ or higher age class didn't decrease significantly before 2001, the addition of the 'Mondori' trap method may be effective for population control of older age classes. In comparison with the effective population decreases of these age classes, the 1+ population could not be controlled easily because of recruitment from the 0+ population. This phenomenon seemed to derive from an increase in the survival ratio of the 0+ population. Such an increase in the survival ratio can be explained by the following two hypotheses. Firstly, there is a strongly negative correlation between the biomass of *M. salmoides* and that of *L. macrochirus* (Guy & Willis, 1990; Novinger, 1990), and thus, the removal of *M. salmoides* may result in an increase in the population of *L. macrochirus*. Secondly, the removal of older age classes may cause an increase in the survival ratio of younger age classes. The latter hypothesis is ascribed to intraspecific competition or predation among the age classes. Such a possibility may be clarified by further investigation of the annual changes in the population structure of *L. macrochirus* in Mizoro-ga-ike.

4.3 Effects of control on the *M. salmoides* population

The population estimate of *M. salmoides* in 1998 was only 84, which was much fewer than that of *L. macrochirus*, and the estimates decreased to 33 in 2000. The recruitment of the 0+ age class of *M. salmoides* was as much as 1,000 or more in order (Table 5). This means that the survival ratio of the 0+ age class continued to be low even after the decrease in population of older age classes. A comparatively higher capture ratio of *M. salmoides* than *L. macrochirus* by 'Eri-ami' fishing (Tables 3 & 5) may be a reason for the effective decrease in the population of *M. salmoides*. If the present efforts for population control of *M. salmoides* are continued, it may be possible to achieve extinction of the population in this pond.

4.4 Effects of population control on other fishes

The population estimates of *C. argus* have been decreasing from the year to year (Table 6). We imagined previously that removal of the two predators *L. macrochirus* and *M. salmoides* would result in an increase in the population of *C. argus*. The result, however, was strikingly the reverse. Reasons for this phenomenon are unknown at present.

According to the decrease in *M. salmoides* and *L. macrochirus* populations, *Pseudorasbora parva* and *Carassius* spp increased in abundance to 5% and 8%, respectively, of the fish community in Mizoro-ga-ike (Fig.3), and this may be an effect of alien fish control. Although the control measures were started in 1998, no recoveries of native fishes were detected in the first three years from 1999 to 2001. There are two possibilities which may explain such very slow recoveries of the native fish species. Firstly, the impacts of *M. salmoides* and *L. macrochirus* may be strong enough even at present levels of population density, and secondly, habitat conditions such as food resources and spawning resources may be unsuitable at present. In order to prove these hypotheses, changes in physical environmental conditions and prey communities during population control of the alien fishes will need to be investigated. Mechanisms of their impacts on the community are also an important subject to study: *e.g.*, competition for food as well as direct predation on fish, eggs and/or fry have been reported as mechanisms (National Federation of Inlandwater Fisheries Cooperatives, 1991).

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References

Azuma, M. (1992) Ecological release in feeding behavior: the case of bluegills in Japan. *Hydrobiologia*, 243/244: 269-276.

Baca, R.M. and R.W. Drenner (1995) Do the effects of piscivorous *M. salmoides* bass cascade to the plankton? *Hydrobiologia*, 316: 139-151.

Bain, M.B. and L.A. Helfrich (1983) Role of male parental care in survival of larval Bluegills. *Transactions of American Fisheries Society*, 112: 47-52.

Berg, S., E. Jeppesen and M. Søndergaard (1997) Pike (*Esox lucius L.*) stocking as a biomanipulation tool. 1. Effects on the fish population in Lake Lyng, Denmark. *Hydrobiologia,* 342/343: 311-318.

Buchanan, S. and A.P. Farrell (2002) Reducing Gill-Net Mortality of Incidentally Caught Coho Salmon. *North American Journal of Fisheries Management,* 22: 1270-1275.

Carpenter, S.R., J.F. Kitchell and J.R. Hodgson (1985) Cascading trophic interactions and lake productivity: fish predation and herbivory can regulate lake ecosystems. *BioScience*, 35: 634-639.

Carpenter, S.R. and J.F. Kitchell (1993) Experimental lakes, manipulations, and measurements. *In*: S.R. Carpenter and J. F. Kitchell, eds., *The Trophic Cascade in Lakes*, Cambridge University Press, Cambridge, pp.15-25.

Cassie, R.M. (1954) Some uses of probability paper in the analysis of size frequency distributions. *Aust. J. Mar. Freshwater Res.*, 5: 513-522.

Chapman, D.G. (1951) Some properties of the hyper-geometric distribution with application to zoological censuses. *University of California Publications in Statistics*, 1: 131-160.

Delury, D.B. (1947) On the estimation of biological populations. *Biometrics*, 3: 145-167.

Delury, D.B. (1951) On the planning of experiments for the estimation of fish populations. *Fisheries Research Board of Canada*, 8: 281-307.

Gilinsky, E. (1984) The role of fish predation and spatial heterogeneity in determining benthic community structure. *Ecology*, 65: 455-468.

Guy, C.G. and D.W. Willis (1990) Structural relationship of *M.*

salmoides bass and bluegill populations in South Dakoda ponds. *North American Journal of Fisheries Management*, 10: 338-343.

Hall, D.J., W.E. Cooper and E.E. Werner (1970) An experimental approach to the production dynamics and structure of freshwater animal communities. *Limnology and Oceanography*, 15: 839-928.

Hamada, A. (2000) Why has the Lake Kasumigaura been filled with the introduced fishes? *Seibutukagaku,* 52: 7-16.

Hambright, K.D., R.J.Trebatoski, R.W. Drenner and D. Kettle (1986) Experimental study of the impacts of bluegill (*Lepomis macrochirus*) and *M. salmoides* bass (*Micropterus salmoides*) on pond community structure. *Canadian Journal of Fisheries and Aquatic Sciences*, 43: 1171-1176.

Hamrin, S.F. (1999) Planning and execution of the fish reduction in Lake Ringsjön. *Hydrobiologia*, 404: 59-63.

Hill, M.H. and D.M. Lodge (1994) Multi-trophic-level impacts of sublethal interactions between bass and omnivorous crayfish. *The North American Benthological Society*, 14: 306-314.

Hosoya, K. (2001) Protection of Japanese freshwater fishes, and alien fishes. *Journal of Japan Society on Water Environment*, 24: 273-278. (In Japanese)

ISSG (1999) 100 of the World's Worst Invasive Alien Species. Global Invasive Species Database, New Zealand.

Kawamura K., T. Ueda, R. Arai, Y. Nagata, K. Saitoh, H. Ohtaka and Y. Kanoh (2001) Genetic introgression by the rose bitterling, *Rhodeus ocellatus ocellatus,* into the Japanese rose bitterling, *R.o.kurumeus* (Teleostei: Cyprinidae). *Zoological Science*, 18: 1027-1039.

Keast, J.A. and D. Webb (1966) Mouth and body form relative to feeding ecology in the fish fauna of a small lake Opinicon, Ontario. *Journal of Fisheries Research board of Canada*, 23: 1862-1873.

Komak, S. and M.R. Crossland (2000) An assessment of the introduced mosquitofish (*Gambusia affinis holbrooki*) as a predator of eggs, hatchlings and tadpoles of native and non-native anurans. *Wildlife Research,* 27: 185-189.

Kyoto City Tourist Bureau (1981) The nature and human in Mizoro-ga-ike, *Mizoro-ga-ike academic investigation report*, Kyoto City Tourist Bureau, Kyoto, 312p. (In Japanese)

Lever, C. (1996) Naturalized fishes of the world. Academic Press, California, 408 p.

Maezono, Y. and T. Miyashita (2003) Community-level impacts induced by introduced largemouth bass and bluegill in farm ponds in Japan. *Biological Conservation,* 109: 111-112.

McDowall, R.M. (1968a) Interactions of the native and alien faunas of New Zealand and the problem of fish introductions. *Transactions of the American Fisheries Society*, 97: 1-11.

McDowall, R.M. (1968b) The proposed introduction of the *M. salmoides* black bass *Micropterus salmoides* (Lacepe'de) into New Zealand. *N.Z.J. mar. Freshwat. Res.*, 2: 149-161.

McDowall, R.M. (1984) Exotic fishes - the New Zealand experience. *In*: W.R. Courteny and J.R. Stauffer, eds., *Distribution, Biology and Management of Exotic Fishes*, Johns Hopkins University Press, Baltimore, pp. 200-214.

Minckley, W.L. (1973) Fishes of Arizona. *Arizona Game and Fish Department*, Phoenix, 293 p.

Minobe, H. and K. Kuwamura (2001) Analysis of the change in fish fauna and ecological environment in "naiko" around Lake Biwa. *Ecology and Civil Engineering*, 4: 27-38.

Mittelbach, G.G. (1988) Competition among refuging sunfishes and effects of fish density on littoral zone invertebrates. *Ecology*, 69: 614-623.

Murakami, O. and I. Washitani (2002) 100 of the Worst Invasive Alien Species in Japan. *In*: The Ecological Society of Japan, eds., *Handbook of alien species in Japa*n, Chijinshokan Press, Tokyo, Japan, pp.362-365.

Myers, G.S. (1965) *Gambusia,* the fish destroyer. *Aust. Zool.*, 13: 102.

Nagata, Y. and M. Hosomichi (1981) Fishes in Mizoro-ga-ike. Their distribution, food habits and habitat for reproduction. "The nature and human in Mizoro-ga-ike", *Mizoro-ga-ike academic investigation report*, Kyoto City Tourist Bureau, Kyoto, pp.189-200.

Nasu, T. (1981) Geological history of Mizoro-ga-ike. "The nature and human in Mizoro-ga-ike", *Mizoro-ga-ike academic investigation report*, Kyoto City Tourist Bureau, Kyoto, pp.11-34.

National Federation of Inlandwater Fisheries Cooperatives (1991) *The Review of Exotic* M. salmoides *Bass* Micropterus salmoides *and Bluegill* Lepomis macrochirus. Fisheries Agency, Tokyo, Japan.

Novinger, G.D. (1990) Slot length limits for *M. salmoides* bass in small private impoundments. *North American Journal of Fisheries Management*, 10: 330-337.

Ogutu-Ohwayo, R. (1990) The decline of the native fishes of lakes Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch, *Lates niloticus*, and the Nile tilapia, *Oreochromis niloticus*. *Environmental Biology of Fishes*, 27: 81-96.

Parker, B.R., D.W Schindler, D.B. Donald and R.S. Anderson (2001) The effects of stocking and removal of a nonnative salmonid on the plankton of an alpine lake. *Ecosystems*, 4: 334-345.

Power, M.E., W.J.J. Matthews and A. Stewart (1985) Grazing minnows, piscivorous bass, and stream algae: dynamics of a strong interaction. *Ecology*, 66: 1448-1456.

Raborn, S.W., L.E. Miranda and M.T. Driscoll (2002) Planning and execution of the fish reduction in Lake Ringsjön. *North American Journal of Fisheries Management*, 22: 406-417.

Sahara, Y. and R. Kouchi (1980) Ecology of *Oryzias latipes* and *Gambusia affinis affinis*. *In*: T. Kawai, H. Kawanabe and N. Mizuno, eds., *Freshwater Organisms in Japan: Ecology of Invasion and Disturbance,* Tokai University Press, Tokyo, Japan, pp.106-117. (In Japanese)

Takahashi, K., T. Onodera and A. Kumadani (2000) The appearance of *M. salmoides* bass and changes in species compositions by fixed net fishing of the fish community in Izu-numa swamp. *Miyagi Fishery Examination Report*, 1: 111-118.

Takemon Y. (2000) Impacts of alien fishes and their control in Mizoro-ga-ike Pond. *In*: Japanese Society of Environmental Entomology and Zoology, ed., *Methods of Faunal Census for Environmental Assessment* vol. 10, Japanese Society of Environmental Entomology and Zoology, Osaka, pp. 48-64. (In Japanese).

Takemon Y., K. Hosoya and O. Murakami (2002) The Mizoro-ga-ike Pond. *In*: Ecological Society of Japan, ed., *Handbook of Alien Species in Japan.* Chijin-Shoin, Tokyo, pp. 269-271. (In Japanese).

Werner, E.E. and D.J. Hall (1988) Ontogenetic habitat shifts in bluegill: the foraging rate-predation risk trade-off. *Ecology*, 69: 1352-1366.

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