Research Article

Success in population control of the invasive largemouth bass *Micropterus salmoides* through removal at spawning sites in a Japanese shallow lake

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Abstract

The control of invasive species is of major importance for ecological conservation, and there is a need for more effective techniques and approaches to control these species, especially in open habitats. Two types of activities were conducted to control the population of largemouth bass (*Micropterus salmoides*) in Lake Izunuma-Uchinuma, Japan. The first activity was a lake wide catch using set nets deployed all along the lakeshore beginning in 2001. The second activity, beginning in 2004, focused on catches during the spawning season over spawning sites, distributed along lakeshore segments with sandy substrates. The efforts of both activities were similar (involving about 140 people/year). From 2001 to 2003, the catch per unit of fishing effort (CPUE) of largemouth bass using set nets increased; however, CPUE decreased dramatically after catches at the spawning sites started. The numbers of nests spawned, larvae, and adults of largemouth bass also decreased after the start of spawning site catches. In 2010, the CPUE of other fish species, whose numbers had decreased due to predation by largemouth bass, recovered to the same number as before the expansion of largemouth bass. Capturing largemouth bass at the spawning sites was an effective approach to controlling this species and conserving fish communities in the lake.

Key words: artificial spawning bed, black bass, conservation, dip net, invasive species, overfishing, pest control

Introduction

The control of invasive species is of major importance for ecological conservation (Williamson 1996). In general, the method of controlling an invasive species is dependent on its abundance and the size of its habitat (Grice 2009; Parkes and Panetta 2009). Some control projects have succeeded in removing invasive species within small or enclosed habitats, however more effective approaches are required for the control of widespread invasive species living in large or open habitats (Kolar et al. 2010; Britton et

al. 2011). The control of invasive fish in such habitats thus requires an approach that focuses on the vulnerabilities of target species such as their reproduction process (Stuart and Jones 2006; Britton et al. 2011).

Black basses are piscivorous fish native to North America that have been introduced into more than 50 countries (Welcomme 1992; CABI 2020). The invasion of black basses in lakes, rivers, reservoirs, or ponds has led to the degradation of fish fauna and the extinction of local fish populations (Takahashi et al. 2001; Fujimoto et al. 2009; Loppnow et al. 2013; Khosa et al. 2019; Pereira and Vitule 2019; Luger et al. 2020).

Many control projects of largemouth bass *Micropterus salmoides* and closely related black basses *M. dolomieu* and *M. punctulatus* have been conducted (Ministry of the Environment of Japan 2004; Michalski 2007; Department of Fisheries and Oceans Canada 2013; Haubrock et al. 2018; van der Walt et al. 2019), and some of the projects were successful in eradicating these species. In small closed habitats such as irrigation ponds, the largemouth bass was successfully eradicated by dewatering (Kleinschmidt Energy and Water Resource Consultants 2008; Tsunoda et al. 2010). In larger open habitats, early action is vital when these species first appear (Kudo and Kimura 2008; Vander Zanden and Olden 2008; Oohama et al. 2012). However, efforts to eradicate largemouth bass have been less successful in established populations living in large-scale habitats such as swamps or lakes connected with other habitats through corridor waters (Michalski 2007; Halfyard 2010; Rytwinski et al. 2019). More effective approaches are required for the control of largemouth bass that have become established in open habitats.

Most fish species, including largemouth bass, have vulnerabilities in terms of their reproduction (Stuart and Jones 2006; Britton et al. 2011). Firstly, their spawning habitat is typically limited to specific areas of the water because fish in the early stage of life prefer conditions without biotic or abiotic stress such as oxygen depletion, infection, and predation (Balon 1975; Vadstein et al. 2013; Taylor et al. 2019). Secondly, during the early larval stage, young fish often school around the spawning site to avoid predators (Davis and Lock 2007; Wallus and Simon 2008). During the reproductive season, adult fish, eggs, and larvae are thus all distributed within a limited area, which presents an opportunity to capture fish more easily than across the entire habitat.

At Lake Izunuma-Uchinuma in northeastern Japan, the largemouth bass population expanded from 1996, while the catch per unit of fishing effort (CPUE) of other fish decreased to 1/14 in number (Takahashi et al. 2001). This decrease in fish numbers led to a decline in fish-eating waterbirds (Shimada et al. 2005) thus damaging broader ecosystem structure. In this study, two types of control activities were conducted annually in the lake: (1) capturing largemouth bass across the entire lake beginning in 2001 and (2) capturing them at their spawning sites during the spawning season
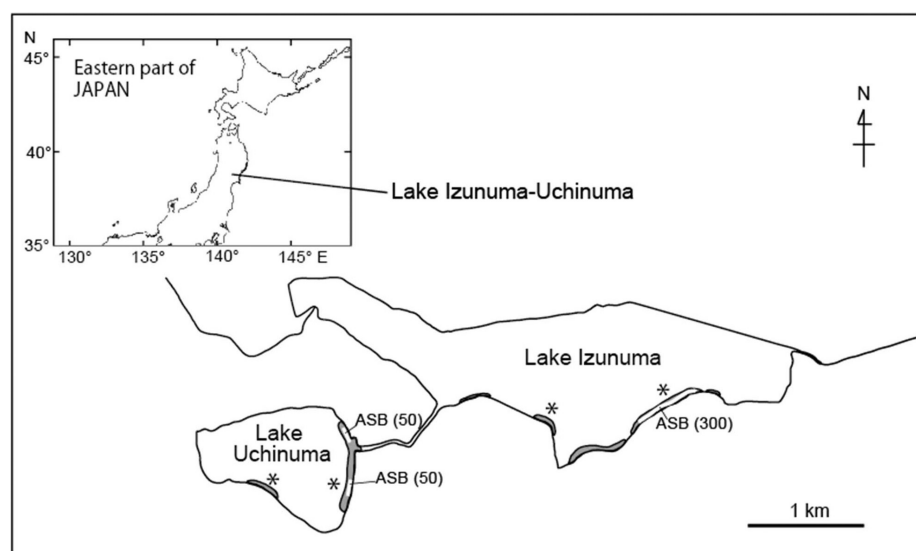
Figure 1. Map of Lake Izunuma-Uchinuma. Lines indicate shorelines. Shaded areas indicate potential spawning sites of largemouth bass investigated using side scan sonar (Kamata et al. 2009). White bars at the spawning sites indicate areas where ASBs were set. Values in parentheses indicate the number of ASBs that were set at each area. Asterisks indicate locations where larvae were caught with dip nets.

beginning in 2004. The results of these two activities and subsequent changes in fish fauna were monitored annually, and effective approaches to the control of largemouth bass in lakes are proposed.

Materials and methods

Study sites

The control activities were conducted at Lake Izunuma-Uchinuma (38°43′N; 141°07′E, sea level 6 m), Miyagi Prefecture, in northeastern Japan (Figure 1). The waterbody actually consists of two lakes connected by a channel of about 0.8 km in length and 30 m in width. The surface areas of the lakes are 3.69 and 1.22 km² with a mean depth of 0.76 and 0.78 m, respectively. The total length of the lakeshore is about 20 km. Fish move freely between the two lakes through the channel. The control activities of largemouth bass have therefore been conducted with the two lakes considered as a uniform habitat.

Gravel substrate is preferred by largemouth bass for spawning (Robinson 1961; Mraz 1964). However, most of the bottom substrate in the lake consists of mud and a number of sandy areas. Previous study has reported that the sandy areas were the main spawning sites of largemouth bass in the lake (Saito et al. 2007). Kamata et al. (2009) found that 74.4% of larvae were distributed in these areas (asterisks in Figure 1). Based on these results, the total area of available spawning sites was estimated to be restricted to 2.0% (9.8 ha) of the area of the lake along 21.9% (4.4 km) of the length of the lakeshore (shaded areas in Figure 1). The lakeshore of the sites was covered in common reed *Phragmites australis* and willows (*Salix* spp.). Some parts of the lakeshore were covered in other submerged plants such as
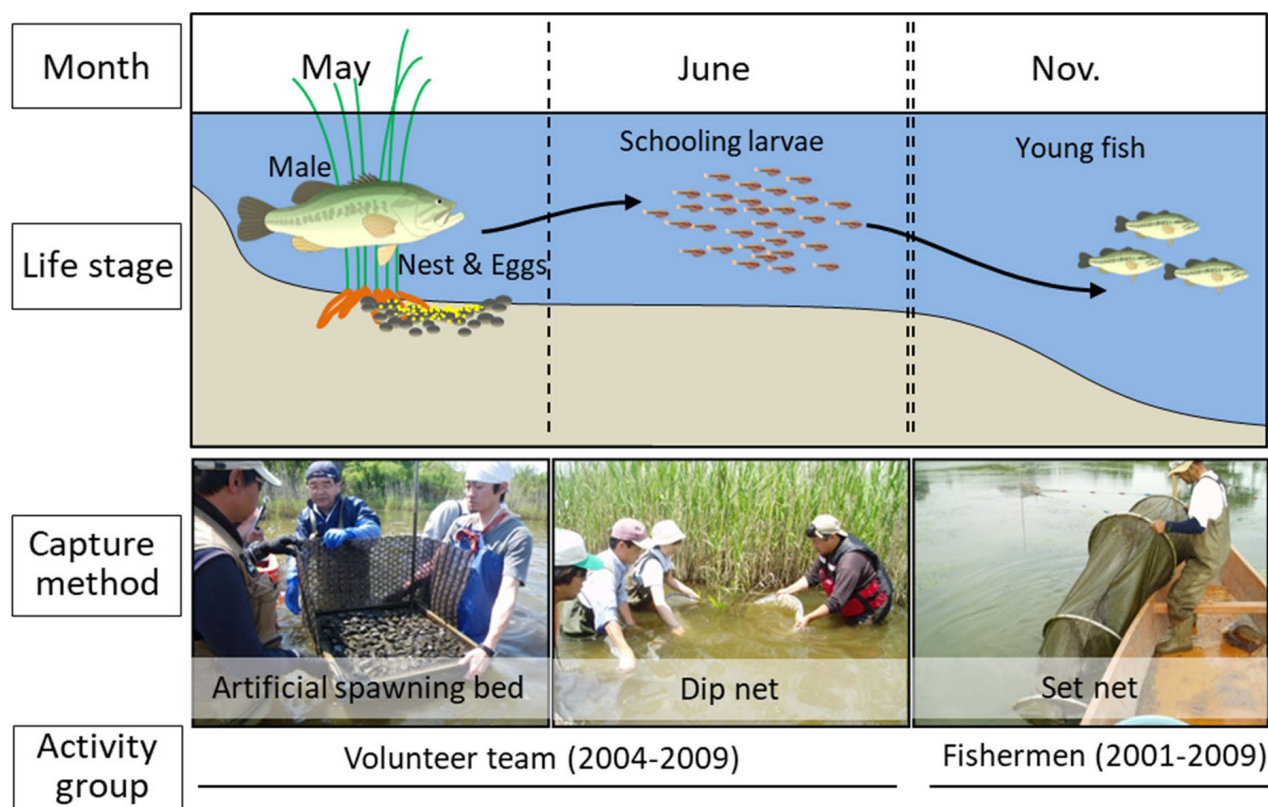
Figure 2. Life stages of largemouth bass (above) and capture methods used in Lake Izunuma-Uchinuma (below).

Schoenoplectus tabernaemontani or *Acorus calamus* that were often used by largemouth bass as a natural spawning bed. The lake is eutrophic, and underwater visibility, monitored by the Miyagi Prefectural Government using a transparency meter, ranged between 0.3–0.5 m during the spawning season of largemouth bass (late April to June) (Miyagi Prefectural Government 2009).

Control activities

Two types of activities were operated: (1) capture by set net deployed lake wide annually, from 2001 to 2009 and (2) capture of eggs and larvae over the spawning site from 2004 to 2009 (Figure 2).

Set net

The set net is a fixed net comprised of a drum net (mesh size: 5 mm, length: 5 m, diameter: 0.6 m) and a long leader net (mesh size: 10 mm, length: 30 m, depth: 1.8 m). This net has traditionally been used by fishermen to catch small fish species in the lake. The long leader net stretches 30 m from the shoreline to an offshore location. The drum net to store fish was set at the offshore end of the leader net. Fish swim along the leader net and then enter the drum net. A previous study reported that many age-0 and age-1 largemouth bass were captured by set nets from November to early December (Obata 2006). A total of 20–100 set nets were deployed by 5–10
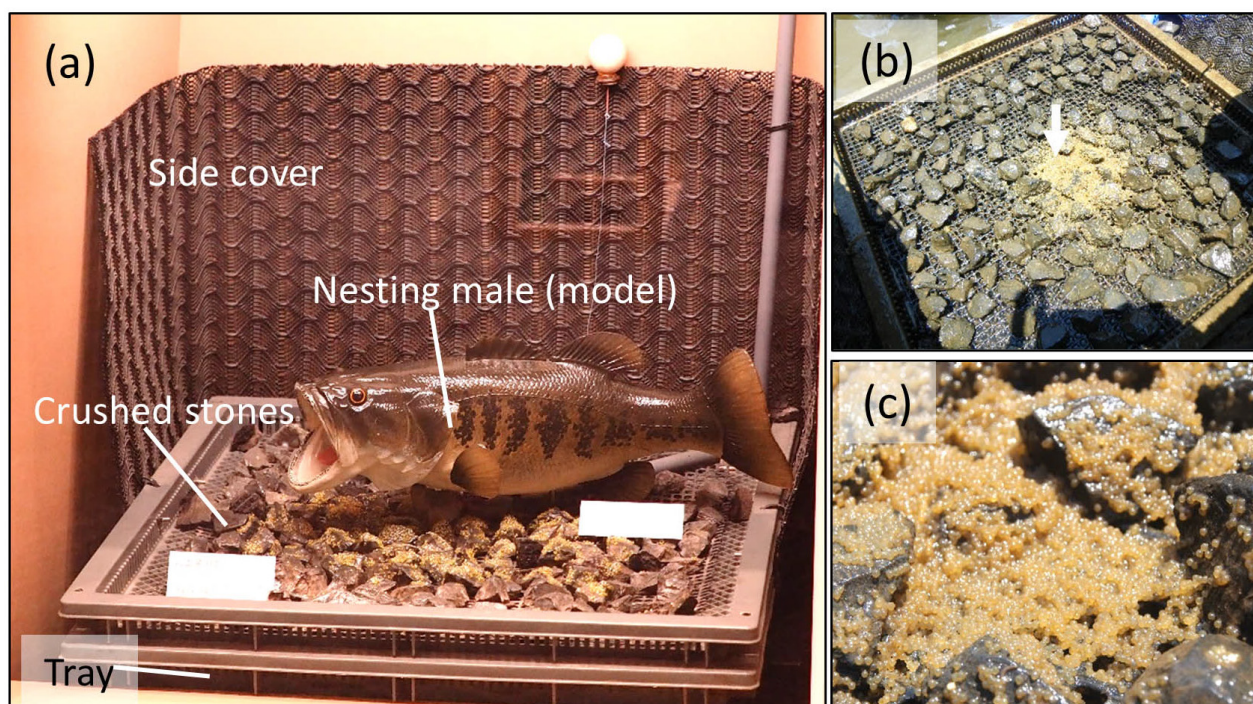
Figure 3. Panel (a) indicates an artificial spawning bed (ASB) with a model of male largemouth bass. Arrow in panel (b) points to spawned eggs on the ASB. Panel (c) shows eggs of largemouth bass (about 1.2 mm in diameter).

fishermen throughout the lakeside. Fishes were collected twice a week between October and early December from 2001 to 2009.

Artificial Spawning Bed

The artificial spawning bed (ASB) is a technique that was developed to attract nesting largemouth bass for spawning, because it is difficult to find natural nests in turbid water like there is at Lake Izunuma-Uchinuma (Figure 3; Takahashi 2005). The ASB (length: 0.64 m, width: 0.64 m, height: 0.45 m) is a meshed tray with gravel on it and a three-sided cover (with the fourth side open). The gravel, about 40 mm in diameter, worked as a spawning substrate by the largemouth bass. The tray, with a mesh size of 0.7 mm, was designed to catch spawned eggs and hatched larvae on the tray. Female largemouth bass attached their eggs onto the gravel and the tray of the ASB. The side cover made of a 3-mm mesh plastic sheet was designed to attract male largemouth bass evading egg eaters to the ASB, based on a previous study (Takahashi et al. 2007).

From late April to late June, 400 ASBs were set in the lake at the spawning sites of largemouth bass (Figure 1; white bars in the shaded area). The ASBs were set at intervals of 5 m along two lines running parallel to the shoreline, one about 5 m and the other about 10 m off the shoreline. The water depth at the lines ranged from 0.4 to 1.0 m. The ASBs were checked twice a week by direct observation to see if any eggs of largemouth bass were present. ASBs containing eggs were removed from the lake and a new ASB was set to replace each of them.

Dip net

Between late May and June, the schools of smaller (smaller than 15 mm total length (TL)) and larger (15–25 mm TL) larvae were captured over the spawning sites by members of the volunteer team donned in water-proof waders (Figure 2). A semicircular dip net (height: 0.8 m, width: 0.8 m, mesh: 1 or 3 mm) was used to capture the larvae of largemouth bass. When a school was discovered, the members surrounded the school and captured it using dip nets. Larvae of largemouth bass form schools (Davis and Lock 2007; Wallus and Simon 2008), and in the lake, many schools of larvae distributed over the spawning sites. Because the natural nests of the largemouth bass were observed at the roots of submerged plants such as *Schoenoplectus tabernaemontani* or *Acorus calamus* along the shoreline, the smaller larvae were mainly distributed at spawning sites along the shore up to 2 m from the shoreline (Ashizawa et al. 2015). The larger larvae were distributed along the shore up to 10 m from the shoreline. Since all larvae could not be captured in one attempt, the members then waited for a few minutes until the larvae had formed small, new schools and then repeated the trial. The members captured schools at most parts of the spawning sites for 7–14 days each year (asterisks in Figure 1). The numbers of captured larvae were estimated by counting approximately 10% of the weight sampled from the fish caught each day.

Monitoring changes in fish populations

Gillnets and set nets were used to monitor changes in fish populations after control activities in the lake had been conducted. Twenty gillnets (length: 70 m, depth: 2 m, mesh: 120 mm) to monitor adult fish were set at various locations of the lake between October and December from 2009 to 2011. The capture using gillnets was repeated 21–29 times each year. Changes in the numbers of fishes in the lake were monitored using set nets during late November in 1996, 2000, and 2004–2009, and early summer (May or July) in 1996, 2000, 2009, and 2010. The data for 1996 and 2000 were referenced from a previous study (Takahashi et al. 2001). The type of the set net was the same as that described above. About 10–20 set nets were set along the shore of the entire lake. The fish were collected twice a week, and since these catches were also very large, the total number of each species was estimated using the same method described above.

Data analysis

The CPUE (individuals/net/day) of each fish species was calculated based on the data obtained from the gillnet and set net catches. The CPUE of each fish species captured by gillnet was analyzed by two-way ANOVA completed with the Tukey's post hoc test, considering all four species and sampling years. The CPUE of each fish species captured by the set net was
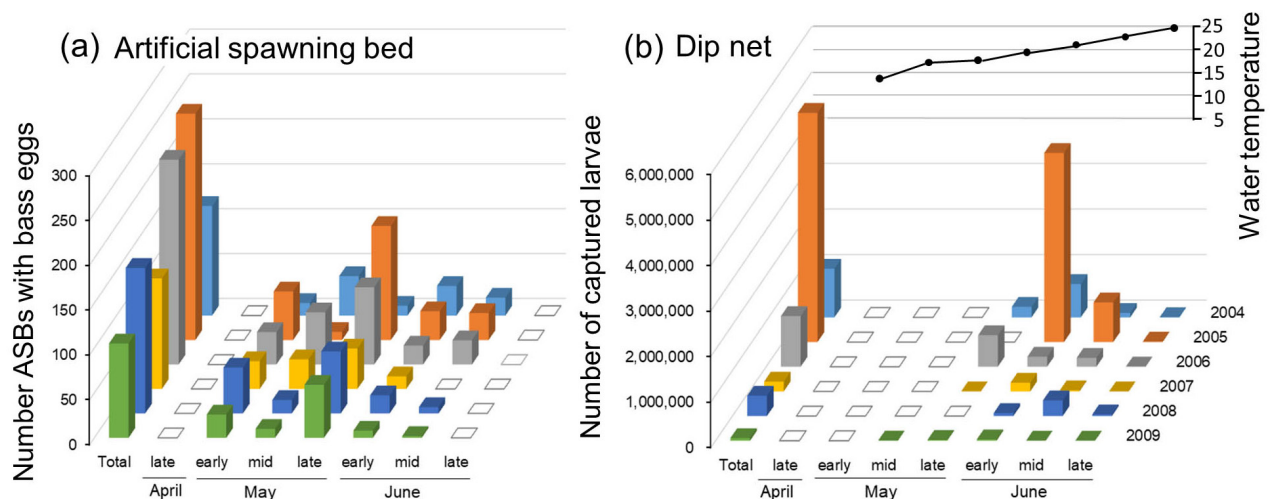
Figure 4. Changes in catches of largemouth bass with (a) ASBs and (b) dip nets during 2004–2009. Colors stand for visualizing yearly changes.

analyzed by Spearman's rank correlation. These data were analyzed using BellCurve for Excel (ver. 3.21, Social Survey Research Information Co., Ltd.). The number of surviving larvae after the dip net activity was calculated using Program CAPTURE (White et al. 1978). In 2007, the ages of random-sampled largemouth bass captured by gillnet were determined by examining the otoliths (Yodo and Kimura 1996).

Results

From 2001 to 2009, an average of 141 people/year (ranging from 26 to 158) were involved in the set net operation for lake wide removal of largemouth bass. From 2004 to 2009, 142 people/year (ranging from 80 to 180) were involved in the capture over spawning sites using ASBs and dip nets.

The spawning of largemouth bass at the ASBs started from early May at a water temperature above 16 °C, showed a peak in late May at about 20 °C, and finished at a temperature above 23 °C in middle June (Figure 4a). Number of ASBs with largemouth bass eggs peaked in 2005 at 252 nests, and then gradually decreased to 105, 41.7% of the peak, in 2009. There was a negative correlation between the number of daily catch of nests by ASBs and each catch date from 2004 to 2009 (Spearman's rank correlation, n = 85, r = −0.23, $p < 0.05$). Total number of larvae captured yearly using dip nets peaked in 2005 over five million individuals, and then rapidly decreased to about 1% of the peak, in 2009 (Figure 4b). There was a negative correlation between the number of daily catch of larvae by dip nets and each catch date from 2004 to 2009 (Spearman's rank correlation, n = 61, r = −0.44, $p < 0.001$). Most of the larvae captured after 4–7 days of the peak of ASB in early June. The number of larvae in some of the schools were counted in 2008. The mean number of larvae was 9,505 individuals (ranged from 246 to 49,483, n = 30). Eight of 30 schools consisted of over 10,000 larvae. Schools of larvae were easily found until 2006. At the end of the capture by dip net each

Table 1. The results of annual capture by ASB and dip net and estimation of the number of survived larvae and adults of largemouth bass in Lake Izunuma-Uchinuma.

Year	Initial number of nests (upper) and larvae (lower)	Numbers of capture		Survived larvae	Survived adults	
		ASB	Dip net		Age 4	Age 5
2004	435	122	1,068,636	371,573	1,379	571
	2,001,409	28.0%	53.4%	18.6%		
2005	1,726	252	5,027,673	1,751,985	6,501	2,692
	7,938,858	14.6%	63.3%	22.1%		
2006	553	228	1,111,337	382,275	1,419	587
	2,542,412	41.3%	43.7%	15.0%		
2007	186	123	214,553	74,065	275	114
	854,418	66.2%	25.1%	8.7%		
2008	307	162	445,540	221,998	824	341
	1,412,738	52.7%	31.5%	15.7%		
2009	125	105	55,870	34,830	129	54
	573,700	84.2%	9.7%	6.1%		
Average	555	165	1,320,602	472,788	1,754	726
	2,553,922	47.8%	37.8%	14.4%		

year, some schools of larvae survived and probably left the spawning sites as they grew. From 2007, schools of larvae over the spawning sites became difficult to find during the capture by dip net. Only a few individual larvae were observed over the sites at the end of the period. The program CAPTURE estimated that 472,788 individuals on an average survived yearly in the lake after the capture by dip net during 2004–2009 (Table 1). Based on Kramer and Smith (1962), where the number of larvae emerged from each nest was assumed as 4,600, the initial number of nests, average elimination rate by ASB and dip net, and the survival rate from 2004 to 2009 were calculated as 555 nests (ranged from 125 to 1,726), 47.8% (ranged from 14.6 to 84.2%), 37.8% (ranged from 9.7 to 63.3%), and 14.4% (ranged from 6.1 to 22.1%), respectively. Estimates based on previous studies of monthly mortality rate of age 0 and annual mortality rate of over age 1 largemouth bass being 0.216 and 0.586 (Timmons et al. 1981) suggest that 1,754 and 726 of these larvae would grow on averages to age 4 and 5, respectively. The numbers of estimated age 4 and 5 individuals decreased from 2005 to 2009.

The CPUE of largemouth bass captured by gillnet decreased by one-third from 2007 to 2009 (Figure 5), while the CPUE of other fish species was unchanged. Two-way ANOVA indicated sampling year ($F_{(2,51)} = 4.63$, $p < 0.01$) and fish species ($F_{(3,50)} = 34.6$, $p < 0.001$) on CPUE of fish, and an interaction effect ($F_{(6,48)} = 2.75$, $p < 0.01$; Figure 5). According to the Tukey's post hoc test, the number of gillnet-caught largemouth bass in 2007 was higher than that of captured in 2008 and 2009 ($p < 0.001$). The standard length of largemouth bass captured by gillnet peaked at 350 mm and ranged from 270 to 430 mm (Figure 6a). Based on the age determination of randomly sampled largemouth bass (66 out of 362 fish), 77.3% of largemouth bass captured by gillnet were at age of 4–5 years (Figure 6b). The averages of the standard length (SL) of age-4 and age-5 largemouth bass were 339 ± 17 mm (n = 28) and 345 ± 19 mm (n = 25), respectively.
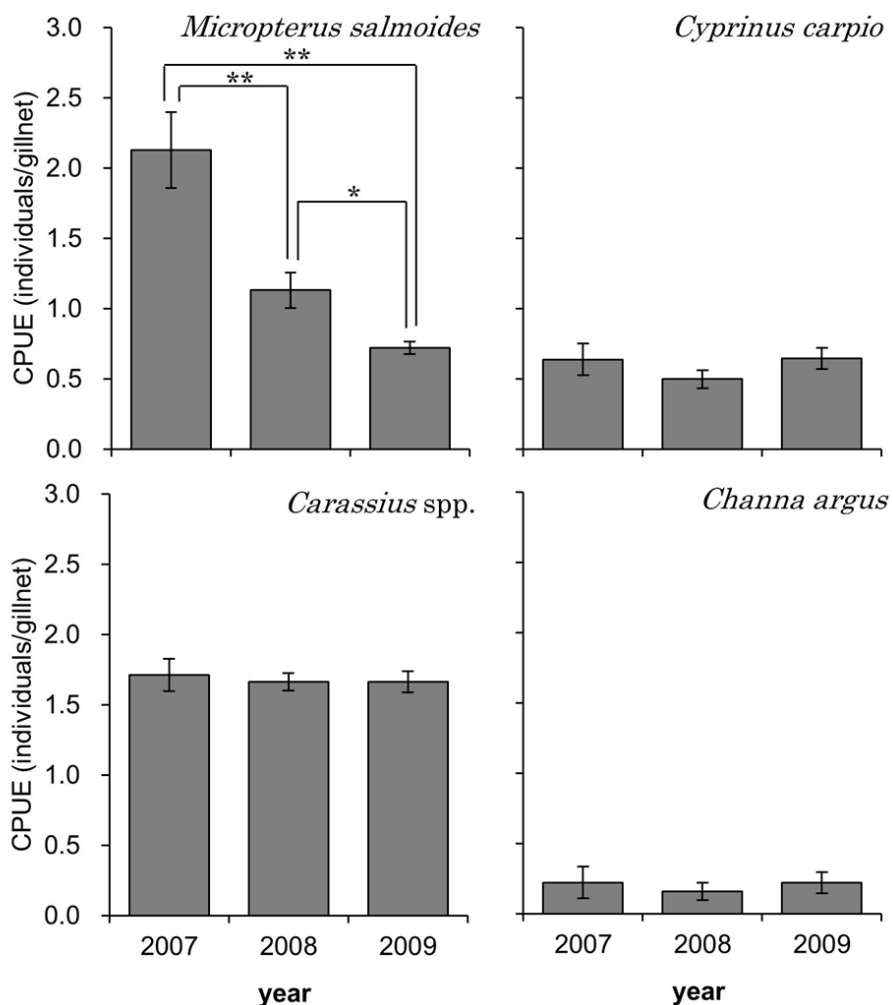
Figure 5. Comparison of gillnet catches of four fish species including largemouth bass during 2007–2009. Bars indicate standard errors of the mean. ***: $p < 0.001$ (Two-way ANOVA followed by Tucky's post hoc test).
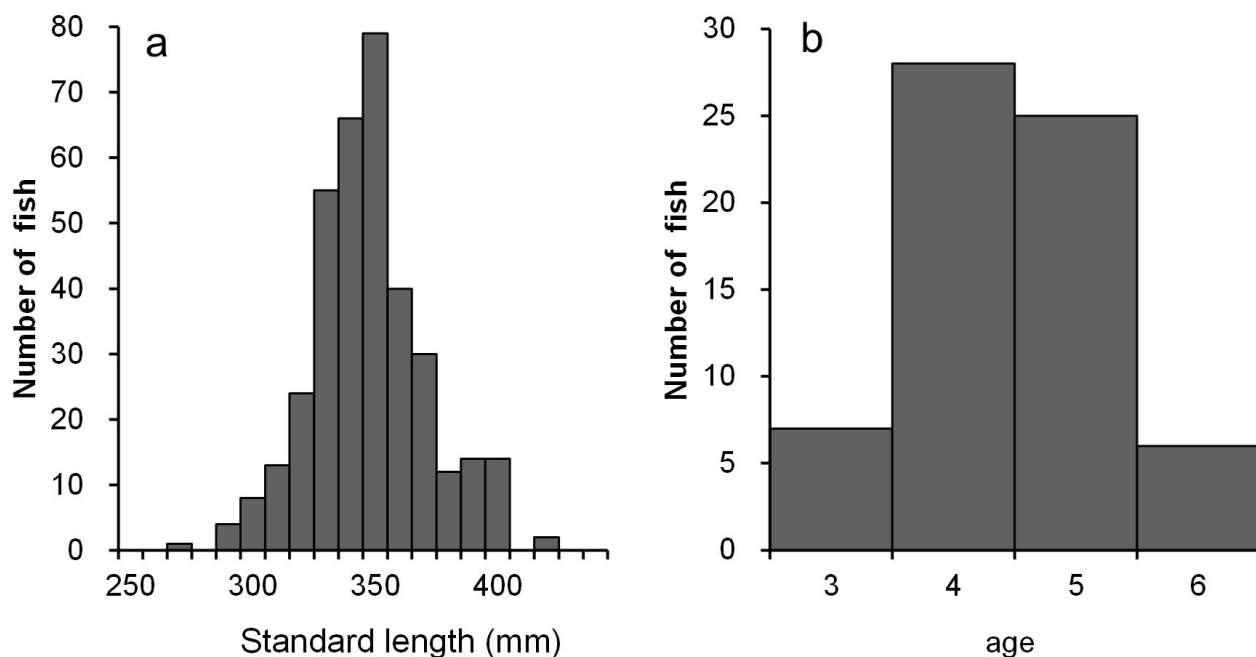

Figure 6. Standard length (a) and age (b) distribution of largemouth bass caught with gillnets.
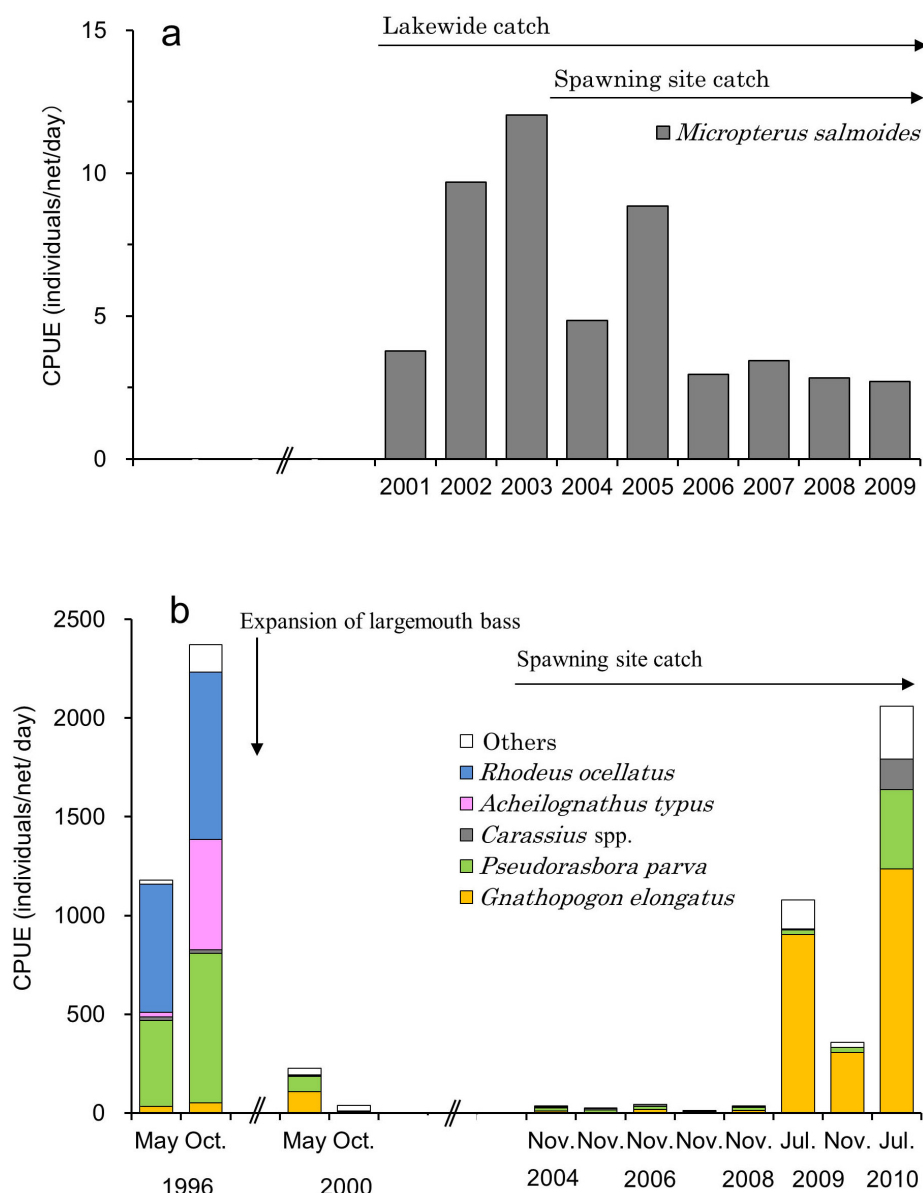
Figure 7. Changes in average daily CPUEs of fish species with set nets during the study period at Lake Izunuma-Uchinuma. (a) largemouth bass during 2001–2009, (b) other fish species during 1996–2010. Data for 1996 and 2000 are referenced from Takahashi et al. (2001).

The CPUE of the set nets, which mostly included age-0 and age-1 largemouth bass, increased until 2003 (Figure 7a). From 2004, when captures over spawning sites started, the CPUE of largemouth bass gradually decreased from the peak of 12.0 in 2003 to 2.7 in 2009 (r = −0.929, $p < 0.001$; Spearman's rank correlation).

The CPUE of other fish captured in the set net had decreased considerably by 2000 when largemouth bass expanded in the lake (Figure 7b), and the CPUE continued to be low until 2008. In 2009, the CPUE recovered to a comparable level recorded in 1996. The CPUE of other fish species showed a positive correlation after 2004 (Spearman's rank correlation; n = 6, r = 0.719, $p < 0.05$). There were positive correlations in the CPUEs of *Gnathopogon elongatus* (Spearman's rank correlation; n = 6, r = 0.77, $p < 0.05$)

and *Pseudorasbora parva* (Spearman's rank correlation; n = 6, r = 0.83, *p* < 0.05) after 2004. There were no positive correlations in *Carassius* sp. (Spearman's rank correlation; n = 6, r = −0.07, *p* > 0.05) and other fishes (Spearman's rank correlation; n = 6, r = 0.69, *p* > 0.05). None of *Acheilognathus typus* and *Rhodeus ocellatus* were captured by setnet after 2004. Therefore, the dominant species composition changed from *Pseudorasbora parva*, *Rhodeus ocellatus*, and *Acheilognathus typus* in 1996 to *Gnathopogon elongates* and *P. parva* in 2009.

Discussion

Comparable efforts (about 140 people/year) were made for set net and spawning site catch, yet different largemouth bass stock outcomes indicate importance on choice of an appropriate measure in space and time for this overfishing operation. The numbers of captured nests, larvae, and adults of largemouth bass also decreased after catches were started over the spawning sites. The set net catch efforts targeted young fish that had dispersed throughout the lake (area: 491 ha) in autumn. The spawning site catch efforts, however, targeted eggs and larvae of largemouth bass restricted in a limited area of the lake (area: 9.8 ha) during the spawning season. These results demonstrated that the focus on an appropriate deployment of effort led to a reduction in the numbers of largemouth bass and the recovery of other fish species in the lake as shown in eradication of the smallmouth bass (Loppnow et al. 2013).

Another factor for the success of the spawning site catch was that it focused on the schooling behavior of larvae, a pattern that made largemouth bass in this life stage more vulnerable to predation and easier to catch. On average, there are about 4,600 larvae per nest (Kramer and Smith 1962). Very large schools (> 10,000 larvae) indicate aggregation of larvae merging their schools after leaving individual nests. This aggregating behavior of larvae enabled effective dip netting. In general, the schooling behavior of fishes increases their chances for survival (Pitcher 1986). However, as anglers know well, targeting fish schools is an efficient method of catching fish (Murphy 1980). The present study demonstrated that schools of larvae at spawning sites concentrated in limited areas of the lake were the most important target in efforts to control the largemouth bass population.

Schools of larvae were effective targets to control the largemouth bass population; however, the appropriate timing to catch the school was limited in early June. Because most of the schools of larvae appeared after 4–7 days of the peak of spawning in the ASBs, we easily predicted the appropriate timing and determined the appropriate deployment of effort to catch the schools along with ASB also working as a monitoring tool. A successful management program usually involves a combination of treatment methods based on available tools and resources (Wittenberg and Cock 2001).

Therefore, the combination of ASBs and dip nets targeted the different life stages of largemouth bass led an effective management in the lake.

The survival rate of larvae was suppressed to 14.4% by ASBs and dip nets, which was lower than the rate of 50% under natural conditions (ranged from 25–75%: Post et al. 1998). For successful control of the invasive population, the rate must lead to a reduction in adult populations. Based on the age of the gillnet-caught cohort, largemouth bass captured in 2007 were born in 2002–2003, when catches at spawning sites had not yet started. On the other hand, most of the largemouth bass captured in 2009 were born after 2004. Therefore, reproductive suppression by ASBs and dip nets was effective in reducing the adult population of largemouth bass in Lake Izunuma-Uchinuma, as indicated by the reduction in the gillnet catches.

In Lake Izunuma-Uchinuma, the CPUE of other fish species decreased due to the expansion of the largemouth bass population from 1996, and the CPUE recovered after catches at spawning sites started in 2004. During the study period, no changes in land use or water quality that would have had a significant impact on fish populations were identified (Miyagi Prefectural Government 2009; Takahashi and Fujimoto 2018). Therefore, changes in fish populations in the lake were likely caused by stock fluctuation of largemouth bass. The results of our study demonstrated the effectiveness of largemouth bass population control in conserving fish populations in lakes.

Unfortunately, in the case of Lake Izunuma-Uchinuma, the fish fauna that increased after decline of largemouth bass were not the same as before the expansion of largemouth bass. Dominant species such as *P. parva* and *G. elongatus* were common before the numbers of largemouth bass increased, but these species are not native to the lake. The species that recovered in 2009 continued to inhabit the lake, although few in number, during the period from 1996 to 2008 when the impact of largemouth bass was expanding. On the other hand, native species such as *A. typus*, *A. melanogaster*, and *Gymnogobius castaneus*, that are listed by IUCN and/or local government in their Red List of Threatened Species, have not yet recovered. However, the three threatened species are still present in the irrigation ponds in the basin. Threatened species in these closed waters had been protected from the expansion of largemouth bass (Fujimoto and Shindo 2012). We expect that threatened species in the lake can be restored by dispersion or reintroduction (Saitoh et al. 2016; Fujimoto and Hayami 2018). The approach of restoring fish fauna following the control activities of invasive fish species will probably become a vital component of plans that are based on the distribution of each fish species in the whole basin.

The possibility of eradicating a once-established largemouth bass population is a topic of a vital interest. More effective approaches to the eradication of largemouth bass populations are needed. There are two ways to address this task. Firstly, reproductive females and males were not targeted in this study. The development of a method to control reproductive

adults is promising in the control of reproduction, before eggs and larvae are released. Secondly, eradication projects can lead to a decrease in the capture efficiency of target fish and increase the bycatch of other fish species, as the set net did from 2009 in this study. The development of an effective method of selective capture or reproductive suppression, such as a sterilization technique (Okamoto et al. 2020), would be an essential approach to achieving eradication. Application of boat electrofishing, for example, was an effective method (Ribeiro et al. 2015) and eradicated the pre-established largemouth bass population in Hokkaido (Kudo and Kimura 2008). A recent study demonstrated that the bile of reproductive male largemouth bass contains a sex pheromone to attract reproductive females (Fujimoto et al. 2020). These methods may also play vital roles in the control of largemouth bass.

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