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Relationship between the impact of invasive largemouth bass and environmental conditions in ponds

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Abstract: To determine the relationship between the impact of introduced largemouth bass on native fish fauna and the environmental conditions in ponds, we compared richness and diversity of fish species, environmental factors and the relationship between them in ponds with and without bass. The study was conducted at 49 ponds in Oshu city in Iwate prefecture, northeastern Japan. For determining the impact of largemouth bass on fish fauna in ponds, Pearson's correlation was used between the dominance of largemouth bass (%BASS), total number (S) and diversity index (H') of occurring fish species. Furthermore, multiple regression analysis was used to determine the relationship between S or H' and environmental factors. %BASS was negatively correlated with both S and H'. In ponds without bass, both S and H' were related to maximum depth and S in ponds with bass was also related to maximum depth. However, H' in ponds with bass was significantly influenced by the coverage of emergent plants and was more clearly explained compared to the relationship between S and maximum depth. It suggested it is possible that emergent plants also provide refuge for prey fish, buffering the impact of largemouth bass.

Key words: emergent plant, fish fauna, invasive alien fish, *Micropterus salmoides*, pond

Introduction

Biodiversity in inland lentic habitats such as lakes and ponds is seriously affected by alien species (Simberloff 2001; Bronmark and Hansson 2005; MEAO 2005). Alien fish species have been introduced into lakes and ponds around the world both intentionally (for fishery, aquaculture, recreational fishing or biological control) and unintentionally. Some of these fish have caused significant biodiversity loss and/or economic damage as in the case of the Nile perch (*Lates niloticus*) in Lake Victoria, East Africa (Ogutu-Ohwayo 1990; Kaufman 1992; Kitchell et al. 1997).

There are more than 200,000 ponds in Japan, most of which were artificially created several decades ago but are important for conserving freshwater biodiversity (Takamura 2003). Since the majority of natural lakes, ponds and marshes have been altered and degraded by human activity, such semi-natural ponds play an important role in providing much-needed habitats for aquatic organisms. Recently, however, the biodiversity in such ponds has been threatened by invasive alien species. One such species is the largemouth bass (*Micropterus salmoides*), a piscivorous fish introduced in 1925 from the U.S. (Yodo and Iguchi 2004). Previous studies have reported the degradation of fish fauna in lakes and ponds invaded by largemouth bass (Maezono and Miyashita 2003; Abekura et al. 2004; Nakai 2004; Sugiyama and Jinguji 2005; Tsunoda et al. 2008). However, the predatory performance of this species is influenced by various biotic and abiotic factors, such as light intensity and water clarity, oxygen depletion, prey size and gape size, behavioral refuge of prey and weed beds as refuge for prey (reviewed in Takamura 2007). Furthermore, habitat structural complexity also influences prey selection by bass (Gotceitas and Colgan 1989; Savino and Stein 1989; Dibble and Harrel 1997), habitat use by prey (Harvey et al. 1988) and impact on prey by bass (Sass et al. 2006). Tsunoda et al. (2008) indicated that the degradation of native fish fauna by the introduction of bass differed among ponds and that many fish species coexist with largemouth bass in one of four farm ponds in southern Iwate prefecture, northeastern Japan. Thus, it is likely that the impact of introduced bass on native fish fauna has changed due to the influence of environmental conditions in ponds, yet little is known in the case of Japanese ponds.

The objective of this study was to determine the relationship between the impact of introduced largemouth bass on native fish fauna and the environmental conditions in ponds. We compared richness and diversity of fish species, environmental factors and the relationship between them in ponds with and without bass. We also discuss how environmental factors relate to fish fauna in ponds and the impact of largemouth bass.

Methods

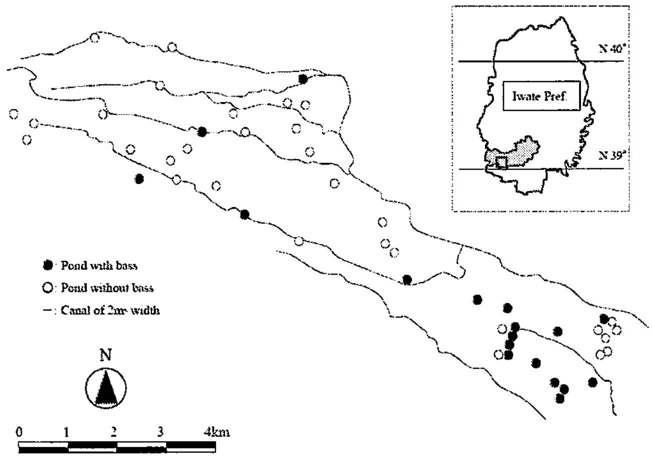

Fig. 1 Study area

The study was conducted at 49 ponds in Oshu city in Iwate prefecture, northeastern Japan (Fig. 1). The area is in the cool temperate zone and the surfaces of ponds freeze during winter. All 49 study ponds are situated within an alluvial fan. Several channels surround the ponds and all of them flow into the Kitakami River. Most of the ponds are connected to a narrow channel (<1 m width) and it is possible for the fish to migrate from channels to ponds. However, many of the fish species including the largemouth bass reproduce within each pond (Mitsuo et al., unpublished data). Environmental features, except for bottom substrate (mud and sand), vary among the ponds. Pond management, such as desiccating the bottom or weeding aquatic plants, has not been conducted for the last three decades (Kamijo Y, personal communication). Although the largemouth bass was introduced into Iwate prefecture after the 1990s (Yodo and Iguchi 2004), the exact time of its introduction into the study area is not known. Other fish such as deep-bodied crucian carp (*Carassius cuvieri*), common carp (*Cyprinus carpio*) and bitterling (*Rhodeus ocellatus ocellatus*) have also been introduced into some ponds.

Surveys were conducted in June, August and October 2008. Fish were collected by cast net (4.4-m diameter with 12-mm mesh size), hand net (40-cm diameter with 2-mm mesh size) and minnow trap (25×40×25 cm with 2-mm mesh size). One cast net, two hand nets and three minnow traps were used for each sampling. In view of the varied pond scale, sampling efforts were regulated according to the surface area scale (Table 1).Sampled fish were identified and the number of individuals counted.

Table 1 Sampling efforts according to the surface area scale of ponds

Surface area of ponds ($100m^2$)	< 0.3	0.3 – 0.6 <	0.6 – 0.9 <	0.9 – 1.2 <	1.2 -
Effort (minutes)	15	30	45	60	75
Number of ponds	18	9	6	4	12

All fish, except for largemouth bass, were released back into the same ponds. Some environmental features of each pond were measured during the field surveys in August. Maximum depth was measured by a Handy Sonar (PS-7FL, Hondex Inc.). Dissolved oxygen (DO; mg/l), pH, conductivity (EC; μS/cm) and transparency (cm) were measured using the appropriate equipment (DO: DO-5509, Fuso Inc.; pH: Twin pH B-212, Horiba Ltd.; EC: Twin Cond B-173, Horiba Ltd.; transparency: AT3, Hoga Inc.). Coverage of floating and emergent plants was recorded as % surface area. Alteration by human activity was recorded as % length of shoreline covered with concrete due to the loss of spatial heterogeneity. The surface area of each pond was measured from a 1:25,000 digital map using KASHMIR 3D Ver. 8.8.2 mapping software (Sugimoto 2008).

For determining the impact of largemouth bass on fish fauna in ponds, Pearson's correlation was used between the dominance of largemouth bass (%BASS), total number (S) and Shannon-Wiener diversity index (H') of occurring fish species. %BASS was quantified as percent individuals of largemouth bass among the total number of collected fish. In the calculation of S and H', largemouth bass was excluded. Furthermore, multiple regression analysis with forward-backward stepwise selection was used to determine the relationship between S or H' and environmental factors.

Results and Discussion

Table 2 Frequency of occurrence of fish species (%), mean of total number of occurred fish (S) and species diversity index (H') in the study ponds

	All ponds n = 49	With bass n = 18	Without bass n = 31
Frequency of occurrence			
Lethenteron reissneri	2.0	0	3.2
Hypomesus nipponensis	8.2	5.6	9.7
Zacco platypus	16.3	33.3	6.5
Tribolodon hakonensis	2.0	0	3.2
Phoxinus logowskii steindachneri	4.1	0	6.5
Pseudorasbora parva	69.4	50.0	80.6
Acheilognathus melanogaster	2.0	0	3.2
A. tabira subsp.	8.2	5.6	9.7
Rhodeus ocellatus ocellatus	34.7	33.3	35.5
Cyprinus carpio	10.2	16.7	6.5
Hemibarbus barbus	2.0	5.6	0
Carassius auratus	34.7	11.1	48.4
C. gibelio langsdorfi	26.5	22.2	29.0
C. cuvieri	24.5	27.8	22.6
C. spp. (unidentified fry)	10.2	11.1	9.7
Misgurnus anguillicaudatus	81.6	66.7	90.3
Cobitis biwae	16.3	0	25.8
Oryzias latipes	2.0	0	3.2
Pseudobagrus tokiensis	20.4	16.7	22.6
Rhinogobius sp. OR	89.8	88.9	90.3
Mean of S (*S.D.*)	4.6 (2.3)	3.9 (2.2)	5.0 (2.2)
Mean of H' (*S.D.*)	1.0 (0.4)	0.9 (0.5)	1.1 (0.4)

A total of 19 fish species, not including largemouth bass, were found during the study period and mean (*SD*) of S and H' was 4.6 (2.3) and 1.0 (0.4), respectively (Table 2). Largemouth bass were found at 18 of the 49 ponds (36.7%, Fig. 1). S and H' were not significantly different between ponds with and without bass (S: *d.f.* = 32, $t = -1.18$, *n.s.*; H': *d.f.* = 36, $t = -1.54$, *n.s.*). %BASS was negatively correlated with both S and H' but only significant in S (S: $r = -0.62$, $p < 0.01$; H': $r = -0.42$, *n.s.*; Fig. 2). Thus, the richness and diversity of fish species decreased with increasing population number of largemouth bass. Largemouth bass has especially influenced the Cyprinidae species in the ponds of western Japan (Mori 2003). Since 12 of the 19 species in the study area were

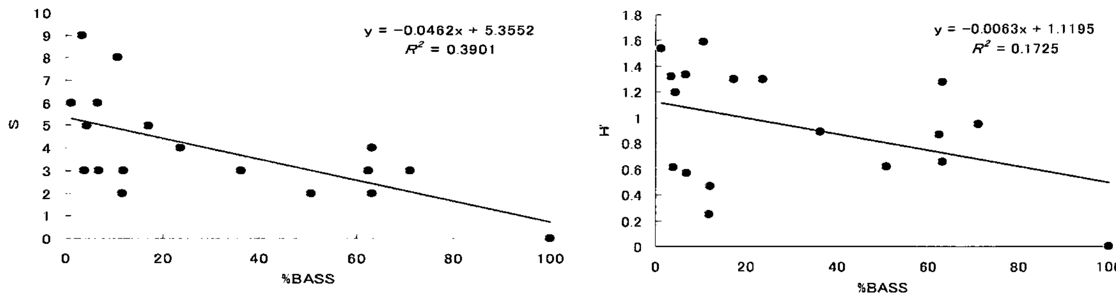

Fig. 2 Relations between % individuals of largemouth bass per total number of collected fishes (%BASS) and number of species (S) or species diversity index (H')

Cyprinidae species, it is likely that the largemouth bass has clearly affected species richness. *Rhinogobius* sp. OR (Gobiidae) was the most frequently occurring species in all of the ponds and both *Misgurnus anguillicaudatus* (Cobitidae) and *Pseudorasbora parva* (Cyprinidae) occurred in more than half the ponds. These three fish species frequently occurred both in ponds with and without bass. Surface area, % length of artificial shoreline, conductivity and coverage of floating and emergent plants were significantly different between ponds with and without bass (Table 3).

Table 3 Mean value (*SD*) of environmental factors in the study ponds. The t-test was used between ponds with and without bass

Environmental factors	All ponds	With bass	Without bass	*p*
Surface area ($100m^2$)	0.78 (0.88)	1.25 (1.12)	0.51 (0.58)	0.017
Maximum depth (m)	1.35 (0.89)	1.73 (1.24)	1.13 (0.50)	*n.s.*
DO (mg/l)	5.98 (1.46)	5.81 (1.08)	6.07 (1.65)	*n.s.*
PH	7.80 (0.60)	7.93 (0.49)	7.72 (0.64)	*n.s.*
EC (μs/cm)	119.65 (36.87)	102.79 (25.20)	129.50 (39.28)	0.006
Transparency (cm)	33.56 (20.53)	36.47 (28.02)	31.86 (14.88)	*n.s.*
Coverage of floating plant (%)	25.48 (26.34)	15.06 (22.93)	31.53 (11.84)	0.029
Coverage of emergent plant (%)	11.15 (10.49)	6.94 (5.76)	13.70 (26.62)	0.011
% length of artificial shoreline	23.65 (26.06)	39.78 (31.42)	14.29 (16.74)	0.004

Thus, environmental conditions in ponds with bass included larger, less vegetation and more extensive alteration by human activity compared to ponds without bass. In ponds without bass, both S and H' were related to maximum depth (Table 4).

Table 4 Results of multiple regression analysis between DLB/S/H' and environmental factors

Type of ponds	Dependent variable	*n*	Independent variable	Regression coefficient	R^2	*F*	*AIC*
With bass	%BASS	18			0.180	3.516	175.2
	S	18	Maximum depth	0.532*	0.283	6.318*	79.0
	H'	18	Coverage of emergent plant	-0.526*	0.608	5.034*	16.9
Without bass	S	31	Maximum depth	0.493**	0.243	9.324**	134.4
	H'	31	Maximum depth	0.394*	0.155	5.334*	31.4

*: $p<0.05$, **: $p<0.01$

Similarly, S in ponds with bass was also related to maximum depth. However, H' in ponds with bass was significantly influenced by the coverage of emergent plants and was more clearly explained compared to the relationship between S and maximum depth (Table 4). Thus, environmental factors influencing fish species diversity differed between ponds with and without bass. Since water depth is related to various chemical, physiological and biological factors (Bronmark and Hansson 2005), it influences fish species richness and diversity through anoxia, habitat heterogeneity and distribution of prey (Tonn and Magnuson 1982; Rahel 1984; Matthews 1998; Godinho et al. 1998; Irz et al. 2002). In ponds with bass, the coverage of emergent plants had a stronger influence on fish species diversity compared to that of maximum depth. Submerged plants, cobbles and logs provide refuge for prey fish to avoid predation (Savino and Stein 1989; Maceina 1996; Dibble and Harrel 1997; Sass et al. 2006). Moreover, aquatic vegetation coverage or density contributes to increasing species richness in lakes and ponds with piscivorous centrarchids (Tonn and Magnuson 1982; Rahel 1984). Therefore, it is possible that emergent plants also provide refuge for prey fish, buffering the impact of largemouth bass. In addition, littoral areas covered with emergent vegetation provide breeding sites and the main habitat of fry/juvenile of Japanese native cyprinids (Hirai 1970; Minobe and Kuwamura 2001). Restoration of emergent vegetation in littoral areas would contribute to decreased predation pressure from bass and increased breeding of native fish and is as important for the conservation of native fish as the extermination or control of largemouth bass.

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