A comparison of results from previous and present investigations of benthic macroinvertebrates in the small and shallow Lake Shoji, Fuji Five Lakes, Japan

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In order to clarify the current status of the benthic community of Lake Shoji, and to examine the difference with the last quantitative data of the lake by Miyadi (1932) and Kitagawa (1973), the distribution of benthic macroinvertebrates in this lake was studied. Also, a comparison of the benthic fauna and density was made between the present and previous studies, with a discussion concerning the succession of benthic macroinvertebrates in relation to changes in the lake bottom environment. On March 1, 2010, and September 7, 2011, bathymetrical sampling surveys were carried out using a standard Ekman-Birge grab at each of the 7 locations in Lake Shoji. The average densities of the benthic communities for all the stations were 4,107 inds. m^{-2}, comprised principally of oligochaetes 50.2%, chironomids 48.6%, and chaoborid 1.2% in March 2010, whereas in September 2011 the average density was 1,185 inds. m^{-2}, and mostly comprised of oligochaetes 86.6% and chironomids 13.4%. On the other hand, the average biomasses (wet weight) of these benthic macroinvertebrates in March 2010 were composed of 33.3% oligochaetes, 62.8% chironomid larvae, and 3.9% chaoborid larvae, as opposed to 48.8% oligochaetes and 51.2% chironomid larvae, respectively, in September 2011. *Propsilocerus akamusi* (Tokunaga, 1938) and *Procladius* sp. of chironomid larvae were the dominant species, making up 10.0% and 17.6%, respectively, of the total chironomid fauna in density, and 83.2% and 9.2% in biomass in March 2010. The mean density of *P. akamusi* was about 2.5 times higher than that reported by Kitagawa in the 1970s. In recent years, the number of *P. akamusi* larvae has tended to increase; they are widely distributed, and the anoxic-layer and anaerobic-layer are thickening, especially during summer to late fall in Lake Shoji, suggesting that the lake is in the process of eutrophication.

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INTRODUCTION

Many studies have been conducted regarding the distribution and abundance of benthic macroinvertebrate populations in relation to various environmental factors (temperature, dissolved oxygen concentration, pH, ionic concentration, depth, water type, substratum, etc.) in lakes (reviewed by Oliver 1971, Brinkhurst 1974). Jonasson (1996) showed that hypolimnion oxygen concentration, food quality and quantity, and water temperature are the main factors influencing the presence and biomass of benthic species in lakes. The oligochaetes, chaoborid larvae and chironomid larvae are common in profundal zones of lakes, and have the capacity to live at very low oxygen concentrations (e.g., Jonasson 1972, Frank 1983, Voss and Humm 1999, Hirabayashi and Hayashi 1994, Berg et al. 1962, etc.). Thus, it is important to relate the distribution and abundance of these benthic macroinvertebrates to the type of lake (trophic level). These organisms, especially chironomid larvae (Sæther 1979, 1980, Real et al. 2000), have been used for many years as indicators of trophic conditions of lakes (reviewed by Lindegaard 1995). In Japan, however, there are few reports on the succession of benthic macroinvertebrates in relation to changes in the lake's bottom environment.

Miyadi (1932) investigated the benthic macroinvertebrate community in Lake Shoji and reported that *Chironomus plumosus* (Linnaeus, 1758), *Polypedilum*, Tanypinae (=Tanypodinae), Orthocladiinae and *Tubifex* were the major taxa. Moreover, Kitagawa (1973) reported that *C. plumosus*, *Spaniotoma akamusi* (= *Propsilocerus akamusi* (Tokunaga, 1938)) and *Tubifex* were the dominant species. According to Yoshizawa et al. (2000), a freshwater red tide occurred in this lake in 1999. The biota and environmental conditions of the lake may have been changing due to the development of tourism and fishing around the lake in recent years.

In this paper, in order to clarify the current status of the benthic community of Lake Shoji and to examine the difference with the last quantitative data by Miyadi (1932) and Kitagawa (1973), we examined the distribution of benthic macroinvertebrates in this lake, and compared the benthic fauna and density of the present and previous studies. The succession of benthic macroinvertebrates in relation to changes in the lake's bottom environment was also discussed.

Study area

Lake Shoji (35°29′ N, 138°36′ E at the center of the lake; surface area 0.50 km^2; maximum depth 16.2 m; mean depth 7.0 m; altitude above sea level 901.0 m) located at the north foot of Mt. Fuji (Figure 1), is one of the Fuji Five Lakes (comprising Lake Kawaguchi, Lake Motosu, Lake Saiko, Lake Shoji and Lake Yamanaka), which are especially familiar to the Japanese people for their beautiful landscapes. Lake Shoji lies to the west of Lake Saiko and has the same water level. It is the smallest of the Fuji Five Lakes and has no appreciable inflowing and outlet streams. It is considered that the water supply of this lake comes mostly from the permeable volcanic substratum of Mt. Fuji (Tanaka et al. 1982).

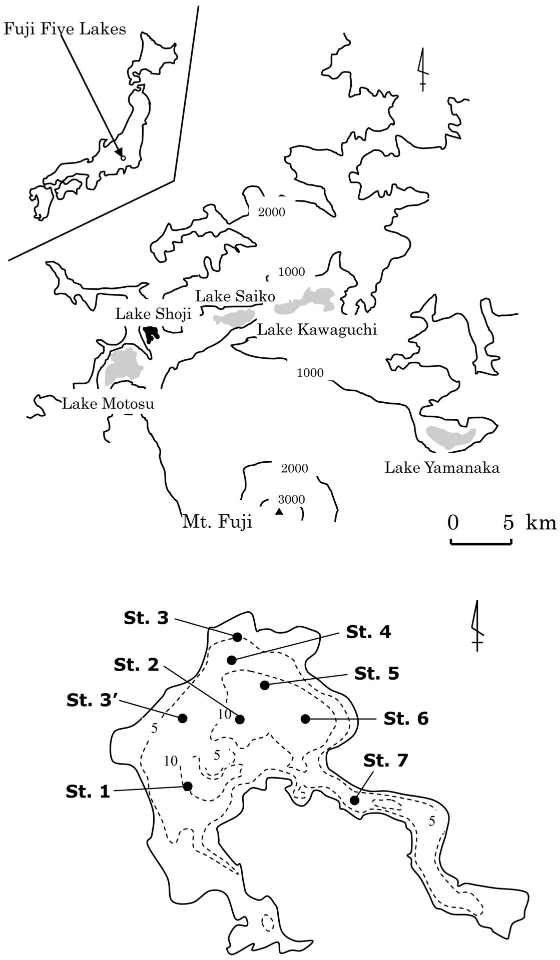

Figure 1. Location of Lake Shoji, isopleths of depth (m), and sampling stations in the lake.

Many limnological studies have been carried out since Tanaka (1904). Tanaka (1992) reviewed the studies of this lake, including water quality, plankton, benthos, fishes and aquatic macrophyte. Aizaki et al. (1981) considered this to be in eutrophic lake, using the modified Carlson's trophic state index (TSI) based on chlorophyll-a, total phosphorus and transparency. Miyadi (1932) reported the transparency of this lake to be 5.5 m in July, 1929 and 5.1 m in October, 1930. However, in 1996 the transparency was in the range of 1.5-2.3 m (Ariizumi et al. 1997).

MATERIAL AND METHODS

On March 1, 2010, and September 7, 2011, bathymetrical sampling surveys were carried out using a standard Ekman-Brige grab (15×15 cm), taking three replicate samples from each of the 7 locations in Lake Shoji (5.0 - 11.5 m in depth; Figure 1).

According to Voss and Humm (1999), chaoborid larvae exhibit daily migration, and during daytime the larvae rest in anoxic mud. We collected all samples at day time (8:00-16:00) and thus expected to sample chaoborids if present. In March 2010, we could not collect samples from Stations 1, 2 and 7 because of a strong wind, leaving only 4 sampling points for that year. In September 2011, we could not collect samples from Station 3 because it was being used as a starting point of a boat race. Thus, we collected the samples at St. 3' (depth; 6.1 m) instead of St. 3 (5.1 m). Since 475 mm of rain fell from August 31 to September 4, 2011 (Japan Meteorological Agency, 2011), the water level on September 7, 2011 was about 1.0 - 1.5 m above average. The sampling stations were determined by a global positioning system (GPS). After sieving the sediment through a Surber net (NGG66; 0.25 mm aperture, RIGOSHA, Tokyo, Japan), benthic macroinvertebrates (chironomid and chaoborid larvae, and oligochaetes) were picked up, counted, and had their wet weight measured (using an electronic balance, AND, HM-202) in the laboratory. To identify chironomids, some larvae were soaked in a 10% KOH solution, mounted on slides with gum-chloral solution, and examined under a microscope. Identifications were made to the generic level according to the keys of Sæther et al. (2000), Wiederholm (1983), and Cranston (1982). To identify larvae of *Chironomus* to the species level, sub-samples collected at St. 3' in September 2011 were reared in the laboratory to allow the emergence of adult midges. They were identified according to the key of Sasa (1978). All six adult midges which emerged from the sediments were *C. plumosus*.

One sediment sample was collected with a core sampler (3 cm inner diameter) at each station to analyze the organic matter content. Mud in the upper 3 cm layer of each core was oven-dried at 110ºC for two days, and ignited in a muffle furnace at 550ºC for 3 hours to determine the ignition loss (IL). We also used the core sampler to measure dissolved oxygen concentration (DO) in the water at the mud-water interface. Water near the mud surface in the core sampler was siphoned carefully into a glass bottle. The dissolved oxygen concentration was determined by Winkler's method with azide modification. In addition, the mud temperature (MT) of the bottom sediment collected in the core sampler was measured with a thermistor thermometer.

RESULTS

Table 1 shows the mean values with standard deviations of some environmental factors, as well as the densities and wet weight of benthic macroinvertebrates, i.e., oligochaetes, chaoborid larvae, and chironomid larvae measured in 2010 and 2011. MT and DO values were almost the same among the stations in March, 2010, because the day of the investigation was during the period of spring overturn. On the other hand, in September, 2011, the mean value and SD of MT was 13.1±2.3ºC (11.4ºC at St. 6 to 17.5ºC at St. 3'), while the DO was 1.9±3.1 mg l^{-1} (0.16 mg l^{-1} at St. 4 to 8.65 mg l^{-1} at St. 3'). At stations deeper than 8 m, DO was below 1.0 mg l^{-1}. The ignition loss values of the sediment ranged from 9.1% to 14.1%, with a mean value of 13.1±1.3%. Most of the lake basin consisted of a soft bottom with an organic matter content higher than 12%. Sediments at St. 1 and 6 contained the highest levels of organic matter (14.1%). Along the northern and northwestern shores of the lake, i.e., Station 3 and 3', the sediment was generally composed of sand and porous volcanic deposits with low IL values (9.1% at St. 3, 10.6% at St. 3').

The average density of the benthic community for all stations was 4,107 inds. m^{-2}, comprised principally of oligochaetes 2,063 inds. m^{-2} (50.2%), chironomids 1,996 inds. m^{-2} (48.6%), and chaoborid 48 inds. m^{-2} (1.2%) in March 2010, whereas in September 2011 the average density was 1,185 inds. m^{-2}, and was mostly comprised of oligochaetes (86.6%) and chironomids (13.4%) (Table 1). Chaoborid larvae were not collected in September. On the other hand, the average biomasses (wet weight) of these benthic macroinvertebrates in March 2010 were 1.45 g m^{-2} (33.3%) for oligochaetes, 2.73 g m^{-2} (62.8%) for chironomid larvae, and 0.17 g m^{-2} (3.9%) for chaoborid larvae, compared to 48.8% oligochaetes and 51.2% chironomid larvae, respectively, in September 2011 (Table 1).

Chironomidae species belonging to three subfamilies were found in both years, i.e., six species belonged to the Chironominae subfamily, two to Orthocladiinae, and one to Tanypodinae (Table 2). In March 2010, at St. 3 (depth: 5 m), there was a large number of young chironomids. Their large quantity and small size made then difficult to identify, so they were categorized as 'other chironomids' in this paper.

The population density of each chironomid species differed

Table 1. Mean values and SDs of the environmental factors on March, 2010 and September, 2011.

Environmental factors	1 March, 2010	7 September, 2011	
Number of sampling stations	4 (St. 3, 4, 5 and 6)	7 (St. 1-7, except St. 3)	4 (St. 3', 4, 5, and 6)*
Depth (m)	8.8±2.4	9.2±2.0	9.7±2.4
Ignition loss (%)	12.5±2.4	13.1±1.3	12.9±1.6
Mud temperature (ºC)	7.4±0.7	13.1±2.3	13.0±3.0
Dissolved oxygen (mg l^{-1})	12.1±0.6	1.9±3.1	2.5±4.1

* compare with the data of 2010.

Table 2. Mean values and SDs of the densities and biomass of main chironomid larvae on March, 2010 and September, 2011.

	1 March, 2010		Distribution of chironomid larvae				7 September, 2011		Distribution of chironomid larvae			
	Density (inds. m^{-2})	Wet weigh (g m^{-2})	Density (inds. m^{-2})				Density (inds. m^{-2})	Wet weigh (g m^{-2})	Density (inds. m^{-2})			
			St. 3	St. 4	St. 5	St. 6			St. 3'	St. 4	St. 5	St. 6
Mean depth (m)	8.8±2.4		5.0m	8.6m	10.3m	11.3m	9.7±2.4		6.1m	10.2m	10.9m	11.5m
Number of stations	4 stations						4 stations					
Chironominae												
Chironomus plumosus	4±6	0.08±0.14				14.8	11±38	0.28±0.96	44.4			
Cladopelma sp.	4±6	-			14.8		0±0	0±0				
Dicrotendipes sp.	4±6	-		14.8			0±0	0±0				
Einfeldia sp.	4±6	-	14.8				0±0	0±0				
Polypedilum sp.	19±24	0.05±0.09	59.2	14.8			0±0	0±0				
Stictochironomus sp.	4±6	-				14.8	178±325	0.06±0.10	711.1			
Tanypodinae												
Procladius sp.	352±510	0.25±0.32	1229.3	148.1	29.6		37±82	0.06±0.12	148.1			
Orthocladiinae												
Propsilocerus akamusi	200±83	2.27±1.04	178	74.1	281.3	266.7	33±43	0.93±1.26		29.6	74.1	29.6
Psectrocladius sp.	4±6	-			14.8		0±0	0±0				
Other chironomids (small size)	1404±2431	0.07±0.13	5614.7				4±13	-	14.8			
Total chironomid larvae	1996±2945	2.73±1.56					263±401	1.32±1.41				
Number of chironomid species	>10		>5	4	4	3	5		4	1	1	1

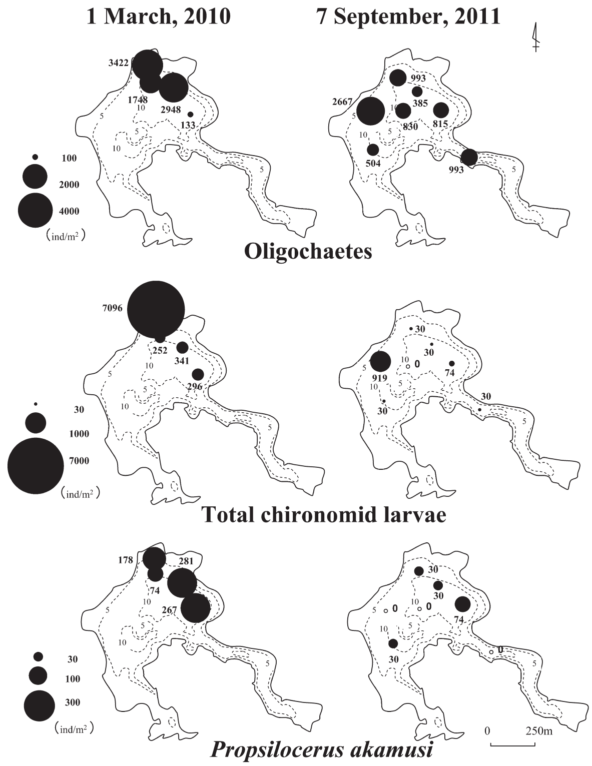

Figure 2. Horizontal distribution of the density of dominant benthos in Lake Shoji, on March, 2010 and September, 2011. Size of dot corresponds to the abundance at the respective sampling point. "o" indicates the absence of benthic animals. Note the different abundance for Oligochaetes, total chitronomid larvae and *Propsilocerus akamusi* larvae.

among sampling stations and sampling seasons. In March 2010, *P. akamusi* inhabited all stations, and *Einfeldia* sp. was collected from the shallowest station (St. 3) only, while *Chironomus* sp. and *Stictochironomus* sp. were collected from the deepest station (St. 6) only. On the other hand, in September 2011, only four species were collected: *C. plumosus*, *Stictochironomus* sp., and *Procladius* sp., (which was collected only at St. 3') and *P. akamusi* (collected from St. 4 to St. 6 in the deeper regions (>10 m)).

Figure 2 shows the horizontal distributions of oligochaetes, total chironomid larvae, and *P. akamusi* larvae in March 2010 and September 2011. Oligochaeta and total chironomid larvae were found at all stations, with an especially high density at the northern and northwestern parts of the lake in March 2010. The most numerous species, *P. akamusi*, was particularly abundant at the center of the lake, i.e., Stations 5 and 6, in March 2010, but by September 2011, they had not taken over the entire lake bottom. Thus, species were not collected from Stations 2, 3' and 7.

Figure 3 shows the bathymetric distribution of the densities of the main benthos (oligochaetes, total chironomid and chaoborid larvae) and the two major species of chironomid larvae

(*Procladius* sp. and *P. akamusi*) in March, 2010 and September, 2011, respectively. Oligochaetes were widely distributed, but with a peak value at 5 m depth in shallower regions. The density of oligochaetes was decreased with increasing water depth, whereas that of chaoborid larvae increased with water depth; its highest density was in the deeper regions (>10 m) and its lowest in the shallower regions (< 6 m) in March 2010. *P. akamusi* was abundant at the lake bottom where the depth was from 5 to 11.3 m, with a peak value at a depth of 10.3 m. *Procladius* sp. was mainly collected only at shallower regions (<6 m), and its density was decreased with water depth. The wet weight distribution pattern of each chironomid larvae was the same as that of their densities.

Table 3 shows the correlation matrix for variables in the density of benthic macroinvertebrates (Oligochaete, *P. akamusi* and total chironomids) as well as environmental factors such as depth, DO, MT and IL, in September 2011. Strong positive correlations were found between the density of Oligochaetes and DO, Oligochaetes and MT, the density of total chironomids and DO, and total chironomids and Oligochaetes. On the other hand, the density of Oligochaetes and IL, and the density of total chironomids and IL, showed negative correlations.

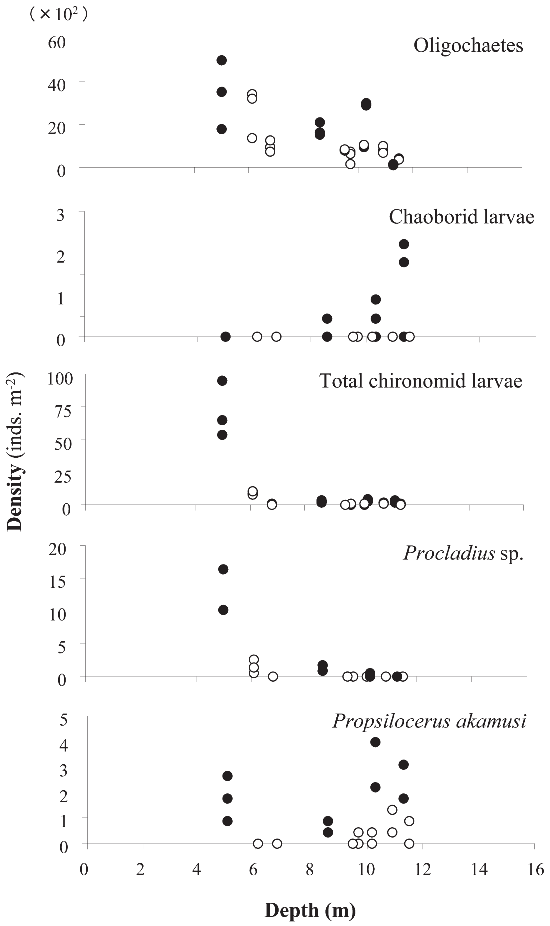

Figure 3. Bathymetric distribution of the densities of main benthos and the two major species of chironomid larvae in Lake Shoji on March, 2010 and September, 2011, respectively. Open circles indicate the data on 7 September, 2011. Closed circles indicate the data on 1 March, 2010.

DISCUSSION

The benthic macroinvertebrates of Lake Shoji have been studied by various researchers (Miyadi 1932, Kitagawa 1973, Yasuno et al. 1983). We compared our results with previous quantitative data on chironomids and oligochaetes reported by Miyadi (1932) and Kitagawa (1973), and tried to clarify the relationship between the eutrophication of Lake Shoji and the dominant species of chironomids and other benthic macroinvertebrates (Table 4). Many researchers have used benthic macroinvertebrates as indicators of the trophic state and organic pollution of lakes (Miyadi 1933, Kitagawa 1978, Sæther 1979, Iwakuma et al. 1988, Kawai et al. 1989). According to Brinkhurst (1974), the densities and biomass of benthic macroinvertebrates increased with the progress of lake eutrophication. It is clear that in Lake Shoji, from the 1930s to 2010, the density of the total benthic macroinvertebrates showed an increase over those in Miyadi's report and Kitagawa's report (ca. 5- to 15-fold). The oligochaetes in particular dominated in recent years. *P. akamusi* is a typical indicator species of

Table 3. Correlation matrix for environmental variables and densities of main benthos in September 2011.

	DO	MT	IL	Oligo	Total Chirono	*P. akamusi*
Depth	-0.79 *	-0.94 **	0.81 *	-0.75	-0.63	0.71
DO		0.94 **	-0.94 **	0.96 **	0.96 **	-0.45
MT			-0.94 **	0.88 **	0.84 *	-0.67
IL				-0.86 *	-0.85 *	0.67
Oligo					0.95 **	-0.42
Total Chirono						-0.33

DO; dissolved oxygen, MT; mud temperature, IL; ignition loss, Oligo; density of oligochaetes, Total Chirono; density of total chironomids, *P. akamusi*; density of *Propsilocerus akamusi*. *P < 0.05; ** P <0.01.

Table 4. Changes in dominant chironomid larvae and other benthos in Lake Shoji

	Miyadi (1932)				Kitagawa (1973)				Present study			
	25 July, 1929		7 October, 1930		28 July, 1972		10 March, 1973		1 March, 2010		7 September, 2011	
	n=23		n=33		n=10		n=11		n=12		n=21	
Mean depth (m)	10.4±3.5		10.4±4.3		10.9±2.0		9.8±1.9		8.8±2.4		9.2±2.0	
Chironomus sp.	68±13#	25.1% **	28±69#	12.3% **	27±31#	39.7% **	41±62#	20.9% **	-	-	6±29##	3.8%**
Pentapedilum spp.	-	-	-	-	41±50	60.3%**	53±148	27.0%**	-	-	-	-
Polypedilum sp.	47±138	17.3%**	2±9	0.8%**	-	-	-	-	19±24	1.0% **	-	-
Stictochironomus sp.	-	-	-	-	-	-	4±14	2.0%**	4±14	0.2%**	104±257	65.4%**
Procladius sp.	23±41	8.5%**	2±9	0.8%**	-	-	-	-	352±510	17.6% **	21±64	13.2% **
Propsilocerus akamusi	-	-	-	-	-	-	82±75	41.8% **	200±83	10.0% **	23±36	14.5% **
Orthocladiinae sp.	115±131	42.4%**	197±199	86.8%**	-	-	-	-	-	-	-	-
Total chironomid larvae	271±271	82.1% *	227±209	95.4% *	68±71	46.9% *	196±260	72.6% *	1,996±2,945	48.6% *	159±336	13.4% *
Oligochaetes	59±80	17.9% *	9±24	3.8% *	77±67	53.1% *	74±120	27.4% *	2,063±1,270	50.2% *	1026±760	86.6% *
Chaoborid larvae	-	-	-	-	-	-	-	-	48±52	1.2% *	-	-
Total benthos	330±269	100%	238±212	100%	145±135	100%	270±324	100%	4107±3957	100%	1185±1084	100%

*: % of total benthos; **: % of total chironomids; #: only *Chironomus nipponensis* or *C. nipponensis* plus *C. plumosus*; ##: only *C. plumosus*.

hypertrophic or eutrophic lakes (Iwakuma et al. 1988). It seems that the maximum density of *P. akamusi* within a lake increases according to the modified Carlson's trophic state index (Yasuno et al. 1983). Although Miyadi (1932) did not describe *P. akamusi* in this lake, it is clear that the density of *P. akamusi* larvae in the present study showed an increase over that in Kitagawa's report in the 1970s. *P. akamusi* was the most abundant species in the chironomid community in biomass in our investigation, and its mean density (200 inds. m^{-2}) was about 2.5-fold higher than that of Kitagawa's study (82 inds. m^{-2}) in March. According to Iwakuma and Yasuno (1981), high temperature and low oxygen concentrations are unfavorable for *C. plumosus* larvae. However, *P. akamusi* larvae can withstand anoxic conditions, especially during the summer, by burrowing deep into the sediment to aestivate (Yamagishi and Fukuhara, 1972). Iwakuma et al. (1988) classified Japanese lakes into four categories based on the presence/absence of three large species of Chironomidae. They indicated that both *P. akamusi* and *C. plumosus* are present in hypertrophic lakes, that *C. nipponensis* are absent in them, and that all three species are present in eutrophic lakes. Yasuno et al. (1983) pointed out that the *C. plumosus* identified by Miyadi and Kitagawa was actually *C. nipponensis*, or that almost all *C. nipponensis* were confused with *C. plumosus*. If so, *C. nipponensis* larvae dominated in the chironomid community in this lake until the 1970s, but *C. nipponensis* was not collected in this lake in the present study. These facts suggest that the dominant chironomid species in Lake Shoji more closely resemble the dominant chironomid species of hypertrophic lakes as opposed to eutrophic ones.

In addition, Miyadi (1932) and Kitagawa (1973) did not describe chaoborid larvae in Lake Shoji. However, in the present study, larvae inhabited the bottom (8.6-11.3 m) of the lake in March 2010. Chaoborid larvae migrate daily and rest in anoxic mud in the daytime to avoid predatory fishes. If fish are absent from a lake, this migration is not observed. Chaoborid larvae can then prey on zooplankton in the water column in the daytime and be unavailable to sampling with an Ekman-Brige grab. In Lake Shoji, however, increasing catches of fish were reported from the 1910s to the 1980s (705 kg in 1917, 4180 kg in 1957, and 10 t in 1982) (Takahashi 1999) and Miyadi (1932) and Kitagawa (1973) both did their sampling in the daytime. Thus, if the chaoborid larvae were present in this lake during the 1930s and 1970s, they would have been caught by investigators. Therefore, it might be suggested that there was an absence of chaoborid larvae in mud of this lake in the 1930s and 1970s.

According to Hirabayashi and Hayashi (1994), chaoborid larvae showed a negative correlation with DO in Lake Kizaki. Our data also showed that the density of chaoborid larvae increased with water depth. Xie et al. (1998) reported that the density of chaoborid larvae is generally higher in eutrophic rather than oligotrophic habitats, and that high temperature and low oxygen concentration were the most important factors limiting the distribution of such larvae in the sediment in summer. According to Miyadi (1932) and Kitagawa (1973), the dissolved oxygen in the summer decreased rapidly from 7 m and 5 m, and the water became anoxic in depths deeper than 9 m and 7 m, respectively. Ariizumi et al. (1997) and Yamanashi Prefecture (2005) reported that the water became anoxic at the depth of 6 m. We also observed in our study that the bottom water became anoxic in September when deeper than 6 m. In other words, the anoxic layer and anaerobic layer have thickened since the 1930s and 1970s. Hirabayashi et al. (2007) reported that the density of oligochaetes increased greatly in Lake Kizaki due to an increase of organic matter in the bottom sediments, and that bacterial activity was high while DO greatly decreased in deep regions. In our study in September 2011, we could not collect chironomid larvae, except for *P. akamusi*, in the deeper regions (>10 m) (Table 2). Therefore, an anaerobic condition was the main reason why profundal chironomid larvae, except for *P. akamusi*, disappeared in September 2011. The above-mentioned facts suggest that the environmental conditions for benthic macroinvertebrate survival in deeper regions will continue to deteriorate.

Consequently, in recent years, the number of *P. akamusi* larvae have tended to increase, are widely distributed, and their anoxic and anaerobic layers are thickening, especially in the summer to late fall. Lake Shoji apparently is in the process of becoming hypertrophic.

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