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Horizontal distribution of benthic macroinvertebrates in Lake Kawaguchi, Japan

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INTRODUCTION

The main factors determining the horizontal distribution patterns of benthic macroinvertebrates are related to the trophic state of the lake. Especially, chironomid larvae and oligochaete communities in the profundal zone have been used as biological indicators of organic pollution[1,2].

Lake Kawaguchi is one of the Fuji Five Lakes(L. Yamanaka, L. Kawaguchi, L. Sai, L. Shoji and L. Motosu), which are especially familiar to the Japanese for their beautiful landscapes(Fig.1). More than 10,000,000 tourist visit these lakes(L. Kawaguchi is a sightseen center) and Mt. Fuji annually. Recently, Lake Kawaguchi seems to be proceeding of the eutrophication[3]. Therefor, in order to indicate of organicpollution, the horizontal distribution of benthic macroinvertebrates were studied in Lake kawaguchi.

STUDY SITE

Lake Kawaguchi (35°31′N, 138°45′E at the center of the lake; surface area 5.96 km^2; maximum depth 16.1 m; mean depth 9.3 m; altitude above sea level 832 m) is located at the northern foot of Mt. Fuji. There is a small island at the center of the lake, which is called Unoshima (Fig.1). *Cladophora sauteri* (Fujimarimo) inhabits the area around Unoshima. This lake was formed by lava flows from Mt. Fuji and related volcanoes, which dammed the streams coming down from the northern mountain ranges. The lake has no appreciable inflowing stream, and lacks outflowing rivers. In its drainage basins, where porous volcanic deposits prevail, the runoff water mostly flows underground but rarely does as a surface stream. The eastern shore of the lake is partly surrounded by cultivated land. There are some towns and villages on northeastern and southeastern shores. This lake is ice-covered from January to February and has a persistent thermocline in summer.

Many limnological studies have been carried out since the first intensive work by Miyadi (1932,[4]). Transparency averaged about 5 m in the late 1920's, when the hypolimnion was observed to be oxygen depletion in summer, suggesting that the lake had already reached a fairly advanced stage of eutrophication.In 1933-48, the transparency showed summer increases, owing to the exhaustion of nutrients in the euphoticzone during the summer stratification. Since 1971, however, the extent of transparency has decreased to about 3.5m due to the progress of eutrophication[3]. Since the end of the 1950's, the cyanobacterium *Microcystis aeruginosa* has bloomed annually in July-August[5]. According to Aizaki et al.(1981,[6]), they ranked this lake as a eutrophic-mesotrophic one, using the modified Carlson's trophic state index based on chlorophyll-a, total phosphorus, and transparency. In 1986, the sewer of a large region was established by the local government.

METHODS

1. Collection of benthic macroinvertebrates

On 5 March, 1993, a multi-point sampling survey was carried out using a standard Ekman-Birge grab (15×15 cm), taking three replicate samples at each of 22 locations (5.6～14.0 m depth) in a 800×800 m grid (Fig.1). After sieving the sediment through a Surber net (NGG 38; 560 μm mesh size), benthic macroinvertebrates (chironomid larvae and oligochaetes) were picked up and counted in the laboratory. The first and second instar larvae of small chironomids were not retained by the 560 μm-mesh sieve.

To identify chironomids, some larvae were soaked in a 10% KOH solution, mounted on slides with gum-chloral solution and examined under a microscope. The identification was made to the generic level according to the keys of Wiederholm (1983,[7]) and Cranston (1982,[8]).

2. Physical environmental factors

Bottom sediment samples for an organic matter analysis were collected with a core sampler (3 cm inner diameter). Mud in the upper 3 cm layer of each core was oven-dried at 110 ℃ for two days and ignited in a muffle furnace at 500 ℃ for two hours to determine the values of loss on ignition.

We used the core sampler to measure dissolved oxygen concentrations in the water at the mud-water interface. The water near 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.

RESULTS

1. Environmental factors

The results of environmental factor analysis are shown in Table 1. The values of loss on ignition of the sediment taken from 22 locations ranged from 1.3 % (sand) to 14.4 % (mud). Most of the lake basin consisted of soft bottom with organic matter contents higher than 10 %. Sediment at Sta.2 contained the highest levels of organic matter (14.4 %). In regions shallower than 6 m, i.e., Sta. 6 (southern part of lake) and around Unoshima island, the sediment was generally sandy and gravel with low values of loss on ignition (less than 8.0%). In regions deeper than 10 m, the bottom sediment consisted mainly of mud with relatively high values of loss on ignition (10.0 - 14.0%) (see Figs. 1 and 2).

The dissolved oxygen concentrations in bottom water ranged from 6.8 (Sta.16) to 11.6 (Sta.13) $mg \cdot l^{-1}$.

2. Distribution of benthic macroinvertebrates

Table 2 shows the mean values with standard deviations in densities and biomass benthic macroinvertebrates, chironomids and oligochaetes. The average densities of the benthic community for the entire lake was 6,745 ind. $\cdot m^{-2}$ and was comprised principally of oligochaetes (81.4%) and chironomids (19.6%). Among Chironomidae, the species belonging to three subfamilies were found, i.e. Chironominae (*Chironomus plumosus*), Orthocladiinae(*Tokunagayusurika akamusi*) and Tanypodinae. The larvae were almost full-grown forth instar larvae of *T. akamusi* and *C. plumosus*. The larval density of *T. akamusi* was twice as high in number as that of C. plumosus. However, the larval biomass of *T. akamusi* was as much asthat of *C. plumosus*. The numerical dominances of *T. akamusi* and *C. plumosus* larvae in chironomid communities were 50.5 % and 27.1 %, respectively.

Figure 2 shows the horizontal distributions of some benthic macroinvertebrates. The population density of them differed among the sampling stations. They inhabited the entire lake bottom, with higher densities in the deeper regions and lower densities in the shallower regions. In addition, they were found abundantly at the northeastern, eastern and western parts of the lake. The maximum number of oligochaetes, *T. akamusi* and *C. plumosus* larvae reached 13,156 ind. $\cdot m^{-2}$ at Sta.9 (depth; 10.4 m), 1,111 ind. $\cdot m^{-2}$ at Sta.20 (depth; 12.0 m) and 711 ind. $\cdot m^{-2}$ at Sta.10(9.3 m), respectively.

Table 3 shows the correlation matrix for the density of benthic macroinvertebrates and environmental factors (water depth, dissolved oxygen concentration and loss on ignition). Water depth and loss on ignition were closely related to dissolved oxygen concentration. The density of *C. plumosus* and *T. akamusi* were closely related to loss on ignition, whereas that of oligochaetes was closely related to *C. plumosus*. The density of Tanypodinae - Water depth showed negative correlations.

We compared our results with previous data on chironomids and oligochaetes in Lake Kawaguchi given by Miyadi(1932,[4]) and Kitagawa(1973,[9]) (Table 4), and tried to clarify the relationship between the eutrophication of Lake Kawaguchi and the dominant species of chironomids. In the case of *C. plumosus*, no noticeable change has occurred in the mean density of larvae except in a sampling taken in 1931, when the density was lower than that on other occasions. As many pupae were described at this time, this term may be the emergence period of *C. plumosus*. Therefore, we think that the individual number of *C. plumosus* might possibly be underestimated. However, the numerical dominance of *C. plumosus* larvae in the chironomid communities are showing a tendency to decrease, according to the present study compared with previous studies. On the contrary, the numerical dominance of *T. akamusi* larvae in the chironomid communities showed an increase than in Kitagawa's report(1973,[9]). The mean density of oligochaeta also increased. In our survey, *T. akamusi* was the most abundant species of chironomid larvae and the estimate of its mean density was 2.5 times as much as the Kitagawa estimate[9].

Table 5 shows mean values with standard deviations in density and biomass of benthic macroinvertebrates obtained by grid surveys in some Japanese lakes. The density of *C. plumosus* in Lake Kawaguchi was comparable to that in Lake Suwa[10] and Lake Kasumigaura[11], highly eutrophic lakes in Japan. *T. akamusi* was much less abundant in Lake Kawaguchi than in these lakes.

DISCUSSION

Many studies have been conducted on the distribution of benthic macroinvertebrate populations in relation to various environmental factors (reviewed by Jonasson, 1972,[12]; Brinkhurst, 1974,[13]; Cowell, 1981,[14]). According to Yasuno et al.(1984,[15]), the oxygen concentration is of primary importance in determining the distribution of benthic macroinvertebrates. Namely, the distribution of benthic macroinvertebrates is influenced by the only lack of dissolved oxygen concentration in deeper regions. However, in Lake Kawaguchi, the density of *C. plumosus* and *T. akamusi* larvae did not clearly show a significant correlation with the oxygen concentration(Table 3). Because the anaerobic conditions in the deeper regions may not be partly formed in Lake Kawaguchi. There are many springs in the bottom where a large amount of inflowing ground water gushes out[16]. Therefore, in the case of this lake, we think that the main factor determining the distribution of both species larvae were not only dissolved oxygen concentration but also other environmental factors (e.g. water temperature, pH, ionic concentration, depth, substratum, etc.). On the other hand, the density of *C. plumosus* and *T. akamusi* larvae showed a positive correlation with the loss on ignition of sediment (Table 3). Both species are able to utilize the organic matter. This suggests the strong possibility that their distribution depends on the organic matter content in the sediment in Lake Kawaguchi.

Many researchers have used the distribution patterns of benthic macroinvertebrates, particularly those in profundal zones, as indicators of trophic state and pollution of lakes [1,2]. In Japan, trophic classifications of lakes have been made using chironomid fauna and chaoborids by Miyadi(1933,[17]), Kitagawa (1978,[18]) and Yasuno et al.(1983,[19]). *C. plumosus* and *T. akamusi* are common in Japanese eutrophic lakes[2]. The benthic macroinvertebrates of Lake Kawaguchi has been studied by someworkers[4,9,19,20]. Table 4 showed the previously reported and present values of densities of dominant chironomid fauna in Lake Kawaguchi. It is difficult to discuss the long - term change of chironomid fauna in this lake, because the sampling season differs among the reports. Therefore, routine survey was carried out at St. 10(depth; 9.3m) from April 1993. According to this survey estimates, in July 19, 1993, mean density of *C. plumosus* and *T. akamusi* larvae were 281 ± 151 ind. $\cdot$ m^{-2} and 0 ind. $\cdot$ m^{-2}, respectively. On the other hand, in February 11, 1994, both species were 133 ± 96 ind. $\cdot$ m^{-2} and 948 ± 84 ind. $\cdot$ m^{-2}, respectively (Hirabayashi unpublished data). According to these data compared with previous one, *C.*

plumosus larvae are showing a tendency to decrease, while *T. akamusi* larvae showed an increase in Lake Kawaguchi.

According to Iwakuma & Yasuno (1981,[11]), the high temperature and low oxygen concentration seem to be unfavourable for *C. plumosus* larvae. On the contrary, *T. akamusi* can withstand anoxic conditions because of these full-grown larvae burrowed deep into the sediment to aestivate during those conditions (especially, during the summer)[21]. There are more individual number of *T. akamusi* larvae than *C. plumosus* in the lakes which are proceeding of eutrophication, e.g. Lake Kasumigaura and Lake Suwa (Table 5). Thus, *T. akamusi* is probably a more adaptable species to eutrophic lakes.

Recently, the number of *T. akamusi* larvae are showing a tendency to increase in Lake Kawaguchi. It's suggested that this lake seems to be proceeding of the eutrophication.

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Table 1. Mean values with standard deviations of some environmental factors at sampling points in the grid survey in March 1993.

Environmental factors	Mean with standard deviation
Number of sampling points	22
Depth (m)	10.6 ± 2.1
Ignition loss (%)	10.37 ± 2.40
Dissolved oxygen (mg/l)	10.75 ± 0.68

Table 2. Mean density and biomass (wet weight) of zoobenthos of 22 sampling stations in March 1993.

Zoobenthos	Mean values with standard deviations No. (inds.)/m²	W.W. (g)/m²
Oligochaeta	5,489 ± 2,769	40.1 ± 20.2
Chironomidae	1,256 ± 268	–
Chironomus plumosus	341 ± 182	12.5 ± 6.7
Tokunagayusurika akamusi	634 ± 280	11.1 ± 4.9
Tanypodinae	67 ± 80	–
Others	214 ± 528	–

Table 3. Matrix of simple correlation coefficients among the density of larvae, and sediment properties in the grid survey in Lake Kawaguchi in March 1993.

	Depth (m)	D.O. (mg/l)	LOI (%)	C.P. (ind./m²)	T.A. (ind./m²)	Tany (ind./m²)	Olig (ind./m²)
Depth	-	0.49*	0.29	-0.23	0.34	-0.60**	-0.32
D.O.		-	0.63**	0.32	0.30	-0.22	0.21
LOI			-	0.52*	0.54*	-0.14	0.37
C.P.				-	0.29	0.25	0.45*
T.A.					-	-0.23	-0.05
Tany						-	0.11
Olig							-

Depth : Water depth, D.O. : Dissolved oxygen, LOI : Loss on ignition of sediment, C.P. : *Chironomus plumosus*, T.A. : *Tokunagayusurika akamusi*, Tany : Tanypodinae, Olig. : Oligochaeta,
* Significant at 0.05 probability level
** Significant at 0.01 probability level

Table 4. Comparison of previously reported and present values of densities of dominant chironomid fauna and oligochaeta in Lake Kawaguchi

Reference	Miyadi (1932, [4])			Kitagawa (1973, [9])		Present study
Sampling date	Jul. 23, 1929	Oct. 5, 1930	May 2, 1931	Jul. 30, 1972	Feb. 17, 1973	Mar. 5, 1993
Number of sampling points	18	39	16	15	12	22
Mean depth (m)	9.2±2.5	10.5±3.1	10.1±1.3	12.6±2.1	10.9±3.2	10.6±2.1
Chironomid density (m^{-2})						
Mean	1069±629	293±272	429±317	591±371	885±384	1256±661
C. plumosus						
Mean	797±467	240±259	75±102	459±287	593±258	341±182
(%)*	74.6	81.8	17.4	77.7	66.9	27.2
T. akamusi						
Mean	-	-	-	0	259±149	634±280
(%)*	-	-	-	0	29.2	50.5
Oligochaeta density (m^{-2})						
Mean	49±50	225±215	1258±500	81±57	139±150	5489±2769
(%)**	4.4	43.4	74.6	12.1	13.6	81.4

(%)* ; the numerical dominance of C. plumosus or T. akamusi larvae in the chironomid communities.
(%)** ; the numerical dominance of oligochaeta in the benthic macroinvertebrates communities.

Table 5. Mean values with standard deviations in densities (inds. / m^2) and biomass (in parentheses: g wet weight / m^2) of benthic macroinvertebrates obtained by grid surveys in some Japanese lakes.

	L. Kawaguchi (Mar. 1993)	L. Yamanaka (Apr. 1994)	L. Shibire (Oct. 1993)	L. Kasumigaura (Takahamairi) (Mar. 1979)	L. Suwa (Mar. 1986)	L. Biwa (Nanko) (Mar. 1993)
Chironomus plumosus	341±182	36±51	47±35	113±140	413±306	
	(12.5±6.7)	(1.3±1.8)		(4.4±5.4)	(17.7±13.8)	
Tokunagayusurika akamusi	634±280	125±142	18±19	1,047±794	4,919±1992	332
	(11.1±4.9)	(2.7±3.0)		(16.5±12.5)	(91.4±33.6)	
Tanypodinae	67±80	525±314	1±4			
		(0.8±0.5)				
Oligochaeta	5,489±2,769	1,299±1,167	559±285			
	(40.1±20.2)	(3.5±3.4)				
	This report	Hirabayashi et. al. (unpublished data)	Hirabayashi et. al. (1993, [22])	Iwakuma & Yasuno (1981, [11])	Yasuda et. al. (1985, [10])	Nishino et. al. (unpublished data)

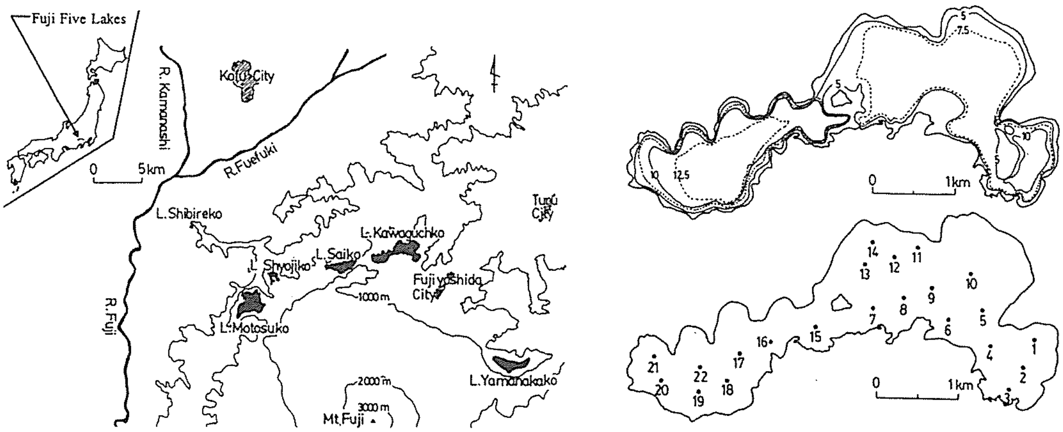

Fig. 1. Maps showing location of Lake Kawaguchi and isopleths of depth (m) and sampling stations in the lake.

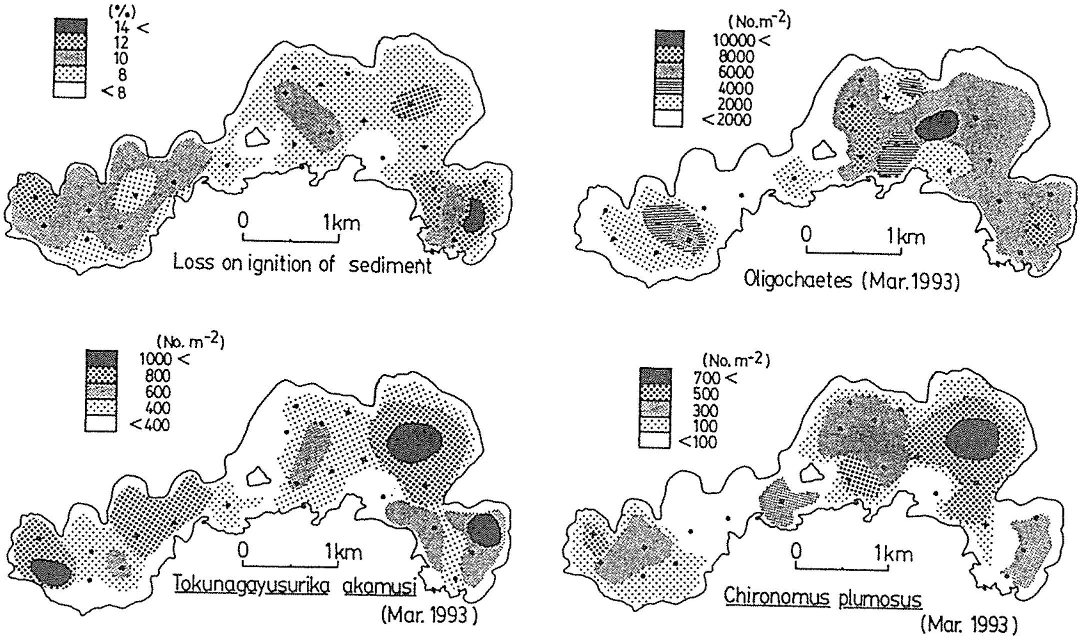

Fig. 2. Horizontal distribution of chironomid larvae, Oligochaetes and % loss on ignition of sediment in Lake Kawaguchi, March 1993.