Horizontal Distribution of Benthic Macroinvertebrates in Lake Kizaki, Japan

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Abstract

The distribution of benthic macroinvertebrates was studied in November 1985 in Lake Kizaki (maximum depth: 29.5m). The average biomass of the benthic community comprised oligochaetes (7.7%), chaoborids (44.9%) and chironomids (47.4%). The oligochaetes inhabited the entire lake bottom, with higher densities in the shallower regions (<10m). In contrast, densities of chaoborid larvae were higher in the deeper regions (>20m) than in the shallower regions. Chironomid larvae, on the other hand, were distributed in higher populations in the transitional regions (10–20m), and a marked decline in the number of species was observed as the depth increased. The most abundant species was *C. nipponensis* which was distributed most widely from 2m to 27m, although the density was very low at depths of 20m or more due to the lack of dissolved oxygen. In the deeper regions, the dominant species of chironomid had changed from *Endochironomus* sp. in the 1930's to *C. nipponensis* in the present study. It is suggested that the environmental conditions for larval survival in deeper regions will continue to deteriorate.

Key words: benthic macroinvertebrates, horizontal distribution, dissolved oxygen concentration, Lake Kizaki

1. Introduction

The biota of Lake Kizaki has been studied by many workers since TANAKA (1930). However, studies of benthic macroinvertebrates have been very few (MIYADI, 1931; KITAGAWA, 1973; ASAKAWA, 1977, 1978, 1980), because of the difficulty of species identification.

From the end of the 1970s to the end of 1980s, the biota and the environmental conditions of the lake changed drastically (HAYASHI, 1990), and this must have had some effect on the bottom fauna, especially on the dominant chironomids.

This paper deals with the distribution of chironomid larvae, chaoborid larvae and the oligochaetes in Lake Kizaki, and discusses the succession of benthic macroinvertebrates in relation to the change in the lake's environment.

2. Study site

Lake Kizaki is located at the eastern foot of the Japanese Northern Alps along the tectonic zone or Fossa Magna which traverses the main island (Honshu) of Japan (36°33'N, 137°50'E at the center of the lake; surface area 1.4km²; maximum depth 29.5m; mean depth 17.9m; altitude above sea level 764m). There are three main inflowing rivers: the Naka-Nougu, Ina-ozawa, and Nishi, while the Shimo-Nougu is the only river flowing out of the lake's southern end (Fig. 1). The lake's eastern shore is partly surrounded by cultivated land. Villages occupy its northwestern and southern shores. This lake is ice-covered from January to February with a persistent thermocline in summer.

Many limnological studies have been carried out since the first major work by TANAKA (1930). Transparency averaged about 5m until 1950 (SAIJO *et al.*, 1983), but had decreased to approx-

imately 3m by 1970 (HAYASHI, 1989). Since the end of the 1970's, *Anabaena* has bloomed annually in July–August (WATANABE *et al.*, 1985), and the coloration of surface water has also risen in frequency due to an increase in the abundance of microorganisms which graze upon *Anabaena* (FUNAKOSHI *et al.*, 1983; Hayashi, 1985). In the autumn of 1987, the dinoflagellate *Peridinium* grew explosively, forming a freshwater red tide (KIDA *et al.*, 1989; PARK and HAYASHI, 1992).

AIZAKI *et al.* (1981) ranked this lake as a mesotrophic one, using the modified Carlson's trophic state index based on chlorophyll-*a*, total phosphorus, and transparency.

3. Materials and methods

3-1. Collection of benthic macro-invertebrates

YAMAGISHI and FUKUHARA (1972), and IWAKUMA and YASUNO (1981) reported that the larvae of *Tokunagayusurika akamusi* burrowed deep into the sediment to estivate during the summer. Benthic macroinvertebrates can be gathered most efficiently from late autumn to early spring, when almost all larvae, especially *T. akamusi*, come close to the surface of the sediment. On 11 November, 1985, a multi-point sampling survey was carried out using a standard Ekman–Birge grab (15×15cm), taking three replicate samples at each of 32 locations (2.1–29.1m) in a 250×250m grid (Fig. 1). After sieving the sediment through a Surber net (NGG 38; 560 μ m mesh size), benthic macroinvertebrates (chironomid larvae, chaoborid 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 μ m 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) and CRANSTON (1982).

3-2. Physical environmental factors

Bottom sediment samples for an organic matter analysis were collected with a core sampler (3cm inner diameter). Mud in the upper

Fig. 1. Map showing sampling stations in Lake Kizaki.

3cm layer of each core was oven-dried at 110°C for two days and ignited in a muffle furnace at 500°C for two hours to determine the values of loss on ignition.

The water temperature was measured on the bottom sediments with a thermistor thermometer (Toho Dentan, ET-5).

We used a core sampler to measure dissolved oxygen concentrations in the water at the mud–water interface. The water near the bottom of the core sampler was siphoned carefully into a glass bottle. The dissolved oxygen concentration was determined by Winkler's method with azide modification.

Table 1. Mean values and standard deviations of the variables representing environmental factors in the multi-point sampling survey in November 1985.

Environmental factors	<10 m	10–20 m	>20 m	Total
Number of sampling points	7	4	21	32
Depth (m)	4.2±1.4	12.0±1.6	24.9±2.8	18.8±9.1
Loss on ignition (%)	6.9±5.4	10.9±1.0	12.0±1.5	10.7±3.5
Water temperature (°C)	10.2±0.5	10.4±0.6	6.2±0.3	7.6±2.0
			*	
		*		
Dissolved oxygen (mg · l ⁻¹)	9.9±0.3	9.4±0.2	0.4±0.3	3.4±4.4
		*	*	
		*		

* : Difference is significant ($P < 0.05$).

3-3. Survival of chironomid larvae under anaerobic conditions

A comparative study was made on the tolerance to anaerobic conditions of chironomid larvae (*Chironomus nipponensis* and *Phaenopsectra kizakiensis*). Fourth instar larvae were used in all cases. The time of survival without oxygen was measured by keeping the larvae in bottles containing nitrogen-saturated water ($< 0.2 \text{ mg O}_2 \cdot \text{l}^{-1}$), which were then kept submerged in a water bath (16°C) in the dark. The number of dead individuals which did not build the nest was counted at intervals. In all cases larvae were enclosed in the proportion of 30 mg. d.w. to 100 ml. water: the number of animals varied from 8 to 14 per bottle according to the size of the larvae. Five replicate bottles were checked for each species.

4. Results

4-1. Environmental factors

The results of environmental factor analysis are shown in Table 1. In this paper, based on environmental factor observations, the lake area was roughly divided into three regions: the shallower region (<10 m), the transitional region (10–20 m) and the deeper region (>20 m).

4-1-1. Loss on ignition of sediment

The values of loss on ignition of the upper 3cm of the sediment taken from 32 locations ranged from 1.5% (sand) to 18.6 % (mud). Most of the lake basin consisted of soft bottom with organic matter contents higher than 10%.

Sediments at Sta. 1 contained the highest levels of organic matter (18.6%) of all the stations.

In regions shallower than 10m, *i.e.*, at Sta. 2 (mouth of the Naka-Nougu River), Sta. 17 (mouth of the Inaozawa River), Sta. 26 (mouth of the Nishi River), Stas. 27, 31, and 32 (southern outlet of the lake), the sediments were generally sandy with low values of loss on ignition (1.5–8.1%). In regions deeper than 10m, *i.e.*, at Stas. 10, 13 and 14, the bottom sediments consisted mainly of mud with relatively high values of loss on ignition (12.0 – 14.0%).

4-1-2. Bottom water temperature

The bottom water temperature ranged from 5.8 (Sta. 14) to 11.1°C (Sta. 31). In regions shallower than 20m, *i.e.*, at Stas. 1–4, 7 (northern part of the lake) and 26, 27, 29–32 (southern part), the bottom water temperatures were over 10°C. In regions deeper than 20m, they were below 6.5°C. The difference was significant between <10m and >20m, and 10–20m and >20m (Mann-Whitney's U-test).

4-1-3. Dissolved oxygen concentration

The dissolved oxygen concentrations in bottom water ranged from 0.0 to 10.2mg·l⁻¹. In regions shallower than 20m, the dissolved oxygen concentrations were over 9.0mg·l⁻¹, and in regions deeper than 20m, they were below 1.0mg·l⁻¹. There was a significant difference between <10m and >20m, <10m and 10–20m, and 10–20m and >20m (Mann-Whitney's U-test).

Table 2. Mean values and standard deviations of the densities of benthic macroinvertebrates in 1985.

Benthic macroinvertebrates	Mean values and standard deviations	
	ind. • m ⁻²	W. W. (mg) • m ⁻²
Chaoboridae	2,636 ± 2,641	5,885 ± 6,055
Oligochaeta	436 ± 422	1,015 ± 1,089
Chironomidae	1,679 ± 3,122	6,215 ± 13,191
Chironominae		
<i>C. nipponensis</i>	596 ± 1,010	2,775 ± 4,597
<i>P. kizakiensis</i>	658 ± 2,249	2,488 ± 8,848
<i>Microtendipes</i> sp.	200 ± 681	290 ± 855
<i>Stictochironomus</i> sp.	40 ± 137	59 ± 207
<i>Corynosera</i> sp.	15 ± 58	8 ± 32
Orthoclaadiinae		
<i>Tokunagayusurika akamusi</i>	21 ± 47	410 ± 911
Tanypodinae		
Tanypodinae spp.*	121 ± 237	156 ± 381
Others	32 ± 96	14 ± 41

* includes 2 genera

4-2. The distribution of benthic macroinvertebrates

Table 2 shows the mean values with standard deviations of the variables representing benthic macroinvertebrates, chironomid and chaoborid larvae, and oligochaetes. The average densities of chironomid and chaoborid larvae and oligochaetes for all the stations were $1,679 \pm 3,122$ (35.3%), $2,636 \pm 2,641$ (55.5%) and 436 ± 422 (9.2%) ind. • m⁻², respectively. On the other hand, the average biomass (wet weight) of these benthic macroinvertebrates were $6,215 \pm 13,191$ (47.4%), $5,885 \pm 6,055$ (44.9%) and $1,015 \pm 1,089$ (7.7%) mg. • m⁻², respectively. Among Chironomidae, five species belonged to the subfamily Chironominae, one species to Orthoclaadiinae, and two genera to Tanypodinae. The predominant species of chironomid was *C. nipponensis*. The larvae of this species were the largest in size, and thus constituted a major portion of the total biomass of chironomid larvae in this lake.

Figure 2 shows the density of some benthic macroinvertebrates (*Chaoborus*, *Oligochaeta*, *C. nipponensis*, *P. kizakiensis*, Tanypodinae spp. and *T. akamusi*) in relation to water depth, while Figure 3 shows the horizontal distributions of some benthic macroinvertebrates. Chaoborid larvae were found at almost all

stations. The population density was low in the shallower regions and high in the deeper regions. Oligochaetes also inhabited the entire lake bottom, with higher densities in the shallower and transitional regions. The population density of chironomid larvae differed among the sampling stations, being very low near the center of the lake and reaching a maximum ($16,000$ ind. • m⁻²) on the northeastern side of the lake.

The most abundant species, *C. nipponensis*, had the widest distribution (from 2.0m to 27.0m in depth) with high densities in the 10–20m regions, and low densities at depths of 25m and more. It was particularly abundant in the northeastern and southern parts of the lake (the maximum number of larvae reached $4,600$ ind. • m⁻² at Sta. 8; depth, 21.7m). *P. kizakiensis* was also widely distributed, although the density was very low in regions shallower than 10m and deeper than 20m depth. The larval density was about 3.5 times higher than that of *C. nipponensis* in the transitional regions. The larvae of this species were numerous at the northern and southern stations. *Microtendipes* sp. and *Stictochironomus* sp. were found along the southern shore. The biomasses of these species were very small. *T. akamusi* was

Fig. 2. Bathymetrical distribution of main benthic macroinvertebrates in Lake Kizaki.

Fig. 3. Horizontal distribution of chironomid larvae, chaoborid larvae and Oligochaetes in Lake Kizaki, November 1985.

numerous at the northern stations near an inlet of domestic waste water (Sta. 3) and in the south near some hotels (Stas. 29, 30, 31, 32).

Table 3 shows the correlation matrix for variables in the number of benthic macro-invertebrates (chaoborid larvae; Cha, oligochaetes; Oli, *C. nipponensis*; C. n. and *P. kizakiensis*; P. k.) as well as such environmental factors as depth, dissolved oxygen concentration (DO), water temperature (WT), and loss on ignition (LOI). Four environmental factors were closely related to each other. The density of Cha was closely related to the water depth, whereas that of Oli was closely related to DO and WT. The density of Cha-DO, Cha-WT and Cha-Oli, and the density of Oli-depth showed

negative correlations. The density of C. n. was closely related to P. k., The density of P. k. was closely related to Oli and DO.

4-3. Survival of larvae under anaerobic conditions

The data on survival of larvae, *C. nipponensis* and *P. kizakiensis*, under anaerobic conditions are given in Figure 4. *C. nipponensis* and *P. kizakiensis* differed strikingly in their survival under anaerobic conditions. *P. kizakiensis* had a low survival rate. The larvae ceased to show respiratory undulation after 20 to 30 hr, and 50% of them died after from 30 to 40 hr. On the other hand, *C. nipponensis* larvae remained alive longer.

Table 3. Correlation matrix for environmental variables and densities of benthic macroinvertebrates.

	DO	WT	LOI	Cha	Oli	C. n.	P. k.
Depth	-0.948**	-0.930**	0.560**	0.771**	-0.688**	-0.043	-0.404
DO		0.987**	-0.693**	-0.723**	0.724**	-0.007	0.388*
WT			-0.548**	-0.730**	0.738**	-0.011	0.336
LOI				0.366*	-0.275	0.205	0.082
Cha					-0.544**	-0.097	-0.267
Oli						0.421*	0.494**
C. n.							0.493**

DO; dissolved oxygen, WT; water temperature, LOI; loss on ignition, Cha; chaoborid larvae, Oli; oligochaetes, C. n.; *C. nipponensis*, P. k.; *P. kizakiensis*

*Significant at 0.05 probability level ($f = 31$)

**Significant at 0.01 probability level ($f = 31$)

Fig. 4. Anaerobic resistance of *C. nipponensis* and *P. kizakiensis* larvae. Vertical bars indicate standard deviations.

5. Discussion

Many studies have been conducted on the distribution of benthic macroinvertebrate populations in relation to various environmental factors (reviewed by JONASSON, 1972; BRINKHURST, 1974). According to YASUNO *et al.* (1984), the oxygen concentration is of primary importance in determining the distribution of benthic macroinvertebrates.

In Lake Kizaki, the density of chaoborid larvae showed a negative correlation with the dissolved oxygen concentration, whereas that of oligochaetes showed a positive correlation. This suggests the strong possibility that their distributions were regulated by the dissolved oxygen concentration. On the other hand, that of chironomid larvae did not clearly show a significant correlation with the oxygen concentration. Thus, *P. kizakiensis* had a weak correlation with the oxygen concentration, and *C. nipponensis* did not show a significant relationship to it (Table 3). There were fewer larvae in the shallower regions. However, the density of chironomid larvae was very low at depths of 25 m or more due to the lack of dissolved oxygen concentration (Fig. 2). These facts suggest that the distribution of chironomid larvae is not determined only by the dissolved oxygen concentration, although that might be an important factor in determining distribution of chironomid larvae. As compared with *P. kizakiensis*, *C. nipponensis* was distributed in the deeper region with a low dissolved oxygen concentration. This fact served to confirm that *C. nipponensis* was more tolerant than *P. kizakiensis* under anaerobic conditions in the laboratory experiment (Fig. 4).

Many researchers have used the distribution patterns of benthic macroinvertebrates, particularly those in profundal zones, as indicators of trophic state and pollution (*e. g.* IWAKUMA *et al.*, 1988). BRINKHURST (1970) reviewed the distribution of tubificid oligochaetes in relation to organic pollution and pointed out they could be used as an indicator of pollution. According to CANNINGS and SCUDDER (1978), the relationship between the chironomid community and lake

type stems from differences in tolerance to oxygen deficiency among various species.

In Japan, trophic classifications of lakes were made using chironomid fauna and chaoborid by MIYADI (1933) and KITAGAWA (1978), and modified by YASUNO *et al.* (1983) who pointed out that MIYADI may have misidentified *C. nipponensis* as *Chironomus plumosus*. YASUNO *et al.* (1983) also reported that lakes where *C. nipponensis* are dominant may be classified as meso-middle (between eutrophic and mesotrophic).

We compared our results with those of MIYADI (1931) and KITAGAWA (1973), and tried to clarify the relationship between the eutrophication of this lake and the dominant species of chironomids. Table 4 shows the distributions of dominant chironomid species according to water depth, based on the data of MIYADI (1931) and KITAGAWA (1973). MIYADI (1931) reported that *Endochironomus* sp. was found at depths over 10 m, the maximum being 16,380 ind $\cdot$ m⁻² at 21 m. According to KITAGAWA's (1973) description, *C. plumosus*-b was found over a relatively wide range of depths from 6 m to 28 m. Moreover, he also found that the density of *Endochironomus* larvae, which seemed to be identical with *Phaenopsectra*, was low and that *C. plumosus*-b not recorded by MIYADI was found abundantly.

YASUNO *et al.* (1984) reported the possibility of *C. nipponensis* which KITAGAWA (1974) described as *C. plumosus*-b based on their size, distribution and the details in his sketch. In our survey, *C. nipponensis* was the most abundant species of chironomid larvae year round, and larvae of *C. plumosus* and *C. nipponensis* are not likely to be found together since *C. plumosus* adults were never caught with a light trap or a net at any time during the year (HIRABAYASHI, unpublished data). One important difference between our results and KITAGAWA's is that *C. nipponensis* were not found even in the deeper regions (>28 m).

According to SASA (1984), *P. kizakiensis* was described by TOKUNAGA (1940) with the name *Pentapedilum kizakiensis* based on male and female reared from larvae abundantly collected from the bottom of Lake Kizaki. TOKUNAGA

Table 4. Change in dominant chironomid fauna and their depth distribution in Lake Kizaki.

Study year (literature)	Dominant species	2 m	6 m	10 m	25 m	28 m
		ind. · m ⁻²				
1929	<i>Endochironomus</i> sp.					
(MIYADI, 1931)	No.	0	0	156	5,044	1,508
	%	0	0	5	100	100
1972	<i>Chironomus plumosus</i> -b					
(KITAGAWA, 1973)	No.		90	225	45	45
	%		100	25	100	100
	<i>Phaenopsectra</i> sp.					
	No.		0	45	0	0
	%		0	5	0	0
1986	<i>Chironomus nipponensis</i>					
(This study)	No.	444	267	889	489	0
	%	13	29	43	100	0
	<i>Phaenopsectra kizakiensis</i>					
	No.	0	0	1,156	0	0
	%	0	0	57	0	0

(1940) stated that the immature stages of this species had been incorrectly reported in limnological papers as *Endochironomus* larvae. If the species described by MIYADI (1931) as *Endochironomus* sp. was *P. kizakiensis*, the larval distribution pattern of this chironomid had changed since MIYADI's study. In 1929, the larvae of *P. kizakiensis* was distributed from 10 m to 27.5 m. In contrast, by 1972 this larvae was found in shallower regions, and was not found at all in the deeper regions (>20 m). The present study showed the same results as those in 1972.

Assuming that a species described by MIYADI (1931) as *Endochironomus* sp. was *P. kizakiensis*, and that KITAGAWA (1974) erroneously identified *C. nipponensis* as *C. plumosus*-b, large environmental changes must have affected chironomid fauna, especially in the deeper regions with low dissolved oxygen concentrations (>28 m). Consequently, the distribution pattern of chironomids in the lake has changed.

The eutrophication of this lake is proceeding. It seems that favorable environmental conditions for larvae in deeper regions are deteriorating, and that larval distribution is shifting to regions shallower than 28 m. Although this lake was classified as mesotrophic in previous

studies (AIZAKI *et al.*, 1981 and others), we think this needs to be reconsidered in light of the circumstances mentioned above.

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摘 要

木崎湖における大型底生無脊椎動物の 水平分布について

1985年11月、木崎湖において大型底生無脊椎動物の分布調査を行った。採集された底生動物は、生物量で水生貧毛類が7.7%、フサカ幼虫が44.9%、ユスリカ幼虫が47.4%であった。水生貧毛類は、湖全体で採集され、特に10mより浅い地点で多く採集された。これとは逆に、フサカ幼虫は20m以深の深い地点で多く採集された。一方、ユスリカ幼虫は10-20mの深さの地点で多く採集され、深さが増すに従って捕獲個体数、ならび

に種類数が減少する傾向がみられた。最も多く採集されたユスリカ幼虫は *C. nipponensis* で、2-27 m と広い範囲で分布した。しかしながら、底層の溶存酸素が欠乏する 20 m 以深の地点では生息数が極めて少なく、過去のデータとの比較から、ユスリカ幼虫の優占種が *Endochironomus* sp. (*P. kizakiensis* と思われる) から *C. nipponensis* に変化していることが明らかとなった。このことは、現在の木崎湖の深底部環境が、1930 年代に比べ、大きく変化していることを示していると思われる。

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