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Benthic macroinvertebrates in the Nishina Three Lakes and Lake Nojiri, highland lakes in Japan

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Abstract: In order to clarify the current status of the benthic communities in the Nishina Three Lakes (Lakes Aoki, Nakatsuna and Kizaki) and Lake Nojiri, highland lakes located at the foot of the Japanese Northern Alps in Nagano Prefecture, we collected benthic macroinvertebrates on 1 and 2 August, 2007. Chironomidae and Oligochaeta were the major macroinvertebrates at all study sites and the taxonomic composition of Chironomidae was different among the sites. *Sergentia* was collected in Lakes Aoki and Kizaki, whereas *Chironomus* was collected in all the lakes except Lake Aoki. Chaoboridae was collected at the center of the Lakes Nakatsuna and Kizaki but not in Lakes Aoki and Nojiri. The comparison of the densities of benthic maroinvertebrates with the previous studies suggests that the densities of Oligochaeta increased in Lakes Aoki, Kizaki and Nojiri, and *Chironomus* increased in Lake Nojiri in recent decades.

Key words: lake, benthic macroinvertebrate, Chironomidae, Oligochaeta, long-term change

Introduction

Lakes Aoki, Nakatsuna and Kizaki form a chain of lakes which is called the Nishina Three Lakes. Together with Lake Nojiri, these highland lakes located at the foot of the Japanese Northern Alps in Nagano Prefecture attracts many tourists for camping and fishing in summer and skiing in the surrounding mountains in winter. Studies on the benthic macroinvertebrates in Lake Kizaki has been extensively conducted for nearly 80 years as one of the representative sites for limnological studies in Japan (Tanaka, 1930; Miyadi, 1931; Kitagawa, 1973; Yasuno et al., 1983; Hirabayashi and Hayashi, 1994, 1996; Hirabayashi et al., 1996; Hirabayashi et al., 2007). Miyadi (1931) and Kitagawa (1973) also investigated the composition and densities of benthic macroinvertebrates in

Lakes Aoki, Nakatsuna and Nojiri, but current status of benthic communities in these lakes remained uncertain.

In order to clarify the long-term changes in the benthic communities from the previous studies, we collected the benthic samples in the four lakes on 1 and 2 August, 2007. The benthic assemblage composition was also compared among the four lakes.

Methods

Table 1. Altitude and morphology of the Nishina Three Lakes and Lake Nojiri. Data from Saijo (2001).

	Nishina Three Lakes			L. Nojiri
	L. Aoki	L. Nakatsuna	L. Kizaki	
Altitude (m a.s.l.)	822	815	764	654
Surface area (km^2)	1.86	0.14	1.40	3.90
Maximum depth (m)	58.0	12.0	29.5	37.5
Mean depth (m)	29.0	5.7	17.9	20.8

Field sampling and survey were conducted in Lake Nojiri on 1 August and in the Nishina Three Lakes on 2 August, 2007 (Table 1). Benthic macroinvertebrates were collected quantitatively using Ekman-Birge grab sampler (15×15 cm^2) with three replications at 6 sites in Lakes Lakes Aoki (A1), Nakatsuna (NK1), Kizaki (K1 and K2) and Nojiri (NJ1 and NJ2) (Fig. 1; Table 2). The substrates collected at these sites were sieved through a Surber net (NGG44, 0.45 mm mesh) and the residues were preserved in 10% formalin. At the same time, water temperature was measured every 1–2 m up to the depth of 30 m (except K2 and NJ2) and the bottom water was collected using a core sampler to measure dissolved oxygen concentration (except K2).

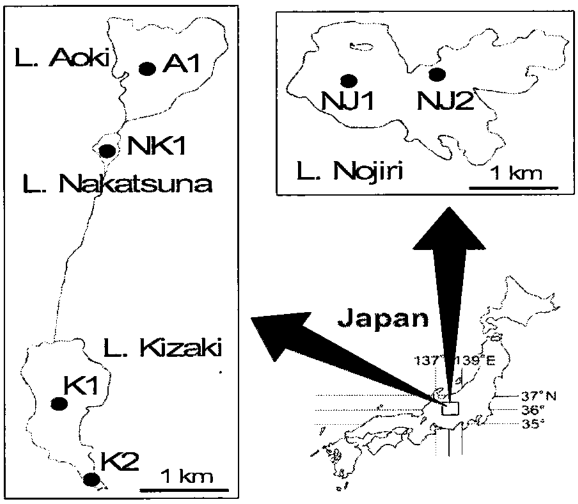

Fig. 1 Map of the Nishina Three Lakes (Lakes Aoki, Nakatsuna and Kizaki) and Lake Nojiri showing the location of the 6 study sites.

In the laboratory, benthic macroinvertebrates were sorted and counted under a binocular dissecting microscope. A part of chironomids were mounted on microscopic slides with gum chloral and identified as genus level except the tribe Tanytarsini mainly according to Wiederholm (1983). The names of macroinvertebrates used in Miyadi (1931) and Kitagawa (1973) were translated following Hirabayashi (2001) and updated the generic names or interpreted as the higher taxonomic groups.

Dissolved oxygen concentration was determined according to Winkler's method with azide modification.

Table 2. Environmental measurements at the study sites in the Nishina Three Lakes and Lake Nojiri.

Site	Nishina Three Lakes				L. Nojiri	
	L. Aoki	L. Nakatsuna	L. Kizaki			
	A1	NK1	K1	K2	NJ1	NJ2
Longitude	N36° 36' 36.0"	N36° 35' 51.1"	N36° 33' 26.3"	N36° 32' 42.0"	N36° 49' 41.1"	N36° 49' 39.4"
Latitude	E137° 50' 56.1"	E137° 50' 37.1"	E137° 50' 11.9"	E137° 50' 29.7"	E138° 13' 31.7"	E138° 12' 49.8"
Depth (m)	59.9	14.9	29.5	5.3	38.6	23.2
Transparency (m)	8.86	6.30	5.80	n/a	7.50	7.57
Dissolved oxygen concentration of the bottom water (mg L^{-1})	3.82	0.24	0.41	n/a	0.96	4.76

n/a: not available.

Results and Discussion

Lake Aoki

The water temperature profile showed that the stratification of the water was weak (Fig. 2). This would be resulted in 3.82 mg L^{-1} of the dissolved oxygen concentration at A1 of 59.9 m in depth

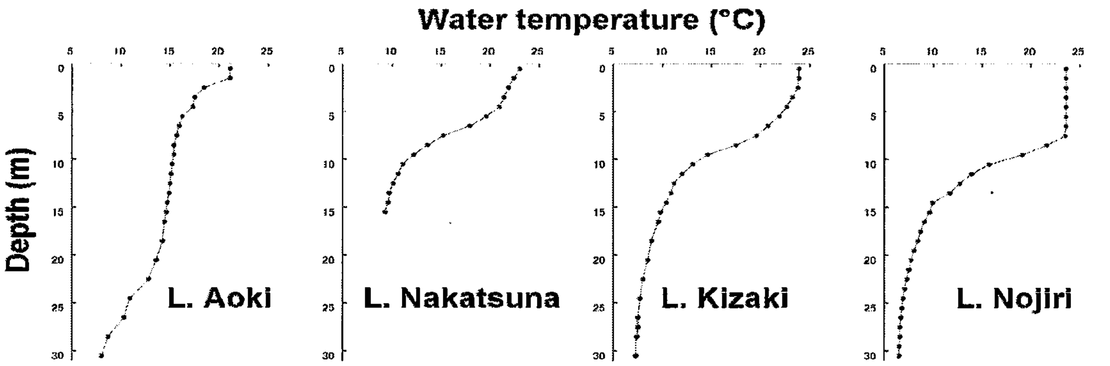

Fig. 2 Vertical profiles of water temperature in the Nishina Three Lakes on 2 August, 2007 and in Lake Nojiri on 1 August, 2007.

(Table 2). Only Oligochaeta and Chironomidae were collected at A1 and the densities were 4,770.4 ± 4,963.9 and 1,170.4 ± 378.0 ind. m^{-2}, respectively (Table 3). Chironomidae was identified as two taxa, *Sergentia* (74.7% of the total chironomid density) and Tanytarsini (25.3%).

Miyadi (1931) reported that only *Sergentia* was collected at 7 sites from 54 to 55 m in depth on 11 August, 1929. On the other hand, Kitagawa (1973) collected Oligochaeta, *Sergentia* and Tanytarsini

Table 3. Densities (ind. m^{-2}) of benthic macroinvertebrates at the study sites in the Nishina Three Lakes and Lake Nojiri. Values are mean±SD.

Site	Nishina Three Lakes				L. Nojiri	
	L. Aoki	L. Nakatsuna	L. Kizaki			
	A1	NK1	K1	K2	NJ1	NJ2
Depth (m)	59.9	14.9	29.5	5.3	38.6	23.2
Insecta						
Diptera						
Chironomidae	(1,170.4±378.0)	(74.1±92.5)	(74.1±67.9)	(5,200.0±546.1)	(222.2±44.4)	(1,363.0±447.4)
Subfamily Chironominae						
Chironomus	-	44.4±77.0	44.4±77.0	88.9±88.9	207.4±25.7	1,348.1±427.1
Cladopelma	-	-	-	103.7±67.9	-	-
Microtendipes	-	-	-	14.8±25.7	-	-
Polypedilum	-	-	-	59.3±67.9	-	-
Sergentia	874.1±400.8	-	14.8±25.7	-	-	-
Stictochironomus	-	29.6±25.7	-	4,474.1±766.4	-	-
Tanytarsini	296.3±25.7	-	-	-	-	14.8±25.7
Subfamily Prodiamesinae						
Monodiamesa	-	-	-	74.1±25.7	-	-
Subfamily Tanypodinae						
Procladius	-	-	-	385.2±142.9	14.8±25.7	-
Chaoboridae	-	296.3±102.6	59.3±25.7	-	-	-
Ephemeroptera	-	14.8±25.7	-	14.8±25.7	-	-
Trichoptera	-	-	-	103.7±111.8	-	-
Mollusca	-	-	-	222.2±88.9	-	-
Nematoda	-	-	133.3±77.0	-	-	-
Oligochaeta	4,770.4±4,963.9	385.2±67.9	15,288.9±2,982.4	3,214.8±1,143.0	1,644.4±160.2	266.7±44.4

at 3 sites from 55.0 to 56.0 m in depth on 20 August, 1972, but the density of Oligochaeta was 405.0 ± 233.8 ind. m^{-2} and much lower than our study. These facts suggest the increase in the density of Oligochaeta in the deep area of the Lake Aoki.

Lake Nakatsuna

There was a distinct thermocline between the depths of about 5 and 10 m (Fig. 2), and the dissolved oxygen concentration at NK1 of 14.9 m in depth was extremely low (Table 2). The benthic macroinvertebrate assemblage was mainly composed of Oligochaeta, Chaoboridae and Chironomidae at NK1, although their densities were low (Table 3).

Miyadi (1931) collected Chaoboridae, Oligochaeta and *Chironomus* at 5 sites from 12 to 13 m in depth on 10 August, 1929 and Chaoboridae was the most abundant taxon which recorded the density of 1,196 ± 303.2 ind. m^{-2}. On the other hand, the density of Oligochaeta reported by Miyadi (1931) was 93.6 ± 43.5 ind. m^{-2}, lower than our study. We could not compare our result with Kitagawa (1973) simply, because he conducted the survey in Lake Nakatsuna in June and October, 1972. However, the densities of Chaoboridae and Oligochaeta in June, 1972 were almost the same level as Miyadi (1931) and an intermediate level between Miyadi (1931) and our study, respectively. These facts suggest the decrease in the density of Chaoboridae and a slight increase of Oligochaeta.

Lake Kizaki

There was a distinct thermocline between the depths of about 5 and 10 m (Fig. 2), and the dissolved oxygen concentration at K1 of 29.5 m in depth was extremely low (Table 2). Oligochaeta was the most abundant benthic macroinvertebrate at K1 which accounted for 98.3% of the total abundance and the density was extremely high (Table 3). On the other hand, Chironomidae was the most abundant at K2 and identified as 7 taxa. *Stictochironomus* accounted for 86.0% of the total chironomid abundance and was more abundant than Oligochaeta.

Miyadi (1931) reported that *Sergentia* was the most abundant taxa with the density of 2,478.7 ± 2,243.4 ind. m^{-2} at 3 sites from 25.5 to 27.5 m in depth on 10 August, 1929. Chaoboridae was the second most abundant (485.3 ± 261.7 ind. m^{-2}) taxon followed by Oligochaeta (398.7±158.9 ind. m^{-2}). On the other hand, Kitagawa (1973) collected only Chaoboridae, *Chironomus* and Oligochaeta at 3 sites from 27.0 to 27.9 m in depth on 21 August, 1972. The densities of Chaoboridae and Oligochaeta were much lower than Miyadi (1931), whereas *Chironomus* was not recorded in Miyadi (1931). These facts suggest that the decrease and extreme increase in the densities of Chaoboridae and Oligochaeta in the deep area of Lake Kizaki.

The benthic macroinvertebrate assemblage in the shallow area would be quite different between the sites even in the same lake, but Miyadi (1931) and Kitagawa (1973) reported much lower densities of Oligochaeta than our study at the sites less than 10 m in depth. In addition, both of them recorded Chaoboridae, *Sergentia*, Tanytarsini and Orthocladiinae, but did not *Stictochironomus*. These facts suggest the increase in the densities of Oligochaeta and *Stictochironomus* in the shallow area of Lake Kizaki in recent decades.

Lake Nojiri

There was a distinct thermocline between the depths of about 9 and 14 m (Fig. 2), and the dissolved oxygen concentration at NJ1 of 38.6 m in depth was low (Table 2). The benthic macroinvertebrate assemblage was composed of Oligochaeta (88.1% of the total macroinvertebrate abundance) and two taxa of Chironomidae (11.9%) at NJ1, whereas Chironomidae, especially

Chironomus, was more abundant than Oligochaeta at NJ2 (Table 3).

Kitagawa (1973) recorded Oligochaeta, *Chironomus*, Tanytarsini and *Procladius* on 22 August, 1972 both at 5 (depth: 33.3 to 37.8 m) and 3 sites (14.5 to 28.5 m), similar depth for NJ1 and NJ2, respectively. The densities of Oligochaeta and Chironomus reported by Kitagawa (1973) were lower than our study, especially Oligochaeta at NJ1 and *Chironomus* at NJ2. Because Miyadi (1931) conducted survey in Lake Nojiri in April and November, 1929, it should not be compared with our results simply. However, the densities of Oligochaeta and *Chironomus* recorded by Miyadi (1931) were lower than our study or nearly the same level. These facts suggest that the densities of Oligochaeta and *Chironomus* were increased after 1970's.

Comparison of benthic macroinvertebrate assemblages among the four lakes

Overall, increase in the density of Oligochaeta in recent decades was suggested in the Nishina Three Lakes and Lake Nojiri. Chaoboridae was so far recorded in Lakes Nakatsuna and Kizaki, and the densities would be decreased than the previous studies.

The composition of Chironomidae was different among the four lakes, e.g. *Sergentia* was collected in Lakes Aoki and Kizaki, whereas *Chironomus* was collected in all the lakes except Lake Aoki. Thus, typology of these lakes would be best explained by Chironomidae. We did not identify Oligochaeta to the lower taxa, but the composition may also be different among the four lakes as well as Chironomidae.

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