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Change of macrobenthic communities in the 1930s, 1970s and 2015 in the mesotrophic Lake Nojiri, Central Japan

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ABSTRACT

We documented the current status of the macrobenthic community of Lake Nojiri (surface area: 4.56 km^2; maximum depth: 38.5 m; altitude: 654 m above sea level; mesotrophic lake), and examined changes over time in the densities of chironomids and oligochaetes, by comparison with previous quantitative data of the lake reported in 1931 and 1973. We discussed the succession of benthic macroinvertebrates in relation to changes in the lake bottom environment, as evidence of lake eutrophication. On March 10, 2015, a bathymetrical sampling survey was carried out using a standard Ekman grab at each of the 5 stations (min. *ca*. 6 m – max. *ca*. 27 m) in Lake Nojiri. The average densities of the benthic communities for all the stations were *ca*. 5000 m^{-2}, comprised principally of oligochaetes *ca*. 2800 m^{-2} (57%) and chironomids *ca*. 2100 m^{-2} (43%), whereas their benthic biomass averaged *ca*. 9.7 g m^{-2}, chironomids *ca*. 7.6 g m^{-2} (77%) and oligochaetes *ca*. 2.3 g m^{-2} (23%). In the shallower stations, the dominant species was *Heterotrissocladius* sp., but *Chironomus nipponensis* Tokunaga was the dominant species in the deeper stations. The densities of *C. nipponensis* was *ca.* 14 times higher than those reported by Miyadi in 1931 and 4 times higher than reported by Kitagawa in 1973a. In recent years the density of the oligochaete *Tubifex tubifex* (Miller), has tended to increase and the anoxic- and anaerobic-layer have thickened, especially in deeper regions where they are widely distributed. Moreover, we found differences in the *C. nipponensis* larval growth rate with water depth, *i.e*., small IV-instar larvae that dominated at the deepest Station 5. At this station, we suggest that low dissolved oxygen concentration and low water temperature during summer-fall suppresses growth of *C. nipponensis*. Large environmental changes must have affected chironomid and oligochaete densities and growth rate of *C. nipponensis*, especially in the deeper regions with low dissolved oxygen concentrations, low water temperature and high organic matter (ignition loss; 15.0% in St. 4 and 13.9% in St. 5) in the sediments. This is a strong evidence that the eutrophication of this lake is continuing.

Key words: Bathymetrical distribution; biomass; chironomids; *Chironomus nipponensis* Tokunaga; density; eutrophication; mountain lake; *Tubifex tubifex* (Miller).

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INTRODUCTION

It has long been well known that indices based on species composition, density, biomass and the distribution of benthic fauna in lakes reveal the status and change of the lakes and their bottom environment (reviewed by Lindegaard, 1995). However, few studies on benthic macroinvertebrates, *e.g.* aquatic Oligochaeta and chironomid larvae, have been undertaken in Japan because of the difficulty of species identification (Yasuno *et al*., 1983). The biota of Lake Nojiri has been studied by many workers since Tanaka (1916). However, studies of benthic macroinvertebrates have been very few. Previous research on Lake Nojiri includes a descriptive study of benthic animals (Miyadi, 1931) and a description of the horizontal distribution of total Oligochaeta and chironomid larvae (Kitagawa, 1973a). Recently, Inoue *et al*. (2010) described the benthic macroinvertebrates in the profundal area of this lake. In 1978, five thousand grass carp, *Ctenopharyngodon idellus,* were introduced in order to manage the aquatic plants, which sometimes interfere with fishery and boat navigation. Three years after its introduction, most aquatic plants including genus *Nitellopsis obtusa* (*stonewort*) were heavily damaged or extinct due to overgrazing by grass carp (Higuchi, 2002). Moreover, large mouse bass, *Micropterus salmoides,* were introduced into the lake in the 2000s, and sports' fishing is also popular (Kitano *et al.*, 2010). At the same time, reduced water transparency due to pollution from these activities has been a growing issue (Nagano Prefecture, 2015). Thus, from the end of the 1980s to the end of the 2000s, the biota and the environmental conditions of the lake changed drastically (Tanaka, 1992, Nagano Prefecture, 2015), and this must have had some effect on the Oligochaeta and chironomid fauna.

The distribution of benthic macroinvertebrates was investigated to document the current status of the macrobenthic community of Lake Nojiri, especially oligochaetes and chironomid larvae, and to examine the difference with the quantitative data reported by Miyadi (1931) and Kitagawa (1973a). The succession of benthic macroinvertebrates in relation to changes in the lake bottom environment is currently under discussion.

METHODS

Lake Nojiri (36°49'30"N, 138°13'20"E at the center of the lake) has a surface area of 3.90 km^2, maximum and mean depths of 37.5 and 20.8 m, respectively, and lies at an altitude of 654 m above sea level at the foot of Mt. Kurohime. Aizaki *et al*. (1981) ranked this lake as mesotrophic, using the modified Carlson's Trophic State Index (TSI; Carlson 1977, 1980) based on transparency, chlorophyll-*a* and total phosphorus. In some parts of the lake the water has been used as a drinking water source.

Larvae of some chironomid species, *e.g.*, *Propsilocerus akamusi* (Tokunaga), burrow deep into the lake sediments to aestivate during the summer (Yamagishi and Fukuhara, 1972; Iwakuma and Yasuno, 1981). Thus, sampling benthic macroinvertebrates is most efficient from late-autumn to early-spring when almost all benthos stay close to the surface of the sediment. A multipoint sampling survey was carried out on 10 March 2015, using a standard Ekman grab (15 x 15 cm). Three samples were taken at each of 5 sampling stations (St. 1: 6.2 m; St. 2: 10.5 m; St. 3: 14.9 m; St. 4: 20.2 m; St. 5: 27.1 m) in Lake Nojiri (Fig. 1). The sampling points were determined with a Global Positioning System (GPS). After sieving the

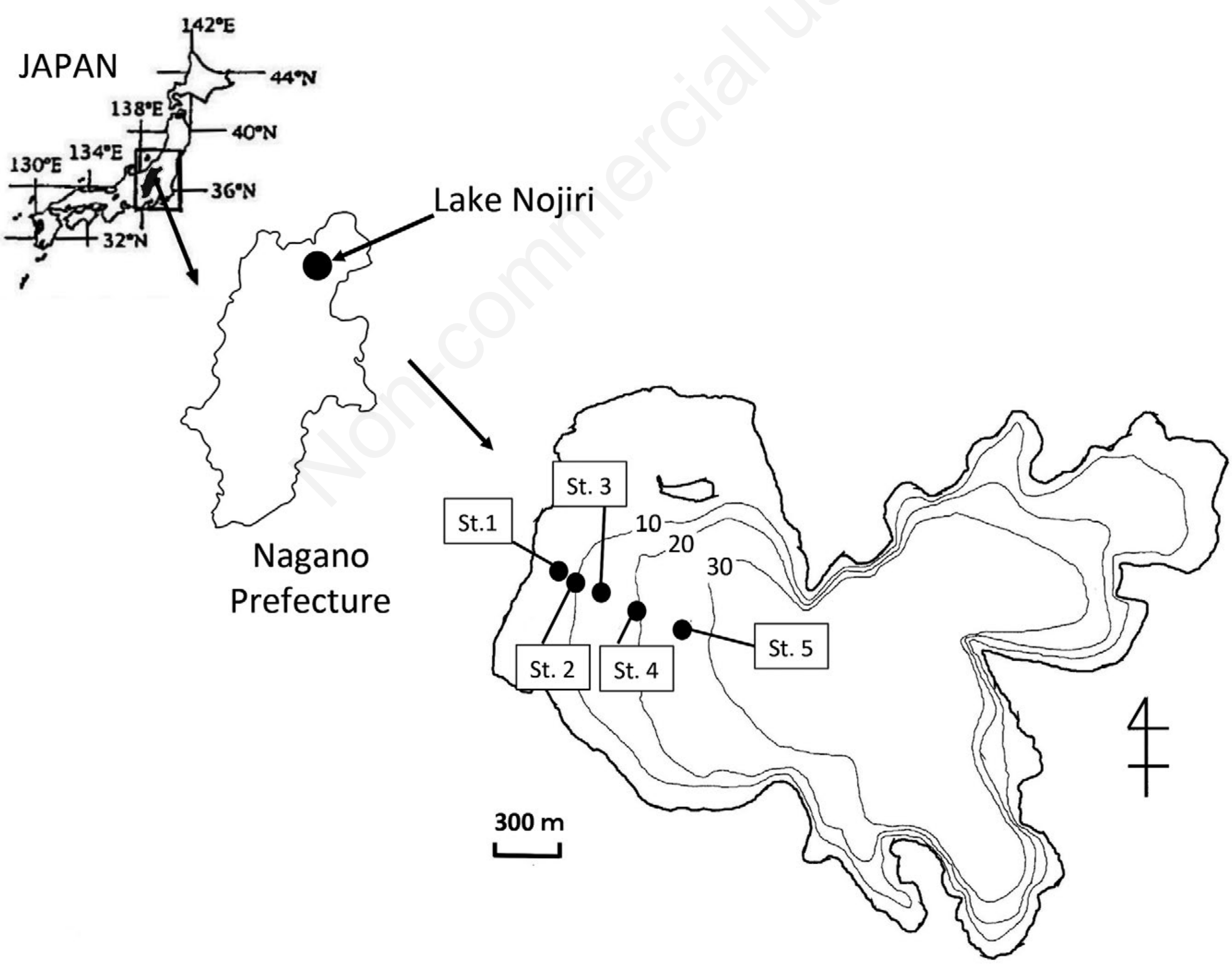

Fig. 1. Map of the sampling stations in Lake Nojiri.

sediment through a Surber net (GG66; 0.25 mm mesh size) chironomid larvae and oligochaetes were counted in the laboratory. Their wet weight was measured with an electronic balance (AND, HM-202).

To identify the chironomids some larvae were soaked in a 10% KOH solution, mounted on slides with gum chloral solution, and examined under a microscope. The chironomids were identified to genus using the keys of Cranston (1982), Wiederholm (1983) and Andersen *et al.* (2013). Reference was made to the list of adult chironomids in 2010 in Lake Nojiri reported by Inoue *et al.* (2010).

Sediment samples for organic matter analysis were collected with a core sampler (3 cm inner diameter) at all stations. Mud from the upper 3 cm layer of each core was oven-dried at 110°C for 2 days and ignited in a muffle furnace at 550°C for three hours to determine the ignition loss (IL). At the same station, the core sampler was also used to measure dissolved oxygen concentrations (DO) in the water at the mud-water interface. The water near the mud surface in the core sampler (which remained above the sediment in the core sampler when it was pulled from the water) was siphoned carefully into a glass bottle. Dissolved oxygen concentration was measured using the Winkler method with azide modification. The bottom water temperature (WT) and mud temperature (MT) in the bottom sediments collected in the core sampler were also measured using a thermistor thermometer (*ca.* 3 cm from the sediment surface).

RESULTS

Dissolved oxygen and temperature at the mud-water interface varied little among stations in March 2015, because this was during the period of spring overturn. The ignition loss values of the sediment ranged from 9.6% to 15.0%, with a mean value of 12.2±2.2%. Most of the lake basin consisted of a soft bottom with an organic matter content higher than 11%. Sediments at St. 4 contained the highest levels of organic matter (15.0%).

The average density (±SD) of the benthos for all the stations was 4961±2303 m^{-2} (Tab. 1), and was comprised principally of oligochaetes, 2809±2138 m^{-2} (56.6%) and chironomids, 2125±2320 m^{-2} (42.8%). Average benthic biomass 9.66±4.71 g m^{-2} was dominated by chironomids at 7.64±4.64 g m^{-2} (77.2%) and oligochaetes at 2.26±1.56 g m^{-2} (22.8%). There were two species of Orthocladiinae, nine species of Chironominae, one Diamesinae and one Tanypodinae. The most abundant species was *Heterotrissocladius* sp. (36.1%), followed by *Chironomus nipponensis* Tokunaga (24.4%). *C. nipponensis* represented the highest biomass (74.7%) followed by *Heterotrissocladius* sp. (14.7%).

The densities of *Tubifex tubifex* (Miller) and total chironomid larvae were widely distributed with depth (Fig. 2). Although the density of total chironomid larvae and *Heterotrissocladius* sp. decreased with increasing water depth, their highest densities were in the shallowest

Tab. 1. Species composition, densities and biomass in Lake Nojiri on March 10, 2015.

	Densities (ind m^{-2})	%	Biomass (g m^{-2})	%
Chironomidae	2125.3±2320.0	42.8	7.64±4.64	77.2
Tanypodinae	222.0±171.1	10.4	0.29±0.19	3.8
Orthocladiinae				
Heterotrissocladius sp.	766.6±1615.2	36.1	1.12±2.38	14.7
Propsilocerus akamusi	11.8±20.3	0.6	0.16±0.33	2.0
Chironominae				
Chironomus nipponennsis	518.0±463.1	24.4	5.71±5.45	74.7
Micropsectra sp.	254.6±306.5	12.0	0.18±0.26	2.4
Tanytarsus sp.	142.1±281.4	6.7		
Polypedilum sp.	65.1±138.2	3.1	—	—
Biwatendipes tsukubaensis	35.5±79.1	1.7	—	—
Cladopelma sp.	17.8±49.8	0.8	—	—
Stictochironomus multannulatus	11.8±20.3	0.6	—	—
Microchironomus sp.	8.9±34.4	0.4	—	—
Nilodosis sp.	8.9±34.4	0.4	0.01±0.02	0.1
Diamesinae				
Protanypus sp.	5.9±22.9	0.3	0.02±0.09	0.3
Pupae of chironomidae	29.6±62.0	1.4	0.34±0.60	2.0
Unknown	26.6±52.5	1.3	—	—
Oligochaetae (*Tubifex tubifex*)	2809.0±2138.4	56.6	2.26±1.56	22.8
Others	26.6±32.7	0.5	—	—
Total	4961.0±2302.7		9.66±4.71	

station. *T. tubifex* and *C. nipponensis* abundance increased with water depth; their highest densities were in the deeper regions (St. 4 and 5; more than 20 m) and their lowest in the shallower regions (St. 1 and 2; less than 10 m).

The frequency distribution of wet body weight of IV-instar larvae and of *C. nipponensis* at each station in Lake Nojiri, as of March 2015 showed striking differences with depth (Fig. 3). *C. nipponensis* larval growth rate varied with water depths. In deeper regions there are many relatively small IV-instar larvae (peak of frequency was 4-6 mg per larva), whereas in shallower regions there are many large IV-instar larvae (peak frequency was at 10-12 mg per larva).

DISCUSSION

Many researchers have used zoobenthos as indicators of the trophic state and organic pollution of lakes (reviewed by Sæther, 1979; Lindegaard, 1995). Brinkhurst (1974) reported density and biomass of benthos increasing with lake eutrophication. We compared our results with previous quantitative data on chironomids and oligochaetes reported by Miyadi (1931) and Kitagawa (1973a) to clarify trends in the benthic community composition. Miyadi (1931) and Kitagawa (1973a) collected the benthic fauna using a standard Ekman grab (15 x 15 cm) and sieving the sediment through a wire netting with meshes of 0.5 mm. Miyadi (1931) collected samples at 30 stations in April 28, 1928 and 10 stations in November 29, 1928. Kitagawa (1973a) collected samples at 12 stations in April 6, 1972 and 18 stations in August 22, 1972. Thus, our sampling stations were selected at similar depths (Tab. 2). Different species composition and relative abundance of single taxon were detected in our study respect to the two previous ones. For example, in 2015 *Heterotrissocladius* sp. were found in the bottom and dominated the shallower regions of the lake where it was absent in 1931 and 1973a. Furthermore, the density of the total Chironomidae and *T. tubifex* were 4.3 and 12.7 times higher than in 1931 and 1973a, respectively. In particular, the density of *T. tubifex* has

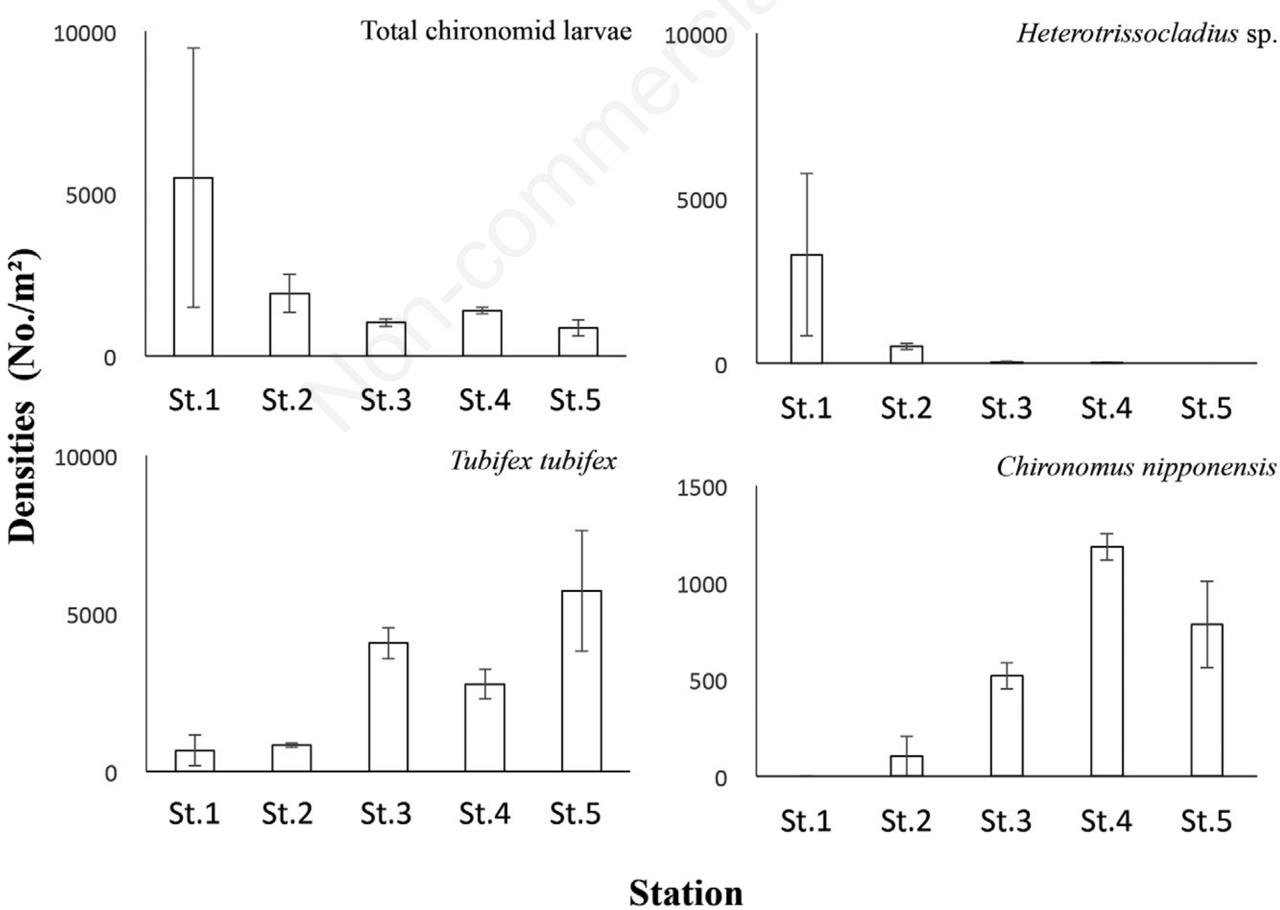

Fig. 2. Depth distribution of the densities of the main benthos in Lake Nojiri on March 10, 2015.

tended to increase in deeper regions and has become widely distributed in 2015. *Tanytarsus* spp. dominated in the chironomid community in the 1930s, whereas *C. nipponensis* has become dominant in the chironomid community in the last 40 years: density of *C. nipponensis* was *ca.* 14 times higher in 2015 than in 1931 and 4 times higher than in 1973a. We could not compare Miyadi's and Kitagawa's results with ours simply, because the mesh size of the net used is different. But, presumably there were extremely few young age chironomid larvae and immature oligochaetes, *i.e.*, small body size benthos, in March and April (water temperature was 3-5°C). Thus, it would be unlikely that many small size benthos (smaller than 0.5 mm) passed through the net at the time of investigation of Miyadi and Kitagawa. Consequently, it seems that there was not any great mistake in a comparison of the densities. Finally, the density of *P. akamusi*, a typical indicator species of hypertrophic or eutrophic lakes (Iwakuma *et al.*, 1988), was low but it was also detected in 2015. Miyadi (1931) and Kitagawa (1973a) also did not describe about this species in other investigation month.

According to Nagano Prefecture (2015), summer stratification occurred in Lake Nojiri from the middle of June to the end of October (TN 0.29 mg L^{-1}, TP 0.005 mg L^{-1}, Transparency 7.5 m in August 2015). From early

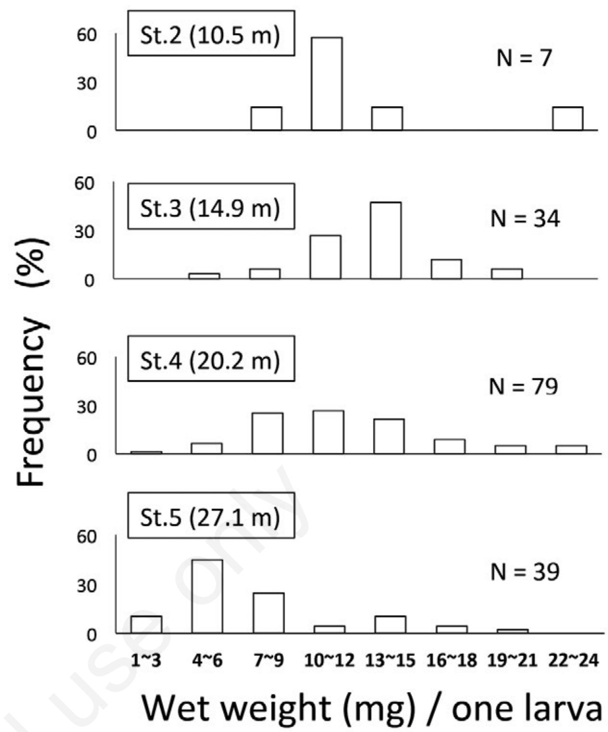

Fig. 3. Percentage frequency of IV-instar larval body wet weight of *Chironomus nipponensis* Tokunaga at each station in Lake Nojiri on March 10, 2015.

Tab. 2. Changes in densities of chironomid larvae and *Tubifex tubifex* in Lake Nojiri.

	April, 1928 (Miyadi, 1931)		April, 1972 (Kitagawa, 1973a)		March, 2015 (Present study)	
Sampling sites (No.)	Total 30	Select 7*	Total 12	Select 8*	Total 15	Select 12*
Mean depth (m)	23.6±12.2	19.0±7.0	15.3±6.5	14.8±5.3	15.8±7.6	18.2±6.5
Chironomidae	739.0±895.7	910.2±1197.4	300.0±312.0	219.4±294.0	2128.2±2330.4	1295.0±512.2
Tanypodinae	85.3±97.3	68.2±88.7		222.0±171.1	196.1±168.8	
Procladius sp.	—	—	37.5±91.7	16.9±33.5	—	—
Orthocladiinae						
Heterotrissocladius sp.	—	—	—	—	766.6±1615.2	136.9±225.2
Propsilocerus akamusi	—	—	3.8±13.0	5.6±15.9	11.8±20.3	14.8±21.9
Spamiotoma sp.	—	—	3.8±13.0	5.6±15.9	—	—
Chironominae						
Chironomus nipponensis	160.4±238.9	45.5±93.9	161.3±228.2	157.5±274.3	518.0±463.1	647.5±426.1
Micropsectra sp.	—	—	—	—	390.7±557.4	207.2±274.6
Stictochironomus multannulatus	—	—	—	—	79.9±166.3	44.4±103.7
Nilodosis sp.	—	—	—	—	32.6±74.0	7.4±17.3
Phaenopsectra sp.	—	—	75.0±219.1	16.9±33.5	—	—
Calopsectra sp.	—	—	18.8±35.7	16.9±33.5	—	—
Cryptochironomus sp.	10.6±57.0	34.1±102.4	—	—	—	—
Tanytarsus spp.	416.4±831.2	745.2±1010.5	—	—	—	—
Diamesinae						
Protanypus sp.	—	—	—	—	5.9±22.9	—
Other chironomid (include pupae)	66.6±97.1	17.1±51.2	—	—	77.0±127.2	25.9±51.7
Unknown chironomid larvae	—	—	—	—	23.7±50.0	14.8±51.3
Tubifex tubifex	297.0±255.6	159.3±158.7	131.3±109.3	140.6±113.9	2809.0±2138.4	3344.8±2052.4

**Among studies sampling stations were selected, because their depths were similar among Miyadi's study, Kitagawa's and ours.*

November, dissolved oxygen concentration near the bottom dropped below 1 mg L^{-1}, the lowest oxygen level observed from the 1980s. Tanaka (1992) reported that the anoxic-layer and anaerobic-layer were thickening, especially, in deeper regions. We found a difference in the *C. nipponensis* body size of the IV-instar larvae collected at different depths, *i.e*., there are many relatively small ones in deeper Station 5 (27.1 m). Rempel and Carter (1987) and Gresens (1997) reported water temperature effects on growth of chironomid larvae. While Jonasson (1965) reported that the growth of *Chironomus anthracinus* Zetterstedt stopped during the summer stagnation period in the profundal zone where the dissolved oxygen concentration drops below 1 mg L^{-1}. This was due to the decrease and stop of feeding at oxygen concentrations below 2-3 mg L^{-1} and 1 mg L^{-1}, respectively. Iwakuma *et al.* (1993) and Hirabayashi *et al*. (1996) suggested that *C. nipponensis* might react in the same way under hypoxia/anoxia. According to these findings, low dissolved oxygen concentration combined with low water temperature may have suppressed the growth of *C. nipponensis* during summer-fall. As a result, it seems that the small body size larvae dominated at the deepest station.

Human activity around the lake during 1930s to 2015 was drastically changed in the water condition and biota in this lake, and these large environmental changes may have affected chironomid and *T. tubifex* density and *C. nipponensis* growth rate especially in the deeper regions with low dissolved oxygen concentrations, low water temperature and high organic matter (ignition loss: 15.0% in St. 4 and 13.9% in St. 5) in the sediments. We previously investigated species composition, density, biomass and distribution pattern of benthic fauna in a wide range of mesotrophic/eutrophic lakes: Lake Shoji (shallow eutrophic; Hirabayashi *et al*., 2012), Lake Kawaguchi (shallow mesotrophic-eutrophic; Hirabayashi *et al*., 2008), Lake Yamanaka (shallow mesotrophic; Hirabayashi *et al*., 2004), Lake Kizaki (deep mesotrophic-eutrophic; Hirabayashi *et al*., 1994) and Lake Suwa (shallow hypertrophic; Hirabayashi *et al*., 2003). In comparison with data of the 1930s (Miyadi, 1931, 1932) and 1970s (Kitagawa, 1973a, 1973b), the present lake bottom environment has greatly changed in these lakes, *i.e.*, an anoxic layer develops during the summer in the deeper regions, as a result of which oligochaetes became dominant taxa, especially *T. tubifex*. In addition, chironomid larvae were not inhabiting the deeper regions and might be restricted to shallower regions. Consequently, we point out a common trend in all the other lakes mentioned above: the densities and biomass of oligochaetes and chironomid larvae have increased in these lakes, especially *P. akamusi* and *T. tubifex*. Our study highlighted the same trend in Lake Nojiri.

In our study, biomass of chironomid larvae seemed to be a useful criterion to define the trophic state of Lake Nojiri, according to Yasuno *et al*. (1983). In Japan, Yasuno *et al*. (1983) reported that the biomass of chironomid larvae exhibited a positive correlation with Carlson's TSI. Moreover, they proposed an equation of relationship with biomass of chironomid larvae and TSI in Japanese lakes, *i.e.*, Log Y=0.04 X + 1.85, Y: Biomass of chironomid larvae (wet weight mg m^{-2}), X: Carlson TSI. We estimated Carlson's TSI from chironomid biomass to be 50.8, categorized as a "Mesotrophic-eutrophic lake." Aizaki *et al.* (1981) and Otsuki *et al.* (1981) reported the modified Carlson's TSI to be useful as one of the water quality criteria for the trophic state of lakes. In recent years, the densities of *C. nipponensis* and *T. tubifex* have shown a tendency to increase. *T. tubifex* was widely distributed especially in deeper regions of Lake Nojiri, indicating that it is in the process of eutrophication. Although classified as mesotrophic in previous studies (Aizaki *et al.*, 1981), our findings suggest that the status of Lake Nojiri should be reclassified.

CONCLUSIONS

Large environmental changes during the 1930s to 2015 must have affected chironomid and oligochaete densities and growth rate of *C. nipponensis*, especially in the deeper regions with low dissolved oxygen concentrations, low water temperature and high organic matter in the sediments of Lake Nojiri. This is strong evidence that the eutrophication of this lake is proceeding. Densities, biomass and the distribution pattern of chironomid larvae and oligochaetes seemed to be useful criteria to define the trophic state.

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