南日本に位置する鰻池における動物プランクトンの種組成と垂直分布

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Species Composition and Vertical Distribution of Limnetic Zooplankton in Lake Unagi, Southern Japan

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Abstract

The species composition and vertical distribution of limnetic zooplankton in Lake Unagi, located in Southern Kyushu, Japan, was investigated from July 1995 to September 1996.

A total of twenty-five species were identified, comprising Rotifera (13 species), Cladocera (6 species) and Copepoda (6 species). Cladocera dominated the zooplankton community followed by Copepoda and Rotifera; they represented 52.2%, 35.2% and 12.6%, respectively.

A remarkable increase in the number of copepod species (6 species) was noted, although they were not previously reported in Lake Unagi.

The vertical distribution study revealed that majority of the zooplankton population remained at a 0-15 m layer. The cladoceran *Diaphanosoma brachyurum* and copepodid and nauplii stages migrated upward at night, whereas *Bosmina longirostris, Ceriodaphnia dubia, Thermocyclops hyalinus and Tropocyclops prasinus* did not show such diel vertical migration.

Lake Unagi (Unagi-ike) is a caldera lake, situated at the southwestern end of Kyushu Island. Hydrographic and limnological features of the lake are given in Table 1. The lake water is supplied for drinking and agricultural purposes in the vicinity. Recently, anxiety about eutrophication has arisen with frequent blooms of the dinoflagellates *Peridinium* spp., although little information has been presented on the biota of the lake (personal communication). Early limnological studies on the lake were done in 1930's by Miyadi[1)] and Yoshimura[2)]. Only Mizuno[3)], and Saisho and Wada[4)] have mentioned the plankton composition of the lake.

In the present study intensive field surveys were carried out to clarify the changes in biota, especially zooplankton community of Lake Unagi.

Table 1 Hydrographic and limnological features of Lake Unagi

Location	31° 13'N, 130° 36'E
Altitude	126 m
Surface area	1.15 km^2
Length of shoreline	4.50 km
Water volume	0.04 km^3
Maximum depth	56.5 m
Mean depth	34.8 m
Water temperature at 0.5 m	12.1-29.4 ℃*
Bottom water temperature	10.1-10.8 ℃*
Transparency	2.8-7.8 m*
pH at 0.5 m	7.7-9.3*
pH at bottom	7.0-7.4*
Dissolved oxygen at 0.5 m	7.7-10.0 mg/1*
Dissolved oxygen at bottom	1.3-8.7 mg/1*

* Data are averages of two years (May 1994 to March 1996) representing the minimum and maximum values (Ann. Rep. Kagoshima Pre. Govt.)[9, 10)]

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Materials and Methods

Zooplankton samples were collected bimonthly from July 1995 to September 1996 at the deepest point of the lake. The water column was divided into three strata on the basis of thermal stratification; 0-15 m (epilimnion and thermocline), 15-30 m (hypolimnion) and 30-45 m (deep layer). Samples were taken by using a Marukawa closing plankton net (diameter 30 cm, mesh size 95 mm) from the three layers, assuming filtering efficiency of the net 100%. Samples for diel vertical migration were taken on September 20-21, 1996 from five layers 0-5 m, 5-10 m, 10-15 m, 15-30 m and 30-45 m. All the samples were fixed with 5% formaline and were concentrated to a volume of 30 ml. Identification of the zooplankton was made from illustrated guides[5-7]. The average number of animals, counted in three 1-ml aliquots with a Sedgwick-Rafter chamber, was expressed as animals per liter. Temperature, dissolved oxygen and pH were measured using a Shimadzu WP-8 electronic bathythermograph in August and September 1996.

Table 2 List of Zooplankton species occurring in Lake Unagi

Rotifera

Asplanchna priodonta GOSSE, 1850
Conochiloides natans (SELIGO, 1900)
Conochilus unicornis ROUSSELET, 1892
Filina sp.
Keratella cochlearis var. *tecta* (GOOSE, 1886)
Keratella valga var. *tropica* (APSTEIN, 1907)
Ploesoma hudsoni (IMHOF, 1891)
Ploesoma truncatum (LEVANDER, 1894)
Polyarthra euryptera (WEIZEJSKI, 1893)
Polyarthra trigla (EHRENBERG, 1834)
Synchaeta sp.
Trichocerca capucina (WEIZEJSKI and ZACHARIAS, 1893)
Trichocerca elongata (GOOSE, 1886)

Cladocera

Bosmina longirostris (O.F.MÜLER, 1785)
Bosminopsis deitersi RICHARD, 1895
Ceriodaphnia dubia RICHARD, 1894
Daphnia longispina O.F. MÜLER, 1785
Diaphanosoma brachyurum LIEVEN, 1848
Diaphanosoma paucispinosum BREHM, 1944

Copepoda

Cyclops vicinus ULJANIN, 1875.
Eodiaptomus japonicus KIEFER, 1913
Limnocaea genuina KOKUBO, 1932
Thermocyclops hyalinus (REHBERG, 1880)
Thermocyclops oithonoides (SARS, 1863)
Tropocyclops prasinus (FISCHER, 1860)

Results

Species composition and seasonal occurrence

A total of 25 species were identified comprising 13 species of Rotifera, 6 species of Cladocera and 6 species of Copepoda (Table 2). The zooplankton community was dominated by Cladocera (52.2%), Copepoda (35.2%) and Rotifera (12.6%).

Among rotifers *Polyarthra trigla* and *P. euryptera* were abundant in March and May, respectively. Both of these species were found aggregated at 0-15 m. *Ploesoma truncatum* appeared in November 1995 to

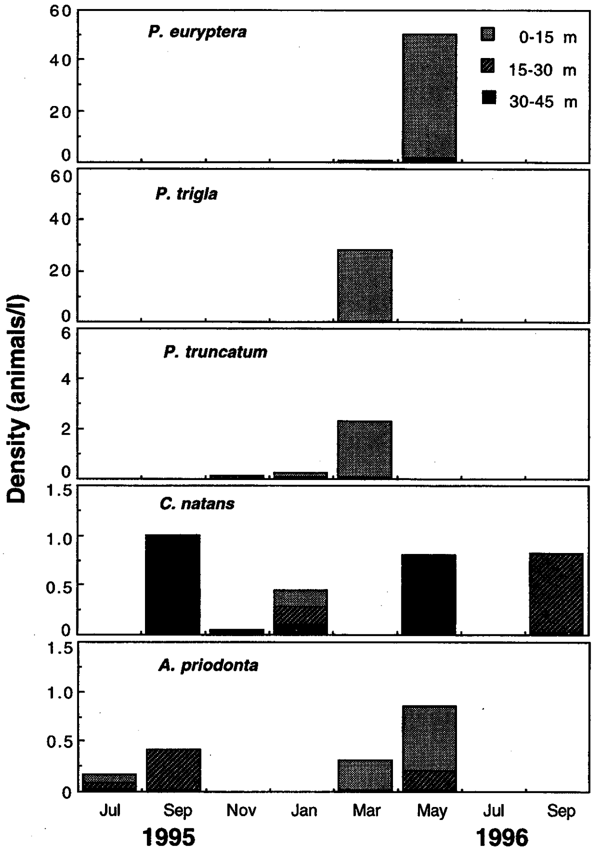

Fig. 1 Occurrence and vertical distribution of rotifer species in Lake Unagi.

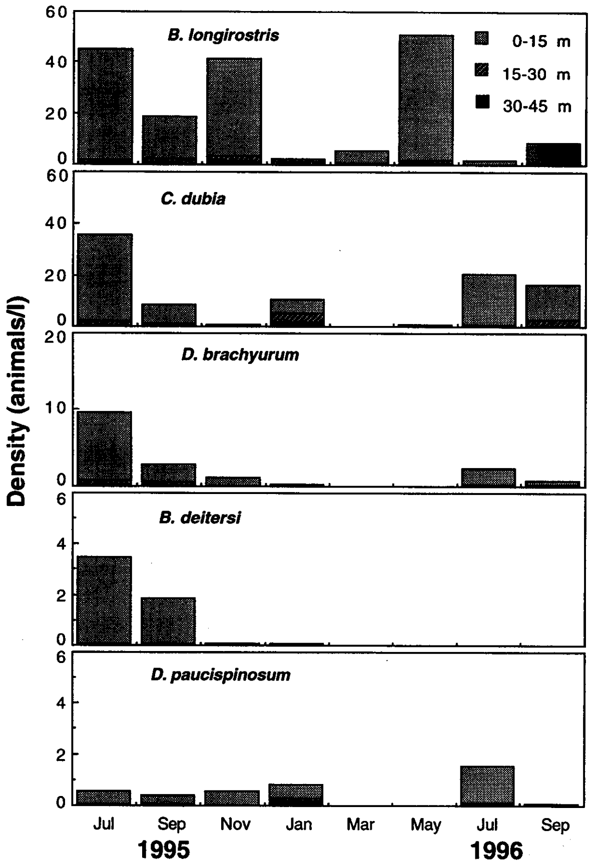

Fig. 2 Occurrence and vertical distribution of cladoceran species in Lake Unagi.

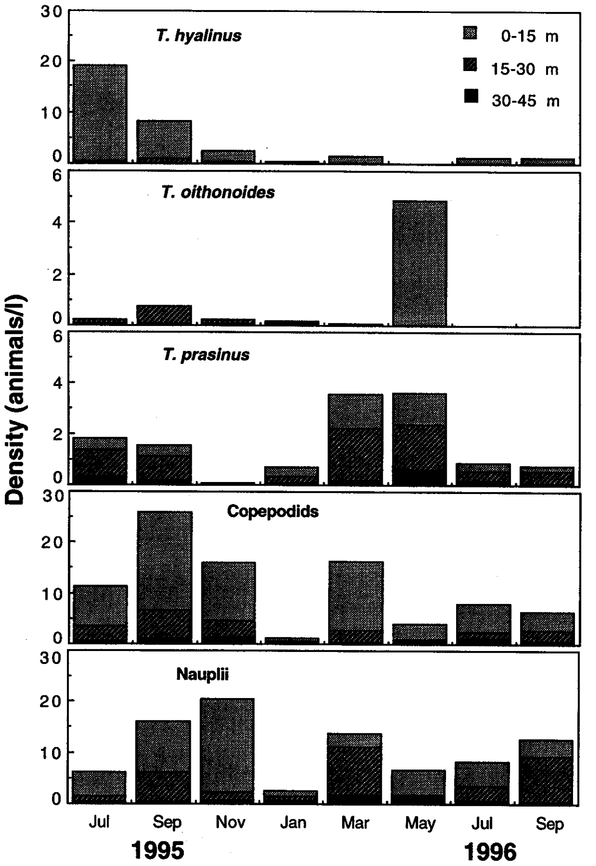

Fig. 3 Occurrence and vertical distribution of copepod species in Lake Unagi.

March 1996 with the highest abundance in March 1996 at 0-15 m (Fig. 1). The other rotifers *Conochiloides natans* and *Asplanchna priodonta* appeared frequently but their densities were lower than 1 animal per liter. The appearance of the former species was restricted to 15-30 m or 30-45 m, except in January 1996, when it was well distributed in the whole water column. The latter species usually appeared at 0-30 m. The remaining rotifer species appeared rarely.

The Cladocerans *Bosmina longirostris* and *Ceriodaphnia dubia* were dominant in the lake. However, the density of *B. longirostris* was higher than that of C. dubia (Fig. 2). *B. longirostris* was abundant in July to November 1995, while the highest abundance occurred in May 1996. Majority of the *B. longirostris* population usually remained at 0-15 m, but a small portion also appeared at 15-30 m. The highest abundance of *C. dubia* occurred in July 1995 at 0-15 m. Majority of the *C. dubia* population also remained at 0-15 m, but in January 1996 it was well distributed in the whole water column. *Diaphanosoma brachyurum* and *Bosminopsis deitersi* exhibited their maximum densities in July 1995 at 0-15 m. Their population decreased gradually and disappeared after January 1996. *D. brachyurum* reappeared in July to September 1996, but *B. deitersi* disappeared afterwards. Another species *D. pucispinosum* was frequently observed with a comparatively higher population in July 1996 at 0-15 m.

The copepods Thermocyclops *hyalinus* and *Tropocyclops prasinus* appeared commonly. The density of *T. hyalinus* was higher than that of *T. prasinus*. These two species occupied different strata in the water column; *T. hyalinus* was restricted to 0-15 m, but majority of the *T. prasinus* population to 15-30 m (Fig. 3). *T. hyalinus* was abundant in July to September 1995, while the peak abundance appeared in July 1995. The population density of *T. prasinus* never exceeded 4 animals per liter, but with a

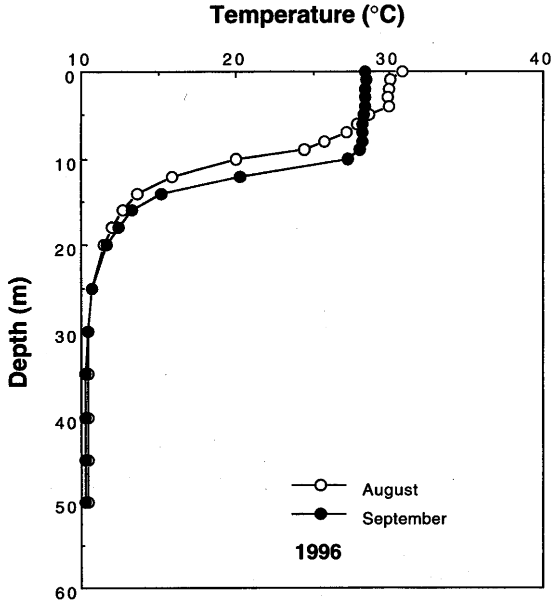

Fig. 4 Vertical profile of water temperature showing epilimnion, metalimnion (thermocline) and hypolimnion in Lake Unagi.

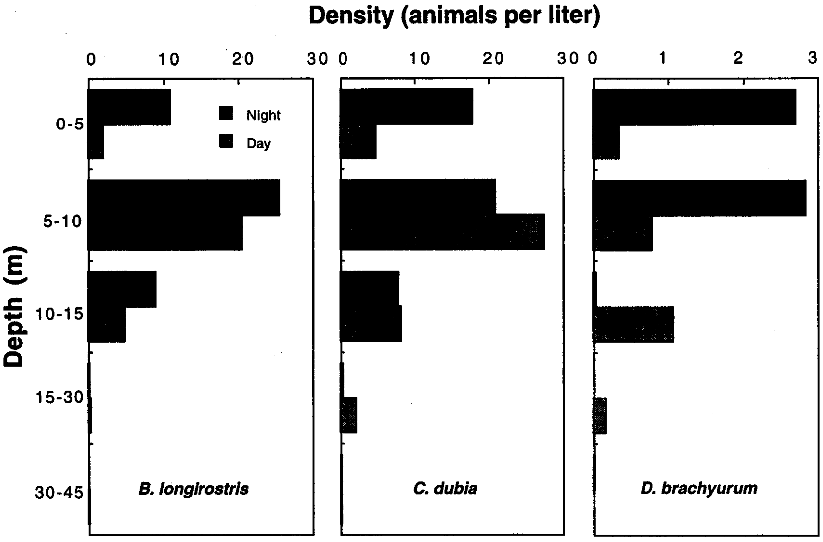

Fig. 5 Diel vertical migration (DVM) of cladoceran species in Lake Unagi.

comparatively higher population in March to May 1996. *Thermocyclops oithonoides* was very scarce in July 1995- March 1996, but in May 1996 the population reached to the maximum at 0-15 m and it replaced *T. hyalinus*. Copepodids and nauplii showed the highest abundances in September and November 1995, respectively. They were well distributed at 0-15 m and 15-30 m.

Diel vertical migration (DVM)

In September 1996, the profile of vertical water temperature showed epilimnion at 0-10 m, thermocline at 10-15 m, and hypolimnion below 15 m (Fig. 4). Dissolved oxygen was 10.6-12.1 mg per liter at 0-2 m, and decreased with increased water depth. The pH was 8.2-8.4 in epilimnion, and decreased to 5.2-5.8 in hypolimnion.

Since rotifers were very scarce during the DVM study, they were neglected.

The maximum population of *B. longirostris* was found at 5-10 m in day- and nighttime, although more animals aggregated at 0-5 m layer at night than that in daytime. Majority of the population preferred to stay above thermocline and did not show any diel migration in the lake (Fig. 5). The population of *C. dubia* also preferred to stay in epilimnion. However, a slight increase in population was noted at 0-5 m at night. *D. brachyurum* exhibited a clear DVM; it migrated upwards at night, when all the population clustered at 0-5 and 5-10 m.

A copepod species *T. hyalinus* was restricted in epilimnion to thermocline. The maximum population at night occurred at 5-10 m, but in daytime it was equally distributed at 5-10 and 10-15 m (Fig. 6). *T. prasinus* was confined in thermocline to hypolimnion with the maximum population at 10-15 m. Copepodids were well distributed in the whole water column, although a slight upward migration at night was observed. Nauplii showed the highest abundance at 0-5 m at night. However, the maximum population in daytime appeared at 15-30 m.

Discussion

There was a considerable change in zooplankton composition, as compared to the studies of Saisho and Wada[4]. Copepod species increased remarkably in number (6 species) in which *T. hyalinus* and *T.*

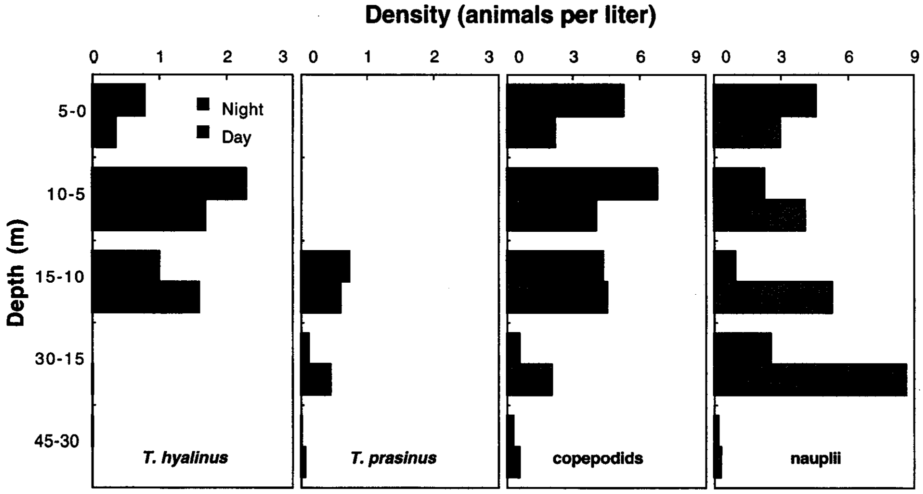

Fig. 6 Diel vertical migration (DVM) of copepod species in Lake Unagi.

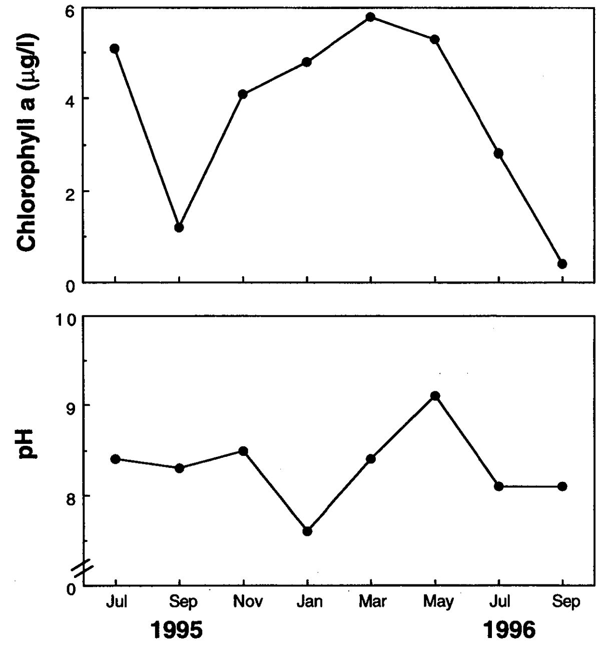

Fig. 7 Chlorophyll-a and pH distribution at 0.5 m in Lake Unagi.

prasinus were commonly present, although copepod was not previously recorded from the lake. They found that rotifers were most abundant (20 species). In the present study the less number of rotifers (13 species) was observed. This was probably due to the sampling frequency but not to the mesh size of the net, because previous workers also used a net of the same mesh size as we did.

Zooplankton were abundant in July 1995 and March and May 1996. Chlorophyll-a was higher in July 1995 and January to May 1996, and was highest in March 1996 (Fig. 7). The higher pH value in May 1996 presumably reflected algal blooming. Zooplankton abundance in Lake Unagi marked the food availability to be an important controlling factor.

All the cladoceran species showed different patterns of occurrence; each species exhibited its peak abundance, except July 1995, when all the species co-occurred. According to Pennak[8] most of the cladoceran species seemed to have generalized grazing habits and compete for the same common pool of material. The higher quantity of chlorophyll-a in Lake Unagi[9,10] in July 1995 suggested the availability of adequate food in the lake. Another factor might be fish predation that could weaken competition sufficiently to allow some cladoceran species to attain their high densities simultaneously[11]. Unfortunately no records were available on fish predation and its effect on the zooplankton of Lake Unagi. Co-occurrence of two or more limnetic cladoceran species of the same genus was uncommon[8]. The simultaneous occurrence of *D. brachyurum* and *D. paucispinosum* in Lake Unagi seemed to be an important characteristic of the lake. The cladocerans did not succeed in oligotrophic lakes[12], whereas in Japanese lakes the copepods dominated in oligotrophic lakes, but cladocerans or rotifers in eutrophic ones[13]. The dominance of Cladocera in Lake Unagi reflected the trophic status to be eutrophic. However, higher copepod but lower rotifer population suggested that eutrophication in Lake Unagi might be in early stage.

Cladocerans were restricted in epilimnion to thermocline, while *T. prasinus*, an omnivorous[14] predator[15] copepod was confined to hypolimnion. It perhaps reflected the result of predation by *T.*

prasinus, because this species was considered as an effective predator of cladocerans[15,16]. The restriction of *T. hyalinus*, a herbivorous copepod in epilimnion was probably due to phytoplankton abundance in the upper water layer. In Lake Ikeda occurrence of herbivorous and predator copepods in different strata was also seen[17]. *T. prasinus* preferred deeper and cooler lakes[15,18]. However, the vertical distribution ranged from surface[19] to deeper depths[15]. In Lake Unagi *T. prasinus* seemed to be temperature-dependent, because the maximum population was always found below thermocline. *T. prasinus* did not show DVM in Placid Lake[15], as seen in Lake Unagi, but exhibited a marked DVM in Belews Lake[20]. Thus each population of *T. prasinus* has its own behavior of DVM. The behavioral character of DVM appears not to be species-specific. The mechanisms for this remains to be studied.

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