Bull. Foc. Fish., Mie Univ.
No. 9 : 1—10
October 1, 1982

Diel Vertical Migration of Zooplankters and Fish Larvae in Lake Biwa

Makoto NAGOSHI

Faculty of Fisheries, Mie University

Studies using midwater trawl and plankton nets and an echo sounder in the northern part of Lake Biwa showed that zooplankters such as *Eodiaptomus iaponicus*, *Mesocyclops leuckarti*, *Diaphanosoma brachyurum* aud *Daphnia longispina*, gammarid of *Anisogammarus annandalei*, shrimp of *Palaemon paucidens*, and fish larvae such as *Rhinogobius brunneus*, *Chaenogobius isaza* and *Plecoglossus altivelis*, undergo a diel vertical migration in various seasons.

D. brachyurum ahd *D. longispina* concentrate near the surface at night and in the 5-20m layer during the daytime. But, no clear diel vertical migration was observed in *E. japonicus* and *M. lauckarti*. The gammarid and shrimp are distributed in deep water of more than 30m depth in the daytime, but they come up to the surface layer at night. Their adults stay near the bottom during the daytime and migrate to the midwater at night. The fry and juveniles of *R. brunneus* and *C. isaza* also stayed on the bottom during the daytime and migrate to the midwater at night. The fry of *P. altivelis* inhabiting near the bottom during the daytime show an upward migration to the midwater at night. The boundary for those vertical migrants exists in 10-20m layer, thermocline in summer, in Lake Biwa.

Keywords. migration, ecology

Various authors have documented fragmentary information on diel vertical migration of organisms in Lake Biwa, e. g. zooplankters (KIKUCHI 1930, YAMAMOTO *et al.* 1966), *Chaenogobiusisaza* (KOBAYASHI and YAMANAKA 1950, NAGOSHI 1966, MIURA 1966a, 1966b, TAKAHASHI 1981), *Plecoglossus altivelis* (AZUMA 1964). In addition the diel actiites of *Palaemon paucidens* and *Rhinogobius brunneus* in the shallow water along the beach have been described and related to vertical migration by MORI (1939).

This paper presents the results of studies of the diel vertical migrations and distributions of the organisms inhabiting the offshore waters of Lake Biwa, carried out during the years 1974 to 1975 as part of a study of the larval ecology of *P. altivelis*.

Materials and methods

Six cruises, in November 1974, February, April, June, August, October 1975, were designed to provide diel series of samples from the station near Tsuzuraozaki-point in the northern part of Lake Biwa.

The collections of the organisms in each cruise were made before sunset (BSS), after sunset (ASS), midnight (MN), before sunrise (BSR), after sunrise (ASR), and noon (N) during 24hrs.

The collections of zooplankter were carried out by vertical tow with Kitahara's closing net with a mesh opening of 0.33mm at 4 layers of 0-5, 5-10, 10-20, and 20-30m depths.

Two kinds of midwater trawl net with 130cm in diameter of mouth with 0.08 and 0.86mm in mesh opening, were used for the collections of *Anisogammarus annandalei*, *P. paucidens*, *R. brunneus*, *C. isaza* and *P. altivelis*. The volume of water, 400m^3, filtered was determined by RGS flow meter set at the center of the mouth of the nets. These nets were horizontally towed for 5 minutes at a speed of 3.6 km hr^{-1} at each depth.

A JRC echo sounder was used to examine the vertical distribution aad vertical migration of the organisms and to ascertain the position of the towing net under water.

Results

Diel vertical distributions of each zooplankter, *Eodiaptomus japonicus*, *Mesocyclops leuckarti*, *Diaphanosoma brachyurum*, *Daphnia longispina*, are presented in Fig. 1.

In the case of *E. japonicus*(Fig. 1A), though they are abundant at surface layer at night in April and seem to migrate from a deeper layer to the surface layer at night, it seems that the diel vertical migration is not so distinct in the other seasons, contray to the previous papers by KIKUCHI (1930) and YAMAMOTO *et al.* (1966), in which the plankters move at night up to the surface layer which they have vacated during the daytime and as a result the animal concentrates in the surface layer at night.

In *D. longispispina* (Fig. 1B) inhabiting the layer of less than 20m depth even during the daytime in June and October no clear migration can be observed. In August, most plankters seem to go down to the deep layer of more than 20m depth and seem to come up to the surface layer at night.

The density of *D. brachyurum*(Fig. 1C)at the 0-5m layer slightly increases at night and decreases in the daytime in August and October. Therefore, the plankter comes up to the surface layer at night.

M. leuckarti (Fig. 1D) concetrate in the layer deeper than 20m throughout the day, but some of them seem to migrate toward the surface layer at night.

A. annandalei exhibits clear diel vertical migration (Fig. 2). Most larvae stay

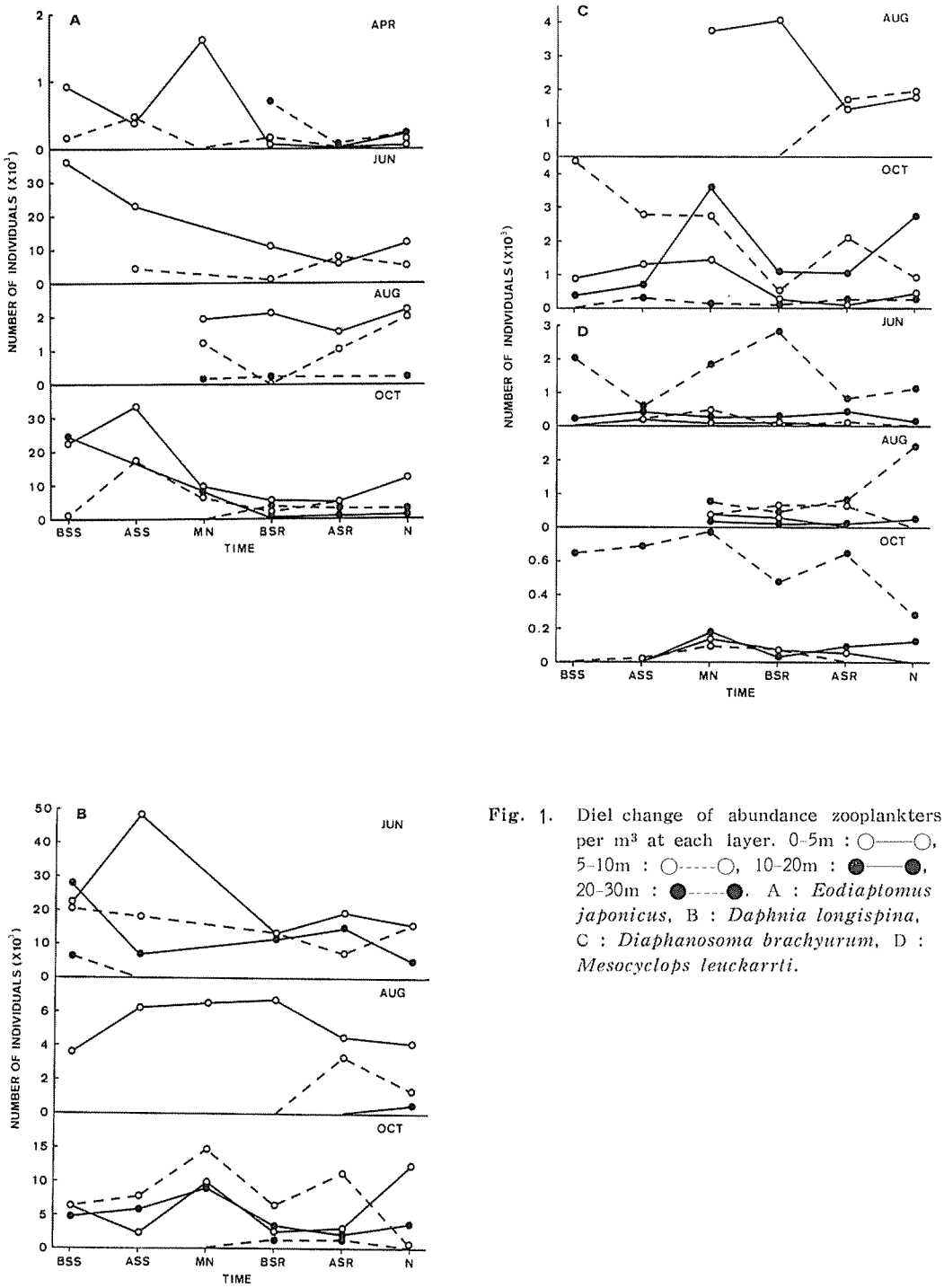


Fig. 1. Diel change of abundance zooplankters per m^3 at each layer. 0-5m : ○——○, 5-10m : ○-----○, 10-20m : ●——●, 20-30m : ●-----●. A : *Eodiaptomus japonicus*, B : *Daphnia longispina*, C : *Diaphanosoma brachyurum*, D : *Mesocyclops leuckarrti*.

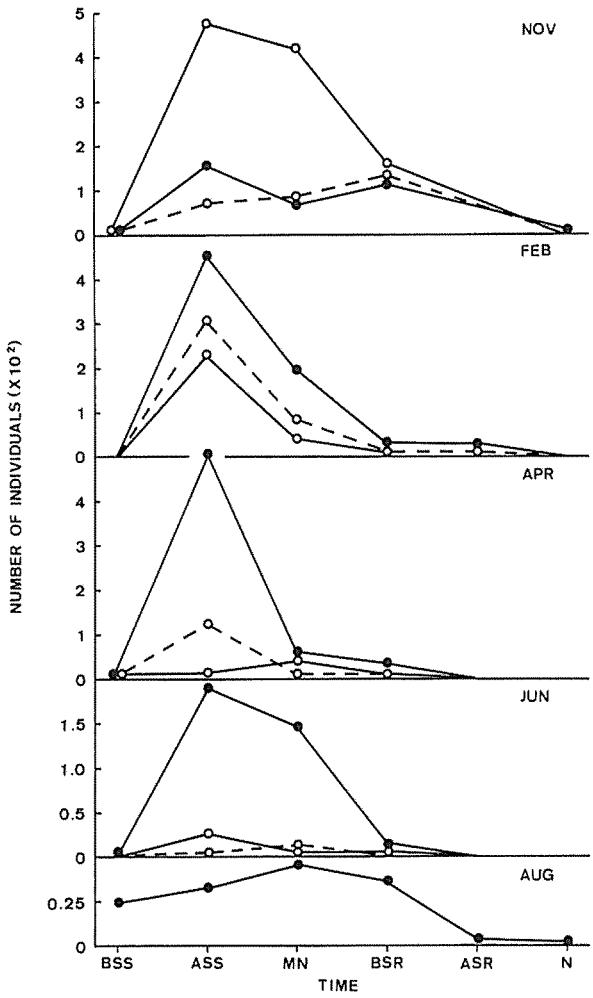


Fig. 2. Diel change in abundance of *Anisogammarus annandalei* per 400m³ at each depth. Surface : ○——○, 10m : ○----○, 30m : ●——●.

below 30m depth during the daytime and after sunset they come up to the upper layer less than 30m depth. In November, just after the spawning season (NARITA 1976), many gammarids come up to the surface layer at night. From February to August, the peak density of their distribution occurs at the 30m depth at night, but no individuals come to the upper layer less than 30m in August. It is noticeable that the densities are highest in early night and then gradually decrease until sunrise in surface layer and 30m depth. The catch by fishing trawl, Isazabiki-ami, shows clearly that the adults stay on the bottom during the daytime (NAGOSHI 1966).

Diel vertical migration of *P. paucidens* is presented in Fig. 3. As the spawning season is the period from June to August(HARADA 1966), the larvae are collected abundantly during this period. In all season the larvae are distributed between surface and

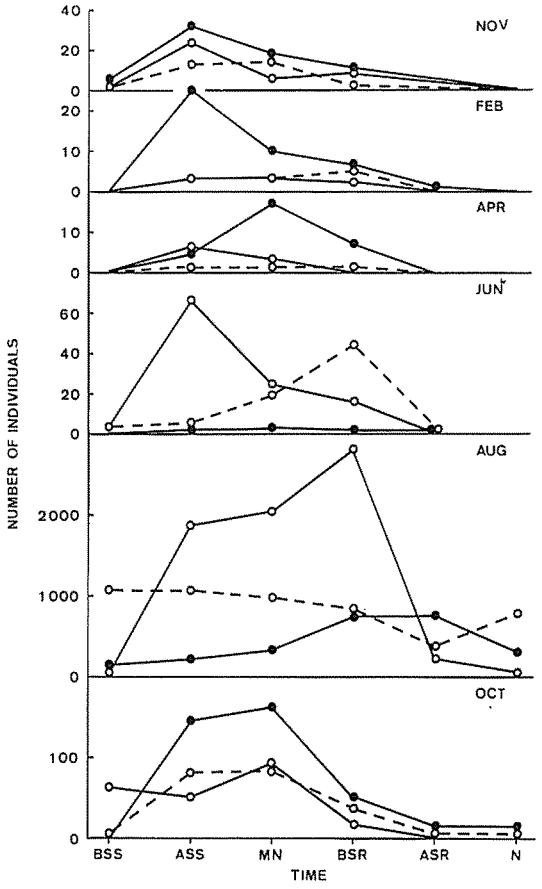


Fig. 3. Diel change in abundance of *Palaemon paucidens* per 400m³ at each depth. Surface : ○——○, 10m : ○----○, 30m : ●——●.

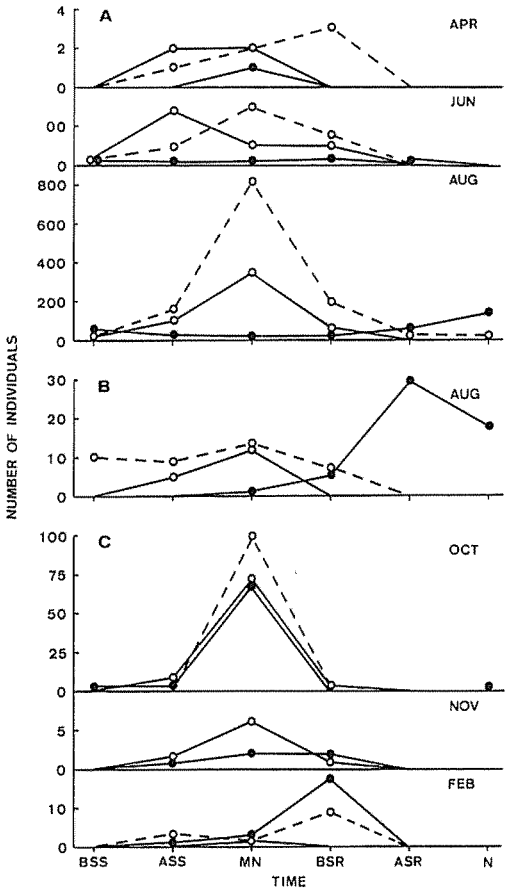


Fig. 4. Diel change in abundance of *Rhinogobius brunneus* (A), *Chaenogobius isaza* (B), and *Plecogossus altivelis* (C) 400m³ at each depth. Surface : ○——○, 10m : ○----○, 30m : ●——●.

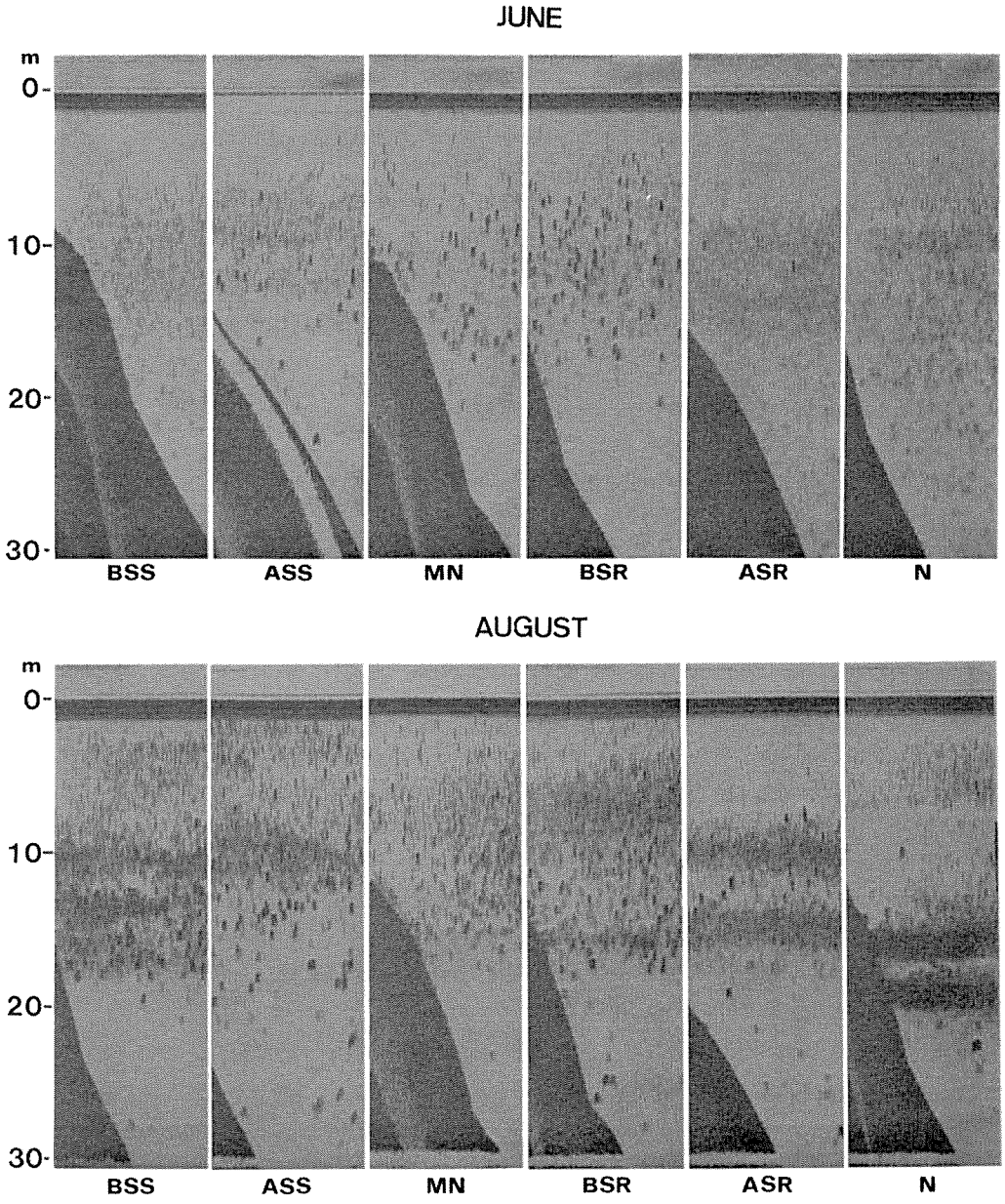
30m layer throughout the day. From June to August, many larvae rise by night toward the surface, but in other seasons the peak densities are shown in 10 to 30m layer throughout the day. As the shrimp grown to adult size stays on the bottom, they can be caught by a bottom trawl net (Isazabiki-ami) during the daytime. The adults come up to the middle layer at sunset and go gradually back to the bottom after midnight (HARADA 1966). Therefore, neither they could not be caught in the present investigation during the daytime.

Diel vertical distribution of fish larvae, *R. brunneus*. *C. isaza*, and *P, altivelis* are illustrated in Fig. 4.

Although the larvae of *R, brunneus*, a body length of 2.4-6.9 mm, are distributed in abundance in 0 and 10m depths during the hour of darkness between sunset and sunrise, they do hardly appear in the upper layer of less than 30m depth in the day-

time in April. In June, the larvae, a body length of 4.1-13.5 mm, concentrate in the upper layer of the thermocline (10m depth), butdisappear from the upper layer during the daytime. The August larvae stay at the deep layer during the daytime and come up around the thermocline at night.

The fry of age 0 group of *C. isaza*, a body length of 16.3-34.8 mm, migrate to the



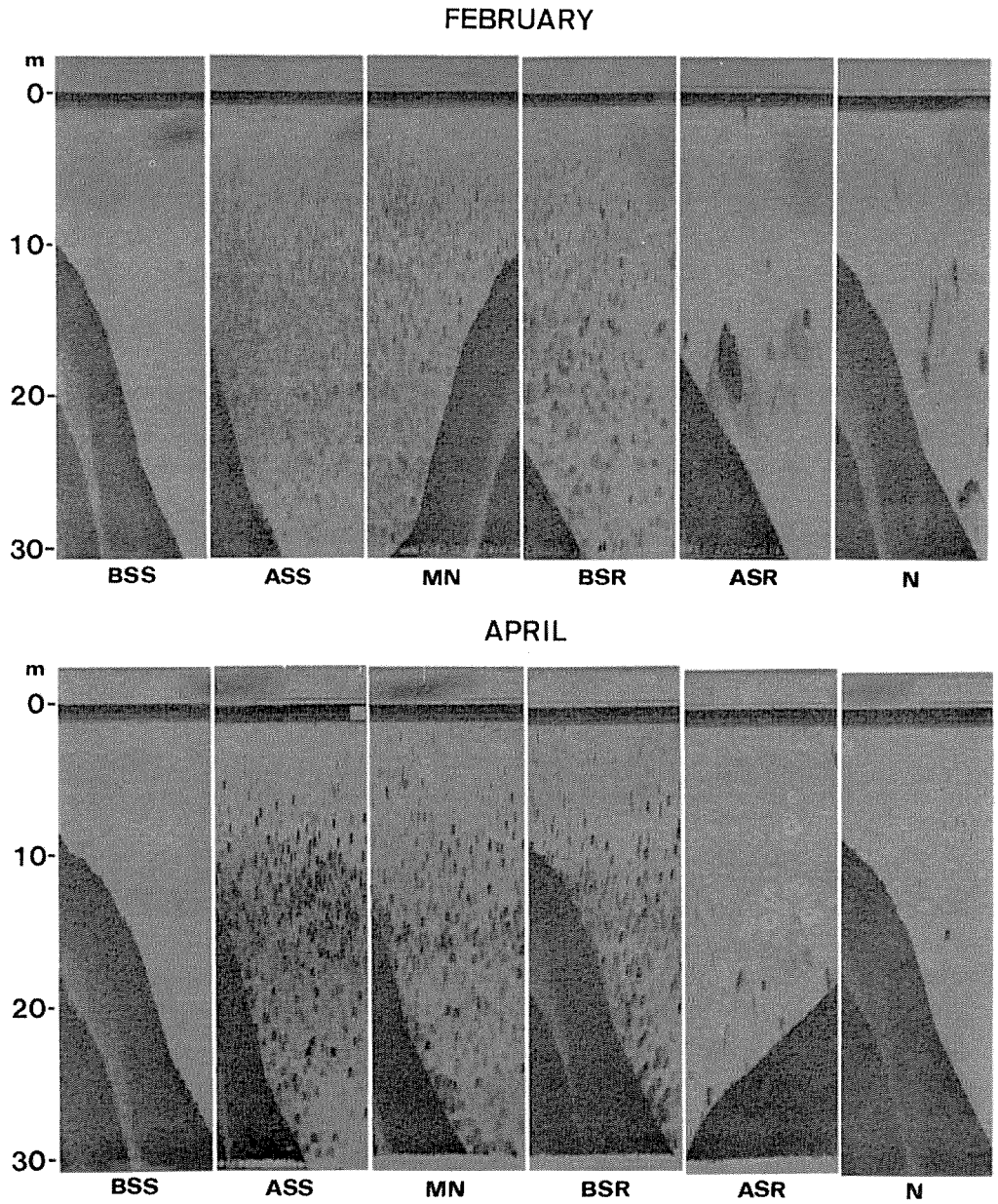


Fig. 5. Diel records of echo sounder between 0-30m depth in each month. BSS : before sunset, ASS : after sunset, MN : midnight, BSR : before sunrise, ASR : after sunrise, N : noon.

0-10m layer at night and some stay around the thermocline during the daytime. Trawling of the fish by fishermen, therefore, is conducted by a bottom trawl net, Isaza-biki-ami, only during the daytime. The adults of age 1 group, a body length of 41.6-58.2mm, were collected at the 10m depth at night(MN), at the 30m depth before sunrise (BSR) and at noon(N). The vertical migration of the fish is found also in the other seasons, since the fish are collected in the midwater layer only at night.

The fry of *P. altivelis*, a body length of 4.8-43.5 mm, are obtained from the layer between surface and 30m depth only at night during October to February but they disappear from the layer during the daytime.

The echo sounder was used to examine the distribution and vertical migration of zooplankters and fish as a whole on each cruise. Typical examples of echo record are shown in Fig. 5a-b.

There is a clear thermocline in June and August. In June, clear small images are densely distributd around the thermocline (15m depth around) even in the daytime. The catch of vertical hauls of the net proved that these images were the zooplankters. The large images of gammarid, shrimp and fish larvae are recorded around the thermocline at night, but the images are not found around this layer during the daytime. In August, though the large images concentrate under the thermocline (20m depth around) during the daytime, they are scattered towards the surface at night. These images were proved to correspond to the catches of gammarid, shrimp, snd the larvae of *C. isaza* and *R. brunneus* by midwater trawling. The upwarp and downward movements of the organisms were also observed in the evening and at morning twilight by echo sounder.

In general, these results of echo sounder agree well with the above mentioned results of the diel vertical migration of zooplankters, shrimp and fishes investigated from the sample of plankton and trawl nets.

Discussion

The diel vertical migrations of zooplankters have been presented dy many investigators. About the present four species KIKUCHI (1930) and YAMAMOTO *et al.* (1966) reported diel vertical migration in the upper layer of less than 20m depth in Lake Biwa. In the present investigation, it was recognized in *D. brachyurum* and *D. longispina*, but not in *E. japonicus* and *M. leuckarti* for rough samplings.

On the contrary, rather clear diel vertical migrations are recognized by the present investigation in larger species in size, such as a gammarid, a shrimp and fishes. YAMAMOTO *et al.* (1966) provides the data suggesting the existence of diel vertical migration of *A. annandalei* in Lake Biwa. The gammarid comes upward in the evening and goes down gradually to the morning twilight.

There is no report on the diel vertical migrations of *P. paucidens* and *R. brunneus*, but it seems to be clear from the results of the present study that they migrate

from a deeper layer towards the surface layer at night. MORI (1939) reports that these shrimp and fish show high feeding activity at night and HARADA (1966) and MIURA *et al.* (1966) state that both shrimp and fish feed on zooplankters offshore in Lake Biwa, so that the diel vertical migration towards the upper layer containing abundant zooplankters at night is advantageous for the migrants.

According to KOBAYASHI and YAMANAKA (1950) and NAGOSHI (1966), both juvenile and adult of *C. isaza* display diel vertical migration in Lake Biwa : they stay on the bottom deeper than 30m depth during the daytime and come up near the surface at night. However, based on the present study, most fish come up to the 10-30m layer from the layer of more than 30m in the evening.

Although the larvae of *P. altivelis*, a body length of less than 40mm, inhabit the layer near the bottom in the daytime, they come up to the upper layer at night in Lake Biwa (AZUMA 1964). But, it is considered that most larvae concentrate at the 10-20m layer at night from this study.

It is considered that as the primary production of the upper layer of less than 10m depth, thermocline, is considerably high in Lake Biwa (NAKANISHI 1975) and abundant zooplankters are distributed in the layer of less than 20m depth, *A. annandalei*, *P. paucidens* and the larvae of *R. brunneus*, *R. isaza* and *P. altivelis* come up to this layer to feed on the plankters.

The zooplankters show a vertical migration in the layer of less than 20m depth, while gammarid, shrimp and fish larvae show the migration in the layer deeper than 10m depth. Therefore, the boundary for those vertical migrants exists in the 10-20m layer in relation to the avoidance of predators and food availability.

Summary

1. To discover the diel vertical migrations of zooplankter, gammarid, shrimp, and fish larva, the vertical distributions of *Eodiaptomus japonicus*, *Mesocyclops leuckarti*, *Diaphanosoma brachyurum*, *Daphnia longispina*, *Anisogammarus annandalei*, *Palaemon paucidens*, and the larvae of *Rhinogobius brunneus*, *Chaenogobius isaza*, and *Plecoglossus altivelis* were analyzed on the basis of the catches made by plankton and midwater trawl nets and of records of an echo sounder in Lake Biwa from 1974 to 1975.
2. *D. brachyurum* and *D. longispina* showed a diel vertical migration in the range between surface and 20m depth, but the migration was not clearly recognized in *E. japonicus* and *M. leuckarti*.
3. *A. annandalei* and *P. paueidens* showed a diel vertical migration between the surface and the bottom or a depth of more than 30m throughout the year.
4. Diel vertical migrations of fish larvae were recognized in the range between the surface and thd bottom.
5. The 10-20m layer, thermoclne in summer, forms the boundary for vertical migrants.

Acknowledgments

The author wishes to express deepest appreciation to Messrs. MASAKAZU MATSUOKA, Takeshi KANDA, Kazushi HORIUCHI, Noboru NAKANISHI, Kenji HORIYA and Minoru SANO and Mrs. Tokiko FUJITA for their assistance in collecting the data throughout the whole course of the present investigation. I am also grateful to Professor Emeritus Denzaburo MIYADI for giving me the opportunity for the present study.

References

AZUMA, M. 1964. The life history of the landlocked ayu-fish (*Plecoglossus altivelis*) in Lake Biwa, with special reference to their developmental stages. *Physiol. Ecol. Japan*, 12 : 55-77 (inJapanese).

HARADA, E. 1966. Crustacea : the interim reprt on the macrocrustacea. *The Interim Report by the Investigative Group on the Biological Resources in Lake Biwa*, pp. 555-603 (in Japanese).

KIKUCHI, K. 1930. A comparison of the diurnal migration of plankton in eight Japanese lakes. *Mem. Coll. Sci. Kyoto Imp. Univ., Ser. B*, 5 : 27-74.

KOBAYASHI, S. & YAMANAKA, Y. 1950. Biology of isaza in Lake Biwa. 1. Spawning habits and growth. *Rep. Shiga Pref. Fish. Res. Lab.*, 2 : 2-9(in Japanese).

MIURA, T. 1966a. Ecological notes of the fishes and the interspecific relations among them in Lake Biwa. *Jap. Limnol.*, 27 : 1-24.

—— 1966b. Comparative influence of isaza, *Chaenogobius isaza*, on ayu, *Plecoglossus altivelis*, in Lake Biwa. *Res. Popul. Ecol.*, 8 : 37-50.

——, T. SUNAGA, H. KAWANABE, I. MAKI, M. AZUMA, S. TANAKA, K. HIRAI T. NARITA, Y. TOMODA, N. MIZUNO, M. NAGOSHI, S. TAKAMATSU, Y. SHIRAISHI, Y. ONODERA, N. SUZUKI, & S. YANAGISHIMA 1966. The interim report on the fishes. *The Interim Report by the Investigative Group on the Biological Resources in Lake Biwa*. pp. 711-906 (in Japanese).

MORI, S. 1939. On the diurnal activities of a frehwater shrimp, *Leander pauciden* (De Haan) and a fish, *Rhinogobius similis* GILL *Annot. Zool. Japon.*, 18 : 75-80.

NAGOSHI. M. 1966. Ecological studies on the population of isaza, *Chaenogobius isaza* Tanaka, in Lake Biwa, with special reference to the effects of population density upon its growth. *Res. Popul. Ecol.*, 8 : 20-36.

NAKANISHI, M. 1975. Primary production by phytoplankton. *JIBP Synthesis*, 10 : 15-22.

NARITA, T. 1976. Occurrence of two ecological forms of *Anisogammarus annandalei* (TATTERSALL) (Crustacea : Amphipoda) in Lake Biwa. *Physiol. Ecol. Japan*, 17 : 551-556.

TAKAHASHI, S. 1981. Vertical distribution and diel migration of Isaza, *Chaenogobius isaza*, pisces, in Lake Biwa. *Zool. Mag.*, 90 : 145-151.

YAMAMOTO, K., T. ITO, T. MIZUNO, & I. YAMAZI 1966. Secondary production : the interim report on the zooplankton. *The Interim Report by the Investigative Group on the Biological Resources in Lake Biwa*, PP. 469-495 (in Japansese).