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Seasonal Variations in Egg Size, Brood Size and Body Length of *Bosmina longirostris* (Crustacea: Cladocera) from Lake Ikeda, Japan

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ABSTRACT Monthly samplings were made for 13 months at a fixed station in Lake Ikeda, a deep crater lake in order to follow the seasonal variations in egg size, brood size and body lengths of *Bosmina longirostris*, which is the main cladoceran species inhabiting this lake. Results of monthly samplings showed that *Bosmina longirostris* in summer matured at relatively small body sizes and carried smaller eggs, which produced smaller individuals. However, in autumn these individuals began to produce bigger eggs that on hatching produced relatively bigger individuals until winter. However in spring, these bigger individuals began to produce relatively smaller eggs that on hatching gave rise to smaller individuals until summer. Bigger females were able to carry more eggs than their smaller counterparts. Brood size was inversely related to egg size.

ABSTRAK Sebuah stesyen yang telah ditetapkan telah disampel setiap bulan selama 13 bulan dalam Tasik Ikeda, sebuah tasik kawah yang sangat dalam untuk tujuan mengkaji variasi bermusim saiz telur, saiz seperinduk dan saiz badan *Bosmina longirostris* iaitu kladosera utama yang menghuni tasik ini. Keputusan pensampelan bulanan menunjukkan bahawa pada musim panas, *Bosmina longirostris* menjadi matang pada saiz badan kecil dan membawa telur yang bersaiz kecil yang menetaskan individu-individu bersaiz kecil. Walaubagaimanapun, pada musim luruh, individu-individu ini mula menghasilkan telur yang lebih besar dan telah menetaskan individu-individu yang lebih besar sehingga musim sejuk. Walaubagaimanapun pada musim bunga, individu-individu besar ini mula menghasilkan telur yang lebih kecil yang menetaskan dan menghasilkan individu-individu kecil sehigga musim panas. Betina-betina bersaiz besar boleh membawa lebih banyak telur berbanding individu-individu yang lebih kecil. Saiz seperinduk didapati berhubung-kait secara songsang kepada saiz telur.

(*Bosmina longirostris,* seasonal variations, egg size, brood size body length, Lake Ikeda)

INTRODUCTION

Much work has been done on the structure and dynamics of zooplankton communities. Most of the workers involved in this field stressed the importance of zooplankton body size and predation by planktivores that select on the basis of size. Body size can be a determinant factor in community structure because individual physiological rates, which are determined by body size, may be extended to population and ecosystem dynamics [1, 2]. Large body size is disadvantageous to zooplankton in the presence of visual feeding planktivorous fish [3-7], while the presence of tactile feeding invertebrate planktivores could be disadvantageous to zooplankton of smaller body size [8-13].

Hence, in a community where only one type of planktivore is predominant, zooplankton may often consist of either large or small-bodied individuals or species in high abundance. However in cases where zooplankton experienced substantial predation from both types of planktivores, zooplankton may show more subtle adaptations to the dual threat of predators that are both large and small selective [11-14].

In Crustacea, the number of parthenogenetic eggs produced by a single female usually depends upon its immediately prior nutritional and metabolic history. Lack of food or deterioration of the environment results in smaller broods, whereas abundance of food or favourable living conditions results in larger broods.

Cladocerans carry their young in special brood chambers formed from the dorsal portion of the carapace. Since the space within the brood chamber is constant, then production of larger eggs would entail smaller brood size, while smaller eggs would allow larger brood size. Thus egg size definitely imposes certain natural restrictions upon brood size [15, 16].

The number of eggs produced by a female cladoceran is influenced by various environmental factors and the influence of these factors based largely on laboratory experiments has been reviewed [17]. The factors that are of importance in influencing natural population are food, temperature, dissolved oxygen and population density. However, the relative importance of each factor under natural conditions is still unclear.

One of the earliest researchers to work on Lake Ikeda was Miyakita [18], who studied the benthos aspect. Other prominent works dealt with the overall plankton composition of this lake [19-21]. More in-depth works dealt with the summer vertical distribution of *Bosmina longirostris* and *Ceriodaphnia reticulata* [22]. These researchers also reported on the summer composition and abundance of zooplankton and elucidated the seasonal succession of the main cladoceran assemblage [23, 24].

Recent works done on this deep crater-lake included the seasonal diel vertical migration (DVM) of the main cladoceran assemblage [25] and the seasonal variations in egg size, brood size and body length of *Ceriodaphnia reticulata* [26].

The aim of this study is to investigate the seasonal variations in egg size, brood size and body lengths of ovigerous females of *Bosmina longirostris* [O.F. Muller] (Cladocera:Crustacea), the most abundant cladoceran found in Lake Ikeda, Japan, and to try and relate it to the various factors that might influence these variations.

Study Site Description

Lake Ikeda is located in Kagoshima Prefecture, Japan at 31°14'N, 130°34'E and is 88m above sea level (Figure 1). It is a crater-lake situated at the southwestern edge of Kyushu Island, Japan. The mean depth is 135m and the deepest point is at 233m. It has a water volume of 1.47 X $10^9 m^3$ with a residence time of 1.7 per year. It has a surface area of 11 km^2 and a shoreline length of 15 km. It is a very deep lake and is surrounded by steep slopes except on its northwestern side. It was formed as a crater-lake during the pyroclastic eruption of the Ibusuki Volcanic Group, which occurred around 4,000 years ago. Together with the neighbouring cone-shaped Mt. Kaimon on its southern side, it offers one of the most scenic spot to the southern Kyushu tourist zone, that of the Kirishima-Yaku National Park.

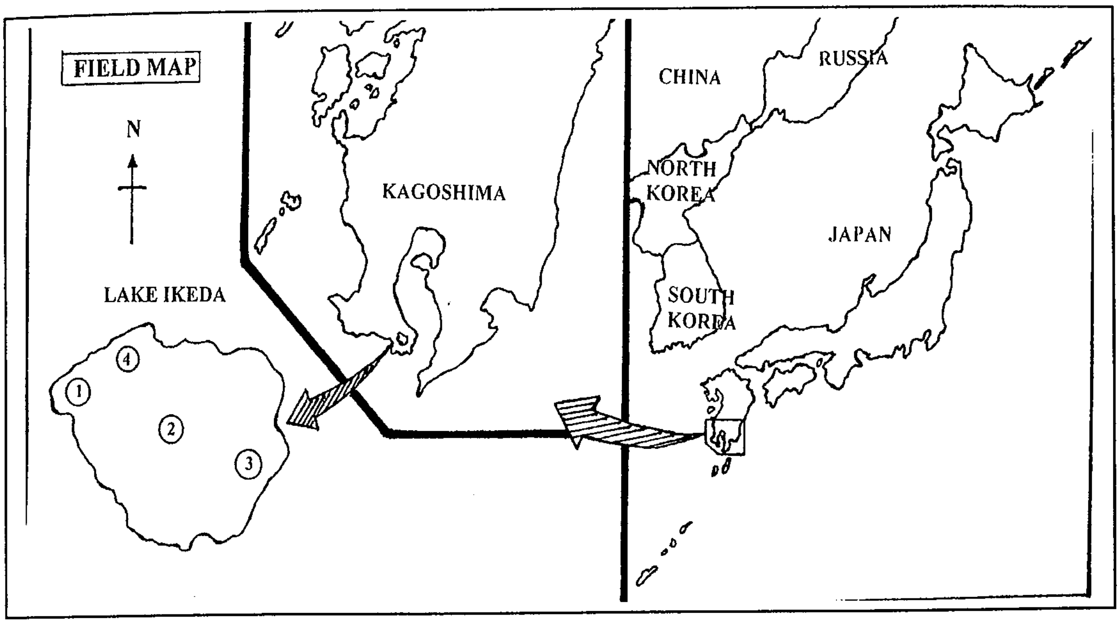

Figure 1. Field map of Lake Ikeda showing the location of Station 4 relative to the other stations in the lake.

MATERIALS AND METHODS

Field Sampling Methods

Samples for seasonal variations in egg size, brood size and body lengths of *Bosmina longirostris* were collected from the months of November 1985 to November 1986 from a fixed sampling station (Station 4) (Figure1). The frequency and timing of sampling was constant during the whole sampling period.

Bosmina longirostris samples were collected by using a 24 cm diameter Kitahara net (NXX13) by vertical net hauls from a depth of 30 m to the surface at a constant speed of $0.5ms^{-1}$. Six replicate samples (ca. 250 ml each) were obtained from Station 4 on each sampling occasion. The mesh size (95 µm) of this net was fine enough to retain all the stages of the smallest cladoceran. The samples were preserved with the cool sucrose formalin technique [27] in order to avoid carapace distortion and loss of eggs especially from the brood chamber of adult *Bosmina longirostris*.

Temperature and dissolved oxygen concentration at the surface were measured with a Yellow-Springs Instrument model 57 probe. Water transparency was measured with a 30 cm diameter white Secchi Disc. Measurements were done in triplicates.

Laboratory Methods

In the laboratory, the samples were concentrated to a volume of 100 ml by passing the 250 ml samples through a sieve made out of exactly the same material used in the samplings (NXX13). The 250 ml that passed through the net was discarded and the contents were finally resuspended in 100 ml of 4% formalin. From each of these, three 0.5 ml sub samples were then drawn and examined for its contents. Cladoceran abundance counts were done under a microscope 200 x magnification from a micrometer scale fixed to the eyepiece. Identification of *Bosmina longirostris* species was done by the aid of keys [28-31]. Characters measured were that of egg and body length of ovigerous females.

Egg numbers were obtained by counting after dissection of the eggs from the brood pouches, so that it represents the mean number of eggs per mature and fertile female, and not the mean number of eggs carried by the total female population.

The lengths of females with eggs were measured with a calibrated eyepiece from the crown of the head to the posterior border of the carapace. Statistical test was performed by the SPSS Statistical package. Difference between means was computed through the Student's t-test.

RESULTS AND DISCUSSION

Physical-chemical parameters

Fluctuations in surface temperature, dissolved oxygen and transparency for station 4 are shown in Figure 2. Surface water temperature ranged from 10.0°C to 30.0°C, with an average of 19.8°C. The hottest month was August while the coldest was in February (Figure 2). Dissolved Oxygen ranged from 8.1 to 12.2 mg/L with an average of 9.2 mg/L. Transparency ranged from 4.8 to 9.2 m with an average of 6.3 m. Transparency decreased from spring to summer but increased from autumn to winter.

Mean body length of ovigerous females

From January to May, mean body length of ovigerous (egg-carrying) females gradually decrease from (390 ± 50μm) (Mean ± standard deviation) in January, down to a mean length of 340 ± 30μm in May (Figure 3). In June it rose to 355 ± 30μm and in July slightly to 360 ± 50μm. However, in August it decreased sharply to 308 ± 25μm and then slightly further to 305 ± 30μm in September before gradually increasing to 330 ± 20μm and to 368 ± 15μm in November. Highest mean body length was 390 ± 50μm in January while the lowest was 305 ± 25μm in September. Ovigerous *Bosmina* decreased its mean body length in summer but increased again in winter. Mean body lengths of ovigerous females in the summer months (June July and August) were significantly different from winter months (December, January and February) (Student's t-test, $P<0.05$).

Egg length

Mean egg length was high in January (127 ± 7.5μm), February (128 ± 7.5μm), March (129 ± 7.5μm), but gradually decreased to a minimum in September (121 ± 6.5μm) (Figure 4). However, in October it started to increase to 123 ± 2.5μm and reached 128 ± 6.5μm in November. Highest mean egg length was 129 ± 7.5μm in March, while lowest was 121 ± 6.5μm in September. Although there were irregular fluctuations in mean egg length between months, it was observed that mean egg length in summer was considerably smaller in winter. Mean egg length in the summer months (June, July and August) were significantly different from winter months (December, January and February) (Student's t-test, $P<0.05$).

Brood size

Mean brood size was 1.2 ± 0.5 in January (Figure 5). From then on it increased gradually up to 1.8 ± 1.0 in May before decreasing slightly in June (1.5 ± 0.7). In July, it increased abruptly to 2.4 ± 1.4 before dropping sharply to 1.1 ± 0.7 in August and continued to decline in September, October and November to a minimum of 1.0 ± 0.1. Highest mean brood size recorded during the study period was 2.4 ± 1.4 while the lowest was 1.0 ± 0.1. Mean brood size was observed to be larger in summer than in winter. Mean brood size in the summer months (June, July, and August) were significantly different from winter months (December, January and February) (Student's t-test, $P<0.05$).

Body size distribution

Figure 6 shows the monthly size distribution of *Bosmina* from December 1985 to November 1986. By looking at the imaginary 300μm line drawn on each month, it can be seen that *Bosmina* females are generally productive in the months of June, July, August and September at body lengths lesser than 300μm. Some individuals were rather small at 250μm in length in June and July. There were occurrences of ovigerous females with body length lesser than 300μm in June, July, August and September. Thus it can be observed that in these months, *Bosmina* matured at smaller body size and remained reproductive at smaller body size in summer, but in winter and spring they matured and were reproductive at a much larger body size. No ovigerous females were found in December and January.

Brood size distribution

Figure 7 shows the brood sizes of reproductive *Bosmina* females plotted against their body lengths. In July, ovigerous *Bosmina* females had a maximum brood size of 6 which was the highest ever recorded during the study period. Ovigerous females in February, April and May had a maximum brood size of 4. In May, June and August, it was 2 while in September, October and November, only 1. It can clearly be seen that brood size is a function of body size in ovigerous females, especially in the months of January, April, May and July. Ovigerous females in summer carried more eggs at a greater body length compared to that of winter. It can also be observed that *Bosmina* matured at a smaller size in summer and at a larger size in winter.

This study is aimed at investigating the seasonal variations in egg size, brood size and body lengths of *Bosmina longirostris* in Lake Ikeda. In the natural population of Lake Ikeda, there is an increase in egg-number (brood size) with body size. However, generally an inverse relationship was observed between body size and egg size. This meant that ovigerous females were bigger in one season and smaller in another season and were carrying smaller eggs in one season while in another season it was carrying bigger eggs.

Generally eggs were larger in winter, which then became smaller in spring. It was smallest in summer and then started to enlarge again as autumn approached. *Bosmina* individuals in summer matured at small body sizes and carried small eggs. However, as winter approaches these small individuals started to produce large eggs, which gave rise to large individuals. In spring these large individuals began producing small eggs, which resulted in smaller summer individuals. Temperature may play a role in determining body size of cladocerans [32]. An inverse relationship between monthly mean body size and temperature was observed [33]. In Frains Lake, Michigan *Bosmina* underwent seasonal changes in length [34]. In Lake Ikeda at the end of summer, brood size of *Bosmina* decreased to 1. This suggests that there are insufficient nutrients available for maximum growth and reproduction at the end of summer. Hence, when brood size decreased at the end of summer, *Bosmina* started to produce bigger eggs in autumn.

Brood size is positively correlated with the size of ovigerous females. In times of favourable environmental conditions there will be abundant food and females will carry more eggs compared with unfavourable conditions. However when the availability of food is limited, females will start to carry fewer but bigger eggs. Rate of egg production is influenced by food availability [34-36]. The brood-size is affected directly while the egg-bearing females are affected indirectly [37]. This would increase instars duration, reduced increment at each moult and decreased brood size [29, 38 and 42].

In Cladoceras, the clutch or brood size is related to the quality and quantity of food available. Growth rate is maximal under ideal conditions [40]. A reduction in the quality or quantity of food available will reduce the growth rate of instars and lowers the number of eggs carried in the brood pouch of ovigerous females [29, 41 and 42].

The fluctuation in egg-size is not strongly associated with nutritional conditions [34]. Many studies have shown that predation is the main source of mortality in cladocerans and thus would influence its productivity. Predation seemed to be the influence that produced small young in one season and larger ones in other seasons. The seasonal changing pattern of size-selective predation could provide an explanation for the peculiar egg-size cycle of cladocerans [35, 39].

In studies done in Frains Lake, Michigan, the larger cladocerans (*Daphnia* and *Ceriodaphnia*) migrate down near or below the thermocline during daytime, escaping from the illuminated upper waters [43, 44]. Heavy visual predation by fishes during summer selects against more conspicuous adults [44, 45]. However, *Bosmina,* which is a smaller species were able to maintain a close association with fishes that remove its larger competitors [4]. In Lake Ikeda precisely the same could have happened. *Bosmina* was able to be in close association with juvenile fishes; especially juvenile ayu (*Plecoglossus altivelus*) and the pond smelt (*Hypomesus nipponensis*) which could be responsible for removing larger competitors such as *Ceriodaphnia, Daphnia*, or *Diaphanosoma.* In another study done in the same lake, large numbers of *Bosmina* are consumed each summer by juvenile crappie, bluegill, and adult golden shiners [34]. Fish usually would select against more conspicuous body pigmentation and thus the bigger ones are vulnerable. However when warm-water fishes cease feeding in late autumn, *Bosmina* enters a period when predation comes most intensively from two invertebrates: *Cyclops* and *Chaoborus.* Predation by these two genera is known to favour large size and smaller size will be at a disadvantage [9, 46-48]. In particular, the blindly searching, grasping nature of *Cyclops* would favour any lineages of *Bosmina* that produced larger than average young.

In Lake Ikeda, intense predation could come from the copepods, namely *Mesocyclops sp.* and *Thermocyclops hyalinus*, which would predate upon the smaller *Bosmina.* Hence any lineage of *Bosmina* that could produce larger than average young would be at an advantage. Heavy visual predation by fishes selects against larger forms during the summer, while invertebrate predation selects against smaller forms during winter. Hence lineages that produce small morphology during summer and large morphology during winter would be at an advantage compared to those that could not carry out this strategy. This hypothesis can be tested in the future when a laboratory-based experiment is done in parallel with fieldwork.

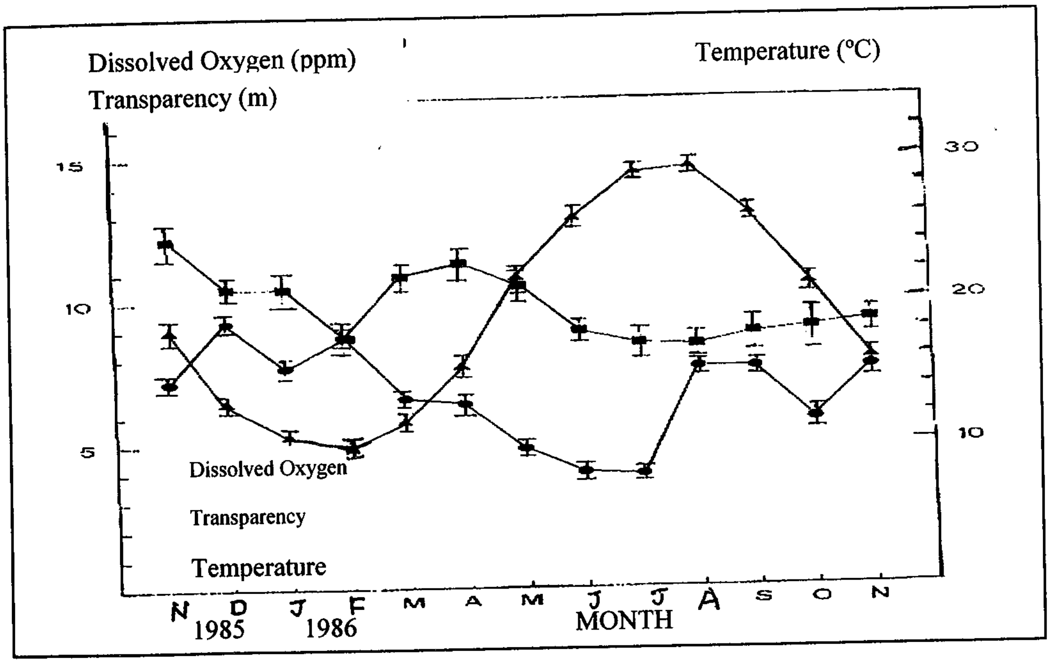

Figure 2. Fluctuations in transparency (m), surface temperature (°C) and surface Dissolved Oxygen (ppm) at Station 4 in Lake Ikeda from November 1985 to November 1986. Measurements were done in triplicates.

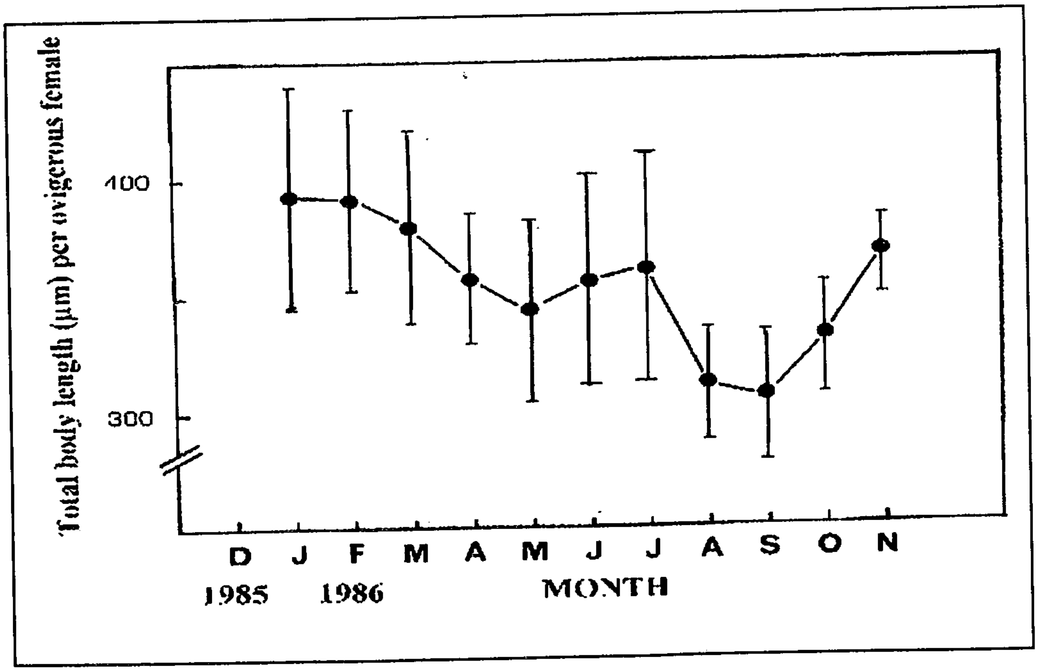

Figure 3. Mean body length of ovigerous *Bosmina longirostris* females (± s.d.) from January to November 1986. Number of individuals measured each month was 30.

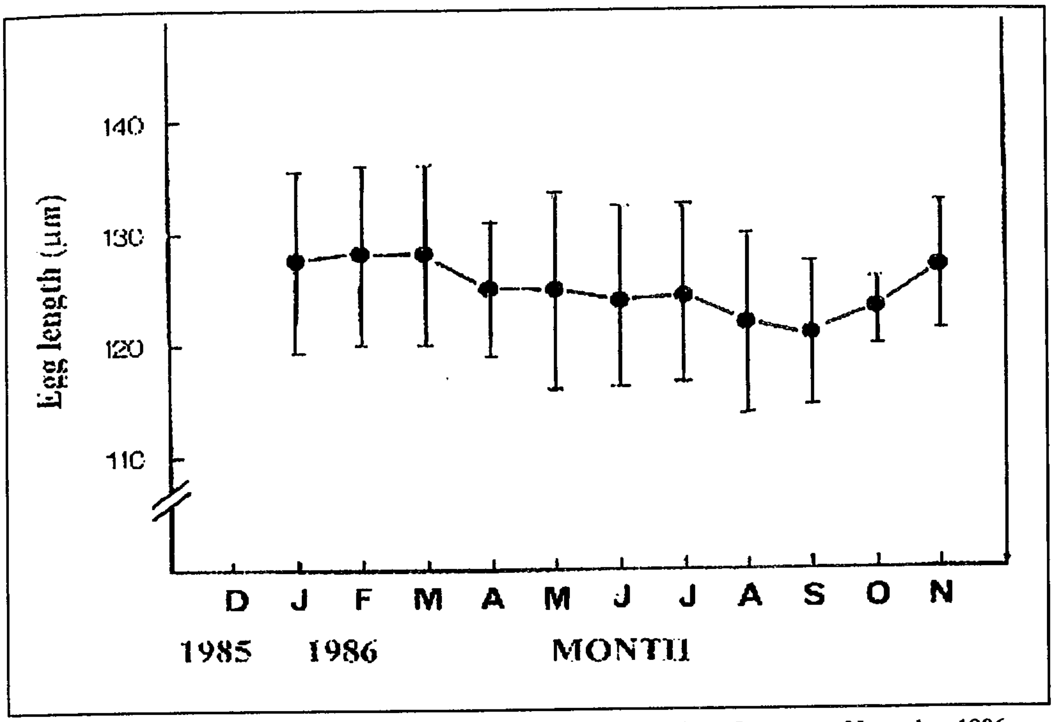

Figure 4. Mean egg length (± s.d.) of *Bosmina longirostris* from January to November 1986. Number of eggs measured each month was 100

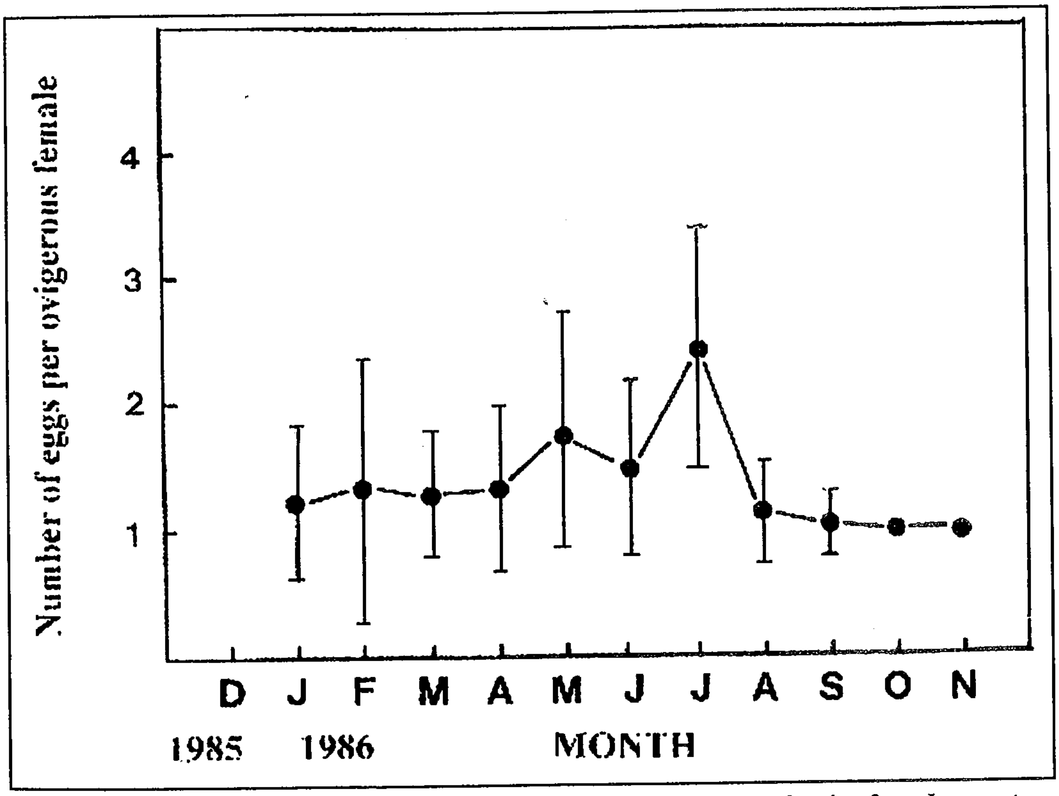

Figure 5. Mean brood size (± s.d.) of ovigerous *Bosmina longirostris* females from January to November 1986. Number of individuals measured each month was 30.

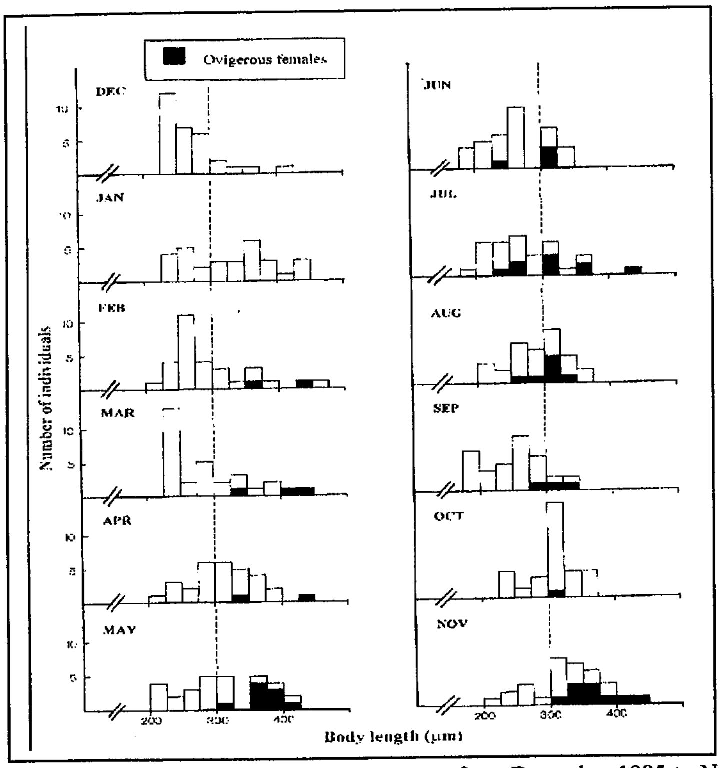

Figure 6. Monthly size distribution of *Bosmina longirostris* from December 1985 to November 1986. Number of individuals measured each month was 30.

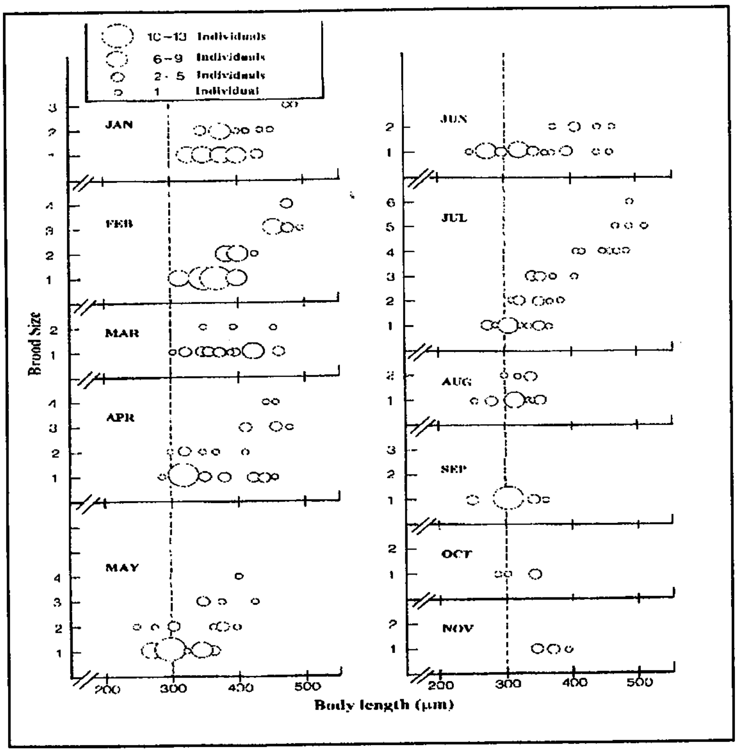

Figure 7. The number of eggs carried by reproductive females of *Bosmina longirostris* plotted against their body length (µm) from December 1985 to November 1986. Number of individuals measured each month was 30.

CONCLUSION

In Lake Ikeda, *Bosmina longirostris* matured at small body sizes and carried smaller eggs in summer. However, in autumn these small individuals produced bigger eggs, which then hatched into big individuals in winter. In spring, these big individuals began producing smaller eggs, which then gave rise to small individuals, which were found in summer. Bigger ovigerous females were able to carry more eggs compared to their smaller counterparts. There was tendency for brood size to enlarge when egg size was small and *vice versa*.

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