Sains Malaysiana 40(6)(2011): 543–547

Cyclomorphism in *Bosmina longirostris* (Crustacea:Cladocera) from Lake Ikeda, Japan

(Siklomorfisme dalam *Bosmina longirostris* (Crustacea:Cladocera) dari Tasik Ikeda, Jepun)

SHAHARUDIN ABDUL RAZAK* & TOSHIO SAISHO

ABSTRACT

Zooplankton were sampled in Lake Ikeda at a fixed station every month with the aid of a plankton net in order to observe whether cyclomorphism was exhibited by the neonates of Bosmina longirostris. *In Lake Ikeda the relative sizes of the antennules and mucrones of* B. longrostris *neonates decreased in relation to carapace length from 65% in winter to 50% in summer. Mucrone lengths also decreased from 30% in winter to 20% in summer. Both appendages were inversely correlated with surface temperature of the lake. Predation seems to be one of the reasons why neonates of* B. longirostris *exhibited seasonal cyclomorphism in their antennule and mucrone.*

Keywords: Antennules; Bosmina longirostris*; cyclomorphism; mucrone; neonate*

ABSTRAK

Zooplankton telah disampel dari Tasik Ikeda pada sebuah stesen tetap setiap bulan dengan menggunakan jaring plankton untuk melihat sama ada neonat B. longirostris *mempamerkan siklomorfisme. Pada Tasik Ikeda saiz relatif antenul dan mukron neonat* B. longirostris *berkurangan berbanding panjang karapas daripada 65% semasa musim sejuk ke 50% semasa musim panas. Panjang mukron juga berkurangan daripada 30% semasa musim sejuk ke 20% semasa musim panas.Kedua-dua apendaj berkadar songsang dengan suhu permukaan tasik. Pemangsaan mungkin salah satu penyebab mengapa neonat* B. longirostris *mempamerkan siklomorfisme bermusim pada anatenul dan mukronnya.*

Kata kunci: Antenul; Bosmina longirostris*; mukron; neonat; Siklomorfisme*

INTRODUCTION

One of the most unique phenomena in the biology of plankton is the occurrence of seasonal changes (cyclomorphosis), some of which are so striking that the summer and winter forms of the same species could be wrongly identified as belonging to different species. While it is certain that not all plankton organisms manifest such seasonal changes, they do occur in a large number of plankters, both plant and animal, scattered through the whole taxonomic range of the plankton series (Welch 1952).

According to Hutchinson (1967), the term cyclomorphosis was first used by Lautferborn in 1904 to describe the "seasonal polymorphism" of plankton. Seasonal changes in the morphology of plankton populations have since then been documented in dinoflagellates, rotifers, copepods and cladocerans (Black 1980). Studies done in the laboratory of Brooks (1946; 1947), Jacobs (1961), Kerfoot (1975b) and Gilbert (1965 1967) showed that cyclomorphism in certain cladoceran and rotifer populations include the production of different phenotypes by the same genotypes in seasonally distinct lake environments. Jacobs (1961), Kerfoot (1975a) and Halbach and Jacobs (1971) have also suggested that genetic change is an important component of cyclomorphosis.

Cyclomorphosis in *Bosmina longirostris* involves changes in the length of the antennule and mucrone, but prior to this work, seasonal changes in the size of parthenogenetic eggs in Lake Ikeda have also been documented (Razak & Saisho 2004; 2005). Hutchinson (1967) reported that several European researchers described decreases in antennule and mucrone length in summer. Kerfoot (1975a; 1977) presented findings of a similar nature for a population of *B. longirostris* in Frains Lake, Michigan. He also determined that the size of both characters decreased relative to body size during summer and that egg size varied seasonally. He attributed these morphological changes in part to different growth rates in seasonally unique environments, and also suggested that a genetic component was involved in the cyclomorphism of the species.

The aim of this study was to ascertain whether neonates (first instar young) of *B. longirostris* exhibited cyclomorphism in Lake Ikeda. As mentioned above, seasonal changes in the size of parthenogenetic eggs of *B. longirostris* have been documented in this lake and it would be interesting to observe whether these eggs also exhibit seasonal changes in their appendages especially the antennules and mucrones once it hatches into neonates.

Materials and Methods

Study Site Description

Lake Ikeda is a crater lake located 40 km south of Kagoshima City, Kyushu Island, Japan at 31° 14'N, 130°34'E and is 88 m above sea level (Figure 1). It is situated at the southwestern edge of Kyushu Island. The mean depth is 135 m and the deepest point is at 233 m. With a water volume of $1.47 \times 10^9 m^3$ it has a residence time of 1.7 per year. It has a surface area of 11 km^2 and a shoreline length of 15 km. For its size it is very deep 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 (Inamoto et al. 1986).

There are resort facilities in the northwestern part of the lake, which attracts around 3 million tourists annually. During the summer months a pumping station situated nearby distributes water from the lake to upland fields in southern Kagoshima Prefecture increasing its drainage basin to a further 30 km^2. This irrigation project contributed considerably to the deterioration of the lake water quality. In 1929, the transparency of the lake was 26.8 m but due to progressive accumulation of nutrient loading, it has considerably decreased to 6.0 m (Inamoto et al. 1986). Other factors such as the presence of a small settlement for tourist accommodation, the presence of a factory and an aquaculture industry coupled with the lack of natural drainage may have played a role in the progressive deterioration of its water quality.

Earlier studies on Lake Ikeda were done by Miyakita (1928), Mizuno (1963), Murayama and Saisho (1967) and Yoshimura (1930). Most of the work dealt on the overall plankton composition of the lake. Much recent studies on this lake went much further and dwelled on the summer mid-day-night vertical distribution of *B. longirostris* and *Ceriodaphnia reticulata* (Razak & Saisho 1998), summer mid-day-night composition and abundance of the main zooplankton assemblage (Razak & Saisho 2002a), seasonal succession of the main cladoceran assemblage (Razak & Saisho 2002b), seasonal diel vertical migrations of the main cladoceran assemblage (Razak et al. 2002), seasonal variations in egg-size, brood size and body length of *B. longirostris* (Razak & Saisho 2004), and *C. reticulata* (Razak & Saisho 2005) of this deep crater-lake.

Sampling Methods

B. longirostris samples were collected at a fixed site named Station 4 in Lake Ikeda using a 24 cm diameter Kitahara net (NXX13) (95 µm). Sampling was done by vertical net hauls from a depth of 30 m to the surface at a constant speed of 0.5 ms^{-1}. They were preserved with the cool sucrose formalin technique (Haney & Prepas 1978) in order to avoid carapace distortion.

Laboratory Methods

In the laboratory, zooplankton samples were concentrated to a volume of 100 mL. From each of these, three 0.5 mL subsamples were then drawn and examined for its contents. Antennule, mucrone and carapace length were measured at 200× magnification from a micrometer scale fixed to the eyepiece. A total of 100 individuals were measured every month. Identification of *B. longirostris* was done by the aid of keys from Goulden and Frey (1963), Mizuno (1964), Hutchinson (1967) and Ueno (1969). *B. longirostris* specimens were measured according to the method of Kerfoot (1975a). In *B. longirostris*, two features highly

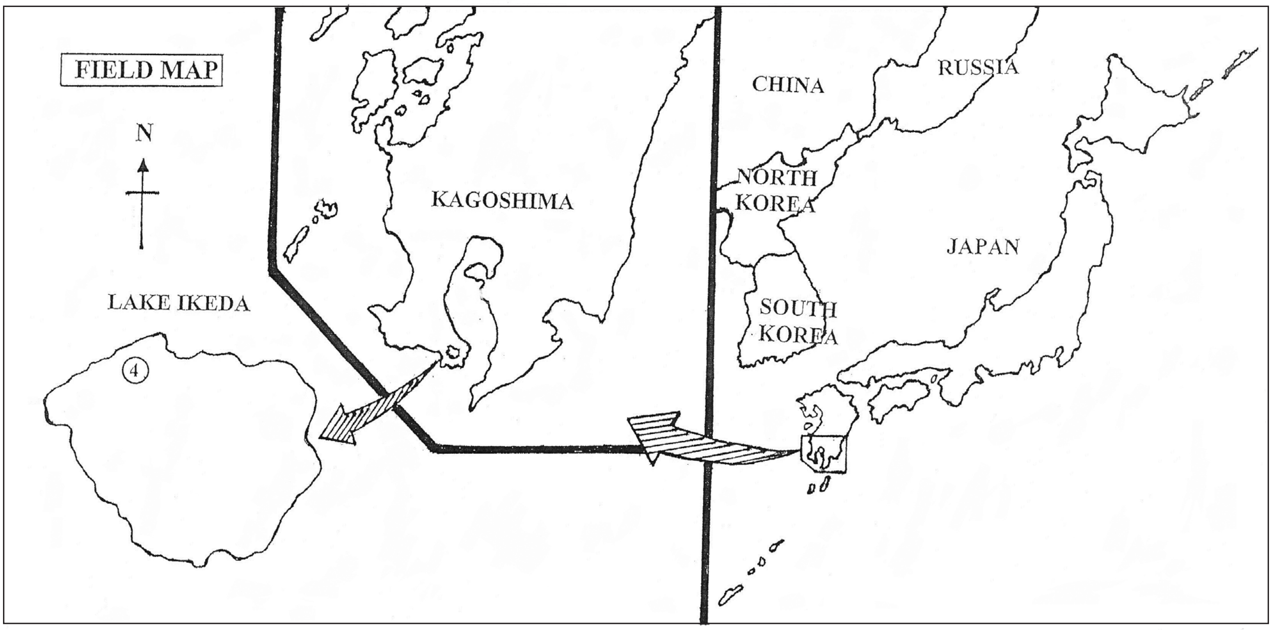

FIGURE 1. Field map of Lake Ikeda showing the location of Station 4

sensitive to environmental changes are antennules and mucrones (Kerfoot 1975a). Method of measurements of these structures, as well as carapace length, was based on the following descriptions:

1. Carapace length: Distance from the top of the posterior fissure to the antero-ventral margin of the carapace
2. Antennule length: Distance from distal portion of the antennule measured from the base of the tooth-like process to the distal tip
3. Mucrone length: Length of tail-like projection, measured from base, taken as the ventral extension of the fissure margin to the tip

Measurement of antennule, mucrone and carapace length were done on neonates (first instar young) every month as illustrated in Figure 2.

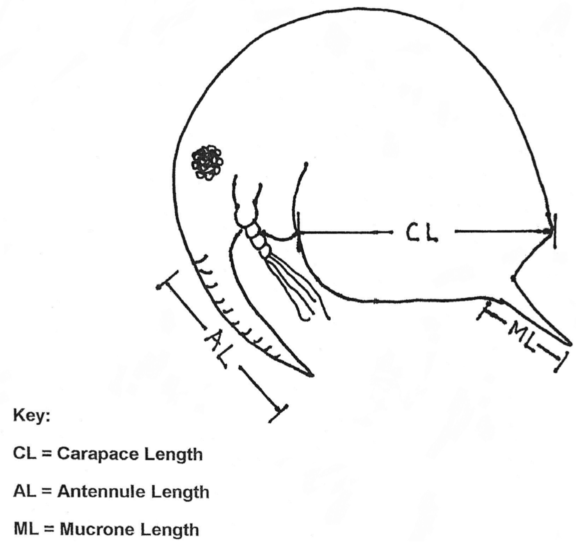

FIGURE 2. Sketch of *B. longirostris* neonate (100X magnification) showing the lengths measured

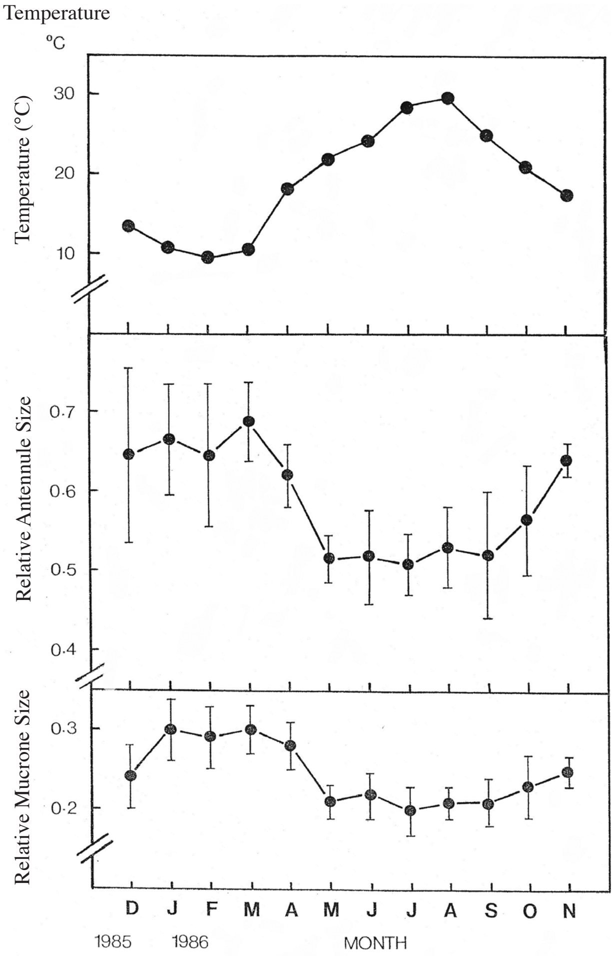

FIGURE 3. Seasonal changes in relative sizes of antennules and mucrones of *B. longirotris* neonates with respect to temperature in lake Ikeda

RESULTS AND DISCUSSION

Figure 3 shows the seasonal changes in the morphology of *B. longirostris* in Lake Ikeda by comparing the relative size of antennules and mucrones with respect to carapace length. Monthly temperature changes were also shown.

The relative length of antennules and mucrones with respect to carapace length in neonates decreased during summer. Antennule length decreased in relation to carapace length from 65% in winter to 50% in summer. Mucrone length also decreased in relation to carapace length from 30% in winter to 20% in summer. When the winter months and summer months were separately pooled and the data then subjected to statistical analysis, there was significant difference between them (t-test, N=100, $P\leq 0.05$). For antennules length, the winter months of November, December, January and February were also significantly different from the summer months of May, June and July (t-test, N=100, $P\leq 0.05$). The same trend was also observed for mucrone length, where the months of January, February, March, and April were significantly different from May, June July and August (t-test, N=100, $P\leq 0.05$). Decrease in the length of both structures was also observed to coincide with an increase in surface temperature (from 10°C to 28°C in summer). This finding is very similar to what Kerfoot (1975a) observed in Frain's Lake, Michigan where the relative sizes of antennules and mucrones in first instar individuals decreased during the summer. Relative to carapace length, the antennules decreased from 68% in winter to 56% in summer while the mucrones decreased from 17% in winter to 11% in summer. Both drops roughly coincided with increases in epilimnion temperature. *B. longirostris* neonates showed a roughly inverse relation to epilimnion temperature. This is similar to what was observed in this present study in Lake Ikeda.

During summer, fishes usually select big and conspicuous organisms (Ivlev 1961; Brooks & Dodson 1965). In Lake Ikeda, cladocerans which are large e.g.

Ceriodaphnia, migrated near or into the thermocline during daytime. Razak and Saisho (1998; 2002a) and Razak et al. (2002) observed and reported that large cladocerans such as *Ceriodaphnia* migrated down the thermocline in order to escape the illuminated upper water layer. In contrast, *B. longirostris*, which is a small species are able to maintain a close association with fishes that remove its larger competitors (Brooks & Dodson 1965). In summer, small body size is achieved through shorter growth periods. Early maturity ensures a constant supply of neonates.

At the onset of winter, planktivorous fishes (pond smelt) usually cease to prey upon the copepods. Therefore, *B. longirostris* may face greater predation pressure from copepods such as *Thermocyclops* and *Mesocyclops* present in the lake (Li & Li 1979; Williamson 1986; Roche 1990). McQueen (1969) and Confer (1971) reported that predation by invertebrates is intense on smaller invertebrates. Hence, size-dependent predation pressures often determine the body-size distribution of animals in natural communities (Enz et al. 2001; Greene 1983; Hanazato & Yasuno 1989; Herzig 1995; Lunte and Luecke 1990; Yan et al. 2002;). In Lake Ikeda, the blindly searching and grasping feeding nature of the two copepods favour any lineages of *B. longirostris* that produce larger offsprings. In *B. longirostris* neonates, larger antennules and mucrones give an impression that they are larger than their actual body size and thus make them difficult for the copepods to handle. Furthermore, these long antennules and mucrones easily break off upon being seized by copepods, allowing the *B. longirostris* individual to readily escape. These antennules and mucrones may be regenerated in subsequent instars (Kerfoot 1975a).

Although there could be other reasons, predation seems to be one of the reasons why *B. longirostris* exhibited seasonality in their morphological characters. Because planktivorous fishes prey upon big zooplankton in summer and invertebrate copepods prey upon small individuals in winter, then *B. longirostris* which are able to produce small phenotypes in summer and larger phenotypes in winter would certainly have an added advantage in escaping from predation as compared to other cladoceras that cannot adopt such a strategy. Furthermore, the shape of the antennule protects the opened ventral carapace situated in the front part of the body and having a longer and bigger antennule will be a key strategy for *B. longirostris* to avoid predation (Sakamoto & Hanazato 2008). Moreover, the longer than usual pointed and sharp mucrone will deter any attack by copepod from the rear part of the body of *B. longirostris*. This protruding appendage can be considered to act as defensive structures against copepod predation (Chang & Hanazato 2002; Kerfoot 1987; 1988).

These results were obtained through sampling in the field and in order to substantiate it even further in the future it will be corroborated with more experimental-base laboratory work together with more robust statistical analysis.

ACKNOWLEDGEMENTS

We would like to thank Mr. Takuya Yoshimine who kindly assisted in the zooplankton samplings, Mr. Shirou Kojima for providing boat transportation to and from the sampling sites, and Mr. Isamu Setoguchi (Head of the Ibusuki Experimental Station) for his kindness in allowing us access to their various research facilities at Lake Ikeda. We are very grateful and indebted and would like to relay our deepest gratitude to the Ministry of Education, Science and Culture, Japan (MONBUSHO) for sponsoring one of us (SAR) during his MSc in Fisheries study and to the kindness received from Japanese colleagues during his memorable stay in Japan.

REFERENCES

Black, R.W. 1980. The nature and causes of cyclomorphosis in a species of the *Bosmina longirostris* complex. *Ecology* 61(5): 1122-1132.

Brooks, J.L. 1946. Cyclomorphosis in *Daphnia*. I. An analysis of *D. retrocurva* and *D. galaeata*. *Ecological Monograph* 16: 409-447.

Brooks, J.L. 1947. Turbulence as an environmental determinant of relative growth in *Daphnia*. *Proceedings of Natural. Academy of Science* 53: 119-126.

Brooks, J.L. & Dodson, S. 1965. Predation, body size and composition of the plankton. *Science* 150: 28-35.

Chang, K.H. & Hanazato, T. 2002. Morphological defense of *Bosmina fatalis* against invertebrate predators in Lake Suwa. *Verhandlungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie* 28: 1279-1283.

Confer, J.L. 1971. Intrazooplankton predation by *Mesocyclops edax* at natural prey densities. *Limnology and Oceanography* 16: 663-666.

Enz, C.A., Heller, C., Muller, R. & Burgi, H.R. 2001. Investigation on fecundity of *Bythotrophes longimanus* in lake Lucerne (Switzerland) and on niche segregation of *Leptodora kindti* and *Bythotrophes longimanus* in Swiss lakes. *Hydrobiologia* 464: 143-151.

Gilbert, J.J. 1965. Rotifer ecology and embryological induction. *Science* 151: 1234-1237.

Gilbert, J.J. 1967. Asplanchna and ostero-lateral spine production in *Brachionus calyciflorus*. *Archiv Fur Hydrobiologie* 64: 1-62.

Goulden, C.E. & Frey, F.G. 1963. The occurrence and significance of lateral pores in the genus *Bosmina* (Claodocera). *Internationale Revue der Gesamten Hydrobiologie* 48: 513-522.

Greene, C.H. 1983. Selective predation in freshwater zooplankton communities. *Internationale Revue der Gesamten Hydrobiologie* 68: 297-315.

Hallbach, U. & Jacobs, J. 1971. Seasonal selection as a factor in rotifer cyclomorphosis. *Naturwissenschaften* 57: 1-2.

Hanazato, T. & Yasuno, M. 1989. Zooplankton community structure driven by vertebrate and invertebrate predators. *Oecologia* 81: 450-458.

Haney, J.E. & Prepas, E. 1978. Sugar-frosted *Daphnia*; an improved fixation technique for Cladocera. *Limnology and Oceanography* 23: 551-559.

Herzig, A. 1995. *Leptodora kindti*: efficient predator and preferred prey item in Neusiedler See, (Austria). *Hydrobiologia* 198: 107-117.

Hutchinson, G.E. 1967. *A Treatise on Limnology. Volume II. Introduction to Lake Biology and the Limnoplankton*. New York: John Wiley and Sons Inc.

Inamoto, N., Yamashita, K., Ueno, K., Koriyama, T., Akatsuka, M. & Mehara, K. 1986. *Studies on the eutrophication of Lake Ikeda-water quality in deep layer and lake water cycle*. Annual Report of Kagoshima Prefectural Institute of Environmental Science, 2: 141-157. (In Japanese).

Ivlev, V.S. 1961. *Experimental Ecology of the Feeding of Fishes*. New Haven: Yale University Press,.

Jacobs, J. 1961. Cyclomorphosis in *Daphnia galaeta mendotae* Birge, a case of environmentally controlled allometry. *Archives Hydrobiology* 68: 7-71.

Kerfoot, W.C. 1975a. Seasonal changes of *Bosmina* (Crustacea:Cladocera) in Frains Lake, Michigan: Laboratory observations of phenotypic changes induced by inorganic factors. *Freshwater Biol*. 5: 227-243.

Kerfoot, W.C. 1975b. The divergence of adjacent populations. *Ecology* 56: 1298-1313.

Kerfoot, W.C. 1977. Implications of copepod predation. *Limnology and Oceanography* 22: 316-326.

Kerfoot, W.C. 1987. Translocation experiment: *Bosmina* responses to copepod predation. *Ecology* 68: 596-610.

Li, J.L. & Li, H.W. 1979. Species-specific factors affecting predator-prey interactions of the copepod *Acanthocyclops vernalis* with its natural prey. *Limnology and Oceanography* 24: 613-626.

Lunte, C. & Luecke, C. 1990. Trophic interactions of *Leptodora* in Lake Mendota. *Limnology and Oceanography* 35: 1091-1100.

McQueen, D.J. 1969. Reduction of zooplankton standing stocks by predaceous *Cyclops bicuspidatus thomasi* in Marion Lake, British Columbia. *Journal of the Fisheries Research Board of Canada* 26: 1605-1618.

Miyakita, D. 1928. Report on benthos research in the littoral zone of Kyushu area. *Japanese Journal of Research in Fisheries* 23(4): 132-140 (In Japanese).

Mizuno, T. 1963. Research on the crater-lake of Kirishima and the limnology of Satsuma Lake. *Japanese Journal of Limnology*. 24(1-2): 22-23 (In Japanese).

Mizuno, T. 1964. *Keys to the Freshwater Plankton of Japan*. Hokuseisha Osaka. (In Japanese).

Murayama, S. & Saisho, T. 1967. Seasonal variations of plankton at Lake Ikeda. *Memoirs of the Faculty of Fisheries, Kagoshima University* 16: 29-33 (In Japanese).

Nagata, T. & Hanazato, T. 2006. Different predation impacts of two cyclopoid species on a small-sized zooplankton community: An experimental analysis with mesocosms. *Hydrobiologia* 556: 233-242.

Razak, S.A. & Saisho, T. 1998. Summer mid-day-night vertical distribution of *Bosmina longirostris* (Crustacea:Cladocera) and *Ceriodaphnia reticulata* (Crustacea:Cladocera) in Lake Ikeda, Japan. *Sains Malaysiana* 27: 19-29.

Razak, S.A. & Saisho, T. 2002a. Summer Mid-Day-Night composition and abundance of the main zooplankton assemblage of a crater lake from Kyushu Island, Japan. *Pertanika Journal of Tropical Agricultural Science* 25(1): 1-9.

Razak, S.A. & Saisho, T. 2002b. Seasonal succession in the main cladoceran assemblage of a crater-lake in Japan. *Malaysian Applied Biology* 31(2): 1-7.

Razak, S.A., Yoshimine, T. & Saisho, T. 2002. Seasonal diel vertical migration of the main cladoceran assemblage in Lake Ikeda, Japan. *Journal of Bioscience* 13(1): 109-118.

Razak, S.A. & Saisho, T. 2004. Seasonal variations in egg-size, brood size and body length of *Bosmina longirostris* (Crustacea:Cladocera) from Lake Ikeda, Japan. *Malaysian Journal of Science*. 23(2): 19-29.

Razak, S.A. & Saisho, T. 2005. Seasonal variations in egg-size, brood size and body length of *Ceriodaphnia reticulata* (Crustacea:Cladocera) from Lake Ikeda, Japan. *Journal of Bioscience*. 16(1): 107-122.

Roche, K. 1990. Some aspects of vulnerability to cyclopoid predation of zooplankton prey individuals. *Hydrobiologia*. 198: 153-162.

Sakamoto, M. & Hanazato, T. 2008. Antennule shape and body size of *Bosmina*: Key factors determining its vulnerability to predacious copepod. *Limnology* 9: 27-34.

Ueno, M. 1969. Lateral head pores and other characteristics of *Bosmina fatalis* Burckhardt. *Annotationes Zooogicae Japanonenses* 41: 159-162.

Welch, P.S. 1952. *Limnology*. New York: McGraw Hill.

Williamson, C.E. 1986. The swimming and feeding behaviour of *Mesocyclops*. *Hydrobiologia* 134: 11-19.

Yan, N.D., Girard, R. & Boudreau, S. 2002. An introduced invertebrate predator (*Bythotrephes*) reduces zooplankton species richness. *Ecology* 5: 481-485.

Shaharudin Abdul Razak*
Institute of Biological Science
Faculty of Science
University of Malaya
50603 Kuala Lumpur
Malaysia

Toshio Saisho
Laboratory of Marine Biology
Faculty of Fisheries
Kagoshima University
Shimoarata 4-50-20
Kagoshima City 890
Japan

*Corresponding author; email: shahdin@um.edu.my

Received: 23 November 2009
Accepted: 1 October 2010