Bull. Fac. Fish. Hokkaido Univ.
40(3), 147-153. 1989.

Seasonal Distribution of *Eurytemora affinis* (Poppe, 1880) (Copepoda ; Calanoida) in Freshwater Lake Ohnuma, Hokkaido

Syuhei BAN* and Takashi MINODA*

Abstract

The seasonal distribution of *Eurytemora affinis* in the inland freshwater Lake Ohnuma, in southern Hokkaido, was investigated from June 7, 1984 to August 29, 1985. In Lake Ohnuma, *E. affinis* occurred for ten months from mid-April to the following February in a year, that is, all months other than the ice covered period. The nauplii appeared in mid-April, when adults were not observed. Adult females carrying eggs occurred in early May, and then the population density increased during the warm season, being 8.0×10^4 inds$\cdot$ m^{-3} at maximum in early June of 1984 and 1985. No recruitment was found between February and mid-April.

Introduction

Eurytemora affinis is widely distributed in most parts of the northern hemisphere (Gurney, 1931 ; Katona, 1970 ; Vaupel-Klein and Weber, 1975). In Japan this species inhabits fresh and brackish waters in Hokkaido and a few brackish waters in northwestern Honshu (Mizuno, 1984). Before the 1950s, however, *E. affinis* was collected only from a few brackish waters in Hokkaido (Motoda, 1950). Recently, it has become known that this species is also distributed in some inland lakes, for example in Lake Akan, Lake Shikaribetsu and Lake Ohnuma. In Lake Akan the occurrence of *E. affinis* instead of *Acanthodiaptomus pacificus* has been observed since 1975 (Hokkaido Fish Hatchery, 1975 ; 1976 ; 1977). In Lake Ohnuma the occurrence of *E. affinis* was first observed in 1981 (Hokkaido Fish Hatchery, 1982). This phenomenon that *E. affinis* spread from brackish to inland waters has been reported in North America (Engel, 1962 ; Faber and Jermolajev, 1966 ; Bowman and Lewis, 1989).

In most European and North American estuaries, *E. affinis* is present in substantial numbers throughout all seasons and commonly becomes abundant in 0-18‰ salinity (Cronin et al., 1962 ; Jeffries, 1962 ; Haertel et al., 1969 ; De Pauw, 1973 ; Soltanpour-Gargari and Wellershaus, 1984 ; 1985 ; Baretta and Malschaert, 1988). In the Chesapeake Bay, the Wadden Sea and some other estuaries, it is known that *E. affinis* occurred at higher salinities in winter than in summer (Bradley, 1975 ; Vaupel-Klein and Weber, 1975 ; Collins and Williams, 1981 ; Baretta and Malschaert, 1988). There have been only a few seasonal investigations of *E. affinis* in inland waters. An investigation in the Great Lakes reports that *E. affinis* increased between spring and summer, and disappeared from the lake water during the winter

* *Plankton Laboratory, Faculty of Fisheries, Hokkaido University*
(北海道大学水産学部浮游生物学講座)

(Balcer et al., 1984).

This paper deals with the seasonal distribution of *E. affinis* in the inland freshwater Lake Ohnuma, Hokkaido.

Materials and Methods

Lake Ohnuma is located in the Oshima Peninsula, in southern Hokkaido, and has a surface area of 5.12 km^2, with a maximum depth of 12.2 m and mean depth of 6.4 m (Handa and Araki, 1930). Three rivers flow into Lake Ohnuma and the lake water flows into Lake Konuma through a short and narrow passage (Fig. 1).

Weekly plankton samplings were performed at Stn T in the narrow passage (Fig. 1) for 15 months between June 7, 1984 and August 29, 1985. The depth at Stn T showed seasonal changes and was between 2 and 4 m. Although most parts of the lake were covered with ice and snow from late December 1984 to mid-April 1985, the narrow passage around Stn T was remained open throughout the study period because of a gentle flow.

Zooplankton was obtained with a 30 cm net (mesh opening; 100 μm) by replicate vertical hauls from the bottom to the surface. Replicates were carried out in order to obtain a sufficient amount for quantitative analysis. Water samples for examining chlorophyll *a* concentration was collected with a bucket, and water temperature at the surface was also recorded. The chlorophyll *a* concentration was

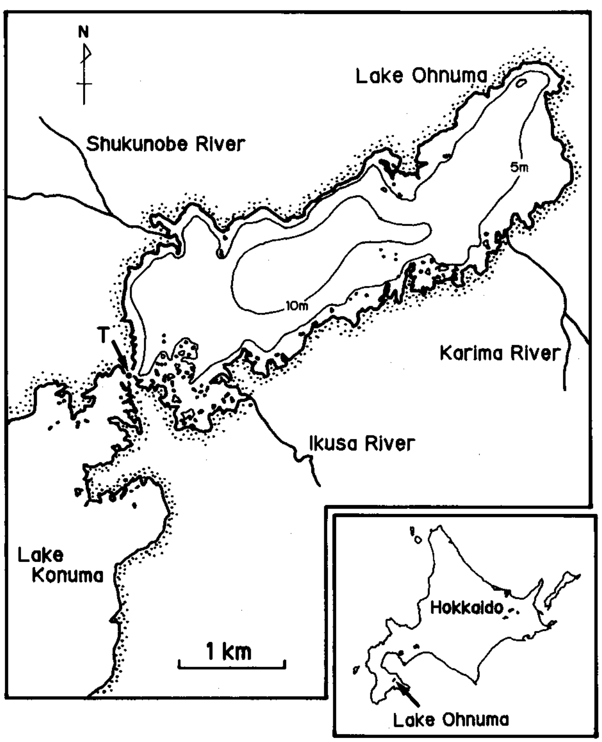

Fig. 1. Location of Lake Ohnuma and sampling station.

determined using the fluorometric method adopted by the Japan Meteorological Agency (Sato et al., 1981). All samples were preserved in 4-5% buffered formalin. Each developmental stage of *E. affinis* was identified and counted under a binocular microscope. Abundance was expressed as the number of individuals per cubic meter of water, assuming that the filtration efficiency of the net was 100% because the towing distance of a net was short.

Results

The surface water temperature ranged from 0.3°C in late December to 28.2°C in mid-August. Low temperatures (<4°C) were recorded from the end of December to mid-April during the ice covered period (Fig. 2). Water temperatures gradually increased from April to mid-August. Chlorophyll *a* concentration was high from May to October, but showed a large fluctuation between 5 and 10 $\mu g \cdot l^{-1}$. After the exclusive peak of 13.04 $\mu g \cdot l^{-1}$ on December 31, 1984, chlorophyll *a* concentration decreased. Low concentrations of chlorophyll *a* (<1 $\mu g \cdot l^{-1}$) continued in the latter half of the ice covered period (Fig. 2).

At Stn T *E. affinis* occurred for about ten months from mid-April to the following February (Fig. 3). A few nauplii appeared in mid-April, when adults were not obtained. Since adult females carrying eggs occurred in early May, nauplii sharply increased to maximum abundance in early June. Maximum abundance in each developmental stage of *E. affinis* was observed in early June in both 1984 and 1985, and this coincided with that of nauplii. The total population was 8.0×10^4 inds$\cdot m^{-3}$ of the annual maximum in early June. Abundance of all developmental stages drastically declined in mid-June. Nauplii and Copepodite stage I-IV (CI-IV) increased again in August, however, adults and CV were confined to a low density (<50 inds$\cdot m^{-3}$) in summer and autumn. The total abundance oscillated

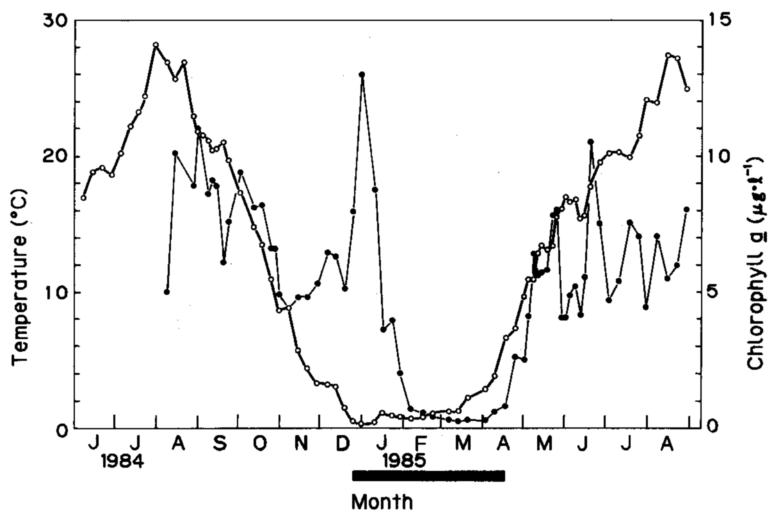

Fig. 2. Seasonal changes of surface water temperature (open circles) and chlorophyll *a* concentration (closed circles) at Stn T. Horizontal bar represents the ice covered period.

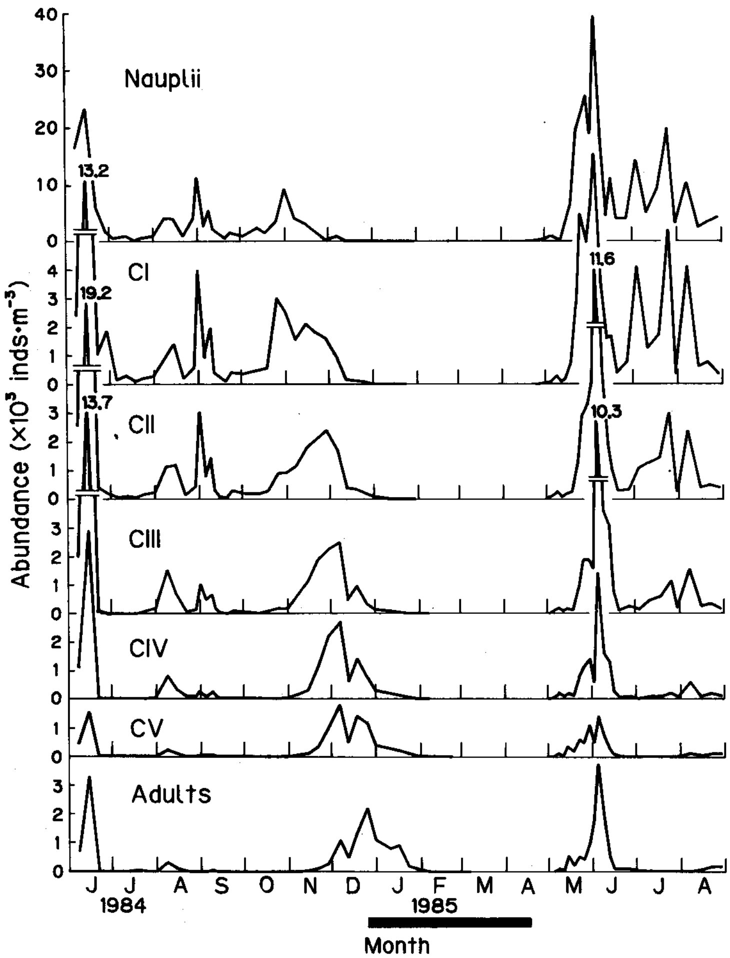

Fig. 3. Seasonal changes in abundance of each developmental stages of *Eurytemora affinis* at Stn T. Horizontal bar represents the ice covered period.

between July and September, being less than 3.0×10^4 inds$\cdot$m^{-3}. In 1984 nauplii were finally increased in October, but adults increased in mid-December. There was a time lag of two months in the abundance. A small number of a new recruitment was found in December and January, and no recruitment was found between February and mid-April. The period of no recruitment coincided with that of low chlorophyll *a* concentration (see Fig. 2).

Discussion

A large number on nauplius of *E. affinis* were observed from May to early November at Stn T. It is thought that this species reproduced during the period between spring and late autumn in Lake Ohnuma. A large number of nauplii were present at Stn T during summer and autumn in spite of the fact that adults were small in number. The adults were concentrated near the lake bottom in a deep basin in summer and autumn (Ban and Minoda, in preparation). The population density of *E. affinis* recorded 8.0×10^4 inds$\cdot$m^{-3} at maximum in the present study and can be compared with 10^5-10^6 inds$\cdot$m^{-3} in the upper estuaries (cf. Hada, 1957; Jeffries, 1962; Haertel et al., 1969; De Pauw, 1973; Heinle and Flemer, 1975; Roddie et al., 1984; Soltanpour-Gargari and Wellershaus, 1984). It is probable that *E. affinis* in Lale Ohnuma is well established as a lake population.

The *E. affinis* population disappeared for about two months between March and mid-April. No occurrence in winter was found in the Great Lakes in North America (Balcer et al., 1984) and Lake Ishikari in Hokkaido (Hada, 1957; Kurohagi and Osanai, 1963). Wells (1970) reported that *E. affinis* overwintered as eggs in Lake Michigan. Recently our data shows that *E. affinis* produces diapause eggs and hibernates as the egg stage for the severe period in Lake Ohnuma (Ban and Minoda, in preparation). On the other hand, in most European and North American estuaries, all developmental stages of *E. affinis* are present in substantial numbers during all seasons (Cronin et al., 1962; Jeffries, 1962; Haertel et al., 1969; De Pauw, 1973; Soltanpour-Gargari and Wellershaus, 1985; Baretta and Malschaert, 1988). *E. affinis* was abundant in winter and spring in the Ems estuary, in the Netherlands (Baretta and Malschaert, 1988). This means that *E. affinis* is able to reproduce even in winter.

In Hokkaido the occurrence of *E. affinis* was probably restricted to some brackish waters before the 1950s (Motoda, 1950), however, it has been distributed to some inland lakes; Lake Akan, Lake Shikaribetsu and Lake Ohnuma since the last decade (Hokkaido Fish Hatchery, 1974; 1975; 1976; 1981; Kurohagi, unpubl.). In North America *E. affinis* spread from estuaries or coastal waters into the Great Lakes since the 1960s (Engel, 1962; Faber and Jermolajev, 1966). Faber and Jermolajev (1966) suggest that *E. affinis* was probably carried from an estuary into the Great Lakes by the brackish bilge water of ocean-going ships. Recently, Bowman and Lewis (1989) reported a further northward extension of *E. affinis* in the Mississippi River and considered that the inland populations were introduced by human activities. Lake Ohnuma is a volcanic dammed lake, completely isolated from the sea. The introduction of *E. affinis* to the lake is caused by neither marine traffic nor penetration of brackish waters. In Lake Ohnuma a large number of pond smelt eggs, *Hypomesus transpacificus nipponensis*, have been introduced from several lakes every year since 1927, when the first introduction was made from Lake Abashiri (Motoda, 1950). We consider that artificial transportation of pond smelts may have played an important role in the immigration of *E. affinis*.

Acknowledgments

We are grateful to the colleagues of the Plankton Laboratory, Hokkaido University, for their help during the sampling.

References

Balcer, M.D., Korda, N.L. and Dodson, S.I. (1984). *Zooplankton of the Great Lakes: A guide to the* *identification and ecology of the common crustacean species*. 174 p. The University of Wisconsin Press, Ltd., Madison and London.

Baretta, J.W. and Malschaert, J.F.P. (1988). Distribution and abundance of the zooplankton of the Ems estuary (North Sea). *Neth. J. Sea Res.* **22**, 69-81.

Bowman, T.E. and Lewis, J.J. (1989). Occurrence of the calanoid copepod *Eurytemora affinis* (Poppe) in the Ohio River at Louisville, Kentucky. *J. Crustacean Biol.* **9**, 83-84.

Bradley, B.P. (1975). The anomalous influence of salinity on temperature tolerances of summer and winter populations of the copepod *Eurytemora affinis*. *Biol. Bull.* **148**, 26-34.

Collins, N.R. and Williams, R. (1981). Zooplankton of the Bristol Channel and Severn Estuary. The distribution of four copepods in relation to salinity. *Mar. Biol.* **64**, 273-283.

Cronin, L.E., Daiber, J.C. and Hulbert, E.M. (1962). Quantitative seasonal aspects of zooplankton in the Delaware River Estuary. *Chesapeake Sci.* **3**, 63-93.

De Pauw, N. (1973). On the distribution of *Eurytemora affinis* (POPPE) (Copepoda) in the Western Scheldt estuary. *Verh. Internat. Verein. Limnol.* **18**, 1462-1472.

Engel, R.A. (1962). *Eurytemora affinis*, a calanoid copepod new to Lake Erie. *Ohio J. Sci.* **62**, 252.

Faber, D.J. and Jermolajev, E.G. (1966). A new copepod genus in the plankton of the Great Lakes. *Limnol. Oceanogr.* **11**, 301-303.

Gurney, R. (1931). *British Fresh-water Copepoda. Vol. 1.* 238 p. The Ray Society, London.

Hada, Y. (1957). Seasonal variation of the zooplankton in Lake Ishikari in Hokkaido. *Bull. Suzugamine Women's Coll., Nat. Sci.* **4**, 71-91. (In Japanese with English resume).

Handa, Y. and Araki, S. (1930). Kosho chosa. Vol. 1. Ohnuma, Konuma, Junsainuma (The survey of lakes in Hokkaido. Vol. 1. The survey of Lake Ohnuma, Lake Konuma, and Lake Junsainuma), *Suisan Chosa Hokoku* **21**, 1-66. (In Japanese).

Haertel, L., Osterberg, C., Curl, H., Jr. and Park, P.K. (1969). Nutrient and plankton ecology of the Columbia River estuary. *Ecology* **50**, 962-978.

Heinle, D.R. and Flemer, D.A. (1975). Carbon requirements of a population of the estuarine copepod *Eurytemora affinis*. *Mar. Biol.* **31**, 235-247.

Hokkaido Fish Hatchery (1975). *Showa 49 Nendo Jigyo Seisekisho* (*Progress Report in 1974*). 208 p. Hokkaido Fish Hatch., Sapporo. (In Japanese).

Hokkaido Fish Hatchery (1976). *Showa 50 Nendo Jigyo Seisekisho* (*Progress Report in 1975*). 249 p. Hokkaido Fish Hatch., Sapporo. (In Japanese).

Hokkaido Fish Hatchery (1977). *Showa 51 Nendo Jigyo Seisekisho* (*Progress Report in 1976*). 239 p. Hokkaido Fish Hatch., Sapporo. (In Japanese).

Hokkaido Fish Hatchery (1982). *Showa 56 Nendo Jigyo Seisekisho* (*Progress Report in 1981*). 246 p. Hokkaido Fish Hatch., Sapporo. (In Japanese).

Jeffries, H.P. (1962). Salinity-space distribution of estuarine copepod genus *Eurytemora*. *Int. Revue ges. Hydrobiol.* **47**, 291-300.

Katona, S.K. (1970). Growth characteristics of the copepods *Eurytemora affinis* and *E. herdmani* in laboratory cultures. *Helgolander wiss. Meeresunters.* **20**, 373-384.

Kurohagi, T. and Osanai, M. (1963). Limnological studies on the old water ways of the Ishikari River. I. The seasonal variation of hydrographic conditions and plankton communities of the Ishikari-Furukawa. *Sci. Rep. Hokkaido Fish Hatch.* **18**, 123-146. (In Japanese).

Mizuno, T. (1984). Nihon no rikusui san Calanoida (Freshwater Calanoida in Japan). p. 475-499. In Mizuno, T. et al. (ed.), *Freshwater Copepoda*. 650 p. Tatara Shobo, Yonago. (In Japanese).

Motoda, S. (1950). Hokkaido koshoshi (Lakes in Hokkaido). *Sci. Rep. Hokkaido Fish Hatch.* **5**, 1-96. (In Japanese).

Roddie, B.D., Leadey, R.J.G. and Berry, A.J. (1984). Salinity-temperature tolerance and osmoregulation in *Eurytemora affinis* (POPPE) (Copepoda : Calanoida) in relation to its distribution in the zooplankton of the upper reaches of the Forth estuary. *J. Exp. Mar. Biol. Ecol.* **79**, 191-211.

Sato, N., Furuhashi, K. and Ebara, S. (1981). Extraction method of phytoplankton pigments without grinding for fluorometric measurement employed by Japan Meteorological Agency. *Bull. Plankton Soc. Japan* **28**, 173-178. (In Japanese with English abstract).

Soltanpour-Gargari, A. and Wellershaus, S. (1984). *Eurytemora affinis* — the estuarine plankton

copepod in the Weser. *Veroff. Inst. Meeresforsch. Bremerh.* **20**, 103-117.
Soltanpour-Gargari, A. and Wellershaus, S. (1985). *Eurytemora affinis* — one year study of abundance and environmental factors. *Ibid.* **20**, 183-198.
Soltanpour-Gargari, A. and Wellershaus, S. (1987). Very low salinity stretches in estuaries — the main habitat of *Eurytemora affinis*, a plankton copepod. *Meeresforsch.* **31**, 199-208.
Tomita, M. and Hada, Y. (1966). The relation between the food of *Hypomesus olidus* (PALLAS) and the plankton in Lake Ishikari. *Sci. Rep. Hokkaido Fish Hatch.* **21**, 81-90. (In Japanese with English resume).
Vaupel-Klein, J.C. von and Weber, R.E. (1975). Distribution of *Eurytemora affinis* (Copepoda: Calanoida) in relation to salinity: field and laboratory observations. *Neth. J. Sea Res.* **9**, 297-310.
Wells, L. (1970). Effects of alewife predation on zooplankton populations in Lake Michigan. *Limnol. Oceanogr.* **15**, 556-565.