霞ケ浦におけるイサザアミ（Neomysis intermedia）個体群の
夏季減少時の稚仔の高死亡率
High Mortality of Juveniles during the Summer Decline of the Mysid \textit{(Neomysis intermedia)} Population in Lake Kasumigaura\textsuperscript{1,2)}

HIDESHIGE TODA\textsuperscript{3)} AND MASAYUKI TAKAHASHI\textsuperscript{4)}

Institute of Biological Sciences, University of Tsukuba, Sakura-mura, Ibaraki 305\textsuperscript{3)},

and Department of Biology, University of Tokyo, Hongo, Tokyo 113\textsuperscript{4)}

Abstract

The summer decline of the mysid \textit{(Neomysis intermedia)} population was analyzed using field data from Lake Kasumigaura. High mortality of juveniles occurred in both summers of 1980 and 1981. A significant positive relationship was found between water temperature and the mortality of juveniles. A laboratory experiment showed that the juvenile mortality increased at higher temperatures. Temperature damage was suggested to be a possible cause of the high summer mortality of juvenile \textit{N. intermedia}.

Summer decreases in mysid populations have been reported for some temperate estuarine species such as \textit{Neomysis americana} Smith (HOPKINS 1965), \textit{N. awatschensis} Brandt (=\textit{N. mercedis} Holmes) (HEUBACH 1969, SIEGFRIED et al. 1979), \textit{N. integer} Leach (BREMER & VIJVERBERG 1982), and \textit{N. intermedia} Czerniawsky (TODA et al. 1982). HEUBACH (1969) found that the summer decline of \textit{N. awatschensis} population was associated with high water temperature (22°C<). Fish predation has also been proposed as one of the possible causes for those summer declines (HEUBACH 1969, TODA et al. 1982).

Previous studies, however, pointed out only relationships between the change in mysid abundance and some environmental factors. The density change of a given population is a result of the balance between its birth and death rates. A decline in a population will be due to a decrease in birth rate and/or an increase in death rate. In order to understand the population dynamics of mysid species, analyses on the change in birth and death rates will be required.

In the present study, we focused on the mortality during the summer decline in the \textit{N. intermedia} population in a shallow brackish lake, Lake Kasumigaura, which is considered to be the southern distribution limit of \textit{N. intermedia} (MURANO 1963). We found a high mortality of juveniles in the summer, and suggest the temperature damage on juvenile \textit{N. intermedia}.

Materials and Methods

Mysids were collected at night by vertical hauls from the bottom (4 m) to the surface with a
The mysids show a diel vertical movement throughout the year, and are evenly distributed through the whole water column at night (TODA et al. 1983b). Temperature was measured in situ and chlorinity was determined by the Mohr's silver titration method for the water collected at the surface. The mysid samples, preserved in 5-10% formalin, were counted and measured by carapace lengths with an eyepiece micrometer for a whole or sub-sample. The eggs of 20-100 gravid females were removed from marsupia, and were counted under a stereoscopic microscope.

In order to estimate the mortality of juveniles in the lake, we used the survival ratio between the number of individuals released from marsupia per day \((R_e, \text{ no. day}^{-1})\) and that passing a given growth stage per day \((R_J, \text{ no. day}^{-1})\). The growth stage of the mysid was evaluated by carapace length; carapace length of a newly released juvenile is 0.65 mm, and 1 mm was arbitrarily selected for the given growth stage. \(R_e\) and \(R_J\) are calculated as follows: \(R_e = N_e \cdot D_e^{-1}\), \(R_J = N_J \cdot D_J^{-1}\), where \(N_e\) (no. m\(^{-2}\)) and \(N_J\) (no. m\(^{-2}\)) are the number of eggs and the number of juveniles of less than 1 mm carapace length on each sampling, respectively, and \(D_e\) (days) and \(D_J\) (days) are durations from egg laying to releasing and from 0.65 mm to 1 mm carapace length, respectively. Instantaneous mortality \((m, \text{ day}^{-1})\) was calculated from \(m = \ln (R_J \cdot R_e^{-1}) \cdot D_J^{-1}\). These calculations of survival ratio \((R_J \cdot R_e^{-1})\) and mortality \((m)\) were made under the assumption of a constant egg laying rate over the two stages (egg and juvenile stages), and no mortality during each stage. That is, mortality occurs only between stages.

![Fig. 1. Relationships between temperature, and durations from egg laying to releasing \((D_e, \text{ circles})\) and durations from 0.65 mm to 1 mm carapace length \((D_J, \text{ triangles})\) of Neomysis intermedia. Dotted line for \(D_e\) was fitted by the Bělehrádek equation: \(D_e = 408 \cdot (T - 2.9)^{-1.31}\), where \(T\) is temperature in °C, and that for \(D_J\) was fitted by eyes.](image-url)
$D_e$ was determined by laboratory culture experiments using 3–7 gravid females at each temperature of 10°, 15°, 18°, 20°, and 25°C in seawater diluted 100 times with aged tap water, with an excess food of cladocerans. $D_j$ was estimated from the growth rates in carapace length, which were converted from the growth rates in body length (TODA et al. 1984) using the following relationship: body length $= -0.28 + 3.44 \times$ carapace length (TODA et al. 1982). Figure 1 shows the relationships between temperature, and $D_e$ and $D_j$. $D_e$ (days) can be described as a function of temperature by Bělehrádek equation: $D_e = 408 \cdot (T - 2.9)^{-1.33}$ ($n=5$, $r^2=0.999$), where $T$ is temperature in °C. Since there was no suitable equation for the approximation of $D_j$ as a function of temperature, we used a curve fitted by eyes. Both $D_e$ and $D_j$ were then estimated from in situ water temperature by using these relations.

In order to examine the possible temperature dependency of the mortality of juveniles, 10 to

![Graph showing seasonal changes in the density of Neomysis intermedia population in the entire water column, and temperature and chlorinity at the surface in Lake Kasumigaura in 1980 and 1981.]
20 of the juveniles, which were newly released from gravid females collected in October 1984, were cultured in the laboratory over 8 days using lake water (41 mg Cl·l⁻¹) at each temperature of 15°, 20°, and 23°C, with an excess food of rotifers.

Results
Figure 2 shows the seasonal changes in the density of the *N. intermedia* population in the entire water column, and temperature and chlorinity at the surface in Lake Kasumigaura in 1980 and 1981. The *N. intermedia* population existed throughout the year in the lake (TODA et al. 1982). The population increased from winter to spring, reaching its maximum density of 10⁴ individuals·m⁻² in April and early May. Thereafter the population showed a marked decline over two orders of magnitude during 2-3 months in summer. The minimum density, observed in July, was 10² individuals·m⁻² in 1980 and 10 individuals·m⁻² in 1981. The population increased again from mid- or late August, and attained a second maximum in November. The maximum density in fall exceeded 10⁴ individuals·m⁻² in 1980, but it was 5×10³ individuals·m⁻² in 1981 and a slight depression was observed in October of 1981. In

![Graphs showing seasonal changes in survival ratios and mortality of Neomysis intermedia. Symbols of crosses and triangles indicate mortality calculated on assumed survival ratios of 0.1 and 0.01, respectively.](image-url)
December the density of mysids started to decrease in both years.

Surface water temperature varied from 3°-5°C in winter to 30°C in summer (TODA et al. 1983a). It was noticed that there was some differences in the seasonal pattern of water temperature between 1980 and 1981. In 1980 surface water temperature showed a sharp increase in spring, but it increased little after mid-June. The temperature was lower than 25°C during most of the summer of 1980. In 1981 water temperature in May and June was lower than that in 1980, but it showed a rapid increase in July and exceeded 25°C from mid-July to August. Surface chlorinity showed no marked seasonal change but fluctuated between 30 and 40 mg Cl·l⁻¹ except for early November in 1981, when chlorinity temporarily decreased to 23 mg Cl·l⁻¹, probably due to the increased inflow from rivers by typhoon.

In the following analysis we focused on the summer decline of the *N. intermedia* population, and therefore we restricted the period of analysis from April to October. Since the survival ratios were zero in the summer of 1981, it was not possible to calculate mortality by the equation given in the previous section. We tentatively applied the values of 0.1 and 0.01 for the survival ratios during that period.

Seasonal changes in survival ratios ($R_t R_e^{-1}$) and mortality ($m$) of juvenile *N. intermedia* are shown in Fig. 3. Although there are large fluctuations observed in both values, a clear and consistent trend was found in their seasonal patterns. The survival ratios were low and the

![Fig. 4. Relationship between temperature and mortality of *Neomysis intermedia*. Symbols of crosses and triangles indicate mortality calculated on assumed survival ratios of 0.1 and 0.01, respectively.](image-url)
mortality was high in both summers of 1980 and 1981. The survival ratios were 0 to 0.1 and the mortality was as high as 0.5 to 1.3 day$^{-1}$ from mid-July to August or September. Low survival ratios and high mortality were also noticed in May and June in 1980 and in early October in 1981.

A significant positive relationship was found between the mortality of juveniles and surface water temperature (Fig. 4, $r=0.395$ when the assumed values are excluded, $n=50$, $t=2.997$, $p<0.01$). The mortality of juveniles increased at higher temperatures. The relationship suggests that the temperature increase is a possible cause of high mortality of juveniles observed in the summer.

In order to confirm this possibility, we reared newly released mysids at 15°, 20°, and 23°C in the laboratory using lake water. Figure 5 shows the survivorship curves of the juveniles over 8 days. All the juveniles survived over 8 days at 15°C. However, the survival ratio decreased with the increase in temperature. Only 50% of the juveniles remained alive at 20°C, and no survival was noticed at 23°C, on the 8th day. MURANO (1966) reported a higher upper lethal temperature such as 35°C by an acute test. However, his result is not directly comparable with the present study because chronic effects on an individual growth, survival, and reproduction cannot be appropriately evaluated by the acute test (cf. GENTILE et al. 1982).

**Discussion**

FAGER (1973) has pointed out the difficulties of the estimation of zooplankton mortality in the field, based on relative numbers of individuals of adjacent developmental stages. He showed that there was a range of values of the mortality that could be consistent with the observed relative numbers of individuals, unless some assumptions such as constancy of mortality over the adjacent stages were made.

For simplicity we made some unrealistic assumptions to calculate the mortality of juveniles (see Materials and Methods). However, even if we made more realistic assumptions, in which mortality was the same for the two adjacent stages or mortality in the first stage (the egg
stage) was zero, the seasonal pattern of mortality of juveniles still remained the same. When mortality over the two adjacent stages was assumed to be the same, the variation in the values of mortality decreased, and when mortality in the egg stage was assumed to be zero, that variation increased.

It is also possible to calculate mortality in the egg stage assuming zero mortality in juveniles. In that case severe mortality would have caused the egg age distribution to be dominated by younger eggs. The egg age distribution could be assessed by using the Kolmogorov-Smirnov statistic, $d_{\text{max}}$ with sign (THRELKELD 1979). The $d_{\text{max}}$ has a range from $+1$ to $-1$, and positive values of $d_{\text{max}}$ indicate the egg age distributions dominated by younger stages. Most of the values of $d_{\text{max}}$ calculated for the eggs of the $N. \text{intermedia}$ population did not greatly deviate from zero in the summer. The maximum, minimum, and average values of $d_{\text{max}}$ in July and August were $+0.12$, $-0.41$, and $-0.14$ in 1980, and $+0.4$, $-0.63$, and $-0.03$ in 1981, respectively (TODA unpubl.). These results indicate that the severe mortality of $N. \text{intermedia}$ would not have mainly occurred in the egg stage but in the juvenile stage in summer. There was few gravid females that had degraded embryos in their marsupia in the lake.

There may be only a little meaning in the absolute values of mortality calculated in the present study, but the seasonal pattern of mortality shown in Fig. 3, and the correlation between mortality and temperature (Fig. 4) would still be valid. Furthermore, the temperature dependency of juvenile mortality was supported by the laboratory experiments (Fig. 5). However, the large variation found between juvenile mortality and temperature (Fig. 4, $r^2=0.16$) suggests that other environmental factors in addition to temperature would also have relation to the juvenile mortality in the lake.

We found that a high mortality of juvenile $N. \text{intermedia}$ occurred in summer in Lake Kasumigaura, and suggest that high temperature is a possible cause of high mortality of the newly released mysids in the lake. This implies that the cold temperate species (MURANO 1963), $N. \text{intermedia}$, has not fully adapted to high temperature in summer in Lake Kasumigaura, though it maintains its population throughout the year and builds up an enormous population in spring and fall in the lake. No resting stage has been known for this species.

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Literature Cited


