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Difficulties in estimating mortality rates of *Eurytemora affinis* in the brackish water region of the Elbe estuary.

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Abstract : Mortality rates of the copepod *Eurytemora affinis* from the Elbe estuary were estimated. From April to September 1989 six samples were taken twice a week during the flood phase at an anchor station (km 695) in the oligohaline section of the Elbe estuary.

Maxima of different instars were found at different times during the flood phase. The peaks of abundance were shifted from low to high water as the organisms grew older : it seems that the population would be slowly driven out of the estuary.

To obtain a representative value of the population density for the calculation of mortality rates a weighted average of the abundance of each sampling day was used. With these data cohort analysis was carried out. Highest daily mortality rates occurred between naupliar stages V and VI. Mean mortality rates of nauplii were 0,15-0,26 d^{-1}. For copopodids low daily mortality rates of 0,05 d^{-1} were estimated. Mortality in estuaries not only consists of predation and physiologically death. In addition the transport of animals from upstream and losses of animals to the downstream part of the estuary that the spatial separated maxima of different instats of *Eurytemora affinis* during a tidal phase affected the estimation of mortality rates.

Résumé : Les taux de mortalité du Copépode *Eurytemora affinis* ont été estimés dans l'estuaire de l'Elbe. D'avril à septembre 1989, six échantillons ont été prélevés deux fois par semaine à marée montante dans une station fixe (km 695) située dans la zone oligohaline de l'estuaire de l'Elbe. Les maximums des différents stades de développement sont observés à différents moments au cours du flot. Les pics d'abondance sont décalés de la basse mer vers la haute mer au fur et à mesure que les organismes deviennent plus âgés.

Il semble bien que la population soit déportée lentement hors de l'estuaire. De manière à obtenir une valeur de densité représentative de la population pour le calcul des taux de mortalité, une moyenne pondérée de l'abondance obtenue à chaque date d'échantillonnage a été utilisée. A partir de ces données, une analyse de cohorte a été pratiquée. Les plus forts taux journaliers de mortalité se produisent entre les stades naupliens V et VI. Les taux moyens de mortalité des nauplii se situent entre 0,15 et 0,26 j^{-1}. Pour les copépodites, les taux de mortalité sont plus faibles, de l'ordre de 0,05 j^{-1}. En milieu estuarien, la mortalité ne résulte pas uniquement de la prédation et du stress physiologique. Le transport des individus depuis l'amont et les pertes vers la partie aval influencent également les taux de mortalité. Il a pu être montré pour l'estuaire de l'Elbe que la séparation spatiale des différents stades de développement de *Eurytemora affinis* pendant le cycle de marée pouvait affecter l'estimation des taux de mortalité.

INTRODUCTION

Population dynamics of zooplankton are mainly regulated by natality and mortality rates. The precision of a mortality rate depends on the estimation of the number of individuals belonging to a population and the time interval between sampling dates. The difficulty in estuaries is to obtain a representative value of population density. Advective processes caused by tidal action are responsible for high variability within zooplankton samples. So the distribution of the population during a tidal cycle has to be well-known to develop an adequate sampling strategy. The problem of sampling strategies is discussed by Gagnon &

Lacroix (1982) and Sameoto (1975). For the Elbe estuary an investigation in 1986/1987 showed that the distribution of the different instars of *Eurytemora affinis* during a tidal cycle was not uniform (Peitsch & Kausch, accept.). So the strategy was to sample at least half a tidal cycle because maxima of different instars were found at different times during a tidal phase.

Investigation of population dynamics of *Eurytemora affinis* in the Elbe estuary were carried out in spring and summer 1989.

There are only a few investigations of population dynamics of zooplankton in european estuaries (Arndt, 1985 ; Castel & Feurtet, 1989 ; Christiansen, 1988 ; Formsma, 1978).

METHODS

Sampling

Zooplankton samples were collected from April to September 1989. Sampling was carried out at an anchor station near the city of Brunsbüttel (km 695) in the oligohaline region. It started at low water and samples were taken every hour until high water. Samples were taken every three or four days.

Zooplankton samples were collected using an electric driven pump with a capacity of 40 l/min. Integrated samples were taken from the river bottom to water surface. 10 l water thus obtained were poured through a 55 µm mesh and preserved in 4 % buffered formaldehyde. Abundance of the different instars of *Eurytemora affinis* was recorded as numbers per liter.

Calculating

To get a representative value of population density the individuals of the population were regarded as a load and therefore the total numbers (L) of an instar passing through the cross section during a flood phase were estimated. The flow of water (Q) through the cross section at km 695 for the time interval from the middle of the time distance between two samplings (S_0, S_1) to the middle of the time distance between the following samples (S_1, S_2) was calculated and multiplied with the number (N) of individuals. This was repeated for all six samples. By using this method samples taken at high current velocities become more important, because more water passes the cross section during the same time interval.

1. Calculation of water flow through the cross section :

$Q = A * v * t$

v = mean current velocity at cross section km 695 during time interval t

A = area of cross section at km 695

$$t = \frac{t1-t0}{2} + \frac{t2-t1}{2}$$

2. Total numbers of an instar passing the cross section during flood tide :

$L = Q_1 * N_1 + Q_{12} * N_2 + \dots\dots\dots\dots Q_6 * N_6$

N = numbers of instar i in the samples

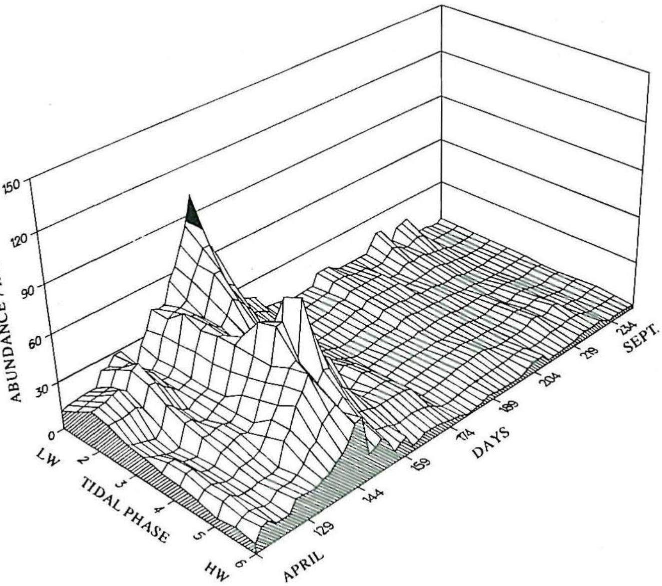

Fig. 1 : *Eurytemora affinis*. Seasonal and tidal dependent distribution of the abundance of naupliar II.

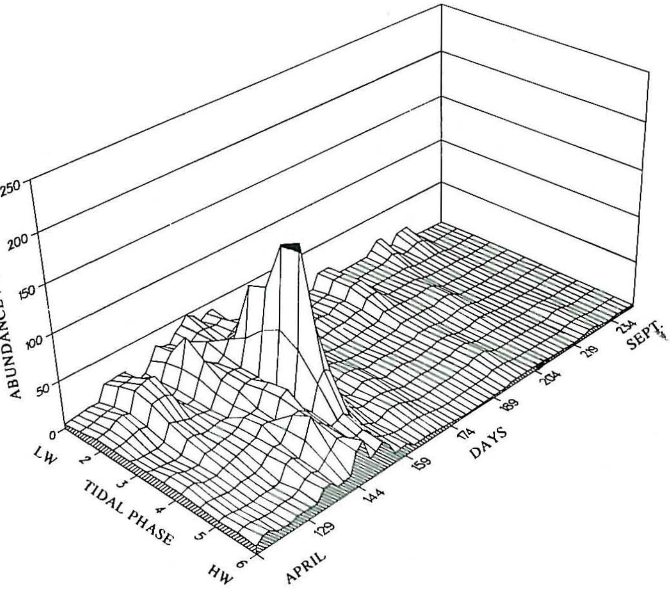

Fig. 2 : *Eurytemora affinis*. Seasonal and tidal dependent distribution of the abundance of naupliar III.

For further calculations of population dynamics it was necessary to get *one* representative value of N for each sampling day. Therefore a weighted average was calculated :

$$Na = \frac{L}{Vf}$$

Na = weighted numbers of instar i

Vf = flood volume ($Q_1 + Q_2 ......+ Q_6$)

Now a two-dimensional distribution of seasonal development of every instar could be plottet. Based on this data cohort analysis of Rigler & Cooley (1974) were used to investigate population dynamics.

The number of an instar in a cohort (Ni) was calculated from the area under the curve of a cohort divided by instar duration time.

For calculation of mortality rates the formula of Landry (1978) was used.

$$m = \frac{-\ln\left(\frac{Ni+1}{Ni}\right)}{t}$$

m = mortality rate

Ni = numbers of instar i

Ni + 1 = numbers of instar i + 1

t = time interval

RESULTS

Distribution

The abundance in every sample (six samples) during the flood phase and the seasonal development of the different instars of *Eurytemora affinis* is shown (Fig. 1 to 4). At the end of May and beginning of June the population maximum occurred. Maximum of the naupliar II (Fig. 1, maximum marked black) was found at low water. The maximum of the naupliar stage III (Fig. 2) is located at the beginning of the flood phase. Copepodid I (Fig. 3) showed highest abundance in the middle of the flood phase and the corresponding maximum of the adults (Fig. 5) appeared at high water.

The maxima of the different instars during the flood phase were found at different times during the flood phase. As the organisms grew older in spring time the abundance maximum was shifted from low to high water and it seems that the population is slowly driven out of the estuary.

Separation of cohorts

Fig. 6 shows seasonal development of the population based on the calculated abundances (Na) of each instar. Three cohorts could be separated by the method of Rigler & Cooley (1974). The first cohort started in at the beginning of May and the third cohort ended at the end of August.

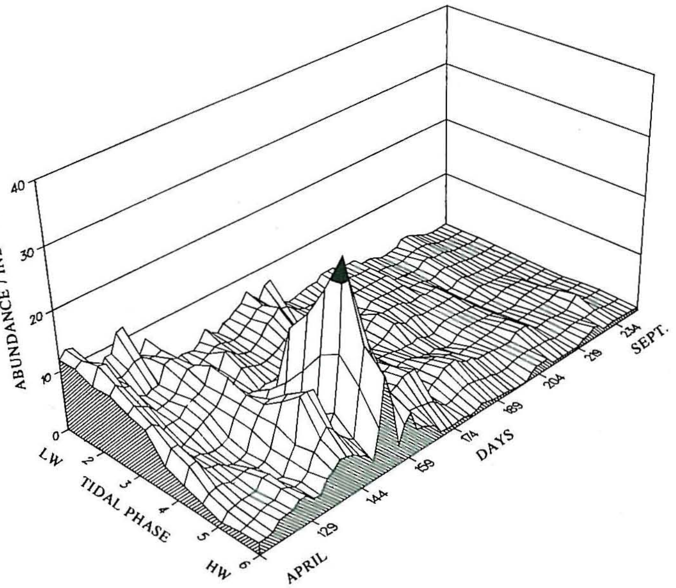

Fig. 3 : *Eurytemora affinis*. Seasonal and tidal dependent distribution of the abundance of copepodid I.

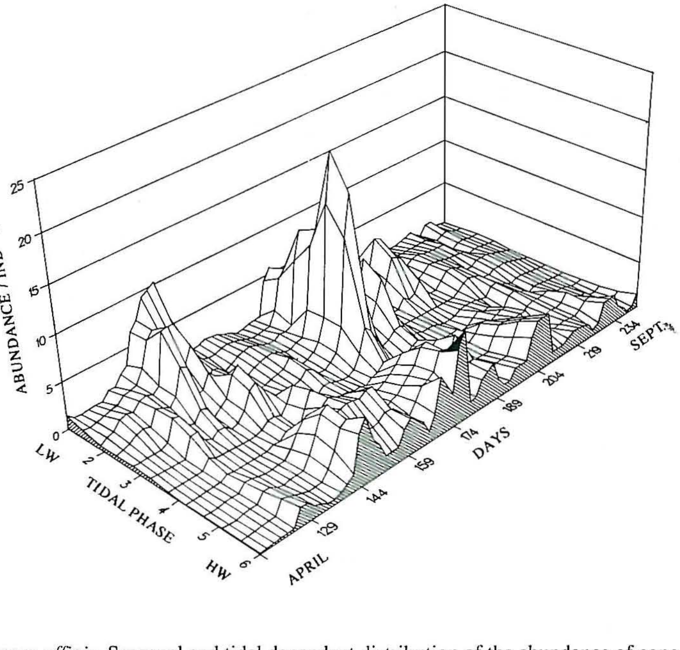

Fig. 4 : *Eurytemora affinis*. Seasonal and tidal dependent distribution of the abundance of copepodid IV.

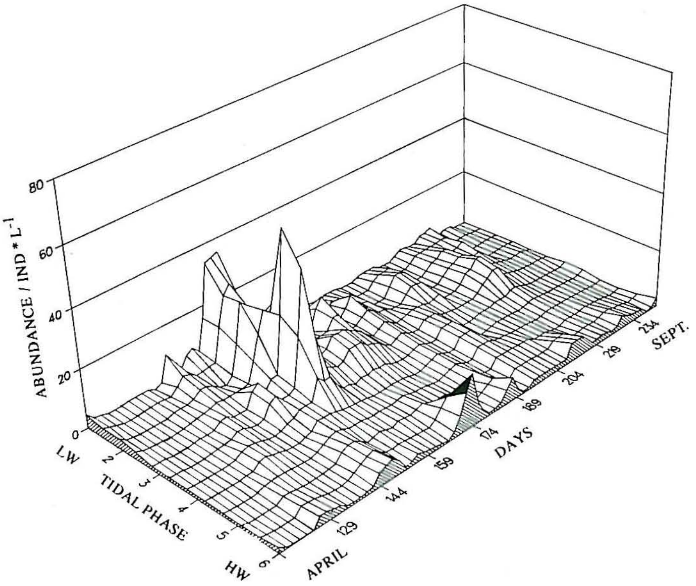

Fig. 5 : *Eurytemora affinis*. Seasonal and tidal dependent distribution of the abundance of adults.

Mortality rates

Instantaneous daily mortalitry rates are shown in Fig. 7-9 for the different instars of the three cohorts. In all cohorts highest daily mortality rates occurred between naupliar stages V and VI and lowest between the first and second copepodid stage. The mean mortality rates of naupliar and copepodids are compared in Tab. I. The mortality rates of the copepodid stages were equal in all three cohorts. Changes of the mortality rate of the naupliar have great influence on the survival rate, which was highest in cohort 2 where lowest mortality of naupliar occurred.

TABLE I

Mean mortality rates (d^{-1}) of naupliar and copepodid stages of *Eurytemora affinis*.

	naupliar	copepodid
cohort 1	0.26	0.05
cohort 2	0.15	0.05
cohort 3	0.25	0.05

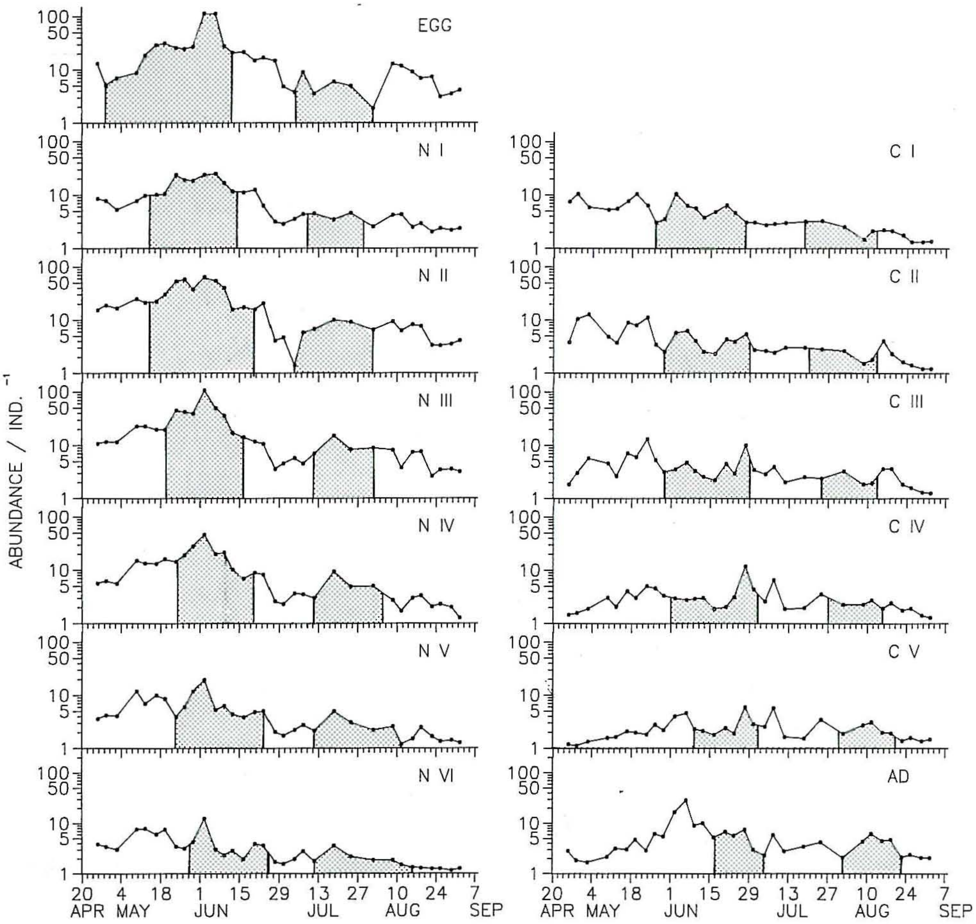

Fig. 6 : Cohorts of different instars of *Eurytemora affinis*.

DISCUSSION

It is an important result that in the Elbe estuary the distribution of the different instars of *Eurytemora affinis* is not uniform during flood phase. As it could already be shown by (Peitsch & Kausch, accept.) for a tidal cycle in 1987 maxima of the instars occur at different times during the tidal phase. So sampling has to include more than one or two samples during a half tidal cycle to catch maxima of all instars. Sampling at hourly intervals are regarded as sufficient because it could be shown that regular tidal dependant change in the instar density occurs (Peitsch & Kauch, accept.).

A representative value of the number of each instar is obtained by calculating a weighted average, which takes into account the different current velocities. A numerical average could lead to an overestimation of the numbers of an instar if the maximum is found during low current velocities or to an underestimation if maximum abundance occurs at high flow.

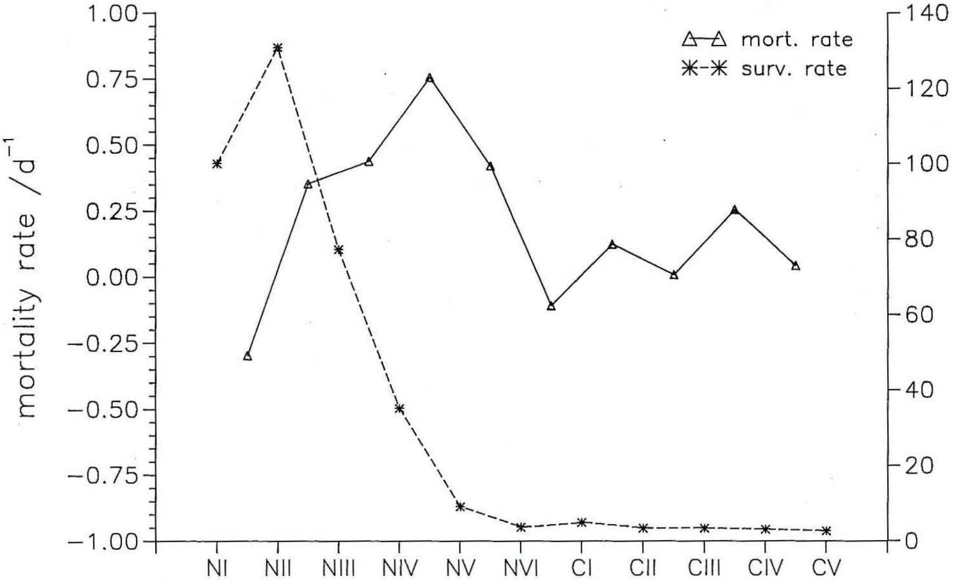

Fig. 7 : Daily mortality rates and survival rates of different instars of *Eurytemora affinis* in cohort 1.

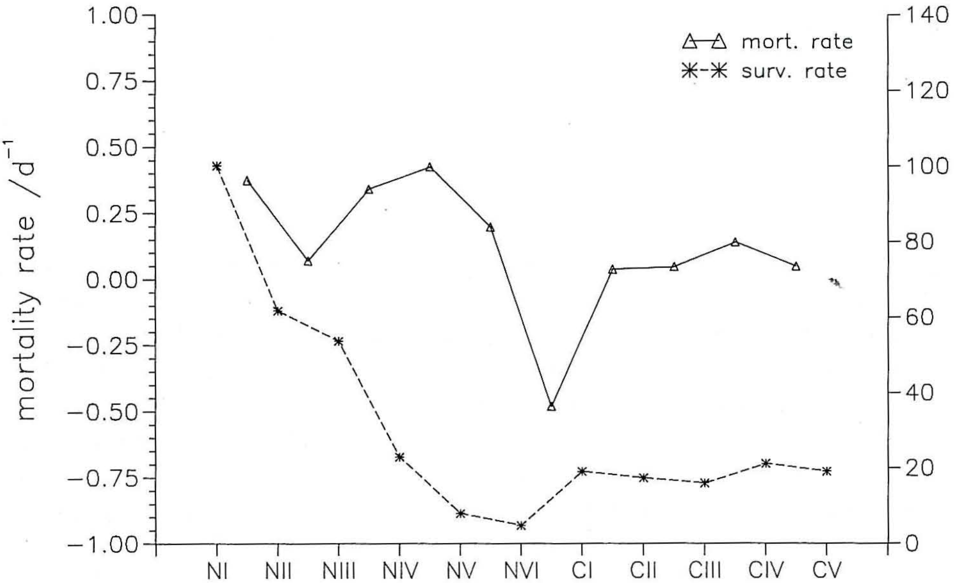

Fig. 8 : Daily mortality rates and survival rates of different instars of *Eurytemora affinis* in cohort 2.

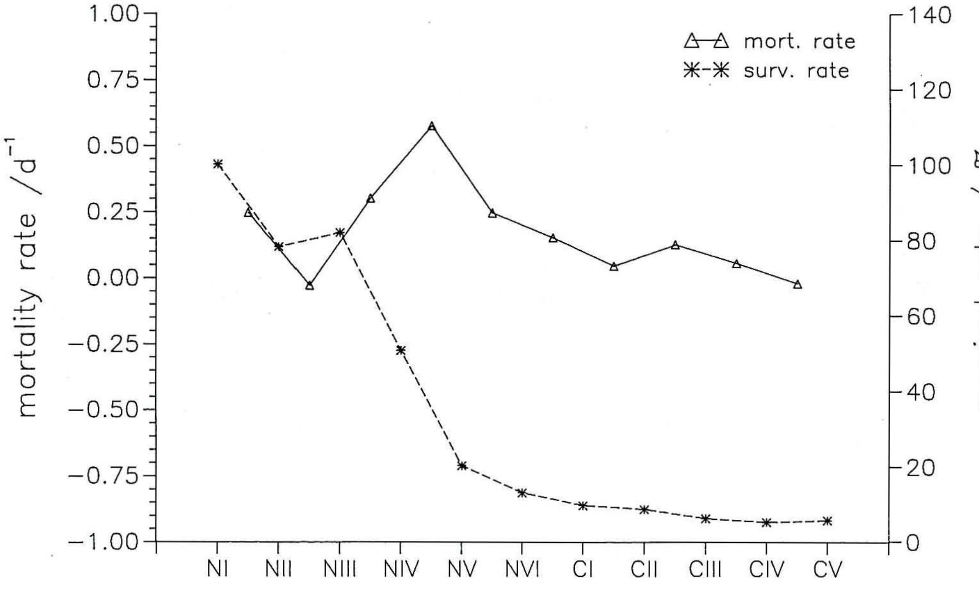

Fig. 9 : Daily mortality rates and survival rates of different instars of *Eurytemora affinis* in cohort 3

Over- or underestimation in fact will cause too low or high mortality rates. So treating the instars as a load and taking samples in sufficient short time intervals, will minimize the error, which is caused by the unequal distribution of the population and the special hydrographic conditions of estuaries.

Even calculating a representative number of individuals of each instar this way, a wrong estimation could be possible. Only a distinct section of the estuary is recorded by sampling during flood phase. At every tide individuals from upstream were added to the population and at the downstream boundary animals get lost from this section. For example the older copepodids i.e. C IV (Fig. 4), show more than one maximum during flood phase of one sampling day. This "additional" maximum at low water could be the reason for an overestimation of numbers of these stages and therefore to low values for the mortality rate are calculated. In addition it has to be taken into account that the development of the population is not uniform in different regions of the estuary. Lower flushing rates in flat water regions or branches of the river may support population development there. Especially, in the Elbe estuary these regions are assumed to be important breeding areas for the *Eurytemora affinis* population. In other estuaries salt marshes are supposed to be breeding places for *Eurytemora affinis* and *Acartia tonsa* (De Pauw, 1973 ; Trinast, 1975).

To solve this problem one needs good models of real flushing and exchange rates of water masses to calculate more realistic mortality rates.

Of course mortality rates in estuaries are also composed of predation rates and physiological death.

An explanation of the high mortality rates of the naupliar stages could be an age dependent mortality like Fager (1973) postulated it for zooplankton. High naupliar mortality for *Eurytemora affinis* was also found by Allan *et al.*, (1976). Mortality rates in the Elbe estuary in spring time were only a little bit higher than estimated by Heinle & Flemer (1975) for the Patuxent river estuary. In the Elbe estuary in spring invertebrate predators and fish larvae feed on naupliar, especially *Osmerus eperlanus* is an important predator of *Eurytemora affinis* (Ladiges, 1935). A regulation of populations at the level of early instars is often found for populations which produce a lot of descendants. Daan (1989) regards food limitation as a reason of high naupliar mortality in the north sea.

In summer fish larvae had grown up and naupliar mortality decreased in the Elbe estuary.

Until now the different components of the mortality rates could not be separated. The contribution of predators and food limitation to mortality rates has to be investigated in particular to get an idea of the special part of "mortality" caused by estuarine conditions.

For the Elbe estuary the importance of the distribution dependent error in estimating mortality rates could be shown.

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