Long-term Investigation of the Distribution of *Eurytemora affinis* (Calanoida; Copepoda) in the Elbe Estuary*

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With 4 Figures and 3 Tables

Key words: Estuary, *Eurytemora affinis*, distribution, river discharge, transport

Abstract

The seasonal and longitudinal distribution of the copepod *Eurytemora affinis* in the Elbe Estuary was studied using long-term data from 1986 to 1994. At an anchor station in the oligohaline zone of the estuary maximum abundance was always found between April and the beginning of June, but maximum numbers showed high interannual variations. During longitudinal sampling maximum abundance of *Eurytemora affinis* was found at different geographical positions between the city of Hamburg (km 630) and the North Sea (km 720). Variation in temperature and salinity could not sufficiently explain the observed differences in distribution patterns of *Eurytemora affinis*. River discharge turned out to be the most important factor controlling the geographical position of maximum abundance within the estuary. The observed distributions along the axis of the river suggest that the main habitat of the copepod is located in the freshwater region of the estuary near Hamburg. The position of maximum abundance is located more downstream during periods of high river discharge and more upstream during periods of lower discharge rates.

Introduction

Estuarine research has become more intensive in the last 15 years but there are very few long-term studies on zooplankton distribution. The zooplankton of the Elbe Estuary was investigated by JENS (1953), KÜHL & MANN (1962, 1967) and SOLTANPOUR-GARGARI & WELLERSHAUS (1987). The calanoid copepod *Eurytemora affinis* accounts for 90–99% of crustacean zooplankton abundance throughout the year (PEITSCH 1992). *Eurytemora affinis* was first mentioned by DAHL (1893). BURCKHARDT (1935) already described swarms of this species in the region of Schweinesand / Hahnöfer Sand (Elbe km 630–650). Seasonal abundance of *Eurytemora* was described for the Baltic Sea (VUORINEN & RANTA 1987; ERIKSSON et al. 1977), the Schlei Fjord (SCHNACK & BÖTGER 1981; CHRISTIANSEN 1988) and the Barther Bodden (ARNDT 1989). Different investigations describe *Eurytemora* to be an important zooplankton organism of European estuaries: in Severn Estuary, England (MOORE et al. 1979); in Forth Estuary, Scotland (RODDIE et al. 1984); in the Gironde (CASTEL & FEURTET 1986); in the Western Scheldt Estuary (DE PAUW 1973; BAKKER & DE PAUW 1975), in the Ems-Dollard-Estuary (BARETTA 1977) and in the Weser (SOLTANPOUR-GARGARI & WELLERSHAUS 1984).

From January 1986 to December 1995 the Elbe Estuary was investigated under different aspects by the research project: “Relationship between abiotic and biotic processes in the tidal Elbe river”. The calanoid copepod *Eurytemora affinis* was the main subject of different studies on zooplankton (BERNÁT 1988; POSEWANG-KONSTANTIN 1990; ORTEGA 1991; PEITSCH 1992; KÖPCKE, unpubl. data). Special aspects of distribution, population dynamics, production and grazing rates were investigated (PEITSCH 1992, 1993, 1995; BERNÁT et al. 1994). The present study tries to fill the lack of long-term investigations by summarizing data on seasonal abundance and longitudinal distribution of *Eurytemora affinis* in the Elbe Estuary from 1986 to 1994. These data could give more insight into the factors controlling the distribution of the dominant copepod within this estuary.

Material and Methods

Study area

The Elbe Estuary (Fig. 1) is a coastal plain estuary, which opens funnel-shaped to the German Bight (North Sea). The river has a total length of 1143 km. Since 1960 a weir at km 586 (city of Geesthacht)....

* This paper is dedicated to Prof. Dr. HARTMUT KAUSCH on the occasion of his 60th birthday.
forms an upstream boundary to the tide. The estuary is channelized to a large extent since the beginning of this century. Tides follow a semi-diurnal rhythm, and the mean tidal range varies between 2 m and 5 m (DuWE 1990). Estuarine conditions in the Elbe river are characterized by a steep salinity gradient, a zone of high turbidity and high current velocities. According to its salinity profiles, the estuary is classified as partially mixed (DuWE 1989).

Sampling

Zooplankton samples were collected using an electric driven pump with a capacity of 40 l min⁻¹ which was connected to a tube. Integrated samples were taken by constantly rising the end of the tube from the bottom of the river to the surface using an electric winch. During longitudinal sampling in 1993 and 1994 samples were taken from a depth of 2 m.

In most cases 10 l, in winter sometimes 20 l, were sieved through a 55 µm mesh concentrator. Samples were preserved with buffered (Hexamethylenetetramin) formaldehyde (4%). Individuals of *Eurytemora affinis* were counted using a dissecting microscope and the abundance was recorded as numbers per liters.

Salinity and temperature were measured by a probe (ME Meeres-elektronik; Trappenkamp, Germany) connected to the end of the tube. Data of river discharge were obtained by ARGE ELBE (1987–1995), measured at the weir near the city of Geesthacht.

Sampling throughout the year was done from 1986 to 1993 from an anchor station at stream-km 695 (Fig. 1) in the oligohaline part of the estuary. Sampling throughout the year was performed weekly to fortnightly from 1986 to 1991 and monthly 1992 and 1993 during the ebb phase. For details of sampling frequency and tidal phase during sampling see Table 1. In 1988 no data were obtained.

Longitudinal samples were collected between 1986 and 1994 from the research vessel “Valdivia” at different times of the year. Sampling sites were located between the city of Hamburg and the North Sea (near the island of Helgoland). Sampling was carried out 1987, 1992, 1993 and 1994 in spring time, 1986 and 1994 in summer and 1987 in autumn. No data were obtained between 1988 and 1991. For detailed information on longitudinal sampling see Table 2, for position of sampling stations in the estuary see Fig. 1.

Results

Seasonal investigations at the anchor station

Water temperature at the anchor station (Fig. 2) exceeds 10 °C in spring time at the mid of April and reaches maximum values of about 20 °C in June/July every year. Little variation of temperature was found during summer. At the end of October temperature drops to values of about 10 °C.

<table>
<thead>
<tr>
<th>Year</th>
<th>Start of sampling</th>
<th>End of sampling</th>
<th>Days of sampling</th>
<th>Sampling frequency</th>
<th>Tidal phase</th>
</tr>
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<tbody>
<tr>
<td>1986</td>
<td>25.04.</td>
<td>17.12.</td>
<td>22</td>
<td>weekly, fortnightly</td>
<td>2 h before high water</td>
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<tr>
<td>1987</td>
<td>19.03.</td>
<td>21.12.</td>
<td>37</td>
<td>weekly, fortnightly</td>
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<tr>
<td>1989</td>
<td>25.04.</td>
<td>01.09.</td>
<td>33</td>
<td>every 3–4 days, weekly</td>
<td>2 h before high water</td>
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<tr>
<td>1990</td>
<td>17.04.</td>
<td>11.12.</td>
<td>24</td>
<td>weekly, fortnightly</td>
<td>1.5 h before high water</td>
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<tr>
<td>1991</td>
<td>05.04.</td>
<td>10.12.</td>
<td>22</td>
<td>weekly, fortnightly</td>
<td>1.5 h before high water</td>
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<tr>
<td>1992</td>
<td>26.02.</td>
<td>11.12.</td>
<td>10</td>
<td>monthly</td>
<td>Low water</td>
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<tr>
<td>1993</td>
<td>28.01.</td>
<td>06.12.</td>
<td>11</td>
<td>monthly</td>
<td>Low water</td>
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Table 2. Date, sampling stations and tidal phase of longitudinal sampling. HT = high tide; LT = low tide; Sampling = shaded area.

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<td>km</td>
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<td>26.4.-27.4</td>
<td>27.9</td>
<td>27.3.-3.4</td>
<td>19.4</td>
<td>11.4.-12.4</td>
<td>19.7.-20.7</td>
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Maximum salinity values recorded at the anchor station reached 8.5 psu. Oligohaline to mesohaline conditions were found during sampling at the anchor station.

Values of mean yearly river discharge and maximum discharge in the years of investigation at the anchor station are shown in Table 3. Abundance of *Eurytemora affinis* and river discharge at the anchor station in the years of investigation are shown in Fig. 3.

Table 3. Mean and maximum values of river discharge in the years 1986–1994.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean river discharge [m$^3$ s$^{-1}$]</th>
<th>Maximum river discharge [m$^3$ s$^{-1}$]</th>
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<tbody>
<tr>
<td>1986</td>
<td>715</td>
<td>1800</td>
</tr>
<tr>
<td>1987</td>
<td>1092</td>
<td>2630</td>
</tr>
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<td>1989</td>
<td>875</td>
<td>1652</td>
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<td>1990</td>
<td>519</td>
<td>1278</td>
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<tr>
<td>1991</td>
<td>414</td>
<td>1017</td>
</tr>
<tr>
<td>1992</td>
<td>515</td>
<td>1588</td>
</tr>
<tr>
<td>1993</td>
<td>510</td>
<td>1827</td>
</tr>
<tr>
<td>1994</td>
<td>859</td>
<td>2181</td>
</tr>
</tbody>
</table>

1986, 1987 and 1994 were years of high yearly river discharge, 1990–1993 were dry years. In 1986, mean river discharge was 715 m$^3$ s$^{-1}$. A maximum value of 1800 m$^3$ s$^{-1}$ was reached in June, peaks with discharge values higher than 1300 m$^3$ s$^{-1}$ were observed in April and June before and after population maximum. 1987 was the year with the highest mean river discharge during the investigation period (1092 m$^3$ s$^{-1}$). Maximum values of more than 2600 m$^3$ s$^{-1}$ were observed in January and April. Values of more than 1000 m$^3$ s$^{-1}$ were measured nearly every day from January until July. Population maximum of *Eurytemora affinis* was found in May when river discharge had dropped to lower values. In 1986 and in 1987, population maximum reached 347 Ind. l$^{-1}$ and 490 Ind. l$^{-1}$ respectively (Fig. 3) at the end of May.

In 1989, mean river discharge was 875 m$^3$ s$^{-1}$. A peak of over 1600 m$^3$ s$^{-1}$ was measured in January. Highest abundance of *Eurytemora affinis* was observed later then in the years before, at the beginning of June (547 Ind. l$^{-1}$).

The following years were characterized by low river discharge values. In 1990 mean river discharge reached only 519 m$^3$ s$^{-1}$. March was the only time of the year with high discharge values (1287 m$^3$ s$^{-1}$). Lowest mean river discharge was found 1991 with only 414 m$^3$ s$^{-1}$. Maximum discharge value of 1017 m$^3$ s$^{-1}$ was measured in January. During these...
two years abundance of *Eurytemora affinis* was low, maximum abundance occurred already in April, several weeks earlier than in the years before. Maximum values of 55 Ind. l⁻¹ and 155 Ind. l⁻¹ respectively were determined.

In 1992 and 1993, low mean river discharge values (515 m³ s⁻¹ and 510 m³ s⁻¹) were found. Maximum values of more than 1500 m³ s⁻¹ were observed only in March and April. Maximum abundance of *Eurytemora affinis* in 1992 and 1993 was 125 Ind. l⁻¹ and 96 Ind. l⁻¹ at the end of April and beginning of May respectively.

In 1994, mean river discharge was 859 m³ s⁻¹. Three peaks with maximum values of more than 2000 m³ s⁻¹ were observed in January, March and April.

reaching a maximum value of 235 Ind. l⁻¹ at km 695. In September 1987, salinity increased clearly from km 695 towards the North Sea. Compared to the previous investigations maximum of the copepod was located more upstream at km 630 near Hamburg (298 Ind. l⁻¹).

In spring 1992, salinity increased strongly downstream km 710. Maximum abundance of *Eurytemora affinis* (326 Ind. l⁻¹) occurred at km 660.

During sampling in April 1993, a strong increase of salinity was measured from km 695 towards the North Sea. Maximum abundance of 579 Ind. l⁻¹ was found at km 650.

In spring 1994, salinity increased clearly downstream km 710. Highest abundance of the copepod was observed at km

Longitudinal investigations

Copepod abundance and values of mean river discharge (RD) of the 20 days before sampling are shown in Fig. 4. This interval was chosen because a particle needs about 20 days to cover the distance between Hamburg and the mouth of the estuary near Cuxhaven (value valid for mean tidal way; Lucht 1964).

Temperature values during longitudinal sampling varied according to the prevailing season, showing a more or less linear decrease between Hamburg and the North Sea. Differences between maximum and minimum values never exceeded 6 °C.

During longitudinal sampling in July 1986, salinity increased clearly downstream km 695. Maximum abundance of 123 Ind. l⁻¹ of *Eurytemora affinis* was observed near Brunsbüttel at stream-km 695. Downstream km 720 no individuals of the copepod were found (Fig. 4).

During sampling in April 1987, a strong increase of salinity was measured from the mouth of the estuary (km 720) towards the North Sea. Abundance was higher than in summer 1986, reaching a maximum value of 235 Ind. l⁻¹ at km 695. In September 1987, salinity increased clearly from km 695 towards the North Sea. Compared to the previous investigations maximum of the copepod was located more upstream at km 630 near Hamburg (298 Ind. l⁻¹).

In spring 1992, salinity increased strongly downstream km 710. Maximum abundance of *Eurytemora affinis* (326 Ind. l⁻¹) occurred at km 660.

During sampling in April 1993, a strong increase of salinity was measured from km 695 towards the North Sea. Maximum abundance of 579 Ind. l⁻¹ was found at km 650.

In spring 1994, salinity increased clearly downstream km 710. Highest abundance of the copepod was observed at km
700 (627 Ind. l⁻¹), a smaller peak of 369 Ind. l⁻¹ was located at km 660. In July 1994 salinity increased strongly from km 680 towards the North Sea. Maximum abundance of *Eurytemora affinis* was found at km 630 near the city of Hamburg (370 Ind. l⁻¹).

Summarizing the results of the seven longitudinal samplings it seems that in case of low river discharge before sampling (September 1987, April 1993 and July 1994) the steepness of the salinity gradient was only moderate and highest abundance of *Eurytemora affinis* was found upstream between km 650 and 630. When higher river discharge preceded sampling (April 1992) the population maximum was found at km 660. In July 1986, April 1987 and April 1994 when river discharge before sampling exceeded 1000 m³ s⁻¹ and reached values over 2000 m³ s⁻¹ the population maximum of *Eurytemora affinis* was shifted towards the mouth of the estuary.

**Discussion**

There are only a few studies about long-term fluctuation of zooplankton in estuaries (CASTEL 1993; ORSI & MECUM 1986). This may be because zooplankton can not be measured by probes or analyzers and has to be carefully counted, which restricts the work of zooplankton scientists to a practicable amount of samples. Another reason for the lack of data might be the variability of zooplankton samples in estuaries, which is even higher than in stagnant environments like lakes. This often makes the interpretation of data difficult.

One of the main problems in estuaries is the variability of the environmental conditions and as a consequence the difficulty of getting comparable samples (PEITSCH 1993). It would be important to follow the same sampling strategy over the whole period of investigation. This could not be realized in this study because different investigators with different aims of their own studies sampled during the years from 1986 to 1994. Nevertheless, all sampling was performed using the same method, all samples for seasonal distribution were taken at the same geographical position (stream-km 695) in the Elbe Estuary even though not exactly during the same tidal phase.

In the years 1986–1993 *Eurytemora affinis* always showed highest abundance in the Elbe Estuary in spring time.
with maximum abundance varying between 95 Ind. l⁻¹ (1993) and 508 Ind. l⁻¹ (1987). Spring time maxima of this copepod are well known from other estuaries like the Western Scheldt Estuary (Bakker et al. 1977), the Weser (Soltanpour-Gargari & Wellershaus 1984; 1985) and the Forth Estuary in Scotland (Roddie et al. 1984). Spring time maxima in these studies never exceeded 500 Ind. l⁻¹. There are more productive estuaries like the Schlei Fjord with highest abundance of 2000 Ind. l⁻¹ (Christiansen 1988) and the Patuxent River Estuary with maximum abundance of 3000 respectively 3100 Ind. l⁻¹ (Heinle & Flemer 1975; Sellner & Bundy 1987). Examples for less productive estuaries are the Delaware River with 14 Ind. l⁻¹ (Cronin et al. 1962) and the Bothnian Bay (Kankaala 1987) showing maximum abundance of *Eurytemora affinis* of 50–80 Ind. l⁻¹.

So in terms of abundance of *Eurytemora affinis* the Elbe Estuary is comparable to other northern European estuaries like the Weser and Forth Estuary.

Longitudinal investigations showed that the copepod is most abundant in the freshwater region of the estuary. Baretta & Malschaert (1988) described *Eurytemora affinis* to occur throughout the salinity range of 0–30 psu in the Ems Estuary in winter (salinity measured in psu is approximately corresponding to °C). During summer the copepod was restricted to salinities below 15 psu. Vitasalo et al. (1994) found *Eurytemora affinis* to avoid salinities above 6.5°C in the northern Baltic Sea. According to Soltanpour-Gargari & Wellershaus (1987) *Eurytemora affinis* in the Elbe is most abundant in salinities from less than 0.1 up to 0.5°C. *Eurytemora affinis* is an eurytherm organism. In the present study spring time maxima of *Eurytemora affinis* were always found several weeks before highest water temperature was measured. Roddie et al. (1984) found *Eurytemora affinis* to survive best at 5–19 °C under laboratory conditions. De Pauw (1973) described a water temperature range of 2–24 °C for this copepod. Neither the measured values of salinity nor those of temperature can give suitable explanations for the observed differences in abundance of *Eurytemora affinis*.

At the anchor station in the oligohaline zone of the estuary (stream-km 695) highest abundance of *Eurytemora affinis* was observed during the two years of highest river discharge (1986 and 1987, Table 3). The other years showed much lower values of abundance with the exception of one peak in 1989. Sampling frequency was much lower in 1993 and 1994, so the peak of maximum abundance could easlier be missed as in the years before.

The seasonal cycle of the *Eurytemora affinis* population is determined by food supply, egg production and mortality rates. The rate of egg production depends on temperature and on food supply (Edmondson et al. 1962; Heinle et al. 1977; Petersen & Kimmerer 1994). Changes in food supply or...
quality could have influenced the abundance of *Eurytemora affinis* at the anchor station.

Population maximum of *Eurytemora affinis* develops in springtime because of high abundance of food. The main food components for *Eurytemora affinis* in the Elbe Estuary are detritus and phytoplankton. Values of chlorophyll a during the longitudinal sampling in the years 1992–1994 are reported by Wolfstein (1996), who always found maximum chlorophyll a values near the city of Hamburg.

Longitudinal sampling confirms the relation between river discharge and the occurrence of *Eurytemora affinis* (Fig. 4). When high river discharge preceded sampling (1986, 1987, and 1994), the position of maximum abundance and of salinity gradient was shifted towards the mouth of the estuary (stream-km 690–700). In April 1993, after a period of medium river discharge the position of maximum abundance was found at stream-km 650. In July 1994, when very low river discharge preceded sampling maximum abundance of *Eurytemora affinis* was recorded near the city of Hamburg (km 630). These results suggest the main habitat of the copepod to be located in the freshwater region of the estuary near Hamburg.

When river discharge is high during spring downstream transport is fast and the maximum peak of *Eurytemora affinis* reaches the anchor station. During years of low river discharge only low abundance of *Eurytemora affinis* is found at the anchor station because the population declines before reaching the anchor station. River discharge is the main parameter causing the displacement of the abundance maximum, and therefore it is also responsible for the observed differences in abundance measured at the anchor station.

Some authors describe *Eurytemora affinis* to be incapable of autonomous displacement, therefore behaving as passive particles in estuaries (Castel & Veiga 1990; Castel 1993). In this case distribution of the organisms would be related mainly to river flow. Other authors reported horizontal and vertical migration of *Eurytemora affinis* as mechanisms to minimize population loss (Heckman 1986; Vuorinen 1987; Haesloop 1990). Our studies confirm the results of Castel (1993) who reported transport of the population maximum downstream or upstream with increasing or decreasing river discharge for *Eurytemora* population of the Gironde Estuary. Castel (1993) found the highest abundance of *Eurytemora affinis* just upstream the zone of high turbidity and salinity increase. The distribution seemed to be only shifted by river discharge.

The results of the presented long-term study show that river discharge influences the geographic position of maximum abundance in the estuary as well as the abundance of *Eurytemora affinis* in the oligohaline zone of the river. This influence could only be shown by comparing the data of several years. High river discharge results in high net river flow. This factor is of major importance for estuarine zooplankton populations because a population can only maintain itself in the estuary when reproduction rate exceeds the rate of loss due to net river flow (Ketchum 1954). Other parameters like temperature, salinity, food conditions and predation have to be considered during investigations on zooplankton, but river discharge should always be regarded as one of the main factors controlling its abundance and distribution in estuaries.

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References


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