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DYNAMICS OF COPEPODS AND FISH LARVAE IN PÄRNU BAY (NE PART OF THE GULF OF RIGA) IN THE SPRING–SUMMER PERIOD

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Abstract. Analysis of seasonal and long-term abundance of copepods and fish larvae during 1957–97 with reference to environmental conditions and predation is presented. The start of the seasonal mass development of copepods and fish larvae depended mainly on the temperature regime. In the warm years with low salinity the peak abundance of *Eurytemora* occurred significantly (about a month) earlier than in the cold years with higher salinity. In the cold years herring dominated among fish larvae and the abundance of fish larvae was higher than in warm years when gobies were the most numerous group of larvae. A rapid decrease in the abundance of *Eurytemora* in shallow Pärnu Bay in July may be due to predation from larval fish, mysids, and in recent years by the exotic cladoceran *Cercopagis pengoi*.

Key words: copepods, fish larvae, long-term changes, seasonal dynamics.

INTRODUCTION

Pärnu Bay is a very important fishing and recreation area of the Estonian coastal sea. It is an extensive shallow water area with important spawning grounds of a number of abundant fish species (herring, smelt, gobies, sand eel, perch, etc.) and large stocks of mysids and other planktonic and benthic invertebrates. In the spawning places a systematic sampling programme of larvae for the estimation of year-class strength of commercial fish stocks was initiated already in 1947. Somewhat later, in 1953, sampling of larval food animals – zooplankton, especially copepod nauplii – was added as the survival rate of fish larvae and their year-class abundance were found to depend on their food supply (Ojaveer, 1974).

Monitoring of zooplankton dynamics revealed that changes in the main part of the Gulf of Riga were somewhat different from those in its NE part. Line & Sidrevics (1995) stated that compared to the 1950s–60s, in the 1970s–80s the biomass and abundance of zooplankton (including the moderately warm-water *Eurytemora* and the eurytherm *Acartia*) had increased in the open part of the Gulf of Riga, probably in response to milder climate conditions in the latter period. However, Simm (1995) found that in the NE part of the Gulf of Riga, in the Pärnu Bay area, the abundances of both *Acartia* and *Eurytemora* were lower in the 1980s than during the preceding three decades. Ojaveer (1995) also reported that in the 1980s the mean abundance of copepod nauplii was about five times lower than the 1961–70 level.

Below the seasonal and long-term abundance dynamics of zooplankton (mainly copepods) and fish larvae will be analysed with particular reference to the impact of environmental conditions and predation.

MATERIAL AND METHODS

Pärnu Bay is an extensive shallow water area in the NE part of the Gulf of Riga within the limits Manilaid Isle – the southernmost point of Kihnu Island – Häädemeeste (Fig. 1). Its maximum depth increases gradually from 7.5 m in its inner part (NE of the Liu–Tahku line) to 23 m in the SW part.

The hydrological conditions in Pärnu Bay are formed under the complex influence of meteorological processes, the river discharge, and the water exchange with the open part of the Gulf of Riga. The currents are generally weak in the area, their direction depends on winds. The Bay is suffering from a heavy anthropogenic eutrophication (Olli, 1996; Suursaar & Tenson, 1998).

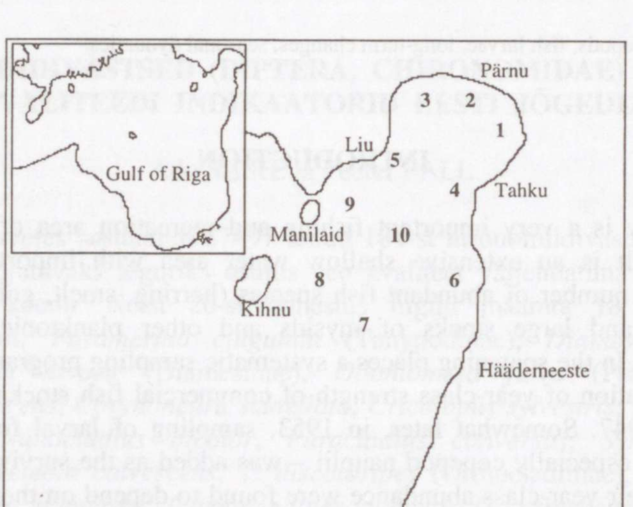

Fig. 1. Scheme of the study area with the sampling stations.

For over 40 years, ichthyo- and zooplankton in Pärnu Bay have been studied based on weekly samples collected in May, June, and July. Ichthyoplankton has regularly been sampled at nine stations with depths from 5 to 11 m in the spawning area of fish (stations 1–9 in Fig. 1). During 1957–70 zooplankton was sampled at the same stations, later on at a 10 m deep station situated in the middle of Pärnu Bay (station 10 in Fig. 1).

Ichthyoplankton was sampled by towing a Hensen net (mouth diameter 800 mm; mesh size 500 μ) in the 1–2 m thick surface layer. All ichthyoplankton data reported are for a 10 min catch (ind. $catch^{-1}$). In the catches herring and smelt larvae were presented by species, the larvae of gobies included mainly larval *Pomatoschistus minutus* L. and *P. microps* L. The larvae of Ammodytidae, Percidae, Gasterosteidae, and Syngnathidae are summed up as a group denoted "others".

Quantitative zooplankton samples were collected by vertical hauls through the whole water column with a Juday type plankton net (mouth diameter 380 mm; mesh size 90 μ). Only the results on copepods are documented here. As the species composition of copepod nauplii was determined only in some years, they are reported as a separate group of organisms. At the stations water temperature in the surface and bottom layers was measured. Data on salinity were obtained from the Kihnu Hydrometeorological Station.

RESULTS

The average water temperatures in May–July varied substantially over the period analysed: from 10.6 °C in 1976 to 15.8 °C in 1966. During the period 1957–97 a statistically significant ($r = -0.584$, $p < 0.01$) decrease in water temperature occurred (Fig. 2). The average salinity in the spring–summer period varied from 4.7 (1958) to 6.1 PSU (1978). During the study period, water salinity increased ($r = 0.582$, $p < 0.001$).

On the basis of long-term changes in water temperature and salinity, the years were classified into the "warm and low salinity" (1957–61, 1963–64, 1966–68, 1970, and 1972) and "cold and high salinity" (1969, 1971, 1976–77, 1983–85, 1994, and 1996–97) groups.

In warm years, water temperature was about 10 °C in mid-May, 15 °C at the beginning of June, and 18 °C in the middle of July. In cold years 10 °C was reached a fortnight later and 15 °C more than a month later than in warm years; even at the end of July the temperature did not exceed 17 °C. The salinity in the cold high salinity years varied in rather narrow limits (5.7–6.0 PSU) and no influence of spring runoff could be detected. In the warm low salinity years the salinity was more variable with low salinity in May reflecting the increase in river discharge.

Copepods are the basic food item of all fish larvae in Pärnu Bay, at least during a certain stage of their development (Rannak & Simm, 1974, 1979). As a rule, *Acartia* and *Eurytemora* constitute over 90% of the total abundance of copepods in Pärnu Bay zooplankton. Considering all investigated years, the

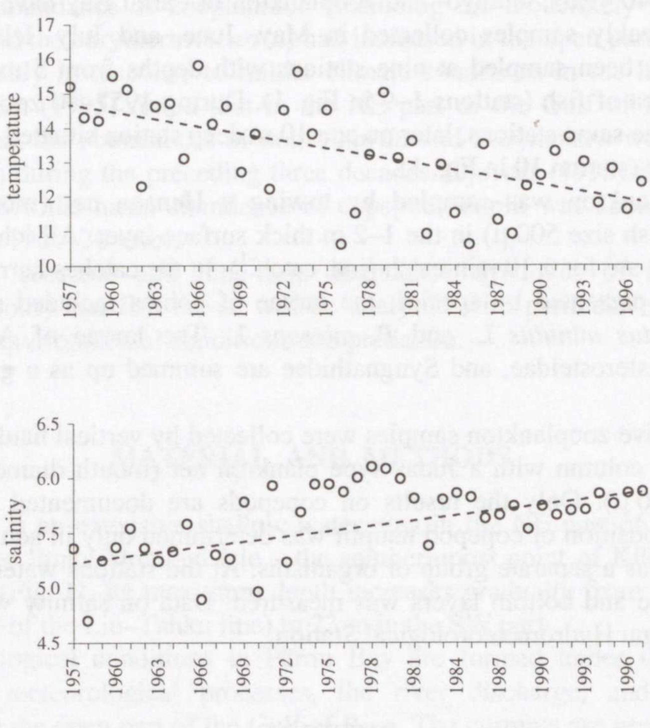

Fig. 2. Average water temperature (°C) and salinity (PSU) in May–July in 1957–97.

abundance of *Eurytemora* was the highest in June–July, but that of *Acartia* in August–September (Table 1). The maximum abundance of copepod nauplii occurred in June–July. Consequently, in the spring–summer period the majority of copepods in Pärnu Bay are *Eurytemora* and copepod nauplii, while the abundance

Table 1. Monthly average abundance of copepods (10^3 ind. m^{-3}) in Pärnu Bay in 1957–97

Month	*Eurytemora*	*Acartia*	Nauplii
January	0.3	0.3	2.5
February	0.1	0.2	2.6
March	0.5	0.4	4.2
April	2.2	1.5	10.2
May	7.2	2.7	19.8
June	13.4	4.2	25.4
July	13.0	8.4	22.7
August	6.7	13.7	17.0
September	2.6	14.0	11.8
October	2.0	8.6	7.0
November	1.5	3.0	3.8
December	0.8	0.8	2.6

of *Acartia* is substantially lower (Table 1). Among copepods, *Acartia* constitutes a somewhat larger fraction only at the end of July of warm years. Therefore, below attention will be focused on the abundance dynamics of *Eurytemora* and copepod nauplii. The average abundance of *Eurytemora* in May–July 1957–97 was 10.2×10^3 ind. m^{-3}. The figure varied from 2.4×10^3 (1985) to 21.9×10^3 (1968) ind. m^{-3}. The average abundance of copepod nauplii varied in the limits from 3.9×10^3 (1987) to 77.5×10^3 (1967) ind. m^{-3} with an average of 24.8×10^3 ind. m^{-3}.

In the warm low salinity years the maximum abundance of *Eurytemora* copepodits and adults was notably higher than in the cold high salinity years (Fig. 3). In the warm years the abundance of *Eurytemora* increased rapidly up to

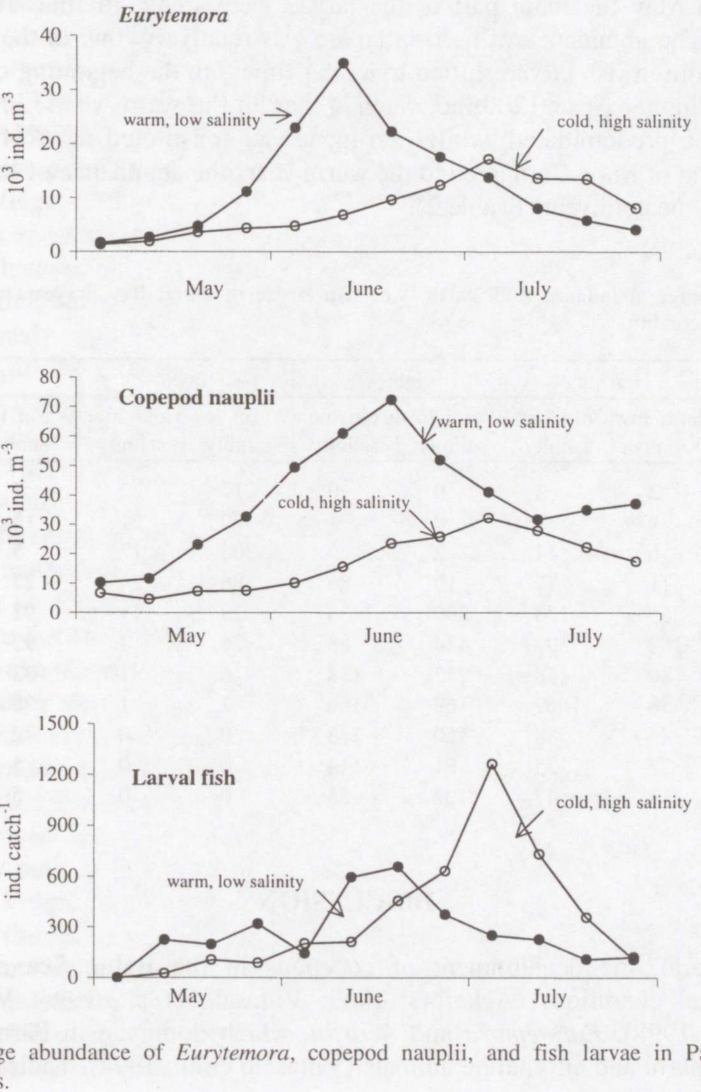

Fig. 3. Average abundance of *Eurytemora*, copepod nauplii, and fish larvae in Pärnu Bay in different years.

the maximum in mid-June and thereafter decreased rather slowly. In the cold years, the number of the copepodits increased comparatively slowly up to the maximum in July. Hence, the mass development of *Eurytemora* in the warm years occurred about a month earlier than in the cold years. The same can be stated about the copepod nauplii (Fig. 3).

The average catch of larval fish in the spring–summer period 1957–97 was 356 ind. catch^{-1}. Most of them were herring and gobies (54.6 and 30.4% respectively). The proportion of smelt larvae remained under 10%, the group "others" made up about 5%.

The total abundance of fish larvae and the relative abundance of different species varied widely by years. In the warm years the abundance maximum of larvae occurred in the first half of June and did not exceed 700 ind. catch^{-1} (Fig. 3). In May the main part of the larvae were smelt, in June–July gobiids (Table 2). The abundance of herring larvae was relatively low. In the cold years the maximum in fish larvae shifted to a later time – to the beginning of July, and was much higher (over 1200 ind. catch^{-1}) than in the warm years. In early May smelt larvae predominated, while herring larvae constituted most of the larvae from the end of May. Compared to the warm years the abundance of larval gobies was low in the cold years (Table 2).

Table 2. Average abundance (ind. catch^{-1}) of fish larvae in Pärnu Bay in years with different hydrological conditions

Month/ week	Herring		Gobies		Smelt		Others	
	Warm, low salinity	Cold, high salinity	Warm, low salinity	Cold, high salinity	Warm, low salinity	Cold, high salinity	Warm, low salinity	Cold, high salinity
May 2nd	2	3	0	0	217	22	4	0
3rd	4	35	0	1	179	61	15	10
4th	6	44	2	5	305	17	5	22
June 1st	11	77	19	86	86	24	27	16
2nd	265	108	209	53	29	14	92	36
3rd	103	307	434	88	26	3	92	56
4th	80	458	253	138	6	1	33	35
July 1st	58	1069	169	166	2	1	20	24
2nd	44	588	160	133	0	0	22	11
3rd	22	235	81	114	0	0	5	7
4th	14	47	102	54	0	0	5	6

DISCUSSION

In general, the development of copepods in the Baltic Sea depends on hydrological conditions (Ackefors, 1969; Viitasalo et al., 1994; Vuorinen & Hänninen, 1998). *Eurytemora* and *Acartia*, which dominate in Pärnu Bay, are both eurytherm and euryhaline animals (Viitasalo et al., 1994). Their distribution in the Baltic Sea depends on salinity. The distribution of *Acartia* is more strongly connected with marine waters than that of *Eurytemora*. With the decrease in salinity from the open part of the Baltic Sea towards the Gulf of Finland and the Gulf of Bothnia, the proportion of *Eurytemora* increases and that of *Acartia* decreases. In the easternmost part of the Gulf of Finland and in Bothnian Bay *Acartia* is absent and among copepods *Eurytemora* dominates (Sandström, 1982; Kankaala, 1987; Lumberg & Ojaveer, 1991; Viitasalo et al., 1994). Data on the distribution of *Acartia* and *Eurytemora* in the open part of the Gulf of Riga are controversial. Kostrichkina et al. (1997) argue that *Acartia* dominates in summer months, others (Line & Sidrevics, 1995; Yurkovskis et al., 1999), however, say that *Eurytemora* does.

Seasonal dynamics in the abundance of *Eurytemora* in Pärnu Bay is characterized by a clear steep maximum in the spring–summer period. The dynamics of the seasonal development of *Eurytemora* in Pärnu Bay is rather similar to the development of the species in North Sea estuaries (Baretta & Malschaert, 1988; Peitsch, 1995) rather than to other parts of the Baltic Sea (Ackefors, 1969; Kankaala, 1987; Viitasalo et al., 1994). Therefore, *Eurytemora* could be described as a "true estuarine" species in Pärnu Bay (Jeffries, 1962; Castel & Veiga, 1990).

Like in zooplankton, the seasonal development of ichthyoplankton in Pärnu Bay is influenced by the warming up of water in spring. In general, it can be expected that the abundance peak of larval fish should occur more or less simultaneously with the maximum of their food organisms (Ojaveer, 1988). Indeed, in all the years studied the abundance maxima of copepod nauplii and fish larvae occurred simultaneously. In the warm years this period was about a month earlier than in the cold years. Consequently, in the time of the transference of fish larvae to exogenous feeding, the abundance of their food animals – copepod nauplii – is generally at the maximum level of the year.

The differences in the species composition of fish larvae in cold and warm years reflect the temperature requirements of the fish species for successful reproduction (formation of abundant year-classes). In spring spawning herring the optimum temperature for the highest survival of embryos is about 7 °C (Ojaveer, 1988). Good year-classes of spring-spawners have appeared under the conditions of early start but rather slow increase in water temperature in spring. In the years with a rapid increase in temperature, year-classes have been poor. Gobies are adapted to higher reproduction temperatures. In our waters the most numerous goby species (*Pomatoschistus minutus*) spawns in warm water in the summer period.

Eurytemora is an eurybiontic, highly tolerant species, which occurs abundantly both in fresh water and at salinities up to 30 PSU (Kankaala, 1987; Castel & Veiga, 1990; Kuosa et al., 1996). Consequently, changes in water salinity in the limits of 1–2 PSU in Pärnu Bay should not directly influence the development of the species. It is probable that the indirect influence through biological processes such as food competition and predation is much more important. For a number of areas of the Baltic Sea predation by fish has been stated to influence *Eurytemora* more than other copepods, especially *Acartia* species (Vuorinen, 1987; Mehner, 1996; Flinkman et al., 1998). The influence of planktivory upon zooplankton is probably also reflected in the dynamics of copepods in Pärnu Bay. A sharp decrease in the abundance of *Eurytemora* occurs when the fish larvae have grown to such dimensions that they are able to consume adult *Eurytemora*. For the visually feeding larvae it is probably simpler to catch female copepods with eggs than hunt for *Acartia* species (Flinkman et al., 1994, 1998).

It is possible that the dynamics of zooplankton communities can be significantly affected also by invertebrate predators. In the period of the sharp decrease in the abundance of *Eurytemora* in July, the abundance of *Neomysis integer* is at its maximum (Kotta, 1976). In the 1990s, the reduction in the abundance of copepod nauplii was stronger than earlier and it was accompanied by a notable increase in the abundance of fish larvae and mysids and the appearance of the predatory cladoceran *Cercopagis pengoi* in Pärnu Bay (Kotta & Kotta, 1997; Ojaveer et al., 1998).

It can be concluded that the annual cycle of the abundance dynamics of copepods in Pärnu Bay depends chiefly on water temperature. In the long time series the abundance of copepods may be influenced by food web interactions. Beginning from June–July the abundance of copepods decreases sharply, obviously due to consumption by predators. The effect is the most obvious in cold years, when herring larval abundance is higher than in warm years. These conclusions reflect mainly correlative, not causal ties. However, they emphasize the necessity for future investigations into connections between zooplankton production and predation pressure.

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AERJALALISTE JA KALALARVIDE DÜNAAMIKA PÄRNU LAHES (LIIVI LAHE KIRDEOSAS) KEVADSUVEL

Mart SIMM ja Evald OJAVEER

Aastatel 1957–1997 tehtud analüüside põhjal sõltus aerjalaliste ja kalalarvide sesoonse massarengu algus peamiselt temperatuurist. Soojadel aastatel oli vee madala soolsuse juures *Eurytemora* arvukuse tipp oluliselt, ligikaudu kuu aega varem kui külmadel, suhteliselt kõrge vee soolsusega aastatel. Külmadel aastatel olid ihtüoplanktonis kõige arvukamad räime, soojadel aastatel aga mudilase larvid. Kalalarvide üldhulk oli külmadel aastatel suurem kui soojadel aastatel. Reeglina juulis toimuv *Eurytemora* arvukuse järsk langus madalaveelises Liivi lahe kirdeosas võib olla tingitud suurenenud röövellusest kalalarvide ja müsiidide poolt, kellele 1990. aastail on lisandunud tulnukvesikirbuline *Cercopagis pengoi*.