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Spatial and temporal variability of Copepoda in the pelagic zone of the Pomeranian Bay (2001-2003)

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Key words: Pomeranian Bay, mesozooplankton, Copepoda, spatial and temporal variability

Abstract

This investigation of Pomeranian Bay waters was conducted from March 2001 to August of 2003 from aboard the r/v *Nawigator XXI*, which is owned by the Maritime Academy in Szczecin. A total of 147 water samples were collected at 15 stations on three transects in the Pomeranian Bay from Świnoujście, Międzyzdroje, and Dziwnów to the Odra Bank. Zooplankton was sampled with a Bongo type planktonometer Ø = 20 cm with a mesh size of 80 µm during 10 min. filtering hauls in the pelagic zone from the bottom to the surface at an average vessel speed of 3 - 4 knots. The method developed and published by Orłowski was used to transform the large amount of seasonal data for the entire study period into isoline illustrations of the spatial structures in the Pomeranian Bay of mesozooplankton and selected species, namely *Acartia bifilosa*, *Acartia*

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longiremis, *Pseudocalanus elongatus*, and *Temora longicornis*. The average mesozooplankton aggregations in ten consecutive seasons at the 15 stations investigated from 2001 to 2003 in the entire Odra estuary area fluctuated from 2,442 to 92,200 ind. m^{-3}. The highest species variety was noted among marine Copepoda, which was the dominant group in virtually every season investigated. Their maximum abundance reached as much as 213,493 ind. m^{-3}. The euryhaline species *A. bifilosa* occurred throughout the research period and at all stations at an abundance that reached 210,443 ind. m^{-3}. The seasonal succession series were as follows: in spring, the dominants were *Acartia* spp. and *Evadne nordmanni*; in summer - *Keratella cochlearis*, *Bosmina coregoni maritima*, and *A. bifilosa*; in fall – *T. longicornis* and *Acartia* spp.; in winter – *T. longicornis* and *Centropages hamatus*.

INTRODUCTION

Plankton organisms are an important element of the trophic, functional and paratrophic structures in the biocenosis of the marine pelagic zone. They are classified as bacterioplankton, phytoplankton, or zooplankton (Arndt 1991; Vinogradov 1977; Renk 1973; Chojnacki 1976, 1984b, 1987; Ciszewski 1963, 1972; Nikolajev 1961). The Baltic zooplankton is comprised of a specific group of animals that developed over the course of the 10,000 year-long geological history of this aquatic basin (Siudziński 1965, 1977; Hernroth and Ackefors 1979; Chojnacki et al. 1986; Wiktor and Żmijewska 1985). Formerly, the Baltic biocenosis was much richer and more marine than it is today. Presently, the coastal zone of the Baltic, similarly to its other regions, exhibits little variety in the number of animal species, which is the result of eutrophication and the degradation of the environment (Żmijewska 1974, Różańska 1976, Mańkowski 1978a, Wiktor et al. 1982, Wiktor and Wiktor 1963). Baltic zooplankton is poor in terms of the number of species due to the selective influence of low water salinity, which allows for few marine species in this sea. However, planktonic zoocenoses are periodically enriched with new zooplankton species from the North Sea that enter the Baltic during salt water inflows (Mańkowski 1951, Chojnacki 1979, Chojnacki and Radziejewska 1980). Freshwater species also enter the Baltic via rivers and inhabit coastal zone waters, which receive freshwater influxes. Endemic forms developed here that are characteristic of great ecotones, such as the Baltic estuaries (Mańkowski 1978a, b).

The ecological group of Baltic zooplankton is mainly composed of various planktonic crustaceans (Cladocera, Copepoda, Mysidacea), Protozoans, Rotatoria, Coelenterates, Chaetognaths, Appendicularia, as well as fish larvae, worms, Malacostraca, Cirripedia, and mollusks (Chojnacki 1973c, 1975, 1986c; Chojnacki and Wróblewski 1975; Postel et al. 1995; Wiktor 1963; Viitasalo et al. 1995). However, the dominant group of the Baltic zooplankton is comprised of Copepoda, whose numbers and biomass can periodically reach even 90% of all zooplankters. This group is dominated by the marine Copepoda species *A. bifilosa* and *Acartia tonsa*, *T. longicornis*, and then *P. elongatus* and

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Eurytemora spp. Another significant group is comprised of Cladocera (Levander and Purasjoki 1947; Chojnacki 1973a, b; Bielecka et al. 2000). The dominant Cladocera species include *Podon polyphemoides* and *Bosmina coregoni maritima*. With regard to the freshwater species, especially in the zone closest to the Szczecin Lagoon, the dominants are *Chydorus sphaericus*, *Bosmina coregoni*, and *Bosmina longirostris*. The most frequently noted Rotatoria genera are *Keratella*, *Brachionus*, and *Synchaeta (*Wiktor 1963, 1991; Chojnacki 1973a, b, c, 1975, 1984, 1986c, 1987, 1991; Drzycimski and Siudziński 1977). There are numerous species of the Tintinnidae order among the microzooplankton in the coastal zone, and the most frequent macrozooplankton elements are *Aurelia aurita* Coelenterates and ichthyoplankton (Drzycimski et al. 1972; Chojnacki 1975).

The Baltic Sea is richest in zooplankton in the southern region; this is due to its shallow coastal waters, particularly in sheltered bays and in the vicinity of river mouths, which are, in turn, sources of rich nutrient loads from rivers and organic waste discharged into the sea (Ciszewski and Żmudziński 1991, Witek et al. 2001, Żmijewska et al. 2000). Environmental monitoring conducted by the Polish authorities indicates that there has been a decline in the average number of mesozooplankton since 1990 (Chojnacki 1984a, b, 1986a, b, 1987, 1991; Chojnacki et al. 1986; Wiktor 1963). This may be connected with significant changes in the volume of nutrient substances on which sea productivity depends.

The low stability of Pomeranian Bay environmental conditions, as well as the influence of climatic factors and meteorological phenomena, lead to more visible seasonal changes in zooplankton development than is observed in open waters, the scarcity of zooplankton in winter, and its rich and rapid development in the May-October period (Chojnacki 1973c, 1975, 1984b, 1986a, 1987; Drzycimski et al. 1972). Nutrient fluctuations in such a changeable environment are probably linked to recent decreases in the waste loads discharged into the Odra River, and perhaps this should be perceived as the reason for the decline in productivity and zooplankton aggregations.

Research conducted between 1976-1980 on the seasonal structure of zooplankton dominants indicated that in spring the dominant species were *A. longiremis*, *A. bifilosa*, and *Pseudocalanus minutus elongatus*, whereas in summer they were *Evande nordmanni*, *Eurytemora* ssp., *Acartia tonsa, Mytilus edulis* larvae*, A. bifilosa*, and *Bosmina coregoni maritima*, in fall - *A. tonsa* and *A. bifilosa*, and in winter - *A.bifilosa*, and *A. longiremis* (Siudziński 1977; Chojnacki 1973c, 1975, 1976, 1983, 1987; Chojnacki et al. 1986).

In the Pomeranian Bay, with its numerous estuaries, the fresh waters carried to the sea by the Odra River from the entire catchment basin clash with the brackish waters of the western Baltic (Majewski 1972, Mutko et al. 1995). In

the Pomeranian Bay at the mouths of the Świna, Dziwna, and Rega rivers, for many years a clearly defined ecotone has been observed which is distinctive in species richness and hydrochemistry dynamics. This has been demonstrated by the results of both previous research and the present investigation (Tadajewski and Kubiak 1976, Kubiak 1983, Machula 2005). The range and qualitative and quantitative structures of the mesozooplankton differ in each of the ecotonal zones of these three rivers; this is probably also connected with the ecological structure of the benthos or even the nekton (Witek et al. 2001).

Based on the results of mesozooplankton research conducted in the Pomeranian Bay in 2001-2003, the authors will attempt to demonstrate some regularities resulting from the spatial structures and aggregations of this ecological group, and in particular of Copepoda, which is the dominant mesozooplankton element. The method of visualizing results proposed by Orłowski (2003, 2005) is applied in relation to Baltic fish.

STUDY AREA

The qualitative and quantitative study of mesozooplankton was conducted using samples collected from fifteen permanent stations located in the region of Świnoujście, Międzyzdroje, Dziwnów, Mrzeżyno, and the Odra Bank (Machula 2005). The locations and depths of the stations and their geographical coordinates are presented in Table 1 and fig. 1.

Table 1

Geographical location of sampling stations in the Pomeranian Bay (2001-2003)

Station No	Geographical coordinates		Depth [m]
	N	E	
SI	53° 56' 50"	14° 18' 10"	7.5
SII	54° 00' 20"	14° 20' 45"	11
SIII	54° 03' 75"	14° 22' 85"	12
MI	53° 56' 50"	14° 26' 00"	9
MII	54° 00' 20"	14° 25' 75"	12
MIII	54° 03' 75"	14° 25' 50"	13
DI	54° 02' 30"	14° 42' 90"	9
DII	54° 04' 00"	14° 37' 00"	10
DIII	54° 05' 70"	14° 31' 15"	11
DIV	54° 03' 20"	14° 47' 90"	9
DV	54° 04' 80"	14° 45' 50"	11
RI	54° 09' 80"	15° 17' 20"	8.5
RII	54° 10' 70"	15° 22' 10"	8.5
RIII	54° 12' 10"	15° 19' 50"	9
LO	54° 07' 40"	14° 25' 20"	10

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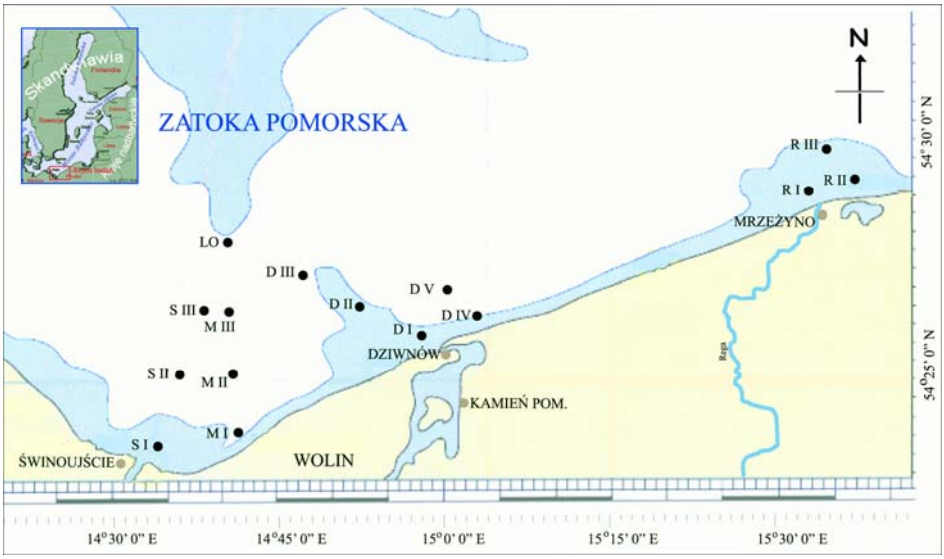


Fig. 1. Study area and sampling station location in the Pomeranian Bay (2001-2003).

MATERIAL AND METHODS

The study of the Pomeranian Bay waters was conducted from May 2001 to August 2003 according to the field method recommended in Standard Methods (1995) on 16.05.2001, 14-15.08.2001, 11-15.11.2001, 25.02.2002, 01.03.2002, 15.05.2002, 09-10.08.2002, 04.11.2002, 07.03.2003, 02-04.06.2003, and 31.07-01.08.2003 from aboard the r/v *Navigator XXI* of the Maritime Academy in Szczecin. Beginning in August 2001, the number of stations was increased from 12 to 15 in order to determine the influence the waters of the Rega River have on Pomeranian Bay waters.

Zooplankton was sampled with a Bongo type planktonometer of Ø = 20 cm (Heral et al. 1976) with a mesh size of 80 µm. The plankton material was preserved immediately after sampling and was subsequently preserved with a 70% solution of ethyl alcohol with hibitan. Qualitative and quantitative determinations were performed as follows: depending on abundance, the material was diluted in Folsom's sample splitter (Mc Evan et al. 1954), and then the entire sub-sample was analyzed in Bogorov's type labyrinth chambers. The abundance of individuals in 1 m^3 was calculated according to the following formula (Machula 2005):

$$L = \frac{l_n \times 2^n}{V} \quad [\text{ind. m}^{-3}] \qquad (1)$$

where:

L – taxon abundance in the water capacity unit (ind. m^{-3}),
l_n – number of individuals in the sub-sample,
n – number of dilutions of the original sample in Folsom's sample splitter,
V – capacity of water filtered through the mesh (m^3)

$$V = \frac{M \times F \times r}{2.66} = 0.000118 \text{ x M} \qquad (2)$$

where:

M – number of full log revolutions during the mesh operation under water,
F– surface of mesh tube inlet [0.0314 m^2],
r – mesh tube radius [0.1 m]
2.66 – constant for a log with speed curves 2030 and 2031 (General Oceanics).

Mathematical procedures for creating visualizations aimed at achieving "a topographical effect" using the biological data from the Pomeranian Bay were applied in accordance with the method developed and published by Orłowski (2003, 2005).

RESULTS AND DESCRIPTION

Seasonal dynamics of Pomeranian Bay mesozooplankton abundance

Average mesozooplankton aggregations in ten consecutive seasons at 15 stations investigated between 2001 and 2003 throughout the Odra estuary fluctuated from 2,442 to 92,200 ind. m^{-3}. This high abundance value occurred only once during the entire research period, and abundance oscillated between 2,442 and 37,182 ind. m^{-3} in the remaining seasons (Fig. 2). This exceptionally high aggregation in the summer season of 2001 was not noted in the subsequent summer seasons of 2002 or 2003, and one of the lowest aggregations levels during the investigation of the Pomeranian Bay was noted in 2002. The cool seasons of fall and winter featured abundances which did not exceed an average of 14,887 ind. m^{-3}. The analyses of the Copepoda aggregations in the spring seasons indicated that only once in 2001 did the abundance of these plankton Crustaceans appear to have had a strong influence on the abundance in the summer season. Unfortunately, in the following years no logical sequence of events was detected. Conversely, it appeared that average aggregations were

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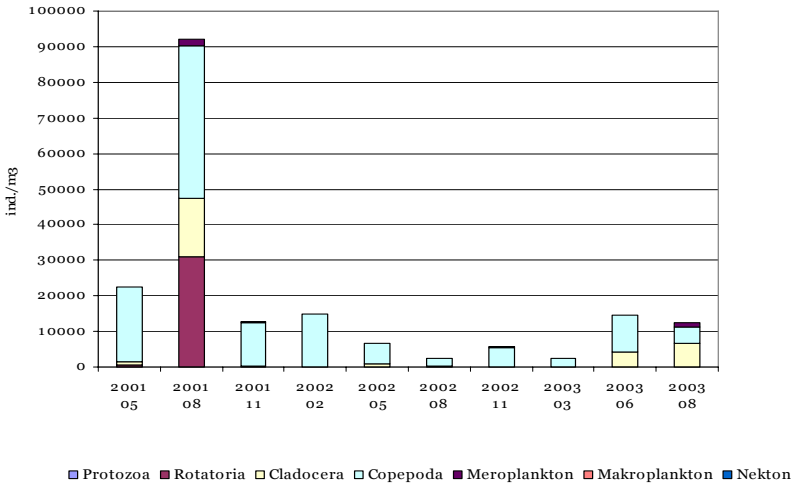


Fig. 2. Average mesozooplankton aggregations in ten seasons from 2001 to 2003 in the pelagic zone of the Pomeranian Bay at 15 sampling stations.

relatively high due to the presence of the Cladocera planktonic crustaceans, whose percentage share oscillated from 15 to over 30%.

Seasonal taxonomic variability of mesozooplankton in the Pomeranian Bay

In order to simplify this analysis, the material was grouped as follows: Protozoa; Rotatoria; Cladocera; Copepoda (adult + nauplii + copepodit); meroplankton (larvae of benthic organisms + ichtyoplankton); macroplankton; nekton. The percentage share of each was determined in all of the ten analyzed seasons and at all the stations in the southern part of the Pomeranian Bay. The absolute quantitative dominant, except in the summer seasons of 2001 and 2003, was Copepoda (Fig. 2). It also occurred that over 90% of the share in the other seasons was also comprised of Copepoda, while in the winter seasons of 2002 and 2003 they constituted 100% of the mesozooplankton. It is worth mentioning that Rotatoria, Cladocera, and meroplankton usually initially appeared in small numbers in spring. Cladocera is the group whose share reached the highest percentage in the summer seasons (>55%) and then declined successively until fall, while in the winter season Cladocera did not occur at all in the mesozooplankton of the Pomeranian Bay.

Over the course of the two-year investigation it was established that because the highest volume of waters entered the Pomeranian Bay via the Świna River, this was also the source of the largest biomass load and allochthonous

organic material delivered to the sea. This resulted in the high productivity of the lower course of the Odra and of the Szczecin Lagoon; this phenomenon was also observed in the 1960s and 1980s as well as currently (Wiktor and Wiktor 1962, Tadajewski and Kubiak 1976, Witek et al. 2001, Machula et al. 2006). It was observed that in the mouth of the Świna "a tongue" of fertile waters that spread over the surface of the bay's coastal zone influenced both the abiotic features of the waters in northern and western directions that far exceeded Międzyzdroje and the waters in the mouths of the Dziwna and Rega rivers. The values of aquatic abiotic indicators in the mouths of the Dziwna and Rega rivers were characteristic for the open waters of the Pomeranian Bay; however, in the region to the north of the Rega River water "lenses" of various sizes were observed that had not yet mixed with the brackish waters of the Pomeranian Bay (Machula 2005). These "lenses" of relocating, autochthonous water masses maintain for some time the "autochthonous" planktonic fauna composition, which is demonstrated in the mosaic-like visualization of mesozooplankton and the groups that can be singled out. This is a temporary situation that lasts only until stronger winds begin to blow and the bay waters are fully mixed.

Copepoda of the Odra estuary in 2001-2003

The most varied group of mesozooplankton with respect of quantity and quality were Copepoda, which occurred in the waters of the Pomeranian Bay in all the seasons investigated during the 2001-2003 period. They were represented by marine species, including, among others: *P. elongatus*; *T. longicornis*; *C. hamatus*; *A. bifilosa*; *A. longiremis*; *A. tonsa*; *Eurytemora* spp.; *Cyclops* sp. There were also brackish and freshwater species such as *Cyclopina gracilis*, *Megacyclops viridis*, *Megacyclops leuckarti*, *Eucyclops speratus*, and *Eudiaptomus gracilis.* Similar species and their occurrence in virtually all seasons of the year was determined in the research conducted earlier by Wiktor (1963), Chojnacki (1973c, 1975, 1984, 1987, 1991), Chojnacki and Wróblewski (1975), Mańkowski (1978a), Hernroth and Ackefors (1979), Wiktor and Żmijewska 1985, and Chojnacki et al. (1986). However, the authors cited here reported abundance values that were mostly significantly higher than those recorded in the ten seasons investigated in the 2001-2003 period.

The structure of seasonal mesozooplankton and Copepoda aggregations in the Pomeranian Bay in 2001-2003 presented in Fig. 3 was shaped by the seasonality of changes in abiotic environmental conditions (Machula et al. 2005) at stations under the impact of anthropogenic factors as well as those free of this pressure. Based on the average aggregations in the ten seasons, Machula et al. (2005) demonstrated that there are two strong aggregations of planktonic zoocenoses:

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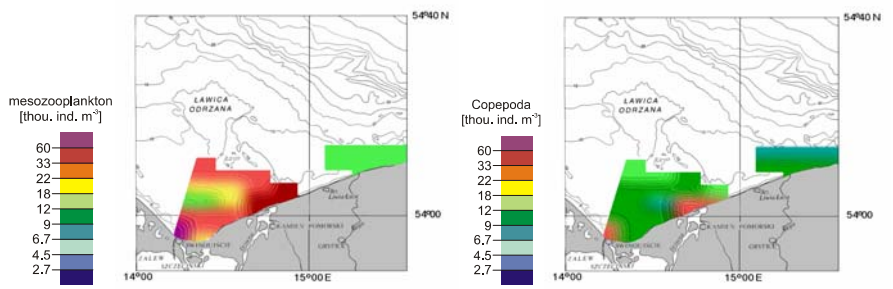


Fig. 3. Spatial structure of average aggregation values: a - of mesozooplankton and b - of Copepoda in Pomeranian Bay waters (2001-2003).

1. in the mouth of the Świna River;
2. in the region of the mouth of the Dziwna River;

and two smaller aggregations of much lower abundance:

3. beyond the reach of fresh waters from the river mouths (Świna, Dziwna and Rega);
4. marine aggregations on the southern edge of the Odra Bank.

Aggregation 1 was influenced by fresh waters with high nutrient contents and BOD_5, higher temperature and lower salinity, and eurytopic fauna. Aggregation 2 formed under slightly higher salinity values and abundance was lower than in aggregation 1, while aggregations 3 and 4 had average higher salinity values and mosaic-like abundances of zooplankton or Copepoda, which can be analyzed in detail by presenting data from each season separately (Fig. 3, Table 2).

Table 2

Averages seasonal abundance of Copepoda at 15 stations in the Pomeranian Bay (2001-2003)

Taxon	2001			2002				2003		
	May	August	November	February	May	August	November	March	June	August
Acartia bifilosa	3149	28070	2782	3734	2391	639	1921	600	3628	1233
Acartia longiremis	2250	3553	1755	890	853	377	1290	554	2665	1165
Acartia tonsa	230	31	271	288	90	10	26	0	229	81
Centropages hamatus	90	218	238	1839	30	9	25	14	11	26
Eurytemora sp.	79	225	367	316	18	8	61	30	82	17
Pseudocalanus elongatus	72	122	859	1254	131	0	158	137	613	110
Temora longicornis	407	902	3092	1913	354	106	319	447	281	1
Megacyclops viridis	2	0	126	72	2	13	68	47	72	0
Eucyclops speratus	164	0	0	136	0	0	0	0	0	0
Eudiaptomus gracilis	1	0	0	0	0	3	0	0	0	0
Cyclopina gracilis	0	0	7	0	0	0	0	0	0	7
Mesocyclops leuckarti	205	0	0	0	0	0	0	0	0	0
Cyclops sp.	5634	4654	834	1457	280	6	16	15	64	0
nauplii Copepoda	2156	3814	235	304	247	406	370	86	864	525
Copepodit	6513	1361	1491	2578	1430	565	1178	510	1827	1195
Total Copepoda	**20958**	**42950**	**12057**	**14781**	**5826**	**2142**	**5432**	**2440**	**10336**	**4360**

The thorough season by season analysis of the spatial mesozooplankton structure as dependant on abiotic environmental factors did not reveal any direct correlation between particular abiotic indicators and mesozooplankton aggregations. The only conclusion that can be drawn definitively is that following relatively harsh winters with low water temperature and springs with water temperatures >11°C zooplankton concentrations of 18 – 60 thou. ind. m^{-3} were observed in the summer season. Lower temperatures in Pomeranian Bay waters in the summer season usually meant much lower mesozooplankton and Copepoda abundance values of barely 2,700-12,000 ind. m^{-3} (Fig. 3, Tables 2, 3).

Drawing conclusions or identifying the direct or indirect influence of environmental conditions on the ecological structures of the mesozooplankton are very difficult tasks (Arndt 1991; Chojnacki 1984b, 1986a, b, 1987, 1991; Wiktor 1963); thus, the visualization of the results of environmental state indicators as isolines allows tendencies to be identified more easily and permits placing the aggregations mentioned above in the context of the entire aquatic area. The technique of visualizing individual transects was used in 1996 by Roman et al. (2001) with zooplankton and salinity in the Chesapeake Bay. The visualization method developed and published by Orłowski (2003) was applied to data from nearly three years of observations of mesozooplankton and environmental indicators in the Pomeranian Bay, during which mesozooplankton abundance and some sea waters quality indicators were analyzed at a dozen or so research stations that were spatially separated. Orłowski (1999, 2000, 2005) uses this technique successfully to interpret the results of acoustic research regarding the horizontal and vertical distribution of Baltic herring and sprat migrations. The current study demonstrates that interrelations between the average values of abiotic factors in the relatively unstable environment of a large river estuary can be determined quickly and relatively easily. Additionally, this method is faster than the application of popular statistical tests. Another benefit of processing the data in this way is that it is easier to interpret results that are presented as colorful areas with average indicator values between isolines.

Pseudocalanus elongatus

This is a common, halophilous Copepoda characteristic of open sea waters, which is found in great numbers throughout the year. As a psychrophilic species of marine origin, it rather stays in deeper, colder waters in the Baltic in summer. It occurs in large numbers in the temperate and polar seas of the northern Atlantic and Pacific. As the surface layer cools, it is found throughout the water column in the open sea and neritic zones, as well as in river estuaries. In the

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Baltic Sea it avoids shallow bays that warm quickly as well as waters affected by the inflow of fresh waters at river mouths (Chojnacki et al. 1986), which was also determined over the course of the current study. Although this species was never a dominant form in the Pomeranian Bay waters in the 2001-2003 period, it was noted in almost all seasons of the investigation except in August 2002 (Fig. 4). In August 2001 and 2003 (with average water temperatures of 19.63

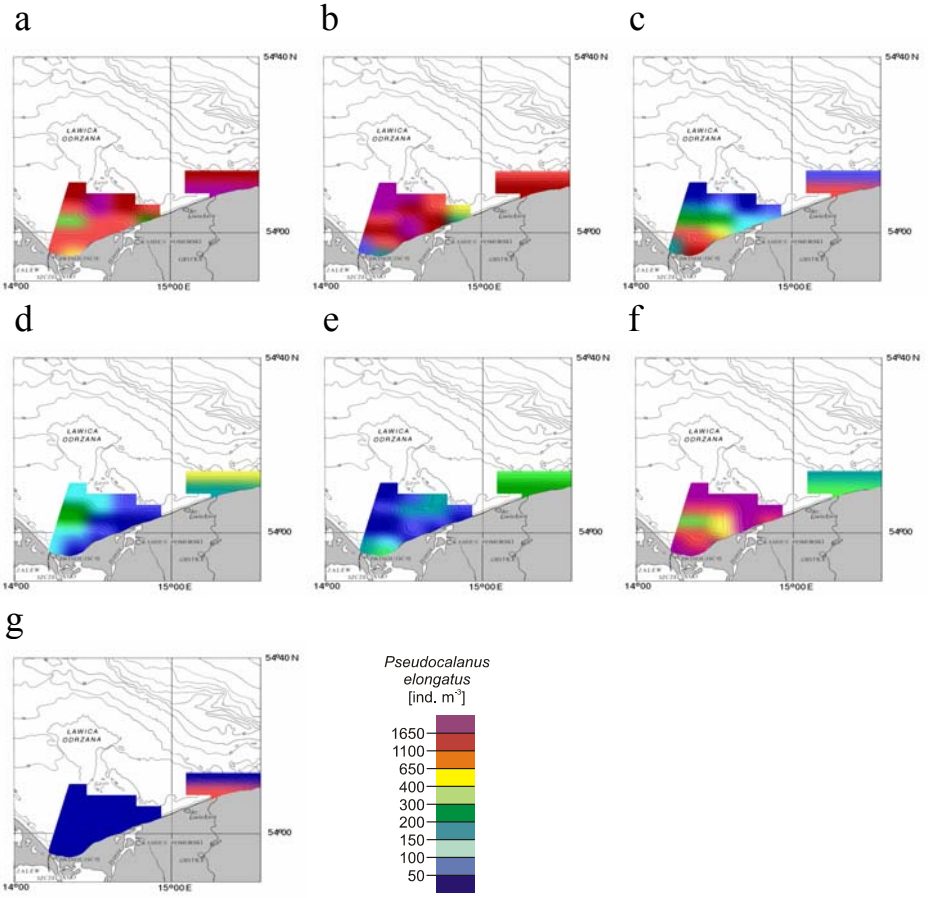


Fig. 4. Spatial and seasonal structure of *Pseudocalanus elongatus* in the Pomeranian Bay from 2001 to 2003 (a - fall 2001, b- winter 2002, c- spring 2002, d- fall 2002, e - winter 2003, f - spring 2003, g - summer 2003).

and 20.75°C) it appeared only at three stations, respectively: DV (663 ind. m^{-3}), RII (353 ind. m^{-3}), RIII (806 ind. m^{-3}) and RI (1465 ind. m^{-3}), RII (149 ind. m^{-3}), RIII (42 ind. m^{-3}). The results of earlier studies by Chojnacki (1973 c, 1975, 1984a, b, 1991) indicated that it was one of the dominant species of Copepoda zooplankton in the deep open waters of the Baltic. According to Wolska-Pyś and Ciszewska (1991), the lack of inflows from the North Sea and decreased salinity and well-oxygenated waters in subsequent years is probably the factor that limits the numbers of *P. elongatus*. It did not dominate in the Pomeranian Bay in any of the ten seasons investigated in the 2001-2003 period.

Reports by researchers of Baltic zooplankton differ significantly as to the occurrence of this species. Ackefors (1969) reported that its maximum was observed in August; Levander and Purasjoki (1947) claimed that it was in winter; and Mańkowski (1978a) reported that it was in both winter and summer. Chojnacki et al. (1986), however, reported that its maximum was in summer or fall depending on the region of the southern Baltic. In 2001-2003 in the Pomeranian Bay, the most frequent and highest aggregations of the species were observed in the fall and winter seasons when water temperatures fell below 8.9°C (Table 3). The maximum abundance of *P. elongatus* was noted in June 2003 at station SI (19,617 ind. m^{-3}) at a salinity range of 6.7-6.8 psu and water temperatures of 15.1-16.9°C. This may confirm the previous observations by Chojnacki et al. (1986). The principle apparent in the visualization of the results seems to be that in river mouths entering the Pomeranian Bay this species occurred in minimal numbers (fig. 4a-f), with the exception of strong mosaic and reverse tendencies in the spring of 2003 (fig. 4g).

Temora longicornis

Common among the Copepoda in the southern Baltic, *T. longicornis* is a typical neritic species that inhabits full salty seas and is found in large near-surface concentrations. Its zoogeography is similar to that of *P. elongatus* and occurs from the North Sea through the Barents Sea to the Baltic and Mediterranean seas. It is also found in the Indian Ocean. It is rather a boreal form that is relocated with the warm currents of sub-arctic waters, and it occurs in various climatic zones (Chojnacki et al. 1986, Nikolajev 1961). It is a common plankton element of cooler water at medium depths in the Baltic Sea, and it occurs throughout the year. Although it is often found in the open waters of the Gdańsk and Pomeranian bays, it avoids most of the shallow areas of the Pucka Bay (Chojnacki et al. 1986, Wiktor and Pliński 1992, Bielecka et al. 2000). Ackefors (1969) reported that this species reaches its maximum abundance in the central Baltic from May to July, while Mańkowski (1978a), Siudziński (1977), and Wiktor (1963) observed two abundance peaks: the first

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was in spring in March and the second was at the end of the summer season in September.

In the Pomeranian Bay in 2001-2003, quite a substantial percentage of *T. longicornis* was noted in the Copepoda group. It even reached approximately 40% in the fall and winter months, which partially confirmed the research conducted by Mańkowski (1978a), Siudziński (1977), and Wiktor (1963). Although *T. longicornis* (average – 447 ind. m^{-3}) occurred at all the sampling stations in March 2003, its abundance was far lower than that in February 2002

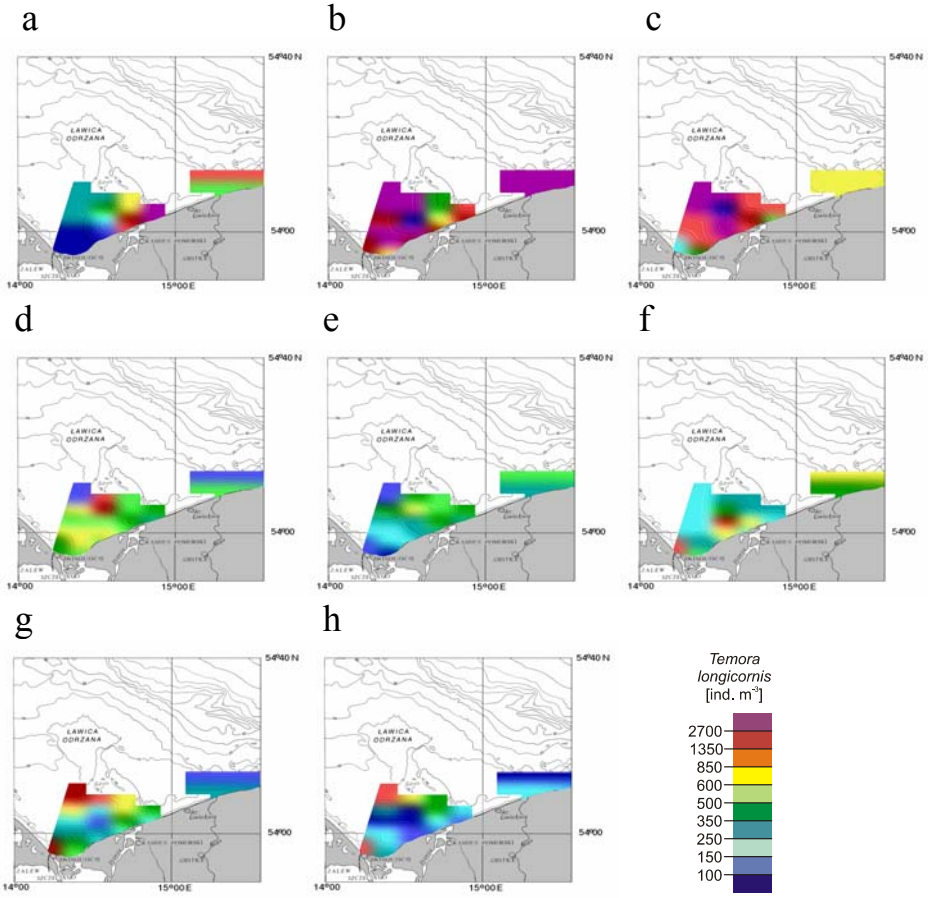


Fig. 5. Spatial and seasonal structure of *Temora longicornis* in the Pomeranian Bay from 2001 to 2003 (a - summer 2001, b - fall 2001, c- winter 2002, d- spring 2002, e - fall 2002, f - winter 2002, g - spring 2003, h - summer 2003).

(LO – 12,387 ind. m^{-3}). This could have been linked to the salinity that was nearly half as low and to the lower temperature that ranged from 0.6-1.4°C (Fig. 5c, Table 2). In spring months, this species occurred at almost all the stations, although its abundance was decidedly lower than it was, for example, in November 2001 (Fig. 5a) at an average of 3,092 ind. m^{-3}. In August 2003 this species occurred only at station RIII, and its numbers were unusually low at an average of 14 ind. m^{-3}. This was despite the fact that the average water salinity there was 7.1psu and the water temperature was 19.9°C, dissolved oxygen reached nearly 10.0 mgO_2 dm^{-3}. In the ten seasons investigated, the abundance of *T. longicornis* was typically higher at stations located further from the coastline (from 3 Nm to station LO), where salinity was higher (usually above 7 psu) (Fig. 5a-h, Table 3). In the cold seasons of the year, it approached the river mouths or hid in the deeper parts of the Pomeranian Bay (Fig. 5a, f).

Acartia bifilosa

A. bifilosa is a typical estuarial form that is widely distributed in the moderate-boreal climatic zone and is characteristic of the neritic zone. It occurs in the northern Atlantic, the North Sea, the English Channel, Kattegat Strait, Skagerrak Strait, the Belts and the Baltic, and in the Sea of Okhotsk (Chojnacki et al. 1986, Siudziński 1965, Ciszewski 1963, Klekowski and Węsławski 1991). It is a very common element of Baltic plankton. This species develops most intensively at the end of the spring season and in the summer months, especially during warm periods (Ciszewski 1963, 1972; Chojnacki 1973c, 1984b; Drzycimski and Siudziński 1977). The salinity at which it occurred in the greatest numbers in the southern Baltic oscillated between 7.5 to 10 psu (Chojnacki 1973c, Chojnacki et al. 1986). Interestingly, Żmudziński (1990) established that this species did not avoid waters that were heavily polluted with domestic sewage, and that it actually grew to larger sizes in them than it did in clean waters.

Throughout the 2001-2003 period, the highest abundance of this species in the Pomeranian Bay was indeed observed in spring and winter (Fig. 6a, g), when water temperature was >10°C. It also appeared in fall but at a much lower abundance (Fig. 6h) when the water temperature range was 6.8-8.9°C, dissolved oxygen content was 9.6-12.2 mgO_2 dm^{-3}, and salinity was 5.5-8.3 psu (Fig. 6, Table 3). As a form that is decidedly thermophilous, it occurs mainly in bays and in the surface layers of the open sea where several generations of this species occur over the course of a season. In winter it occurs in 0-30 m surface layers irrespective of the water depth of an area, although it has also been found at greater depths (Chojnacki 1973c, Chojnacki et al. 1986).

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In the research conducted in the Pomeranian Bay in 2001-2003, it occurred in much lower aggregations in winter than in summer, which could be linked to low water temperature (Fig. 6c, f, Tables 2, 3). However, it must be mentioned that abundance in March 2003 was lower (range of 124-1,840 ind. m^3) in comparison to that in February 2002 (range of 611-1,5404 ind. m^{-3}). This may have been linked to the lower water temperature at the Odra Bank of 0.6-1.4°C and 2.7-3.6°C, respectively, as well as to a salinity level that was half as low (in March 2003 the average was 4.0 psu). In spring and fall the species moved

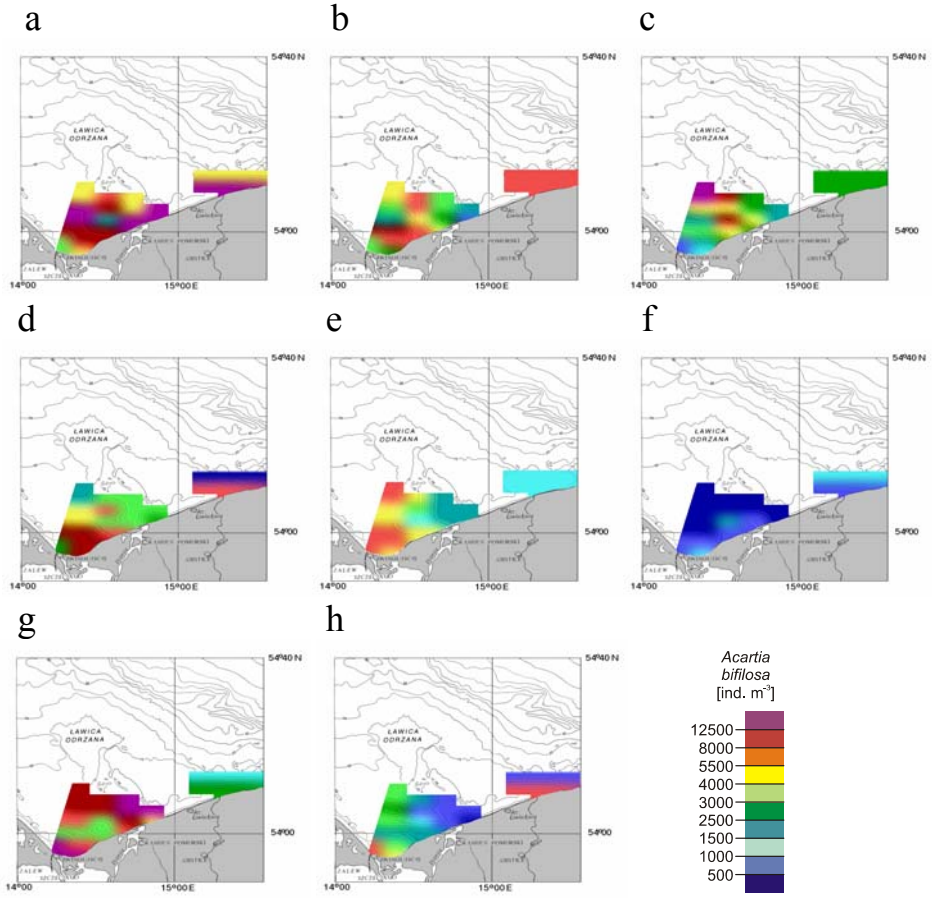


Fig. 6. Spatial and seasonal structure of *Acartia bifilosa* in the Pomeranian Bay from 2001 to 2003 (a - summer 2001, b - fall 2001, c- winter 2002, d- spring 2002, e - summer 2002, f - winter 2003, g - spring 2003, h - fall 2003).

distinctly towards the surface, and in the 0-15 m layer it formed concentrations distributed in the neritic zone. It was also noted at the Odra Bank (Fig. 6b, d, g) at a significant abundance, at least for this species. In summer its vertical distribution was similar to that of winter (when abundance was much lower) but its horizontal distribution was decidedly different and irregular (Fig. 6a, h). This species occurred at all sampling stations in all the seasons investigated in 2001-2003 in the Pomeranian Bay. It was often the dominant among Copepoda (in August 2001 at stations DI (21,443 ind. m^{-3}), DIV (74,214 ind. m^{-3}), and MIII (27,692 ind. m^{-3}) when its percentage share reached values exceeding 90%. Its abundance throughout the research period oscillated from 124 to as much as 210,443 ind. m^{-3}, while higher abundance was noted at salinity levels over 7 psu (Table 2, 3).

Acartia longiremis

This species occurs throughout the southern Baltic, and, similarly to ocean waters, it usually occurs in the neritic zone and is characteristic of surface layers, where it sometimes forms massive concentrations. It is a euryhaline form that lives in boreal and sub-arctic seas (Chojnacki et al. 1986, Klekowski and Węsławski 1991). It occurs in the Baltic all year round and is a common planktonic species that lives in the relatively cold waters of the open Baltic, where it develops in greatest numbers at the end of summer. According to Chojnacki (1973c) and Nikolajev (1961), this is a species which prefers warmer waters, while Ciszewski (1972) considers it to be a psychrophilic form. In the warmest part of the year *A. longiremis* also occurs in large numbers in coastal waters, including shallow bays (Ciszewski 1963, Chojnacki 1973c, Chojnacki et al. 1986, Żmudziński 1990). During the investigation of the Pomeranian Bay conducted in 2001-2003 this species occurred throughout the entire research period but in small numbers. *A. longiremis* was more numerous at feeding grounds near river mouths (Fig. 7a, b, e, f, g). It was a dominant among the Copepoda in the summer of 2002 at stations MII (13,209 ind. m^{-3}), SI (9,032 ind. m^{-3}), and LO (4,243 ind. m^{-3}), and it occurred in equally high numbers in July 2003 at stations SI (73,119 ind. m^{-3}), MI (10,963 ind. m^{-3}), DV (18,044 ind. m^{-3}), and LO (6,393 ind. m^{-3}) (Fig.7e, g) at an average water temperature of 14.0°C and an average salinity of 7.3 psu. It occurred in smaller numbers (several hundred individuals per m^3) when the water temperature decreased and when the salinity was lower (in March 2002 and 2003, at an average water temperature of 0.95°C and an average salinity of 4.0 psu), then it migrated further from the river mouths towards the Odra Bank (Fig. 7c, f, Table 3). These results do not concur with those of Ciszewski (1972).

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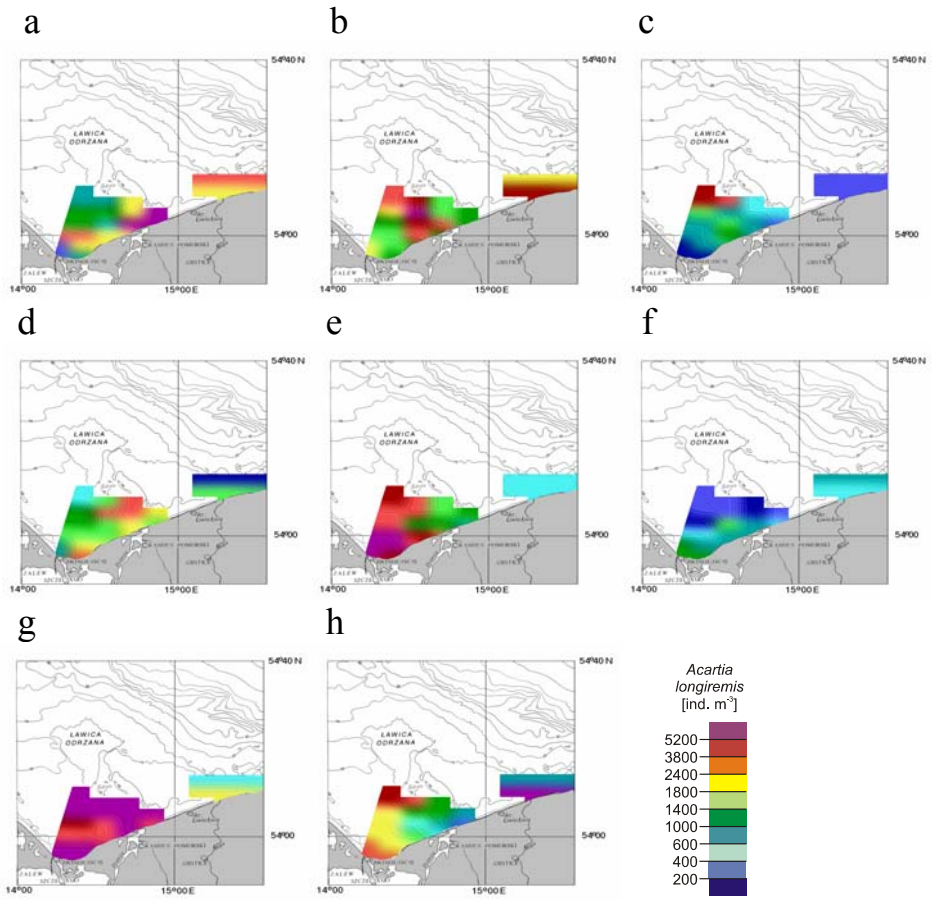


Fig. 7. Spatial and seasonal structure of *Acartia longiremis* in the Pomeranian Bay from 2001 to 2003 (a - summer 2001, b - fall 2001, c- winter 2002, d- spring 2002, e - summer 2002, f - winter 2003, g - spring 2003, h - summer 2003).

Acartia tonsa

A. tonsa is a relatively rare Baltic inhabitant. It is distributed in the surface waters to depths of approximately 15 m. As a species that inhabits brackish waters, it is distributed in great numbers in sea lagoons and lake mouths, and it occurs mainly in the middle of summer (Chojnacki 1973c, Żmudziński 1990). It occurred in the Pomeranian Bay in far smaller numbers than did *A. bifilosa* and

A. longiremis in the 2001-2003 period. In August 2001, it only occurred at a few stations, while in other seasons it occurred only occasionally, and it was not noted at all in samples taken in March 2003 (Table 2).

Centropages hamatus

C. hamatus is another common planktonic element of the open Baltic that occurs throughout the year and develops in the greatest numbers in fall. A boreal, sub-arctic form, it quite distinctly avoids very shallow bays and river mouths (Chojnacki 1973c, 1975; Klekowski and Węsławski 1991). Although Nikolajew (1961) considers it to be a thermophilous form, during the present study this species occurred in all the seasons, but it was noted at all the sampling stations only in November 2001 and in February 2002 when the temperature range was approximately 2.7-8.0°C. This may be an indication that it prefers lower temperatures. Maximum abundance (10,640 ind. m^{-3} at LO) was observed in February 2002 at temperatures of 3.2-3.3°C and salinity of 8.3-10.6 psu (Tables 2, 3).

Cyclopina gracilis

The species *C. gracilis* is found in the waters of overgrown Baltic bays, where it sometimes occurs in huge numbers (Żmudziński 1990). In the 2001-2003 period, it occurred in the Pomeranian Bay only in November 2001 at station DV (105 ind. m^{-3}) and in August 2003 at stations SIII (193 ind. m^{-3}) and LO (105 ind. m^{-3}) (Table 2). This may be an indication that it was found there by accident and without favorable habitat conditions, it died. This is confirmed by the fact that it was not noted at any other stations and that it was not found in other seasons.

Megacyclops viridis

M. viridis is a species found in shallow Baltic waters above areas overgrown with vegetation (Żmudziński 1990). The species was not a dominant among the Copepoda in the 2001-2003 period in the Pomeranian Bay. At most sampling stations it occurred only eight times (Table 2), as follows: May and November 2001 (max. fall abundance SII - 785 ind. m^{-3}, DII - 918 ind. m^{-3}, DV - 941 ind. m^{-3}); February, May, and August (max. summer abundance MII - 961 ind. m^{-3}); November 2002 (max. abundance SII - 225 ind. m^{-3}); March (max. abundance DII - 206 ind. m^{-3}) and June 2003. It usually occurred in higher concentrations at stations located nearer the coast (up to 3 Mm) in the neritic zone of the Odra estuary.

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Unidentified - Cyclops

Mostly the freshwater *Cyclops* genus was noted in the waters of the southern Pomeranian Bay in the 2001-2003 period. In May 2001, it was a dominant at stations SI, SIII, MI, and MII, which are in the "tongue" of fresh water of the Szczecin Lagoon. This may demonstrate that there was a higher influx of fresh waters into the lagoon at this time. During this period, the surface water salinity ranged from 4.9 to 5.6 psu and water temperature ranged from 15.9 to 16.3°C (Tables 2, 3).

Numerous nauplius and copepodit at various stages of development were noted in the samples. Although these were not identified to the species, all of their features seemed to indicate that these forms were of a currently dominant species.

Significance of salinity in the distribution of mesozooplankton

The theory put forth in the literature that salinity is the major abiotic factor shaping the ecological structures of the freshwater, sea water, and brackish water biocenosis was confirmed by the current research. This is particularly visible in the range, seasonality, and mosaic-like structure of the occurrence of the planktonic fauna (Ciszewski 1963, 1972; Różańska 1976; Wiktor 1963). Over the two-year study, the influx of fresh water that spread in a wide belt from the Świna mouth up to the Dziwna mouth was clearly visible; however, the gradient of increasing salinity values was small to the east and north in the direction of the Odra Bank (Machula 2005, Machula et al. 2006). In this last region, the bay waters were of a decided sea character, although psu oscillated around 7.6. The mouth of the Rega River provided an interesting picture since no such distinct salinity gradient was observed there (average 6.96-7.06 psu), which was probably due to the small amounts of waters the river deposits into the sea in comparison to the Świna (average 5.79-6.84 psu for period 2001-2003) and Dziwna (average 6.4-7.23 psu for the 2001-2003 period), and there was a stronger littoral current (Table 3).

In this environment, the distribution of the spatial mesozooplankton structures was characteristic (Drzycimski et al. 1972) (Fig. 3a). Ubiquitous species, which have a wide tolerance to salinity and are considered to be euryhalophilous, typically fit into the group characteristic of fresh and ecotone waters. It was in the ecotones of coastal sea areas, not only of the Baltic but also in those in rivers with a majority of fresh water, that the marine and freshwater species occurred. This was observed previously in the southern Baltic by Chojnacki (1983, 1984b, 1986a, b, 1987, 1991), Chojnacki et al. (1986), Mańkowski (1978a, b), Wiktor (1963), Wiktor and Żmijewska (1985), and Żmijewska (1974). The plankton fauna examined, and the Copepoda in

particular, treat the labile environment of the Pomeranian Bay (in the 2001-2003 period), with its changeable thermal conditions, oxygen content, and BOD_5 (including nutrients, of course) and salinity, as a specific environment where they can survive easily and even reach quite significant abundance, exceeding 200,000 ind. m^{-3}, with the seasonal dominance of various taxonomic groups of mesozooplankton at a few stations (Tables 2, 3).

Seasonal succession of mesozooplankton in 2001-2003

Baltic zooplankton, including Pomeranian Bay mesozooplankton, exhibited significant seasonal qualitative and quantitative variation, the rhythm of which depends on the climatic zones characteristic of the waters of the boreal-temperate zone (Ackefors 1969; Chojnacki 1984a, b, 1987, 1991; Chojnacki and Chojnacka 1985; Wiktor 1963). This characteristic variation was identified by Margalef (1967) as the seasonal succession of both phytoplankton and zooplankton in marine ecosystems.

The investigations that were conducted in the waters of the southern part of the Pomeranian Bay in 2001-2003 confirmed that temperature and salinity had the greatest influence on the seasonal changes of planktonic zoocenoses structures, as was established previously by Chojnacki (1986a, 1987, 1991). Water temperature affected plankton aggregations, their taxonomic structure, as well as species dominance and the taxonomic sequence. It permitted identifying dominant organisms in particular seasons which formed characteristic seasonal succession series in the Pomeranian Bay (Fig. 8).

A. bifilosa was the decided dominant in the mesozooplankton and among the Copepoda throughout the investigation. Its dominance was markedly visible at coastal, and neritic zone stations, in particular at stations SI in spring and DI in summer. This is where there was a constant, strong influx of fresh waters. This indicates that this species is highly ecologically tolerant, both with respect to salinity and water temperature. It should also be stressed that in the transects of stations SI, SII, SIII and LO; MI, MII, MIII and LO; and RI, RII and RIII its abundance decreased as the distance from the coastline increased.

During the coldest season of winter, the zooplankton in the Pomeranian Bay in 2001-2003 was poor in both abundance and species variety. Copepoda occurred almost exclusively in this period. In spring, after a period of slight warming in the epipelagic zone, an increase in zooplankton numbers and species variety was typically noted. At stations SI and SII there was a characteristic dominance of early stages of Copepoda development. In this season, at stations located furthest from the coastline (SII, SIII, MII, MIII, and LO) the brackish water Cladocera species *E. nordmanni* began to dominate in numbers (Chojnacki and Machula 2006). Maximum abundance and the richest

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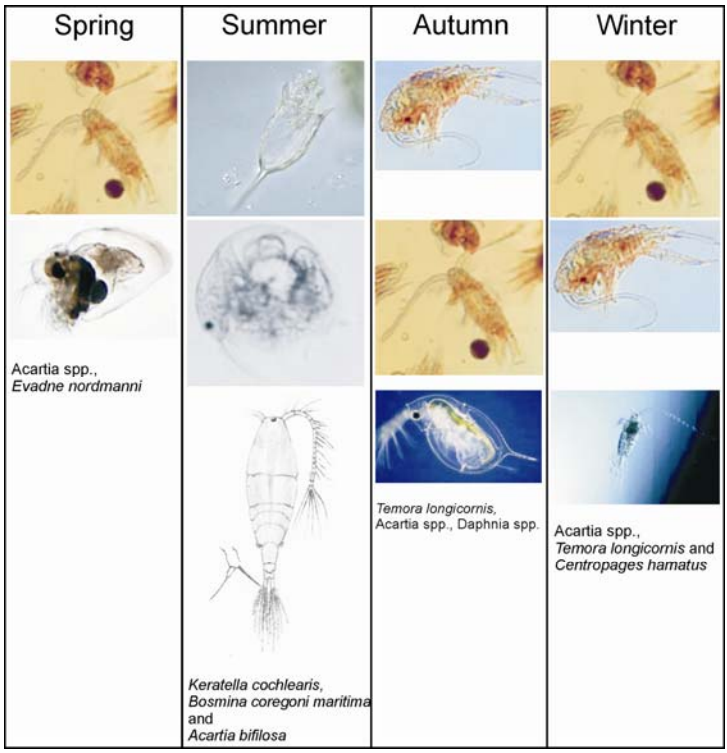


Fig. 8. Scheme of seasonal succession in the Odra River estuary (southern end of the Pomeranian Bay) in 2001-2003.

species variety were noted in Pomeranian Bay waters from late spring until the end of summer. *Keratella cochlearis*, *B. coregoni maritima*, and *A. bifilosa* were the species which occurred alternatively as dominants according to Chojnacki and Machula (2006). They did, however, take different forms locally at each of the examined transepts of the river mouths in the Odra estuary. Most frequently, the dominants at stations near the Świna and Dziwna mouths were *K. cochlearis* (Rotatoria), but as the distance from the coastline increased their abundance decreased. However, they remained a subdominant in the summer season. It is worth noting that at station LO their quantitative advantage over other zooplankton species was high. Simultaneously, *B. coregoni maritima (*Cladocera) occurred in the greatest abundance at stations DIV, DV, DII, and RIII. In fall, mesozooplankton aggregations in the Odra estuary decreased drastically, but Copepoda still dominated with *A. bifilosa*, *A. longiremis*, early stages of Copepoda, *T. longicornis*, and *Cyclops* spp. (with the exception of station SII, where high numbers of fresh water *Daphnia* spp. Cladocera were noted) (Machula 2005, Chojnacki and Machula 2006). This freshwater species

occurs in large numbers in the Szczecin Lagoon and periodically in the area near the mouth of the Świna River in the Pomeranian Bay. Similar rhythm in seasonal zooplankton changes was presented in the research of Chojnacki (1984a, b) on the Pomeranian Bay and by Wiktor (1993) on the Puck Bay.

Table 3

Average values of selected physical and chemical parameters of Pomeranian Bay waters in ten seasons from 2001 to 2003. (A – upper layer, B – bottom layer)

A

Station	Parameter						
	P_{total} [mg dm^{-3}]	N_{total} [mg dm^{-3}]	pH	Salinity [psu]	Temperature [^{0}C]	O_2 [mg dm^{-3}]	BOD_5 [mg dm^{-3}]
SI	0.083	0.319	8.0	5.79	12.89	10.816	3.932
SII	0.082	0.234	8.0	6.24	12.85	10.832	3.584
SIII	0.075	0.237	7.9	6.84	12.65	10.792	3.200
MI	0.072	0.278	8.1	6.42	12.60	10.640	3.750
MII	0.077	0.260	8.0	6.56	12.56	10.450	3.496
MIII	0.058	0.250	7.9	7.08	12.36	10.650	3.494
DI	0.071	0.292	8.0	6.40	11.54	10.664	2.928
DII	0.061	0.251	8.0	6.97	11.83	10.760	3.222
DIII	0.063	0.237	7.9	7.23	11.82	10.592	2.958
DIV	0.083	0.267	8.0	6.69	11.48	10.544	3.300
DV	0.077	0.221	7.9	6.95	11.48	10.336	3.300
RI	0.056	0.194	8.0	6.96	10.73	10.498	3.302
RII	0.067	0.240	8.0	7.06	10.53	10.507	3.173
RIII	0.064	0.213	8.0	7.03	10.40	11.093	3.538
LO	0.073	0.198	7.9	7.11	12.33	10.512	3.072

B

Station	Parameter						
	P_{total} [mg dm^{-3}]	N_{total} [mg dm^{-3}]	pH	Salinity [psu]	Temperature [^{0}C]	O_2 [mg dm^{-3}]	BOD_5 [mg dm^{-3}]
SI	0.085	0.275	7.9	6.13	11.84	10.208	3.748
SII	0.010	0.225	7.9	6.56	11.55	9.740	3.586
SIII	0.061	0.229	7.9	7.02	11.75	10.552	3.384
MI	0.069	0.280	8.0	6.78	11.47	9.720	3.380
MII	0.063	0.233	7.9	7.11	11.41	10.260	3.564
MIII	0.069	0.218	7.9	7.10	11.26	10.320	3.104
DI	0.084	0.296	8.0	6.57	10.95	10.128	3.328
DII	0.065	0.236	8.0	7.08	10.95	10.360	3.224
DIII	0.075	0.234	8.0	7.27	11.09	10.656	3.266
DIV	0.073	0.242	8.0	6.81	10.82	10.168	3.198
DV	0.074	0.261	7.9	7.14	10.71	10.584	2.954
RI	0.071	0.195	8.0	6.97	10.46	10.453	3.147
RII	0.069	0.188	8.0	7.01	10.37	10.436	3.117
RIII	0.063	0.183	8.0	7.06	10.23	10.960	3.647
LO	0.070	0.219	7.9	7.36	11.54	10.584	3.488

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CONCLUSIONS

The results of the mesozooplankton study in the Pomeranian Bay in the 2001-2003 period presented as colorful isolines of aggregations in relation to the more significant abiotic environmental indicators permit analyzing the spatial structure of the order I estuary ecosystem of the Odra River.

1. The highest species variety was found among marine and brackish water Copepoda – *P. elongatus*, *T. longicornis*, *A. bifilosa*, *A. longiremis*, *A. tonsa*, *C. hamatus*, *Eurytemora* spp., *Cyclops* sp., *M. viridis*, *M. leuckarti*, *E. speratus*, *E. gracilis*, and *C. gracilis*, which were the dominant group in virtually every studied season with a maximum abundance reaching as much as 213,493 ind. m^{-3}. The euryhaline species *A. bifilosa* occurred throughout the investigation period and at all stations, and its abundance reached 210,443 ind. m^{-3}.
2. The relationships among some abiotic environmental factors and zooplankton aggregations are reflected in the mosaic-like distribution of Copepoda species in the Pomeranian Bay. The values were characterized by the water masses in that mesozooplakton aggregations varied along with changes in water temperature and salinity.

The water temperature in the Pomeranian Bay greatly affected the structure of the plankton aggregations and their taxonomic structure, which permitted identifying dominant organisms and seasonal succession series. In spring, the dominants were Copepoda in early stages of development, *Acartia* spp., and *E. nordmanni* (Cladocera); in summer - *K. cochlearis*, *B. coregoni maritima*, and *A. bifilosa*; in fall – *T. longicornis* Copepoda and *Acartia* spp., the freshwater cladoceran *Daphnia* spp.; in winter – *T. longicornis* and *C. hamatus*.

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