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Spatio-temporal variability of mesozooplankton from the Gulf of Gdańsk (Baltic Sea) in 1999-2000

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Abstract

The spatio-temporal variability of mesozooplankton in the Gulf of Gdańsk was studied using samples collected in the western part of this basin every month in the 1999-2000 period. The investigation indicated that the qualitative composition of zooplankton was typical of this area and was comprised of Copepoda, Cladocera, Rotatoria, Appendicularia, and meroplankton. *Acartia bifilosa* and *Temora longicornis* were present permanently, while Cladocera, *Acartia tonsa*, *Centropages hamatus*, *Eurytemora* sp., the genus *Keratella*, as well as Mollusca and *Balanus improvisus* larvae exhibited clear preferences for warmer months. *Acartia longiremis*, *Pseudocalanus elongatus*, and *Fritillaria borealis* were encountered in the cooler season (from November to April). *Synchaeta* spp. dominated among Rotatoria and Polychaeta larvae among meroplankton. The presence of *Brachionus calyciflorus* indicated the presence and influence of riverine water from the Vistula.

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INTRODUCTION

Coastal waters, and especially estuarine areas, are an important element of the Baltic Sea ecosystem as they serve as filtering systems between rivers and adjacent marine waters. The character of these waters is shaped by the general conditions in the Baltic Sea and the undeniable influence of the Vistula River. The prevailing hydrological situation in the Gulf of Gdańsk is a combination of these two elements and is illustrated well by the organisms living in it.

The Baltic Sea is characterized by exceptional thermohaline conditions that are the result of its semi-enclosed character and seasonality (Kwiecień 1990, Andrulewicz 1996). The Baltic Sea basin is situated in the boreal zone, its northern tip reaching the arctic climate. Very briefly, the climate changes the Baltic Sea is subjected to include the warming of surface waters in summer, considerable cooling in winter with an ice season in the northern areas, and water mixing due to advective temperature unification in fall. These changes initiate a number of abiotic processes in this marine environment and are also evident in the variability of the pelagial fauna including aspects such as concentration and spatial distribution, species succession, occurrence of seasonal components, specific development stages, etc. Baltic-wide and regional studies that address the influence of seasonality on zooplankton have been ongoing for a number of years (e.g., Ackefors 1965, Chojnacki 1984, Dahmen 1997). The majority of papers published followed the same research scheme; the differences recorded were related to specific quantitative descriptors (abundance, biomass) of the entire zooplankton population or its particular components and certain (usually insignificant) shifts in the times of their occurrence. Since zooplankton is the most abundant and diverse in summer, the studies focused on this season and frequently disregarded the cooler part of the year (Schultz and Breuel 1984, Lumberg and Ojaveer 1997, Uitto et al. 1997). Siudziński (1977) and Wiktor (1990) have examined most extensively the zooplankton community of the Gulf of Gdańsk, and the latter provided an overview of observations made by a number of other researchers and the author herself (Mańkowski 1951, 1978; Żmijewska 1974; Wiktor et al. 1982; Chojnacki 1984; Wiktor and Żmijewska 1985).

Published data on zooplankton from a wider area in the Gulf of Gdańsk, not just the shallow coastal area (Bielecka et al. 2000), date to the 1980s. This provided the primary impetus for undertaking the present study, the aim of which was to determine if the patterns of zooplankton occurrence in the gulf described previously had remained stable or not. This was achieved by determining annual variation in the spatio-temporal variability of this ecological formation in the Gulf of Gdańsk by continuing sample collection at similar stations.

MATERIAL AND METHODS

Zooplankton samples were collected every month from September 1999 until August 2000, with the exception of December 1999, when meteorological conditions prevented sailing in the gulf. Hauls were made using a closing Copenhagen net (50 cm diameter, 100 µm mesh size as recommended by Wiktor (1982) for this region) from the vessel *Oceanograf 2* owned by the Institute of Oceanography, University of Gdańsk. Sampling was completed at eight measurement stations of differing depths located in the central as well as littoral zones of the Gulf of Gdańsk (Fig.1, Table 1).

Table 1

Location of sampling stations in the western part of the Gulf of Gdańsk

Station	Latitude	Longitude	Depth	Distance from the coast
M2	54° 39.0′ N	18° 33.8′ E	10 m	2.2 Nm
J23	54° 32.0′ N	18° 48.2′ E	40 m	9.5 Nm
So4	54° 30.7′ N	18° 46.0′ E	30 m	7.8 Nm
So3	54° 29.7′ N	18° 43.7′ E	20 m	5.8 Nm
So2	54° 27.7′ N	18° 36.7′ E	10 m	1.5 Nm
So1	54° 27.0′ N	18° 34.8′ E	5 m	0.3 Nm
G2	54° 25.6′ N	18° 39.3′ E	10 m	1.3 Nm
G1	54° 25.2′ N	18° 39.6′ E	5 m	0.5 Nm

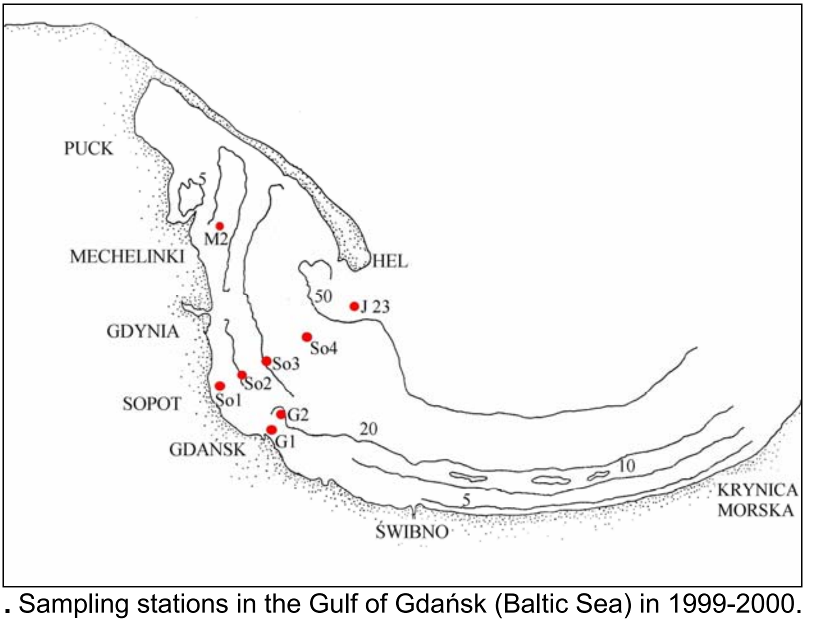

Fig. 1. Sampling stations in the Gulf of Gdańsk (Baltic Sea) in 1999-2000.

At shallow stations not exceeding 10 m in depth, net hauls were done from the bottom to the sea surface, while at deeper stations 10 m water layers were sampled separately. The biological material collected was preserved with 4% formaldehyde and later analyzed under a binocular microscope in the laboratory. Depending on the organism concentration, the samples were split into sub-samples (from 1/2 to 1/128) using a Motoda box-splitter (Motoda 1959). Holoplanktonic organisms were determined to the genus or the species (Mańkowski 1955, Ackefors and Hernroth 1972). Copepod nauplii were determined to the species even though this was done rarely in other studies (e.g., Siudziński 1977). Due to considerable similarities between young forms within the genus *Acartia*, species differentiation was only performed on adult forms (similarly to Ackefors (1969)).

The abundance of specimens from sample to 1 m^3 was calculated according to the following formula:

$$x = n \times (h \times \pi \times r^2)^{-1}$$

where

x – number of specimens in 1 m^3;
n – number of specimens in the whole sample;
h – thickness of net–haul [m], here 5 m or 10 m;
r – radius of net mouth [m], here 0.25 m.

RESULTS

Between September 1999 and August 2000, the mean mesozooplankton abundance in the western part of the Gulf of Gdańsk reached 12 178 ind. in 1 m^3 (SD = 14 594), with the lowest abundance noted in February (758 ind. m^{-3}) and the maximal zooplankton development observed in August (45 744 ind. m^{-3}) (Table 2). In spatial distribution the maximal zooplankton concentrations were noted at shallow coastal stations in the vicinity of Sopot and Gdańsk and also at the deepest station (J23) in water layers to depths of 30 m (Fig. 2). The Puck Lagoon (station M2 at 10 m) was exceptional among the shallow water stations because of markedly lower zooplankton abundance values recorded there throughout the year.

The pelagic fauna species composition in the Gulf of Gdańsk during the present study was typical for this region. During the study period holoplanktonic organisms formed the core of the mesozooplankton community, namely Copepoda, Cladocera, and Rotatoria and, to a lesser extent, the only representative of Appendicularia – *Fritillaria borealis*. Moreover, the authors

Table 2

Changes in the average abundance of mesozooplankton from the Gulf of Gdańsk in subsequent months (September 1999 – August 2000)

Date	Abundance [ind. m^{-3}]	SD	Min.	Station (layer)	Max.	Station (layer)
IX 1999	8 596	10 003	669	So4 (30-20 m)	32 024	So1 (5-0 m)
X 1999	6 195	4 243	1 287	So4 (30-20 m)	13 566	So2 (10-0 m)
XI 1999	1 657	1 228	318	M2 (10-0 m)	4 771	G1 (5-0 m)
I 2000	1 738	1 822	221	So3 (20-10 m)	7 109	So1 (5-0 m)
II 2000	758	625	188	So3 (20-10 m)	2 199	G1 (5-0 m)
III 2000	1 553	1 048	223	So3 (20-10 m)	3 626	So1 (5-0 m)
IV 2000	1 785	1 544	245	J23 (40-30 m)	5 270	G2 (10-0 m)
V 2000	16 359	8 779	5 287	So2 (10-0 m)	29 196	G1 (5-0 m)
VI 2000	29 698	31 019	1 277	J23 (40-30 m)	103 117	G1 (5-0 m)
VII 2000	19 870	11 779	1 364	J23 (30-20 m)	37 308	So1 (5-0 m)
VIII 2000	45 744	52 054	5 359	So4 (20-10 m)	171 014	J23 (20-10 m)

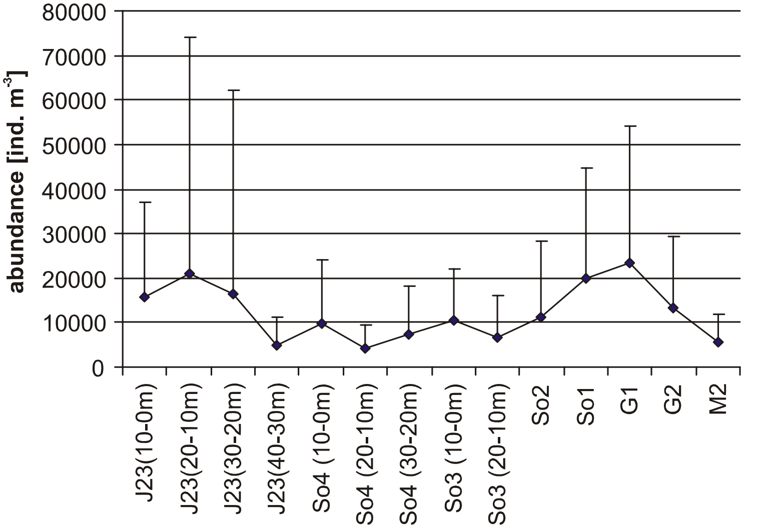

Fig. 2. Spatial variability in the average abundance of Gulf of Gdańsk mesozooplankton (September 1999 - August 2000).

observed zoobenthos larvae, i.e., meroplankton. Certain groups occurred in particular months; Cladocera was noted from May to August, while Appendicularia appeared in very small numbers in winter (January, March, April) and in May (Fig. 3). The three remaining fractions, i.e., Copepoda, Rotatoria, and meroplankton, occurred throughout the year in various proportions. Copepods dominated from September to April, attaining up to 75-96% of the total zooplankton abundance, while Rotatoria and benthic fauna larvae usually constituted the remaining part (Fig. 3). In May, Rotatoria became the dominant component (76%), Cladocera appeared at the same time, while the contribution of Copepoda diminished to 14%. In June, all four of the examined taxa were found in comparable proportions, and meroplankton reached the maximal annual contribution (28% of zooplankton). In July, the Copepod contribution increased again (to 52%), and the proportions of meroplankton and Cladocera declined. Rotatoria remained at approximately the same level as in June (about 30%). The most prolific occurrence of Cladocera, with a 47% contribution to the total zooplankton abundance, was noted in August (Fig. 3).

The spatial distribution of zooplankton in the Gulf of Gdańsk was analyzed by averaging the annual data for individual stations and water layers (Fig. 4). Copepoda attained more than a third of the total zooplankton abundance throughout the studied area of the Gulf of Gdańsk. It is worth noting that in deeper water layers at stations J23 (40-30 m) and So4 and So3 below 10 m, as well as in the Puck Lagoon (station M2), Copepoda constituted over 50% of the total zooplankton abundance (Fig. 4). Rotatoria abundance was distributed nearly evenly reaching 20-40% at all studied stations. The highest contributions (>20%) of Cladocera were found at the deepest station (J23) to depths of 30 m and in the surface layer of station So4 and close to the coast at station G2. Cladocera did not play any significant role at other stations (Fig. 4). The most abundant meroplankton (10-30%) was found at shallow stations close to Sopot and Gdańsk and also at the deepest station J23 (throughout the water column). Meroplankton accounted for only a few percent of the total zooplankton abundance at the remaining stations (Fig. 4). The presence of *Fritillaria borealis* (Appendicularia) was nearly undetectable regardless of station location.

The analysis of raw data, prior to averaging, indicated a marked distinction in zooplankton composition in the Puck Lagoon. At station M2, Rotatoria made a much greater contribution than elsewhere and was the second most important group (after Copepoda) of animals noted throughout the year, while the Cladocera contribution was small even in months when their mass occurrence was noted in other Gulf of Gdańsk areas.

As mentioned previously, Copepoda formed the permanent core fraction of the mesozooplankton community in the Gulf of Gdańsk. Annual changes of

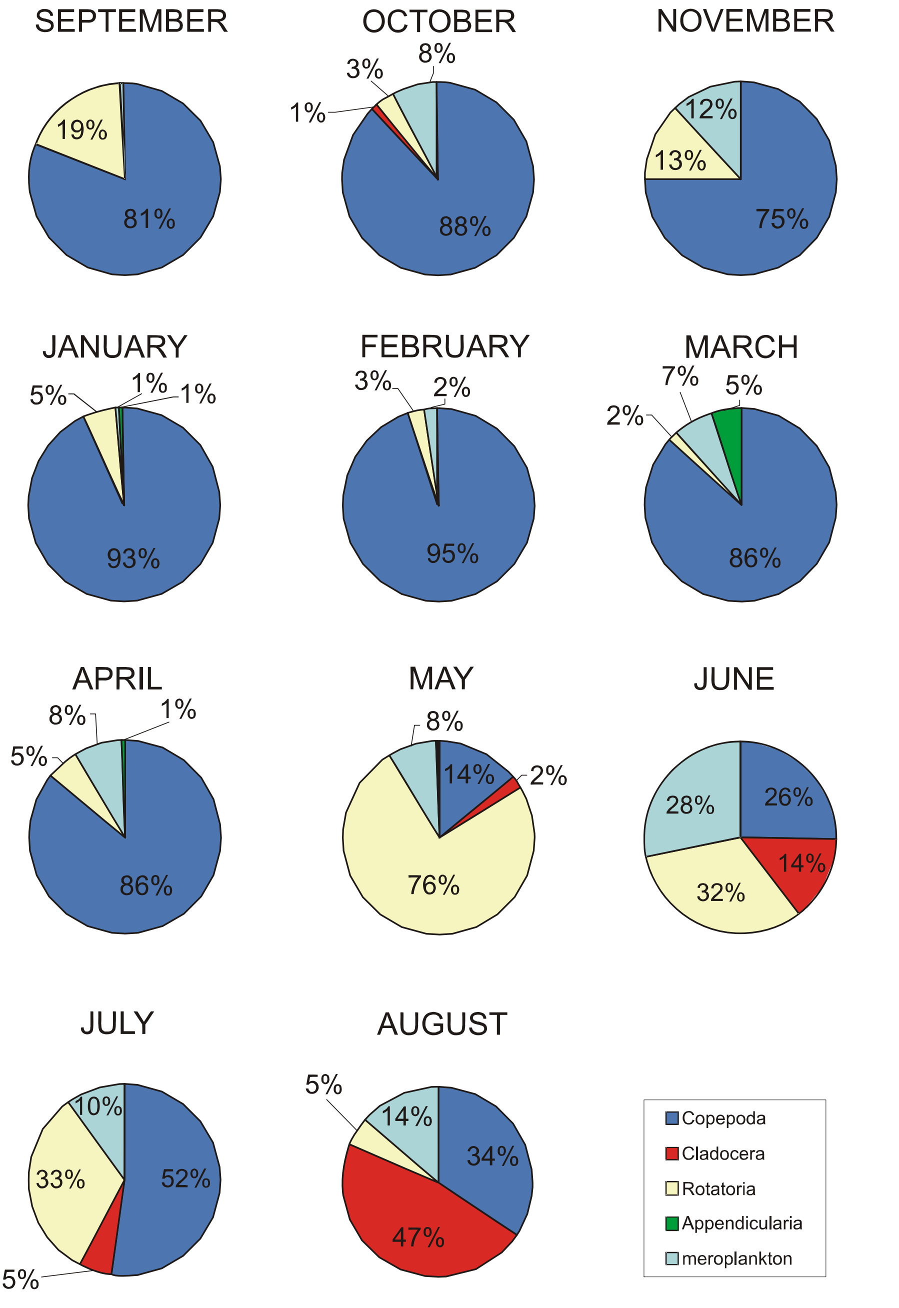

Fig. 3. Monthly changes in the taxonomical composition of Gulf of Gdańsk zooplankton (September 1999 - August 2000).

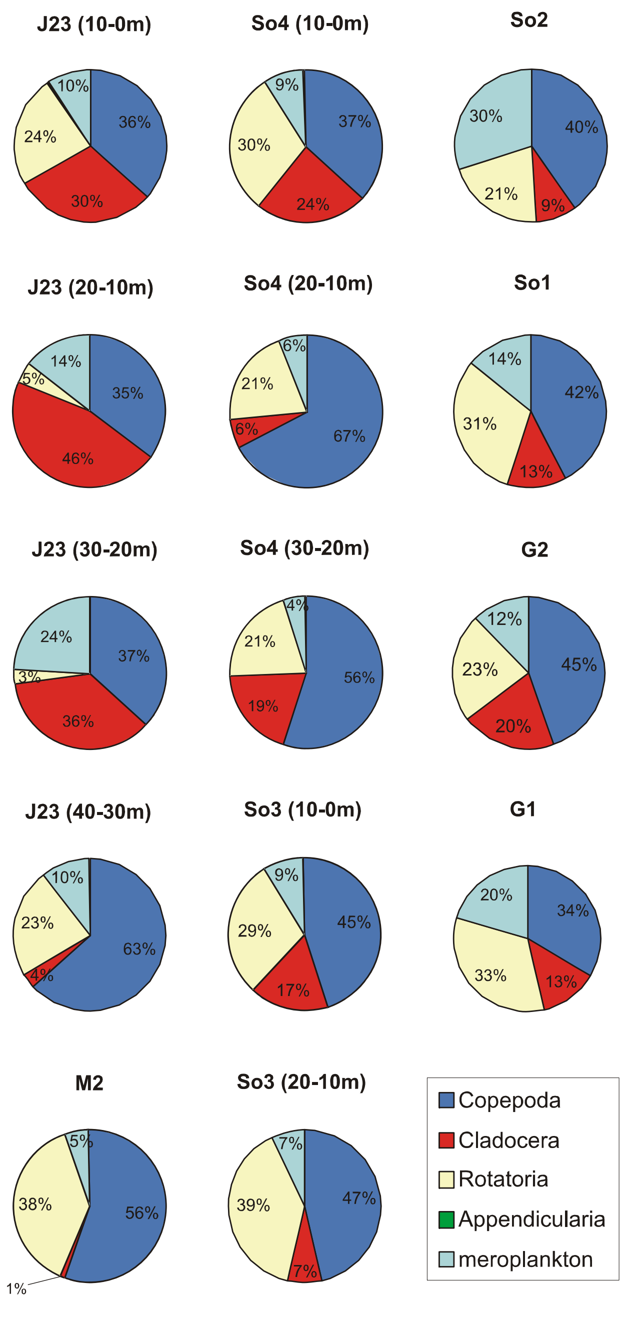

Fig. 4. Spatial variability in the taxonomical composition of Gulf of Gdańsk zooplankton (September 1999 - August 2000).

abundance of this taxon are presented in Table 3. Considering species structure, the genus *Acartia* played the dominant role throughout the better part of the year (usually attaining >50% of the Copepoda abundance). The maximal

Table 3

Annual changes in abundance of particular taxa of mesozooplankton from the Gulf of Gdańsk (September 1999 – August 2000)

DATE	ABUNDANCE OF PARTICULAR TAXA [ind. m^{-3}]				
	Copepoda	Cladocera	Rotatoria	Appendicularia	meroplankton
IX 1999	6937 (SD 8638)	6 (SD 17)	1608 (SD 2280)	3 (SD 9)	41 (SD 55)
X 1999	5462 (SD 3687)	52 (SD 53)	203 (SD 237)	0	477 (SD 651)
XI 1999	1243 (SD 800)	2 (SD 3)	214 (SD 253)	1 (SD 3)	197 (SD 404)
I 2000	1622 (SD 1847)	0	92 (SD 103)	11 (SD 41)	14 (SD 18)
II 2000	720 (SD 613)	0	21 (SD 20)	1 (SD 3)	16 (SD 18)
III 2000	1346 (SD 897)	0	27 (SD 31)	73 (SD 78)	107 (SD 118)
IV 2000	1872 (SD 2117)	1 (SD 3)	117 (SD 166)	15 (SD 35)	175 (SD 324)
V 2000	2366 (SD 2328)	328 (SD 328)	12267 (SD 8553)	43 (SD 79)	1347 (SD 1916)
VI 2000	7611 (SD 4164)	4184 (SD 6943)	9471 (SD 9843)	0	8432 (SD 13717)
VII 2000	10386 (SD 5483)	1016 (SD 1278)	6478 (SD 5961)	0	1990 (SD 2282)
VIII 2000	15595 (SD 14397)	21667 (SD 27966)	2078 (SD 1969)	0	6403 (SD 11554)

abundance was noted in September at 98% and the minimal in June at 27% (Fig. 5). In months of dynamic Copepoda development, its contribution diminished in favor of *Temora longicornis* and, to a lesser extent, of *Centropages hamatus* or *Eurytemora* sp. at coastal stations and *Pseudocalanus elongatus* in the deeper gulf waters. The contribution of the genus *Acartia* then reached nearly 50% or less, although it has to be borne in mind that it was represented by three species, namely *A. bifilosa*, *A. tonsa*, and *A. longiremis.* This characteristic composition pattern was observed throughout the Gulf of Gdańsk in June and also at deeper stations in May, July, October, and November (Fig. 5). Within the genus *Acartia*, only adult specimens were determined as species. The species *Acartia bifilosa* was recorded in all samples while the thermophilous *A. tonsa* appeared from May until November (mainly in late July and early August) and the psychrophilic *A. longiremis* was

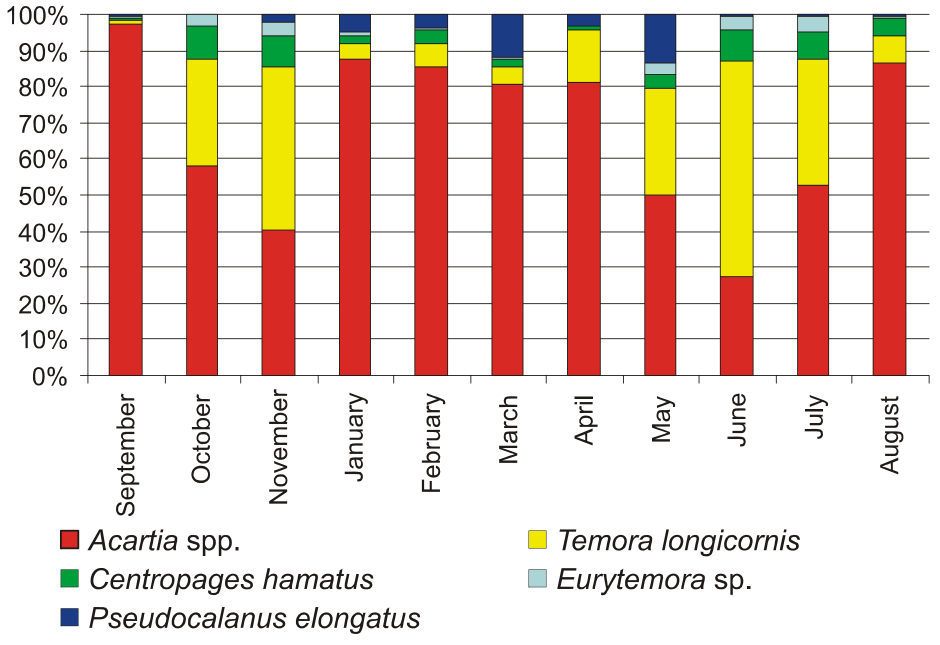

Fig 5. Temporal variability in the taxonomical composition of Gulf of Gdańsk Copepoda (September 1999 - August 2000).

encountered from November until June (dominating the adult forms of the genus in February and March).

As a thermophilous taxon, peak Cladocera concentration occurs in the summer months (Table 3). The Cladocera peak in June was attributed mainly to *Podon polyphemoides*, which dominated almost throughout the period of Cladocera occurrence (comprising from 53 to 99% of all Cladocera). In August, *Bosmina coregoni maritima* occurred on a mass scale comprising up to 94% of the Cladocera. The abundance of *Evadne nordmanni* and *Podon intermedius* did not exceed a few percent (Fig. 6).

A distinction between deeper parts and coastal areas close to Sopot and Gdańsk was evident regarding spatial distribution. The maximum abundance of Cladocera was observed at deeper stations in August, while in the coastal region it was usually in June.

Rotatoria played the most important role in the total abundance of zooplankton in May, although a significant contribution of them was also observed in subsequent warm months including September (Fig. 3). Changes in the quantity of this taxon in subsequent months are shown in Table 3. The lowest abundances (below 100 ind. m^{-3}) were observed from January to March,

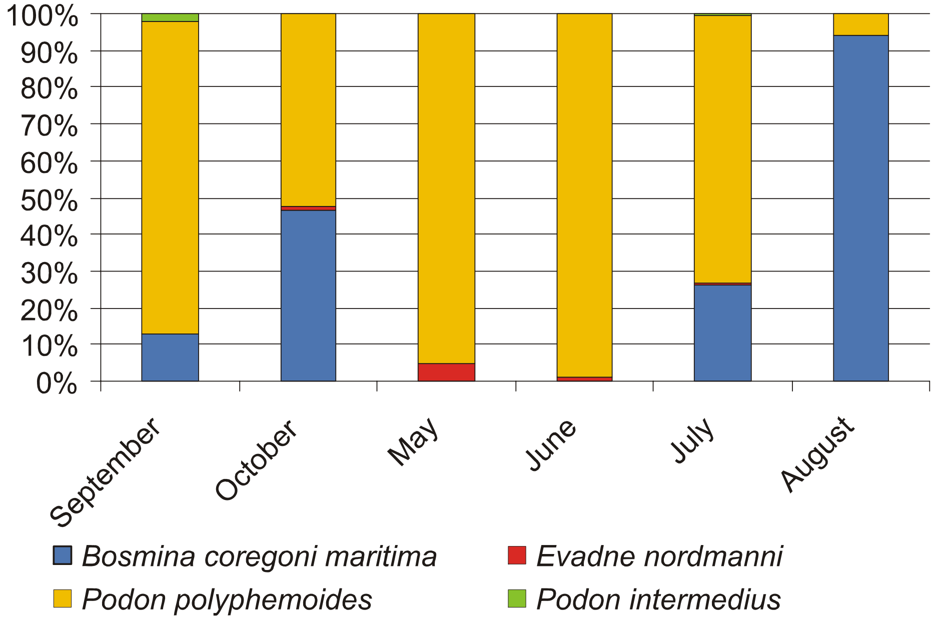

Fig 6. Temporal variability in the taxonomical composition of Gulf of Gdańsk Cladocera during months of its occurrence (September 1999 - August 2000).

while the highest (about 10 000 ind. m^{-3}) were noted in May and June (Table 3). The dominant species alternated between the genus *Synchaeta* (May-June) and *Keratella* (mainly *K. quadrata*) (July-September) (Fig. 7). In winter it was difficult to determine species or genus dominance due to the generally low abundance of Rotatoria (Table 3). It is worth mentioning that *Brachionus calyciflorus* appeared exclusively in May and mainly in coastal waters close to Sopot and Gdańsk (Fig. 7).

The abundance of meroplankton throughout the year exceeded 100 ind. m^{-3}, except in September (41 ind. m^{-3}) and the winter months of January and February (14-16 ind. m^{-3}) (Table 3). The qualitative composition of meroplankton in September 1999 was similar to that of warmer months; veliger Bivalvia were dominant (62% of the total number of zoobenthic larvae) and *Balanus improvisus* nauplii and Gastropoda and Polychaeta larvae were present. A qualitative reconstruction of this group of zooplankton took place in October. The Polychaeta larvae became the most important component, while *Balanus improvisus* nauplii and veliger Bivalvia were recorded less frequently. This structure pattern was characteristic for cooler months (up to March) (Fig. 8). From April to August veliger Bivalvia were dominant, and other representatives

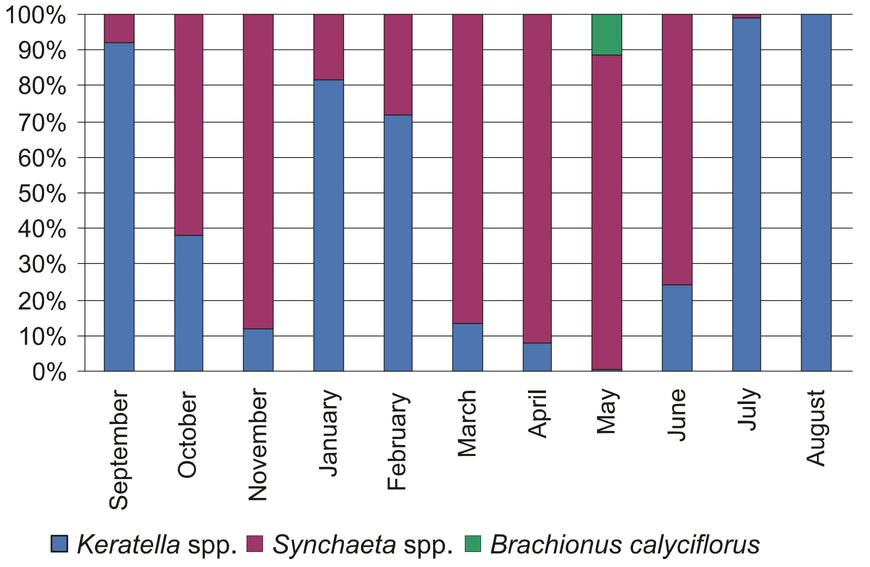

Fig 7. Temporal variability in the taxonomical composition of Gulf of Gdańsk Rotatoria (September 1999 - August 2000).

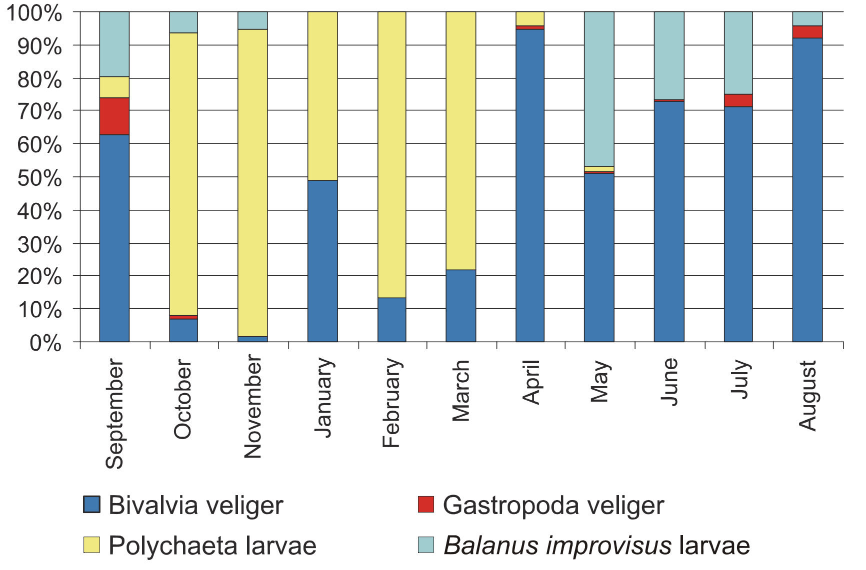

Fig. 8. Temporal variability in the taxonomical composition of Gulf of Gdańsk meroplankton (September 1999 - August 2000).

of meroplankton assumed higher abundances only locally. In May, the contribution of *Balanus improvisus* nauplii was as high as 90% in the surface layer of the central stations in the gulf and in the coastal area (station So1), while a 67% contribution of Polychaeta larvae was noted in the deepest water layer at station J23. In July, older larval stages of *Balanus improvisus* (cypris) and Gastropoda larvae were noted at contributions that reached 10% (station G1). Polychaeta larvae were not detected in this month.

DISCUSSION

The Gulf of Gdańsk is located in the southern part of the Baltic Proper and is an integral part of this basin as water exchange between the gulf and the offshore region is not restricted (Witek et al. 2003). The proximity of land and the Vistula River mouth, which discharges significant amounts of fresh water into the gulf, both shape the particular features of this aquatic region. In addition to their strictly physical impact, these two factors are also vectors of anthropogenic stress. Human activities on the land bordering the Gulf of Gdańsk as well as in the Vistula River catchment area alter water quality and are manifested by increased eutrophication and pollution (Błażejewski and Schuller 1994). In order to determine the effects of these two processes, investigations of various ecological formations have been performed. Changes in the Gulf of Gdańsk caused by either of these factors were determined using phytoplankton, zoobenthos, and fish communities (Wiktor and Pliński 1992). Zooplankton has been considered to be immune to such changes; recently, however, the parasitic Protozoa infection of copepods has often been attributed to increasing pollution (Wiktor and Krajewska 1994). This type of pathogenic change in Copepoda has been noted throughout the Baltic Sea, and infected individuals were also noted in the samples collected for the present project.

The main focus in this study was, however, the issue of whether, in comparison to long-term data, zooplankton structure exhibited changes similar to those noted in phytoplankton, zoobenthos, or fish in the Gulf of Gdańsk.

The study of the annual cycle of zooplankton variability was conducted on material collected from the same network of stations in the western part of the gulf that had been studied previously (Siudziński 1977, Wiktor 1990). The results of the present study were similar to those of these earlier studies. Copepoda comprised the core of the zooplankton community in the Gulf of Gdańsk. This fraction of zooplankton occurred permanently in gulf waters and was dominant in cooler months (September to April). In the warmer period, other taxa of the pelagic fauna assumed dominance, namely Rotatoria in May and Cladocera in August. Several earlier studies (Siudziński 1977, Wiktor and Żmijewska 1985, Wiktor 1990) reported the same pattern of zooplankton occurrence in the gulf. The spatio-temporal occurrence of the species noted was also typical of the region. *P. elongatus* and *A. longiremis* were encountered in the cooler part of the year, mainly in deeper water layers, while thermophilous representatives like *Acartia tonsa*, *Centropages hamatus*, *Eurytemora* sp. (Copepoda), the genus *Keratella* (Rotatoria), all cladoceran species, and the larvae of mussels, snails and *Balanus improvisus* were noted mainly in summer in the surface water layer. A similar zooplankton composition in the Gulf of Gdańsk was reported previously by Mańkowski (1951), Ciszewski (1962), Siudziński (1977), Wiktor et al. (1982), Wiktor and Żmijewska (1985), and Wiktor (1990). Similar results were also obtained during monitoring activities conducted by the Institute of Meteorology and Water Management (IMGW) (IMGW 1999, 2000, 2001). The discrepancies that occurred concerned certain freshwater species that were not noted in the present study. This can be explained by the location of the measurement stations since the other authors cited focused their investigations on areas farther to the east of the gulf nearer to the Vistula River mouth. This explains the freshwater species noted in their samples. It must also be borne in mind that Vistula discharge usually spreads eastward (Chojnacki et al. 1986, Wiktor 1990), which is in the opposite direction of the current study polygon. During the study period (1999-2000), the influence of the river plume was detected clearly in May 2000 and manifested as a decline in salinity and the wide occurrence of the freshwater Rotatoria - *Brachionus calyciflorus*. With the exception of this incident of the riverine water plume reaching the study area, the average salinity in the studied region was approximately 7 psu in the surface layer and seasonal temperature variability was marked. Therefore, the changes observed in the annual cycle of the zooplankton community structure were caused mainly by temperature fluctuations.

The seasonal variability of Baltic zooplankton has been described based on short-term (Bielecka et al. 2000) and long-term (Dippner et al. 2000, Möllman et al. 2000) data analyses, as well as for various locations such as offshore areas (Ciszewski 1962, Żmijewska 1974, Ciszewska 1990, Viitasalo et al. 1994), bays (Wiktor 1963, Siudziński 1977, Ackefors et al. 1978, Kankala 1987, Andrushaitis and Vitinsh 1997, Behrends 1997), and estuaries and lagoons (Arndt et al. 1984, Heerkloss and Schnese 1999).

The zooplankton data from various regions of the Baltic Sea and different years leads to the conclusion that the general pattern of taxonomic succession is stable. The differences that occur are related to time shifts between regions and certain changes in zooplankton composition although these are mainly dependant on salinity. Some differences also occur in the abundance and biomass of particular species in the same region but in different years. However, the times when particular species occurred did not differ (Siudziński 1977, Wiktor et al. 1982, Wiktor and Żmijewska 1985, Bielecka et al. 2000). The situations observed in the present study were similar to those of earlier data. Despite certain quantitative differences, the zooplankton taxonomical composition and species succession between 1999-2000 did not change considerably in comparison to the data presented in the other papers cited.

Heerklos and Schnese (1999) made similar observations in the Dars-Zinst estuary (western Baltic) concluding that the general pattern of Copepoda and Rotatoria occurrence is the same despite considerable interannual variability in abundance.

To recapitulate, no long-term change was noted in the composition or structure of zooplankton in the Gulf of Gdańsk and other Baltic Sea regions. The occurrence of particular taxa depends on their ecological requirements regarding water salinity or temperature. The animals reflect the variability of these two parameters in the Gulf of Gdańsk water without any apparent reaction to increasing human impact in the area.

The resistance or immunity of the Gulf of Gdańsk zooplankton community to anthropogenic pressure most probably results from the considerable part of this community being composed of eurythermic and euryhaline taxa. Wide tolerance of changes in these parameters can be related to increased tolerance of other environmental factors. It is also probable that the changes observed due to anthropogenic pressure to date have not yet exceed the carrying capacity threshold of the zooplankton. However, this cannot be considered as a constant element of zooplankton behavior; in regions with much more intense eutrophication processes, like the Gulf of Riga or the Black Sea, changes in pelagic fauna have recently been detected (Kostrichkina et al. 1990, Kideys et al. 2000). Since the impact of anthropogenic pressure is increasing in spite of protective measures already taken (Błażejowski and Schuller 1994, Rydén et al. 2003), it must be borne in mind that the Gulf of Gdańsk zooplankton may exhibit a more pronounced reaction to these changes. Therefore, it is recommended to continue monitoring the status of this ecosystem element in the Gulf of Gdańsk.

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