Studies of Zooplankton in Gdańsk Basin (2010-2011)

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Abstract**—**In 2010-2011, the research on zooplankton was conducted in the southern part of the Baltic Sea to determine seasonal variability in changes occurring throughout the zooplankton in 2010 and 2011, both in the region of Gdańsk Deep, and in the western part of Gdańsk Bay. The research in the sea showed that the taxonomic composition of holoplankton in the southern part of the Baltic Sea was similar to that recorded in this region for many years. The maximum values of abundance and biomass of zooplankton both in the Deep and the Bay of Gdańsk were observed in the summer season. Copepoda dominated in the composition of zooplankton for almost the entire study period, while rotifers occurred in larger numbers only in the summer 2010 in the Gdańsk Deep as well as in May and July 2010 in the western part of Gdańsk Bay, and meroplankton – in April 2011.

Keywords**—**Baltic Sea, composition, Gdańsk Bay, zooplankton.

I. Introduction

ZOOPLANKTON is represented by animal organisms floating in the pelagic zone. It is composed of taxa from various taxonomic units with varying dimensions of the body, and crustaceans dominate both in the Baltic Sea, and in other seas and oceans worldwide. In addition to animals that spend their entire life in the pelagic zone (holoplankton), zooplankton also consists of larval forms of the benthic fauna (meroplankton) as well as the spawn and fish larvae.

Up to 90% of the zooplankton biomass in the Baltic Sea is represented by Copepoda: *Temora longicornis*, *Pseudocalanus elongatus*, *Acartia* spp., and Cladocera: *Eubosmina maritima* and *Evadne nordmanni* [1], [2]. Species composition, the abundance and biomass of zooplankton in the Southern Baltic are exposed to seasonal changes, typical of the boreal waters. The phenomenon depends on several factors, such as water temperature, or availability of light – throughout the year and the water column [3], [4].

The main function of zooplankton in the marine ecosystem consists in transferring the energy accumulated in the process of primary production to higher trophic levels [5]. These organisms are an important food for fish throughout their entire life cycle, or in the first period of their growth [6], [7]. The ecosystem of the Baltic Sea in the last century has been exposed to diverse transformations as a result of global climate change and broadly defined human impact (anthropopressure). This has a very negative impact on the marine life. Therefore, the efficient management of the marine environment is extremely important and requires extensive research, the main objective of which is to develop new and more accurate methods of environmental monitoring and prediction of the environmental response to different economic activities and global climate change.

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Evaluation of productivity of marine ecosystems is extremely difficult and requires knowledge about the mechanisms affecting the primary production in the pelagic zone and the functional relationships between physiological processes of zooplankton, and parameters of the marine environment, and how they affect the food chain. In order to assess the productivity of marine ecosystems, long-term *in situ* measurements are currently used from many regions of the sea, taken in different hydro-meteorological conditions, as well as the results of remote satellite measurements.

The main objective of this study was to describe changes in the species composition, the abundance and the biomass of zooplankton in Gdańsk Basin based on the research conducted in 2010-2011 in Gdańsk Deep and in the western part of Gdańsk Bay.

II. Study Material and Methods

A. Sample Collection Methods

Planktonic material which is the basis of *in situ* studies was collected in the southern part of the Baltic Sea from two stations: Gdańsk Deep and the western part of Gdańsk Bay.

The first series consists of biological material collected aboard the ship of the Institute of Oceanology of the Polish Academy of Sciences − r/v "Oceans" during 7 voyages in the area of Gdańsk Deep (54º50'φN, 19º19'λE) (Fig. 1, point P1), in the period from February 2010 to November 2011. The maximum depth of this site is ca. 100 m.

Vertical hauls were carried out using two nets: a Copenhagen net with an inlet diameter of 50 cm and a mesh diameter of 100 μm (in 2010) and WP-2 net from KC Denmark with an inlet diameter of 57 cm and a mesh diameter of 100 μm (in 2011).

The plankton net mesh size was selected so as to collect the mesozooplankton together with younger developmental stages of Copepoda, i.e. the main object of the study. A flow meter was placed at 1/3 of the diameter of the net inlet to determine the amount of filtered water.

The material was collected in accordance with the Helcom guidelines (Helcom). Vertical net hauls were performed in three layers: the bottom – the upper limit of the halocline (with no halocline – 75 m), the upper limit of the halocline – thermocline (with no thermocline – 25 m), the upper limit of the thermocline – the surface. A total of 21 samples were collected, both during the day and at night. The analysed study material from the Gdańsk Deep was used to determine the composition and seasonal changes in the abundance and the biomass related to time and space.

Fig. 1 Location of the sampling stations in the southern Baltic Sea in 2010-2011

The second series of the study material consisted of monthly zooplankton samples collected in the western part of Gdańsk Bay (54°32'φN, 18°48.2'λE) (Fig. 1, point P2) in the period from 11 February 2010 to 29 November 2011, from aboard the ship of the Institute of Oceanography of the University of Gdańsk – kh "Oceanography 2". The site of biological material collection was characterized by a depth of 40 m and was located 9.5 Mm away from the shore. Vertical net hauls were performed along the water column from the bottom up to the surface, divided into 10-m thick layers. The exception was the 27th of July 2011 when samples were collected from the following layers: 20-0, 30-20 and 40-30 m because of the equipment failure. In total, 71 samples were collected in this series.

Net hauls were carried out only during the day, using (like in Gdańsk Deep in 2011) a closed WP-2 net with an inlet diameter of 57 cm and mesh size of 100 µm. A flow meter was placed at 1/3 of the net inlet diameter to determine the amount of water filtered. The collected material was immediately moved into plastic bottles and exposed to 4% solution of formaldehyde to preserve animals for subsequent analysis. A total of 92 samples were analysed.

B. Taxonomic Composition of Zooplankton

The composition of zooplankton in the Gdańsk Deep and the western part of Gdańsk Bay did not significantly differ during the conducted research from that described since the 1930s by [8]-[15] etc. The main characteristic discriminating the obtained results were two alien species of Cladocera – *Cercopagis pengoi* (observed in the Bay of Gdańsk since the late 1990s – [16]) and *Evadne anonyx* (observed in the Baltic Sea since 2000 – [17]).

Mesozooplankton was represented mostly by organisms living their entire life in the pelagic zone (holoplankton) – copepods, cladocerans, rotifers and the only taxon of Appendicularia occurring in the Baltic Sea – *Fritillaria borealis*. Furthermore, the presence of eggs and juveniles of unidentified Ctenophora, several specimens of the species *Hyperia galba*, larvae of the benthic fauna (meroplankton) as well as eggs and fish spawn (ichthyoplankton) were found. The contribution of individual taxa and their horizontal and vertical distribution were determined by meteorological and hydrological conditions prevailing in a given period.

A total of 24 taxa were identified in the analysed material, including: 10 Copepoda, 4 Rotifera, 7 Cladocera, Ctenophora, *Fritillaria borealis* and *Hyperia galba*. In addition, larvae of the benthic fauna were counted (Polychaeta, Bivalvia, Gastropoda and Cirripedia); however, they were not identified to the species level, but generally defined as meroplankton. Ichthyoplankton was not analysed in detail.

III. Differences in the Abundance and the Biomass of Zooplankton

Taxa occurring in the samples occasionally or in small quantities (*Hyperia galba*, *Oithona similis*, Ctenophora, freshwater Cyclopoida, Harpacticoida) were not included in the determination of the abundance and the biomass of zooplankton.

The average count of zooplankton in the Gdańsk Deep (at station P1) during the conducted studies was 10685 ind. m^{-3} (SD 12027), whereas in 2011 – 14607 ind. m^{-3} (SD 9565). The highest mean values of abundance in the water column were recorded in the summer season of 2010 and 2011, i.e. 24238 ind. m^{-3} and 23659 ind. m^{-3}, respectively. On the other hand, minimum values were observed in the winter-spring season of 2010 and 2011 (1283 ind. m^{-3} and 2807 ind. m^{-3}) (Fig. 2).

The average count of zooplankton in the western part of Gdańsk Bay (at station P2) in 2010 was 87122 ind. m^{-3} (SD 104836), and in 2011 – 31649 ind. m^{-3} (SD 20487). In 2010, the maximum average count of zooplankton in the water column was recorded in July, whereas in the following year – in September, i.e. 282166 ind. m^{-3} and 56657 ind. m^{-3}, respectively. Whereas the minimum values were recorded in March 2010 (3617 ind. m^{-3}) and in April 2011 (7249 ind. m^{-3}) (Fig. 3).

Given the abundance of zooplankton in the water column, two distinct peaks were observed in 2010 – the first one in May (244207 ind. m^{-3}) and the second one in July. In 2011, the abundance gradually increased from April, and it was basically stable in the period from June to September (from 46926 ind. m^{-3} to 56657 ind. m^{-3}).

Seasonal changes in the zooplankton species composition were observed at stations P1 and P2 throughout the year, which is clearly presented in Figs. 3-5. In winter, the zooplankton is poor in terms of the species diversity and the abundance of organisms. During the biological spring, the importance of zooplankton begins to grow suddenly because of the so-called seasonal components of zooplankton, i.e. cladocerans and rotifers. In autumn, the zooplankton becomes poor again.

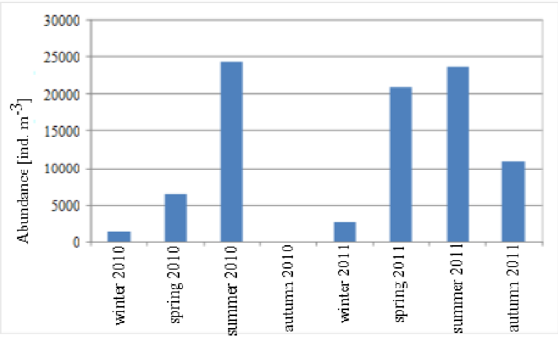

Fig. 2 Abundance of zooplankton at station P1, years 2010-2011

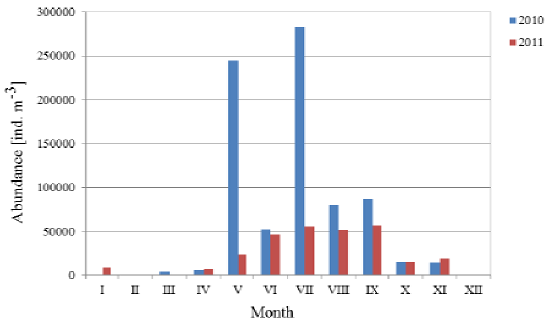

Fig. 3 The abundance/month of zooplankton at station P2, in 2010-2011

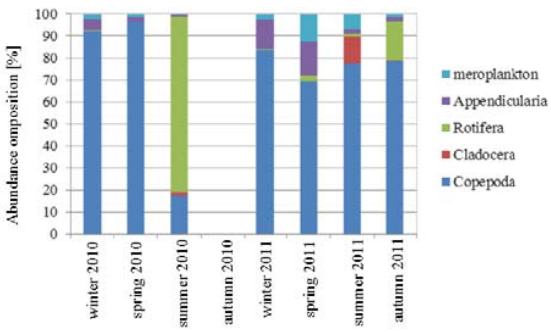

Fig. 4 Taxonomic community structure of zooplankton abundance, P1 station, 2010 – 2011

Zooplankton at station P1 varied depending on the seasons, but not as significantly as in shallow regions of Gdańsk Bay.

In the two-year cycle of the scientific studies, Copepoda were the main component of zooplankton, representing from 69.24% of the total zooplankton in spring 2011 to 96.30% in the spring 2010 (except for summer 2010, 17.58%) (Fig. 4).

At station P2 in 2010, Copepoda occurred throughout the study Appendicularia were the second, very abundant taxonomic unit in the winter-spring season of 2010 and 2011. Their contribution in the zooplankton ranged from 0.83% (in summer 2010) to 15.72% (in spring 2011).

The largest contribution of rotifers in the zooplankton was observed in summer 2010. In autumn 2011, it was also significant, i.e. 17.75%. In the remaining seasons, rotifers represented from 0.01 to 2.43%.

Cladocerans, a typical element of the summer zooplankton, accounted for 1.24% in 2010, and for 12.14% in 2011, i.e. ten times more.

During the study period, meroplankton did not play so important role in the Gdańsk Deep as in the coastal waters, and accounted for up to 12.56% of the total zooplankton abundance (in spring 2011), with the dominance of Polychaeta larvae. In the other seasons, its contribution was low and ranged from 0.28 to 7.07%.

At station P2 in 2010, Copepoda occurred throughout the study period and for most of the months they were the main component of zooplankton with the contribution ranging from 66.62% (in September) to 92.06% (in March). The exceptions were May (24.40%) and July (9.31%) when rotifers dominated in the zooplankton. In August, the contribution of Copepoda was similar to Cladocera and Rotifera, i.e. 39.73% (Fig. 5).

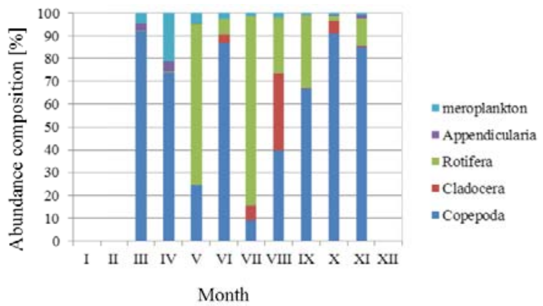

Fig. 5 Taxonomic community structure of zooplankton abundance, P2 station, 2010

Cladocerans – as typical thermophilic species – occurred from June to October, but only in August their contribution in the zooplankton was high (33.82%). In the other months, they represented only a few per cent of the total number of zooplankton (from 0.54% in September to 6.20% in July).

In terms of abundance, Rotifera were the main component of zooplankton in May when they accounted for 70.49% and in July – 83.05% of the total zooplankton abundance. Their importance was also high in August and September – 24.34% and 31.79% of zooplankton, respectively.

The only taxon of Appendicularia occurring in the Baltic Sea – the psychrophilic species *Fritillaria borealis* was present only in autumn and winter, and in early spring. However, it represented only a few per cent of the total zooplankton abundance (max 4.88% in April).

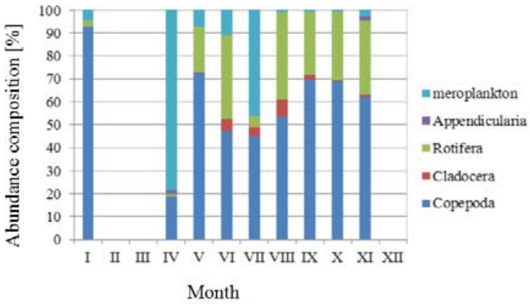

Fig. 6 Taxonomic community structure of zooplankton abundance, P2 station, 2011

Meroplankton accounted for 21.03% of the zooplankton abundance only in April, and was represented mostly by veliger Bivalvia. Furthermore, its contribution ranged from 0.85% (in November) to 4.60% (in May).

In 2011, Copepoda at station P2 were the main component of the zooplankton for most of the year (from 47.05% in June to 92.88% in January). The exceptions were April and July when pelagic fauna was dominated by meroplankton – mainly veliger Bivalvia (Fig. 6).

Due to slow warming up of the sea in 2011, Cladocera appeared only in June. Their contribution in zooplankton was much lower compared to 2010 and amounted to just a few per cent (max 7.32% in August).

For most of the year, starting from June to November (except for July), Rotifers accounted for ca. 30% of the zooplankton abundance. In May, their contribution was still at the level of 19.77%, whereas in January, April and July – only a few percent.

As in the previous year, *Fritillaria borealis* did not occur in summer, and in the remaining months its contribution was minor and did not exceed 5% (the maximum 4.88% in April).

Meroplankton was the main component of zooplankton in April (78.26%) and in July (46.05%). Otherwise, its contribution ranged from 0.4% (in October) to 10.75% (in June).

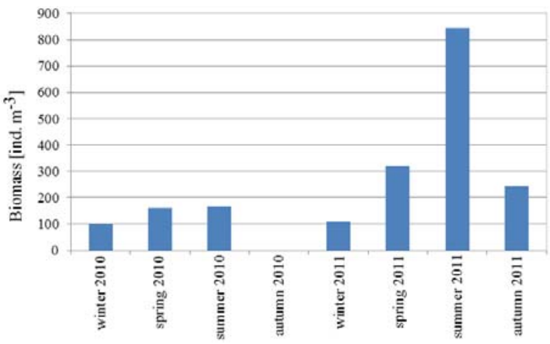

Fig. 7 The biomass of zooplankton at P1 station, years 2010-2011

The mean value of biomass in 2010 at station P1, i.e. at the level of 142.44 mg m^{-3} (SD 38), was 2.5 times lower compared to 2011 – 378.89 mg m^{-3} (SD 323). The highest mean values of the biomass in the water column were recorded in the summer of both years, i.e. 166.74 mg m^{-3} and 844.84 mg m^{-3}, respectively (Fig. 7). On the other hand, the minimum values were observed in the winter-spring season (98.81 mg m^{-3} in 2010 and 107.77 mg m^{-3} in 2011).

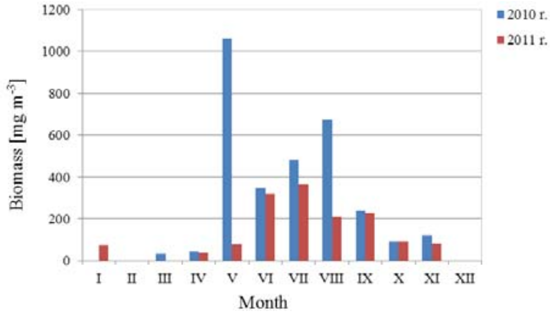

Fig. 8 The biomass of zooplankton at P2 station, years 2010-2011

In 2010, the mean biomass value at station P2 was at the level of 344.42 mg m^{-3} (SD 344), and in 2011 – 162.93 mg m^{-3} (SD 109). The maximum mean values of the biomass in the water column were recorded in May 2010 (1061.80 mg m^{-3}) and in July 2011 (365.05 mg m^{-3}), whereas the minimum values – in March 2010 (35.81 mg m^{-3}) and in April 2011 (39.05 mg m^{-3}) (Fig. 8).

In 2010, there were two peaks in the values of the zooplankton biomass – the first one in May and the second one, slightly lower in August – 671.25 mg m^{-3}. In 2011, the first, very clear peak in the biomass occurred as late as July, and the second one in September (230.16 mg m^{-3}).

Taking into account the contribution in the zooplankton biomass at station P1, Copepoda were the main component throughout the study period, ranging from 55.29% in summer 2010 to 99.19% in winter 2010 (Fig. 9).

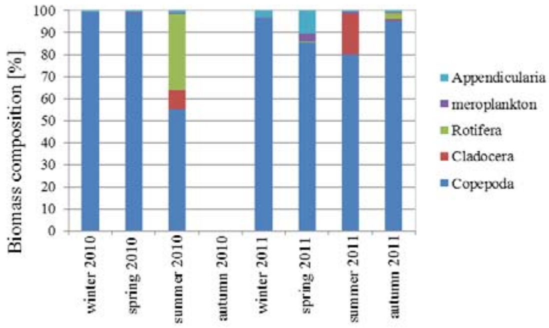

Fig. 9 Taxonomic community structure of zooplankton biomass, P1 station, 2010 – 2011

Thermophilic Cladocerans were most abundant in the zooplankton biomass in summer 2010 – 8.42%, and 2011 – 18.42%.

Only in summer 2010, Rotifera accounted for as much as 34.91% of the zooplankton biomass. In the remaining period of the conducted research, their contribution was minor (from

0 to 2.41%). In winter 2011, Appendicularia accounted for 3.48% of the zooplankton biomass, and in spring 2011 – 10.29%; whereas in 2010 as well as in the summer and autumn 2011 – only 1%.

Both in 2010 and 2011, meroplankton accounted for a small proportion of the zooplankton biomass, and it ranged from 0.13% in winter 2010 to 3.64% in spring 2011.

The situation was different at station P2. In 2010, Copepoda dominated in the zooplankton biomass from March to April, in June as well as from September to November – from 67.59% in October to 94.59% in March.

In May, July and August, this contribution significantly decreased and ranged from 24.15 to 36.74% as a result of the occurrence of seasonal zooplankton components, such as Cladocera (Fig. 10).

Cladocerans in the first year of the studies occurred from May to October, representing from 6.63% of the zooplankton biomass in September to 72.49% in August. A gradual increase in their abundance was observed till August; in September, there was a significant drop, followed by another increase up to 30.53% in October.

Rotifers were the main component of the zooplankton biomass only in May – 44.85%. In July, their contribution was 16.92%, whereas in September – 13.87%. In the other months, it ranged from 0.06 (in March) to 4.26% (in November).

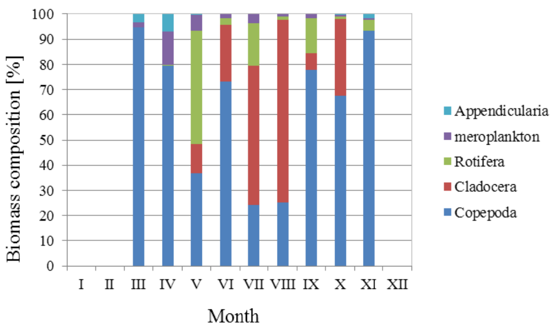

Fig. 10 Taxonomic community structure of zooplankton biomass, P2 station, 2010

Larvaceans occurred in spring, autumn and winter, with the largest contribution in the zooplankton biomass in April – 6.99%.

Meroplankton had the largest contribution in the zooplankton biomass also in April – 13.35%, while otherwise it fluctuated within the range from 0.46 (in November) to 6.19% (in May).

Copepods dominated in the following year at station P2. Almost throughout the entire study period, except for April, their contribution in the biomass ranged from 31.75% (in April) to 96.65% (in January) (Fig. 11).

Cladocerans occurring in the pelagic zone from May to November accounted for 2.29% of the zooplankton biomass in October to max 31.91% in June. From July to September, their contribution was also significant, i.e. on average 25%.

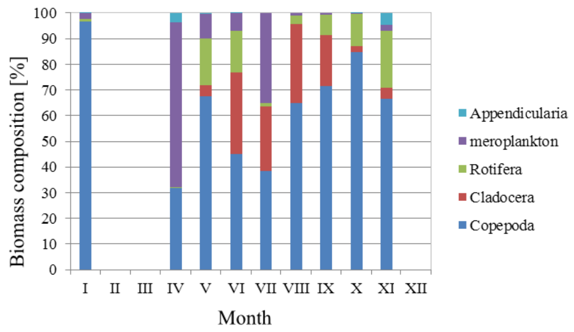

Fig. 11 Taxonomic community structure of zooplankton biomass, P2 station, 2011

Only in May, June, October and November, Rotifera had a higher contribution in the zooplankton biomass (from 12.73 to 21.88%). Outside these months, their contribution fluctuated from 0.34% in April to nearly 8% in September.

In the studied region, *Fritillaria borealis* occurred outside the summer season. The highest representation of this taxon in the biomass – 4.56% was observed in November.

Juvenile stages of the benthic fauna were represented by the largest number in the zooplankton biomass in April – 64.35%. In the following months, their contribution dropped to 7.03%, and in July – increased again to 34.95%.

IV. Conclusion

1) Environmental studies have shown that taxonomic composition of the pelagic fauna in the Bay of Gdańsk in 2010 and 2011 was similar to that observed in this region for many years. The exceptions are two invasive species of Cladocera, which occurred in summer of 2010 in the shallow part of Gdańsk Bay – *Cercopagis pengoi* and *Evadne anonyx*.
2) Copepoda were the dominant component of zooplankton in Gdańsk Basin during the study period. Their dominance, both in terms of the abundance and the biomass, underwent minor changes in the summer as a result of large numbers of Rotifera, Cladocera and meroplankton (mostly larvae of Polychaeta) in the pelagic zone.

Acknowledgment

This work was supported by the Polish State Committee under grant number NN306 353239. Partial support was also provided by the Satellite Monitoring of the Baltic Sea Environment – the SatBałtyk project funded by the European Union through the European Regional Development Fund contract No. POIG 01.01.02-22-011/09.SatBałtyk

References

[1] K. Wiktor, "Zooplankton biomass in the coastal waters of Gdańsk Bay", Scientific Papers of the University of Gdansk, Oceanography, 12: 109-134, 1990. (in Poland)

[2] H. Ojaveer, A. Janus, B. R. MacKenzie, G. Martin, S. Olenin, T. Radziejewska, I. Telesh, M. L. Zettler, A. Zaiko, "Status of Biodiversity

in the Baltic Sea". LOS ONE, Edited by Yan Ropert-Coudert, vol. 5, issue 9, p. 12467, 2010

[3] J. Chojnacki, I. Drzycimski., K. Siudziński, "Ecological characteristics of main planktonic crustaceans in the Southern Baltic", Studies and Materials of the Marine Fisheries Institute, Gdynia, Ser.A, 27, 5-24, 1986. (in Poland)

[4] E. Ojaveer, A. Lemberg, H. Ojaveer, "Highlights of zooplankton dynamics in Estonian waters (Baltic Sea) ", ICES J Mar Sci 55: 748–755, 1998.

[5] C. Möllmann, G. Kornilovs, L. Sidrevics, "Long- term dynamics of main mesozooplankton species in the central Baltic Sea" Journal of Plankton Research. 22: 2015–2038, 2000.

[6] W. Mańkowski, "Biological changes in the Baltic Sea during the last fifty years", Papers of the Marine Fisheries Institute, Gdynia, 6, 95-118., 1951. (in Poland)

[7] P. M. Cury, Y.-J. Shin, B. Planque, J.M. Durant, J.-M Fromentin. et. al., "Ecosystem oceanography for global change in fisheries", Trends Ecol Evol 23: 338-346. doi:10.1016/j.tree.2008.02.005. PubMed: 18436333, 2008.

[8] W. Mańkowski., "Notes on zooplankton in the Bay of Gdańsk", Bulletin of the Marine Station in Hel, 3, 1937. (in Poland)

[9] W. Mańkowski, "Notes on zooplankton in the Bay of Gdańsk", Bulletin of the Marine Station in Hel, 4, 1938. (in Poland)

[10] W. Mańkowski, "Biological changes in the Baltic Sea during the last fifty years", Papers of the Marine Fisheries Institute, Gdynia, 6, 95-118, 1951. (in Poland)

[11] K. Siudziński, „Zooplankton of Gdańsk Bay", Studies and Materials of the Marine Fisheries Institute, Gdynia, 18A: 1-111, 1977

[12] Wiktor K. Cylkowska U. Ostrowska K. 1982. Zoooplankton coastal waters of the Gulf of Gdansk, Marine Biology 6, SIMO 39. KBM PAN. 81-133. (in Poland)

[13] Ciszewski P. 1985. Long-term trends in mesozooplankton biomass development in .the Southern Baltic, Oceanologia. 22: 63-70.

[14] K. Wiktor, M.I. Żmijewska, "Zooplankton biomass in the coastal waters of Gdańsk Bay", Marine Biology 7, SIMO 46, KBM PAN. 70-111, 1996 (in Poland)

[15] S. Mudrak, M. I. Zmijewska, "Spatio-temporal variability of mesozooplankton from the Gulf of Gdansk (Baltic Sea) in 1999-2000.", Oceanological and Hydrobiological Studies 36(2): 3-19, 2007.

[16] L. Bielecka, M.I. Żmijewska, A. Szymborska, „A new predatory cladoceran Cercopagis (Cercopagis) pengoi (Ostroumov 1891) in the Gulf of Gdańsk", Oceanologia. 42(3). 371-374, 2000.

[17] N. V. Rodionova, V.E. Panov, "Establishment of Ponto-Caspian predatory cladoceran Evadne anonyx in the eastern Gulf of Finland, Baltic Sea", Aquatic Invasions. 1 (1): 7–12, 2006.