ABSTRACT

For the sustainable management of marine resources, a thorough knowledge of cause-effect processes in relations among organisms living in the ecosystem is necessary. Therefore, zooplankton, especially Copepoda, are becoming an important indicator for determining the directions of marine resources management. As plankton organisms, they respond rapidly to changes in the environment, whereby they may be very good bioindicators of its ecological status and serve as a tool for modern management of the Baltic Sea ecosystem. Copepods are one of the most important links in the food chain, playing a significant role in the transfer of energy between lower and higher trophic levels in the pelagic food web, being among other things a food for many pelagic planktivorous fish. Phytophage copepods—such as *Acartia* spp., *Temora longicornis* and *Pseudocalanus* sp. — are one of the main sources food of commercial fish, i.e. herring (*Clupea harengus*) and sprats (*Sprattus sprattus*) in the Baltic Sea.

Regular research into copepod population dynamics and taxonomic changes, along with steady monitoring of the environmental conditions, provides valuable information and allows assessment of how environmental parameters can affect the development of the Copepoda, controlling the dynamics of the entire food chain in this area. This research type is particularly important due to the fact, that the Baltic Sea ecosystem has undergone various transformations over the last century, due to global climate change and anthropopressure among others and the physicochemical properties of Baltic waters are constantly changing.

Governed by the need to broaden the knowledge about Baltic copepods, which are good indicators of the ecological status of the ecosystem, the main goal of this doctoral dissertation was to study and determine changes in the development of dominant Baltic copepods, including *Acartia* spp., *Temora longicornis* and *Pseudocalanus* sp. in the Gulf of Gdansk area. To realize the main goal, scheduled following research tasks, specific research objectives have been detailed, such as:

- Analysis of the abundance and biomass data of *Acartia* spp., *Temora longicornis* and *Pseudocalanus* sp. from the Gulf of Gdansk region;
- Determination of the population structure of the analyzed copepods;
- Determination of the secondary production and mortality rates of individuals at particular ontogenetic stages using mathematical expressions;

- Determination of the time duration of ontogenesis stages for the copepods as a three-variable function – temperature, salinity and food concentration—in the southern Baltic using mathematical expressions;
- Determination of the impact of abiotic and biotic factors on the seasonal population dynamics of *Acartia* spp., *Temora longicornis* and *Pseudocalanus* sp. in the Gulf of Gdansk.

Environmental, laboratory, statistical and numerical research conducted during the research work made it possible to determine the dynamics of seasonal population changes in selected copepods occurring in the Gulf of Gdansk (Paper I, II), the impact of environmental factors on the time duration of individuals ontogenetic stages of Copepoda in the Southern Baltic (Paper III), as well the impact scope of abiotic factors on the seasonal dynamics of *Acartia* spp., *Temora longicornis* and *Pseudocalanus* sp. in the Gulf of Gdansk (Paper IV).

The research determined that the *Acartia* genus still remains the main component of Copepoda in the Gulf of Gdansk, and the largest part of biomass was observed from May to September. *Temora longicornis* was the co-dominating species, which dominated in the biomass in autumn (with maximum abundances in November), while among the copepods analyzed, that with the lowest abundance and biomass was *Pseudocalanus* sp., whose maximum value of biomass was observed in winter (Paper I, II).

The secondary production rate of the analyzed copepods showed high variability during the research period. Inter-annual and seasonal statistically significant differences were observed. The highest secondary production values were recorded in the summer season, with particularly high values in 2007. *Acartia* spp. and *Temora longicornis* were distinguished by higher production rates, compared to *Pseudocalanus* sp. achieving the highest production rate in summer (Paper I, II). The statistical analysis carried out for the first study period confirmed a correlation between production rate and water temperature for *Acartia* spp. and for the majority of *Temora longicornis*. However, for *Pseudocalanus* sp. this relationship was not observed, which could be related to the lower number of data, or the significant influence of another factor on the value of production (Paper I). For later years of the study, the results of statistical analysis showed a clear correlation between temperature and secondary production for dominant copepod species *Acartia* spp. (Paper II). The obtained results seem to show a correlation with the natural dynamics of the Copepoda population in the investigated water region.

Furthermore, the research has shown a tendency towards increased mortality of copepods in spring and summer, which could be associated with increased pressure of

planktivorous fish during this period. The lowest mortality rate fluctuations between stages was noted for *Acartia* spp., whereas for *Temora longicornis* the results showed a significant difference in mortality rates between the various development stages. In autumn and winter, the highest mortality rate concerned the first-stages of copepodit, and in the summer the older individuals. The research has shown that for *Pseudocalanus* sp. the mortality rate was the lowest in winter and spring, and it increased in the summer (Paper I).

The next stage of the research was numerical analysis, with the aim of determining the impact of environmental factors, such as temperature, salinity and food concentration on the development of *Pseudocalanus* sp., *Temora longicornis* and *Acartia* spp. (Paper III).

Analysing the obtained model results for *Acartia* spp. it was clearly determined that temperature and food concentration have a significant impact on the development rate of *Acartia* spp. at all ontogenetic stages, and these factors are controlling the population status of this taxon in the Southern Baltic Sea. Significant differences in the development of *Acartia* spp. are apparent in the winter and early spring, when the increase in temperature and the amount of food have a significant impact on the development of the analyzed copepod. In turn, in summer the decisive role is played mainly by temperature. Numerical simulations carried out suggest that in the studied region over the next hundred years, the *Acartia* spp. population will increase by at least one to two per year, the growth rate at each ontogenetic stage will be faster, and the first yearly appearance of the first population will occur earlier. In the case of *Temora longicornis*, the calculations made showed, as in the case of *Acartia* spp., that temperature and food concentration are the decisive factors that influence the development of this species at all ontogenetic stages. For *Temora longicornis*, salinity in accordance with the created function *fs,* has a noticeable effect on its development, which slightly limits the effect of temperature. The obtained numerical results suggest that in the studied region the population of *Temora longicornis* may increase by one generation over during the one year. The development of this species will be faster in the winter-spring period and, as in the case of *Acartia* spp., the first *Temora longicornis* population will appear earlier in the year. Considering the obtained model data for *Pseudocalanus* sp., they have shown that temperature and salinity as abiotic factors have a significant impact on the development of *Pseudocalanus* sp. at all ontogenetic stages. Salinity is a deciding factor, because as the masking factor in accordance with the adopted function *fs,* it limits the development of this species in winter, and in the summer it heightens the effect of temperature. Significant differences in development are observed in winter and in spring, when despite the temperature increase in relation to the initial model state, the development of individuals is

inhibited as a result of the decrease in salinity. Numerical simulations indicate that salinity has a bigger effect on the development of individuals than temperature during this period. In contrast, in the summer season both salinity and temperature, above the optimal value of T_o, limited the development of *Pseudocalanus* sp., reducing the growth rate and increasing the duration of the individual stages of development. The presented mathematical results suggest that in the studied area, i) the *Pseudocalanus* sp. population will decrease, ii) development of individuals will be inhibited, iii) total development time may last for more than one year, and iv) appearance of the first population of the year will occur later (Paper III).

According to statistical methods, 26,1% of the total variability observed in the biomass and population composition of the copepod species has been explained by environmental factors such as: water temperature, salinity, air temperature, cloudiness, wind speed and direction, and the depth of the sampling station. The environmental variable in the Gulf of Gdansk with the greatest explanatory power of the composition variability of the population and copepod biomass is water temperature. In addition, using the Generalized Additive Models (GAM), the effect of abiotic factors on copepod biomass was analyzed. The important parameters were the water temperature and salinity for all stages of *Acartia* spp. and *Temora longicornis* and for most stages of *Pseudocalanus* sp. – apart from C1 for temperature and salinity, and for males only for salinity (Paper IV).

The research carried out as part of the doctoral thesis allowed confirming the main research hypothesis, that abiotic and biotic environmental factors have a significant impact on the seasonal and long-term dynamics of development changes of *Acartia* spp., *Temora longicornis* and *Pseudocalanus* sp. in the southern region of the Baltic Sea. In the context of global climate change, the presented research results show that the factor having the greatest impact on the copepods population in the southern Baltic Sea region is temperature, but that the salinity and availability of food also determine the pace of development of copepods occuring in this region.

The results presented in the work are a valuable source of information, in a high degree complementing the previous research of Copepoda from the Gulf of Gdansk. Biomonitoring taking into above environmental factors that affect plankton to a greater or lesser extent are an important tool for managing the marine ecosystem. Whereas, modeling can be used to predict long-term changes in the ecosystem, even in a distant time. Numerical simulations allow us to recreate processes occurring in the marine environment and to and to determine how these processes will affect the development of biological life under conditions disparate than those commonly observed.

The research conducted for the needs of the doctoral dissertation shows that there will be significant changes in the number and biomass of copepods in the future. Copepoda play a key role in the transformation of organic matter, therefore an early determination of the direction of these unavoidable changes can be of particular importance, providing new elements of knowledge concerning the processes determining the state of marine ecosystems, in particular the brackish waters such as the Baltic Sea. Such knowledge has a direct impact on the scope and degree of use of its living resources, which in turn translate into the condition of the maritime economy.

In-depth knowledge about the mechanisms of copepods functioning, their taxonomic structure, abundance, biomass, production, development and mortality rate allows to follow the direction of changes taking place in the ecosystem. Only integrated environmental research, modeling and statistical work make it possible to predict the negative or positive effects of environmental changes and to predict changes in the food base of planktivorous fish.