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Research Article

PREDICTIONAL MODEL OF BIOCENOTIC CHANGES IN OFFSHORE BALTIC PLANKTON DUE TO TEMPERATURE INCREASE

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Abstract

Over the last 20 years, more and more reliable data concerning global climate change, mainly climate warming, have become available in the literature. Change such as this has also been documented in the Gulf of Gdañsk. Climate change has an influence on aquatic ecosystems and especially their biocoenoses, and plankton is one of its most sensitive ecological fractions. Positive and negative statistical correlation in the exclusive relationship between the quantity of plankton groups and water temperature has been observed. When time was applied as a factor, only the annual increments of the blue-green algae correlation were statistically significant, and the regression equation calculated in this paper was applied to predict a rise in the population number of this algae in response to increasing temperature. It was not possible to perform this calculation with the other plankton components.

INTRODUCTION

Investigating and understanding the complicated interrelations between ecosystem components is the main task of contemporary ecology. This is apparent in the development of the environmental sciences and their application in the service of human needs. Modeling has been used as a research method for solving problems in ecology for several years. Although fieldwork provides the most reliable information on mechanisms and processes, it requires comprehensive and costly *in situ* observations conducted under a variety of hydrological conditions for long periods of time. They are, nevertheless, essential for the collection of sufficient statistical data sets for the diagnosis of the state of the environment and for making forecasts (Dzierzbicka-G³owacka 2000).

The application of modeling methods in ecology mainly stems from the analytical nature of this branch of science and from the need to make generalizations based on the magnitude of biological data already gathered. The advantages of applying mathematical models in ecology were summarized by Daget (1976) in four points: 1) simplification of the description of an observed phenomenon; 2) ease of interpolation and extrapolation; 3) a starting point for new concepts; 4) universalism. Although the universal application of a given model is usually quite limited, the possibility of generalizing is the basic function of a mathematical model. In an effort to maintain precision, complication of the model can occur during data adjustment which disallows generalization. Such dilemmas are commonplace in ecology, and compromise is the best solution. It follows then that the model should not be too complicated, should be precise enough and should be adaptable to many similar conditions. The simplest model possible is always the best one, as long as it is verifiable (Pliński 1979a).

The principles above were the basis for building a simple, ecological model of long-term tendencies in ecosystem changes as reflected by the plankton in Baltic Sea coastal waters. One of the primary ecological factors which influences many biological processes is temperature, and every species has a particular thermal optimum at which development is the most intense. Small plankton organisms respond to this with a higher proliferation rate and increased population size. Thus, the question arises of whether the biological relationship between temperature, as an environmental factor, and the size of given populations or even the biocenosis as a whole is reflected in natural conditions as seen in recorded and predicted climate change.

Over the last 20 years, more and more reliable data have been reported in the world literature concerning global climate change, mainly climate warming

caused by excessive CO_2 emissions (Hasselmann 1991, Antonovsky and Buchsteber 1991, Bennets 1992, Matthaus 1995). Kawasaki (1991) described the impact of global climate change on marine ecosystems. Based on research in the central Pacific Ocean, he revealed that the chlorophyll concentration level in the water increased with rises in temperature and storm frequency. Although climate change will undoubtedly have the greatest impact on the biocenoses of the polar region, it will also have an impact on seas which are considerably isolated, such as the Baltic Sea. The results from the Baltic Sea water balance study performed by Cyberski (1995) indicate that if carbon dioxide concentration doubles, not only a rise in temperature will occur, but there will also be a decrease in salinity by approximately 1.5 PSU. Such environmental changes will undoubtedly be reflected in biocenotic structures. Long-term studies of phytoplankton (Pliński 1995, Pliński et al. 1982, Pliński et al. 1985) and zooplankton (Siudziński 1977, Wiktor et al. 1982, Wiktor, Żmijewska 1985, Żmijewska et al. 2000) indicate that fluctuations occur in the population number and composition of dominant species. If the rising temperature trend which was noted by Łysiak-Pastuszak (2000) in the waters of the Gulf of Gdansk in recent decades is taken into consideration in the causal analysis of the phenomenon mentioned above, it can be presumed that this is the beginning of ecosystem change which will occur in the coastal waters of the Baltic Sea. It was assumed that there is a cause-effect relationship between temperature and plankton growth dynamics, and a mathematical formalization of this relationship was undertaken by creating a predictional model of changes in the Gulf of Gdansk plankton due to predicted global climate change.
The aim of this work is to verify which biological parameters correlated with temperature enough significantly in the many years trend and therefore can be used in the predictional procedure for describing the biocoenotical changes caused by global temperature increase in the Gulf of Gdańsk as an example.

MATERIAL AND METHODS

Data concerning plankton number was derived from various publications (Pliński et al.. 1982, Pliński et al. 1985, Pliński 1995, Wiktor et al. 1982, Wiktor and Żmijewska 1985) and from the authors' own investigations which spanned two decades (1977 – 1998). Samples were collected according the standard procedures described for phytoplankton in a publication by Pliński (1995) and for zooplankton in one by Wiktor and Żmijewska (1985).
Temperature data was obtained from measurements performed by the Institute of Meteorology and Water Management. The average, annual temperature of surface waters in Gdynia and Hel was used in the calculations. For seasonal

comparisons, the average temperatures from April, May and June corresponded to the beginning, middle and end of spring, while those from July, August and September corresponded to the beginning, middle and end of summer. Furthermore, local temperature was measured in the middle of the bay at the surface and at depths of 5 and 10 m.

The data gathered was mathematically processed with the computer program Statistica for Windows, version 5.5 – Statsoft Inc. The aim of the first stage of statistical calculations was to determine the correlation coefficients between the number of specimens in different taxonomic groups and assigned water temperatures. Due to the clearly visible domination of certain species groups in different seasons, data from the spring and summer seasons of given years were assessed and compared separately. The aim of the second stage of calculations was to determine the regression equation for cases which were significantly dependent. Regression equations were treated as models that described the tendency of changes where temperature was the cause factor and effect was the number of a given taxonomic plankton group.

RESULTS

Phytoplankton

Phytoplankton was analyzed in five taxonomic groups - Cyanophyta, Dinophyceae, Flagellata (excluding Dinophyceae), Bacillariophyceae and Euchlorophyceae (planktonic Chlorophyta). Viewed as an ecological fraction, there was a distinct rise in the overall quantity of phytoplankton during the study period. This tendency is clearly linked with the rise in average, annual temperature. (Fig. 1).

Cyanophyta (blue-green algae). The number of blue-green algae were correlated significantly with summer temperatures. This was the period when *Aphanizomenon flos-aquae* and *Nodularia spumigena* blossoming. The highest correlation coefficient values were noted in mid season both in Gdynia (r=0.75) and Hel (r=0.73). Lower values were noted at the beginning of the season (Gdynia r=0.67, Hel r=0.66) and by the end of the season in Hel (r=0.60). During the remaining seasons of the year, the correlation coefficient values were statistically insignificant.

Dinophyceae (dinoflagellates). No statistically significant correlation was found between the number of dinoflagellates and water temperature.

Flagellata (excluding dinoflagellates). A statistically significant correlation was detected between the number of this group and the surface water temperature in Gdynia and Hel at the beginning and in the middle of both spring and summer.

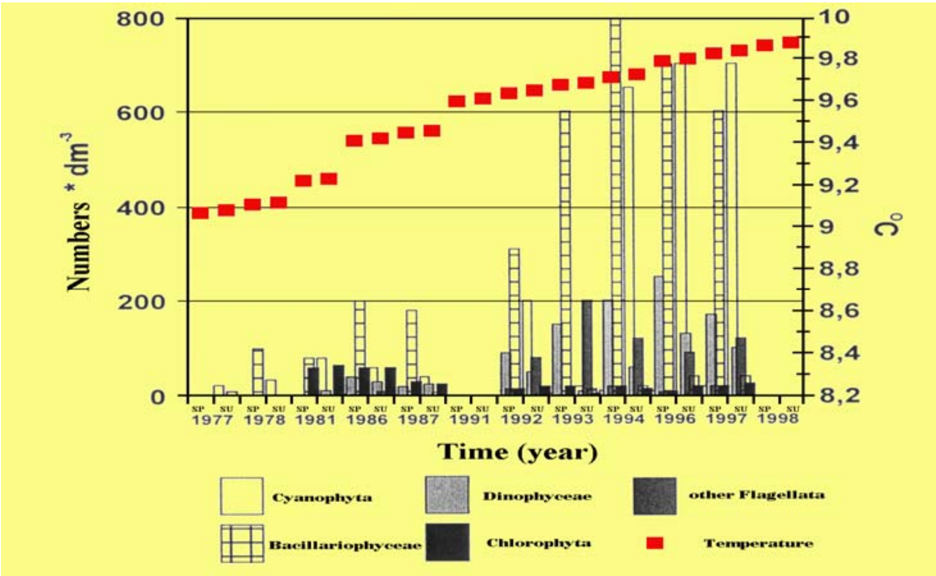

Fig. 1. Long-term average means of phytoplankton population numbers in the Gulf of Gdańsk and general trends in temperature changes during the 1977-1998 period (SP – spring, SU – summer) (no bars means no data)

The correlation coefficients were very similar, independent of time or place, and ranged from 0.65 to 0.67.

Bacillariophyceae (diatoms). There was a statistically significant negative correlation between the number of diatoms and surface water temperature in both regions at the beginning of the season (Gdynia: r=-0.73, Hel: r=-0.74) and in the middle of it (Gdynia: r=-0.64, Hel: r=-0.74). The same was recorded between diatom number and the temperature of the open waters in the Gulf of Gdansk at depths of 5 m (r=-0.77) and 10 m (r=-0.78).

Chlorophyta (Euchlorophyceae – planktonic green algae). No statistically significant correlation was found between the number of planktonic green algae and water temperature.

The comparison of phytoplankton quantity from long-term observations with the clear tendency of increasing water temperature produced satisfying correlation coefficient values for individual species groups: blue-green algae - spring r=0.77, summer r=0.78; dinoflagellates - spring r=0.90, summer r=0.74; phytoflagellates (excluding dinoflagellates) - spring r=0.71, summer r=0.77; diatoms - spring r=0.88, summer r=0.74. The statistically significant correlation between the numbers in separate taxonomic phytoplankton groups and the temperature change trend stem from the fact that both of these variables increased in the period studied. However, this dependency only makes sense when correlation between specific temperatures and the numbers of organisms are taken into consideration, otherwise incorrect conclusions might be drawn. Diatoms may well be an example of this as the correlation between them and temperature was negative, which is justified as they are psychrophilic, but over the long-term their population numbers rose. This indicates that the increase cannot be linked to temperature, but is caused by other factors. This is also true of dinophlagellates and planktonic green algae; no correlation between their population numbers and temperature was detected.

Zooplankton

Fluctuations which have no apparent link with temperature and which are difficult to identify have been observed in the overall population numbers of zooplankton (Fig. 2). Detailed calculations of the correlation between a particular water temperature and zooplankton numbers were performed for the following groups - Rotatoria, Cladocera, Copepoda, Tintinnids and meroplankton.

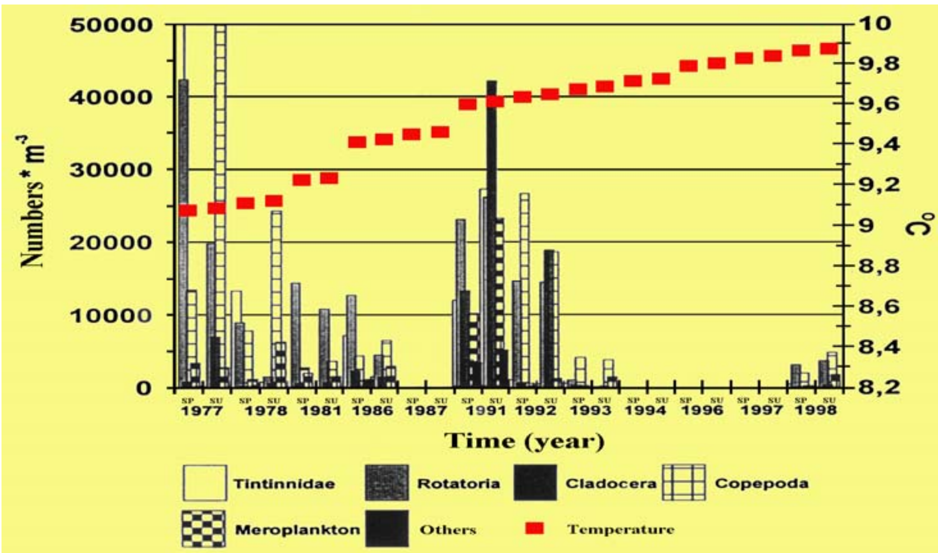

Fig. 2. Long-term average means of zooplankton population numbers in the Gulf of Gdańsk and general trends in temperature changes during the 1977-1998 period (SP – spring, SU – summer) (no bar s means no data)

Rotatoria (rotifers). The number of rotifers is statistically significantly correlated with the average annual surface water temperatures in Gdynia - r=0.84 and in Hel - r=0.88, but only in years when they were observed in Gulf of Gdansk waters.

Cladocera (cladocerans). As was the case with rotifers, in years when they were observed the number of cladocerans correlated statistically significantly with the average annual water temperature in Hel - r=0.82 and with that in the same location at the end of the season – r=0.90. This regularity is certainly impacted by the number of the dominant species *Bosmina coregoni maritima*, as the correlation between it and temperature was more than 0.90.

Copepoda (copepods). The overall population number of copepods did not exhibit a satisfyingly significant correlation with water temperature. Of all the species noted, a statistically significant negative correlation was only found for *Pseudocalanus elongatus* in all areas of the bay. Correlation in coastal waters ranged from –0.85 to more than –0.90, while in open waters the correlation coefficient was r = -0.77.

Tintinnidae (tintinnids). The correlation between the number of this protozoa and average annual surface water temperature was only statistically significant in Hel (r = 0.83) and in the same location at the end of the season (r = 0.91).

Meroplankton. Meroplankton consisted of cirriped (Cirripedia), mollusc (Mollusca) and polychaete (Polychaeta) larvae. Of the organism groups belonging to meroplankton, only numbers of polychaete and mollusc larvae were correlated statistically significantly with temperature. The polychaete larvae correlation was highly positive with a coefficient value exceeding 0.90. Although the number of mollusc larvae decreased in the spring during the period studied (r = -0,83), its population numbers were steady in summer.

The positive or negative statistically significant correlation between the population numbers of zooplankton in various groups and water temperature indicate that the latter plays an important role in shaping the biological activity of these groups. However, since the tendency of increasing temperature was not reflected in zooplankton population changes during the analyzed period, this ecological fraction cannot be used as an indicator of temperature change. The fluctuations observed in zooplankton population numbers are probably caused by ecological factors other than temperature.

By taking into consideration statistically significant correlation and multiple regression, the authors attempted to determine which temperatures influenced the population numbers in a given taxonomic group to a statistically significant degree. The temperature-dependent increase in the number of specimens was not completely linear, thus, non-linear regression analysis was performed (segmented linear regression) on the temperatures which qualified as statistically significant by the discriminatory analysis of multiple regression. This meant that the dependencies better fit the empirical data (i.e. there was a decrease in differences between empirical and predicted values). Exponential dependencies for the study variables were determined for the same reason.

Multiple regression calculations indicate that the population numbers of blue-green algae, dinoflagellates, other flagellates and diatoms are statistically significantly dependent on the average monthly temperatures in mid season, i.e. in May during spring and in August during summer. The numbers of blue-green algae are dependant on the temperature in Gdynia, while the numbers of "other flagellates" are dependent on that in Hel. The influence of temperature on the remaining two groups, dinoflagellates and diatoms, is statistically significant in both locations. In no other cases, including all of the analyzed zooplankton groups, was a statistically significant dependency obtained with the application of multiple regression.

DISCUSSION AND CONCLUSIONS

Temperature is the most important ecological factor which influences the vital activity of organisms. Metabolic rate, which is reflected in reproduction and ultimately in the population numbers of the animal, is dependent on species-specific thermal optimums (Hessle and Vallin 1934, Waldmann 1959, Siudziński 1977, Sidrevics 1980, Sommer 1989, Kawecka and Eloranta 1994). Thermal optimum is the parameter which controls seasonal succession. Diatoms bloom during spring in the Gulf of Gdansk, and those which create these blooms are psychrophilic species whose thermal optimum is between 10-15˚C. During the summer there are blooms of blue-green algae, which is considered to be a thermophilic species with a thermal optimum extending above 20˚C (Pliński 1979a). The zooplankton representatives in the Gulf of Gdansk waters should be regarded as species which prefer cool waters. Koszteyn (1982, after Sidrevics 1980) determined that the thermal optimum for the dominant cladocerans representative *Bosmina coregoni maritima* is between 14.5 – 18ºC, and for the copepods *Pseudocalanus elongatus* it is from 3.5 – 6ºC. It is the opinion of many scientists that Baltic zooplankton is present more frequently in warm waters which do not drop below 10ºC or exceed 18ºC (Hessle and Vallin 1934, Waldmann 1959). Higher temperatures limit development, for example, 22ºC is the upper boundary temperature for cladoceran *Evadne nordmanii*; it was not noted at higher temperatures (Siudziński 1977).

Not only does the thermal optimum determine the seasonal species succession, it is also responsible for long-term fluctuations in plankton quantity. The rise of

1.5 degree in the surface water temperature near the Southern California coast over the 50 years caused an approximate 80% decrease in zooplankton biomass (Valiela 1995, after Roemmich and McGowan 1995). Decreases in rotifers biomass have also been noted in the Baltic Sea as the temperature increased (Heerkloss and Schnese 1999). Dippner *et al*. (2000) used the results of long-term data to assert that the populations of basic zooplankton components in the Baltic Proper are controlled by temperature. Kostrichkina *et al.* (1992) suggested that in the Gulf of Riga (eastern Baltic) the zooplankton concentration size is determined by temperature in spring and indirectly by phytoplankton growth. According to Möllmann *et al*. (2000), the concentration density of *P. elongatus* in the Baltic Proper depends mainly on salinity while that of *T. longicornis* and copepods from the genus *Acartia* depends on thermal conditions. Therefore, most authors which analyze long-term zooplankton population number or biomass fluctuations agree that these changes are connected with environmental conditions; temperature and salinity are probably the main factors. Zooplankton growth in the Gulf of Gdansk is also dependent on temperature. The dependencies observed during the current study confirm the role of thermal optimum in forming quantitative ratios of the various species, and the dramatic decrease in overall zooplankton population numbers in the two decades studied could be linked with a rise in temperature.

Many authors consider temperature to be the most important of the environmental factors which influence plankton growth dynamics. This dependency has been observed in diversified water ecosystems located in different geographical zones (Munawar and Wilson 1978, Lee 1999, Alam *et al.* 2001, Zhao 2002). Since this dependency is of a global character, the authors decided to analyze the dependency between the plankton population number in the Gulf of Gdansk and temperature in relation to a time factor. The best method to mathematically describe this dependency is regression with temperature as the independent variable and plankton population size as the dependent variable. Regression is applied by biologists as a method to describe time phenomenon, and it has also been applied with respect to plankton (Pliński 1979b, Kostrichkina *et al.* 1992). Using regression to characterize an ecological phenomenon is only sensible when the cause and effect relation it describes is biologically justified. Based on the available literature and the correlation coefficients which were calculated for the analyzed period, the authors believe that using such a simple method was justified.

Precise analysis of the statistical calculations indicated that it was necessary to evaluate the predictive value of the calculated regression equations. In view of the fact that it was not possible to calculate statistically significant regression for zooplankton, the significance of this ecological formation in the description of temperature rise is limited, and undoubtedly inapplicable in the Gulf of Gdansk. It is possible that the jumps in zooplankton quantity noted during the current study were connected to blue-green algae blooms; it has been demonstrated that zooplankton population numbers decrease dramatically during blue-green algae blooms. Engström-Öst *et al*. (2000) reported that blue-green algae from the genus *Nodularia* limits copepod population numbers by lowering fecundity in *Acartia* spp., increasing mortality in *Eurytemora affinis* and prompting copepods such as *A. bifilosa* to avoid areas where strong blooms occur. These studies fully confirm the observations of Teegarden *et al*. (2001) regarding the influence of toxic peridinieae from the genus *Alexandrium* on zooplankton in the Gulf of Mexico.

The dependency between temperature and phytoplankton population numbers appears to be much better in the current study. This dependency shows distinct variety between phytoplankton groups. Diatoms, which were characterized by a negative correlation between growth and temperature, are not a convincing index for the description of a rising temperature trend. Although dinoflagellates and other flagellates are generally positively correlated with temperature, in some situations they failed to react. Therefore, it is difficult to unequivocally link their number with temperature changes. Only with blue-green algae is the analyzed dependency distinct enough. This is why the authors consider it to be the only taxonomic group which can be used to describe and predict the effects of temperature rise in Gulf of Gdansk waters. This is justified by the high values of the blue-green algae thermal optimum. This tendency is described for Gulf of Gdańsk waters by the following regression equation (for r=0.75):

$$y = 812x - 7466$$

where, y represents the quantity of blue-green algae (expressed by the number of cells per dm^3), and x is temperature expressed to the nearest 0.1ºC (average annual surface water temperature in the Gulf of Gdansk).

The ability to predict the phenomenon of blue-green algae blooms based on the calculated equation is limited by temperature values which exceed the range of the thermal optimum. Since temperatures above the optimum impact growth, the predictive range of the model presented in this paper is limited.

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