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UNIVERSITY of BUDAPEST

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MODELLING OF THE POSSIBLE EFFECTS OF CLIMATE CHANGE BASED ON A DANUBIAN PHYTOPLANKTON DATABASE

PhD thesis

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INTRODUCTION

The 24 years long data set of Danubian phytoplankton (collected from the Danube River, at Göd, Hungary) contains 528 taxa. Samples were taken weekly between 1979 and 2002. Based on this data set, I analysed the composition, seasonal dynamics and fluctuations in diversity of the phytoplankton. By using this long-term phytoplankton database a good opportunity presents itself to develop a model of extensive applicability for global warming related issues

Beyond doubt, in order to recognize the effects of global changes expected in the future the methodology of ecological modeling seems to be a very useful tool. Questions related to the hazards of global warming are in the focus of attention in recent science.

A number of modeling approaches have been proposed so as to sketch the main trends in variation of physical, chemical and biological components of freshwater systems under the pressure of climate change. Modeling methodology, however, which brings relevant pieces of information to the field of climate change research, is rather fuzzy now. This shortcoming is due to the lack of complex models and their complicated applicability. These models require quite a lot of information of which one is not familiar with definitely. Often one manage to set up a complex model, but its parameters cannot be determined due to lack of field data. Thus, instead of complex ecosystem models tactical ones are used often, which focus on the essence and may neglect some important pieces of information at the same time. (In general, the "tactical model" is a model prepared to provide solution for practical problems, in order to make predictions.) Still they can be useful tools to understand the general functioning of the system. This is achieved through stressing the factor regarded as the most crucial one and neglecting the other processes.

We aimed to simulate the seasonal dynamics of phytoplankton by means of a discrete, deterministic model on the basis of data collected in the Danube River at the station of Göd, Hungary. A „strategic model", which is considered as a theoretical simulation model was used as starting point. Within this tactical approach, predictability was considered as primary purpose by stressing few factors expected as crucial driving forces instead of creating a rather complex ecosystem model considering all environmental and biotic factors accounting for phytoplankton production. Treating temperature as the most significant factor in seasonal dynamics modeling seems to be obvious. The model assumes that temperature is the only factor accounting for biomass variation, thus, the pattern is determined by the daily temperatures, other environmental factors – e.g. trophic links, interpopulation interactions – appear within this term or hidden. In addition, reaction curve describing temperature dependence is expected to be the sum of optimum curves because the individual optimum curves of species and groups add up to the optimum curve of the community. The availability of light needs to be taken into consideration as well according to recent knowledge on phytoplankton of the Danube River. What is more, we considered that decreased angle of incidence limits winter phytoplankton grow.

I have tried to reveal the expected effects of climate change by developing the temperature dependant tactical model of Danubian phytoplankton.

AIMS

1. We planed to analysing the composition, seasonal dynamics and fluctuations in diversity of the phytoplankton based on a 24-year long monitoring database.
2. We aimed to develop a tactical model, which can answer questions of potamoplankton seasonal dynamics by means of temperature data as input parameters.
3. By using the tactical model we aimed to reveal the most probable effects of warming on examined phytoplankton community

MATERIALS AND METHODS

Phytoplankton was sampled weekly from the Danube River at the station of Göd (1669 rkm) throughout the period of 1979-2002, within the continuous plankton recorder program of the Hungarian Danube Research Station of the Hungarian Academy of Sciences. Phytoplankton data were presented in mg l^{-1}. Biomass was calculated by considering density and biovolume of specimens. When calculating biomass, corrections factors were added describing the dependence on season and hydrologic regime.

The diversity was calculated by Shannon index based on long-term phytoplankton database. Method of three-dimensional illustration was used to present annual and monthly trends on the same diagram. Temporal patterns were examined by Multivariate Data Analysis, such as Hierarchical Clustering and non-metric multidimensional scaling: "NMDS". In this analysis the spatial changes were left out of consideration, only temporal markings were studied. The datamatrix constructed from the sample data was also logarithmically transformed in order to emphasize rare species in the analysis.

The intensive sampling frequency makes the data of the Hungarian Danube Research Station able to being employed in simulation models dependent upon weather conditions. We aimed to describe the seasonal dynamics of phytoplankton with a discrete, deterministic model.

First, the so-called „TEGM" – Theoretical Ecosystem Growth Model – was used, which is the model of a purely theoretical algal community covering the potential temperature spectrum by the help of temperature optimum curves of 33 theoretical species. These theoretical species include 2 supergeneralists, 5 generalists, 9 transients and 17 specialists according to their degree of tolerance.

The strategic model of the theoretical algal community was adapted to the measured data resulted in the tactical model of DPGM („Danubian Phytoplankton Growth Model”). Model fitting was performed using the Solver optimizer program of MS Excel.

All statistical analyses was performed with the Past software version 1.36. Degree of fitting was tested with correlation analysis by means of different indices and indicators and accepted when correlation coefficient reached significant levels. We defined indicators each of which assignes a number to individual years or certain periods of a year, then, we analysed the linear correlation of measured and simulated values.

The model was running with the different temperature data set (e. g. data of climate change scenarios specified for the period of 2070-2100, and data for the cities that are “geographical analogies” to Budapest – the climate of these lands at present is similar of the future climate of Budapest). We employed the database of PRUDENCE EU project namely A2 and B2 scenarios of „HadCM3” climate change model ran by Hadley Centre and the run results of the Max Planck Institute for A2 scenario. The above mentioned indicators were used to contrast phytoplankton biomass and phenology under various temperature regimes. The effect of linear temperature rise was also analysed: each value of the measured temperatures between 1979 and 2002 was increased by 0.5, 1, 1.5 and 2 °C, respectively, then, the model was run with these data.

One-way ANOVA was applied to demonstrate possible differences between model outcomes. In order to point out what groups do differ from the others, the post-hoc Tukey test was used, homogeneity of variance was tested with Levene’s test, when this assumption failed, Welch F-test was used.

SUMMARY OF THE RESULTS

A clear decrease in density of the phytoplankton quantity was indicated in the examined period. At the same time I have observed an increased tendency in the phytoplankton diversity. That can be explain by the decrease of dominant species quantity. The observed trends in temporal coenological patterns can be explain based on dominant species too. According to the results of multivariate analysis – that was conducted based on logarithmic transformation of the data – the long-term changes were clearly indicated: The first (1979-1990) and the last (1991-2002) part of the examined period can be clearly separated (Fig. 1). Changes of the beginning of the 1990’s can be explained by the decrease of nutrient excess.

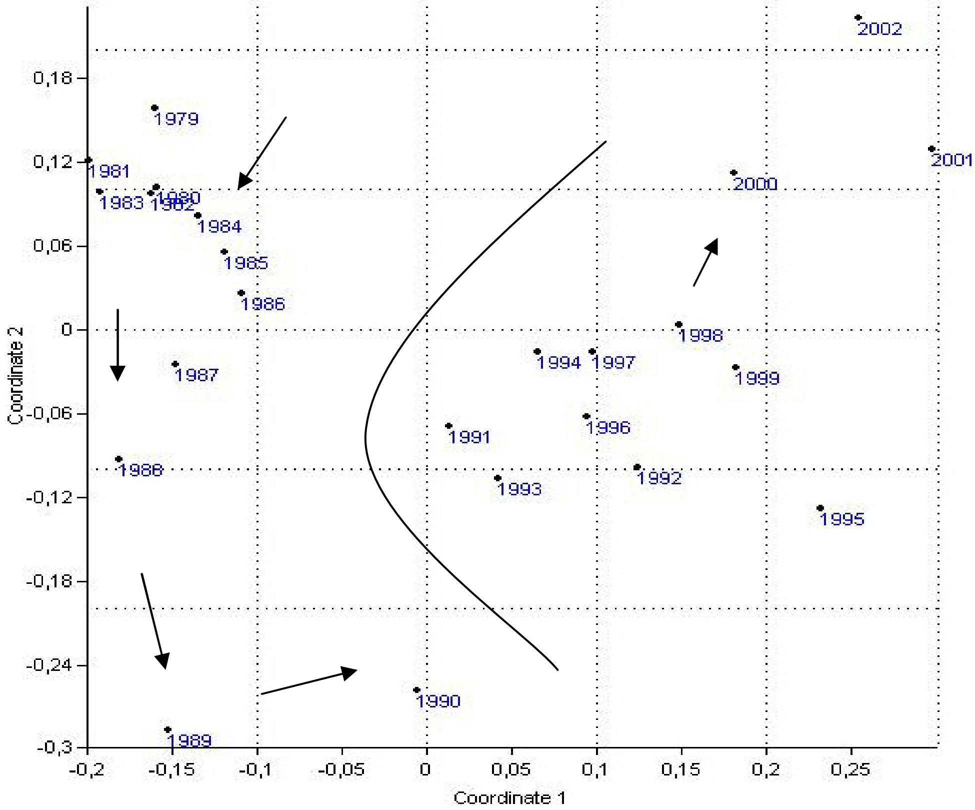

Figure 1. NMDS ordination of the years sampled based on log-transformed algal biomass data

A „strategic model", which is considered as theoretical simulation model, the so-called TEGM (Theoretical Ecosystem Growth Model) was adapted to field data from the Danube River (tactical model). The Danubian Phytoplankton Growth Model (DPGM) describes the seasonal dynamics of riverine phytoplankton biomass (mg l^{-1}) by using daily temperature data as input parameters. This discrete-deterministic model besides the temperature it also pay attention to the availability of the light. Assuming that the excess nutrients represent a specific environment for phytoplankton, two sub-models were developed, one for the period of 1979-1990 with large nutrient excess (DPGM-sA) and one for the period of 1991-2002 with small nutrient excess (DPGM-sB). The DPGM-sAB portraying 24 years is derived from the combination of two sub-model (Fig. 2). The model correlates well with the observed data such as the annual sum of biomass, certain phonological indicators and indicators developed for the description of certain periods of the year.

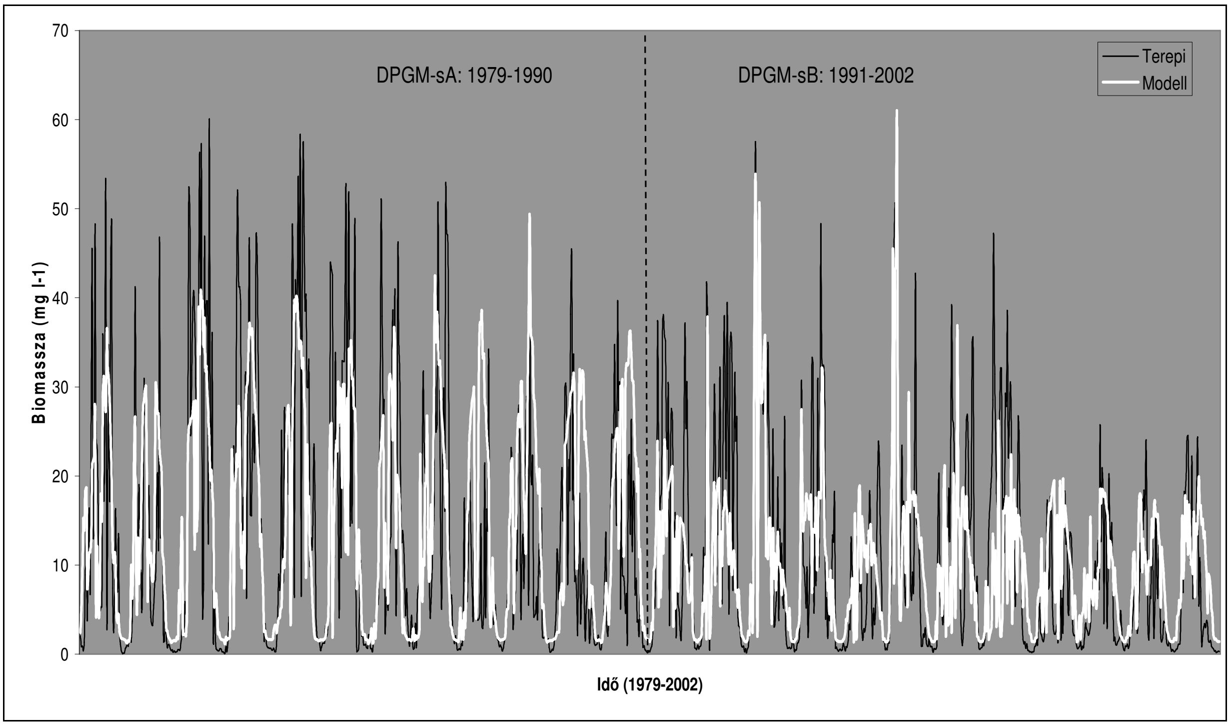

Figure 2. DPGB-sAB as a result of the combination of DPGM-sA and DPGM-sB

I have developed three case studies for the examination of the warming effects. In the first case I have run the model based on the series of data of the climate change scenarios. I have also examined the effect of linear temperature rise furthermore I have also run the model based on the temperature data for the cities that are “geographical analogies” to Budapest. (Using geographical analogy we are searching for land areas whose climate at present is similar of the future climate of the study region.) Based on the three case studies I have come to the conclusion that the warming only in case of increased excess nutrient leads to drastic changes which can be seen in the biomass increase especially in the summer months.

NEW SCIENTIFIC RESULTS

Long-term dynamic patterns and diversity of danubian phytoplankton communities

- A clear decrease in density of the phytoplankton quantity was indicated in the examined period (between 1979 and 2002) at Göd, Hungary. A decrease of phytoplankton peaks were also observed under this period.
- At the same time I have observed an increased tendency in the numbers of taxa and the phytoplankton diversity based on Shannon index.

- Seasonal changes can be observed in the examined period. Early years show early spring blooms and summer – early autumn periods with intensive algal growth. In the latter years only early spring blooms were found in the samples and the other ones disappeared. This trend can be observed more clearly based on the quantity of the most dominant group (*Stephanodiscus spp*).
- The groups cannot be clearly separated in the ordination plot based on the multivariate analisys of the similarity patterns of the phytoplankton assemblage. The patterns can be explained by the rank of dominant species.
- Similarity patterns based on logarithmic transformation of the data matrix: A temporal trend can be observed in the groups. Furthermore, the first (1979-1990) and the last (1991-2002) part of the examined period can be clearly separated. The temporal trend in the examined period can refer to the possibility of the existence of gradually changing environmental factor. Assumable the changes in the degree of nutrient excess (expressed by PO_4-P concentration) could cause this.

Results of DPGM and sub-models

- A „strategic model”, the so-called TEGM was adapted to field data from the Danube River. The Danubian Phytoplankton Growth Model (DPGM) can describe the seasonal dynamics of riverine phytoplankton biomass by using daily temperature data as input parameters. This model besides the temperature it also pay attention to the availability of the light. Linear combination of 21 theoretical populations resulted in the best fitting to measured phytoplankton biomass data
- In order to eliminate shortcomings of DPGM, we have to take into account further environmental variables.
- On the basis of long-term water chemical data, variation in nutrient load (expressed in PO_4-P concentration) and the temporal coenological patterns, we assume that the first (1979-1990) and the last (1991-2002) part of examined period serve a different kind of environment for algae. Consequently, we propose that, among unidentified environmental variables, degree of nutrient load is the major cause behind decreasing trend of phytoplankton biomass. Two sub-models were developed for the two periods: DPGM-sA and DPGM-sB. Combining the above-mentioned submodels into DPGB-sAB, we get a more realistic picture of phytoplankton biomass variation within the period of 1979-2002, and at the same time, the decreasing tendency of abundance becomes distinct.

- Simulated biomass by DPGM-sA and DPGM-sB showed significant correlation with measured biomass regarding three indicator groups of different types. The first group includes indicators of yearly total biomass, the second group includes phenological indicators, and the third group includes indicators of certain seasons and months.

Case studies for the examination of the warming effects

- In case of climate change scenarios can be experience higher values compared the observed ones indeed, but not only in case of series of data regarding future (2070-2100) but also in case of the control period (1960-1990). This results draws attention to the constraints of applicability of scenarios.
- A number of indicators implied larger variation among submodels rather than within a submodel with different input data of temperatures based on data of scenarios and control periods.
- In case of DPGM-sA (assuming higher level of nutrient load) higher biomass are detected, and the timing of phytoplankton growth (i. e. timing of biomass peak and timing of the initial phytoplankton growth) are later than in case of DPGM-sB. The DPGM-sA responds positively to warming.
- The effect of linear temperature rise becomes apparent at DPGM-sA in case of high temperature rise: the biomass increases with rising temperatures explicitly especially in the summer. Rising temperatures cause a positive shift in case of phenological indicators.
- The model was running for the temperature data series of near cities (Bucharest, Calarasi) and distant cities (Rabat, Tunis, Alger, Cairo) based on geographical analogy. In case of near analogous regions the indicators did not show any significant variation, but in case of distant analogous regions (especially in case of Tunis, Alger, Cairo) most indicators show strong significant variation: drastic biomass increases, especially in the summer, and positive shift in case of phenological indicators. These findings are valid only in case of DPGM-sA (assuming higher level of nutrient load).
- Based on the three case studies the DPGM-sB (assuming low level of nutrient load) is less sensible to the warming. However the DPGM-sA (assuming high level of nutrient load) is more sensible to the warming.
- Based on the case studies the expected warming can enhance the effects of eutrophication: assuming high level of nutrient load the phytoplankton rising is drastic especially in summer, without changes in phosphorus load.

CONCLUSIONS

Early years of the examined period show with intensive algal growth in the summer periods. The highest numbers in phytoplankton were found during these blooms. This phenomenon due to extreme gradation of few dominant species (*Stephanodiscus spp*).

The highest average values of diversity are detected in the last years of the study. In these last years, as it could have been forecasted from the lesser abundance and biomass values, few abundant Centrales species diminished from the phytoplankton community so other rare species gained more emphasis. Late winter and early spring periods have the lowest diversity indices. Also these low diversity periods appear at a slightly different time during the years: the low diversity periods started to appear a little earlier.

The multivariate analyses have led us to different results. The patterns were determined by the dominant species based on the results of the first investigation without transformation. The reason we couldn't separate the groups clearly might be the high representation of dominant species.

In cases of logarithmic transformation of the data matrix the temporal patterns could be unambiguously recognized. The temporal trend in the examined period (years following one another) can refer to the possibility of the existence of gradually changing environmental factor. Assumable the changes in the degree of nutrient excess could cause this. The economic and environmental consequences of change of regime, that was significant historical event in Hungary, could lead to separation of the two periods. The breakdown of the Socialist large-scale industry and the development of sewerage could lead to the decrease of nutrient load in the Danube. According to the statistics the nutrient load has decreased by 40-50 % in Danube's watershed.

The DPGM model pointed out that variation of phytoplankton biomass within and over years can be simulated through considering daily temperatures and also light availability. Generally, the model estimates biomass variation within years quite well, however, underestimation of phytoplankton biomass in early years and overestimation in the last four years – the extent of which lags behind those of the underestimations in the early years – suggest drastic change in environmental variables beyond temperature over the study period. Throughout the 24-year long sampling period (1979-2002) nutrient load followed a trend. From the 90's, light conditions have not exhibited profound variation, in addition, nutrient oversupply decreased which might account for decreased algal biomass. However, the degree of nutrient excess may determine the potential maximum biomass of algae, thus, after all, we expect long-term change in nutrient load to affect phytoplankton biomass in the Danube River.

On the basis of long-term water chemical data, variation in nutrient load (expressed in PO_4-P concentration) can answer the question discussed above. Results of temporal coenological patterns constructed from phytoplankton database supported this scenario, where change in phosphorus load goes hand in hand with phytoplankton clusters in ordination plot. Assuming that high level of nutrient excess serves a different kind of environment for algae than does low level of nutrient oversupply, purely temperature variation improves simulation of algal biomass without building a nutrient variable into the model. Results suggest that different levels of nutrient oversupply (characterized with PO_4-P concentration) create different environments to phytoplankton, and – according to those levels of oversupply – algae display different dynamics in answer to global warming.

In case of climate change scenarios can be experience higher values compared the observed ones indeed, but not only in case of series of data regarding future (2070-2100) but also in case of the control period (1960-1990). This results draws attention to the constraints of applicability of scenarios. Based on the three case studies examined the effects of warming the role of environmental variable is important. It can be explained based on nutrient excess. Assuming high level of nutrient load the response of Danubian phytoplankton similar to effects of eutrophication. Accordingly the warming enhances the effects of eutrophication in accordance with other international scientific observations and assumptions. Assuming higher level of nutrient load the phytoplankton biomass rising is drastic due to the warming, without changes in phosphorus load. Consequently if the nutrient load is also rising, the changes in danubian phytoplankton biomass will be dramatic.

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