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## Community ecological effects of climate change

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### 1. Introduction

The ranges of the species making up the biosphere and the quantitative and species composition of the communities have continuously changed from the beginning of life on earth. Earlier the changing of the species during the history of the earth could be interpreted as a natural process, however, in the changes of the last several thousand years the effects due to human activity have greater and greater importance. One of the most significant anthropogenic effects taken on our environment is the issue of climate change. Climate change has undoubtedly a significant influence on natural ecological systems and thus on social and economic processes. Nowadays it is already an established fact that our economic and social life is based on the limited natural resources and enjoys different benefits of the ecosystems ("ecosystem services"). By reason of this, ecosystems do not only mean one sector among the others but due to the ecosystem services they are in relationship with most of the sectors and global changes influence our life mainly through their changes.

In the last decades direct and indirect effects of the climate change on terrestrial and marine ecosystems can already be observed, on the level of individuals, populations, species, ecosystem composition and function as well. Based on the analysis of data series covering at least twenty years, statistically significant relationship can be revealed between temperature and the change in biological-physical parameters of the given tax on in case of more than 500 taxes. Researchers have shown changes in the phenological, morphological, physiological and behaviour characteristics of the taxes, in the frequency of epidemics and damages, in the ranges of species and other indirect effects.

In our present study we would like to examine closely the effects of climate change on community ecology, throwing light on some methodological questions and possibilities of studying the topic. To understand the effects of climate change it is not enough to collect ecological field observations and experimental approaches yield results only with limited validity as well. Therefore great importance is attached to the presentation of modelling methods and some possibilities of application are described by means of concrete case

studies. This chapter describes the so-called strategic model of a theoretical community in detail, with the help of which relevant results can be yielded in relation to ecological issues such as “Intermediate Disturbance Hypothesis” (IDH). Adapting the model to real field data, the so-called tactical model of the phytoplankton community of a great atrophic river (Danube, Hungary) was developed. Thus we show in a hydro biological case study which influence warming can have on the maximum amount of phytoplankton in the examined aquatic habitat. The case studies of the strategic and tactical models are contrasted with other approaches, such as the method of „geographical analogy”. The usefulness of the method is demonstrated with the example of Hungarian agro-ecosystems.

## 2. Literature overview

### 2.1. Ways of examination of community ecological effects of climate change

In the first half of the 20th century, when community ecology was evolving, two different concepts stood out. The concept of a „super organism” came into existence in North America and was related to Clements (1905). According to his opinion, community composition can be regarded as determined by climatic, geological and soil conditions. In case of disturbance, when the community status changes, the original state will be reached by succession. Practically, the community is characterized by stability or homeostasis. Since the 1910s, the Zürich-Montpellier Phytocoenological School has evolved within this framework with the participation of Braun-Blanquet, and the same tendency can be observed in the field of animal ecology, in the principal work of Elton (1927). The same concept characterizes the Gaia concept of Lovelock (1972, 1990), which is the extension of the above-mentioned approach to biosphere level. Another concept, entitled „individualistic” (Gleason, 1926), stands in contrast with it. It postulates that the observed assembly pattern is generated by the stochastic sum of the populations individually adapted to the environment.

Nowadays, contrasting these concepts seems to be rather superfluous, as it is obvious that one of them describes communities regulated by competition, which are often disturbed, whereas the other one implies coevolved, stable communities, which have been permanent for a long time. However, it is true for both habitat types that community ecological and production biological processes, as well as species composition and biodiversity depend on the existing climate and the seasonal patterns of weather parameters.

According to our central research hypothesis, climate change takes its main ecological effects through the transitions between these two different habitats and ecological states. Testing of the present hypothesis can be realized by simulation models and related case studies, as it is evident that practically; these phenomena cannot be investigated either by field observations or by manipulative experiments.

The important community ecological researches have three main approaches related to methodology considering climate change. Ecologists working in the field observing real natural processes aspire to interfere as little as possible with the processes (Spellerberg, 1991). The aim is to describe the community ecological patterns.

The other school of ecological researches examines hypotheses about natural processes. The basis of these researches is testing different predictions in manipulative trials. The third group of ecologists deals with modelling where a precise mathematical model is made for basic and simple rules of the examined phenomena.

The work of the modelling ecologists consists of two parts. The first one is testing the mathematical model with case studies and the second one is developing (repairing and fitting again) the model. These available models are sometimes far away from the observations of field ecologists because there are different viewpoints. In the course of modelling the purpose is to simplify the phenomena of nature whereas in case of field observations ecosystems appear as complex phenomena.

It is obvious that all the three approaches have advantages and disadvantages. There are two approaches: monitoring- and hypothesis-centred ones. In case of monitoring approaches the main purpose is to discover the relationships and patterns among empirical data. This is a multidimensional problem where the tools of biomathematics and statistics are necessary. Data originate from large monitoring systems (e.g. national light trap network, Long Term Ecological Research (LTER)).

In case of hypothesis-centred approaches known or assumed relationships mean the starting point. There are three types of researches in this case:

- Testing simple hypotheses with laboratory or field experiments (e.g. fitotron plant growth room).
- Analyzing given ecosystems with tactical models (e.g. local case studies, vegetation models, food web models, models of biogeochemical cycles) (Fischlin et al., 2007, Sipkay et al., 2008a, Vadadi et al., 2008).
- Examination of general questions with strategic modelling (e.g. competition and predation models, cellular automata, evolutionary-ecological models).

In the examination of the interactions between climate change, biodiversity and community ecological processes the combined application of these main schools, methodological approaches and viewpoints can yield results.

## 2.2. Intermediate Disturbance Hypothesis (IDH)

Species richness in tropical forests as well as that of the atolls is unsurpassable, and the question arises why the theory of competitive exclusion does not prevail here. Trees often fall and perish in tropical rainforests due to storms and landslide, and corals often perish as a result of freshwater circulation and predation. It can be said with good reason that disturbances of various quality and intensity appear several times in the life of the above mentioned communities, therefore these communities cannot reach the state of equilibrium. The Intermediate Disturbance Hypothesis (IDH) (Connell, 1978) is based on this observation and states the following:

- In case of no disturbance the number of the surviving species decreases to minimum due to competitive exclusion.
- In case of large disturbance only pioneers are able to grow after the specific disturbance events.
- If the frequency and the intensity of the disturbance are medium, there is a bigger chance to affect the community.

There are some great examples of IDH in case of phytoplankton communities in natural waters (Haffner et al., 1980; Sommer, 1995; Viner & Kemp, 1983; Padisák, 1998; Olrik & Nauwerk, 1993; Fulbright, 1996). Nowadays it is accepted that diversity is the largest in the second and third generations after the disturbance event (Reynolds, 2006).

### 2.3. Connection between IDH and diversity

The connection between the diversity and the frequency of the disturbance can be described by a parabola (Connell, 1978). If the frequency and the strength of the disturbance are large, species appear which can resist the effects, develop fast and populate the area quickly (r-strategists). In case of a disturbance of low frequency and intensity the principle of competitive exclusion prevails so dominant species, which grow slowly and maximize the use of sources, spread (K-strategists).

Padisák (1998) continuously took samples from different Hungarian lakes (such as Balaton and Lake Fertő) and the abundance, uniformity (in percentage) and Shannon diversity of phytoplankton were examined. In order to be able to generalize, serial numbers of the phytoplankton generations between the single disturbance events are represented on the horizontal axis, and this diagram shows similarity with that of Connell (1978). This graph also shows that the curve doesn't have symmetrical run as the effect of the disturbance is significantly greater in the initial phase than afterwards.

According to Elliott et al. (2001), the relationship between disturbance and diversity cannot be described by a Connell-type parabola (Connell, 1978) because a sudden breakdown occurs on a critically high frequency. This diagram is called a cliff-shaped curve. The model is known as PROTECH (Phytoplankton ResPonses To Environmental CHange); it is a phytoplankton community model and is used to examine the responses given to environmental changes (Reynolds, 2006).

### 2.4. Expected effects of climate change on fresh-water ecosystems

Rising water temperatures induce direct physiological effects on aquatic organisms through their physiological tolerance. This mostly species-specific effect can be demonstrated with the examples of two fish species, the eurythermal carp (*Cyprinus carpio*) and the stenothermal *Splenius alpinus* (Ficke et al., 2007). Physiological processes such as growth, reproduction and activity of fish are affected by temperature directly (Schmidt-Nielsen, 1990). Species may react to changed environmental conditions by migration or acclimatization. Endemic species, species of fragmented habitats and systems with east-west orientation are less able to follow the drastic habitat changes due to global warming (Ficke et al., 2007). At the same time, invasive species may spread, which are able to tolerate the changed hydrological conditions to a greater extent (Baltz & Moyle, 1993).

What is more, global warming induces further changes in the physical and chemical characteristics of the water bodies. Such indirect effects include decrease in dissolved oxygen content (DO), change in toxicity (mostly increasing levels), trophic status (mostly indicating eutrophication) and thermal stratification.

DO content is related to water temperature. Oxygen gets into water through diffusion (e. g. stirring up mechanism by wind) and photosynthesis. Plant, animal and microbial respiration decrease the content of DO, particularly at night when photosynthesis based oxygen production does not work. When oxygen concentration decreases below 2-3 mg/l, we have to face the hypoxia. There is an inverse relationship between water temperature and oxygen solubility. Increasing temperatures induce decreasing content of DO whereas the biological oxygen demand (BOD) increases (Kalff, 2000), thus posing double negative effect on aquatic organisms in most systems. In the side arms of atrophic rivers, the natural process of phytoplankton production-decomposition has an unfavourable effect as well. Case studies of the side arms in the area of Szigetköz and Gemenc also draw attention to

this phenomenon: high biomass of phytoplankton caused oxygen depletion in the deeper layers and oversaturation in the surface (Kiss et al., 2007).

Several experiments were run on the effects of temperature on toxicity. In general, temperature dependent toxicity decreases in time (Nussey et al., 1996). On the other hand, toxicity of pollutants increases with rising temperatures (Murty, 1986.b), moreover there is a positive correlation between rising temperatures and the rate at which toxic pollutants are taken up (Murty, 1986.a). Metabolism of poikilothermal organisms such as fish increases with increasing temperatures, which enhances the disposal of toxic elements indirectly (MacLeod & Pessah, 1993). Nevertheless, the accumulation of toxic elements is enhanced in aquatic organisms with rising temperatures (Köck et al., 1996). All things considered, rising temperatures because increasing toxicity of pollutants.

Particularly in lentic waters, global warming has an essential effect on trophic state and primary production of inland waters through increasing the water temperature and changing the stratification patterns (Lofgren, 2002). Bacterial metabolism, rate of nutrient cycle and algal abundance increase with rising temperatures (Klapper, 1991). Generally, climate change related to pollution of human origin enhances eutrophication processes (Klapper, 1991; Adrian et al., 1995). On the other hand, there is a reverse effect of climate change inasmuch as enhancement of stratification (in time as well) may result in concentration of nutrients into the hypolimnion, where they are no longer available for primary production (Magnuson, 2002). The latter phenomenon is only valid for deep, stratified lakes with distinct aphetic and tropholitic layers.

According to the predictions of global circulation models climate change is more than rise in temperatures purely. The seasonal patterns of precipitation and related flooding will also change. Frequency of extreme weather conditions may intensify in water systems as well (Magnuson, 2002). Populations of aquatic organisms are susceptible to the frequency, duration and timing of extreme precipitation events including also extreme dry or wet episodes. Drought and elongation of arid periods may cause changes in species composition and harm several populations (Matthews & Marsh-Matthews, 2003). Seasonal changes in melting of the snow influence the physical behaviour of rivers resulting in changed reproduction periods of several aquatic organisms (Poff et al., 2002). Due to melting of ice rising sea levels may affect communities of river estuaries in a negative way causing increased erosion (Wood et al., 2002). What is more, sea-water flow into rivers may increase because of rising sea levels; also drought contributes to this process causing decreased current velocities in the river.

Climate change may enhance UV radiation. UV-B radiation can influence the survival of primary producers and the biological availability of dissolved organic carbon (DOC). The interaction between acidification and pollution, UV-B penetration and eutrophication has been little studied and is expected to have significant impacts on lake systems (Magnuson, 2002; Allan et al., 2002).

## **2.5. Feedback mechanisms in the climate-ecosystem complex**

The latest IPCC report (Fischlin et al., 2007) points out that a rise of 1.5-2.5 °C in global average temperature causes important changes in the structure and functioning of ecosystems, primarily with negative consequences for the biodiversity and goods and services of the ecological systems.

Ecosystems can control the climate (precipitation, temperature) in a way that an increase in an atmosphere component (e.g. CO<sub>2</sub> concentration) induces the processes in biosphere to decrease the amount of that component through biogeochemical cycles. Pale climatic researches proved this control mechanism existing for more than 100,000 years. The surplus CO<sub>2</sub> content has most likely been absorbed by the ocean, thus controlling the temperature of the Earth through the green house effect. This feedback is negative therefore the equilibrium is stable.

During the climate control there may be not only negative but positive feedbacks as well. One of the most important factors affecting the temperature of the Earth is the albedo of the poles. While the average temperature on the Earth is increasing, the amount of the arctic ice is decreasing. Therefore the amount of the sunlight reflected back decreases, which warms the surface of the Earth with increasing intensity. This is not the only positive feedback during the control; another good example is the melting of frozen methane hydrate in the tundra.

The environment, the local and the global climate are affected by the ecosystems through the climate-ecosystem feedbacks. There is a great amount of carbon in the living vegetation and the soil as organic substance which could be formed to atmospheric CO<sub>2</sub> or methane hereby affecting the climate. CO<sub>2</sub> is taken up by terrestrial ecosystems during the photosynthesis and is lost during the respiration process, but carbon could be emitted as methane, volatile organic compound and dissolved carbon. The feedback of the climate-carbon cycle is difficult to determine because of the difficulties of the biological processes (Drégelyi-Kiss & Hufnagel, 2008).

The biological simplification is essential during the modelling of vegetation processes. It is important to consider several feedbacks to the climate system to decrease the uncertainty of the estimations.

### **3. Strategic modelling of the climate-ecosystem complex based on the example of a theoretical community**

#### **3.1. TEGM model (Theoretical Ecosystem Growth Model)**

An algae community consisting of 33 species in a freshwater ecosystem was modelled (Drégelyi-Kiss & Hufnagel, 2009). During the examinations the behaviour of a theoretical ecosystem was studied by changing the temperature variously.

Theoretical algae species are characterized by the temperature interval in which they are able to reproduce. The simulation was made in Excel with simple mathematical background. There are four types of species based on their temperature sensitivity: super-generalists, generalists, transitional species and specialists. The temperature optimum curve originates from the normal (Gaussian) distribution, where the expected value is the temperature optimum. The dispersion depends on the niche overlap among the species. The overlap is set in a way that the results correspond with the niche overlap of the lizard species studied by Pianka (1974) where the average of the total niche overlap decreases with the number of the lizard species. 33 algae species with various temperature sensitivity can be seen in Figure 1. The daily reproductive rate of the species can be seen on the vertical axis, which means by how many times the number of specimens can increase at a given temperature. This corresponds to the reproductive ability of freshwater algae in the temperate zone (Felföldy, 1981). Since the reproductive ability is given, the daily number of specimens related to the daily average temperature is definitely determinable.

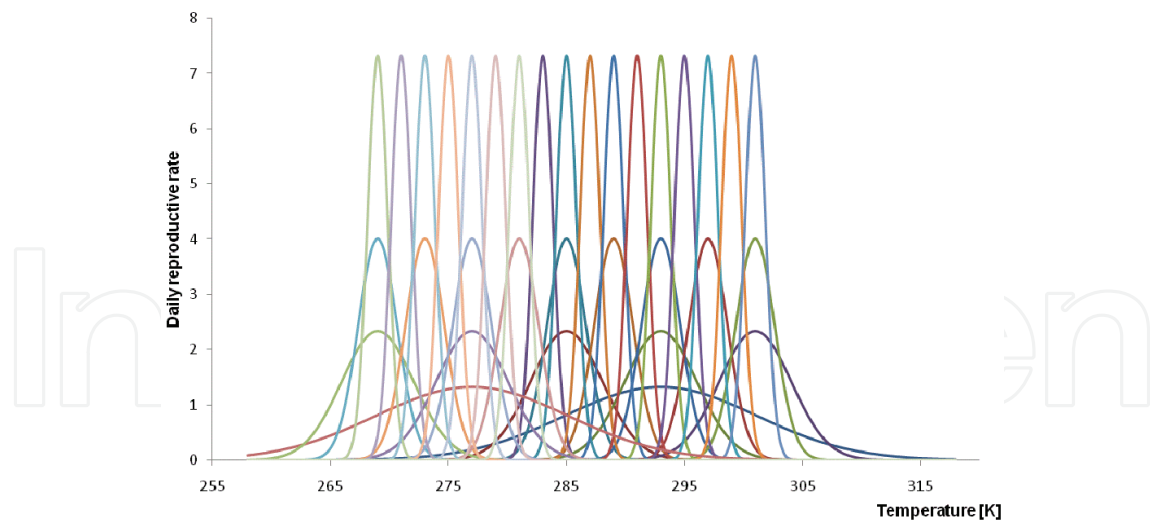


Fig. 1. Reproductive temperature pattern of 33 algae species

The 33 species are described by the Gaussian distribution with the following parameters:

- 2 super-generalists ( $\mu_{SG1}=277$  K;  $\mu_{SG2}=293$  K;  $\sigma_{SG}=8.1$ )
- 5 generalists ( $\mu_{G1}=269$  K;  $\mu_{G2}=277$  K;  $\mu_{G3}=285$  K;  $\mu_{G4}=293$  K;  $\mu_{G5}=301$  K;  $\sigma_G=3.1$ )
- 9 transitional species ( $\mu_{T1}=269$  K;  $\mu_{T2}=273$  K;  $\mu_{T3}=277$  K;  $\mu_{T4}=281$  K;  $\mu_{T5}=285$  K;  $\mu_{T6}=289$  K;  $\mu_{T7}=293$  K;  $\mu_{T8}=297$  K;  $\mu_{T9}=301$  K;  $\sigma_T=1.66$ )
- 17 specialists ( $\mu_{S1}=269$  K;  $\mu_{S2}=271$  K;  $\mu_{S3}=273$  K;  $\mu_{S4}=275$  K;  $\mu_{S5}=277$  K;  $\mu_{S6}=279$  K;  $\mu_{S7}=281$  K;  $\mu_{S8}=283$  K;  $\mu_{S9}=285$  K;  $\mu_{S10}=287$  K;  $\mu_{S11}=289$  K;  $\mu_{S12}=291$  K;  $\mu_{S13}=293$  K;  $\mu_{S14}=295$  K;  $\mu_{S15}=297$  K;  $\mu_{S16}=299$  K;  $\mu_{S17}=301$  K;  $\sigma_S=0.85$ ).

We suppose 0.01 specimens for every species as a starting value and the following minimum function describes the change in the number of specimens.

$$N(X_i)_j = N(X_i)_{j-1} \cdot \text{Min} \left\{ \left( RR(X_i)_j \right)^r ; (RF_j)^r \right\} + 0.01 \quad (1)$$

where  $i$  denotes the species,  $i=1,2,\dots,33$ ;  $j$  is the number of the days (usually  $j=1, 2,\dots, 365$ );  $RR(X_i)_j$  is the reproduction rate of the  $X_i$  species on the  $j^{\text{th}}$  day;  $RF_j$  is the restrictive function related to the accessibility of the sunlight;  $r$  is the velocity parameter ( $r=1$  or  $0.1$ ); the 0.01 constant means the number of the spore in the model which inhibits the extinction of the population.

The temperature-dependent growth rate can be described with the density function of the normal distribution, whereas the light-dependent growth rate includes a term of environmental sustainability, which was defined with a sine curve representing the scale of light availability within a year. The constant values of the restrictive function were set so that the period of the function is 365.25, the maximum place is on 23<sup>rd</sup> June and the minimum place is on 22<sup>nd</sup> December. (These are the most and the least sunny days.)

In every temperature interval there are dominant species which win the competition. The output parameters of the experiments are the determination of the dominant species, the largest number of specimens, the first year of the equilibrium and the use of resources. The



use of the resources shows how much is utilized from the available resources (in this case from sunlight) during the increase of the ecosystem.

#### Functions of temperature patterns

1. Simulation experiments were made at constant 293 K, 294 K and 295 K using the two velocity parameters ( $r=1$  and  $0.1$ ). The fluctuation was added as  $\pm 1 \dots \pm 11$  K random numbers.
2. The temperature changes as a sine function over the year (with a period of 365.25 days):

$$T = s_1 \cdot \sin(s_2 \cdot t + s_3) + s_4 \quad (2)$$

where  $s_2=0.0172$ ,  $s_3=-1.4045$  since the period of the function is 365.25 and the maximum and the minimum place are given (23th June and 22nd December, these are the most and the least sunny days).

3. Existing climate patterns
  - a. Historical daily temperature values in Hungary (Budapest) from 1960 to 1990
  - b. Historical daily temperature values from various climate zones (from tropical, dry, temperate, continental and polar climate)
  - c. Future temperature patterns in Hungary from 2070-2100
  - d. Analogous places related to Hungary by 2100

It is predicted that the climate in Hungary will become the same by 2100 as the present-day climate on the border of Romania and Bulgaria or near Thessaloniki. According to the worst prediction the climate will be like the current North-African climate (Hufnagel et al., 2008).

The conceptual diagram of the TEGM model summarizes the build-up of the model (Figure 2).

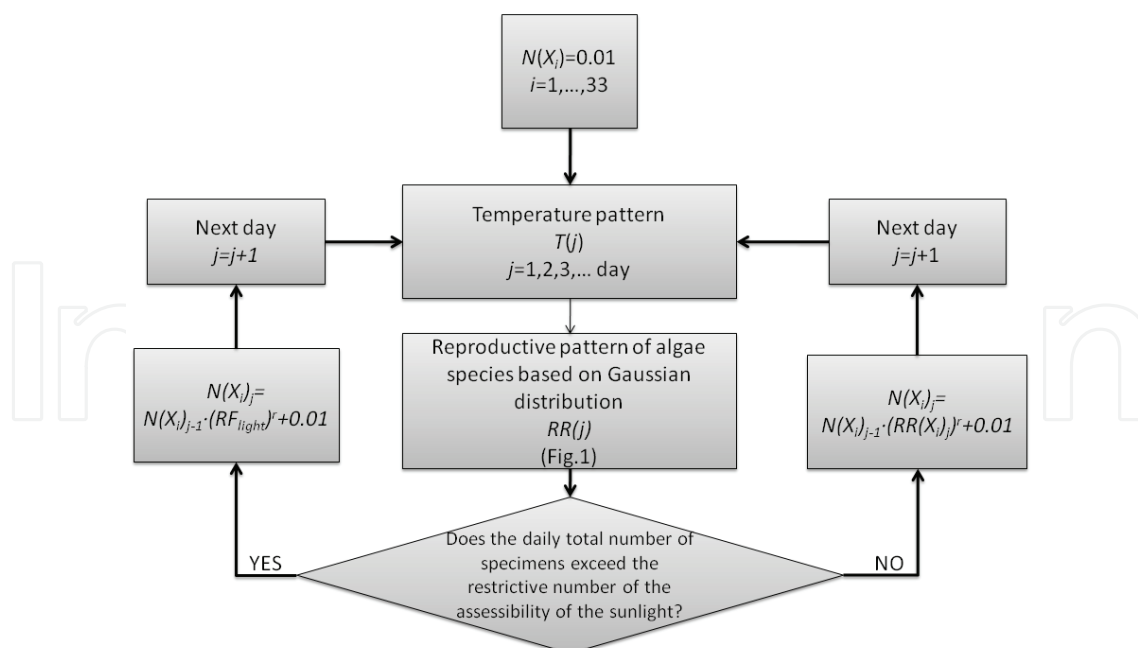


Fig. 2. Conceptual diagram of the TEGM model ( $RR$ : reproduction rate,  $RF$ : restriction function related to the accessibility of the sunlight,  $N(X_i)$ : the number of the  $i^{th}$  algae species,  $r$ : velocity parameter)

### 3.2. Main observations based on simulation model examinations

Changing climate means not only the increase in the annual average temperature but in variability as well, which is a larger fluctuation among daily temperature data (Fischlin et al., 2007). As a consequence, species with narrow adaptation ability disappear, species with wide adaptation ability become dominant and biodiversity decreases.

In the course of our simulations it has been shown what kind of effects the change in temperature has on the composition of and on the competition in an ecosystem. Specialists reproducing in narrow temperature interval are dominant species in case of constant or slowly changing temperature patterns but these species disappear in case of fluctuation in the temperature (Drégelyi-Kiss & Hufnagel, 2009). The best use of resources occurs in the tropical climate.

Comparing the Hungarian historical data with the regional predictions of huge climate centres (Hadley Centre: HC, Max Planck Institute: MPI) it can be stated that recent estimations (such as HC adhfa, HC adhfd and MPI 3009) show a decrease in the number of specimens in our theoretical ecosystem.

Simulations with historical temperature patterns of analogous places show that our ecosystem works similarly in the less hot Rumanian lowland (Turnu Magurele), while the number of specimens and the use of resources increase using North African temperature data series. In further research it could be interesting to analyze the differences in the radiation regime of the analogous places.

Regarding diversity the annual value of the Shannon index increases in the future (in case of the data series HC adhfa and MPI 3009), but the HC adhfd prognosis shows the same pattern as historical data do (Budapest, 1960-1990). According to the former predictions (such as UKLO, UKHI and UKTR31) the composition of the ecosystem does not change in proportion to the results based on historical data (Drégelyi-Kiss & Hufnagel, 2010).

Further simulations were made in order to answer the following question: what kind of environmental conditions result in larger diversity in an ecosystem related to the velocity of reproduction. The diversity value of the slower process is the half of that of the faster process. Under the various climate conditions the number of specimens decreases earlier in case of the slower reproduction ( $r=0.1$ ) than in the faster case ( $r=1$ ), and there are larger changes in diversity values. Generally it can be said that an ecosystem with low number of specimens evolves finally. Using the real climate functions it can be stated that from the predicted analogous places (Turnu Magurele, Romania; Cairo, Egypt (Hufnagel et al., 2008)) Budapest shows similarity with Turnu Magurele in the number of specimens and in diversity values (Hufnagel et al., 2010).

Our strategic model was adapted for tactical modelling, which is described later as "Danubian Phytoplankton Model".

### 3.3. Manifestation of the Intermediate Disturbance Hypothesis (IDH) in the course of the simulation of a theoretical ecosystem

In the simulation study of a theoretical community made of 33 hypothetical algae species the temperature was varied and it was observed that the species richness showed a pattern in accordance with the intermediate disturbance hypothesis (IDH).

In case of constant temperature pattern the results of the simulation study can be seen in Fig. 3, which is the part of the examinations where random fluctuations were changed by up to  $\pm 11K$ . The number of specimens in the community is permanent and maximum until

daily random fluctuation values are between 0 and  $\pm 2K$ . Significant decrease in the number of specimens depends on the velocity factor of the ecosystem. There is a sudden decrease in case of a fluctuation of  $\pm 3K$  in the slower processes while the faster ecosystems react in case of a random fluctuation of about  $\pm 6K$ .

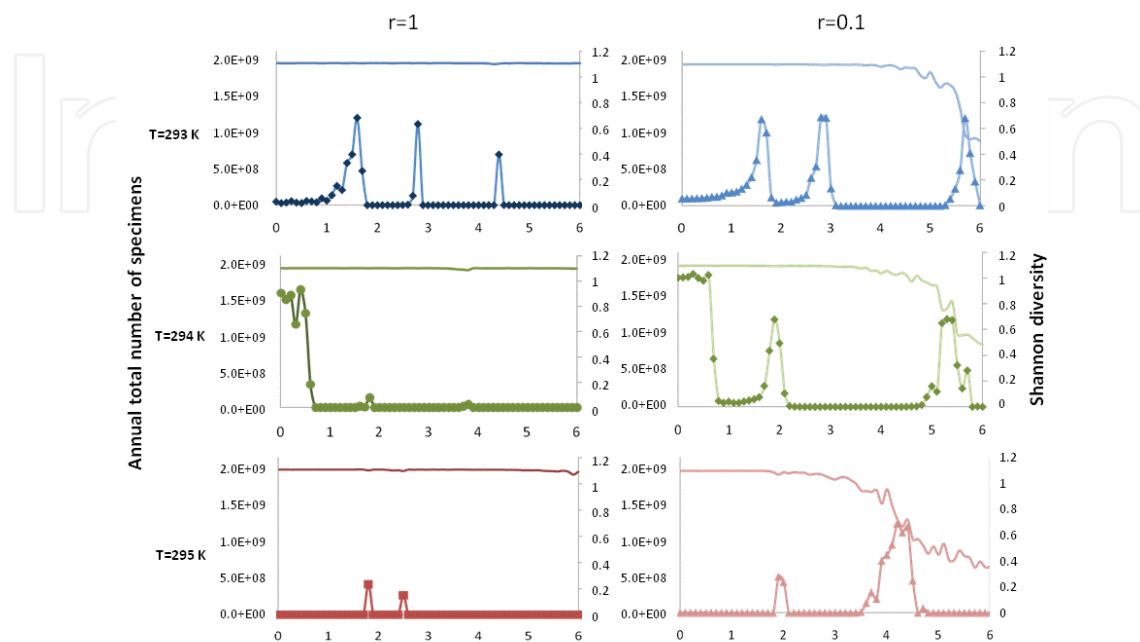


Fig. 3. Annual total number of specimens and diversity values versus the daily random fluctuation in constant temperature environment (The signed plots show the diversity values.)

There are some local maximums in the diversity function. In case of low fluctuation the diversity values are low; the largest diversity can be observed in case of medium daily variation in temperature; in case of large fluctuations, just like in case of the low ones, the diversity value is quite low. The diversity of the ecosystem which has faster reproductive ability shows lower local maximum values than that of the slower system in the experiments.

The degree of the diversity is greater in case of  $r=0.1$  velocity factor than in case of the faster system. If there is no disturbance, the largest diversity can be observed at 294 K in case of both speed values. If the fluctuation is between  $\pm 6K$  and  $\pm 9K$ , the diversity values are nearly equally low. In case of the largest variation ( $\pm 11K$ ) the degree of the diversity increases strongly.

In case of constant temperature pattern the Intermediate Disturbance Hypothesis can be seen well (Fig. 3.). In case of  $r=1$  and  $T=293 K$  the specialist (S13) wins the competition when the random daily fluctuation has rather low values (up to  $\pm 1.5K$ ). Then, increasing the random fluctuation the generalist (T7) is the winner and the transition between the exchanges of the two type genres shows the local maximum value in case of disturbance, which is related to IDH. The following competition is between the species T7 and G4 in case of a fluctuation of about  $\pm 2.8K$ , then between G4 and the super generalist (SG1) in case of

about  $\pm 4.5K$ . These are similar fluctuation values where the IDH can be observed as it can be seen in Fig. 3.

The shapes of the IDH local maximum curves show similarity in all cases. The maximum curves increase slowly and decrease steeply. The main reason of this pattern is the competition between the various species. If the environmental conditions are better for a genre, the existing genre disappears faster, which explains the steep decrease in the diversity values after the competition. There are controversies regarding the shape of the local maximum curves in diversity values versus the random daily fluctuation (Connell, 1978; Elliott et al., 2001).

In case of sine temperature pattern the parameter  $s_1$  was changed during the simulations. The results of the experiments can be seen in Fig.4. The initial low diversity value increases as the value of the parameter  $s_1$  grows then decreases again.

There are two peaks in diversity when increasing the amplitude of the annual sine temperature function ( $s_1$ ) in case of low values. The annual total number of specimens is permanent when  $s_1=0\dots 3.5$  in case of both velocity parameters, only the diversity value changes. In case of annual fluctuation (i.e. sine temperature pattern) the Intermediate Disturbance Hypothesis could be observed as well, and there are two local peaks similarly to the case of daily fluctuation.

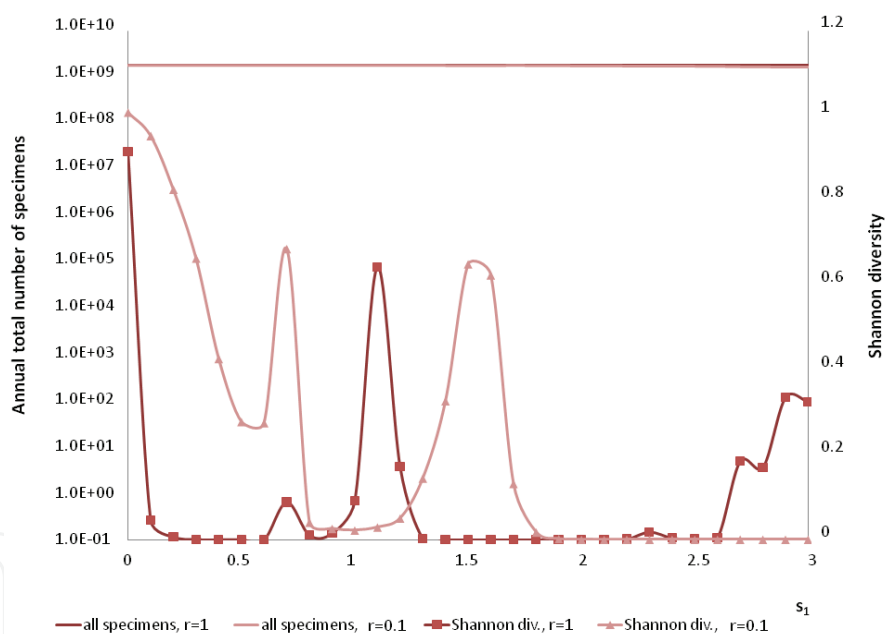


Fig. 4. Annual total numbers of specimens and Shannon diversity values plotted against the parameter  $s_1$  in case of sine temperature pattern

### 3.4. Future research

Ecosystems have an important role in the biosphere in development and maintenance of the equilibrium. Regarding the temperature patterns it is not only the climate environment which affects the composition of ecosystems but plants also provides a feedback to their environment through the photosynthesis and respiration in the global carbon cycle.

The specimens of the ecosystems do not only suffer the change in climate but they can affect the equilibrium of the biosphere and the composition of the air through the biogeochemical cycles. There is an opportunity to examine the controlling ability of temperature and climate with the theoretical ecosystem.

In our further research we would like to examine the feedback of the ecosystem to the climate. These temperature feedbacks are very important related to DGVM models with large computation needs (Friedlingstein et al., 2006), but the feedbacks are not estimated directly. We would like to examine the process of the feedback with PC calculations in order to answer easy questions.

#### **4. Tactical modelling case study using the example of the phytoplankton community of a large river (Hungarian stretch of River Danube)**

The present subchapter describes the seasonal dynamics of the phytoplankton by means of a discrete-deterministic model on the basis of the data gathered in the Danube River at Göd (Hungary). The strategic model, so-called "TEGM" was adapted to field data (tactical model). The "tactical model" is a simulation model fitted to the observed temperature data set (Sipkay et al. 2009). The tactical models could be beneficial if the general functioning of ecosystems is in the focus (Hufnagel & Gaál 2005; Sipkay et al. 2008a, 2008b; Sipkay et al. 2009; Vadadi et al. 2009).

##### **4.1. Materials and methods**

Long-term series of phytoplankton data are available on the river Danube at Göd (1669 rkm) owing to the continuous record of the Hungarian Danube Research Station of the Hungarian Academy of Sciences collecting quantitative samples of weekly frequency between 1979 and 2002 (Kiss, 1994). Phytoplankton was sampled from the streamline near the surface and after processing of samples biomass was calculated ( $\text{mg l}^{-1}$ ).

The relatively intensive sampling makes our data capable of being used in simulation models, which are functions of weather conditions. We assume that temperature is of major importance when discussing the seasonal dynamics of phytoplankton. What is more, the reaction curve describing the temperature dependency may be the sum of optimum curves, because the temperature optimum curves of species or units of phytoplankton and of biological phenomena determining growth rate are expected to be summed. On the other hand, the availability of light has also a major influence on the seasonal variation of phytoplankton abundance; therefore it was taken into account as well. Further biotic and abiotic effects appear within the above-mentioned or hidden.

First, a strategic model, the so-called TEGM (Theoretical Ecosystem Growth Model) (Drégelyi & Hufnagel, 2009) was used, which involves the temperature optimum curves of 33 theoretical species covering the possible spectrum of temperature. The strategic model of the theoretical algal community was adapted to field data derived from the river Danube (tactical model), with respect to the fact that the degree of nutrient oversupply varied regularly during the study period (Horváth & Tevanné Bartalis, 1999). Assuming that nutrient oversupply of high magnitude represents a specific environment for phytoplankton, two sub models were developed, one for the period 1979-1990 with nutrient oversupply of great magnitude (sub model „A”) and a second one for the period 1991-2002 with lower oversupply (sub model „B”). Either sub model can be described as the linear

combination of 20 theoretical species. These sub models vary slightly in the parameters of the temperature reaction curves. Biomass ( $\text{mg l}^{-1}$ ) of a certain theoretical species is the function of its biomass measured the day before and the temperature or light coefficient. So as to define whether temperature or light is the driving force, a minimum function was applied. Temperature-dependent growth rate can be described with the density function of normal distribution, whereas light-dependent growth rate includes a term of environmental sustainability, which was defined with a sine curve representing the scale of light availability within a year.

The model was run with the data series of climate change scenarios as input parameters after being fitted (with the Solver optimization program of MS Excel) to the data series of daily temperatures supplied by the Hungarian Meteorological Service. Data base of the PRUDENCE EU project (Christensen, 2005) was used, that is, A2 and B2 scenarios proposed by the IPCC (2007), the daily temperatures of which are specified for the period 2070-2100. Three data series were used including the A2 and B2 scenarios of the HadCM3 model developed by the Hadley Centre (HC) and the A2 scenario of the Max Planck Institute (MPI). Each scenario covers 31 replicates of which we selected 24 so as to compare to measured data of 24 years between 1979 and 2002. In addition, the effect of linear temperature rise was tested as follows: each value of the measured temperatures between 1979 and 2002 was increased by 0.5, 1, 1.5 and 2 °C, and then the model was run with these data.

The outcomes were analyzed with statistical methods using the Past software (Hammer et al., 2001). Yearly total phytoplankton biomass was defined as an indicator; however, it was calculated as the sum of the monthly average biomass in order to avoid the „side-effect“ of extreme values. One-way ANOVA was applied to demonstrate possible differences between model outcomes. In order to point out which groups do differ from each other, the post-hoc Turkey test was used, homogeneity of variance was tested with Levene's test and standard deviations were compared with Welch test.

## 4.2. Results

On the basis of field and simulated data of phytoplankton abundance (Fig. 5), it can be said that the model fits to the observed values quite well. Yearly total biomass measured in the field and calculated as the sum of monthly average biomass correlated with the simulated values ( $r=0.74$ ).

Phytoplankton biomass varied significantly within outcomes for scenarios and real data (one-way ANOVA,  $p<0.001$ ), however, variances did not prove to be homogeneous (Levene's test,  $p<0.001$ ), resulting from the significant differences of standard deviations (Welch test,  $p<0.001$ ). Turkey's pair wise comparisons implied significant differences between outcomes of the scenario A2 (of MPI) and the others in sub model „A“ only ( $p<0.05$ ).

Examining the effect of linear temperature rise there were also significant differences between outputs (one-way ANOVA,  $p<0.001$ ), similarly, variances were not homogeneous (Levene's test,  $p<0.001$ ), and again, this was interpreted by the significant differences of standard deviations (Welch test,  $p<0.001$ ). Turkey's pair wise comparisons pointed out that there are significant differences between the outcomes for the period 1979-2002 and outcomes at a temperature rise of 2 °C in case of sub model „A“, furthermore, rises in temperature of 0.5, 1 and 1.5 °C in sub model „A“ implied significant differences from the

outcomes of sub model „B” ( $p < 0.05$ ). However, outcomes within sub model „B” showed large similarity ( $p = 1$ ).

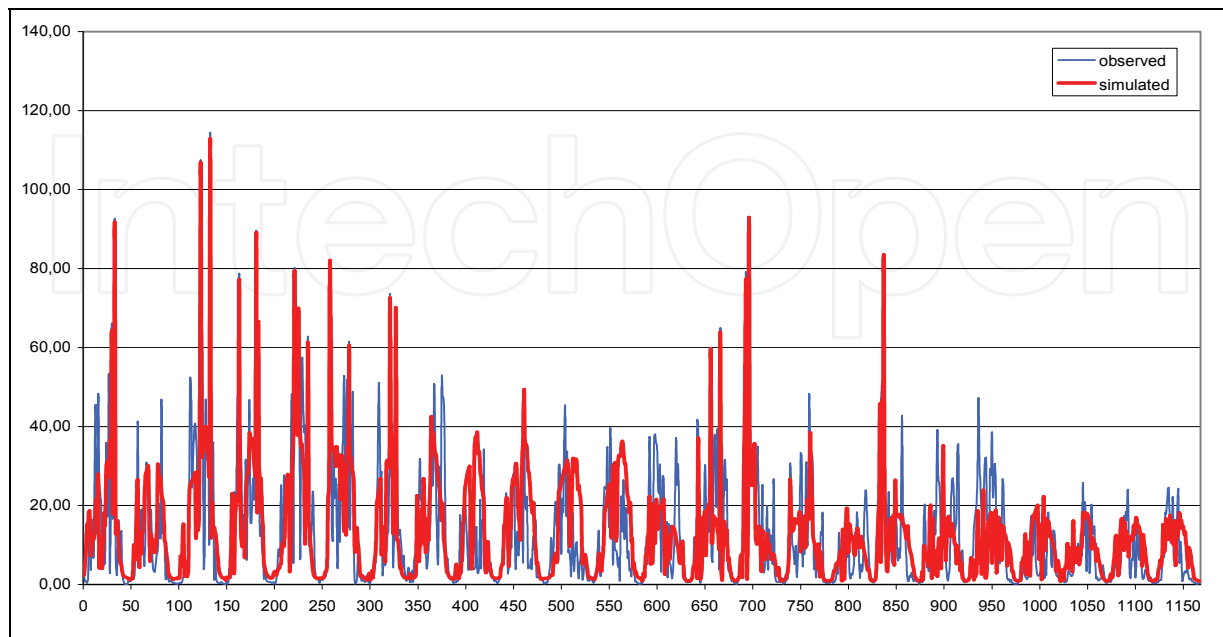


Fig. 5. The Danubian Phytoplankton Model fitted to the data series of 1979-1990, including sub model „A” for the period 1979-1990 and sub model „B” for the period 1991-2002.

Fig. 6. shows outputs of means and standard deviations of yearly total biomass of algae on the basis of monthly averages, from which it is evident that biomass increased largely in case of scenario A2 (MPI), however, biomass output for the period 1960-1990 increased notably as well (sub model „A”). Sub model „B” showed minor variations in biomass compared to model outputs for the period 1979-2002. Nevertheless, standard deviation showed major increase in each case. Temperature rise of 0.5 °C (Fig. 7.) obviously implied remarkable increase in biomass in case of sub model „A” and negligible changes in case of sub model „B”.

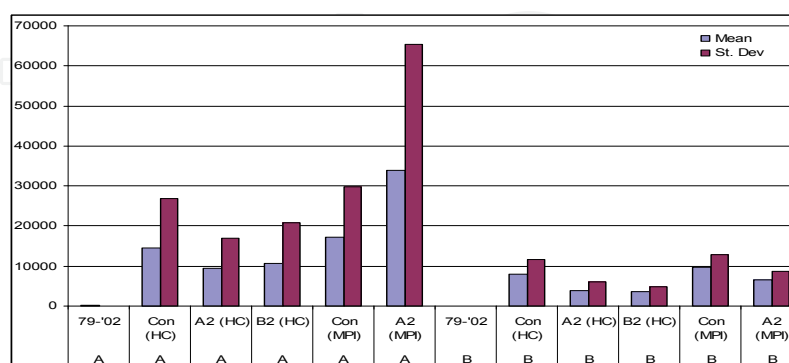


Fig. 6. Monthly means and standard deviations of yearly total algal biomass ( $\text{mg l}^{-1}$ ) in case of the model outputs for the period 1979-2002 (based on measured data of temperatures) compared with outputs of the model run with data series of the climate change scenarios. Sub models „A” and „B” are presented separately. HC=Hadley Centre; MPI=Max Planck Institute; A2 and B2 scenarios; Con=control

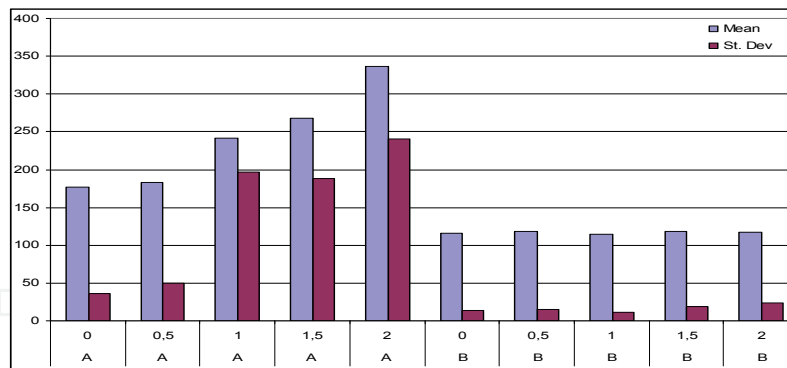


Fig. 7. Monthly means and standard deviations of yearly total algal biomass ( $\text{mg l}^{-1}$ ) in case of the model outputs for the period 1979-2002 (based on measured data of temperatures) compared with outputs of the model run with data series of linear temperature rises of 0.5 °C. Sub models „A” and „B” are presented separately. 0; 0.5; 1; 1.5; 2: degree of linear temperature rise (°C).

### 4.3. Discussion

Adapting the TEGM model we managed to develop a model that fits to the measured data quite well. Beyond the indicator of yearly total biomass introduced in the paper, further indicators can be defined and used in order to get a better understanding of the possible effects of climate change concerning the phytoplankton in the Danube River.

Interpretation of model outcomes for climate change scenarios is rather difficult. Comparing the model outcomes for the control period 1960-1990 with the outcomes for the case of applying the observed temperature data of 1979-2002 as input parameters, there are remarkable differences. Major variation within data series of certain climate change scenarios may account for the increased standard deviations observed in the model outputs. Sub model „B”, assuming minor nutrient oversupply, implied minor increase in biomass and variation within scenarios was of minor importance.

In case of linear temperature rise a clear answer is received: the more drastic warming results in greater abundance of phytoplankton if only the environment rich in nutrients is assumed (as it was experienced between 1979 and 1990). Moderate nutrient supply does not favour algae even if temperatures increase by 2 °C, thus biomass is not expected to increase notably. All these draw attention to the increased hazard of nutrient loading in rivers: global warming brings more drastic changes to nutrient rich environments.

Global warming can influence the trophic state and primary productivity of inland waters in a very fundamental way (Lofgren, 2002). Bacterial metabolism, rate of nutrient cycling and algal production all increase with rising temperatures (Klapper, 1991). Generally, climate change together with anthropogenic pollution enhances eutrophication (Klapper, 1991; Adrian et al., 1995). Several studies derived their findings from models forecasting increased phytoplankton abundance mostly through rising trophic (Mooij et al., 2007; Elliot et al., 2005; Komatsu et al., 2007). These are in line with our results of linear temperature rise, but only in case of high nutrient load. Global warming does not have so severe effects on phytoplankton biomass under conditions of lower nutrient load.

Looking at the variation in phytoplankton biomass only is not relevant enough in order to explore the effects of climate change. Freshwater food webs show rather characteristic seasonal dynamics, thus the effect of climate is the function of the season (Straille, 2005). If



we are interested in the phenomena within a year, further indicators can be introduced into the model. Such indicators include those showing the day of population peak (blooms) within a year or those representing 50% of the yearly total biomass. Some day the model will be able to provide us with an insight into the effects of global warming from a broader perspective by taking advantage of new indicators.

## 5. Spatial climatic analogy (SCA)

With the method of the spatial climatic analogy we search for regions which have the same climate at present as the scenarios indicate for the future. With the spatial analogy we can make the climate scenarios easier to understand. In this research the analogue regions for Debrecen, which is an agriculturally important region in Hungary, were examined.

According to the result we can say, in line with international results, that our climate will be similar to that of regions south of Hungary. This shifting will be 250-450 km in the next decades (2011-2040) and it could be 450-650 km in the middle of the century and maybe there will be no spatial analogues in Europe by the end of the century. Different methods were used to calculate the analogues, but they indicate the same regions. These analogue regions are North-Serbia, the region Vojvodina, South Romania and North Bulgaria in the next decades, and South Bulgaria and North Greece in the middle of the century. We developed the inverse analogy method, with the help of which we can search for regions which will have the same climate in future as there is in Debrecen at present. If we accept the results of spatial analogy, we can identify the analogue regions and compare their data.

Data were collected from the databases EUROSTATs and CORINE. We collected all the data on land use, crops and natural vegetation. These data show that land use may become more diverse, which is advantageous in adaptation to climate change. The ratio of forests and pastures may become higher. In the next decade's maize and wheat will be more important because climatic conditions will become better for them (because of the "corn belt").

The tendency of a potential global climate change is still not obvious, but the most accepted models predict warming and increase in extreme weather events. As the climate change has an overall impact on human health, natural systems and agricultural production and also has socio-economic impacts, it is very important to predict potential changes to have enough time for appropriate decision-making. Analogue scenarios involve the use of past warm climates as scenarios of future climate (temporal analogue scenario) and the use of the current climate in another (usually warmer) location as a scenario of future climate in the study area (spatial analogue scenario). Our aim was to find spatial analogues to describe the potential future climate of Hungary. However, we must note that climate depends also on other effects, especially on elevation, topography and storm track conditions, which cannot be considered in this kind of analysis.

### 5.1. Materials and methods of spatial climatic analogy

Climate scenarios can be defined as relevant and adequate pictures of how the climate may look like in the future. Our work is based on General Circulation Models (GCMs) downscaled to Debrecen, an important centre of agricultural production in Hungary and we used the method of geographical analogies to explain the results. We used different GCM scenarios (HadCM3 A1FI, B2), the IPCC CRU Global Climate dataset and the Hungarian meteorological database for 30 years (1961-1990). To find the analogues, monthly data were

used. Monthly temperature averages and precipitation sums were used for 4 different time periods, for the base period 1961-1990 and for the future periods 2010-2019, 2020-2029, 2030-2039 and 2040-2069. To calculate and find the analogue regions we used the SCA method, which was improved by us.

$$T_{dj} = \frac{1}{12} \cdot \sum_{i=1}^{12} |TEMP_{ji} - T_i| \quad (3)$$

$$P_{dj} = \frac{1}{12} \cdot \sum_{i=1}^{12} \frac{|PREC_{ji} - P_i|}{1 + a \cdot (PREC_{ji} + P_i)} \quad (4)$$

$$I_{Tj} = e^{-\lambda \cdot k_T \cdot T_{dj}} \quad (5)$$

$$I_{Pj} = e^{-(1-\lambda) \cdot k_P \cdot P_{dj}} \quad (6)$$

$$CMI_j = I_{Tj} \cdot I_{Pj} \quad (7)$$

Where:

- j: grid point identity number (j=1-31143)
- i: month (i=1-12)
- TEMP<sub>ji</sub>: monthly mean temperature of the grid point j for the base period
- T<sub>i</sub>: monthly mean temperature of the grid point j for the scenario
- PREC<sub>ji</sub>: monthly precipitation of the grid point j for the base period
- P<sub>i</sub>: monthly precipitation of the grid point j for the scenario
- T<sub>dj</sub>: average of temperature differences
- P<sub>dj</sub>: average of precipitation differences
- I<sub>Tj</sub>: similarity of the climate for the scenario in temperature
- I<sub>Pj</sub>: similarity of the climate for the scenario in precipitation
- CMI<sub>j</sub>: „Composite Match Index“, if CMI>90%, we can call the grid point the analogue for the scenario

## 5.2. Analogue regions

First we looked for the analogue regions for the base period. We found that we got back our regions after looking for the analogues in the future. We found that the analogue regions are south of Debrecen. This climate shifting was the same in case of different scenarios because in the first decades they do not differ very much but we can see more differences in the middle of the century. Finally, we defined the analogue regions for the scenarios and time periods. We found that the climatic shifting would be 250-450 km in the next decades and 450- 650 km by the middle of the century. Unfortunately we could not find any similar regions for the end of the century, but some analogues can be found in North Africa.

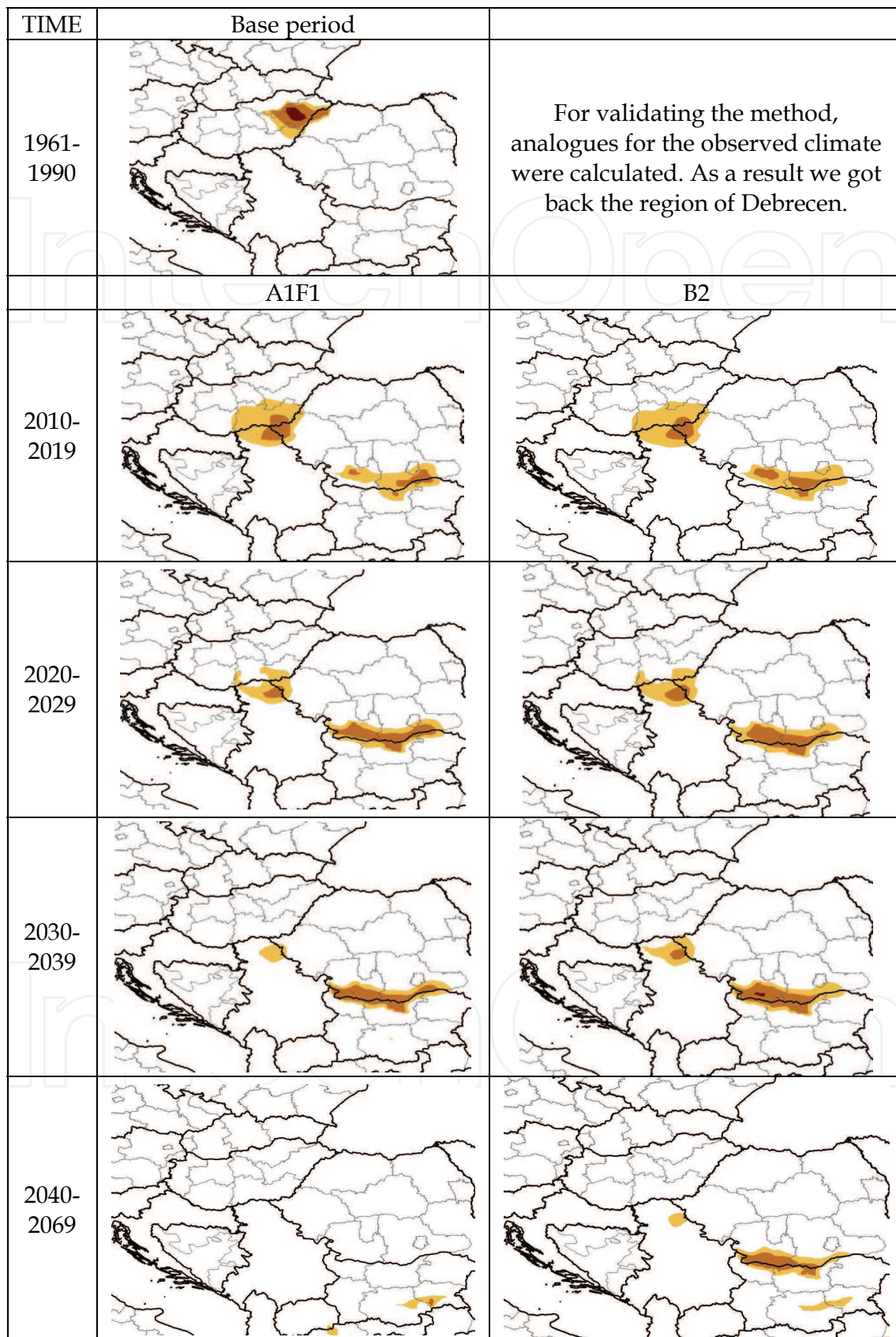


Fig. 8. Analogue regions in the next decades and in case of different climate scenarios for Debrecen

We developed a new method to find inverse analogue regions; these are the regions the climate of which will be similar to that of our study area in the future. We found a same shifting to the north. These analogue regions are in Poland (Fig. 9.) and were defined for the scenario A2.

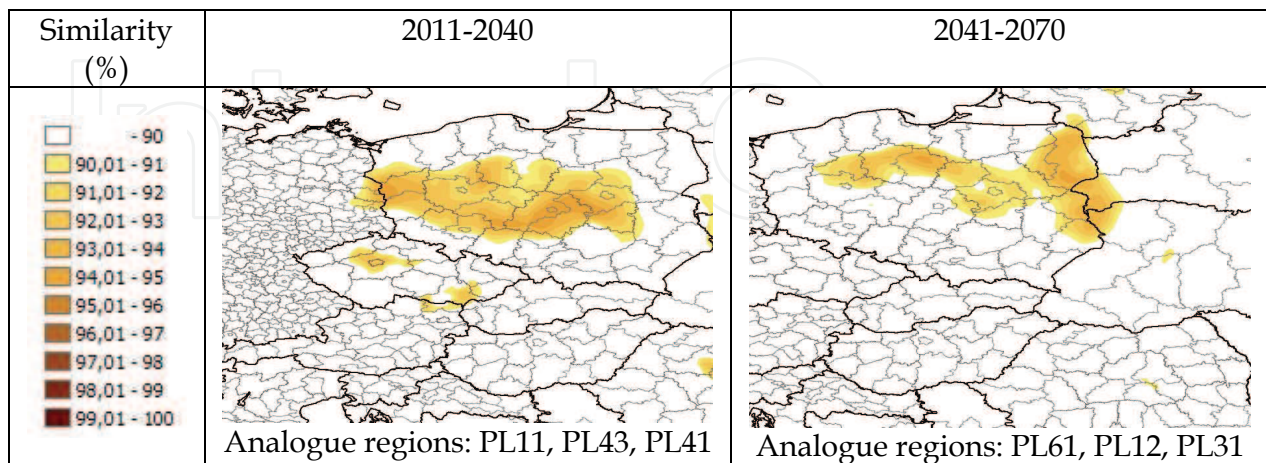
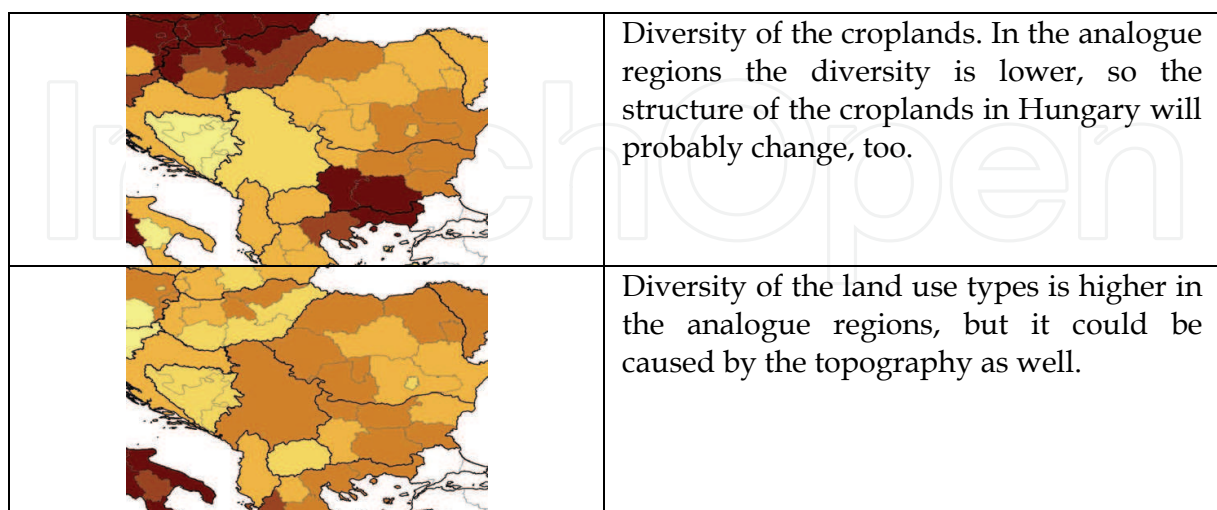


Fig. 9. Analogue regions in the next decades and in case of different climate scenarios for Debrecen

It can be seen that analogue regions are south-east of Debrecen about 250-450 km away but later this distance is larger. The analogue regions are Vojvodina in Serbia as well as the RO04 (Sud-Vest) and the RO03 (Sud) NUTS regions in Romania. For further analyses only these regions were taken into consideration (Fig. 10.). We calculated the diversity of croplands and the land use and we found opposite changes. While the diversity of croplands is lower than in Hungary, the diversity of land use is higher. It is mostly because of the main crops. The ratio of wheat and maize is higher in the South, just because the climatic conditions are better for them. Meanwhile the yield is lower; it is more economical to use these crops because the better conditions necessitate less agronomic techniques.



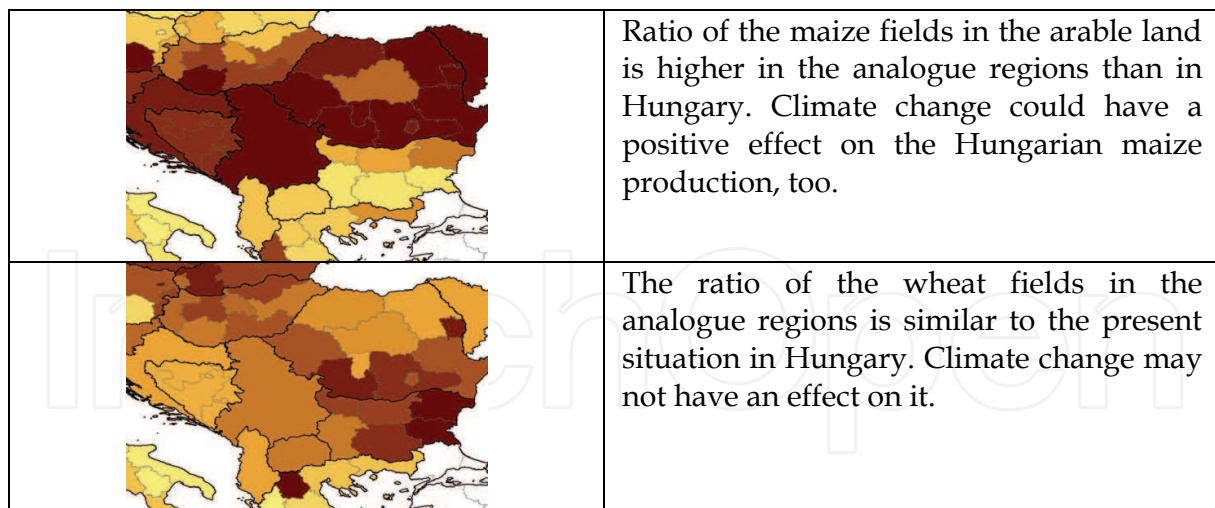


Fig. 10. Land use and cropland ratio of the analogue regions

### 5.3. Discussion

Debrecen, the basic object of our calculations, is an important centre of agricultural production in Hungary, so we would like to interpret the results in this aspect.

Climate, especially temperature and precipitation, basically determines agricultural production. Results show that in Hungary we have to count on an increase in temperature and decrease in precipitation. The possible future climate predicted by the scenarios will be similar to the present climate of South-Southeast Europe. Of course climate depends also on other effects, especially on elevation, topography and storm-track conditions, which could not be considered in this kind of analysis. However, the method of spatial analogies seems to be a good tool to understand and interpret the results of the GCM scenarios and the effects of climate change, so we want to go ahead in this research. This method and additional data on the analogue regions can provide information on the impacts of climate change on ecosystems or on agricultural production, such as the changes in land use, cropping system or yields and on the possibilities for disappearing or introducing new crops or weeds and pests into an area.

Increase in mean annual temperatures in our region, if limited to two or three degrees, can generally be expected to extend the growing season. In case of crops (or animals), where phenological phases depend on accumulated heat units, the phenophases can become shorter. Whether crops respond to higher temperatures with an increase or decrease in yield depends on whether their yield is currently strongly limited by insufficient warmth or the temperature is near or little above the optimum. In Central Europe, where temperatures are near the optimum under current climatic conditions, increases in temperature would probably lead to decreased yields in case of several crops. Increased temperature could be favourable for example for pepper and grapes; however, it is unfavourable for green peas and potato. Decrease in precipitation could be a great limiting factor in agriculture.

If we accept the results of the GCMs, according to the A1FI scenario for the period 2011-2040, the analogue regions of Debrecen will be the Vojvodina region in Serbia and South Romania. It means a shifting of about 250-450 km south, which corresponds to other international results.

The detailed analyses of the analogue regions can help us to adapt to the changing climate. From the analogue regions we should collect all kind of available ecological, agricultural,

economic, social and public sanitation data. We can study what kind of problems there are, and what the solutions are. We can learn from there how to solve the possible problems and develop strategies. This would be a good base for further research and an important base for decision makers.

With the method of spatial analogy we can build a new way of knowledge transfer from where we can learn adaptation techniques and to where we can transfer our knowledge.

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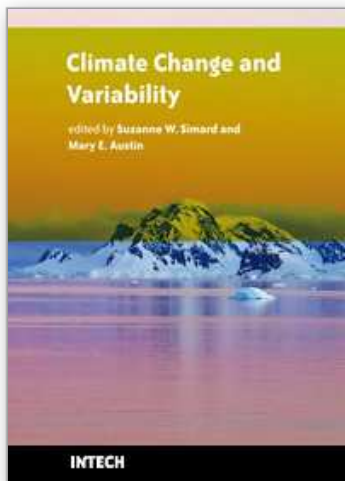
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Climate change is emerging as one of the most important issues of our time, with the potential to cause profound cascading effects on ecosystems and society. However, these effects are poorly understood and our projections for climate change trends and effects have thus far proven to be inaccurate. In this collection of 24 chapters, we present a cross-section of some of the most challenging issues related to oceans, lakes, forests, and agricultural systems under a changing climate. The authors present evidence for changes and variability in climatic and atmospheric conditions, investigate some of the impacts that climate change is having on the Earth's ecological and social systems, and provide novel ideas, advances and applications for mitigation and adaptation of our socio-ecological systems to climate change. Difficult questions are asked. What have been some of the impacts of climate change on our natural and managed ecosystems? How do we manage for resilient socio-ecological systems? How do we predict the future? What are relevant climatic change and management scenarios? How can we shape management regimes to increase our adaptive capacity to climate change? These themes are visited across broad spatial and temporal scales, touch on important and relevant ecological patterns and processes, and represent broad geographic regions, from the tropics, to temperate and boreal regions, to the Arctic.

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