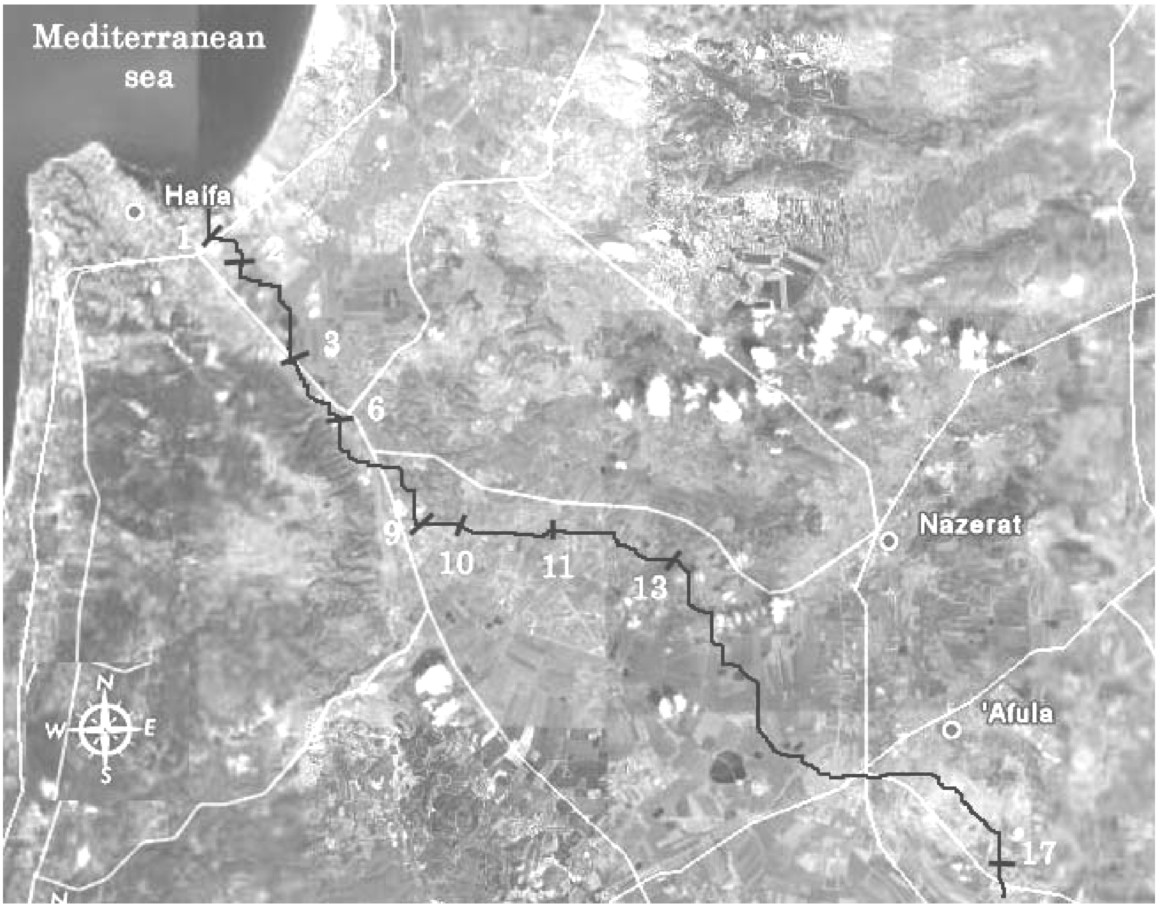
# Applied Ecology and Environmental Research

International Scientific Journal



VOLUME 6 * NUMBER 4 * 2008

http://www.ecology.uni-corvinus.hu
ISSN 1589 1623

# HEAT STRESS EFFECTS ON GROWTH AND DEVELOPMENT IN THREE ECOTYPES OF VARYING LATITUDE OF *ARABIDOPSIS*

E. KIPP

*Pace University Department of Biology and Health Sciences 1 Pace Plaza*
*NewYork, NY 10038*
*(phone: 212-346-1373; fax: 212-346-1256)*

*e-mail: ekipp@pace.edu*

(Received 22nd October 2006 ; accepted 23rd October 2007 )

**Abstract**. Global temperatures have increased 0.6 °C over the past century; however regional temperatures have shown greater fluctuations. Since local environmental conditions vary along latitudinal clines, latitude has become an essential component in projecting plant response to warming. Three ecotypes of *Arabidopsis* were selected from varying latitudes in order to investigate heat stress within an ecotype and project potential effects across a gradient. Control and heat stressed groups received 12 hour photoperiods. Control plants were grown at 2.7/22.7 °C day/night mean temperatures and heat stressed plants were grown at 22.7/29 °C day/night mean temperatures. Plants were quantified and harvested 35 days after sowing. The number of rosette leaves, flower buds, and fruits resulted in significant differences both between control and heat stressed plants of the same ecotype and also across ecotypes. Heat overwhelmingly resulted in a quantitative decrease across all parameters, including overall plant size, with the exception of flowers in ecotype 902. And even though the heat stressed 902 plants flowered while the control group plants did not, neither produced fruit. Thus, heat adversely affects growth and development as well as reproductive success in *Arabidopsis*.
**Keywords:** *Arabidopsis, global warming, heat stress*

## Introduction

Concern about temperature increases on a global level has sparked research in quantifying plant responses to heat stress. This has become of particular interest to a wide range of scientists and disciplines as evidence suggests that increased temperatures such as that associated with global warming will have widespread adverse effects on species diversity [7] [19] [30], food-web and ecosystem structuring [10] [5] [19], dominant vegetation [10] [25], plant physiology and development [18] [26] [17] [20] [9], climate [15] [30], and phenology [16] [30]. As a result, some governments have become more involved in setting up panels to review environmental trends, explore alternative energy options, and curb fossil fuel consumption.

Environmental and ecological changes due to temperature increases such as those associated with global warming have been well documented. Global warming is a two-part problem that is directly related to ozone depletion and greenhouse gas accumulation. It is characterized by rising atmospheric levels of greenhouse gases such as carbon dioxide coupled with an increase in average global temperatures. And while global temperatures have increased by 0.6 °C over the past 100 years [30] [24], the majority of this documented increase has taken place from 1976 to the present [30]. One must bear in mind, however, that reporting an average global temperature increase tends to oversimplify the extent of global warming, as more marked temperature changes are noted on a regional scale [10] [19] [25] [15] [30].

Many studies have imposed heat stress on plants in order to quantify the thermal stress response. Research clearly indicates a heightened sensitivity of plants to an


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

increase in carbon dioxide and temperature with respect to respiratory rate, propagule size, production, and viability, and biomass production [22] [1] [21]. Further studies have also shown altered photosynthetic rates linked to an increase in temperature [1] [14] [21].

It was determined that heat adversely affected pollen and anther development in *Lycopersicon esculentum* (Solanaceae), the tomato, which, in turn, contributed to a decreased fruit set [18[ [26]. Work with another crop plant, the common bean *Phaseolus vulgaris* (Fabaceae), showed that heat applied prior to anthesis resulted in pollen and anther development abnormalities [20]. Flax, *Linum usitatissimum,* (Linaceae), is another financially viable plant that is detrimentally affected by heat stress [6]. Heat was found to affect the reproductive capacity of *L. usitatissimum* when applied after floral initiation. The fruits (boll) weighed less than the fruits of control plants and were three times more likely to have malformed, sterile seed [6]. Since these are economically valuable plants, reduced crop yields may result from increasing temperatures.

Climate changes, linked to environmental warming, may significantly alter air and soil temperatures as well as soil water content [14]. Precipitation levels have been shown to have direct effects on species, as water stress is an important factor determining species distributions and diversity [15]. The distribution and diversity of terrestrial vegetation in particular, is most reliant on a combination of both temperature and water availability [11].

Overall, global climate change models predict a 2-6° C temperature increase over the next 100 years [11] [19] [30] [24]. Overwhelmingly, anthropogenic activity has been indicated to have impacted the natural balance of biotic and abiotic factors contributing to the world's ecosystems. Since plants are sessile organisms, they are, for the most part, unable to relocate in the face of inhospitable environmental conditions created in large part by anthropogenic activity. Because global warming is believed to cause a variety of heat-related stress responses in plants that may alter their ability to survive, the following research was conducted to help quantify plant responses to global warming.

## Materials and methods

### *Background on Arabidopsis thaliana*

Controlled laboratory experiments were conducted using *Arabidopsis thaliana*, a plant in the Brassicaceae or mustard family. *A. thaliana,* often referred to simply as *Arabidopsis*, is widely used in research for a great many reasons and has quickly become a model organism across plant biology and genetics. Since space, time, and money are all considerations when choosing a research subject, *A. thaliana* lends itself particularly well as it is easy and inexpensive to grow, grows well in small spaces, only reaches about 25 cm at maturity, and completes its life-cycle within 6-8 weeks.

*A. thaliana* is a small herbaceous rosette annual and one of about 3, 000 species of the Brassicaceae, a family of dicotyledonous plants. It inhabits a wide range of ecological and geographical regions and is commonly found throughout the Americas, Europe and Western Asia, northern Africa and East Asia. While it is most common in temperate North America, it is suspected to have originated in Eurasia. The ideal temperature range for *A. thaliana* is 16-25 °C while 22-23 °C is considered optimum.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

*A. thaliana* can grow in a photoperiod ranging from 8–24 hours, however, Weigel et al. (2002) suggest that > 12 hour photoperiods tend to accelerate the reproductive cycle and < 12 hours favors vegetative growth. Koornneef et al. (1998) further determined that flowering was promoted by long photoperiods and delayed during short photoperiods. Hence, as flowering time is accelerated under long photoperiods, the resulting tradeoff is a reduction in vegetative growth. Optimum humidity should be between 25-75%.

The *Arabidopsis* flower is complete, perfect, and self-compatible. The flower, typical of Brassicaceae, has four sepals and four petals. The androecium generally consists of six longitudinally dehiscent stamens, four upper and two lower, although some have been documented to contain only four or five stamen in total. The gynoecium is superior, the style is reduced and the base is formed of two fused carpels. The fruit type in *Arabidopsis*, as is typical of Brassicaceae, is the silique.

### *Origin of germplasm*

Seed stock of three ecotypes (ecotype Cvi-O stock number 902; ecotype Est-O stock number 1148; and ecotype Col-O stock number 6673:) representing different latitudes (N15, N58, and N38, respectively) were obtained from the *Arabidopsis* Biological Resource Center (ABRC). Since an ecotype is a population within a species that has developed distinct physiological characteristics in response to a specific set of environment conditions. These characteristics will persist even if individuals of the population are moved into a different environment.

ABRC was established in 1991 at The Ohio State University (http://www.biosci.ohio-state.edu/~plantbio/Facilities/abrc/abrchome.htm). ABRC seed stock was accessed via The *Arabidopsis* Information Resource (TAIR) web site (http://www.arabidopsis.org). Table 1 lists stock numbers and corresponding origin, latitude, elevation, habitat and other relevant information for all three ecotypes.

***Table 1.*** *Summary of information for the three ecotypes of* A. thaliana *used in this study. Compiled from The Arabidopsis Information Resource (TAIR). Localities and habitats of seed stock origin*

| Stock No. | Name | Abb. Name | Country/ Location | Latitude/ Longitude (min) | Altitude (m) | Habitat | Description |
|---|---|---|---|---|---|---|---|
| 902 | Cape Verdi Islands | Cvi-O | Cape Verdi | N 15, W 23 | 1200 | Rocky wall | Serrated lf margins, height =30cm |
| 6673 | Columbia | Col-O | USA/ Columbia | N 38, W 92 | 1-100 | - | (slightly) Serrated lf margins, height =25-35cm. |
| 1148 | Eastland | Est-O | Russia/ Eastland | N 58, E 23 | 100-200 | Sandy hill | Light green rosette, glabrous lvs, height =25-35cm. |


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

### *Germplasm selection process*

Local environmental conditions such as latitude and altitude can affect plant growth [13] [2] [28]. High altitude and latitude regions are expected to be especially sensitive to temperature increases [24]. Additionally, plants grown at higher altitudes or geographical latitudes have been documented to be more tolerant of UV-B radiation [8]. Therefore, the three ecotypes were selected to represent high, mid, and low range latitudes. In doing this, research findings presented here can help describe the patterns of variation in growth and overall plant size across a latitudinal cline.

### *Seed germination*

Petri dishes were fitted with Whatman brand filter paper cut to size and wetted with tap water ($H_2O_{[t]}$). Separated by ecotype, seeds (of the three ecotypes) were placed onto the wetted filter paper, covered with the Petri dish top, and placed into a 4°C refrigerator to initiate the process of cold germination. The stages of germination were observed using a dissecting microscope after 2, 3, and 4 days. At day = 4, the root-hypocotyl transition zone was obviously extended from the swollen seed coat and deemed ready for planting.

### *Sowing seed*

On day = 4, the three different ecotypes were planted in Park's Starts brand styrofoam blocks measuring 2 ½" x 3" x 6," obtained from Connecticut Valley Biological Supply Company. Each block contained 18 cells fitted with peat moss plugs. The peat moss was held together with a natural biodegradable binder and was both pasteurized and pre-moistened by the manufacturer. Two full blocks of 18 were planted for each ecotype. The initial sowing density was 3 seeds per cell. A Leica Zoom 2000 dissecting microscope and nickel-plated steel forceps were used in order to plant three seeds per preformed hole in each of the cells. Plants were thinned three days after sowing. Only one plant per cell was retained, for a total of n=36 seedlings for each of the three ecotype and a grand total of n=108 seedlings for the experiment.

### *Growing conditions*

Since ultraviolet radiation can increase leaf temperature 5 °C above ambient temperatures (Frohnmeyer, 2003), the experimentally heat stressed *Arabidopsis* plants received a temperature of 29 °C, representing an increase of about 5 °C above the upper limit of optimum growth temperature for *Arabidopsis*.

The experimental plants were placed on the growth cart on top of plastic grating which was in turn set atop ½ pound of pebbles, average diameter 13mm, into each of two 21" x 10" (internal measurement) plastic trays. The water ($H_2O_{[t]}$ ) level was kept at or just above the pebble line. Each styrofoam block of plants was fitted with plastic film similar to saran wrap which extended down the entire height of the blocks for the first 10 days. The cart itself was fitted with a plastic tarp in order to maintain a higher than ambient humidity.

Night treatments additionally received a 100% cotton breathable tarp, detailed below, in order to create complete darkness and compensate for any drop in temperature on the cart overnight. Experimental humidity was maintained at an average of 55.24% on the


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

growth cart both day and night; the mean temperature was 22.7 °C, both day and night for 35 days, the duration of the experiment.

Indoor Garden, 52” X 23” X 74”, purchased from Fisher Scientific. The plants received an initial day light length of 24 hours for three days, prior to thinning, to ensure the seeds were established before subjecting ½ to heat stress. GrowLab II light was provided by two 40 Watt Gro-Lux wide-spectrum Osram Sylvania Inc. bulbs placed 20 inches away from the top of the styrofoam blocks. Initial lumen for the bulbs was 1,700 lumens.

After this initial three day period of 24 h day, the day length was held at 12 hours (12 h day) and night length 12 hours (12 h night) for 35 days, the duration of the experiment in order to minimize favoring elevated photoperiods in one direction.

One block of cells for each ecotype (for a total of 3 blocks in each of 2 sets) received daily heat stress treatments of 29 °C for the 12-hour periods. During this same 12 hour period, the control set (no heat treatment) remained on the plant growth cart with the Gro-Lux lights turned off and a 14-15oz, 100% breathable cotton canvas tarp, 7’ x 9’ placed over the cart to create darkness. Heat stressed plants were placed into a low temperature Fisher Scientific Isotemp brand incubator, model 146E, set to 29 °C with a manufacturer’s temperature guarantee constancy of +/- 0.2 °C and a uniformity temperature reading of +/- 1 °C.

For the duration of the experiment, temperature was maintained at a mean of 22.7 °C on the growth cart, 29 °C in the growth chamber, and a mean humidity of 55.24% on both the cart and in the chamber. Therefore, the control set received 22.7/22.7 °C mean day/night temperature with a 12 hour photoperiod, while the heat stressed set received 22.7/29 °C mean day/night temperature with a 12 hour photoperiod. During the 12 h d, both control and heat stress sets were grown next to each other. In order to prevent a loss of genetic integrety, cross-pollination was avoided by covering flower buds with pollination bags.

### *Parameters observed*

Both heat stressed and control plants for each ecotype were assessed 35 days from sowing the seeds. Observations taken were: (1) number of rosette leaves, (2) length of main bolt, (3) length of additional bolts, (4) number of flower buds (5) number of flowers, and (6) number of fruits(Figures 1-6). At the end of the experiment, at day = 35, all plants were uprooted and measured from shoot tip to root tip. Additionally, the mean plant length was calculated for each treatment within each ecotype (Figure 7).

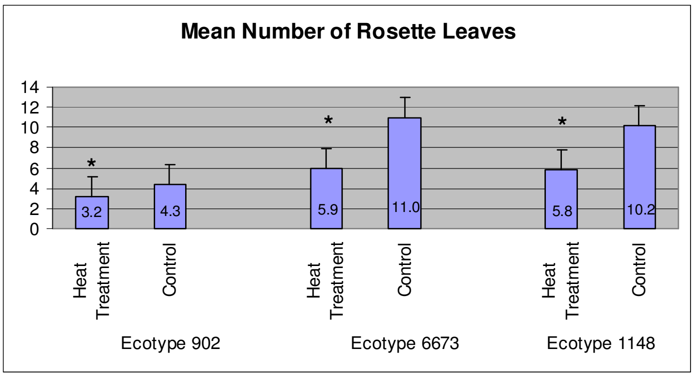



***Figure 1.*** *Mean number (+/- SD) of rosette leaves plotted for heat treated and control plants for each of the three ecotypes.*


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

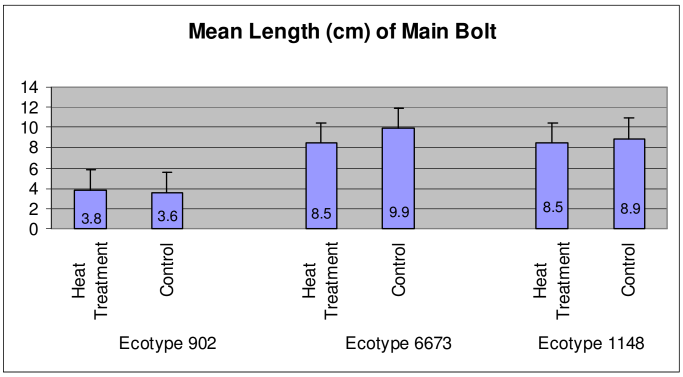



***Figure 2.*** *Mean length (+/- SD) of main bolt plotted for heat treated and control plants for each of the three ecotypes.*

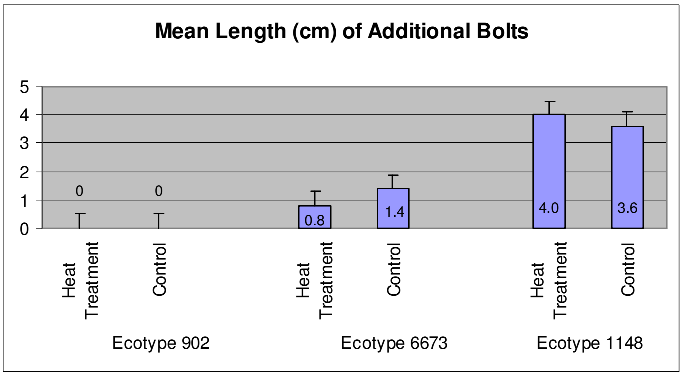



***Figure 3.*** *Mean length (+/- SD  of additional bolts plotted for heat treated and control plants for each of the three ecotypes.*

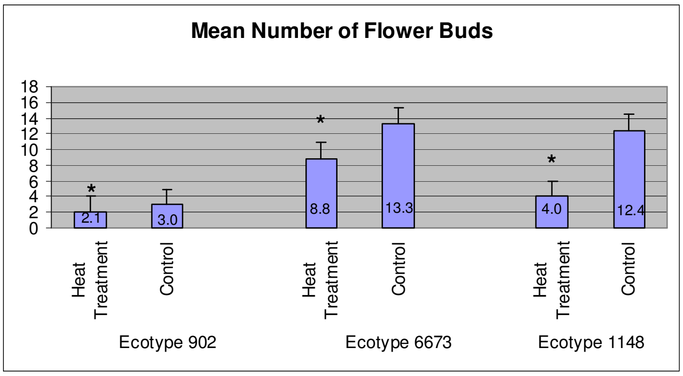



***Figure 4.*** *Mean number (+/- SD) of flower buds plotted for heat treated and control plants for each of the three ecotypes.*


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

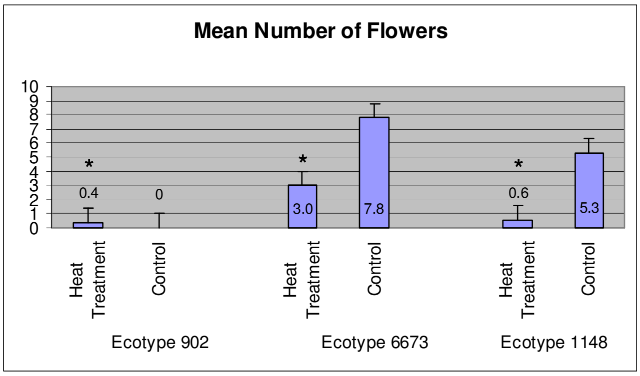



***Figure 5.*** *Mean number (+/- SD) of flowers plotted for heat treated and control plants for each of the three ecotypes.*

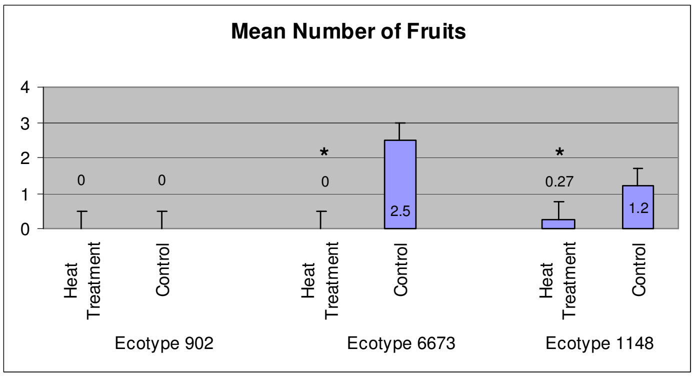



***Figure 6.*** *Mean number (+/- SD) of fruits plotted for heat treated and control plants for each of the three ecotypes.*

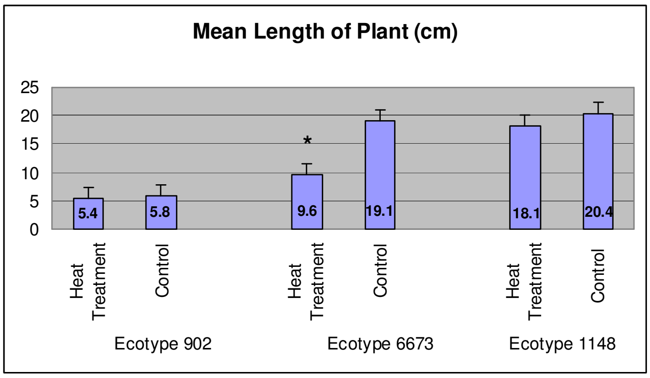



***Figure 7.*** *Mean length (+/- SD) of plant for heat treated and control plants for each of the three ecotypes.*

## *Statistical analysis*

One-way ANOVAs were performed for each of the six parameters (number of rosette leaves, length of main bolt, length of additional bolts, number of flower buds, number of flowers and number of fruit) in order to determine whether overall plant growth and reproductive development varied significantly between heat stressed and control plants for each of the three ecotypes.

If the ANOVA resulted in a significant P-value, Post Hoc testing was conducted in order to determine which ecotype showed significant difference between heat stressed and control plants.

The percent change between heat and control plants within each of the three ecotypes was additionally calculated for each parameter (Table 2).

Li et al. (1998) collected data from the growth of 40 Arabidopsis ecotypes from a wide range of altitudes and latitudes. They determined, by performing multiple regressions involving both latitude and altitude for the 40 test subjects, that altitudinal differences between ecotype sites were insignificant. Since I do not have a robust data set for altitude (n=3, one altitude associated with each of the three ecotypes), I cannot determine significance via regression analysis. I will therefore not discus altitude as a factor which may affect growth parameters, and will take only latitudinal differences into consideration when projecting heat stress across a (latitudinal) cline.

***Table 2.*** *Summary of statistical analysis for each parameter*

| **Rosette Leaves** | | |
|---|---|---|
| Ecotype | % change | *P-value* |
| 902 | -24% | <.05 |
| 6673 | -47% | <.001 |
| 1148 | -43% | <.001 |
| | | |
| **Main Bolt** | | |
| Ecotype | % change | *P-value* |
| 902 | +.06% | No significant difference |
| 6673 | -.14% | No significant difference |
| 1148 | -.04% | No significant difference |
| | | |
| **Additional Bolts** | % change | P-value |
| 902 | 0% | No significant difference |
| 6673 | -.40% | No significant difference |
| 1148 | +.08% | No significant difference |
| | | |
| **Flower Buds** | % change | *P-value* |
| 902 | -30% | <.05 |
| 6673 | -34% | <.01 |
| 1148 | -68% | <.001 |
| | | |
| **Flowers** | % change | *P-value* |
| 902 | See below[1] | <.001 |
| 6673 | -62% | <.001 |
| 1148 | -87% | <.001 |
| | | |
| **Fruit** | % change | *P-value* |
| 902 | 0% | No significant difference |
| 6673 | -100% | <.001 |
| 1148 | -77% | =.05 |

[1]Heat stressed showed a mean of 8 while the control produced 0 flowers.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

## *Results and discussion*

This study examined the ecotypic variation in plant growth and development with respect to the number of rosette leaves, the length of the main bolt, the number of additional bolts, the number of flower buds, the number of flowers, and the number of fruits produced at the end of a 35-day growth cycle.

Data clearly indicate a significant difference between heat and control groups within each of the three ecotypes with respect to the number of rosette leaves, the number of flower buds, the number of flowers, and the number of fruits produced.

All three ecotypes showed no significant difference between heat stressed and control plants with respect to the length of the main bolt and the number of additional bolts produced. This stands to reason as niether the bolts are neither reproductive nor a major photosynthetic site.

### *Ecotype 902*

Ecotype 902 is the most southern of the three ecotypes with a latitude and longitude of N 15, W 23 (Table 1). Ecotype 902 is native to the Cape Verde Islands, an archipelago in the North Atlantic Ocean just off the coast of western Africa. August to October is the only time frame routinely receiving rainfall; otherwise the Cape Verde Islands are relatively dry. Temperature ranges from 22 °C in February up to 27 °C in September.

Consistently, ecotype 902 had the smallest percent change between heat stressed and control plants among all six parameters tested, compared to heat and control plants of 1148 and 6673 (Table 2). However, there were still significant findings with respect to the number of rosette leaves ($P=< .05$), the number of flower buds ($P=<.05$), and the number of flowers produced ($P=< .001$). In spite of this statistical significance, while both heat and control 902 plants produced flower buds, the control 902 plants produced neither flowers nor fruits. Although the heat stressed 902 plants had modest flower production, they never developed into fruits. As a result, neither control nor heat stressed 902 plants produced seeds. Therefore, since heat was applied to only one set of 902 plants, heat was apparently not the only factor affecting the reproductive success of this ecotype.

### *Ecotype 6673*

Ecotype 6673 is the median latitude representative with a latitude and longitude of N 38, W 92 (Table 1). This corresponds to Columbia, Missouri, a Midwestern city with temperature ranging from -1.3 °C in January to 25.4 °C in July and the heaviest rainfall occurring from May to August.

Control plants of ecotype 6673 overwhelmingly grew better than heat stressed plants with respect to the number of rosette leaves ($P=<.001$), the number of flower buds ($P=< .01$), the number of flowers ($P=< .001$) and the number of fruits produced ($P=<.001$). Heat stressed 6673 plants produced no fruits, demonstrating that elevated heat adversely affected reproduction in this ecotype. Control 6673 plants performed better than heat stressed plants for all six parameters, however only four of the six were deemed statistically significant. Moreover, control 6673 plants produced 34% more flower buds, 62% more flowers, and 100% more fruits than the heat treated 6673 plants (Table 2).

### *Ecotype 1148*

Ecotype 1148 is the Northernmost of the three ecotypes, with a latitude and longitude of N 58, E 23 (Table 1). Located within the former Union of Soviet Socialist Republics, this area receives its heaviest rainfall from June to September and ranges in temperature from -6.1 °C in February to 17.3 °C in July.

Control plants did significantly better than heat stressed plants with respect to the number of rosette leaves (P=< .001), the number of flower buds (P=<.001), the number of flowers (P=< .001), and the number of fruits (P=.05). With respect to reproductive ecology, control 1148 plants produced 68% more flower buds, 87% more flowers, and 77% more fruits than heat stressed 1148 plants (Table 2).

All climate information was obtained from a combination of the following two web sites: http://www.britannica.com and http://www.worldclimate.com/.

### *Effects of latitude*

It stands to reason that since ecotype 902 is the least Northern latitude with respect to the other two ecotypes that it was the least effected by heat when comparisons were made between heat stressed and control plants. However, since ecotype 902 had growth far less than published growth means for this ecotype, conditions other than heat have apparently negatively impacted its growth and development.

Since ecotype 902 is from a region that receives little rainfall and all plants were watered equally throughout this experiment, it is possible that ecotype 902 received too much water. Additionally, arid regions are typically associated with low humidity levels. The optimum scope of humidity for Arabidopsis growth is reported to range from 25% - 75% which is why I chose to maintain humidity at 55%, however ecotype 902 may do better in an environment with 25% humidity.

As the Northernmost ecotype of the three, ecotype 1148 was understandably the most affected by heat. The highest percent change regarding flower buds and flower production was in fact found in control 1148 plants, with heat stressed plants doing 68% and 87% poorer than control plants. Since reproductive success is a mark of fitness, control 6673, the mid-latitude representative ecotype, did the best with the highest number of fruits produced of any ecotype for both heat stressed and control.

### *Overall plant size*

According to TAIR, ecotype 902 averages 30cm, ecotype 6673 averages 25-35cm, and ecotype 1148 averages 25-35cm (Table 1). Experimental mean plant sizes were all less than the aforementioned database plant lengths (Figure 7). Ecotype 6673 was the only ecotype to show a significant overall growth difference between heat stressed and control plants (P=<. 001). Ecotype 902 showed the most reduced overall plant growth for both heat stressed and control plants with an 82% decrease in growth from the database mean for this plant. Taken as a whole, control plants faired better than heat stressed plants for all three ecotypes with, ecotype 6673 on average growing 50% more than heat treated 6673.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

### *Future studies*

Since the seed is an integral stage in the development of higher plants, it would be valuable to determine the number of viable propagules produced within each fruit in order to make a comparison between heat stressed and control plants as this information could be directly related to the survival of the species.

Pollination biology is another aspect of Arabidopsis development that could provide information as to how higher plants may be affected by augmenting global temperatures. Arabidopsis has a striking and delicate stigma morphology which would facilitate a visual comparison of any structural distortions between heat stressed and control plants. Potential alterations in stigma cytochemsitry due to elevated temperature are another area of prime importance in successful pollination and germination of compatible pollen tubes leading to fertilization.

Estimation of pollen viability has been published for a great many species including several economically valuable food plants. There exists a gap in the literature, however, with respect to differences in pollen viability between heat stressed and optimally grown plants.

Koornneef et al. (1983) identified the four recessive homeotic mutations that disrupt the development of flowers in Arabidopsis. These four mutations: agamous, apetala2, apetala3, and pistillata are further described by Bowman et al. (1989). Since homeotic genes can take the place of another member in a repetitive series, for example, transform sepals into petals, it would be interesting to see how these genes directing flower development are affected by temperatures in excess of optimum.

Finally, the molecular genetics controlling the time of flowering can give insight into the phenotypic variation in natural populations such that agriculturally valuable plant species and the floriculture industry can adapt, if necessary, to a warming climate. Flowering time can give insight into the ecology of plant reproduction. Stinchcombe et al. (2004) found a significant latitudinal cline with respect to flowering time among 70 experimentally grown ecotypes of A. thaliana. Caicedo et al. (2004) showed that epistatic gene interaction between FRIGIDA (FRI) and FLOWERING LOCUS C (FLC), the two genes responsible for flowering time in Arabidopsis, interact in such a way that they both contribute to a latitudinal cline in flowering time. Since flowering time in Arabidopsis has been correlated with fecundity, this will prove a valuable life history trait within Arabidopsis.

## Conclusions

The results clearly indicate a significant difference between heat stressed and control plants for rosette leaf production, flower buds, flowers, and fruits with heat treatment resulting in a reduction of the aforementioned parameters observed.

A decrease in leaf biomass was noted across all heat treated plants. Decreased leaf biomass may lead to a reduced surface area for reactions, such as photosynthesis and transpiration. In turn, this reduction may lead to an overall decrease in plant size. In fact, all three sets of heat treated plants not only had less leaf production, but also had reduced overall growth compared to control plants.

It is often noted that plants typical of low latitudes require less exposure to cold temperatures before flowering. This overall reduction in vernalization may become more apparent in plants of varying latitudes, as global temperatures increase.

An increase in growth is often associated with a reduction in reproduction. This tradeoff was not noted in heat treated plants as they were reduced in size and produced little or no fruits demonstrating that both growth and reproduction were negatively affected. While temperature and humidity, water, soil composition, and light were all regulated throughout the experiment, heat may not be the only variable affecting the outcome of this experiment. Nonetheless, data indicates that heat it is a significant factor in the reduction of growth and development in Arabidopsis thaliana.

In summation, as global temperature increases, plants and animals will more significantly exhibit an increased sensitivity on an ecosystem level; however the research findings referred to throughout clearly indicate that cumulative microclimate and species alterations will have far reaching effects. And while all interactions at the population level and up may be impossible to definitively project as a result of heat stress effects, much literature suggests raising temperatures 3-5 °C significantly alters species distributions and abundances [7] [19] [30], and most likely will cause wide-spread changes in food-web and ecosystem structuring [10] [5] [19]. Shifts in dominant vegetation due to global temperature increases [10] [25] may lead to a shift in both inter- and intraspecies competition, for example.

Changes in plant physiology and development [18] [26] [17] [20] [9], all ways of dealing with temperature increase, greenhouse gas increases, ozone depletion, higher incidence of UV exposure, and loss of soil moisture, may not be an option for many species as not all plants have the genetic ability to respond via changes in physiology. As a result, their abundance will be reduced as they are out-competed by those able to acclimate. Those plants without the ability to respond genetically will experience reduced fitness as they trade-off reproduction in order to counter long-term consequences of heating.

The research presented here provides a basic framework for describing variation in plant growth and development as a direct result of heat stress. It additionally serves to project these findings across a latitudinal gradient to determine if plants growing at varying latitudes are differentially affected by temperature increases as well as to apply the findings to agronomic practices. Plant growth and development, global temperatures, alterations to the physical and chemical characteristics of the landscape, and range shifts can all impact the forestry business and the agricultural industry in terms of crop plants and productivity.

**Acknowledgements.** I'd like to thank Dr. Michael Zimmerman for valuable advice, comments, and discussions; Dr. Richard Schlesinger for his help with the statistical analysis and interpretation of statistical data; Dr. Lisa Dorn for her guidance and helpful suggestions working with *Arabidopsis*; and Pace University, Dyson College of Arts and Sciences, Department of Biology and Health Sciences for providing the research site.

## REFERENCES

[1] Betts R.A. (1997): Contrasting Physiological and structural vegetation feedbacks in climate change simulations. – Nature 387: 796-799.

[2] Bisseling T., Weigel D. (2001): Plant development: From cell fate to organ formation. – Plant Cell 13: 221-227.

[3] Bowman J.L., Smyth D.R., Meyerowitz E.M. (1989): Genes directing flower development in *Arabidopsis*. – The Plant Cell 1: 37-52.

[4] Caicedo A.L., Stinchcombe J.R., Olsen K.M., Schmitt J., Purugganan M.D. (2004): Epistatic interaction between *Arabidopsis FRI* and *FLC* flowering time genes generates a latitudinal cline in a life history trait. – P. Natl. Acad. Sci. USA 101: 15670-15675.

[5] Cao M., Woodward F.I. (1998): Dynamic responses of terrestrial ecosystem carbon cycling to global climate change. –Nature 393: 249-252.

[6] Cross R.H., McKay S.A.B., McHughen A.G., Bonham-Smith P.C. (2003): Heat-stress effects on reproduction and seed set in *Linum usitatissium* L. (flax). – Plant Cell Environ. 26: 1013-1020.

[7] Davis A.J., Jenkinson L.S., Lawton J.H., Shorrocks B., Wood S. (1998): Making mistakes when predicting shifts in species range in response to global warming. – Nature 391: 783-786.

[8] Frohnmeyer H., Staiger D. (2003): Ultraviolet-B radiation-mediated responses in plants. Balancing damage and protection. – Plant Physiol. 133: 1420-1428.

[9] Gray J.E., Holroyd G.H., Van Der Lee F.M., Bahrami A.R., Sijmons P.C., Woodward F.I., Schuch W., Hetherington A.M. (2000): The *HIC* signaling pathway links $CO_2$ perception to stomatal development. – Nature 408: 713-716.

[10] Harte J., Shaw R. (1995): Shifting dominance within a montane vegetation community: Results of a climate-warming experiment. – Science 267: 876-880.

[11] Intergovernmental Panel on Climate Change (IPCC) (2001): Climate change 2001: the scientific basis. Contribution of working group I to the second assessment report of the IPCC. – Cambridge University Press, New York.

[12] Koornneef M., Alonso-Blanco C., Peeters A.J., Soppe W. (1998): Genetic control of flowering time in *Arabidopsis*. – Annu. Rev. Plant Physiol. Plant Mol. Biol. 49: 345-370.

[13] Li B., Suzuki J., Hara T. (1998): Latitudinal variation in plant size and relative growth rate in *Arabidopsis thaliana*. Oecologia 115: 293-301.

[14] Loik M.E., Redar S.P., Harte J. (2000): Photosynthetic responses to a climate-warming manipulation for contrasting meadow species in the Rocky Mountains, Colorado, USA. – Funct. Ecol. 14: 166-175.

[15] McCarty J.P. (2001): Ecological consequences of recent climate change. – Conserv. Biol. 15: 320-331.

[16] Menzel A., Fabian P. (1999): Growing season extended in Europe. – Nature 397:659.

[17] Morgan J.A,. Lecain D.R., Mosier A.R., Milchunas D.G. (2001): Elevated $CO_2$ enhances water relations and productivity and affects gas exchange in $C_3$ and $C_4$ grasses of the Colorado shortgrass steppe. – Glob. Change Biol. 7: 451-466.

[18] Peet M.M., Sato S., Gardner R.G. (1998): Comparing heat stress effects on male-fertile and male sterile tomatoes. – Plant Cell Environ. 21: 225-231.

[19] Petchey O.L., McPhearson T.P., Casey T.M., Morin P.J. (1999): Environmental warming alters food-web structure and ecosystem function. – Nature 402: 69-72.

[20] Porch T.G., Jahn M. (2001): Effects of high-temperature stress on microsporogenesis in heat-sensitive and heat-tolerant genotypes of *Phaseolus vulgaris*. – Plant Cell Environ. 24: 723-731.

[21] Prasad P.V.V., Boote K.J., Allen J.R. L.H., Thomas J.M.G. (2002): Effects of elevated temperature and carbon dioxide on seed-set and yield of kidney bean (*Phaseolus vulgaris* L.) – Glob. Change Biol. 8: 710-721.

[22] Reekie E.G., Reekie J.Y.C. (1991): The effect of reproduction on canopy structure, allocation and growth in *Oenothera biennis.* – J. Ecol. 79: 1061-1071.

[23] Roeder A.H.K., Yanofsky M.F. (2005): Fruit development in *Arabidopsis*. In: American Society of Plant Biologists. The *Arabidopsis* Book. – Rockville (MD) p 1-50.

[24] Saavedra F., Inouye D.W., Price M.V., Harte J. (2003): Changes in flowering and abundance of *Delphinium nuttallianum* (Ranunculaceae) in response to a subalpine climate warming experiment. – Glob. Change Biol. 9: 885-894.

[25] Sanford E. (1999): Regulation of keystone predation by small changes in ocean temperature. – Science 283: 2095-2097.

[26] Sato S., Peet M.M., Thomas J.F. (2000): Physiological factors limit fruit set of tomato (*Lycopersicon esculentum* Mill.) under chronic, mild heat stress. – Plant Cell Environ. 23: 719-726.

[27] Schimel D.S., House J.I., Hibbard K.A., Bousquet P., Ciais P., Peylin P., Braswell B.H., Apps M.J., Baker D., Bondeau A., Canadell J., Churkina G., Cramer W., Denning A.S., Field C.B., Friedlingstein P., Goodale C., Heimann M., Houghton R.A., Melillo J.M., Moore B., Murdiyarso D., Noble I., Pacala S.W., Prentice I.C., Raupach M.R., Rayner P.J., Scholes R..J, Steffen W..L, Wirth C. (2001): Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. – Nature 414: 169-172.

[28] Stinchocome J.R., Weinig C., Ungerer M., Olsen K.M., Mays C., Halldorsdottir S.S., Purugganan M.D., Schmitt J. (2004): A latitudinal cline in flowering time in *Arabidopsis thaliana* modulated by the flowering time gene *FRIGIDA*. – P. Natl. Acad. Sci. USA 101: 4712-4717.

[29] Torabinejad J., Caldwell M.M. (2000): Inheritance of UV-B tolerance in seven ecotypes of *Arabidopsis thaliana* L. Heynh. And their F1 hybrids. – Am. Genet. Assoc. 91: 228-233.

[30] Walther G.R., Post E., Convey P., Menzel A., Parmesan C. Beebee T.J.C., Fromentin J.M., Hoegh-Guldberg O., Bairlein F. (2002): Ecological responses to recent climate change. – Nature 416: 389-395.

# RENEWABLE ENERGY RESOURCES FOR CLIMATE CHANGE MITIGATION

S.P. RAGHUVANSHI* – A.K. RAGHAV – A. CHANDRA

*Indian Institute of Technology Delhi, Hauz Khas, New Delhi, India.*
*(phone : +91-11-26591227)*

**Corresponding author*
*e-mail: spriitd@gmail.com*

(Received 13rd November 2006 ; accepted 4th July 2007)

**Abstract.** Climate change has been identified as one of the greatest challenge by all the nations, government, business and citizens of the globe. The threats of climate change on our green planet 'Earth' demands that renewable energy share in the total energy generation and consumption should be substantially increased as a matter of urgency. India's energy development programme has been put under severe pressure with the ever-increasing demand supply gap. Due to predominance of fossil fuels in the generation mix, there are large negative environmental externalities caused by electricity generation. So it has become imperative to develop and promote alternative energy sources that can lead to sustainability of energy and environment system. Renewable electricity has become synonymous with CO2 reduction. Present communication provides a brief description about such alternative and sustained energy sources, i.e., renewable energy resources, their potential and achievements in India. Also role as important tool for climate change mitigation.

**Keywords:** *Renewable energy, GHGs, Climate change, Carbon dioxide, mitigation*

## Introduction

Climate change has implications for both human and natural systems and could lead to significant changes in resource use production and economic activity. In response to the impact and possible affects of climate change international, regional, national and local initiatives are being developed and implemented to limit and mitigate GHGs concentration in the Earth's atmosphere. The global concern for sustainable development and climate change has brought concentration of energy policy makers towards the renewable energy sources since these provide energy, without emissions of greenhouse gases (GHGs) and are also abundant resource available for future. Climate change affects populations by changing basic life conditions, for example, food availability, and by causing habitat loss and fragmentation [1, 2, 3, 4].

Renewable energy refers to energy resources that occur naturally and repeatedly in environment and can be harnessed for human benefit. Examples of renewable energy systems include solar, wind, hydro and geothermal energy (getting energy from the heat in Earth). Biomass, rivers, and even garbage (waste generated) are also source to renewable energy.

Climate change occurred as a consequence of anthropogenic activities like combustion of fossil fuels, industrial processes, deforestation and GHGs release into atmosphere. Power sector alone contributes to the scale of 40% to the total carbon emissions [5]. In a study covering the period 1901-87 for India have shown that the countrywide mean maximum temperature has risen by 0.6°C, and the mean minimum temperature has decreased by 0.1°C [6]. Last ten years (1995-2004), with exception of

1996 are among the warmest 10 years on record with 2004 as the 4th warmest year since accurate records commenced in 1861 [7].

A wide range of climatic change impacts are observed, for instances, greater frequency and intensity of tsunamis, droughts, wildfires, floods, storms; also snowstorms, tornados, spread of infectious pests, pathogens and heat waves which, could cause greater human illness and premature mortality. Also, it is intimately connected to the alarming rate of extinction of species and biodiversity loss that could become the sixth largest extinction spasm in planetary history. Clean air policy, including the promotion of renewable energy and energy efficiency, can substantially reduce these negative impacts.

Renewable energy technologies meet the two basic conditions, to be eligible for assistance under UNFCCC mechanism; firstly, they contribute to global sustainability through GHGs mitigation; and secondly, they confirm to national priorities by leading to the development of local capacities and infrastructure. In addition, the steadily growing awareness of the importance of environmental protection is an important aspect of renewable energy.

## Energy scenario in India

The share of fossil fuel in the current primary fuel-mix of the country is dominant as coal, oil and gas together account for around 65 per cent. Share of renewables, including large hydro, nuclear and others is 34 percent. During the previous decade (1991-2001), total primary energy has grown at an annual average rate of 3.6 per cent whereas primary commercial energy growth has been higher at an annual average rate of 5 per cent. Non-commercial energy, however, grew at a lower rate of 1.3 per cent per annum during the decade. The growth rate of electricity generation was 5.5 per cent per annum.

Power generating capacity of India is expected to increase from 106GW to 212GW from 1996 to 2010. Indian power sector is prominently based on fossil fuels, with about 3/5th of the country's power generation capacity being dependent on vast indigenous reserves of coal. Natural Gas based generation capacity has grown very rapidly in the last decade due to lower capital requirements, shorter construction periods, and higher efficiencies and has a twelfth share in overall capacity. Nuclear capacity remains almost restricted at about 3 percent of the total [8]. Hydro power continues to grow very slowly due to various socio-environmental barriers and has almost a quarter shares in the total generation capacity at present. In the national energy scene, renewable technology capacity (renewables in this communication refer to small hydro, wind, cogeneration and biomass-based power generation, and solar technologies and exclude large hydropower), aggregating 4000 MW as of March 2006 [9]. This is a minuscule 3 percent of the present estimated potential of renewables in the country with over total capacity of over 126,838 MW. This percentage has grown to double since last year when it was just 1.5%of the total installed capacity. Fig 1 shows the installed capacity of India with their percentage contribution in present generation.

Current growth rate of renewable contribution will continue at a slower pace and energy from renewables is not expected to increase its share in the fuel-mix in any significant manner at least upto 2051-52 as under the likely and optimistic scenarios its share is expected to increase to 39.23 and 53.13 percent respectively. [10]

The current per-capita energy use in the country is around one-third the global average and one-ninth that of OECD countries. The energy intensity of the national


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

growth process is 0.20 MMTOE/US$ PPP1billion whereas the global average is 0.24 MMTOE/US$ PPP 1 billion, thereby demonstrating that the Indian economy consumes a somewhat lesser amount of energy per unit of output than the global average.

A marked disparity between the energy consumption pattern in urban and rural segments also forces a shift of energy scenario towards renewable energy systems. Villages and areas situated in remote and far flung areas can be depended on only self generating source like renewables.

Renewable technologies are now matured and well understood technologies, thus it is now possible to connect them to grid and also they offer possibilities of distributed generation at or near actual load centre, thereby saving on costly establishment and maintenance of transmission and distribution networks.

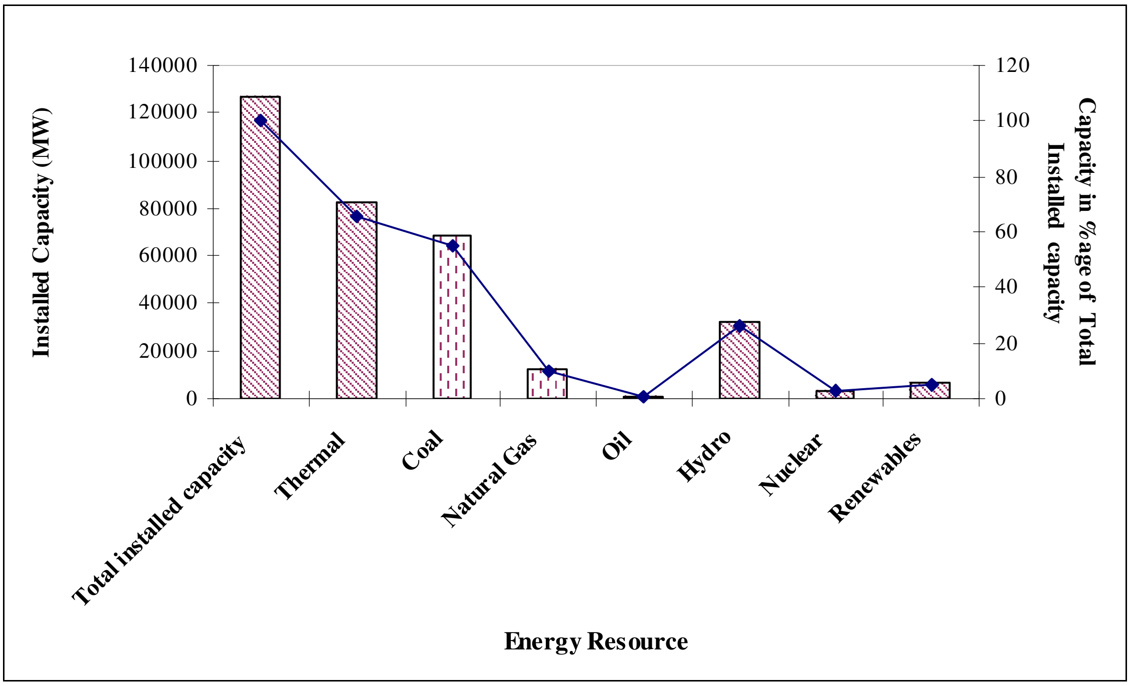



***Figure 1.*** *Total installed capacity distribution India (126838.97 MW)*

## Indian renewable energy programme (IREP)

India has the largest decentralized solar energy programme, the second largest biogas and improved stove programme, and the fifth largest wind power programme in the world. The energy policy also focuses on development of decentralised energy systems based on renewable sources especially for use in rural areas. Key drivers for renewable energy in the country are large untapped potential IREP is the largest and the most extensive among developing countries of the world. Today,; Demand-supply gap; Concern for environment; Need to strengthen India’s energy security; Pressure on high-emission sectors from their shareholders and Solution for rural electrification.

Indian renewable energy program was primarily launched as a response to the perceived rural energy crisis in the 1970s [11]. Initiated with a target oriented supply push approach, it primarily sought to develop niche applications, such as in rural areas where grid electricity was unavailable. Cash subsidies were and are still being provided for promoting renewable energy technologies (RETs) in India. CASE (Commission on

Additional Sources of Energy) was created in 1980, and then the DNES (Department of Non-conventional Energy Sources) was set up in September, 1982 [12]. In the initial stages of the programme, the technologies were not mature and there was little international experience in implementation. However, renewables were promoted as a panacea to the energy problems, and doing 'too much too soon' resulted in unrealistic expectations leading to failures [13]. In the early nineties, under the economic liberalization process, the programme received an impetus with a shift in emphasis from purely subsidy-driven dissemination programs to technology promotion through the commercial route. DNES was converted into a fully-fledged Ministry (Ministry of Non-conventional Energy Sources, or MNES) in July 1992, making India the only country in the world with a ministry dedicated to promoting renewable energy technologies (RETs) [14]. By 1998, a multi-pronged strategy led to the development of the world's largest SPV lighting program, fourth largest wind power program, and second largest biogas and improved stove programs [15].

Under Renewable Energy Plan, 2012, government has proposed draft renewable energy policy and programme interventions required to achieve goals of meeting the minimum rural energy needs; 10% share for renewables to set up about 12,000 MW generation capacity; deployment of solar water heating systems in 1million homes; electrification by renewables of at least one quarter of 18,000 un-electrified villages; deployment of 5 million solar lanterns and 2 million solar home lighting systems; coverage of 30 million households through improved Chullhas (wood stoves); setting up of further 3 million family size biogas plants. The remaining 1.25 lakh census villages and 56 per cent households are unelectrified. The Government has announced coverage of all these unelectrified census villages with 100 per cent household coverage by 2009.

Further RE plan 2012 aims at more female participation in the RE programme for their employment and empowerment; availability of minimum cooking energy to all households; to provide cost effective energy for water pumping, irrigation, drinking and for rural electrification and all round rural development through the Integrated Rural energy Programme (IREP). India has a vast potential (of over 100,000 MW) for renewable energy resources [12]. Table 1 presents the available potential and achievements in India. Data in the table predicts that while several technologies have made considerable progress, the achievements as compared to potential are still very small.

Although considerable experience and capabilities exist on renewable electricity technologies including the development of indigenous biomass gasifier technology and manufacturing base for wind power and solar photovoltaic, a number of barriers still remain to be overcome. The push policies adopted since the nineties have been successful in creating a fairly large and diversified manufacturing base and an infrastructure (technology-support groups and facilities, as well as the nodal agencies) to support RET design, development, testing, and deployment. But commercialization of the technologies have been limited due to low reliability of the devices, lack of remunerative tariffs for RET-generated electricity, and a lack of consumer-desired features (in terms of the services and the financial commitments) in the design and sales-package. Further Distortions in the energy and electricity prices and non-internalisation of the socio–environmental externalities have impeded the progress of RETs by adversely affecting their competitiveness compared to conventional energy sources.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

***Table 1.*** *Renewable energy potential & achievement in India (as on March 2004) [10]*

| Source/Sector | Potential | Achievement |
|---|---|---|
| **A. Power From Renewables** | | |
| 1. Wind | 45,000 MW | 2,002 MW |
| 2. Solar Photovoltaic Power | 20MW/sq km | 47 MW |
| 3. Small hydro (upto 25 MW) | 15,000 MW | 1,520.35 MW |
| 4. Biomass Cogeneration power | 19,500MW* | 570.9MW |
| 5. Energy Recovery from waste | 1700 MW | 30.8 MW |
| **Total power from Renewables** | **81, 200 MW** | **4127. 37 MW** |
| **B. Decentralised Systems** | | |
| 1. Solar water heating (Collector area) | 140Million $m^2$ | 0.70 Million $m^2$ |
| 2. Solar PV | 20 MW/sq.km | 47MW |
| a. Street lighting systems | - | 47969Nos |
| b. Home lighting systems | - | 256673 Nos. |
| c. Solar lanterns | - | 509894Nos |
| d. SPV power Plants | - | 1637 kW |
| 3. Solar PV Pumps | - | 6368 Nos. |
| 4. Wind pumps | - | 945 Nos. |
| 5. Hybrid Systems | - | 199.35 kW |
| 6. Biogas Plants | 12 Millions | 3.44 Millions |
| 7. Improved Chullas (wood stoves) | 120 Millions | 35.89 Millions |
| 8. CBP/IBP/NBP plants | - | 3,902 Nos. |

MW= Mega Watt; sq m =Square meter; kW=kilo watt;* Gasifiers are included

## Renewable energy sources

Renewables can also replace fossil fuels for reducing the greenhouse gases emissions. The country possesses renewables energy sources in abundance the potential capacity is estimated to be 126,000MW.The largest source (79,000 MW) including ocean, thermal and tidal/wave power [16]. Major renewable energy sources of interest to us are biogas, improved cooking stoves, biomass, solar energy, wind energy, small hydro power, energy recovery from wastes and other new and emerging technologies. Figure 2 presents the achieved capacity (in MW) of renewable energy sources in India.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

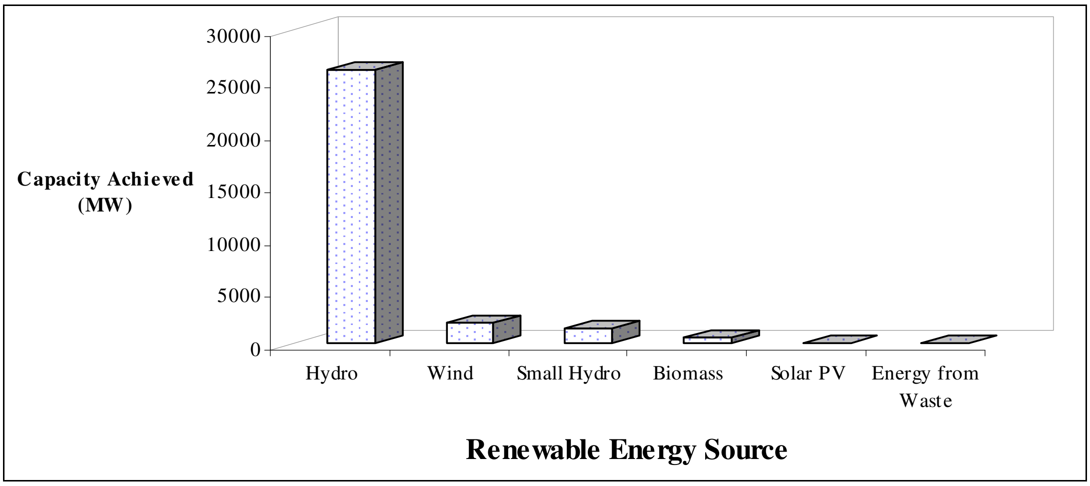



***Figure 2.*** *Renewable energy status in India*

### *Wind energy*

Wind energy, although intermittent, is one of the fastest growing renewable resources in terms of installed capacity. Being the fifth largest wind power producer after Germany, US, Denmark and UK, the generation capacity of country is 2002 MW (1210MW power from commercial projects). About 6.5 billion units from wind power projects are fed to various state grids or to the captive consumers. Major states with higher capacity and potential of wind power are Tamil Nadu Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh and Maharastra.

It is intermittently and strongly influenced by geography and topography (terrain effects). There is a cubic relationship between instantaneous wind speed and available power. It have been observed that the net energy output of a 600kW machine operating in a wind farm would be 1500MWh/yr on a site with an annual mean wind speed of 7.5 m/s at a height 25m above ground level and 2100MWh/y on a site with an AWMS of 9.0m/s at 25 m. The use of wind as a renewable energy source involves the conversion of power contained in masses of moving air into rotating-shaft power. The conversion process utilizes aerodynamic forces (lift and/or drag) to produce a net positive turning moment on a shaft, resulting in production of mechanical power that can be converted to electrical power.

The country's wind power potential has so far been assessed at 45,000 MW with 1% land availability for wind power generation in potential areas. Assuming a capacity utilization factor of 25 percent, the identified potential can generate electricity equivalent to around 8.5 MMTOE per annum. It has been assumed that with better resource assessment and further increase in conversion efficiencies, the identified potential will be harnessed and around 10 MMTOE equivalent of electricity will be generated by 2051-52 [10,14].

### *Biomass power : cogeneration and gasifiers*

Biomass is potentially the world's largest and most sustainable energy source. Biomass is and will remain central to any strategy for determining a rural energy solution. Current biomass share in the primary fuel-mix is not expected to decrease significantly as most scenarios suggest that the share of biomass would hover around 25


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

per cent or more during the 21st century. Biomass, on the other hand, is renewable and if consumed with care, its ill effects such as excessive smoke and release of particulate matter in the atmosphere can be nullified. Biomass, although available in abundance in rural India is paradoxically in short supply mainly because of the inefficient utilization route it is currently being put through.

Currently, biomass accounts for around 30 percent of the domestic primary energy consumption. A major task for energy scientist and policy makers is to increase biomass yield from energy plantations. By incorporating improved plantation techniques through elite planting material developed from clonal propagation plantation, around 15-25 MT biomass/hectare can be obtained using short rotation period of 6-8 years. Considering that some estimates place the quantum of such land at more than 100 million hectare, around 1200 million MT of biomass production per year is achievable from 60 per cent of the waste land. Primary energy demand of 564 MMTOE can be thus met from this source.

In a country like India, biomass holds considerable promise as 540 million tons of crop and plantation residues are produced every year, a large portion of which is either wasted, or used inefficiently. Conservative estimates indicate that even with the present utilization pattern of these residues and by using only the surplus biomass materials, estimated at about 150 million tons, about 17,000 MW of distributed power could be generated [17].

India being an agricultural based country. About 12 million biogas plants for 4 million cattle dung, thus tapping a third of the potential, which is good in comparison to simple-to-disseminate energy device like the LPG in rural India (users are about 7 millions) [18]. A target of installing 0.18 million family type biogas plants had been set up for the year 2004-05. Recent estimates suggest that the impact of traditional biomass cook stove results annually in 0.5 million deaths and around 500 million cases of various illness forms that include acute upper and lower respiratory problems, chronic bronchitis, asthma, tuberculosis and cataract. Women and child in the country are the worst sufferers of this form of pollution.

The deployment of gasification/biomethanation processes in conjunction with bio-fuel run generators, cook stoves and lamps will help in mitigating the problem of rural energy related pollution to a very large extent. The various applications of biomass energy include thermal or heat, mechanical water pumping for irrigation and power generation including village electrification and industrial applications. Biomass combustion efficiency in a traditional cookstove is around 10 per cent. In an improved cook stove it could be anywhere from 20 per cent upwards. In high pressure high temperature combustion electricity producing systems, efficiency levels could be anywhere between 20-40 per cent. The current efficiency level of bio-energy use of 10 percent or less is sought to be doubled, if not tripled through more efficient conversion processes. Through increased biomass production coupled with higher conversion efficiency attainment of a higher per-capita energy consumption level is sought to be achieved in rural areas.

Currently, biomass contributes 14% of the total energy supply worldwide and 38% of this energy is consumed in developing countries, predominantly in rural and traditional sectors of the economy. About 90% of the extracted wood is used for fuel [19]. Photosynthesis provides 120 billion tonnes of biomass every year, corresponding to about five times the total world's energy need. There are several routes of converting biomass into useable energy form. Most conventional form is to burn it to produce heat.

Bio-ethanol and bio-diesel are now produced which can be used to fuel transport sector [20]. Cogeneration technology, with socio-economic benefits to produce both process heat and electricity, based on multiple and sequential use of a fuel for generation of steam and power, aims at surplus power generation in process industries such as sugar mills, paper mills, rice mills and wastes like rice husk, coconut, wood and agriculture waste.

Since biomass fuels have high nitrogen content, control of NOx would also need to be addressed. It have been estimated that around one-third the land area of the country or around $10^7$ m ha is waste-lands, which can be put to use in a major way for energy crop plantations. For the purpose of this Policy Statement, it has been assumed that around one-half of the estimated extent of waste-lands could be developed for energy cropping to include wood, leafy biomass and bio-fuels. Mature cost-effective technology availability is the major barrier to the deployment of bio-energy systems. Bio-energy conversion systems need to be developed, perfected and made cost-effective. Development of bio-energy technology for grid electricity, distributed generation and stand alone systems/devices will be in furtherance of the aforesaid aim. Bio-energy will be mainstreamed as a major energy source through technology development and energy crop plantations.

Biofuel, whose characteristics can be made more or less to resemble diesel with transesterification, is a promising alternate fuel. Cultivation of oil seeds required for bio-fuels is being encouraged in several states. Although current estimated yield is only 1 MT/ hectare, biodiesel has the added advantage of being a great employment generator. Biofuels are being tried out in modified primus stoves, petromax lamps and diesel engines, the latter for stationary, portable and transport applications.

### *Small hydro power (SHP)*

Presently, an estimated potential of about 15,000 MW of SHP exists in India. MNES currently has a database of 4,096 potential sites with an aggregate capacity of 10,071 MW for projects upto 25 MW. Keeping in view of the policy of Government of India to encourage private participation in the field of power generation, thrust of SHP programme is to set up commercial SHP projects.

As per estimates presented by the Central Electricity Authority (CEA), the economically exploitable hydro potential in the country has been assessed at 84,044 MW at 60% load factor which corresponds to an approximate installed capacity of 150,000 MW from 845 schemes.

Assuming that even if 50 percent of this potential was to be harnessed by 2050, the total hydro installed capacity could be around 100,000 MW by then (including around 25,000 MW already installed). This will translate into around 50 MMTOE equivalent of electricity. With numerous rivers and their tributaries in the country, the small hydro sector presents an excellent energy opportunity with an estimated potential of 15,000 MW. About 10 percent of this has been exploited so far.

### *Solar photovoltaics and thermal*

India receives about 300 clear sunny days in a year i.e., equivalent to over 5,000 trillion kWh/year, which is greater than the total energy consumption of India in a year. Solar photovoltaics (SPV) with an aggregate capacity of 47 MWp, has a two and a half percent contribution in the renewable based power generation capacity [21].

SPV systems have found applications in households, agriculture, telecommunications, defense and railways others. Solar thermal power generation potential in India is about 35 MW per sq. km [14]. Also widely employed by in India are non-grid thermal technologies, solar water heating, solar cookers, solar air heating, and, solar thermal building design. Solar water heaters in domestic field, saves energy (electricity or furnace oil) that used to heat water and thus conserves conventional sources of heat energy.

Solar technologies for most applications currently having low efficiencies, are highly capital intensive and not cost-competitive. Single Crystal Czocharalski (CZ) Silicon cells have efficiencies in the range of 14 – 17 per cent, whereas passive emitter, rear locally diffused (PERL) cell have efficiencies approaching 25 per cent. The challenge is to increase overall system efficiency and bring down costs so as to make solar products affordable apart from making solar electricity cost-competitive.

It has been assumed from literature that 1 million hectare area is capable of generating 236 MMTOE of solar electricity. Even if only 5 million hectare or around 5 per cent of the waste lands were to be deployed for solar power generation, a total amount of around 1200 MMTOE electricity demand could be met from this source alone. However, if system efficiency could be raised from the current level of 15 per cent assumed herein, the land mass area required for the purpose would reduce proportionately. Estimates indicate 800 MW per year potential for solar thermal based power generation in India during the period 2010 to 2015, with worldwide advancements in the parabolic trough technology [22].

## Emerging developments in renewables

Urban, municipal and industrial wastes can be pyrolysed or plasma gasified, which have high potential for energy extraction to the tune of 1,700 MW, comprising 1,000 MW of power from urban and municipal wastes and about 700 MW from industrial waste. Gasification process produces syngas that consist mainly of hydrogen and CO and it can be burned in suitably equipped gas turbines and reciprocating engines. Concentration have also been shifted towards the Energy from Chemical Sources i.e., Fuel Cells; Hydrogen Energy; Geothermal Energy; Alternative Fuels for Surface Transportation; Biofuels; Ocean and Tidal Energy.

At least two major barriers that would need to be addressed in the case of hydrogen are system efficiency and system cost, apart from safety related aspects. Despite the fact that fuel cells are theoretically capable of achieving 83 per cent efficiency levels for combined heat and electricity applications since they are not constrained by the limits imposed by the Carnot cycle (real fuel cells, in general, generate only about 60-70 per cent of the theoretical maximum), the electrolysis electricity to hydrogen to fuel cell electricity route offers only 40 per cent efficiency for combined heat and power applications and even lower for only electricity applications.

Hydrogen obtained from electrolysis is around 3 items more expensive then that obtained from fossil fuel. At present, natural gas is the cheapest source of hydrogen with coal as the second choice.

The cost of some fuel cells per peak watt of output could be the same as that for solar photovoltaic cells, which currently cost around Rs 150/watt$_p$ as compared to Rs. 2/ watt for an IC engine. A mid-size passenger car requires around 75 kw$_p$ (equivalent to 100 hp) power output, with city buses requiring atleast three times that level. This apart,


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

switching to a hydrogen infrastructure would require heavy investments in the region of atleast Rs 1,00,000 crore. [10]

Other emerging renewable resources on which now government is shifting its concentration as sustainable energy source is ocean energy. There are a number of other renewable energy technologies, such as tidal, ocean currents, wave, hot dry rock, ocean thermal energy which are currently at technology demonstration stage [16]. Some of these technologies will offer potential in the future.

### *Energy from wastes*

The rising piles of garbage in urban areas caused by rapid urbanization and industrialization throughout India represent another source of non-conventional energy. On an average Almost 450 gms of solid waste is generated per person per day in India. Good potential exists for generating approx. 15,000 MW of power from urban and municipal wastes and approx. 100 MW from industrial wastes in India [17]. It has been estimated that about 70 MW equivalent power could be generated from urban & municipal waste alone. This potential is likely to increase further with our economic growth [23,16]. Energy from waste can be in form of biogas, steam, fuel pallets or direct electricity generation. Waste can be animal waste, agriculture residue, abbatoir waste.

Ministry of Non conventional Energy sources in its recent estimates have indicated that about 40 million tonnes of solid waste and about 5000 million cubic metres of liquid waste is generated every year in the urban areas of the country. National Programme on Energy Recovery from Urban and Industrial Wastes was launched during the year 1995-96 with the following objectives: (i) creation of conducive conditions with financial and fiscal regime to promote, develop and demonstrate the utilisation of wastes for recovery of energy; (ii) improvement in the waste management practices through adoption of renewable energy technologies for processing and treatment of wastes prior to disposal; and (iii) promotion of projects for recovery of energy from wastes from Urban and Industrial sectors.

### *Geothermal*

The best geothermal fields are located within well-defined belts of geologic activity. Today, geothermal power generation plants have a total installed capacity worldwide of more than 8,000 MW and can be deployed for base-load electricity production. Geothermal energy converting systems can provide electricity with an annual capacity load factor of over 90 percent. Low–medium temperature geothermal resources exist at seven geothermal provinces in India in the form of 400 thermal springs with surface temperatures varying from 47 – 98°C [14].

### *Ocean Energy*

Ocean energy consists of two types of energy: thermal energy from the sun's heat, and mechanical energy from the tides and waves. Oceans cover (361,132,000 sq km) i.e., 70.8% of Earth's surface, making them the world's largest solar collectors. India has a water area of 314,400 sq km [16]. The sun warms the surface water a lot more than the deep ocean water, and this temperature difference stores thermal energy. Thermal energy is used for many applications, including electricity generation. There are three types of electricity conversion systems: closed-cycle, open-cycle, and hybrid.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

The total power of waves breaking on the world's coastlines is estimated at 2 to 3 million megawatts. In favorable locations, wave energy density can average 65 megawatts per mile of coastline. India has a coast line of 8,041 kms which can act as a suitable option. For wave energy conversion, there are three basic systems; channel systems, float systems and oscillating water column systems. The mechanical power created from these systems either directly activates a generator or drives a turbine/generator.

Further oceans act as sinks and are currently absorbing 7.4GtCO2/yr (0.9ppmv/yr). The amount of CO2 that can be taken up by the oceans in a given year is a function of wind speed, air, and water temperatures and concentration gradient and is, therefore difficult to determine [16].

## Climate change mitigation initiatives

Three major advantages of renewable energy resources are, firstly, these powers will never run out; secondly these reduce dependence on current power sources and most importantly they put extra burden on environment by reducing Carbon dioxide emissions**.**

Technological improvements in efficient combustion of coal, renewable energy sources can effectively reduce CO2 emissions. Electricity generation from renewables is assuming increasing importance in the context of large negative environmental externalities caused by electricity generation, due to the predominance of fossil fuels in the generation mix. Rising energy demand has led to a rapidly rising trend of energy emissions from India. Although the per capita carbon emissions for India are quite low at present (about 20 times lower than US per capita emissions), total annual emissions exceed 200 million tonnes of carbon [21]. The economy has high carbon intensity due to a large share of coal in the energy mix. Following a low carbon intensity path is complicated by the fact that there are large indigenous coal reserves, but limited oil and gas reserves. While India has experience with emerging renewable technologies, the capital and foreign exchange constraints are likely to restrict a shift away from coal, unless the economic and fiscal policies to relax these constraints are instituted under a cooperative global regime.

Present, the only mechanism by which any responsible and developing country like India can participate in the global emissions limitations regime is through a cooperative instrument such as the Clean Development Mechanism (CDM). CDM is a voluntary mechanism for promoting GHG emissions mitigation projects in Non- Annex I countries in cooperation with Annex I countries [25]. CDM projects can reap benefits such as technology transfers, improvements in local environment and share of surplus from CDM projects [26].Indian is party to UNFCC and also have agrees the Kyoto protocol.

In order to mitigate Greenhouse gases on large scale use of renewable energy resources is a must. Latest projections by the Ministry of Non-conventional Energy Sources plan an additional 10 GW of renewable capacity between 2000 and 2012, constituting 10 percent of the overall power generation capacity additions [14]. A study by Ghosh et al, 2002 [27] suggest that Biomass and cogeneration technologies have more than a 60 percent share in the total mitigation by RETs. These technologies have the highest share in mitigation in the short-term (by 2015), as they offer cheap mitigation opportunities. Wind and solar generation, being guided by availability of wind and sunshine, limits the mitigation potential of these technologies. Generation by small hydro, and hence its mitigation potential, is constrained by water availability due to sharing of water resources for irrigation purposes. Mitigation by wind progressively increases over time with stricter mitigation requirements, but their share in overall mitigation is limited to about 15 percent of the total by all renewable technologies.

## Conclusions

Tightening of carbon emission constraints leads to alterations in the energy mix on the supply side, and this thereby increases investments in renewable energy. The challenges of present energy scenario offers India a window of opportunity in the form of renewable energy sources to expand and diversify its energy supply towards greater sustainability, as well as environmental and social responsibility. India has witnessed substantial growth of renewable energy technologies in the country during the last two decades. This growth can be attributed to the participation of the private sector, as a consequence of favourable policy frameworks and investment options and opportunities available for such technologies. However, much more remains to be done in harnessing the true potential of renewables in the country. MNES, IREDA and other networking agencies are to achieve the targets by 2012 to reduce dependence on fossil fuels, which would result in a clean and green 'Earth'.

**Acknowledgement.** Authors acknowledge the Council for Scientific and Industrial Research, (CSIR) India for providing the financial support for the present research.

## REFERENCES

[1] Crick, H.Q.P., Sparks, T.H. (1999): Climate change related to egg laying trends. *Nature* 399, 423.
[2] Post, E., Peterson, R.O., Stenseth, N.C., McLaren, B.E. (1999): Ecosystem consequences of wolf behavioural response to climate. – Nature 401: 905-907.
[3] Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., de Siquiera, M.F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., Van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Townsend Peterson, A., Phillips, O.L., Williams, S.E. (2004): Extinction risk from climate change. – Nature 427: 145-148.
[4] Wang, G.M., Hobbs, N.T., Singer, F.J., Ojima, D.S., Lubow, B.C. (2002): Impacts of climate changes on elk population dynamics in Rocky Mountain National Park, Colorado, USA. – Clim. Change 54: 205-223.
[5] Shukla P.R., Ghosh D., Chandler W., Logan J. (1999): Developing countries and Global Climate Change: Electric Power Options in India. – Prepared for the Pew Centre on Global Climate Change, Arligton, US
[6] Kumar R., Kumar K., and Pant D. (1994): Diurnal Asymmetry of Surface Temperature Trends Over India – Geophysical Research Letters 21: 677-680.
[7] www.melbourne.indymedia.org/news/2004/12/85201.php , as viewed on 26 oct 2006
[8] Ghosh D, Shukla PR, Garg A, Ramana PV. (2001): Renewable energy strategies for Indian power sector. – Centre de Sciences Humaines (CSH) Occasional Paper no. 3/2001, A publication of the French Research Institutes in India, New Delhi, India


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

[9] Jagdeesh A. (2000): Wind energy development in Tamil Nadu and Andhra Pradesh, India Institutional dynamics and barriers. – Energy Policy 28:157–68.

[10] MNES Ministry of Non-Conventional Energy Sources (2005): New and Renewable Energy Policy Statement 2005 draft report II MNES, 2005-06 http://www.mnes.nic.in/Rene%202005_new.pdf as viewed on 30 Oct 2006

[11] Shukla PR. ( 1997): Penetration of renewable energy technologies in India: assessment of future trajectories and macro policies. – In: Ramana PV, editor. Renewable and Rural Energy Policy Perspective in Developing Countries. New Delhi: Tata Energy Research Institute

[12] Sinha CS. (1993): Renewable energy programs in India: some recent developments. – Natural Resources Forum 18(4):213–24.

[13] Ramana PV, Shukla PR. (1998): Climate change policies and long-term rural energy trends in India. – In: Shukla PR, editor. Climate Change Mitigation: Shaping the Indian Strategy. New Delhi, India: Allied Publishers

[14] MNES (2001): Annual Report 2000–2001. Ministry of Nonconventional Energy Sources, New Delhi

[15] MNES (2000): Annual Report 1999–2000. Ministry of Nonconventional Energy Sources, New Delhi

[16] Raghuvanshi**,** S. P., Chandra A. and Raghav A. K. (2006): Carbon dioxide emissions from coal based power generation in India – Energy Conversion and Management 47: 427-441.

[17] http://www.buyusa.gov/kern/indiaenergyreport.html

[18] Chanakya H. N., Bapaiah P. and Modak J. M. (2004): Evolving biomass-based Biogas plants: The Astra experience. – Current Science

[19] Das T. K. and Banerjee S. (1995): Energy Technology Choice in Rural India. – Energy, Vol. 20 (7): 683-685.

[20] http://www.renewingindia.org/bio1.html

[21] Shukla P.R., Ghosh D., Chandler W., Logan J.( 1999): Developing Countries and Global Climate Change: Electric Power Options in India. – Prepared for the Pew Centre on Global Climate Change, Arlington, US

[22] Tata Energy Research Institute. TERI Energy Data Directory and Yearbook. New Delhi, India: Tata Energy Research Institute, 1999/2000.

[23] http://www.geda.org.in/bio/biomass_energywaste.htm

[24] Chandrasekharam, D. (2004): A Prehistoric View of the Thermal Springs of India, Stories from a Heated Earth – Our Geothermal Heritage (Ed.)

[25] UNFCCC (1997): Kyoto Protocol to the United Nations Framework Convention on Climate Change – United Nations, New York

[26] Shukla P.R, Audinet P, Grare F, editors. (2000): India's Energy: Essays on Sustainable Development. – New Delhi: Manohar Publications

[27] Ghosh D., Shukla PR, Garg A, Ramana PV. (2002): Renewable energy Technologies for Indian power sector: Mitigation potential and operational strategies – Renewable and Sustainable Energy Reviews 6: 481–512.

# REGIONAL INFLUENCES ON ALGAL BIODIVERSITY IN TWO POLLUTED RIVERS OF EURASIA (RUDNAYA RIVER, RUSSIA, AND QISHON RIVER, ISRAEL) BY BIOINDICATION AND CANONICAL CORRESPONDENCE ANALYSIS

S. BARINOVA[1]* – L. MEDVEDEVA[2] – E.NEVO[1]

[1] *The Algology Laboratory in the Institute of Evolution, University of Haifa*
*Mount Carmel, Haifa 31905 Israel*

[2]*Institute of Biology and Soil Science, Far-East Branch of Russian Academy of Science,*
*Stoletiya Str., 159, Vladivostok 690022 Russia*
*(phone: +972-4-8249697; fax: +972- 4-8246554)*

**Corresponding author*
*e-mail: barinova@research.haifa.ac.il*

(Received 29th August 2007; accepted 1st March 2008 )

**Abstract.** In our study we investigated two polluted rivers of Eurasia from silicate and carbonate regions. We revealed an algal diversity consisting of 184 algal species and cyanoprokaryotes in the Rudnaya River, and 175 in the Qishon River. The distributions of species over the 7 higher taxa were very similar for both rivers with diatom prevealing. Bioindicational analysis in respect salinity, acidification, oxygenation, and organic pollution show that the water is cleaner and the diversity is higher in the Rudnaya River than in the Qishon River. The indices of saprobity S ranged similar. The impact of pollution on Rudnaya River increases downstream. In tha case of Qishon River, the impact of pollution decreases downstream.As a result of CCA, we revealed biosensors group sensitive to borates and fluorides in the case of Rudnaya River and these were: *Ankistrodesmus acicularis*, *A. angustus*, *Scenedesmus acuminatus*, *Lyngbya kuetzingii, Neidium ampliatum,* and *Sellaphora rectangularis.* In the case of Qishon River, *Audouinella pygmaea, Characium ornithocephalum*, and *Chamaesiphon amethystinus* were found as biosensor species. We found that algal biodiversity is more sensitive to technogenic pollution in the silicate province being more tolerant to the same organic pollutants in the carbonate province. Therefore, the combination of bioindicational methods and statistics are effective for determination of the main factors influencing algal diversity, indicators or biosensing species for the most important environmental variables.
**Keywords:** *CCA, algal biodiversity, ecology, Russia, Israel.*

## Introduction

According to our research, algal diversity is significantly influenced by changes in the environmental parameters. We can use this contiguity in bioindication methodology. However, the major parameters used in bioindication are individual for each species, while the reaction of the entire community is left unseen.

To change this situation, in this research we reveal the reaction of the entire algal community present in two rivers in Eurasia, the Rudnaya River and the Qishon River (Figure 1) as a result of the changes in water parameters under anthropogenic pollution and regional climatic influence.

The main characteristic of the Israeli climate is a short rainy season,which lasts from December to March. The cliamte of the Far-East is mainly characterized by a summer-humidity season which lasts from April to October.

Therefore, we have assumed that water quality during the rainy season can represent the sum of all climatic influences and anthropogenic impacts in both regions. The bioindicational analysis is able to define the major influencing factors. Oridnation as a statistical method can also be used if bioindicational analysis fails to give the desired results. This method can be used to show, for example, the unique light and temperature responses of cyanobacterial species from two differens habitats on Antarctic and Arizona (Banerjee, Sharma 2004).

## Study sites description

### *Rudnaya River*

The Russian Far East is basically a basaltic volcanic area (Meybeck & Helmer 1989). The Rudnaya River starting at the eastern slope of Sikhote-Alin Range and it empties into the Rudnaya bay of the Sea of japan. The river is 73 km long, its basin occupies 1140 square kilometre. The water flow varies over the year: 96 percent during the warm season, from April to November, and only 4 percent during the cold period, from December to March (Berezneva 2006).

The Rudnaya River Basin is ecologically the most polluted area in the Primorye Region. Ore mines, enrichment factories and other industries contribute to the pollution in the river valley.

Both surface and underground waters are heavily polluted and lost their utility as a water source over the river flow from Krasnorechensk to Rudnaya Pristan'. The Rudnaya River had lost its significance as fishing water (Kuznetsova 2005).

About 20,000 tons of various technogenic substances are discharged to the river per anuum. The concentration of Mn, Zn, Cd and Pb in the polluting substances is more than ten times higher than their natural level. The residents suffer from serious lead poisoning caused by the old smelters and the insecure transporation of the lead concentrate from the local mining site.

The sources of water pollution can be grouped according to their origin and their impact. However, an objective information on the pollution sources is lacking. The tentative assessments given below are lesser than real. The discharges, in t/year are the following: Cu-0.13; Zn-4.66; Fe-1.12; Pb-0.49 (Kuznetsova 2005).

According to the most recent study, lead concentrations in the residential gardens (476-4310 mg/kg) and in roadside soils (2020-22900 mg/kg) exceed USEPA regulations by orders of magnitude. These data suggest that drinking water, dust in the air, and garden plants also likely contain dangerous levels of lead. Water discharged from the smelter 2900 $m^3$ as a daily average with concentrations up to 100 kg of lead and 20 kg of arsenic (Von Braun et al. 2002; Kachur et al. 2003; Sharov 2005; Shilov 1997).

### *Qishon River*

The Qishon River is the second largest river among the coastal rivers of Israel, and also regarded as the most polluted river system in Israel (Herut et al., 2000; Herut & Kress 1997). In general, pH is relatively constant fluctuating between 9.1 and 7.5 down the river channel corresponding to the regional norm for carbonate provinces (Meybeck & Helmer 1989). The river drains an area of approximately 1100 $km^2$ and flows through agricultural, domestic, and industrial districts before joining the Mediterranean Sea near the city of Haifa. The Qishon's water is contaminated by agricultural runoff, various types of industrial effluents, and domestic sewage (Herut & Kress 1997); by heavy metals and a mixture of organic materials (Richter et al. 2003; Herut et al. 1994; Krumgalz 1993) including polycyclic aromatic hydrocarbons (PAHs), alkylated benzenes, halogenated alkanes, and chlorinated aromatic organic compounds; and some radionucleotides. As a result, the lower part of the Qishon River has been denuded for years of its multicellular life forms (Richter et al. 2003). Moreover, tissue analyses of fishes, crustaceans, and mollusks from the shallow waters of Haifa Bay at the mouth of Qishon River revealed high levels of heavy metals and deviations in oxidizing enzyme activities (Kress et al. 1999; Herut et al. 1999). Herut et al. (2003) reported medium degree of pollution in the Qishon estuary by heavy metals (mercury, copper, zinc, cadmium, nickel) and high degree of pollution upstream by international environmental criteria. Not surprisingly, the Qishon River has been identified as the main source of mercury, cadmium and other heavy metals pollution in the Haifa ports. High concentrations of Tributyltin (TBT) (> 100 µg/Kg), probably originating from anti-fouling paints, were found in the sediments at both, the Haifa port, and Qishon river. Probably, as the consequences of the TBT pollution the entire female population of the snail *Murex forskoehli* collected in the vicinity of Haifa Port (~ 800 specimens) exhibited male sexual characteristics. The sediments at the Ports of Haifa, and Qishon river are also significantly contaminated by PCB's and by polycyclic aromatic pollutants (PAH's) not to speak about high levels (recorded from 1990 to 2002) of dissolved inorganic nutrients (nitrogen and phosphorous), representing a high degree of pollution by international environmental criteria (Herut et al. 2003). The Qishon River has also elicited major public concern for its potential long-term cancer risks to fisherman working in its vicinity and to navy soldiers who used to dive in the river (Richter et al. 2003).

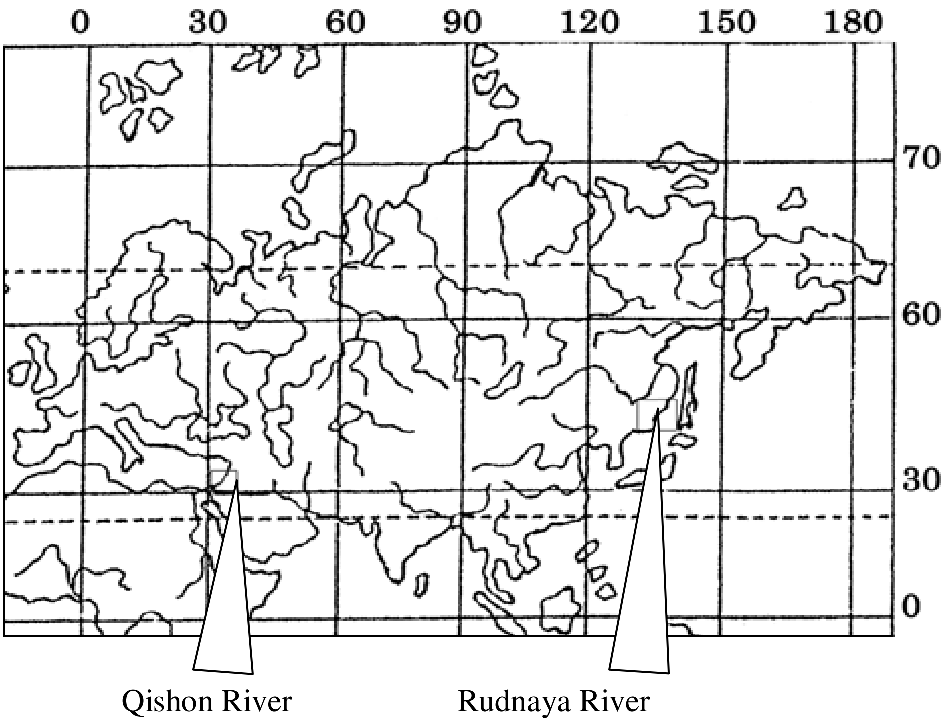



***Figure 1.*** *Map of the study site.*


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

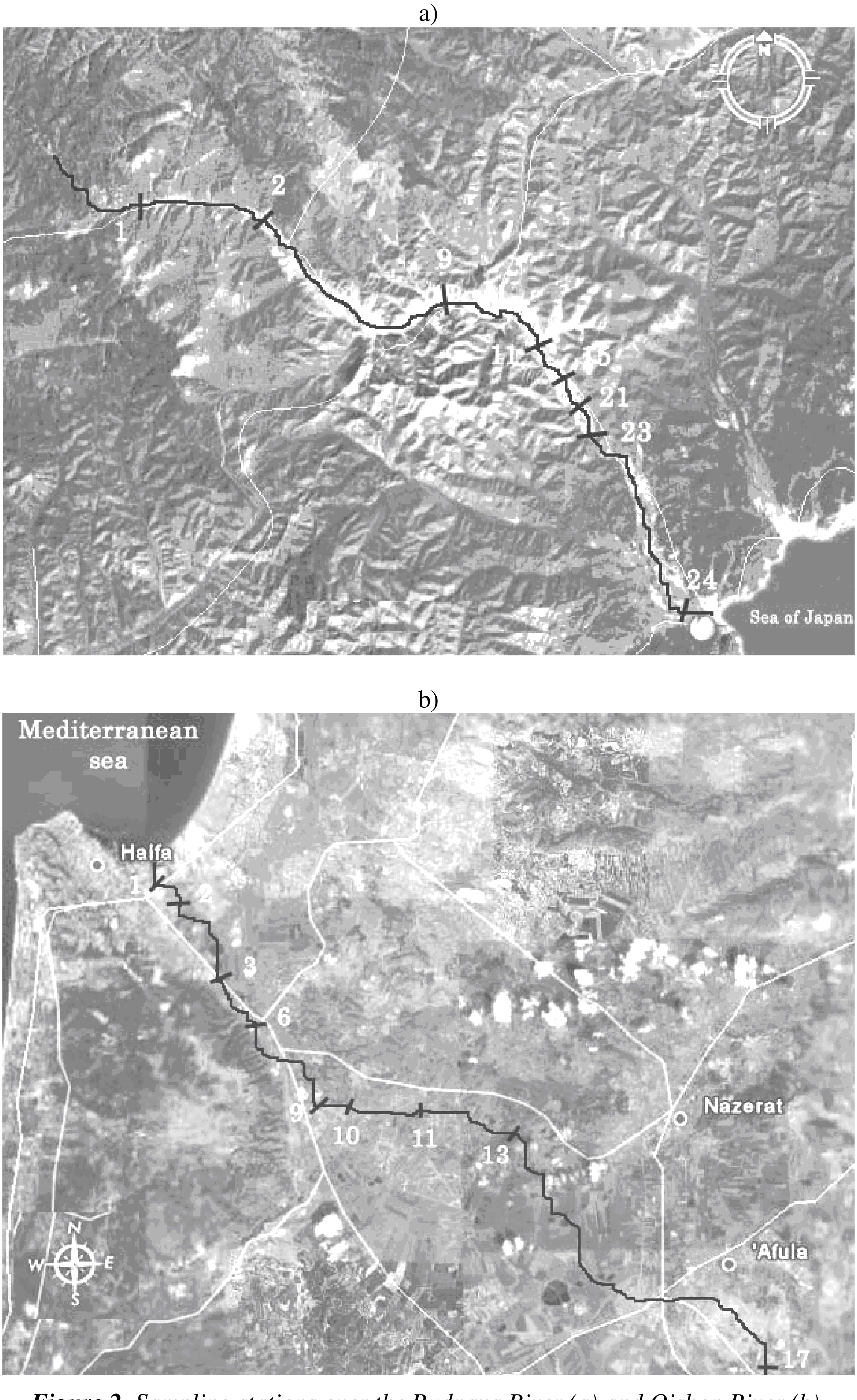



***Figure 2.** Sampling stations over the Rudnaya River (a) and Qishon River (b).*

## Materials and methods

### *Materials*

For our study we have collected 649 samples of planktonic and periphytonic algae from 24 stations over the Rudnaya River in 1978-1990 (Figure 2a), as well as 117 algological samples from 19 stations over the Qishon River (Figure 2b) that were collected during the winter and summer seasons, from February 2002 to November 2005.

The samples were obtained by scooping up for phytoplankton and by scratching for periphyton and were fixed in 3% formaldehyde. Algae were studied with a dissecting Swift and Amplival microscopes under magnifications of 740–1850 and were photographed with the digital camera Inspector 1. The diatoms were prepared with the peroxide technique (Swift 1967) modified for glass slides (Barinova 1997). The diatoms were studied both under light microscope and scanning electron microscope JEOL JSM 35C. The taxonomy of this study mainly follows the systems adopted in the "Süswasserflora von Mitteleuropa".

Table 1. shows the chemical data for Rudnaya River come from Elpatievsky et al. (1976).

In parallel with sampling for algae in Qishon River, we measured conductivity, mineralization and pH with HANNA HI 9813. In addition to our sampling we have used data of chemical analysis regularly performed by "Mekorot Water Co." shown in Table 2.

***Table 1.*** *Chemical variables over the Rudnaya River stations.*

| Station | 1 | 2 | 9 | 11 | 15 | 21 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| pH | 7.54 | 7.54 | 7.56 | 7.56 | 7.72 | 8.3 | 8.3 | 7.61 |
| $HCO_3^-$, mg/l | 39.0 | 39.0 | 40.0 | 40.0 | 52.0 | 63.0 | 63.0 | 40.0 |
| $Cl^-$, mg/l | 4.9 | 4.9 | 7.2 | 7.2 | 6.4 | 12.7 | 12.7 | 8.6 |
| $SO_4^{3-}$, mg/l | 11.8 | 11.8 | 27.5 | 27.5 | 24.0 | 116.0 | 116.0 | 35.5 |
| $Ca^{2+}$, mg/l | 9.0 | 9.0 | 17.0 | 17.0 | 16.3 | 63.0 | 63.0 | 11.0 |
| $Mg^{2+}$, mg/l | 2.1 | 2.1 | 4.5 | 4.5 | 4.0 | 3.8 | 3.8 | 2.5 |
| $K^+$, mg/l | 0.5 | 0.5 | 1.2 | 1.2 | 1.1 | 1.8 | 1.8 | 1.4 |
| $Na^+$, mg/l | 3.5 | 3.5 | 5.3 | 5.3 | 5.2 | 13.2 | 13.2 | 6.7 |
| $SiO_2$, mg/l | 7.2 | 7.2 | 6.8 | 6.8 | 5.8 | 6.3 | 6.3 | 5.2 |
| $B_2O_3$, mg/l | 0 | 0 | 0 | 0 | 0 | 9.4 | 9.4 | 1.4 |
| F, mg/l | 0.06 | 0.06 | 0.1 | 0.1 | 0.1 | 0.42 | 0.42 | 0.17 |
| TDS, mg/l | 71.2 | 71.2 | 110.6 | 110.6 | 100.4 | 272.2 | 272.2 | 118 |
| Cu, mkg/l | 2.2 | 2.2 | 6.0 | 6.0 | 2.5 | 8.3 | 8.3 | 9.7 |
| Zn, mkg/l | 16.5 | 16.5 | 180.3 | 180.3 | 47.8 | 78.7 | 78.7 | 100.0 |
| Pb, mkg/l | 5.7 | 5.7 | 17.0 | 17.0 | 10.4 | 30.8 | 30.8 | 40.5 |
| Sn, mkg/l | 4.5 | 4.5 | 5.9 | 5.9 | 3.0 | 8.5 | 8.5 | 19.7 |
| Ag, mkg/l | 0.8 | 0.8 | 0.2 | 0.2 | 0.5 | 0.6 | 0.6 | 0.8 |
| As, mkg/l | 0 | 0 | 1.8 | 1.8 | 1.5 | 4.4 | 4.4 | 5.5 |
| Index S | 1.32 | 1.76 | 2.22 | 2.18 | 2.05 | 2.26 | 2.13 | 2.18 |
| No of Species | 35 | 13 | 26 | 16 | 15 | 24 | 17 | 22 |


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

***Table 2.*** *Chemical variables over the Qishon River stations.*

| Station | 17 | 13 | 11 | 10 | 9 | 6 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|---|---|---|
| T | 22.4 | 22.8 | 24.7 | 25.8 | 25.8 | 24.7 | 24.8 | 29.4 | 30 |
| pH | 7.89 | 7.83 | 8.07 | 7.91 | 7.85 | 8.05 | 7.97 | 8.1 | 8.58 |
| E ms/cm | 3.56 | 6.05 | 5.5 | 5.11 | 4.87 | 5.04 | 4.93 | 9.42 | 9.97 |
| TDS, mg/l | 4000 | 6000 | 5000 | 5000 | 4500 | 5000 | 4500 | 8000 | 8000 |
| TSS 105 | 322 | 172 | 133 | 68 | - | 114 | 200 | 36 | 74 |
| $O_2$, mg/l | 8.8 | 8.2 | 9.4 | 11.1 | 8.5 | 9.1 | 6.8 | 20.1 | 29.6 |
| Saturated | 98 | 92 | 105 | 136 | 104 | 110 | 90 | 235 | 370 |
| Sulfides, mg/l | 0 | 0.14 | 1.8 | 0.42 | 0 | 1.2 | 0 | 0.04 | 0.51 |
| $PO_4^+$, mg/l | 0 | 0 | 0.3 | 0 | 0 | 0.4 | 0 | 0 | 1.2 |
| Total P, mg/l | 0.5 | 0.6 | 0.5 | 0.9 | - | 0.7 | 0.6 | 1.9 | 2.3 |
| $NO_3^-$, mg/l | 27 | 13.4 | 11.3 | 6 | 8.1 | 6.2 | 7.2 | 11.1 | 6 |
| $NO_2^-$, mg/l | 0.1 | 0.087 | 0.006 | 0.35 | - | 0.33 | 0.059 | 0.33 | 0.33 |
| $NH_4^+$, mg/l | 0.05 | 0.05 | 0.05 | 0.05 | - | 0.05 | 0.05 | 1.3 | 0.6 |
| N org., mg/l | 2.5 | 1.5 | 1.8 | 2.9 | - | 1.7 | 2.3 | 4.7 | 5.7 |
| Total N | 29.6 | 15 | 13.2 | 9.3 | - | 8.2 | 9.6 | 16.1 | 12.03 |
| BOD, mg/l | 9 | 6.3 | 6 | 11.1 | - | 10.2 | 8 | 12.3 | 15.3 |
| Min. oil, mg/l | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | - | 0.5 | 0.5 |
| Total oil, mg/l | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | - | 0.5 | 0.7 |
| E. Coli t/l | 3300 | 9000 | 3500 | 14000 | - | 24000 | 12000 | 12000 | 500 |
| Chl *a*, mg/l | 0.005 | 0.021 | 0.013 | 0.024 | - | 0.021 | 0.005 | 0.093 | 0.021 |
| $Cl^-$, mg/l | - | - | 1306 | - | - | 773 | - | 10263 | 11663 |
| COD, mg/l | - | - | 32 | - | - | 58 | - | 49 | 58 |
| TOC, mg/l | - | - | 8.8 | - | - | 14.2 | - | 13.6 | 15 |
| Detergents, mg/l | - | - | 0.2 | - | - | 0.24 | - | 0.17 | 0.26 |
| Benzene, mg/l | - | - | 0.05 | - | - | 0.05 | - | 0.05 | - |
| Toluol, mg/l | - | - | 0.05 | - | - | 0.05 | - | 0.05 | - |
| Xylen, mg/l | - | - | 0.05 | - | - | 0.05 | - | 0.05 | - |
| Phenol, mg/l | - | - | 0.002 | - | - | 0.002 | - | 0.002 | - |
| microtox | - | - | 22 | - | - | 13 | - | 0 | - |
| Chlorine, mg/l | - | - | 0.06 | - | - | 0.06 | - | - | - |
| Index S | 2.51 | 2.49 | 2.48 | 2.03 | 2.31 | 2.2 | 2.53 | 2.33 | 2.31 |
| No of Species | 20 | 28 | 26 | 36 | 32 | 28 | 18 | 9 | 17 |

Density scores were calculated using a 5-score scale (Whitton & al. 1991) and 6-score scale (Korde 1956). Saprobity indices were obtained for each algal community (Pantle & Buck 1955; Sladeček 1986) and then used for integral assessment of the species habitats. Ecological and horological characteristics of the species are summed up in our database (Barinova & al. 2006).

Our ecological analysis revealed freshwater algae ecological groups in respect to pH, salinity, and saprobity, as well as temperature, streaming, and oxygenation. Each group was separately assessed in respect to its significance for bioindication. Species that respond predictably to these variables can be used as bioindicators reflecting the response of aquatic ecosystems to eutrophication, pH levels (acidification), salinity, and organic pollutants.

Diagrams of species distribution were constructed for each group of ecological indicators. The algal groups were ordinated according to their increasing tolerances for a given environmental variable. A polynomial/linear trend line was defined (as a


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

statistic function in the Microsoft EXCEL program) for distribution of algal groups in response to individual variables, showing the general tendency of the diversity changes in respect to fluctuations of a given variable.

The distribution in the number of species between the groups in the different indicator systems shows the total range of environmental conditions in the river, on one hand, and the prevailing conditions, on the other. The summit of the trend line corresponds to the optimal conditions in respect to the given variable.

Out of the many possible the ordination methods available we have chosen to use Canonical Correspondence Analysis (CCA). We were able to obtain quantitative information on the relationship between species and environmental variables using CCA with the CANOCO for Windows 4.5 package.

Estimation of the explanatory power for each environmental variable was performed using the variable as the sole constraining variable. Statistical significance for each variable was assessed using the Monte Carlo unrestricted permutation test involving 999 permutations (ter Braak 1987; 1990).

The CCA biplot represents the ordination of species in relation to the combination of the different environmental variables. Environmental variables are represented by arrows, the maximal value for each variable is located at the arrow head. Therefore, species marked near arrow head are bioindicators in respect this variable. Species marked near opposite end of arrow are biosensors, which is sensitive even to presence of given variable.

## Results and discussion

### *Rudnaya River*

Data on water hydrochemistry of the Rudnaya River are cited in table I (Elpatievsky et al. 1976). Unfortunately, the existing data pertain to metal concentrations only except the data on stations 1 and 2, which show normal distribution of chemical elements in the natural unpolluted water sources in the Russian Far East. Insignificant pH fluctuations suggest that the river waters are fresh over the most of the watercourse. Even at the mouth station 24 pH does not exceed 7.6. An increase of pH up to 8.3 was measured at stations 21 and 23 only. These stations are situated down current of the polluting tributaries of the Rudnaya River.

The analysis of table 1 shows that concentrations of $HCO_3^-$, $Cl^-$, $Ca^{2+}$, $Na^+$, TDS, Cu, Pb, Sn in the Rudnaya River, in general and at the station 21 and 23 in particular are higher than the background level. The concentration of borates, sulfates, and fluorides increase up to ten times at these stations. Notable also is a significant increase of Zn at the stations 9 and 11.

As it was expected, the saprobity index is the lowest at the clear water station 1 (S=1.32) up current of the major pollution sources. Similar values of saprobity indices are obtained for the majority of water sources in the Russian Far East (Barinova & Medvedeva 1987). The influences of polluting discharges are reflected in the increase in the saprobity index up to 2.18-2.26. The maximal biological diversity of algal communities was observed at the clear-water station 1, appreciably decreasing down the current.

### *Qishon River*

The physico-chemical environmental variables and their dynamics over the Qishon River stations are indicated in Table 2. The pH and conductivity show that Qishon River is fresh water in the upper and middle reaches, is influenced by sea tides in the lower reaches (chloride fluctuated from 773 mg per liter to 11663 mg per liter (Qishon River Authority http://www.kishon.org.il/) and remains alkaline all year-round. The concentration of N-$NO_3$ is 0.6-10.5 mg per liter. The concentration of P-total is 0.2-7.93 mg per liter. In winter, conductivity tends to increase from station 10 to the mouth, while pH tends to decrease in the same direction. Connection between conductivity and salinity levels as well as other chemical variables and Index of saprobity S indicated in the Table 2. In general, pH in Qishon River is relatively constant fluctuating between 9.1 and 7.5 down the river channel corresponding to the regional norm for carbonate provinces (Meybeck & Helmer 1989).

In samples from Qishon River we found 175 species of algae from 7 divisions (Barinova et al. 2004; 2006). In samples from Rudnaya River we found 184 species of algae from 7 divisions (Medvedeva et al. 1986a,b; Medvedeva & Barinova 1992; Barinova & Medvedeva 1989, 1992a,b). As we can see on the Table 3, the species diversity in each river is significantly different, that reflects their regional ecological preferences. The comparison of found diversity (Table 3) is on the Figure 3.

***Table 3.*** *Abundance and ecological preference of algal species revealed in the Rudnaya River and Qishon River.*

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cyanoprokaryota** | | | | | | | | | | |
| 1 | *Anabaena spiroides* Kleb. | ANSPIH | 0 | 1-3 | P | - | st-str | - | o | i | - |
| 2 | *Anabaena variabilis* f. *rotundospora* Hollerb. | ANAVRQ | 0 | 1-6 | B | - | - | - | - | - | - |
| 3 | *Anabaena* sp. | AN001Y | 0 | 1-3 | - | - | - | - | - | - | - |
| 4 | *Aphanocapsa elachista* W. et G.S. West | MICPUR | 1 | 0 | - | - | - | - | - | - | - |
| 5 | *Aphanothece elabens* (Bréb.) Elenk. | APHACQ | 0 | 2 | P-B | - | - | - | - | - | - |
| 6 | *Aphanothece microscopica* Näg. | APHAMR | 2 | 0 | B | temp | - | - | o | hb | |
| 7 | *Aphanothece stagnina* (Spreng.) A. Braun in Rabenh. | ATS01Y | 0 | 1 | P-B | - | - | - | b-a | hl | ind |
| 8 | *Arthrospira fusiformis* (Woronich.) Komárek et Lund | ARTHSQ | 0 | 1 | P | - | - | - | - | mh | - |
| 9 | *Calothrix fusca* f. *parva* (Erceg.) V. Poljansk. | CAFUSR | 6 | 0 | - | - | - | - | - | - | - |
| 10 | *Chamaesiphon amethystinus* (Rostaf.) Lemm. | CHAMAQ | 0 | 1-5 | Ep | - | str | - | - | - | - |
| 11 | *Chroococcus minor* (Kütz.) Näg. | GLOCAR | 1 | 0 | B | - | - | - | o-b | - | - |
| 12 | *Crinalium endophyticum* Crow | CRINAQ | 0 | 1 | Ep | - | - | - | - | - | - |
| 13 | *Hydrococcus rivularis* (Kütz.) Menegh. | HYDRCQ | 0 | 4 | B | - | - | - | x | - | - |


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | *Limnothrix amphigranulata* (Van Goor) Meffert | LIA01Y | 0 | 6 | B | - | st | - | - | mh | - |
| 15 | *Lyngbya kuetzingii* Schmidle | LYNKUL | 3 | 0 | B | - | st-str | - | o-b | - | - |
| 16 | *Lyngbya limnetica* Lemm. | LYL01Y | 0 | 2 | P-B | - | st-str | - | o-b | hl | - |
| 17 | *Lyngbya pusilla* (Rabenh.) Hansg. | LYPUSR | 4 | 0 | - | - | - | - | - | - | - |
| 18 | *Lyngbya scottii* f. *minor* (F.E. Fritsch) Elenk. | LYSCOR | 3 | 0 | - | - | - | - | - | - | - |
| 19 | *Lyngbya* sp. | LY001Y | 0 | 1-4 | - | - | - | - | - | - | - |
| 20 | *Merismopedia glauca* (Ehrb.) Kütz. | MRG01Y | 1 | 0 | P-B | - | - | - | o-a | i | ind |
| 21 | *Merismopedia punctata* Meyen | MPUN0A | 3 | 0 | P-B | - | - | - | o-a | i | ind |
| 22 | *Merismopedia tenuissima* Lemm. | MRT01Y | 0 | 2-6 | P-B | - | - | - | b-a | hl | - |
| 23 | *Microcystis aeruginosa* (Kütz.) Kütz. | MIA01Y | 0 | 2-6 | P | - | - | - | o-a | hl | - |
| 24 | *Oscillatoria animalis* Gom. | OSAN1Y | 0 | 3 | P-B | - | str | - | o | - | - |
| 25 | *Oscillatoria brevis* Gom. | OSB01Y | 0 | 1-4 | P-B | - | st | - | b-p | - | - |
| 26 | *Oscillatoria formosa* Gom. | OSFO0A | 0 | 1 | P-B | - | st | - | b-p | - | - |
| 27 | *Oscillatoria guttulata* Van Goor | OSGU1Y | 0 | 2 | P | - | st | - | a | - | - |
| 28 | *Oscillatoria mougeotii* Kütz. | OSCMOQ | 0 | 1 | P-B | - | st | - | o-a | - | - |
| 29 | *Oscillatoria princeps* Gom. | OSP01Y | 0 | 1 | P-B | - | st-str | - | b-p | - | - |
| 30 | *Oscillatoria* sp. | OS001Y | 0 | 1-6 | - | - | - | - | - | - | - |
| 31 | *Phormidium ambiguum* Gom. | PRA01Y | 5 | 0 | B | temp | st-str | - | b | i | ind |
| 32 | *Phormidium autumnale* (Ag.) Gom. | PRAU1Y | 1-6 | 0 | B | - | st-str | - | b | - | - |
| 33 | *Phormidium foveolarum* Gom. | PHOFOQ | 0 | 2 | B | - | - | - | b-o | - | - |
| 34 | *Phormidium* sp. | PR001Y | 0 | 1-3 | - | - | - | - | - | - | - |
| 35 | *Phormidium subfuscum* Gom. | PHORSJ | 6 | 0 | B | - | st-str | - | b | - | - |
| 36 | *Phormidium uncinatum* Gom. | PRU01Y | 1-5 | 0 | P-B | temp | - | - | b | i | - |
| 37 | *Planktolyngbya regularis* Kom.-Legn. et Tavera | PLR01Y | 0 | 2-3 | P | warm | st | - | - | - | - |
| 38 | *Pleurocapsa crepidinum* Collins | PCC01Y | 0 | 4 | Ep | - | - | - | - | ph | - |
| 39 | *Rhabdogloea smithii* (R. et F. Chodat) Komárek | DACTRR | 1 | 0 | P | - | st-str | - | - | - | - |
| 40 | *Schizothrix pulvinata* (Kütz.) Gom. | SZP01Y | 0 | 2 | Ep | - | st-str | - | - | | - |
| 41 | *Spirulina major* Kütz. | SPM01Y | 0 | 2-4 | P | - | st | - | - | ph | - |
| 42 | *Spirulina platensis* (Nordst. ex Gom.) Geitler | SPP01Y | 0 | 2 | P | - | st | - | b | - | - |
| 43 | *Spirulina* sp. | SPIRUQ | 0 | 1 | - | - | - | - | - | - | - |

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 44 | *Xenococcus pallidus* (Hansg.) Komarek et Anagn. | XENCPQ | 0 | 1-2 | Ep | - | - | - | - | ph | - |
| | **Chrysophyta** | | | | | | | | | | |
| 45 | *Hydrurus foetidus* (Villars) Trevisan | HYDFOL | 2-6 | 0 | B | - | - | - | o-x | - | - |
| 46 | *Lagynion janei* Bourr. | LAGYJQ | 0 | 6 | Ep | - | - | - | - | - | - |
| 47 | *Stylococcus aureus* Chod. | SYA01Y | 0 | 2-4 | Ep | - | - | - | - | - | - |
| | **Xanthophyta** | | | | | | | | | | |
| 48 | *Characiopsis microcysticola* Skuja | CHAMIR | 2 | 0 | - | - | - | - | - | - | - |
| 49 | *Gloeobotrys monochloron* Ettl | GLOEBR | 6 | 0 | - | - | - | - | - | - | - |
| 50 | *Heterothrix monochloron* Ettl | HETERR | 1-2 | 0 | - | - | - | - | - | - | - |
| 51 | *Tribonema subtilissimum* Pasch. | TRISUR | 4 | 0 | B | - | - | - | - | i | - |
| 52 | *Tribonema vulgare* Pasch. | TRIVUR | 2 | 0 | P-B | - | - | - | o-a | i | - |
| | **Cryptophyta** | | | | | | | | | | |
| 53 | *Cryptomonas* sp. | CRYPTQ | 0 | 1 | - | - | - | - | - | - | - |
| | **Euglenophyta** | | | | | | | | | | |
| 54 | *Euglena acus* Ehrb. | EUA01Y | 0 | 1-2 | P | eterm | st | - | b | i | ind |
| 55 | *Euglena ehrenbergii* Klebs | EUE01Y | 0 | 1 | P-B | eterm | st-str | - | b | - | ind |
| 56 | *Euglena oxyuris* Schmarda | EUOXYL | 3 | 0 | P | | | - | b-a | - | - |
| 57 | *Euglena proxima* Dang. | EUP01Y | 0 | 1 | P-B | eterm | st-str | - | p | mh | ind |
| 58 | *Euglena* sp. | EU001Y | 0 | 1 | - | - | - | - | - | - | - |
| 59 | *Euglena texta* (Duj.) Hübn. | EUT01Y | 0 | 1-3 | P | eterm | st-str | - | b | - | ind |
| 60 | *Petalomonas mediocanellata* Stein | PETALR | 1 | 0 | B | warm | st-str | - | a | - | ind |
| 61 | *Phacus acuminatus* Stokes | PHACAQ | 0 | 1 | P-B | eterm | st-str | - | b-a | i | - |
| 62 | *Phacus parvulus* Klebs | PHAPAQ | 0 | 5 | P | eterm | st-str | - | b | i | ind |
| 63 | *Phacus pleuronectens* (Ehrb.) Duj. | PHP01Y | 0 | 1 | P-B | - | st-str | - | b-a | i | ind |
| 64 | *Phacus pyrum* (Ehrb.) Stein | PHPY1Y | 0 | 1 | P | eterm | st-str | - | b | i | ind |
| 65 | *Phacus* sp. | PHACUH | 0 | 1 | - | - | - | - | - | - | - |
| 66 | *Phacus striatus* Francé | PHASTQ | 0 | 1 | P-B | eterm | st-str | - | b-a | - | ind |
| 67 | *Trachelomonas hispida* Delf. | TRH01Y | 1 | 0 | P-B | eterm | st-str | | b | i | |
| | **Bacillariophyta** | | | | | | | | | | |
| 68 | *Achnanthes chlidanos* Hohn et Hellerman | AC9960 | 4 | 0 | B | - | - | sx | o | i | ind |
| 69 | *Achnanthes delicatula* subsp. *hauckiana* (Grun. in Cleve et Grun.) Lange-Bert. et Ruppel | ACDE1R | 1 | 0 | - | - | - | - | - | - | - |

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | *Achnanthes lanceolata* f. *capitata* O. Müll. | ACLC1L | 2 | 0 | B | - | - | - | x-b | i | ind |
| 71 | *Achnanthes lanceolata* f. *ventricosa* Hust. | ACLV1L | 1-2 | 0 | B | warm | - | sx | x-b | i | alf |
| 72 | *Achnanthes lanceolata* (Bréb.) Grun. var. *lanceolata* | AL001Y | 1-3 | 0 | P-B | warm | st-str | sx | o-x | i | alf |
| 73 | *Achnanthes lineariformis* Lange-Bert. | AC9959 | 3-6 | 1 | B | eterm | st-str | es | x-o | i | ind |
| 74 | *Actinocyclus normanii* (Greg. ex Grev.) Hust. ex Van Landingham | ACTINQ | 0 | 1 | P | - | st-str | - | - | mh | - |
| 75 | *Amphora coffeaeformis* (Ag.) Kütz. | AMC01Y | 0 | 1-6 | B | - | st-str | - | - | mh | - |
| 76 | *Amphora montana* Krasske | AMMONO | 0 | 1 | B | - | ae | - | - | i | alf |
| 77 | *Amphora ovalis* (Kütz.) Kütz. | AMO01Y | 1-2 | 1 | B | temp | st-str | sx | a-b | i | alf |
| 78 | *Amphora pediculus* (Kütz.) Grun. | AMP01Y | 1 | 1 | B | temp | st | es | o-a | i | alf |
| 79 | *Amphora veneta* Kütz. | AM004A | 0 | 1-2 | B | - | - | es | o | i | alf |
| 80 | *Anomoeoneis sphaerophora* (Ehrb.) Pfitz. | AN009A | 0 | 1-2 | P-B | warm | st-str | - | x-b | hl | alb |
| 81 | *Anomoeoneis sphaerophora* f. *sculpta* Kramm. | ANOSSQ | 0 | 1 | B | - | - | - | - | mh | - |
| 82 | *Aulacoseira granulata* (Ehrb.) Simons. | AUL01Y | 1 | 1-3 | P-B | temp | st-str | es | b-a | i | alf |
| 83 | *Bacillaria paxillifer* (O. Müll.) Hendey | BAP01Y | 0 | 1-4 | P-B | - | - | es | o | mh | ind |
| 84 | Cal*oneis leptosoma* (Grun.) Kramm. in Kramm. et Lange-Bert. | CALLER | 1 | 0 | B | - | - | - | o | - | - |
| 85 | *Caloneis molaris* (Grun.) Kramm. | CALMOR | 1 | 0 | B | - | str | es | - | i | ind |
| 86 | *Caloneis permagna* (J.W. Bailey) Cleve | CLP01Y | 1 | 1-2 | B | - | - | - | - | hl | - |
| 87 | *Caloneis silicula* (Ehrb.) Cl. var. *silicula* | CASILR | 1 | 0 | - | - | - | - | - | - | - |
| 88 | *Caloneis silicula* var. *truncatula* (Grun.) Cl. | CALSTL | 1 | 0 | B | - | st | - | - | i | alf |
| 89 | *Caloneis silicula* var. *ventricosa* (Ehrb.) Donk. | CALSVL | 1 | 0 | B | - | st | - | - | i | - |
| 90 | *Campylodiscus bicostatus* W. Smith in Roper | CMPCBH | 0 | 1 | B | - | - | - | - | mh | - |
| 91 | *Cocconeis placentula* var. *euglypta* (Ehrb.) Grun. | CCCPEQ | 1-4 | 1 | P-B | temp | st-str | sx | - | i | alf |
| 92 | *Cocconeis placentula* Ehrb. var. *placentula* | CCP01Y | 1-3 | 0 | P-B | temp | st-str | es | o-b | i | alf |
| 93 | *Cocconeis placentula* var. *pseudolineata* Geitl. | CCCPPQ | 0 | 1 | P | - | st-str | sx | - | i | alf |
| 94 | *Craticula accomoda* (Hust.) D.G. Mann | CRA01Y | 0 | 1 | P | - | - | sp | o-a | i | |
| 95 | *Craticula ambigua* (Ehrb.) Mann | CRA00A | 1 | 0 | B | warm | st | es | o | i | alf |


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 96 | *Craticula cuspidata* (Kütz.) D.G.Mann | CRC01Y | 1 | 1 | B | temp | st | es | o | i | alf |
| 97 | *Craticula halophila* (Grun. ex Van Heurck) Mann | CRATGO | 0 | 1 | B | - | st-str | es | - | mh | alf |
| 98 | *Cyclotella meneghiniana* Kütz. | CYM01Y | 1 | 1-6 | P-B | temp | st | sp | o-a | hl | alf |
| 99 | *Cyclotella stelligera* (Cleve et Grun. in Cleve) Van Heurck | CYSTER | 1 | 0 | P-B | - | st | es | x | i | ind |
| 100 | *Cyclotella tuberculata* Makar. et Log. | CYCTUQ | 0 | 1 | P | - | - | - | - | hl | - |
| 101 | Cylindrotheca gracilis (Bréb. ex Kütz.) Grun. in Van Heurck | CYLIGQ | 0 | 2 | B | - | st | - | o | hl | - |
| 102 | *Cymatopleura librile* (Ehrb.) Pant. | CL001A | 1-3 | 0 | P-B | - | - | - | o | i | alf |
| 103 | *Cymbella affinis* Kütz. | CYAFFR | 2 | 0 | B | temp | st-str | sx | b-o | i | alf |
| 104 | *Cymbella aspera* (Ehrb.) Perag. in Pelletan | CYASPR | 2 | 0 | B | - | st-str | es | b-o | i | alf |
| 105 | *Cymbella cistula* (Ehrb.) Kirchn. | CYCISR | 1-4 | 0 | B | - | st-str | sx | o-b | i | alf |
| 106 | *Cymbella cornuta* (Ehrb.) R. Ross | CYLANR | 2 | 0 | B | - | - | sx | o | i | alf |
| 107 | *Cymbella cuspidata* Kütz. | CYCUSR | 1 | 0 | B | temp | - | - | o-a | i | ind |
| 108 | *Cymbella ehrenbergii* Kütz. | CYEHRR | 1 | 0 | B | - | st-str | - | b-o | i | alb |
| 109 | *Cymbella hybrida* Cleve | CYMHYQ | 0 | 1 | B | - | - | - | - | hl | alb |
| 110 | *Cymbella microcephala* Grun. in Van Heurck | CYMBMO | 0 | 1-2 | B | - | - | es | b | i | alf |
| 111 | *Cymbella naviculiformis* (Auersw. ex Heib.) Cleve | CM009A | 1 | 0 | B | - | - | es | o | i | ind |
| 112 | *Cymbella reinhardtii* Grun. | CM099A | 1 | 0 | B | - | - | - | - | - | - |
| 113 | *Cymbella* sp. | CYMBEH | 0 | 1 | B | - | - | - | - | - | - |
| 114 | *Cymbella subcuspidata* Kramm. | CYHETL | 1 | 0 | B | - | - | - | - | i | acf |
| 115 | *Cymbella tumidula* Grun. in A. Schmidt | CM109A | 1 | 0 | B | - | - | - | - | i | alf |
| 116 | *Cymbella turgidula* Grun. | CYTURL | 1 | 0 | B | - | st-str | es | - | - | ind |
| 117 | *Diatoma hiemale* (Roth) Heib. | DIHIER | 2-4 | 0 | P-B | cool | st-str | sx | b-o | hb | ind |
| 118 | *Diatoma mesodon* (Ehrb.) Grun. | DT021A | 1-6 | 0 | B | cool | st-str | sx | o-b | hb | - |
| 119 | *Diatoma tenue* Ag. | DITENR | 1-4 | 0 | P-B | - | st | sx | b-a | hl | ind |
| 120 | *Diatoma vulgare* Bory | DIVULR | 1-3 | 0 | P-B | - | st-str | sx | b-a | i | ind |
| 121 | *Didymosphenia geminata* (Lyngb.) M. Schm. in A. Schmidt | DYDGER | 1 | 0 | B | - | st-str | sx | o-a | i | ind |
| 122 | *Diploneis ovalis* (Hilse) Cleve | DIPLOR | 1 | 0 | B | - | - | sp | b | i | alb |
| 123 | *Encyonema elginense* (Kramm.) D.G. Mann | ENCELQ | 0 | 2 | B | - | st | sx | - | hb | acf |

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 124 | *Encyonema minutum* (Hilse ex Rabenh.) D.G. Mann | ENCMML | 1 | 0 | B | - | - | es | o-b | oh | ind |
| 125 | *Encyonema silesiacum* (Bleisch in Rabenh.) Mann | ENCSIQ | 1 | 3 | B | - | st-str | sx | x-o | i | ind |
| 126 | *Entomoneis alata* (Ehrb.) Ehrb. | ENO01Y | 0 | 1-3 | P-B | - | st | - | - | mh | alf |
| 127 | *Entomoneis paludosa* (W. Sm.) Reim. | ENP01Y | 0 | 1-3 | B | - | - | - | - | - | - |
| 128 | *Epithemia adnata* var. *porcellus* (Kütz.) R. Ross | EPIAPR | 1 | 0 | B | - | - | - | b | i | alb |
| 129 | *Eunotia bilunaris* (Ehrb.) Mills | EUNBIR | 1 | 0 | B | temp | - | es | b | i | acf |
| 130 | *Eunotia diodon* Ehrb. | EUNDIR | 1 | 0 | B | cool | st | - | o-x | i | acf |
| 131 | *Eunotia exigua* (Breb ex Kütz.) Rabenh. | EUNGRR | 1 | 0 | B | - | - | - | a | hb | ind |
| 132 | *Eunotia minor* (Kütz.) Grun. | EU110A | 1 | 0 | B | - | - | es | x | - | - |
| 133 | *Eunotia praerupta* Ehrb. | EUNPPR | 1 | 0 | B | cool | st-str | sx | b | hb | acf |
| 134 | *Eunotia steineckei* Petersen | EUNEXR | 1 | 0 | B | - | - | es | o-b | hb | acf |
| 135 | *Fallacia pygmaea* (Kütz.) Stickle et Mann | FP001Y | 0 | 1-4 | B | - | - | es | b-o | mh | alf |
| 136 | *Fallacia subhamulata* (Grun.) Mann | FS001Y | 1 | 0 | B | - | - | - | - | i | ind |
| 137 | *Fragilaria capucina* Desm. var. *capucina* | FRACAQ | 3 | 3 | B | - |  | es | o | i | alf |
| 138 | *Fragilaria capucina* var. *rumpens* (Kütz.) Lange-Bert. | FR009G | 1-5 | 0 | B | - | st-str | es | o | i | acf |
| 139 | *Fragilaria capucina* var. *vaucheriae* (Kütz.) Lange-Bert. | FRAVCR | 3-4 | 0 | P | - | - | sx | o-b | i | alf |
| 140 | *Fragilaria construens* f. *construens* (Ehrb.) Hust. | STRSCQ | 0 | 1 | P-B | temp | st-str | sx | o | i | alf |
| 141 | *Fragilaria crotonensis* Kitt. | FRACRR | 1 | 0 | P | - | st | es | a-b | hl | alf |
| 142 | *Fragilaria fasciculata* (Ag.) Lange-Bert. | FR057A | 0 | 1-2 | B | - | st | sx | o | hl | alf |
| 143 | *Fragilaria pulchella* (Ralfs ex Kütz.) Lange-Bert. | CTEKRL | 2 | 0 | Ep | - | - | - | b | hl | - |
| 144 | *Fragilaria ulna* var. *acus* (Kütz.) Lange-Bert. | SYNACR | 1 | 0 | P | - | st-str | es | b | i | alb |
| 145 | *Fragilaria vaucheriae* (Kütz.) Peters. | FRAVVR | 1-4 | 0 | P | - | - | sx | o-b | i | alf |
| 146 | *Fragilariforma bicapitata* (Mayer) Will. et Round | FRFOBR | 1 | 0 | B | - | - | - | o-b | hb | ind |
| 147 | *Fragilariforma virescens* (Ralfs) Williams et Round | FRFVIR | 1 | 0 | P-B | - | st | es | o | i | ind |
| 148 | *Frustulia rhomboides* (Ehrb.) De Toni | FRURHR | 1-2 | 0 | B | - | st | es | x-b | hb | acf |
| 149 | *Frustulia vulgaris* (Thw.) De Toni | FU001A | 1-3 | 0 | P-B | - | st | es | x-b | i | alf |


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 150 | *Gomphoneis quadripunctatum* (Østr.) Dawson ex Ross et Sims | GOMPQR | 1-2 | 0 | B | - | - | es | - | i | ind |
| 151 | *Gomphonema acuminatum* Ehrb. var. *acuminatum* | GOMACR | 1 | 0 | P-B | - | st | es | x-b | i | alf |
| 152 | *Gomphonema acuminatum* var. *coronatum* (Ehrb.) W. Sm. | GOMAAR | 1 | 0 | P-B | - | st | - | b | i | ind |
| 153 | *Gomphonema affine* Kütz. | GO020A | 0 | 1-5 | P-B | - | st | es | o-b | - | - |
| 154 | *Gomphonema angustatum* (Kütz.) Rabenh. | GOA01Y | 1-4 | 1 | P-B | - | st-str | es | b | i | alf |
| 155 | *Gomphonema angustum* Ag. | GO073A | 0 | 1 | P-B | - | st-str | es | o-b | i | ind |
| 156 | *Gomphonema clavatum* E. Reichardt | GO029A | 1 | 0 | B | - | str | es | o-b | i | ind |
| 157 | *Gomphonema minutum* (Ag.) Ag. | GOMMIO | 0 | 1 | B | - | - | es | o-b | oh | alf |
| 158 | *Gomphonema parvulum* Kütz. | GO013A | 1-3 | 1 | B | temp | str | es | x | i | ind |
| 159 | *Gomphonema productum* (Grun.) Lange-Bert. et E. Reichardt | GO003B | 1-5 | 0 | B | - | str | es | b | i | alf |
| 160 | *Gomphonema truncatum* Ehrb. sensu Patrick et Reim. | GO023A | 1 | 0 | P-B | - | - | es | o-x | - | - |
| 161 | *Gyrosigma acuminatum* (Kütz.) Rabenh. | GY005A | 1 | 1-5 | B | cool | - | - | o-x | i | alf |
| 162 | *Hannaea arcus* f. *arcus* (Ehrb.) Patr. | HANNAR | 1-6 | 0 | B | - | str | es | o | i | alf |
| 163 | *Hannaea arcus* f. *recta* (Cl.) Foged | HANNRR | 1-5 | 0 | B | - | - | sx | - | - | - |
| 164 | *Hannaea arcus* var. *amphioxys* (Rabenh.) Patr. | HANAAL | 1-3 | 0 | B | cool | str | - | x | i | alf |
| 165 | *Hantzschia amphioxys* (Ehrb.) Grun. in Cl. et Grun. | HA001A | 1-2 | 1 | B | temp | - | es | b-o | i | ind |
| 166 | *Licmophora* sp. | LICMOQ | 0 | 1-2 | - | - | - | - | - | - | - |
| 167 | *Luticola mutica* (Kütz.) Mann | LUM01Y | 1-2 | 1 | B | - | st-str | sp | o | i | ind |
| 169 | *Luticola muticopsis* (Van Heurck) D.G. Mann | LUS01Y | 0 | 1 | B | - | st-str | - | - | - | - |
| 189 | *Melosira varians* Ag. | ME015A | 2 | 0 | P-B | temp | st-str | es | a-b | hl | alf |
| 170 | *Meridion circulare* (Grev.) Ag. var. *circulare* | MECI0A | 1-6 | 0 | B | - | str | es | o-b | i | alf |
| 171 | *Meridion circulare* var. *constrictum* (Ralfs) Van Heurck | MECIRR | 1-2 | 0 | P-B | - | st-str | sx | x | hb | - |
| 172 | *Navicula angusta* Grun. | NA037A | 0 | 1 | B | - | - | sx | | hl | acf |
| 173 | *Navicula capitata* Ehrb. var. *capitata* | NACAPR | 1 | 0 | B | temp | - | es | o-b | hl | alf |

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 174 | *Navicula capitata* var. *hungarica* (Grun.) Ross | NACUSR | 1 | 0 | B | - | - | es | o | i | - |
| 175 | *Navicula crucicula* (W. Sm.) Donk. | NACRUR | 1 | 0 | B | - | - | | | mh | ind |
| 176 | *Navicula erifuga* Lange-Bert. | NAE01Y | 0 | 1-5 | B | - | - | es | x-o | | |
| 177 | *Navicula gregaria* Donkin | NAG01Y | 1-4 | 1 | P-B | temp | - | es | x-b | mh | alf |
| 178 | *Navicula peregrina* (Ehrb.) Kütz. | NAPERR | 1 | 0 | B | - | - | es | - | mh | alf |
| 179 | *Navicula perminuta* Grun. in Van Heurck | NAPERQ | 0 | 1-6 | B | - | - | es | - | hl | |
| 180 | *Navicula radiosa* Kütz. | NA003A | 1 | 0 | B | temp | st-str | es | o | i | ind |
| 181 | *Navicula recens* (Lange-Bert.) Lange-Bert. | NAR01Y | 0 | 1-5 | P-B | - | - | es | o-b | i | - |
| 182 | *Navicula schroeterii* Meist. | NAS01Y | 0 | 1 | B | - | - | es | a-b | i | alf |
| 183 | *Navicula* sp. | NA001Y | 0 | 1 | - | - | - | - | - | - | - |
| 184 | *Navicula spicula* Hickie | NASPIQ | 0 | 1-6 | P-B | - | - | - | - | mh | - |
| 185 | *Navicula stroemii* Hust. | NA650A | 0 | 1 | B | eterm | - | es | o | oh | alf |
| 186 | *Navicula tripunctata* (O. Müll.) Bory | NATRIO | 0 | 2 | B | - | st-str | es | b | i | ind |
| 187 | *Navicula trivialis* Lange-Bert. | NATRVO | 0 | 1-3 | B | - | - | sp | b-o | i | alf |
| 188 | *Navicula veneta* Kütz. | NA054A | 0 | 1-6 | B | - | - | es | x-o | hl | alf |
| 189 | *Navicula viridula* (Kütz.) Ehrb. | NAV01Y | 1 | 0 | B | - | | es | o | hl | alf |
| 190 | *Naviculadicta protracta* Grun. | NADICR | 1 | 0 | B | - | - | es | x-b | mh | ind |
| 191 | *Neidium affine* (Ehrb.) Cl. | NE003A | 2-3 | 0 | B | - | - | - | o | i | alf |
| 192 | *Neidium ampliatum* (Ehrb.) Kramm. | NEAMPO | 1 | 0 | B | - | st | es | | hb | ind |
| 193 | *Neidium bisulcatum* (Lagerst.) Cleve | NEBISR | 1 | 0 | B | - | - | es | o-b | hb | alf |
| 194 | *Neidium iridis* var. *diminutum* (Pant.) Wislouch et Kolbe | NEIRDR | 1 | 0 | B | - | - | - | o | i | ind |
| 195 | *Neidium iridis* (Ehrb.) Cl. var. *iridis* | NEIRIR | 1 | 0 | B | - | st | es | o-x | hb | ind |
| 196 | *Nitzschia acicularis* (Kütz.) W. Sm. | NI042A | 0 | 1 | P-B | temp | - | es | o-b | i | alf |
| 197 | *Nitzschia amphibia* Grun. | NIA01Y | 1-3 | 1 | P-B | temp | - | sp | o | i | alf |
| 198 | *Nitzschia aurariae* Choln. | NITZAQ | 0 | 1-6 | B | - | - | - | - | oh | - |
| 199 | *Nitzschia communis* Rabenh. | NITCOR | 2 | 0 | P-B | - | st-str | sp | o | i | alf |
| 200 | *Nitzschia compressa* var. *balatonis* (Grun.) Lange-Bert. | NIC02Y | 0 | 1-2 | B | - | - | - | - | hl | |
| 201 | *Nitzschia desertorum* Hust. | NITDSQ | 0 | 1-2 | B | - | st-str | - | b | mh | alf |
| 202 | *Nitzschia frustulum* var. *bulnheimiana* (Rabenh.) Grun. in Van Heurck | NI008A | 1-5 | 1 | B | temp | - | sp | b | hl | alf |

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 203 | *Nitzschia grandifera* Hust. | NITGRO | 0 | 1 | B | - | - | - | | hl | - |
| 204 | *Nitzschia inconspicua* Grun. | NITINO | 0 | 1-5 | B | - | - | es | a-b | - | - |
| 205 | *Nitzschia laevis* Hust. | NITLEO | 0 | 1 | B | - | - | - | - | mh | - |
| 206 | *Nitzschia linearis* (Ag.) W. Sm. | NI031A | 1-4 | 2 | B | temp | - | es | x | i | alf |
| 207 | *Nitzschia monachorum* Lange-Bert. | NITMOQ | 0 | 1 | B | - | st | - | - | - | - |
| 208 | *Nitzschia obtusa* W. Sm. | NI036A | 0 | 1-6 | B | - | - | es | b | mh | - |
| 209 | *Nitzschia palea* (Kütz.) W. Smit | NI017A | 1-6 | 1-6 | P-B | temp | - | sp | o-x | i | ind |
| 210 | *Nitzschia pseudofonticola* Hust. | NI028A | 1 | 1 | B | - | - | es | o-p | i | alf |
| 211 | *Nitzschia reversa* W. Sm. | NIR01Y | 0 | 1-3 | P | - | - | - | - | hl | - |
| 212 | *Nitzschia scalpelliformis* (Grun.) Grun. in Cleve et Grun. | NISC1Y | 0 | 1-4 | B | - | - | sp | - | hl | - |
| 213 | *Nitzschia sigma* (Kütz.) W. Sm. | NIS01Y | 0 | 1-4 | B | temp | - | es | - | mh | ind |
| 214 | *Nitzschia solita* Hust. | NISL1Y | 0 | 1-3 | B | - | st | es | a-b | mh | alf |
| 215 | *Nitzschia umbonata* (Ehrb.) Lange-Bert. | NI184A | 2 | 0 | P | - | st-str | es | b-o | i | ind |
| 216 | *Nitzschia vermicularis* (Kütz.) Hantzsch in Rabenh. | NI049A | 1 | 0 | B | - | - | - | o | i | alf |
| 217 | *Pinnularia borealis* Ehrb. | PINBOQ | 2 | 1 | B | - | ae | es | o-b | i | ind |
| 218 | *Pinnularia brevicostata* Cl. | PINBRR | 1 | 0 | B | cool | - | - | - | i | ind |
| 219 | *Pinnularia gibba* var. *linearis* Hust. | PINGIR | 1 | 0 | B | - | - | - | - | i | ind |
| 220 | *Pinnularia globiceps* Greg. | PINGLR | 1 | 0 | B | - | - | - | - | i | acf |
| 221 | *Pinnularia infirma* Kramm. | PINPUR | 1 | 0 | B | - | - | - | - | i | ind |
| 222 | *Pinnularia intermedia* (Lagerst.) Cleve | PI047A | 2 | 0 | B | - | st | - | x | i | ind |
| 223 | *Pinnularia interrupta* W. Smith | PINMER | 1-3 | 0 | B | - | - | - | o-x | i | ind |
| 224 | *Pinnularia major* (Kütz.) Rabenh. | PINMAR | 1-2 | 0 | B | temp | st-str | | x | i | ind |
| 225 | *Pinnularia microstauron* var. *brebissonii* (Ehrb.) Cleve | PIMIBL | 2 | 0 | B | - | st-str | es | o-x | i | ind |
| 226 | *Pinnularia microstauron* (Ehrb.) Cleve var. *microstauron* | PINMMR | 1-3 | 0 | B | temp | - | sp | x | i | ind |
| 227 | *Pinnularia viridis* (Nitzsch) Ehr. | PINVIR | 1-3 | 0 | P-B | temp | - | - | o-x | i | ind |
| 228 | *Placoneis elginensis* (Greg.) E. Cox | PLACER | 2 | 0 | B | - | - | sx | x-o | i | ind |
| 229 | *Placoneis gastrum* (Ehrb.) Mereschk. | PLAGAR | 5 | 0 | B | - | - | sx | x-o | i | ind |
| 230 | *Placoneis placentula* f. *rostrata* A. Mayer | PLAPLR | 1 | 0 | B | - | - | - | - | i | alf |

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 231 | *Pleurosigma salinarum* Grun. | PL050A | 0 | 1-6 | B | - | - | - | - | mh | |
| 232 | *Pleurosira laevis* (Ehrb.) Compère | PLELEQ | 0 | 1-6 | B | temp | - | - | - | mh | alf |
| 233 | *Reimeria sinuata* (Greg.) Kociolek et Stoermer | REIMER | 1-3 | 0 | B | - | st | sx | - | i | ind |
| 234 | *Rhoicosphenia abbreviata* (C. Ag.) Lange-Bert. | RC002A | 0 | 1-2 | P-B | - | - | es | x-o | i | alf |
| 235 | *Rhopalodia brebissonii* Kramm. | RHOPAQ | 0 | 1 | B | - | - | | | hl | |
| 236 | *Rhopalodia gibba* (Ehrb.) O. Müll. | RHPG1Y | 1 | 0 | B | temp | - | es | x-o | i | alb |
| 237 | *Sellaphora bacillum* (Ehrb.) D.G. Mann | NAVBAR | 1-2 | 0 | B | - | - | sx | o-b | i | alf |
| 238 | *Sellaphora pupula* (Kütz.) Mereschk. | SELLUL | 1-2 | 0 | B | eterm | st | sp | o-x | hl | ind |
| 239 | *Sellaphora rectangularis* (Greg.) Lange-Bert. et Metzeltin | SELLRL | 1-2 | 0 | B | temp | - | sx | - | hl | ind |
| 240 | *Stauroneis anceps* Ehrb. var. *anceps* | STAUAR | 2-3 | 0 | P-B | - | - | sx | x | i | ind |
| 241 | *Stauroneis anceps* var. *linearis* Rabenh. | STAALR | 1 | 0 | B | - | - | sx | b | i | alf |
| 242 | *Stauroneis phoenicenteron* (Nitzsch) Ehrb. | STAPHR | 1 | 0 | B | temp | - | es | x-o | i | ind |
| 243 | *Stauroneis producta* Grun. | STAUPQ | 0 | 1 | B | - | st | sx | o | mh | ind |
| 244 | *Stauroneis smithii* Grun. | SA003A | 1 | 0 | P-B | - | st-str | | x-o | i | alf |
| 245 | *Staurosirella leptostauron* (Ehrb.) Williams et Round | STRSLL | 3-5 | 0 | B | - | st | es | a-b | hb | alf |
| 246 | *Staurosirella pinnata* (Ehrb.) Williams et Round | STRSPL | 2-3 | 0 | B | temp | st-str | es | b-a | hl | alf |
| 247 | *Stephanodiscus hantzschii* Grun. in Cl. et Grun. | STH01Y | 0 | 1-4 | P | temp | st | es | a-b | i | alf |
| 248 | *Surirella angusta* Kütz. | SU001A | 1-3 | 1 | P-B | - | st-str | es | o | i | alf |
| 249 | *Surirella biseriata* Bréb. ex Godey | SURBIR | 1 | 0 | P-B | - | st-str | sx | o-b | i | alf |
| 250 | *Surirella brebissonii* Kramm. et Lange-Bert. | SUBREQ | 1 | 1 | B | - | st-str | - | x | i | alf |
| 251 | *Surirella capronii* Bréb. ex Kütz. | SURCAO | 0 | 1 | P-B | - | st | | x | i | ind |
| 252 | *Surirella minuta* Bréb. in Kütz. | SURMIR | 1-4 | 0 | B | - | st-str | es | o-a | i | ind |
| 253 | *Surirella ovalis* Bréb. | SUV01Y | 0 | 1-3 | P-B | - | st-str | es | o | mh | alf |
| 254 | *Surirella peisonis* Pant. | SUPIEQ | 0 | 1 | B | - | - | - | a | - | - |
| 255 | *Surirella splendida* (Ehrb.) Kütz. | SURSPR | 1-2 | 0 | P-B | - | - | - | o-b | i | alf |
| 256 | *Surirella tenera* Greg. | SURTER | 1 | 0 | P-B | - | st | es | o | i | alf |

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 257 | *Synedra inaequalis* Kobayasi | SYINAL | 1 | 0 | - | - | - | sx | - | - | - |
| 258 | *Synedra* ulna var. *amphirhynchus* (Ehrb.) Grun. | SYNUAR | 2-4 | 0 | B | - | - | es | - | i | alf |
| 259 | *Synedra ulna* var. *contracta* Østr. | SYNUCR | 1 | 0 | - | - | - | es | - | - | - |
| 260 | *Tabellaria fenestrata* (Roth) Kütz. | TAFERR | 1-2 | 0 | P-B | - | st-str | es | x | hb | acf |
| 261 | *Tabellaria flocculosa* (Roth) Kütz. | TA001A | 1-2 | 0 | P-B | eterm | st-str | es | o-a | hb | acf |
| 262 | *Thalassiosira weissflogii* (Grun. in Van Heurck) Fryx. et Hasle | THAWEQ | 0 | 1-2 | P-B | - | - | sp | o | hl | alf |
| 263 | *Tryblionella acuminata* W. Sm. | TRYACA | 0 | 1-2 | P | - | st | sx | b-p | mh | alf |
| 264 | *Tryblionella apiculata* Greg. | TYA01Y | 0 | 1-6 | B | - | - | es | o-a | mh | alf |
| 265 | *Tryblionella debilis* Arnott in O'Meara | TRYBDQ | 0 | 1-3 | P-B | - | ae | es | o | i | alf |
| 266 | *Tryblionella gracilis* W. Sm. | TYG01Y | 1 | 1-3 | B | - | - |  | a-b | hl | alf |
| 267 | *Tryblionella hungarica* (Grun.) Mann | TYH01Y | 0 | 1-6 | P-B | - | - | sp | a-b | mh | alf |
| 268 | *Tryblionella punctata* W. Sm. | TRYBPQ | 0 | 1 | B | eterm | - | - | - | mh | - |
| 269 | *Ulnaria acus* (Kütz.) Aboal | FRAUAR | 1 | 0 | P-B | - | st-str | es | o-a | i | alb |
| 270 | *Ulnaria ulna* (Nitzsch) Compère in Jahn et al. | FRU01Y | 1-5 | 1-5 | P-B | temp | st-str | es | b-o | i | ind |
|  | **Chlorophyta** |  |  |  |  |  |  |  |  |  |  |
| 271 | *Actinastrum hantzschii* var. *subtile* Wolosz. | ACHS1Y | 0 | 1 | P-B | - | - | - | b | i | - |
| 272 | *Characium ornithocephalum* A. Br. | COR01Y | 0 | 3 | Ep | - | - | - | - | i | - |
| 273 | *Chlamydomonas* sp. | CHM01Y | 0 | 1 | P | - | - | - | b-p | - | - |
| 274 | *Chlorococcum* sp. | CHC01Y | 0 | 1-2 | - | - | - | - | - | - | - |
| 275 | *Cladophora glomerata* (L.) Kütz. | CLAG1Y | 0 | 1-6 | P-B | - | st-str | - | b-o | i | alf |
| 276 | *Closterium acerosum* (Schrank) Ehrb. ex Ralfs | CLSA1Y | 1 | 0 | P-B | - | st-str | - | a-b | i | ind |
| 277 | *Closterium peracerosum* Gay | CLOPEH | 0 | 1-4 | P-B | - | st-str | - | b | - | - |
| 278 | *Coelastrum astroideum* de Not. | COEA1Y | 0 | 1-5 | P | - | st-str | - | b | - | - |
| 279 | *Coelastrum microporum* Näg. | COEM1Y | 0 | 1 | P-B | - | st-str | - | b | i | ind |
| 280 | *Cosmarium subprotumidum* Nordst. | COSSSQ | 0 | 1 | P-B | - | st-str | - | - | - | acf |
| 281 | *Desmodesmus abundans* (Kirchn.) Hegew. | SCEQUR | 1-3 | 0 | P-B | - | st-str | - | o-a | - | - |
| 282 | *Desmodesmus armatus* var. *armatus* (Chod.) Hegew. | DEA01Y | 0 | 1 | P-B | - | st-str | - | o-a | - | - |


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 283 | *Desmodesmus armatus* var. *spinosus* (Fritsch et Rich) Hegew. | DESASH | 0 | 2 | P | - | st-str | - | b | - | - |
| 284 | *Desmodesmus communis* (Hegew.) Hegew. | SCEQQL | 1-3 | 0 | P-B | - | st-str | - | b | i | ind |
| 285 | Desmodesmus costato-granulatus (Skuja) Hegew. | DECG1Y | 0 | 2 | P-B | - | st-str | - | b | - | - |
| 286 | *Desmodesmus intermedius* (R. Chod.) Hegew. | DEIT1Y | 0 | 2 | P-B | - | st-str | - | b | - | - |
| 287 | *Desmodesmus opoliensis* (P. Richt.) Hegew. | SCEOPR | 2 | 0 | P-B | - | st-str | - | b | - | - |
| 288 | *Desmodesmus protuberans* (Fritsch et Rich) Hegew. | DEP01Y | 0 | 1 | P-B | - | st-str | - | - | - | - |
| 289 | *Desmodesmus spinosus* (R. Chod.) Hegew. | DES01Y | 0 | 1 | P-B | - | st-str | - | o-b | - | - |
| 290 | *Dunaliella* sp. | DUNALQ | 0 | 1-6 | - | - | - | - | - | - | - |
| 291 | *Gloxidium rotatoriae* Korsch. | GLOXIRL | 1 | 0 | - | - | - | - | - | - | - |
| 292 | *Gongrosira* sp. | GONGRQ | 0 | 1 | Ep | - | - | - | - | - | - |
| 293 | *Microspora quadrata* Hazen | MICSPR | 5 | 0 | B | - | - | - | b | - | - |
| 294 | *Monoraphidium contortum* (Thur.) Kom.-Legn. | MOCONA | 0 | 2 | P-B | - | st-str | - | b | - | - |
| 295 | *Monoraphidium griffithii* (Berk.) Kom.-Legn. | MOG01Y | 1 | 1 | P-B | - | st-str | - | b | i | - |
| 296 | *Monoraphidium irregulare* (G.M. Smith) Komárkova-Legnerova | ANKANL | 1-2 | 0 | P | - | - | - | - | i | - |
| 297 | *Monoraphidium minutum* (Näg.) Kom.-Legn. | MOM01Y | 0 | 6 | P-B | - | st-str | - | b-a | - | - |
| 298 | *Mougeotia* sp. ster. | MU001Y | 1-3 | 0 | B | - | - | - | o | - | - |
| 299 | *Oedogonium* sp. ster. | OE001Y | 1 | 2-4 | B | - | - | - | - | - | - |
| 300 | *Oocystis lacustris* Chod. | OOLA0A | 0 | 2 | P-B | - | st-str | - | b-o | hl | - |
| 301 | *Oocystis submarina* Lagerh. | OOC01Y | 0 | 1 | P-B | - | st | - | - | i | - |
| 302 | *Pandorina morum* (Müll.) Bory | PAM01Y | 0 | 4 | P | - | st | - | b | i | - |
| 303 | *Pediastrum duplex* Meyen | PDD01Y | 0 | 3-4 | P | - | st-str | - | o-a | i | ind |
| 304 | *Pediastrum tetras* (Ehrb.) Ralfs | PETETH | 0 | 2 | P-B | - | st-str | - | o-a | i | ind |
| 305 | *Raphidocelis sigmoidea* Hind. | RCS01Y | 0 | 1-4 | P | - | st-str | - | - | - | - |
| 306 | *Raphidocelis* sp. | RAPHIQ | 0 | 1 | - | - | - | - | - | - | - |
| 307 | *Rhizoclonium hieroglyphicum* (Ag.) Kütz. | RHZ01Y | 1-6 | 6 | B | - | st-str | - | o | hl | - |
| 308 | *Scenedesmus acuminatus* var. *acuminatus* (Lagerh.) Chod. | SA001Y | 2-4 | 1 | P-B | - | st-str | - | b | i | ind |

| No | Taxon | Code | Rud | Qish | Hab | T | Oxy | D | S | Hal | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 309 | *Scenedesmus acuminatus* var. *biseriatus* Reinh. | SCEACR | 2 | 0 | P | - | - | - | - | i | - |
| 310 | *Scenedesmus bijugatus* (Turp.) Kütz. | SCEBIR | 2 | 0 | P | - | - | - | o-a | i | ind |
| 311 | *Scenedesmus incrassatulus* Bohl. | SCEINH | 0 | 1-3 | P-B | - | st-str | - | - | - | - |
| 312 | *Scenedesmus obliquus* var. *alternans* Christjuk | SCEOAL | 1-4 | 0 | - | - | - | - | - | - | - |
| 313 | *Scenedesmus obliquus* var. *obliquus* (Turp.) Kütz. | SCEOBQ | 1 | 1 | P-B | - | st | - | b-p | i | - |
| 314 | *Scenedesmus obtusus* Meyen | SO001Y | 0 | 2 | P-B | - | st-str | - | b | - | - |
| 315 | *Schroederia setigera* (Schröd.) Lemm. | SDS01Y | 1-2 | 0 | P | - | st-str | - | b-o | i | - |
| 316 | *Spirogyra* sp. ster. | SPG01Y | 3-6 | 4 | B | - | | - | - | - | - |
| 317 | *Stigeoclonium tenue* (Ag.) Kütz. | SCT01Y | 1-6 | 0 | B | - | st-str | - | b-p | - | - |
| 318 | *Stylosphaeridium epiphyticum* (Korsch.) Korsch. | STYE1Y | 0 | 2 | Ep | - | - | - | - | - | - |
| 319 | *Tetraedron minimum* (A. Br.) Hansg. | TETMMA | 0 | 1-2 | | - | - | - | - | - | - |
| 320 | *Ulothrix tenerrima* Kütz. | ULOTTL | 2-6 | 0 | B | - | - | - | o-a | i | - |
| 321 | *Ulothrix zonata* (Weber et Mohr) Kütz. | ULZONL | 1-6 | 0 | P-B | - | st-str | - | o-a | i | ind |
| 322 | *Uronema confervicolum* Lagerh. | URC01Y | 0 | 2-4 | B | - | st-str | - | o-a | - | - |
| | **Rhodophyta** | | | | | | | | | | |
| 323 | *Audouinella pygmaea* (Kütz.) Weber-van Bosse | AUDOUO | 0 | 5-6 | B | - | str | - | x-o | - | alf |

***Note**: Hab – habitat (Ep – epiphytes, B – benthic, P-B – plankto-benthic, P- planktonic); T – temperature (eterm – eurytermic; temp – temperate; warm – warm water; cool – cool water); Oxy – streaming and oxygenation (st – standing water; st-str – low streaming water; str – streaming water); S – degree of saprobity on the Pantle-Buck's (Pantle & Buck 1955) (x – xenosaprobes, x-o – xeno-oligosaprobes, o-x – oligo-xenosaprobes, x-β – xseno-betamesosaprobes, o – oligosaprobes, o-β – oligo-betamesosaprobes, β-o – beta-oligosaprobes, o-α – oligo-alphamesosaprobes, β – betamesosaprobes, β-α – beta-alphamesosaprobes, α-β – alpha-betamesosaprobes, α – alphamesosaprobes); D– degree of saprobity on the Watanabe's (Watanabe 1986) (sx – saproxenous, es – eurysaprobes, sp – saprophiles); Hal – halobity degree (hb – oligohalobes-halophobes, i – oligohalobes-indifferent, mh - mesohalobes, hl – halophiles, ph - polyhalobes); pH – pH degree (alf – alkaliphiles, ind – indifferents; acf – acidophiles, alb - alcalibiontes).*

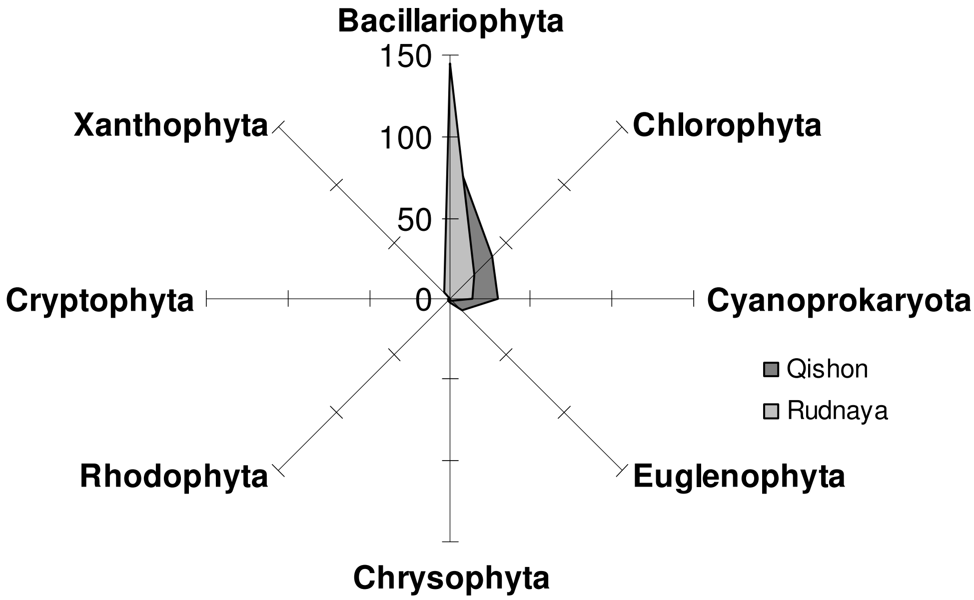



***Figure 3.*** *Distribution of the species community between the algal Divisions in the Rudnaya River and Qishon River.*

The diversity of the species is similar in the two rivers with diatoms prevailing. Figure 3 shows that green algae are second in importance in the both rivers, followed by the cyanoprokaryotes. The presence of red algae can be noted as a unique element of the Qishon River algoflora.

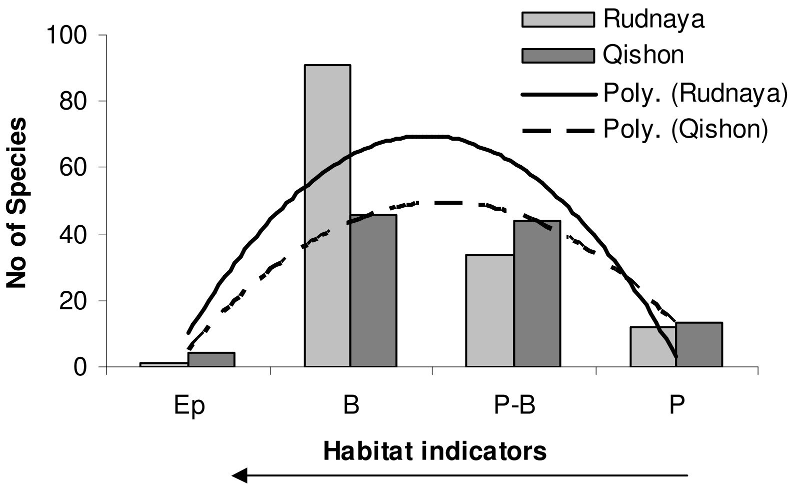



***Figure 4.*** *Distribution of the species diversity in both rivers between habitat ecological groups.*

Distribution of species diversity over the substrate habitation groups in both rivers is shown in Figure 4. The arrow specifies a direction of strengthening of communication with substrate. In the Rudnaya River, the substrate bound species prevail. In the Qishon River, the benthic and plankto-benthic algae are represented by almost even species numbers because the river is low streaming. However the trend lines for the both distributions are similar. Their peaks occur between the groups of benthic and plankto-benthic algae.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

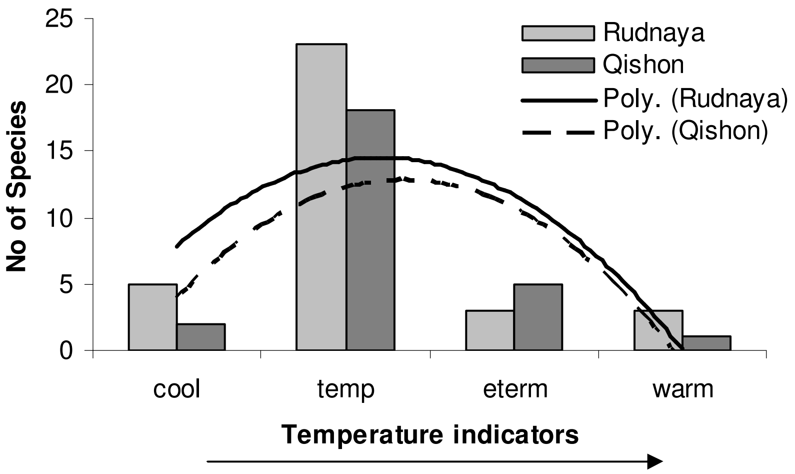



***Figure 5.*** *Distribution of the species diversity in both rivers between temperature indicator groups.*

The whole range of the temperature indicators is represented (Figure 5), predominated by the temperate indicators in both rivers. The arrow specifies strengthening parameter. The trend lines of both distributions are similar, and their peaks occur between the groups of temperate and eurythermic algae.

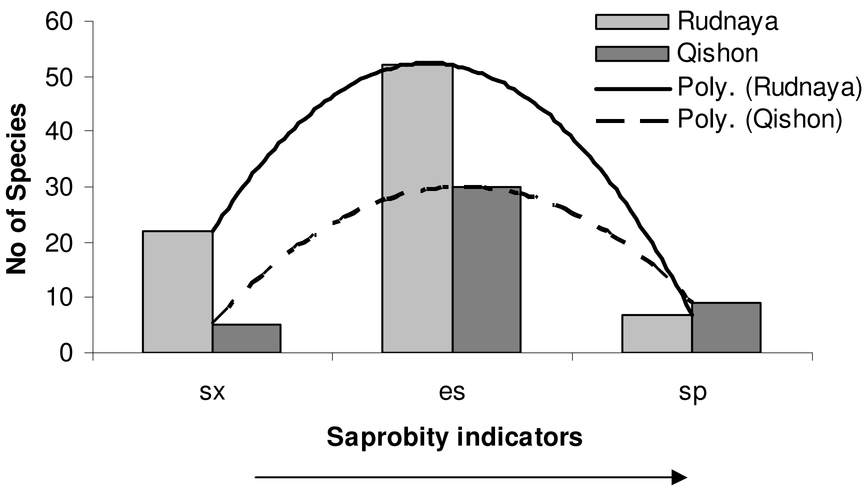



***Figure 6.*** *Distribution of the species diversity in both rivers between indicator groups of organic pollution (Watanabe's system).*

Figure 6 shows distribution of saprobity indicators defined by Watanabe's method (1986). The arrow specifies strengthening parameter. Both distributions are dominated by eurysaprobic group; however the peak for the Qishon River is displaced toward the saprophile diversity, hence, these indicators show a somewhat greater organic pollution in the Qishon River, than in the Rudnaya River.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

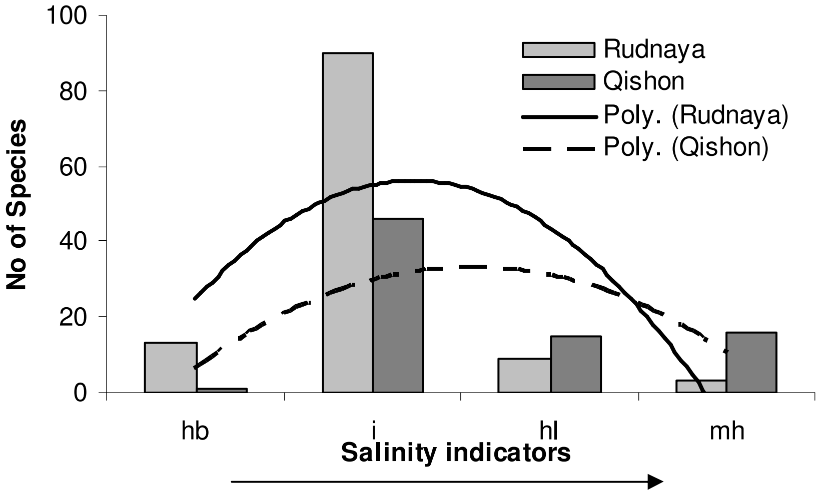



***Figure 7.*** *Distribution of the species diversity in both rivers between salinity indicator groups.*

Salinity indicators represent the oligohalobe and medohalobe groups for both rivers (Figure 7). The arrow specifies strengthening parameter. Among the oligohalobes, the group of indifferents dominates in both rivers. The peak of a trend line for the Qishon River is somewhat displaced towards the indicators of high chloride concentrations. The group of mesohalobes in the Qishon River is also relatively prominent. It testifies to an appreciable influence of marine tidal waters on the algal diversity in the Qishon River, whereas the waters of the Rudnaya River are fresher.

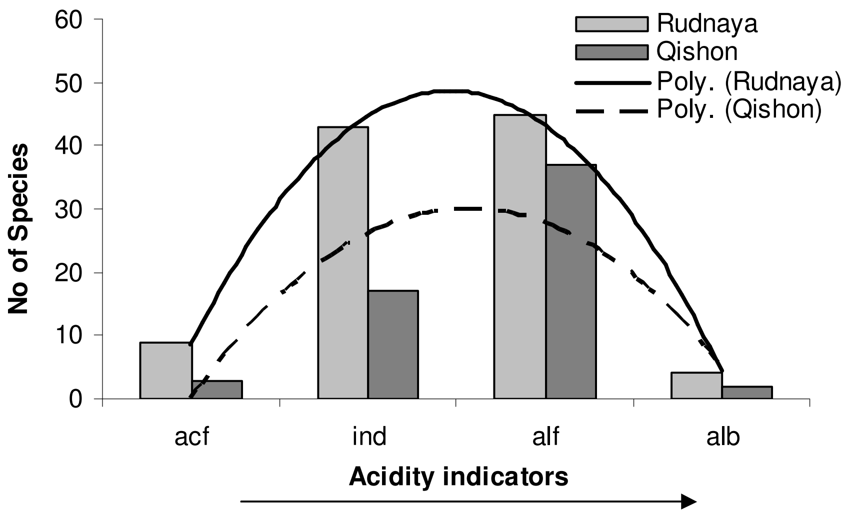



***Figure 8.*** *Distribution of the species diversity in both rivers between acidity indicator groups.*

Algae in both rivers represent the whole spectrum of pH indicators (Figure 8). The arrow specifies strengthening parameter. In the Rudnaya River the group indifferents, preferring neutral waters, predominates. In the Qishon River a prevalence of alcalic species is better marked. Hence, with due attention to the peaks of the trend lines, we conclude that the algae from the Rudnaya River show preference of neutral, subacidic


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

or alkalic waters characteristic of silicate bedrocks, whereas in the Qishon River indicators reflect the regional norm for carbonate provinces (Meybeck & Helmer 1989).

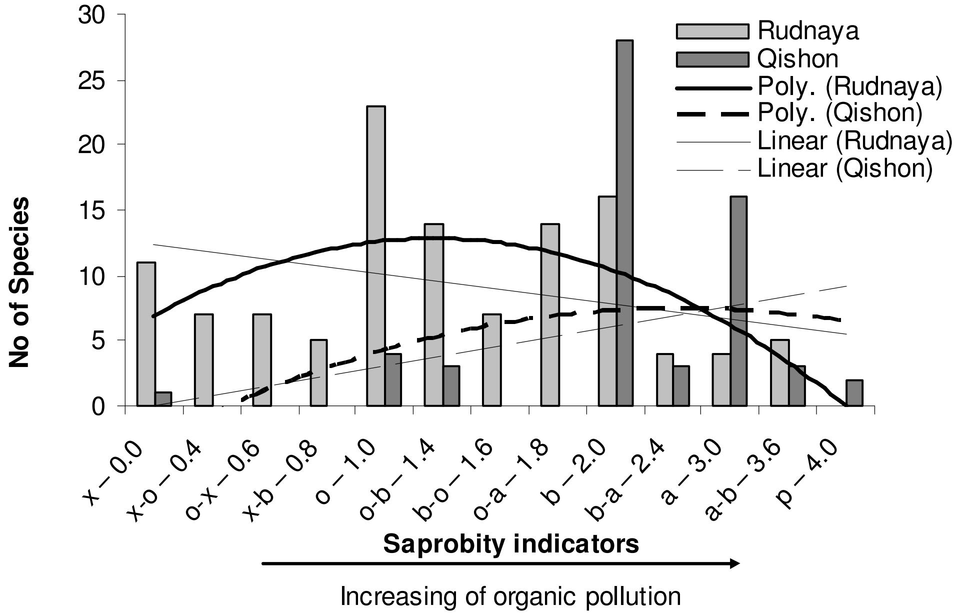



***Figure 9.*** *Distribution of the species diversity in both rivers between indicator groups of organic pollution (Sládeček system).*

The indicators of organic pollution defined by the method of Pantle and Buck (1955) modified by Sládeček (1986) came from a wide range of ecological groups (Figure 9). The arrow specifies strengthening parameter.

In the Rudnaya River, the group of oligosaprobiontes is the largest, whereas in the Quishon River, the betamesosaprobiontes is better represented. The polynomial trend lines reflect a greater number of clear-water species in the Rudnaya River, while the indicators of moderate pollution are more numerous in the Quishon River. The oligo- and xenosaprobic groups are particularly prominent in the Rudnaya River, while the alphmesosaprobic species are more prominent in the Qishon River, which is fairly obvious when the line trends are compared. Therefore, the organic content is greater in the Qishon then in the Rudnaya River.

At the same time, the polluted sections of these rivers differ in the composition of pollutants. The Rudnaya River is clear in the upper reaches being polluted down of Dal'negorsk industrial town. In distinction, the Qishon River is most heavily polluted by agricultural wastes in the upper reaches, with the industrial wastes added downstream. These distinctions are reflected by the dynamics of the saprobity indices in both rivers.

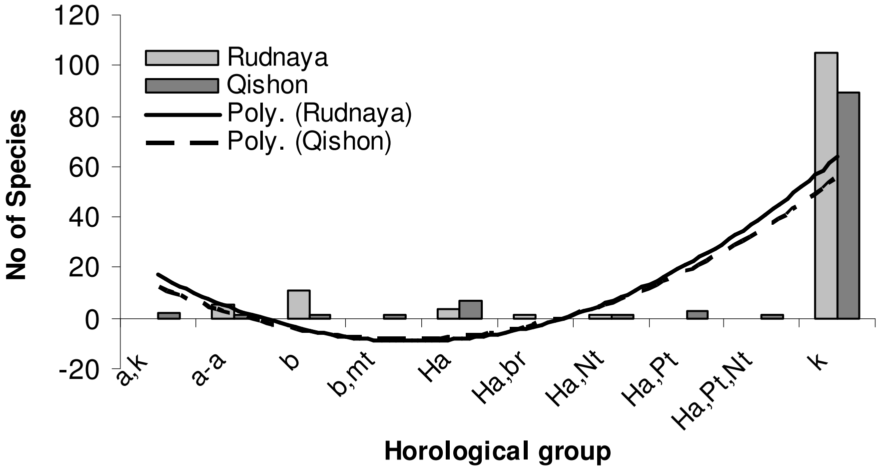



***Figure 10.*** *Distribution of the species diversity in both rivers between chorological groups.*

For geographical analysis, we revealed differentiation of algal species over the major chorological groups (Figure 10). Despite the minor differences in the content of the boreal and holarctic species, the trend lines are similar for both river being dominated by cosmopolitan species.

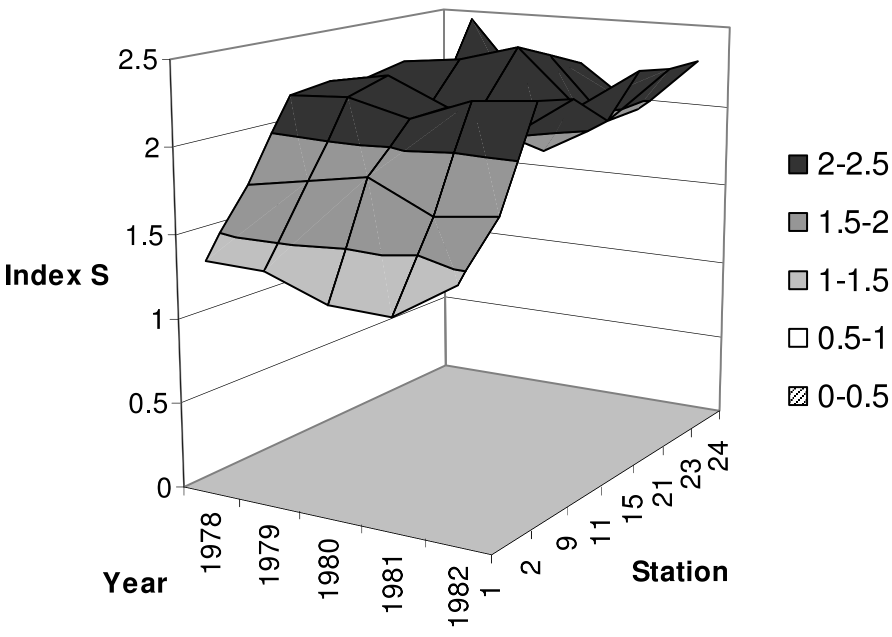



***Figure 11.*** *Saprobity index S dynamic over the sampling station of the Rudnaya River.*

Fig. 11 shows that the saprobity index S for the Rudnaya River (Barinova, Medvedeva 1989;1992a,b; Medvedeva et al. 1986b) fluctuates from the oligosaprobic zone, Class II in the upper reaches (where indices ranged 0.5-1.5) to the betamesosaprobic zone, and Class III near the mouth (where indices ranged 1.5-2.5). During the whole period of observation, the concentration of organic pollutants tended to increase from the upper reaches towards the mouth, where we found a weak 2-year cyclicity of the index.

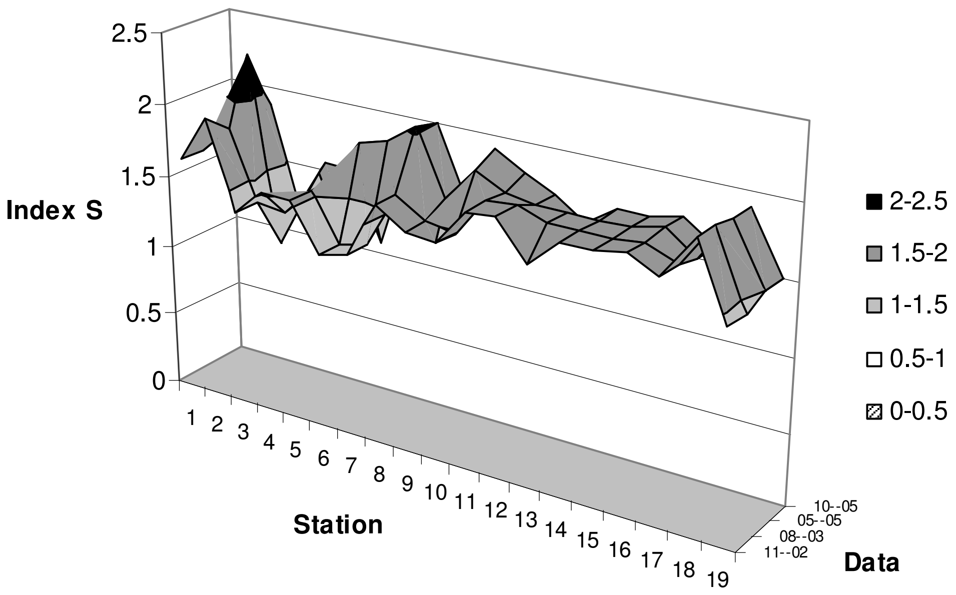



***Figure 12.*** *Saprobity index S dynamic over the sampling station of the Qishon River.*

Fig 12 shows the dynamics of the saprobity index S in the Qishon River during the period 2002 – 2005 (Barinova et al. 2004). The index fluctuates, as in the Rudnaya River, from the oligosaprobic zone, Class II to the betamesosaprobic zone, Class III. The least polluted water was found in the upper reaches (where indices ranged 1.43-1.5). Then, across the agricultural area and before the industrial zone of Haifa the water quality degraded while fluctuations of the index increased (1.93-2.04). This is considered as evidence of misbalance of the system over this segment. At stations 2 and 3, over the zone of industrial toxic wastes, the saprobity index decreased (1.0-1.36) then rising again toward its maximal values in the tidal zone (2.29).

The dynamics of the saprobiyty indices in both rivers show a lesser anthropogenic impact for Rudnaya River than for Qishon River. This is attested by the low amplitude fluctuations and the evidence of natural cyclicity in the Rudnaya River, whereas in the Qishon River the fluctuations are greater and the pollution is more dramatic in the upper reaches.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

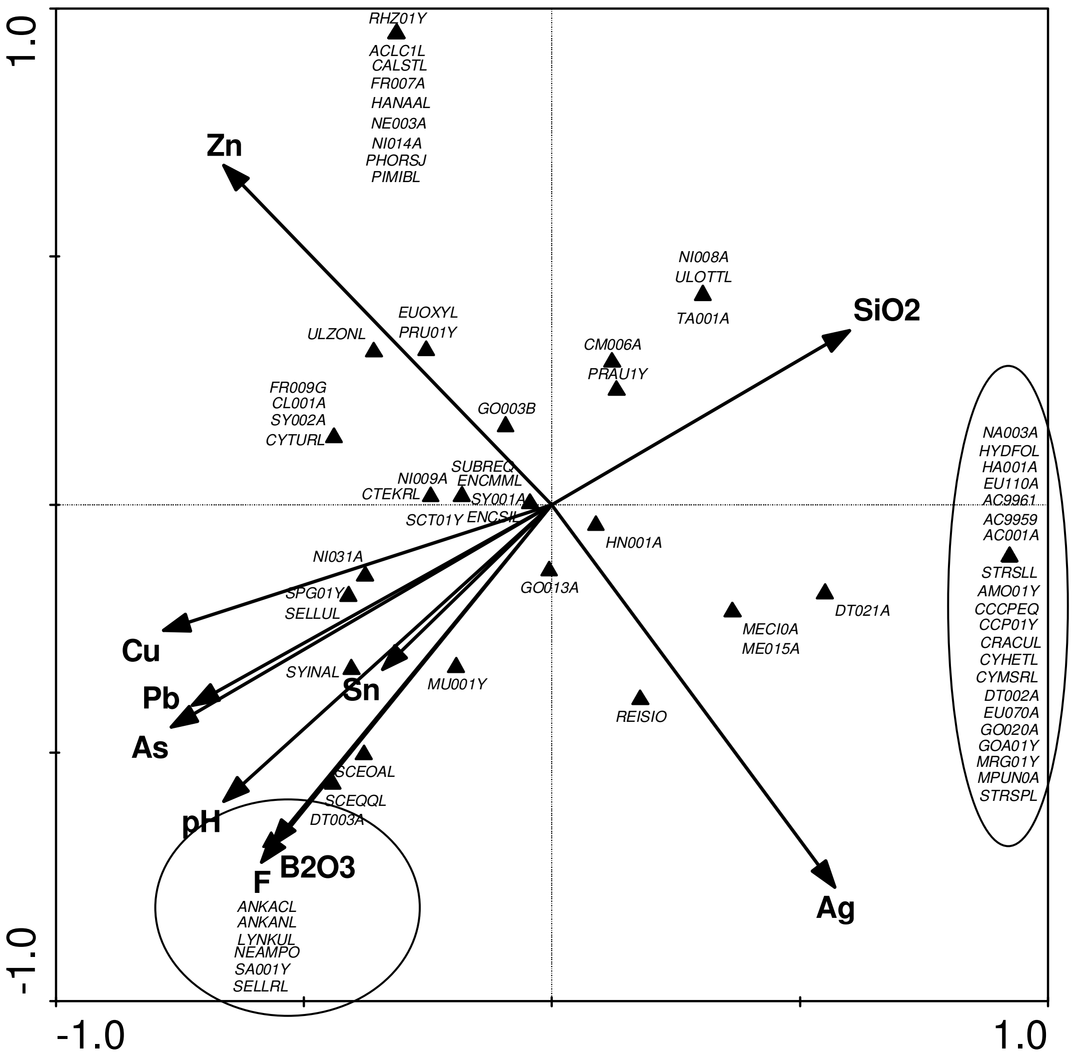



***Figure 13.*** *Biplot of environmental variables and species scores in a CCA of the Rudnaya River. Full names of species are presented in Table 3.*

Figure 13 presents the main factors influencing algal species abundance in the Rudnaya River. It can be seen that the borate salts, fluorides, copper, lead and their associated arsenic all have the same anthropogenic source. It seems that their concentration is related to the pH fluctuations. In distinction, both zinc and silver are of natural origins and their influence on biodiversity is different, even opposite to that of anthropogenic elements.

As a whole, the species of polluted waters are fairly tolerant to individual pollutants, which is in sharp contrast to the group of the neutral pH clear-water species (marked out by the ellipse to the right).

Marked by the lower left ellipse is a biosensor group sensitive to borates and fluorides. This group includes the green algae *Ankistrodesmus acicularis*, *A. angustus*, *Scenedesmus acuminatus*, that are used for biotesting of toxicants, the blue-green algae *Lyngbya kuetzingii* and also the diatoms *Neidium ampliatum* and *Sellaphora rectangularis.*


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

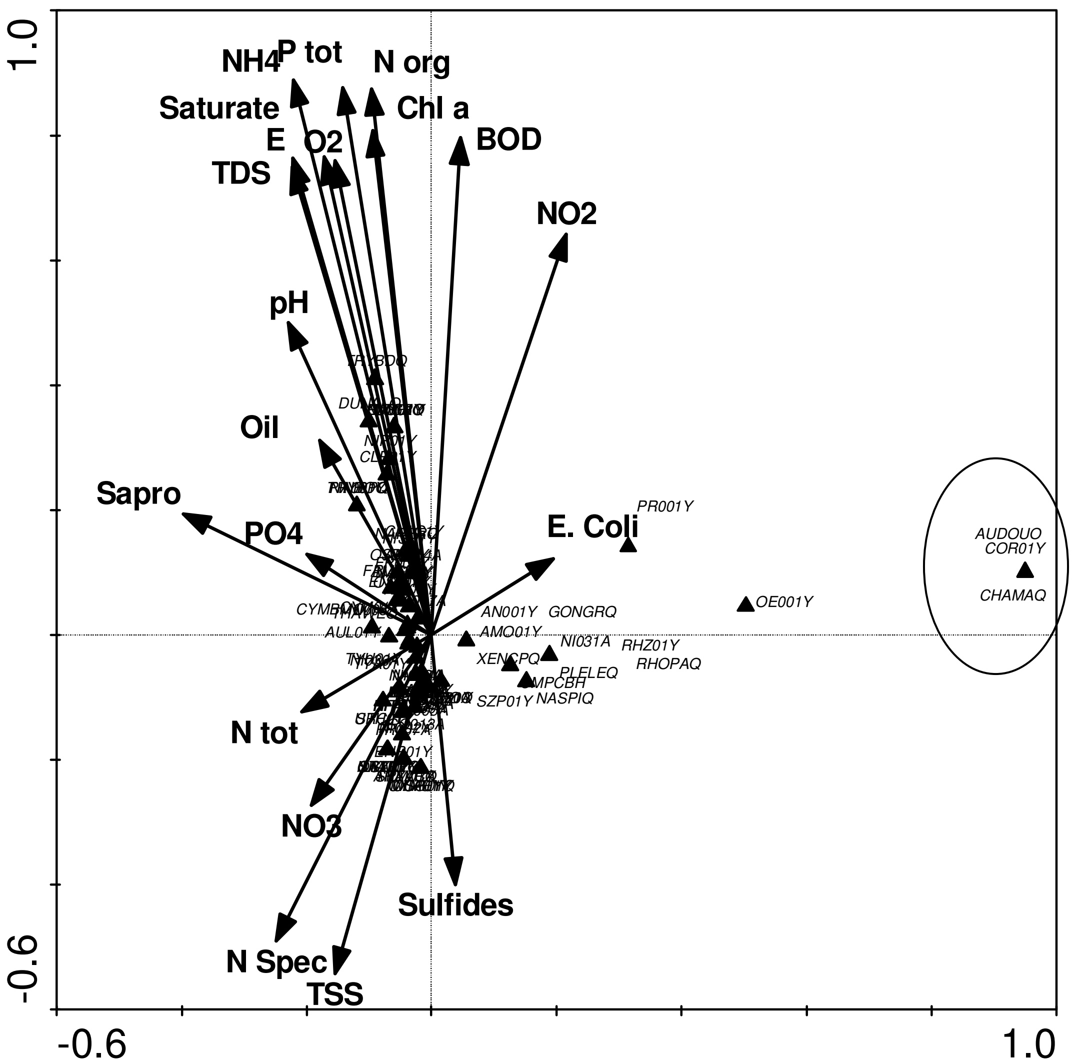



***Figure 14.*** *Biplot of environmental variables and species scores in a CCA of the Qishon River. Full names of species are presented in Table 3.*

The pallet, Figure 14, gives the results of calculation of all environmental factors influencing the algal diversity in the Qishon River. According to the pallet the environmental factors can be divided into two separate groups. The first group includes factors of salinity and the pollution by ammonia, oil and sulfites, as well as the ecosystems activity factors – the concentrations of oxygen, nitrogen, phosphates, BOD and the chlorophyll *a*. The second group of factors includes nitrates and the related total nitrogen, as well as the water turbidity (TSS) and anoxia (sulfides) factors.

We identified a group of species that prefers clear and clean fresh water with low species diversity (right circle). This group includes the red algae *Audouinella pygmaea,* the seldom encountered green algae *Characium ornithocephalum* and the rare blue-green species *Chamaesiphon amethystinus*.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

## Conclusion

In two polluted rivers we revealed algal diversity consisting of 184 algal species and cyanoprokaryotes in the Rudnaya River, and 176 in the Qishon River. The diversity of species was higher in the Rudnaya River. Species diversity in the rivers is significantly different but the distribution of species over the higher taxa were very similar for both rivers.

Based upon the indicator analysis, accepted in the EC (European Parliament 2000), we conclude, that the water is cleaner and the algal diversity is higher in the Rudnaya River than in the Qishon River. The bioindication analysis of species preferences over the ecological groups in respect of salinity, acidification, and oxygenation shows similar distributions. Autecology of algal species is similar in both river communities but the Qishon is more alkalic and organically more polluted than the Rudnaya River. The indices of saprobity S affirm this conclusion. In addition, the Rudnaya River shows a weak 2-year cyclicity of organic pollution which may be a consequence of natural climatic cycles. The impact of pollution here increases downstream to the mouth, whereas the Qishon River is more polluted in the upper reaches, with periodically fluctuating pollution near the Haifa Chemicals. The impact of this pollution decreases down to the mouth.

The CCA determines the most significant factors affecting the species diversity in both rivers. As we know, the most effective application of this statistical approach is the comparison of communities' preferences from different phytogeographical provinces and seasons (Rédei et al. 2003).

As a result, we found a group of biosensors in Rudnaya River sensitive to borates and fluorides: *Ankistrodesmus acicularis*, *A. angustus*, *Scenedesmus acuminatus*, which are used in biotesting of toxicants, as well as *Lyngbya kuetzingii, Neidium ampliatum,* and *Sellaphora rectangularis.*Low clean water requiring species richness was identified in Qishon River. This group includes the red algae *Audouinella pygmaea,* low abounded green algae *Characium ornithocephalum*, as well as the rare blue-green species *Chamaesiphon amethystinus*. These species can be used as biosensors of high pollution in carbonate provinces.The similarity of species diversity distribution over the major bioindicating groups for the both rivers and the specificity of their response to the increasing pollutant concentrations leads us to the following conclusion.

We found that algal biodiversity is more sensitive to technogenic pollution in the silicate province being more tolerant to the same organic pollutants in the carbonate province.This can be related to the presence of metal ions in the water of silicate province with ph less than 7. In contrast, in the carbonate province, the metals are precipitated and their toxic impact is lower.

Thus, our comparison of two polluted rivers shows, that the combination of bioindicational methods and statistics are effective to determine the main factors affecting algal diversity, and are helpful in recognition of indicators or biosensing species for the most important environmental variables.

**Acknowledgements.** We thank Moti Tavassi, who collaborated in collecting algal samples from the Qishon River. This work has been partially funded by the Israel Ministry of Absorption.

## REFERENCES

[1] Banerjee, M. & Sharma, D. (2004): Regulation of phosphatase activity in Chroococcidiopsis isolates from two diverse habitats: effect of light, pH and temperature. – Applied Ecology and Environmental Research 2 (1): 71-82.

[2] Barinova, S.S. (1997): Morphology of connective spines in diatom algae of the genus *Aulacoseira* Thwaites. – Paleontological J. 31(2): 239-245.

[3] Barinova, S.S., Anissimova, O.V., Nevo, E., Jarygin, M.M. & Wasser, S.P. (2004): Diversity and Ecology of Algae from Nahal Qishon, Northern Israel. – Plant Biosystems 138(3): 245-259.

[4] Barinova, S.S., Anissimova, O.V., Nevo, E., Wasser, S.P., Jarygin, M. (2006): Fresh and brackish water algae new for Israel found in Nahal Qishon (N-Israel). – Flora Mediterranea 15: 73-98.

[5] Barinova, S.S., Medvedeva, L.A. (1987): Biological analysis of water quality in major reservoirs of Primorsky region. – Bottom invertebrate of the rivers in Far East and East Siberia. The question of productivity and bioindication of pollution., Far-East Sci. Center of Russian Academy of Science. Vladivostok: 57-63 (Rus).

[6] Barinova, S.S., Medvedeva, L.A. (1989): Sanitary – biological analysis of modern state of the Rudnaya River. – Ecological Problems in Dalnegorsk Region and Possible Solutions (Abstr.). Sci. Appl. Seminar, 6-8 December 1989. Dalnegorsk: 22-23. (Rus).

[7] Barinova, S.S., Medvedeva, L.A. (1992a) A long-term assessment of seasonal pollution dynamics in the Rudnaya River, Primorskiy Region on the basis of algal diversity. – Ecological Regulation. Problems and Methods. Inst. Nat. Cons. Moscow: 10-12. (Rus).

[8] Barinova, S.S., Medvedeva, L.A. (1992b): The comparative analysis of two methods of an estimation of water quality on algal saprobity. – The estimation of a condition and stability of ecosystems (Abstr.). Inst. Nat. Cons., Moscow: 41-43.

[9] Barinova, S.S., Medvedeva, L.A., Anissimova, O.V. (2006). Diversity of algal indicators in environmental assessment. – Pilies Studio, Tel Aviv. (In Russian); http://herba.msu.ru/algae/materials/book/title.html

[10] Berezneva T.Y. (2006): Rudnaya River. – www.Primpogoda.ru April 12, 2006.

[11] Elpatievsky, P.V., Chudaeva, V.A., Zazykina, E.F., Arzhanova, V.S. (1976): Role of the technogenic factor in formation of an ionic drain (on an example of one of the rivers of Primorski Region). – Geochemistry of a zone hypergenesis and technical activity of the peoples. Vladivostok: Far-East Scientific Center of Academy of Science of the USSR: 17-27.

[12] European Parliament (2000): Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy, p. 1-72. – O.J. L 327.

[13] Herut B., Shefer E., Cohen Y. (2003): Environmental Quality of Israel's Mediterranean Coastal waters in 2002. Annual Report of the National Marine Environmental Monitoring Program. – IOLR Report H39/2003a.

[14] Herut, B., Hornung, H., Kress, N. (1994): Mercury, lead, copper, zinc and iron in shallow sediments of Haifa Bay, Israel. – Fresenius Environ. Bull. 3: 147-151.

[15] Herut, B., Kress, N. (1997): Particulate metals contamination in the Kishon River estuary, Israel. – Mar. Pollut. Bull. 34: 706-711.

[16] Herut, B., Kress, N., Hornung, H. (2000): Nutrient pollution at the lower reaches of Mediterranean coastal rivers in Israel. – Water Sci. Technol. 42: 147-152.

[17] Herut, B., Kress, N., Shefer, E., Hornung, H. (1999): Trace element levels in mollusks from clean and polluted coastal marine sites in the Mediterranean, Red and North Seas. – Helgoland Mar. Res. 53: 154-162.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

[18] Kachur, A.N., Arzhanova, V.S., Yelpatyevsky, P.V., Von Braun, M.C. and Von Lindern I.H. (2003): Environmental conditions in the Rudnaya River watershed – a compilation of Soviet and post-Soviet era sampling around a lead smelter in the Russian Far East. – The Science of the Total Environment 303(1-2): 171-185.
[19] Kress, N., Herut, B., Shefer, E., Hornung, H. (1999): Trace element levels in fish from clean and polluted coastal marine sites in the Mediterranean Sea, Red Sea and North Sea. – Helgoland Mar. Res. 53: 163-170.
[20] Krumgalz, B. (1993): "Fingerprints" approach to the identification of anthropogenic trace metal sources in the nearshore and estuarine environments. – Estuaries 16: 488-495.
[21] Kuznetsova O. V. (2005): Industrial activity and the ecological problems in the Dalnegorsk region. – Proceedings Far-Eastern State Technical University. 131. Vladivostok.
[22] Medvedeva, L.A. Barinova, S.S., Kukharenko, L.A. (1986a): Algae of the Rudnaya River Basin (Primorskiy Region). – Flora and Systematics of Spore Plants in Far East. Vladivostok: Acad. Sci. USSR, Far East Branch: 36-48. (Rus).
[23] Medvedeva, L.A., Barinova, S.S., Kukharenko, L.A. (1986b): Sanitary and Biological characteristic of the Rudnaya River Basin. – Bentic Organisms in Fresh Waters of Far East. Vladivostok: Acad. Sci. USSR, Far East Branch: 108-115. (Rus).
[24] Medvedeva, L.A., Barinova, S.S. (1992): Seasonal changes of water quality in the Rudnaya River (Primorye Region). – The estimation of a condition and stability of ecosystems (Abstr.). Inst. Nat. Cons., Moscow: 43-45.
[25] Meybeck, M., Helmer, R. (1989): The quality of rivers: from pristine stage to global pollution. – Palaeogeography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section) 75: 283-309.
[26] Pantle, E., Buck, H. (1955): Die biologische Uberwachung der Gewässer und die Darstellung der Ergebnisse. - Gas- und Wasserfach 96(18): 1-604.
[27] Qishon River Authority. (2006): http://www.Qishon.org.il/.
[28] Rédei, D., Gaál, M., Hufnagel L. (2003): Spatial and temporal patterns of true bug assemblages extracted with Berlese funnels (data to the knowledge on ground-living Heteroptera of Hungary, № 2). – Applied Ecology and Environmental Research 1 (1-2): 115-142.
[29] Richter, E.D., Friedman, L.S., Tamir, Y., Berman, T., Levy, O., Westin, J.B., Peretz, T. (2003): Cancer risks in naval divers with multiple exposures to carcinogen. Environ. – Health Perspect. 111: 609-617.
[30] Sharov, P.O. (2005): Lead Contamination of Environment in Rudnaya Pristan, Russia and associated Health Risks. Far Eastern Health Fund. – Vladivostok, Dalnauka.
[31] Shilov, V.N. (1997): Comparison of Neogene-Quaternary volcanism in Sakhalin and the East Sikhote Alin: 3. A comparative study of the rock chemistries. – Journal of Volcanology and Seismology 18: 667-672.
[32] Sládeček, V. (1986): Diatom as indicators of organic pollution. - Arch. Hydrochim. Hydrobiol. 14: 555-566.
[33] Swift, E. (1967): Cleaning diatom frustules with ultraviolet radiation and peroxide. – Phycologia 6: 161-163.
[34] ter Braak, C.J.F. (1987): The analysis of vegetation-environment relationships by canonical correspondence analysis. – Vegetatio 69: 69-77.
[35] ter Braak, C.J.F. (1990): Interpreting canonical correlation analysis through biplots of structural correlations and weights. – Psychometrica 55: 519-531.
[36] Von Braun, M.C., Von Lindern, I.H., Khristoforova, N.K. et al. (2002): Environmental lead contamination in the Rudnaya Pristan-Dalnegorsk mining and smelter district, Russian Far East. – Environmental Research, Section A 88: 164-173.
[37] Whitton, B.A., Roth, E.,Friedrich, G. (eds.). (1991): Use of algae for monitoring rivers, Institut für Botanik. – Univ. Press. Innsbruck.

# MICROHABITAT USE BY GREY JUNGLEFOWL (*GALLUS SONNERATII)* AT THENI FOREST DIVISION, WESTERN GHATS OF TAMIL NADU, SOUTH INDIA

C. SUBRAMANIAN[1]* – C. RAMESH KUMAR[2] – M.C.SATHYANARAYANA[2]

[1]*Department of Biology, Eritrean Institute of Technology,*
*Mainefhi, The State of Eritrea, North-east Africa*

[2]*Division of Wildlife Biology, A.V.C.College (Autonomous) Mayiladuthurai, India*

**Corresponding author*
*e-mail: csubramanian24@yahoo.co.in*

(Received 28th August 2007; accepted 20th February 2008 )

**Abstract.** The overall results showed 64% of Grey Junglefowl sightings in <40% canopy cover category. The results indicated that majority of the sightings (77%) was in >41% shrub cover category. Use of litter cover categories was (67%) in <40 % and the use of litter depth was in <4 cm litter category. The 67% sightings were obtained in <4 tree number category.
**Keywords:** *Habitat use; Grey Junglefowl; Western Ghats*

## Introduction

The habitat use is a critical facet in the management of wildlife species [1]. Habitat provides food and cover essential for the population to survive. Central to the study of animal ecology is the usage an animal makes of its environment: specifically, the kinds of food it consumes and the varieties of habitats it occupies [2]. Many analytic procedures have been devised to treat data on the usage of such resources, particularly in relation to information on their availability to the animal, for the purpose of determining “preference”.

Attempts always go beyond simple documentation of habitat use to determine if specific habitats are selected; i.e., used more or less than availability [3]. The importance of knowing the detailed habitat requirements if want to develop an effective conservation strategy for protecting a wild game bird species [4]. A general idea of the broad biotype that a species occupies (e.g. forest, agricultural land, marshes etc) is not sufficient. We need to find how it uses habitat types within these areas and which of these are most important for its continued survival. In order to acquire this type of information detailed studies of the bird’s location are required.

It is stressed the birds adapt to areas with suitable habitat, which provides nesting site, nesting material, food and protection from other species [5]. It is reported [6] that within geographical areas, species are not evenly distributed across all available habitats, but tends to use some habitats more than others. A species is found with greatest frequency and abundance in the habitats to which it is best adapted. These preferences might change across geographical areas and over seasons. Alteration and destruction of habitats by humans can have a drastic effect on some species, while others adapt to the modified habitat. Therefore data on the habitat requirements of a species could be useful for predicting the effects of habitat destruction due to humans on natural communities. This paper is the first report on habitat use by *Gallus* *sonneratii* due to lack of previous information on Grey Junglefowl, at Theni forest division, Western Ghats of southern India (*Fig 1*). The grey junglefowl is one of the endemic to south peninsular India which is vulnerable in status.

## *Study area*

The Theni Forest Division (9° 31’- 10° 10’-N, 77° 20’-77° 40’ E) is located 76 Km west of Madurai City in Theni district, Tamilnadu South India. This area forms part of the Western Ghats and it is located on the boundary of Tamilnadu and Kerala State. This forest covers an area of 723 $km^2$. It comprises of Bodi, Cumbum, Gudalur and Meghamalai Forest Ranges.

The Theni Forest Division provides habitat for several mammals such as lion tailed macaque (*Macaca silenus*), common langur (*Trachypithecus entellus*) Nilgiri langur (*Trachypithecus johnii*), slender loris(*Loris tardigradus*), tiger (*Panthera tigris*), leopard (*Panthera pardus*), Jungle cat (*Felis chaus*), sloth bear (*Melursus ursinus*), Nilgiri marten (*Martes gwatkinsi*), Travancore flying squirrel (*Petinomys fuscocapillus*), Asian elephant (*Elephas maximus*), gaur (*Bos gaurus*), Nilgiri tahr (*Hemitragus hylocris*), sambar deer (*Cervus unicolor*), spotted deer (*Axis axis*), barking deer (*Muntiacus muntjak*), mouse deer (*Tragilus meminna*), and Indian wild boar (*Sus scrofa*). In addition to Grey Junglefowl a total of 97 bird species belonging to 15 orders and 36 families were also recorded.

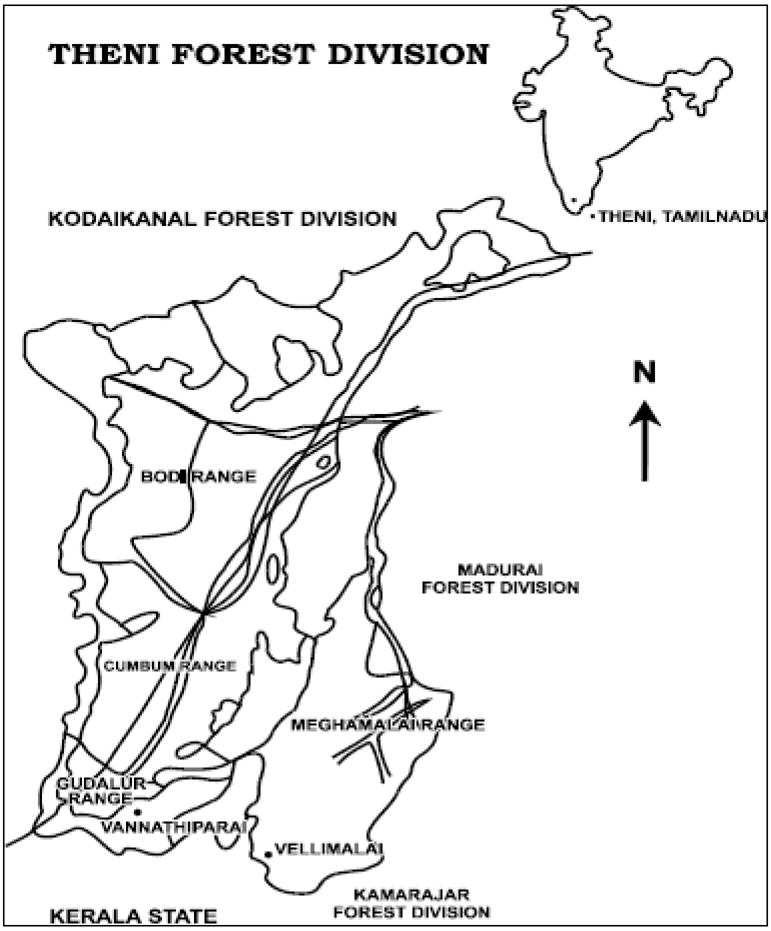



*Figure 1. Map of the study area*


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

## Methods

The habitat type and microhabitat variables used by Grey Junglefowl were recorded for all sightings obtained along the transects. For this purpose, bird focal plots (10m x 10 m) were laid to quantify variables (the immediate environment) such as canopy cover (%) and tree numbers (N). Within these bird focal plots, sub plots (5m x 5m) were laid to quantify shrub cover (%) followed by laying of smaller quadrats (1m x 1m) to estimate the grass cover (%) litter cover (%) and litter depth (cm). This method adapted by Young *et al* [7]. For every Grey Junglefowl sighting only on transects, the "location site" was marked as "bird focal plots" and the selected parameters were quantified. The Availability-Utilization of micro habitat variables by Grey Junglefowl was analysed by using Ivlev's [8] index of selectivity.

$$\text{Ivlev's index of selectivity} = \frac{U - A}{U + A} \qquad \text{(Eq.1)}$$

Whereas U = Used micro habitat variables
A = Available microhabitat variables.

## Results

In order to assess the use of habitat variables such as canopy cover, shrub cover, grass cover, litter cover, litter depth and tree number, all the 88 sightings of Grey Junglefowl were taken into account. The uses of habitat variables by Grey Junglefowl in different seasons in the Study Area are given in the *Table 1.*

***Table 1.*** *. Use of habitat variables by Grey Junglefowl in different seasons*

| Parameters | Post-monsoon | Summer | Pre-monsoon | Monsoon | Overall |
|---|---|---|---|---|---|
| Canopy cover (%) | NS | P<0.01 (21-40%) LOW | P<0.05 (21-40%) LOW | NS | P<0.02 (<40%) LOW |
| Shrub cover (%) | P<0.05 (41-60%) MODERATE | P<0.01 (41-60%) MODERATE | P<0.21 (41-60%) MODERATE | P<0.001 (41-60%) MODERATE | NS |
| Grass cover (%) | P<0.01 (21-40%) LOW | P<0.001 (<20%) VERY LOW | P<0.001 (21-40%) LOW | P<0.001 (21- 40%) LOW | P<0.05 (<40%) LOW |
| Litter cover (%) | P<0.20 (21-40%) LOW | P<0.01 (21-40%) LOW | P<0.02 (21-40%) LOW | P<0.02 (21-40%) LOW | P<0.01 (>41%) MODERATE |
| Litter depth (cm) | P<0.001 (<4cm) LOW | NS | NS | P<0.001 (<4cm) LOW | P<0.05 (<4cm) LOW |
| Tree number (N) | P<0.20 (>4N) LOW | NS | NS | NS | NS |

Chi-square test: NS= Not significant

The overall results indicated that majority of the Grey Junglefowl sightings were used <40% canopy cover category, >41% shrub cover category, <40% grass cover


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

category, >41% litter cover category, <4cm litter depth category and <4 tree number in bird focal plots.

### *Use of canopy cover*

The overall results showed 64% of Grey Junglefowl sightings in <40% canopy cover category ($\chi^2$ = 10.309, df= 3, P< 0.02). It was found that there were differences in the canopy cover use during all the seasons (*Table 2*).

***Table 2.*** *. Use of canopy cover (%) in different seasons in the Study Area,1999-2000*

| SEASON | Use of canopy cover (%) Categories | | $\chi^2$ | df | P |
|---|---|---|---|---|---|
| | I <40 % | II >41 % | | | |
| *Post-monsoon* | 57 | 43 | 0.428 | 1 | P>0.05* |
| Summer | 83 | 17 | 10.666 | 1 | P<0.01 |
| Pre-monsoon | 74 | 26 | 4.262 | 1 | P<0.05 |
| Monsoon | 42 | 58 | 0.666 | 1 | P>0.05* |

Chi Square test: $\chi^2$ =10.309, df=3, P<0.02; * Significant

### *Use of shrub cover*

The overall results indicated that majority of the Grey Junglefowl sightings (77%) were in >41% shrub cover category. It was observed that there were no differences in the shrub cover use in a season ($\chi^2$ = 2.782, df= 3, P>0.05). 88% of the Grey Junglefowl sightings in monsoon, 79% in summer, 71% in post-monsoon and 68% in pre-monsoon utilized >41% shrub cover category (*Table 3*).

***Table 3.*** *Use of shrub cover (%) in different seasons in the Study Area, 1999-2000*

| SEASON | Use of shrub cover (%) Categories | | $\chi^2$ | df | P |
|---|---|---|---|---|---|
| | I <40 % | II >41 % | | | |
| *Post-monsoon* | 29 | 71 | 3.856 | 1 | P<0.05 |
| Summer | 21 | 79 | 8.166 | 1 | P<0.01 |
| Pre-monsoon | 32 | 68 | 2.578 | 1 | P<0.20 |
| Monsoon | 12 | 88 | 13.5 | 1 | P<0.001 |

Chi Square test: $\chi^2$ =2.782, df=3, P>0.05

### *Use of grass cover*

About 93% sightings of Grey Junglefowl was in <40% grass cover category (*Table 4*). There was a significant difference in the use of grass cover across the seasons ($\chi^2$=9.366, df= 3, P<0.05).

***Table 4.*** *Use of grass cover (%) in different seasons in the Study Area, 1999-2000*

| SEASON | Use of grass cover (%) Categories | | $\chi^2$ | df | P |
|---|---|---|---|---|---|
| | I <40 % | II >41 % | | | |
| *Post-monsoon* | 81 | 19 | 8.046 | 1 | P<0.01 |
| Summer | 100 | 0 | 24 | 1 | P<0.001 |
| Pre-monsoon | 100 | 0 | 19 | 1 | P<0.001 |
| Monsoon | 92 | 8 | 16.666 | 1 | P<0.001 |

Chi Square test: $\chi^2$=9.366, df=3, P<0.0.5

### *Use of litter cover*

The overall results indicated that 67% of Grey Junglefowl sightings were in the >41% litter cover category and this was statistically significant ($\chi^2$=14.666, df= 3, P<0.01). It was found that there were differences in the litter cover use during all the seasons (*Table 5*).

***Table 5.*** *Use of litter cover (%) in different seasons in the Study Area, 1999-2000*

| SEASON | Use of litter cover (%) Categories | | $\chi^2$ | df | P |
|---|---|---|---|---|---|
| | I <40 % | II >41 % | | | |
| *Post-monsoon* | 67 | 33 | 2.541 | 1 | P>0.20 |
| Summer | 21 | 79 | 8.166 | 1 | P<0.01* |
| Pre-monsoon | 21 | 79 | 6.368 | 1 | P<0.02* |
| Monsoon | 25 | 75 | 6 | 1 | P<0.02* |

Chi Square test: $\chi^2$=14.333, df=3, P<0.01; * Significant

### *Use of litter depth*

The overall results revealed that a majority of Grey Junglefowl sightings (75%) were in <4 cm litter depth category (*Table 6*). It is observed that there were differences in the litter depth use between seasons ($\chi^2$=23.536, df= 3, P<0.05).

***Table 6.*** *Use of litter depth (cm) in different seasons*

| **SEASON** | **Use of litter depth (cm) Categories** | | $\chi^2$ | **df** | **P** |
|---|---|---|---|---|---|
| | **I** **<4 cm** | **II** **>5 cm** | | | |
| *Post-monsoon* | 86 | 14 | 10.714 | 1 | P<0.001* |
| Summer | 42 | 58 | 0.666 | 1 | P>0.05 |
| Pre-monsoon | 73 | 27 | 4.262 | 1 | P<0.20* |
| Monsoon | 100 | 0 | 24 | 1 | P<0.001 |

Chi Square test: $\chi^2$=23.536, df=3, P<0.05; * Significant

## *Use of trees (number)*

The overall results showed that the Grey Junglefowl sightings were obtained in <4 trees (in bird focal plots) number category ($\chi^2$=1.14, df= 3, P>0.05) which was not significant (*Table 7*).

***Table 7.*** *Use of tree number in different seasons in the Study Area, 1999-2000*

| **SEASON** | **Use of tree number Categories** | | $\chi^2$ | **df** | **P** |
|---|---|---|---|---|---|
| | **I** **<4 n** | **II** **>5 n** | | | |
| *Post-monsoon* | 67 | 33 | 2.332 | 1 | P<0.02* |
| Summer | 54 | 46 | 0.166 | 1 | P>0.05 |
| Pre-monsoon | 53 | 47 | 0.052 | 1 | P>0.05 |
| Monsoon | 62 | 38 | 1.5 | 1 | P>0.05 |

## Discussion

The Grey Junglefowl appears that canopy cover and tree number do not have any direct significant influence on Grey Junglefowl habitat use. The result indicates that choice of habitat by Grey Junglefowl largely depends on the interspersion of moderate shrub cover (41-60%), high litter cover (>41%) low litter depth (<4 cm) and low grass cover (<40%). Though [9] recorded Cheer in a variety of forest types, they showed a strong preference for open areas with dense ground cover. Moreover, Cheer inhabited mainly open areas with few trees and saplings, dense cover of tall grass and moderate shrub cover.

It was primarily because the shrub layer provides protection from predators (escape cover) and shade, while litter and grass or herb layers determined the invertebrate abundance, which are food items of Grey Junglefowl. The Grey Junglefowl at northwestern parts of the Bori Wildlife Sanctuary, Madyapradesh, preferred. 0-25% cover in woods, shrubs and grass lands [10].

The observation [11] showed that the Kalij used mostly the 1-25% tree cover and 26-50% category; Monal used mostly the 1-25% tree cover and 0% category. The 26-50% shrub cover category was used mostly by Kalij and the 1-25% and 0% shrub cover category by Monal. Kalij mostly used the 1-25% grass cover category and Monal the 26-50% grass cover category.

According to report [12] Cheer showed significantly preferred areas with no or little cover. Tall and dense vegetation, both at ground level and also at shrub level were significantly avoided. The study concluded that within major plant associations Tragopans consistently selected areas for dense shrub and short deciduous life forms within the major plant associations in north eastern Pakistan [13].

It opined that a tall and dense layer provides visual cover, escape cover, and food for Lady Amherst pheasants [14]. The used plots had greater litter may provide an important foraging substrate for Lady Amherst pheasants. Low grass and herb cover probably result from the high canopy closure at organism used plots. Ring-necked pheasants selected areas near woodland and rich in food resources, with less ground cover, more shrubs and canopy. Probably, both food abundance and cover were important in habitat selection before the nesting season [15]. It [16] opined that in winter, cover becomes more important as protection from predator and woods, wetlands are selected more often.

**Acknowledgements.** We express our gratitude to the Ministry of Environment Govt. of India, New Delhi, for providing financial assistance and the Chief Conservator of Forest, Tamil Nadu Forest Department, Chennai for having given us permission to take up our studies at Theni Forest Division. We express our gratitude to Dr.V. Radhakrishnan, Principal and Prof. S. Swetharanyam, HOD, Division of Wildlife Biology, AVC College (Autonomous), Mayiladuthurai for their constant encouragement.

## REFERENCES

[1] White, G.C., Garrot, R.A. (1990): Habitat analysis. – In: Analysis of Wildlife Radiotracking data. Academic Press, London. pp 183-204 .

[2] Johnson, D.H. (1980): The comparison of usage and Availability measurements for evaluating resource preference. – Ecology 61 (1): 65-71.

[3] Alldredge, R.J. (1986): Comparison of some statistical techniques for analysis of resource selection. – Journal of Wildlife Management 50 (1): 157-165.

[4] Dowell, S.D., Abischer Robertson, P.A. (1993): Analysing habitat use from radio-tracking data – In: Jenkins, D. (ed) Pheasants in Asia 1992. World Pheasant Association Reading, UK. pp 62-66.

[5] Cody, M.L.( 1980): Species packing in insectivorous bird community: density, diversity and productivity. – Proceedings of international ornithological congress XVII: 1071-1077.

[6] Crowell, L.L. (1962): Reduced inter specific competition among birds of Bermuda. – Ecology 43:75-88.

[7] Young, L., Zheng, G.M., Zhang Z.W. (1991): Winter movements and habitat use by Cabot`s Tragopans Tragopan caboti in Southeastern China. – Ibis133: 121-126.

[8] Ivlev, V.S. (1981): Ivlev`s index of selectivity in Experimental Ecology of feeding on herbivores. – Yale University Press, London.

[9] Kalsi, R.S. (2001): Status and Habitat of Cheer Pheasant in Himachal Pradesh, India-Results of 1997-1998 surveys. – Tragopan 13/14:20-26.

[10] Tata, R., Gautam, P. (1992): Habitat utilization by Grey Junglefowl in Bori Wildlife Sanctuary, India. – Journal of World Pheasant Association XVII & XVIII: 9.

[11] Sathyakumar, S., Prasad,. S.N, Rawat, G.S. (1993): Ecology of Kalij and Monal pheasants in Kedarnath Wildlife Sanctuary, Western Himalaya. – In: Jenkins, D. (ed.) Pheasants in Asia 1992. World Pheasant Association, Reading, UK. pp 83-90.
[12] Kaul, R. (1993): Habitat utilization by Cheer Pheasant. – In: Jenkins, D. (ed) Pheasants in Asia 1992. World Pheasant Association, Reading, UK. pp 157.
[13] Islam, K., Crawford, J.A. (1987): Habitat use by western Tragopan Tragopan melanocephalus (Gray) in Northeast Pakistan. – Biological conservation. 40:101-115.
[14] Bland, J.D., Lianxian, H. (1993): Unintentional maintenance of Lady Amherst Pheasant habitats in Rural Yunnan. – In: Jenkins, D. (ed) Pheasants in Asia 1992. World Pheasant Association, Reading, U.K. pp 134-136.
[15] Zhang, Z.W., Niu, F., Sun, Q. (1993): Ecology of the Chinese Ring-necked Pheasant. – In: Jenkins D, (ed.) Pheasants in Asia 1992. World Pheasant Association, Reading, UK. pp 91-94.
[16] Hill, D.A., Robertson, P.A. (1988): The pheasant: ecology, management and conservation – BSP Professional Books. pp 281.

# CLUSTER ANALYSIS IN SEARCH OF WIND IMPACTS ON EVAPORATION

V. GÜLDAL[1] — H. TONGAL[2]

[1]*S.D.U. Faculty of Engineering and Architecture, Civil Engineering Department, Isparta, Turkey*

[2] *S.D.U. Natural and Applied Sciences, Civil Engineering Department, Isparta, Turkey*

**Corresponding author*
*e-mail: vguldal@mmf.sdu.edu.tr*

(Received 22nd February 2008; accepted 12nd June 2008 )

**Abstract.** Clustering deals with finding a structure in a collection of uncategorized data and can be examined the most important unsupervised learning problem and the other problems as kind of this. The aim of this study is to cluster the monthly evaporation losses with the monthly winds speed and wind blow number of Eğirdir Lake, one of the most important fresh water storage of Turkey. For this aim, wind speed and evaporation data also wind blow number depend on hourly and daily mean records measured in Eğirdir Lake Catchment, are used. In the clustering analysis of the data, as a non-parametric approach hierarchical clustering algorithm was successfully applied at different similarity stages.
**Keywords***: Clustering analysis,* h*ierarchical clustering algorithm, Eğirdir Lake, wind speeds and blow number, evaporation.*

## Introduction

Clustering is a division of data into groups of similar objects. Each group, called cluster, consists of objects, similar between themselves and dissimilar to objects of other groups. By representing data with fewer groups, indispensable certain details can be lost but a simplification state can be achieved. Clustering can be considered as an unsupervised method for classification. If there is no prior information on the labels of the data (i.e. in which class they are), clustering algorithms determine the data to a usually pre-specified number of clusters (each cluster represented by a different stage). Clustering algorithms have been applied to a wide range of topics and areas. Uses of clustering techniques can be found in statistics, pattern recognition, machine learning [1], compression, classification and various disciplines as psychology, business, marketing, biology, libraries, insurance, city-planning and earthquake studies. [4, 5]

Many data clustering algorithms have been proposed in the literature. These algorithms can be classified into hierarchical clustering, partitional clustering algorithms, artificial neural networks for clustering, statistical clustering algorithms, density-based clustering algorithm, evolutionary approaches for clustering, search-based approaches and so on, [1, 2, 6, 7]. In these techniques, hierarchical and partitional clustering algorithms are the primitive approaches for data clustering. Hierarchical clustering algorithms can usually find pleasure clustering results. It is able to find different clustering results for different similarity or dissimilarity requirements.

The aim of this study is to determine the effects of the winds on the evaporation losses and to demonstrate whether according to the winds,( i.e. monthly mean wind speed and/or wind blow number ) and evaporation loses, the months for each year can be clustered climatologically. For the aim, the data of (1) monthly mean wind speed


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

obtained from hourly mean wind speed, wind blow number measured for one day and the data of (2) monthly mean evaporation obtained from daily measured data, in the area of Eğirdir Lake have been used. Hierarchical clustering algorithm was used for clustering.

## Hierarchical clustering algorithm

A clustering result established by a hierarchical clustering algorithm has a hierarchical structure. "The operation of a hierarchical clustering algorithm is illustrated using the two-dimensional data set in *Fig. 1*. This figure depicts seven patterns (or observation, datum or feature vector) labelled A, B, C, D, E, F, and G in three clusters. A hierarchical algorithm yields a *dendrogram* representing the nested grouping of patterns and similarity levels at which groupings change. A dendrogram corresponding to the seven points in *Fig. 1* (obtained from the single-link algorithm [Jain and Dubes, 1988]) is shown in *Fig. 2*. The dendrogram can be broken at different clustering of the data, [6]".With the hierarchical structure different clustering results can be obtained for different similarity requirements as shown in *Fig. 1*. For instance If the similarity requirement is set at level 1, the input dataset is partitioned into three clusters, i.e., {(A, B, C)}, {(D, E)} and {(F, G)}.

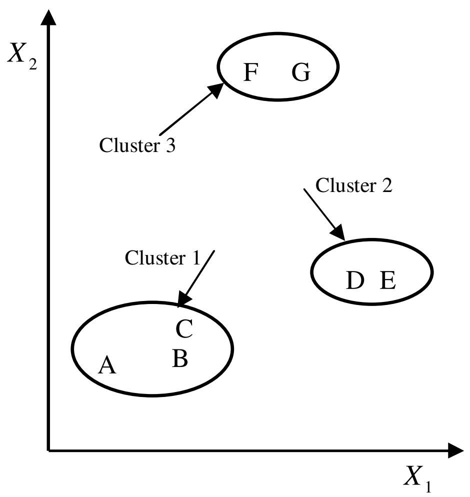



***Figure 1.*** *Points fall in three clusters [6].*

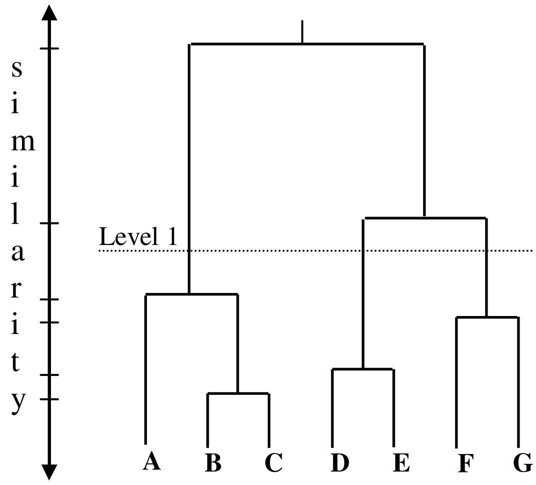



***Figure 2****. The dendrogram obtained using single-link algorithm [6].*

Most of hierarchical clustering algorithms are variations of the single-link and complete-link algorithms. The both of them characterize the similarity between a pair of clusters in different way. In the first method the distance between two clusters is the minimum of the distances between all pairs of patterns obtained from two clusters. And in the other, the distance between two clusters is the maximal distance of all pair-wise of patterns in the two clusters. These algorithms are also explained superficially [7] and comprehensively in [6] studies.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

## Similarity measures

A measure of the similarity between two patterns derived from the space, having same characteristic, is essential to most clustering procedures. Hence, similarity is fundamental for determining a cluster. The distance measure/measures must be chosen carefully due to the variety of feature types and scales. For calculating the dissimilarity between two patterns, the most popular method is to use a distance measure defined on the feature space.

The well-known distance measure, used for patterns of which features are all continuous, is the *Euclidean distance* which is a special case of: [8]

$$d_{ij} = d_m(x_i, x_j) = \left( \sum_{k=1}^{n} \left| x_{ik} - x_{jk} \right|^m \right)^{1/m} \qquad \text{(Eq.1)}$$

where; m varies in case of a distance measure to assign similarity. For m=1, 2 and 3, the eq.(1) gives the City block distance, the Euclidean distance and the Minkowski distance, respectively. The Euclidean distance is commonly used to evaluate the proximity of objects in two or three dimensional space.

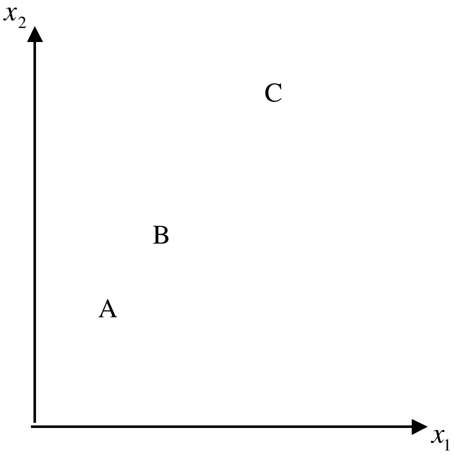



***Figure 3.*** *A and B are more similar than A and C [4].*

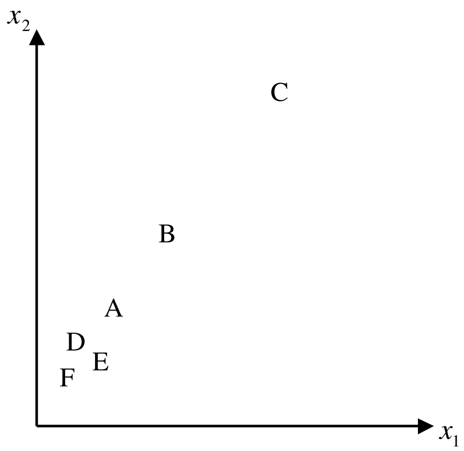



***Figure 4.*** *After a change in context, B and C are more similar than B and A* [4].

There are some distance measures reported in Gowda and Krishna [6] that take into account the effect of surrounding or neighbouring points. The set of surrounding points is called *context*. A metric defined by using context is *the mutual neighbour distance* (MND), proposed in Gowda and Krishna [1977]. It is explained comprehensively in [6].

This measure is given by;

$$MND(x_i, x_j) = NN(x_i, x_j) + NN(x_j, x_i) \qquad \text{(Eq.2)}$$

where $NN(x_i, x_j)$ is the neighbour number of $x_j$ with respect to $x_i$. *Fig. 3* and *4* give an example. In *Fig. 3*, the nearest neighbour of A is B, B's nearest neighbour is A. So, $NN(A, B) = NN(B, A) = 1$ and the MND between A and B is 2. However, $NN(B, C) = 1$


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

but $NN(C,B)=2$ and therefore $MND(B,C)=3$. *Fig. 4* was obtained from *Fig. 3* by adding three new points D, E, and F. Now $MND(B,C)=3$ (as before), but $MND(A,B)=5$. The MND between A and B has been increased by introducing additional points, even though A and B haven't been moved.

## Available data

The data used in this study were obtained from the Regional State Hydraulic Works and State Meteorological Works' meteorological stations in the basin of the Lake area, situated about 917 meters above sea level on the south western part of the Mediterranean Region in Turkey, at about 30° 18′-31° 22′ eastern longitudes and 37° 48′-38° 26′ northern latitudes. It is one of the most important lake (the second largest freshwater) in Turkey and operated for multiple purposes [3, 9].

The wind climate of the region is normal but in summer, especially, north winds blow intensively. These effective winds blow through the south-north direction, which is the longer part of the Lake (i.e., it is about 50 km length). Also, in summer, evaporation losses gain more importance with respect to the reservoir of the Lake and water demand.

Based on the records of the wind gauge station and Class-A evaporation pans situated near the Lake, the used average monthly data sets were obtained from the records between 1930-1999. For simplicity, the monthly evaporation loss was directly obtained from the daily observation data, by multiplying the measured rate by the pan coefficient.

## Application

In this study, as a nonparametric approach hierarchical clustering algorithm is applied in clustering analysis of the monthly evaporation losses with the monthly mean wind speeds and wind blow numbers of the Lake Egirdir. In the clustering, the similarity is determined by the mutual neighbour distance (MND) algorithm.

The winds have two important characteristics, increase the lateral transport as well as turbulent diffusion in the vertical direction and therefore have an important effect on the evaporation rate. These are speed and direction. The first characteristic has been represented by numerical values such as monthly mean speeds. Because of the lack of monthly mean values of directions, practically, the effective wind direction can be chosen for the general wind direction to determine the effect of the winds on the evaporations. In the application; (1) the wind speed and evaporation data sets (2) wind blow number and evaporation data sets were clustered in different stages. And for the different similarity levels, the relationships between winds and evaporation loss were illustrated.

The hierarchical clustering algorithm is applied to three observed dataset which their mean values are given in *Table 1*. One of these is the wind speed, the second is the wind blow number and the last one is the evaporation losses. In the first clustering analysis the wind speed and in the second analysis the wind blow number was accepted as a first dimension and the evaporation loss was chosen as a second dimension in both of analysis.

***Table 1.*** *The mean values of the data sets*

| Months | Oct (1) | Nov (2) | Dec (3) | Jan (4) | Feb (5) | Mar (6) | Apr (7) | May (8) | June (9) | July (10) | Aug (11) | Sept (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind speed (m/sn) | 2,4 | 3,6 | 3 | 3,2 | 3,5 | 3,3 | 3,3 | 2,9 | 3,2 | 3 | 2,9 | 2,7 |
| Wind blow number | 407 | 375 | 388 | 438 | 364 | 422 | 319 | 424 | 577 | 799 | 732 | 599 |
| Evaporation (mm) | 112.1 | 48,3 | 0 | 0 | 0 | 35 | 124 | 182,8 | 235,9 | 305,5 | 287 | 200 |

***Table 2.*** *Proximity matrixes of (a) wind speed-evaporation, (b) wind blow number-evaporation(a)*

| | Euclidean distance | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Months** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| **1** | 0,00 | 63,86 | 112,12 | 112,12 | 112,13 | 77,13 | 11,93 | 70,67 | 123,79 | 193,42 | 174,9 | 87,94 |
| **2** | --- | 0,00 | 48,27 | 48,27 | 48,27 | 13,27 | 75,75 | 134,52 | 187,64 | 257,27 | 238,75 | 151,79 |
| **3** | --- | --- | 0,00 | 0,20 | 0,50 | 35,00 | 124,02 | 182,79 | 235,91 | 305,54 | 287,02 | 200,06 |
| **4** | --- | --- | --- | 0,00 | 0,30 | 35,00 | 124,02 | 182,79 | 235,91 | 305,54 | 287,02 | 200,06 |
| **5** | --- | --- | --- | --- | 0,00 | 35,00 | 124,02 | 182,79 | 235,91 | 305,54 | 287,02 | 200,06 |
| **6** | --- | --- | --- | --- | --- | 0,00 | 89,02 | 147,79 | 200,91 | 270,54 | 252,02 | 165,06 |
| **7** | --- | --- | --- | --- | --- | --- | 0,00 | 58,77 | 111,89 | 181,52 | 163,00 | 76,04 |
| **8** | --- | --- | --- | --- | --- | --- | --- | 0,00 | 53,12 | 122,75 | 104,23 | 12,27 |
| **9** | --- | --- | --- | --- | --- | --- | --- | --- | 0,00 | 69,63 | 51,11 | 35,85 |
| **10** | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0,00 | 18,52 | 105,48 |
| **11** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0,00 | 86,96 |
| **12** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0,00 |

(b)

| | Euclidean distance | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Months** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| **1** | 0,00 | 71,42 | 113,72 | 116,33 | 120,08 | 78,57 | 88,80 | 72,69 | 210,30 | 437,12 | 369,07 | 221,18 |
| **2** | --- | 0,00 | 50,00 | 79,37 | 49,51 | 48,84 | 94,20 | 143,17 | 275,70 | 495,95 | 429,48 | 270,59 |
| **3** | --- | --- | 0,00 | 50,00 | 24,00 | 48,80 | 141,92 | 186,30 | 302,28 | 512,13 | 448,01 | 290,77 |
| **4** | --- | --- | --- | 0,00 | 74,00 | 38,48 | 171,88 | 183,33 | 273,82 | 472,94 | 410,87 | 256,80 |
| **5** | --- | --- | --- | --- | 0,00 | 67,74 | 131,93 | 192,39 | 317,84 | 531,58 | 466,70 | 308,62 |
| **6** | --- | --- | --- | --- | --- | 0,00 | 136,14 | 147,80 | 253,75 | 464,03 | 399,52 | 242,02 |
| **7** | --- | --- | --- | --- | --- | --- | 0,00 | 120,33 | 281,22 | 513,18 | 444,00 | 290,14 |
| **8** | --- | --- | --- | --- | --- | --- | --- | 0,00 | 161,96 | 394,58 | 325,16 | 175,85 |
| **9** | --- | --- | --- | --- | --- | --- | --- | --- | 0,00 | 232,66 | 163,21 | 42,06 |
| **10** | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0,00 | 69,51 | 226,11 |
| **11** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0,00 | 158,91 |
| **12** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0,00 |

In both of applications, the values of these dimensions are plotted on x and y axis. The distance between each point in both dataset is calculated by using the Euclidean distance, a special case of equation 1. The distance measures, showed in the proximity matrixes of the wind speeds-evaporation losses and wind blow number-evaporation losses with 12x12 dimensions (*Table 2.*), are ordered from the smallest to highest. Hence, the neighbour degrees of each dual point $[ND\,[N_i, N_j]\,]$, represent dual months, are determined. It can be clearly perceived that the nearest neighbour is itself for each point. So, $ND(N_i, N_i) = 0$ and the neighbour degree of the furthest point from the current point will be 11 subject to the number of proximity objects or the surrounding points. Relatively, for each 12 points, the total neighbour number of the dual points $N(ND)$ is equal to 144.

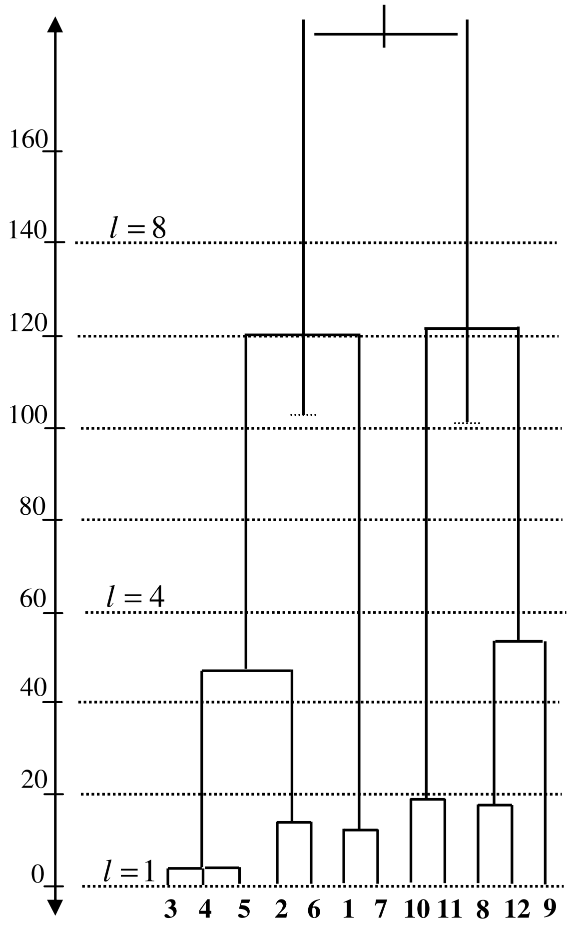



***Figure 5.*** *The dendrogram depends on hierarchical single-linkage for the first application.*

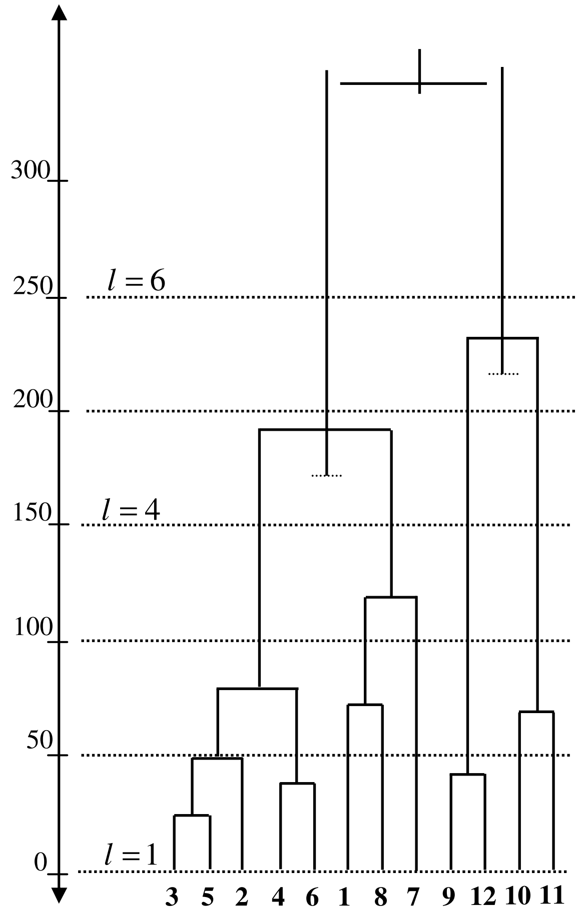
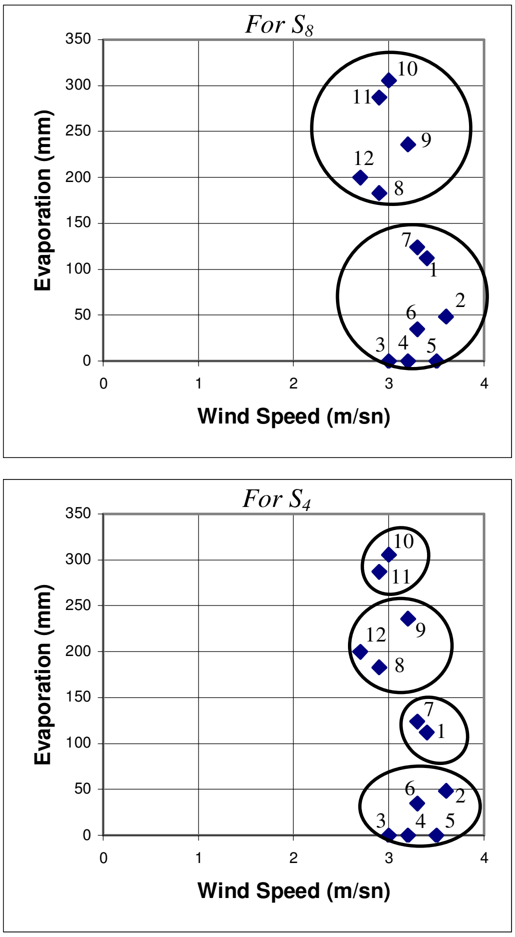



***Figure 6.*** *The dendrogram depends on hierarchical single-linkage for the second application.*

To make easy to generate the dendrogram, the neighbour degree of each point with itself is taken into account as 1 and the $MND$ between $x_i$ and $x_j$ is calculated by summation of $ND(N_i, N_j)$ and $ND(N_j, N_i)$. Also, the $MND$ is the sum of the number of the combinations of the different proximity objects in which there are sub-clusters. In both of applications or surveys, the $MND\,s$ are 78, (i.e. $C\binom{12}{1} + C\binom{12}{2} = 78$). The dendrogram, derived from the proximity matrix that emphasizes the distance of a point from the other points, for each group, depends on hierarchical single linkage, were generated independently and given in *Figs. 5* and *6*. In these dendrograms, the dataset can be grouped for different similarity levels.

The similarity level is represented by $S_l ; l = 1,2,3,...,m$. As it can be seen from both *Figs. 5* and *6*, the dendrogram can be broken at any similarity level to yield different clustering results. For wind speed-evaporation the similarity level ($l$) varies from 1 to 9 and for wind blow number-evaporation it varies from 1 to 7. $S_1$ means that there is no cluster. In other words, each cluster has only one pattern. For instance, for the wind speed-evaporation dendrogram there are 4 and 2 clusters at $S_4$ and $S_8$ , respectively, whereas these clusters can be seen at $S_4$ and $S_6$ for the wind blow number-evaporation dendrogram. For $S_7$ and $S_9$ in both dataset there is only one cluster. This means that all the patterns belong to only one cluster. The clusters of various similarity levels for the first ($l = 4\, and\, 8$) and second ($l = 4\, and\, 6$) analysis, are shown in *Fig. 7* and *Fig. 8*.



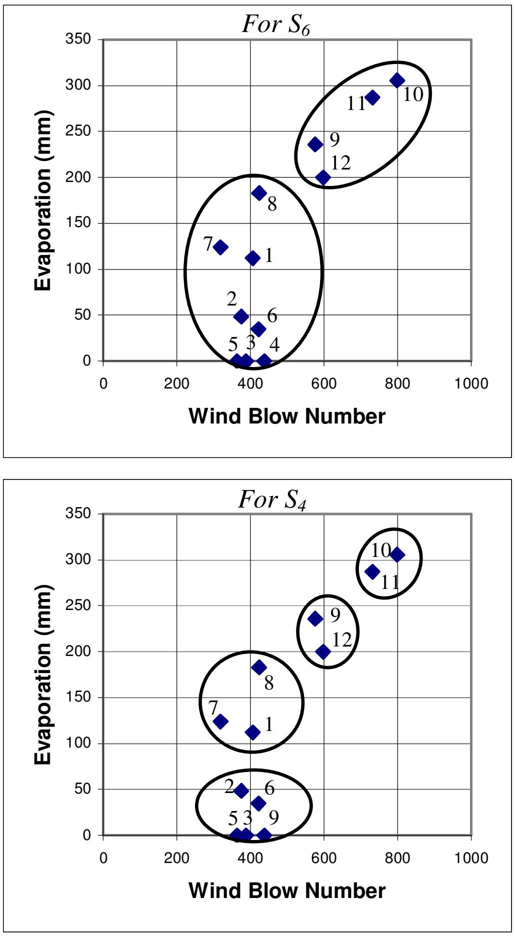




***Figure 7.*** *The cluster for $l = 4$ and $l = 8$.*

***Figure 8.*** *The cluster for $l = 4$ and $l = 6$.*

## Result and conclusion

It is known that, in general, any change in the wind speed and blow number causes the change in evaporation rate when the other meteorological factors, effecting on the evaporation rate, are assumed as constant. In this study, effects of the winds on the evaporation losses were investigated. The following interpretations were obtained.

(1) It can be considered that the clustering at $S_1$ (i.e. all the patterns belong to only one cluster.) for the first data set, shows that there cannot be seen any statistical


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

relationship between the change in the wind speed and the change in the evaporation amount ($R^2 = 0{,}02$), however, for the second data set, the same similarity level indicates that the effects of winds on the evaporation rate ($R^2 = 0{,}69$) has a quite important effect, statistically.

(2) Although the first derived explanation, it is thought that the clustering for a second data set from the same data source, for instance; at $S_8$ ($l = 8$) similarity level for wind speed-evaporation rate, the cluster which contains July, August, Jun, May and September and at $S_6$ ($l = 6$) similarity level for the wind blow number-evaporation rate, the cluster which contains July, August, Jun, and September; state the above relations strongly ($R^2 = 0{,}29$ for wind speed change and evaporation rate; $R^2 = 0{,}85$ for the wind blow number-evaporation rate).

(3) It can be possible that making some critical analyses by clustering method for resolving the problems such as there can't be seen clearly a correlation between two or more patterns selected for examination related to the problem analysis. For instance, in this study when looking into the wind blow number-evaporation rate data set it cannot be asserted any statistical statement exactly about the relationship between these two patterns however, by clustering at $l = 6$ (the cluster which contains June, July, August, September) a strong relationship can be easily stated ($R^2 = 0{,}96$).

(4) It is considered that the clustering should be used in determining of the different operation level for each similarity level or in making efficient operating decisions and making accurate prediction.

(5) In general, in order to introduce the determination of a stress relation between anyhow two objects or patterns, having a scientific or statistic meaning, the clustering method presents that what data types and groups represents the objects in the best way.

## REFERENCES

[1] BERKHIN, P. (2005): Survey of Clustering Data Mining Techniques – Accrue Software, Inc. http://www.ee.ucr.edu/~barth/EE242/clustering_survey.pdf

[2] BUHMANN, J.M. (2002): Data Clustering and Learning – Handbook of Brain Theory and Neural Networks, M. Arbib (ed.), 2nd edition, MIT Press

[3] DSİ, Eğirdir Gölü Hidrolojisi, Revize Raporu, T.C. ETKB-DSİ Gen. Müd., 18.Bölge Müdürlüğü, Isparta, 2002.

[4] FUNG, G. (2001): A Comprehensive Overview of Basic Clustering Algorithms. – http://www.cs.wisc.edu/~gfung/clustering.pdf

[5] JAIN, A.K., MURTY, M.N and FLYNN P.J. (1999): Data Clustering: A Review – ACM Computing Surveys, Vol. 31, No. 3,

[6] JAIN, A.K. and DUBES, R.C. (1988): Algorithms for Clustering Data. – Prentice-Hall advanced reference series. Prentice-Hall, Inc.,Upper Saddle River,NJ.

[7] LİN, Cheng-Ru and CHEN, Ming-Syan (2005): Combining Partitional and Hierarchical Algorithms for Robust and Efficient Data Clustering with Cohesion Self-Merging – IEEE Transactions On Knowledge And Data Engineering, Vol. 17, No. 2.

[8] LIONEL, E., et al. (2004): Efficient Clustering-Based Genetic Algorithms in Chemical Kinetic Modelling – K. Deb et al. (Eds.): GECCO, LNCS 3103, pp. 932–944.

[9] Utku, M. (1990): Isparta İklim Etüdü, DMİ Arş. Bil. İşlem D. Baş. Arş. Şb. Müd., ISP.

# GENETIC PARAMETERS FOR GROWTH TRAITS OF THE HUNGARIAN MERINO AND MEAT SHEEP BREEDS IN HUNGARY

I. KOMLÓSI

*Institute of Animal Science, Debrecen University*
*H-4032 Debrecen Böszörményi str. 138, Hungary*
*(phone: +36-52-508-438; fax: +36-52-508-438)*

*Corresponding author:*
*e-mail: komlosi@agr.unideb.hu*

(Received 30th Sept 2008; accepted 3rd Dec 2008)

**Abstract**. Heritabilities and genetic correlations between weaning weight (WW) and average daily gain (ADG) for the Hungarian Merino, Ile de France, Charollais, German Mutton Merino, German Blackheaded, Texel, Fleisch Merino and Suffolk were studied. The selection of replacements is based on the two traits. The amount of records provided by the Hungarian Sheep Breeder's Association and by the Hungarian Agriculture Department varied by breeds (462-124680). The general linear model included sex, birth type and age of dam as fixed effects, while maternal permanent environment, the birth flock-year-season and animal genetic effect as random effects. The heritability of WW varied between 0.09±0.02 and 0.62±0.09, for ADG it varied between 0.16±0.01 and 0.28±0.01. The $r_g$ varied between -0.10±0.02 and 0.44±0.09. The permanent environmental variance ratio varied between 0.009±0.007 and 0.06±0.01. The models and parameters calculated by the REML method varied by breeds that necessitates a separate genetic evaluation by breeds.
**Keywords:** *weaning weight, average daily gain, heritability, genetic correlation, sheep*

## Introduction

The present breeding objectives of sheep breeds in Hungary are reproduction, growth, wool and milk traits. Reproduction traits are prolificacy (number of lambs born) and lambing interval; growth traits include weaning weight (in all breeds), average daily gain after weaning (in meat breeds) and yearling weight; milk trait is the milk produced during the lactation period (in dairy breeds); and wool production traits which include greasy fleece weight and fibre diameter (in Merino breeds and Romney). The weighing of these traits in the selection is presented in *Table 1.* The selection for wool traits is based on independent culling level.

***Table 1.*** *The weighing of traits (%) in the index for different breed types*

| Breed type | Number of lambs weaned | Lambing interval | Weaning weight | Average daily gain after weaning | Yearling weight | Standard lactation milk production |
|---|---|---|---|---|---|---|
| wool-meat | 60 (50*) | 0 (10*) | 30 | 0 | 10 | 0 |
| meat-wool | 60 (50*) | 0 (10*) | 30 | 0 | 10 | 0 |
| prolific | 75 (65*) | 0 (10*) | 25 | 0 | 0 | 0 |
| meat | 40 (30*) | 0 (10*) | 0 | 60 | 0 | 0 |
| dairy | 40 (30*) | 0 (10*) | 10 | 0 | 0 | 50 |
| local breed | 50 | 0 | 20 | 0 | 30 | 0 |

* in flocks where frequent lambing is practiced in the last 5 years


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

To calculate selection index it is necessary to know the heritability and the correlation between the traits in addition to the economic weight of the traits. The last study on Hungarian Merino genetic parameters was published in 2000 (Nagy, 2000). The population has changed in the last 8 years, and different breeds were also introduced in Hungary. Several estimates have been published for sheep traits (de Vries et al., 1998, Ap Dewi et al., 2002; Safari et al., 2005). The genetic parameters are population specific. It is imperative to calculate these parameters in order to obtain an efficient selection response.

The objective of the present study was to estimate the heritability and genetic correlation for the growth traits (weaning weight and average daily gain) in eight sheep breeds (Hungarian Merino, Ile de France, Charollais, German Mutton Merino, German Blackheaded, Texel, Fleisch Merino and Suffolk), and to test their difference. If no difference is found, the pooling of the breeds within one breeding value evaluation procedure is possible in order to save computer time.

## Materials and methods

### *Animals and traits*

Performance data were collected by the Hungarian Sheep Breeder's Association in nucleus flocks in the period of 1984 and 2007. The performance testing procedure is regulated by the Sheep Breeding Codex (Radnóczi et al., 2007), which is updated every year. Lambs were born throughout the year with a peak in spring and were weighed at weaning (WW) (between 30 and 80 days of age) on a scale with 0.1 kg precision. The lambs consumed hay and concentrates in addition to the mothers' milk. For meat breeds a fattening test was carried out. Only those healthy lambs were put on test which reached at least 16 kg live weight, and were not over 80 days old in both sexes. Male and female lambs were fattened separately for 38-45 days. The group size was below 50, in 0.7-1.0 $m^2$ /boxes. Commercially available concentrates were fed ad. lib. with a maximum of 0.1-0.3 kg of hay consumption. The lambs were measured at the beginning and at the end of the test, and their average daily gain was calculated (ADG). The number of records and averages are given in *Table 2*. The total number of individuals with records ranged from 462 (Charollais) to 124680 (Hungarian Merino). Animals with missing data on environmental effects or having record only on one of the traits (other than Hungarian Merino) were excluded from the analysis. The pedigree links were considered for the animals with records, and all the pedigree information was utilised in the prediction of parameters.

### *Statistical analysis*

The WW was adjusted for 60 days. An univariate procedure of SAS (SAS, 1996) was used to edit data and check for normality. The significance of fixed effects for sex, birth type (single or twin), age of dam, and random effect for flock-year-season was tested on each trait separately by using the SAS MIXED procedure (SAS, 1996). Three dam age groups were formed, dams younger than 3 years, dam age between years 3 and 6, and dams older than 6 years. Preliminary analyses showed that these three age groups affect growth traits differently.

Heritabilities and genetic correlations were estimated by the VCE5 software package (Kovac-Groeneveld, 2003) which applies restricted maximum likelihood procedure (REML) in the estimation.

***Table 2.*** *Number of observation and mean values (phenotypic with standard deviation) for weaning weight and average daily gain for the breeds*

| Breed | Number of flocks | Years | Total number of individuals (in the pedigree) | Number of individuals with records | Weaning weight (kg) | | Average daily gain (g) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | mean | st. dev. | mean | st. dev. |
| Hungarian Merino | 957 | 1984-2007 | 510268 | 124680 | 18.7 | 3.84 | - | - |
| Ile de France | 159 | 1989-2007 | 34020 | 6153 | 19.7 | 4.31 | 294.7 | 62.10 |
| Fleisch Merino | 26 | 1990-2007 | 5708 | 1016 | 23.3 | 4.30 | 307.5 | 77.38 |
| German Blackheaded | 87 | 1987-2007 | 18848 | 2063 | 23.1 | 4.53 | 337.6 | 85.73 |
| German Mutton Merino | 474 | 1986-2007 | 106343 | 14933 | 20.1 | 3.40 | 319.8 | 72.0 |
| Suffolk | 120 | 1988-2007 | 18052 | 2829 | 22.4 | 4.58 | 321.4 | 73.4 |
| Texel | 38 | 1994-2007 | 4455 | 860 | 22.1 | 4.88 | 307.6 | 89.46 |
| Charollais | 33 | 1998-2007 | 2357 | 462 | 23.2 | 4.45 | 313.3 | 81.46 |

A single-trait (WW) model was applied for the Hungarian Merino, and two-trait models (WW, ADG) were applied for all the other breeds. The models included all the above-mentioned effects if they were found significant for the relevant trait and breed, with the random animal and permanent maternal environment effects included. Maternal ability represents the dam's milk production and mothering ability that is supposedly effect all of her progenies to the same extent. The genetic relationship between direct and maternal effects was not investigated, partly due to the controversial opinion in the literature on the matter (Nasholm and Danell, 1994; Matika et al, 2003), partly due to the lack of a long pedigree on the dam's side in many breeds that is required for accurate parameter estimation.

Heritability is considered as an intraclass correlation, and a test of homogeneity for correlation coefficients (on Z transformed correlations) was conducted (Steel and Torrie, 1987). When the test criterion $Chi^2$ was significant ($P<0.05$) a pairwise comparison for heritability estimates amongst breeds was carried out by two-sample z-tests since the number of individuals was above 30. Performing two-sample tests instead of multiple comparisons, however, increases type error I, incorrectly rejecting the null hypothesis.

## Results and discussion

### *The significance of factors*

The sex significantly affected WW in all breeds (*Table 3*). The birth type also affected significantly the trait except for the Fleisch Merino and German Balckheaded. Single lambs generally weighed more at weaning than twins in the breeds (e.g.

Mavrogenis, 1988; Yilmaz et al., 2007), due to the restrained uterine capacity and the mother's milking ability. This was also found in our study. The exception for Fleisch Merino and German Balckheaded might indicate that twin lambs' growth are not constrained by their mothers's capacity in these two breeds. This needs to be further investigated in physiological studies. The age of dam significantly affected WW in all breeds with the exception of Charollais and Fleish Merino. This could indicate persistent mothering ability for these two breeds. The phenotype of an individual is influenced by genetic and environmental factors. The fixed and random environmental effects in the model explained from 18% (Hungarian Merino) to 46% (Texel) of the variation on WW. The Hungarian Merino is kept in the most distinct environment in the largest number of flocks and there could be other environmental factors that are not controlled by the breeder, or available but not included in the model. Such grouping factors might be the geographic region (that could explain food availability during a year), nutritional strategy of the breeder (e.g. flushing or no flushing before mating, separation of twin bearing pregnant ewes or no separation).

The sex influenced ADG after weaning for all breeds. The birth type had effect on daily gain only in German Mutton Merino. The lack of influence of birth type on this trait in other breeds is not in agreement with the finding of others (Mavrogenis, 1988; Ceyhan et al, 2008). One explanation for the phenomenon is the compensatory growth during the fattening period. Compensatory growth is referred to as the rapid weight gain that follows a period of reduced nutrient intake of an animal, when it is placed on a high quality diet. Before weaning twin lambs' nutrient requirement is usually not met, but ad libitum access to nutrients during the fattening period makes fast growth for twin possible. The age of dam effected ADG (P<0.05) for Charollais, Fleisch Merino, German Blackheaded and Suffolk. The fixed and random environmental effects in the model explained from 26% (Suffolk) to 48% (Fleisch Merino) of the variation on daily gain.

***Table 3.*** *The level of significance for the fixed effects and the $R^2$ for the models† tested by breeds*

| **Breed** | **Hungarian Merino** | | **Texel** | | **Ile de France** | | **German Mutton Merino** | |
|---|---|---|---|---|---|---|---|---|
| **Traits/Effects** | **WW§** | | **WW** | **ADG#** | **WW** | **ADG** | **WW** | **ADG** |
| Sex | <0.0001 | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Birth type | <0.0001 | | <0.0001 | 0.5159 | <0.0001 | 0.6800 | <0.0001 | 0.0002 |
| Age of dam | <0.0001 | | <0.0001 | 0.2552 | <0.0001 | 0.1121 | <0.0001 | 0.3467 |
| $R^2$ | 0.18 | | 0.46 | 0.48 | 0.41 | 0.33 | 0.28 | 0.39 |
| | **Charollais** | | **Fleisch Merino** | | **German Blackheaded** | | **Suffolk** | |
| **Traits/Effects** | **WW§** | **ADG** | **WW** | **ADG** | **WW** | **ADG** | **WW** | **ADG** |
| Sex | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Birth type | <0.0001 | 0.0998 | 0.1404 | 0.4485 | 0.6944 | 0.2084 | <0.0001 | 0.1414 |
| Age of dam | 0.0998 | <0.0001 | 0.5966 | 0.0173 | <0.0001 | 0.0021 | <0.0001 | 0.0004 |
| $R^2$ | 0.29 | 0.42 | 0.27 | 0.48 | 0.36 | 0.34 | 0.34 | 0.26 |

† The models included the random effect of flock-year-season in addition to the fixed effects.
§, Weaning weight, # Average daily gain.

***Table 4.*** *Estimated genetic parameters with standard errors for growth traits by breeds*

| **Breed** | **Hungarian Merino** | **Texel** | | **Ile de France** | | **German Mutton Merino** | |
|---|---|---|---|---|---|---|---|
| **Traits/Effects** | **WW**[§] | **WW** | **ADG**[#] | **WW** | **ADG** | **WW** | **ADG** |
| $h^2$ | 0.09 ± 0.02 | 0.29 ± 0.04 | 0.28 ± 0.01 | 0.11 ± 0.01 | 0.16 ± 0.01 | 0.07 ± 0.01 | 0.19 ±0.03 |
| $r_g$ | | | 0.31 ± 0.07 | | 0.17 ± 0.02 | | 0.11 ± 0.02 |
| $c^2$ | 0.02 ± 0.001 | 0.04 ± 0.01 | 0.01 ± 0.003 | 0.02 ± 0.003 | 0.01 ± 0.001 | 0.03 ± 0.01 | 0.005 ±0.002 |
| $v^2$ | 0.34 ± 0.07 | 0.29 ± 0.09 | 0.31 ± 0.11 | 0.42 ± 0.02 | 0.21 ± 0.007 | 0.39 ±0.08 | 0.35 ±0.09 |
| $e^2$ | 0.53 ± 0.08 | 0.37 ± 0.09 | 0.39 ± 0.07 | 0.45 ± 0.01 | 0.62 ± 0.001 | 0.49 ±0.07 | 0.44 ±0.11 |
| | **Charollais** | | **Fleisch Merino** | | **German Blackheaded** | | **Suffolk** |
| **Traits/Effects** | **WW** | **ADG** | **WW** | **ADG** | **WW** | **ADG** | **WW** | **ADG** |
| $h^2$ | 0.62 ± 0.09 | 0.25 ± 0.07 | 0.09 ± 0.02 | 0.16 ± 0.01 | 0.24 ± 0.02 | 0.20 ±0.03 | 0.14 ± 0.02 | 0.24 ±0.02 |
| $r_g$ | | -0.01 ± 0.31 | | 0.28 ± 0.14 | | -0.10 ±0.02 | | 0.10 ±0.10 |
| $c^2$ | 0.003 ± 0.001 | 0.06 ± 0.03 | 0.06 ± 0.01 | 0.01 ± 0.01 | 0.03 ± 0.01 | 0.001 ± 0.001 | 0.009 ±0.007 | 0.004 ±0.006 |
| $v^2$ | 0.21 ± 0.09 | 0.62 ± 0.09 | 0.50 ± 0.04 | 0.50 ± 0.04 | 0.32 ± 0.08 | 0.27 ± 0.06 | 0.32 ±0.02 | 0.25 ±0.02 |
| $e^2$ | 0.30 ± 0.08 | 0.48 ± 0.05 | 0.34 ± 0.04 | 0.32 ± 0.01 | 0.40 ±0.07 | 0.52 ± 0.08 | 0.52 ±0.02 | 0.50 ±0.02 |

§, Weaning weight, # Average daily gain.
$h^2$ is the heritability of the trait, $r_g$ is the genetic correlation between the weaning weight and the average daily gain, $c^2$ the variance proportion of the maternal permanent environment effect; $v^2$ the variance proportion of the flock-year-season effect, $e^2$.is the error variance proportion.

## *Heritabilities, variance ratios*

Models including only significant factors were used in parameter estimation for the breeds. The parameters were estimated by a single-trait model for the Hungarian Merino, and a two-trait model for all the other breeds. The heritability of WW ranged from 0.07 to 0.62, its value was lower in Merino breeds and higher in meat breeds (*Table 4*). The heritability is a ratio of additive genetic and phenotypic variance. The low value for Merinos reflects the wide range of environment in which these breeds are kept. The meat breeds are used for terminal crossing, and the high market value of breeding males requires better nutrition and management, which decreases the environmental variance component. These heritabilities are in the range of those presented by Janssens et al. (2000) and Safari et al. (2005). The ratio of maternal permanent environment variance to the total phenotypic variance was below 0.06 for the two traits in all breeds. Irrespective of the low ratio, studies showed that the inclusion of permanent maternal effect significantly improve the model fit (Matika et al, 2003;

Miraei-Asthiai et al, 2007). The flock-year-season variance ratio exceeded the size of heritability for all breeds except for the Charollais. This large variation of environmental factors shows the exposure of the species to environmental changes by flock, by year and by season.

### *Genetic correlations*

Parameter estimates varied in magnitude between breeds (*Table 4*), ranged from -0.10 to 0.31. These correlations were only different from zero for Texel, Ile de France, German Mutton Merino and German Blackheaded. Weaning weight is the most important factor in determining postweaning liveweight, growth rates and survival of Merino lambs (Hatcher, 2008). This positive relationship was also proved in this study, except for the German Blackheaded. Lambs of this breed with low WW gain more after weaning and vice versa, that could be a sign of compensatory growth. The most important environmental factor that causes this phenomenon is the twin status. In this breed though the birth type had no significant effect on WW and ADG. Further studies are needed to explain the fact. A safe solution in a two trait model in breeding value evaluation for this breed is to use zero correlation between the two traits.

### *Comparison of parameters between breeds*

The Z values of the tests conducted for heritabilities are presented in *Table 5*. The $Chi^2$ value in the homogeneity test was 284.8 for WW, which is significant ($P<0.05$) at 7 degrees of freedom. A pairwise comparison was followed.The heritability of WW for Hungarian Merino was not different from that of the Ile de France and Fleisch Merino. The breeding value evaluation for the latter two breeds though is done for two growth traits, while for the Hungarian Merino only for WW, so possible pooling of the three breeds in one evaluation is not possible. The $Chi^2$ value in the homogeneity test was 33.08 for the heritability of ADG, which is significant ($P<0.05$) at 6 degrees of freedom.

Despite the fact that the heritability for the two traits was identical for the German Mutton Merino and the Fleisch Merino, the prediction models were different, due to the different significant effects, therefore the combination of the two breeds in one run is not possible. The $Chi^2$ value in the homogeneity test for correlation between the WW and ADG was 187.72 ($P<0.05$, df 6). According to the genetic correlations between WW and ADG, there were only three cases, where the correlations were not significantly different (Suffolk-German Mutton Merino; Texel-Fleisch Merino; Suffolk-Charollais) (*Table 6*). In heritabilities, however, these breeds differed. The genetic correlation is the correlation between the breeding values of two traits. The correlation is composed of the covariance between breeding values and the standard deviation of breeding values. These components are subjected to selection. Due to the characteristics of the breed the selection intensity for traits is different for different breeds. This can result in different correlations for the breeds.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

***Table 5.*** *Z values (absolute) for pairwise comparisons between estimated heritabilities in different breeds for weaning weight and average daily gain after weaning*

| Breed | HME§ | IDF | FME | GBL | GMM | SUF | TEX | CHA |
|---|---|---|---|---|---|---|---|---|
| **HME** | | 0.89# | 0 | **5.30** | 0.89 | 1.76 | **4.47** | **5.74** |
| **IDF** | | | 0.89 | **5.81** | **2.82** | 1.34 | **4.36** | **5.63** |
| **FME** | | 1.26 | | **5.33** | 0.89 | 1.76 | **4.47** | **5.74** |
| **GBL** | | 0.0 | 1.26 | | **7.60** | **3.53** | 1.11 | **4.12** |
| **GMM** | | **3.57** | 0.0 | 0.94 | | **3.13** | **5.33** | **6.07** |
| **SUF** | | **8.48** | **3.57** | 1.10 | **2.21** | | **3.35** | **5.20** |
| **TEX** | | 1.27 | **8.48** | **2.52** | **3.79** | 1.78 | | **3.35** |
| **CHA** | | **16.0** | 1.27 | 0.65 | 1.18 | 0.14 | 0.42 | |

§ Breed codes: HME- Hungarian Merino, IDF – Ile de France, FME – Fleisch Merino, GBL – German Blackheaded, GMM – German Mutton Merino, SUF - Suffolk, TEX-Texel, CHA- Charollais.
# Z values above diagonal are for weaning weight, below diagonal are for daily gain. Values above 1.96 are significant at P<0.05 level and are in bold.

***Table 6.*** *Z values (absolute) for pairwise comparisons between breeds' weaning weight and average daily gain estimated correlation*

| Breed | FME§ | GBL | GMM | SUF | TEX | CHA |
|---|---|---|---|---|---|---|
| **IDF** | **3.42#** | **10.68** | **4.04** | **3.14** | **4.08** | **3.34** |
| **FME** | | **10.11** | **5.45** | **5.11** | 0.70 | **4.93** |
| **GBL** | | | **8.96** | **6.92** | **10.35** | **2.13** |
| **GMM** | | | | 0.49 | **5.98** | **2.11** |
| **SUF** | | | | | **5.64** | 1.79 |
| **TEX** | | | | | | **5.37** |

§Breed codes are the same as in Table 5.
# Z values above diagonal are for weaning weight, below diagonal are for daily gain. Values above 1.96 are significant at P<0.05 level and are in bold.

## Conclusion

The effects for predicting WW and ADG in the eight breeds were different in some cases. The heritabilities and genetic correlations for the traits were also different in most of the comparisons. They require separate runs for breeding value evaluation in each breed.

## REFERENCES

[1] Ap Dewi, I., Saachi, M., Ulutas, Z. (2002): Genetic parameters of weights, ultrasonic muscle and fat depts, maternal effects and reproductive traits in Welsh Mountain sheep. – Animal Science 74: 399-408.

[2] Ceyhan, A., Sezenler, T., Erdogan, I. (2008): The estimation of variance components for prolificacy and growth traits of Sakiz sheep. – Livestock Science (in press).

[3] De Vries, M.J., van der Waaij, E.H., van Arendonk, J.AM. (1998): Estimation of genetic parameters for litter size in sheep – a comparison of repeatability and a multivariate model. – Animal Science 66: 685-688.

[4] Hatcher, S, Eppleston, J., Graham, R.P., McDonald, J., Schlunke, S., Watt, B., Thornberry, K.J. (2008): Higher weaning weight improves postweaning growth and survival in young Merino sheep. – Australian Journal of Experimental Agriculture 48(6-7): 966-973.
[5] Janssens, S., Geysen, D., Vandepite, W. (2000): Genetic parameters for live weight in Belgian Texel sheep. – Proceedings of the 51st Annual Meeting of the European Association for Animal Production. Session 1.6. pp. 1-8.
[6] Kovac, M., Groeneveld, E. (2003): VCE-5 Users's Guide and Reference Manual Version 5.1. – University of Ljubljana.
[7] Matika, O., van Wyk J.B., Erasmus, G.J., Baker, R.L. (2003): Genetic parameter estimates in Sabi sheep. – Livestock Production Science 79:17-28.
[8] Mavrogenis, A.P. (1988): Adjustment factors of growth traits of Chios sheep. – Livestock Production Science 19(3-4):409-416.
[9] Miarei-Asthiani, S.R., Seyedalian, S.A.R., Shahrbabak, M.M. (2007): Variance components and heritabilities for body weight traits in Sangsari sheep, using univariate and multivariate animal models. – Small Ruminant Research 73: 109-114.
[10] Nagy, I. (2000): Quantitative genetic studies on the Hungarian Merino sheep population. PhD thesis. – University of Agriculture, Debrecen
[11] Nasholm, A., Danell, O. (1994): Maternal effects on lamb weights. – Proceedings of the 5th World Congress of Genetics Applied for Livestock Production 18: 163-166.
[12] Radnóczi, L., Domanovszky, Á., Hajduk, P., Juhász, P., Kádas, A., Komlósi, I., Kukovics, S., Nagy, L., Sáfár, L., Toldi, Gy. (2007): Juh Teljesítményvizsgálati Kódex (Sheep Breeding Codex) – Országos Mezőgazdasági Minősítő Intézet, Budapest.
[13] Safary, E., Fogarty, N.M., Gilmour, A.R. (2005): A review of genetic parameter estimates for wool, growth, meat and reproduction traits in sheep. – Livestock Production Science 92: 271-289.
[14] SAS (1996): Users's Guide. – SAS Institute Inc., Cary, NC.
[15] Steel, R.G.D., Torrie, J.H. (1987): Principles and procedures of statistics. – 2nd ed. McGraw-Hill Book Company, Auckland
[16] Yilmaz, O., Denk, H., Bayram, D. (2007): Effects of lambing season, sex and birth type on growth performance in Norduz lambs. – Small Ruminant Research 68:336-339.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

# STOCHASTIC BEHAVIOUR OF HEAT WAVES AND TEMPERATURE IN HUNGARY

A. RÉVÉSZ

*Corvinus University of Budapest, Faculty of Horticultural Sciences, Department of Mathematics and Informatics*
*1118 Budapest, Villányi út 29-43, Hungary*
*(phone: +36-1-482-6181; fax: +36-1-466-9273)*

*e-mail: andras.revesz@uni-corvinus.hu*

(Received 25th October 2008 ; accepted 13rd December 2008)

**Abstract**. One of the adverse effects of climate change is the proliferation of heat waves. Our investigations show that according to the most widely accepted climate change scenarios heat waves are expected to be essentially longer and hotter than in the past. It might happen that events we now define as heat waves last through entire summer. Although it will not be general, the length and intensity of present heat waves could also multiply. Based on data provided by some global circulation models, we might be face an event that exceeds the hottest heat waves of the 20th century by as much as 12°C. This study also offers a survey of the methodology of heat wave definition. Besides traditional calculations, we present two unconventional methods by introducing minimum and maximum temperature heat waves. We show in what points this approach is different from those usually adopted and what extra information it may offer. As an extension of the usual studies, with considering the length of events, we analyse the development of two variants – temperature and duration – and, as a result, classify the extreme heat events according to both length and intensity.
**Keywords:** *Duration of heat waves, frequency of heat waves, distribution of heat waves, minimum and maximum temperature heat waves.*

## Introduction

In this study we show that, according to the current climate scenarios, the change of the climate in Hungary may have serious effect on society from the point of human beings, veterinary as well as economy. For this investigation we made statistical and risk analysis calculations on historical meteorological time series data and three selected scenarios. Our research was conducted within the frames of the project "Preparing for Climate Change: Environment – Risk – Society (KLIMAKKT) (Harnos, 2007). The model runs in the centre of our investigation were the three runs of the two scenarios also studied by the other participants of the project. As IPCC – playing a leading role in climate change research – has set down four possible socio-economic scenarios (IPCC, 2007) widely used as input parameters by the research centres studying climate change for their own mathematical models, we have decided to examine the same scenarios. Our possibilities do not allow us to develop the circulation models of our own, in fact, the enormous amount of calculation these require have even prevented us from running existing models and therefore we have to be satisfied with models runned by other research institutes (PRUDENCE, 2007) and use them as inputs for our own investigation. With several institutes involved in the latest research by the IPCC, we have had several dozens of model runs at our disposal. The researchers in the project have selected three of these, only, to make sure that a comparable studies of the possible changes emerge from the research in the various fields. Accordingly, we also work with these three runs in the following study, namely the A2 and B2 scenarios of Hadley

Center and the A2 scenario of the Max Planck Institute. These new runs all refer to the time interval 2070-2100 and contain the daily meteorological data (minimum, maximum and average temperature) required for our research. We compared these with the 100 year (1901-2000) meteorological time series data of Budapest and Debrecen. For much of our calculations we used a module containing time series and risk factors, created specifically for our research (Szenteleki at al., 2007.) and included in the software package of KKT (Council for Climatic Research) (Szenteleki et al., 2007.) developed to create a standard database in the KLIMAKKT project.

The main goal of our research was to determine whether a change can be expected in the frequency and intensity of heat waves and if so, what would be its direction and volume. Researchers and public at large received the first warnings of the extraordinary effects of heat wave in Chicago in 1995, followed by one with tragic consequences in Paris in 2003 (Poumadère et al., 2004). Dramatic processes were triggered off in both cases by extraordinary meteorological events (Schär at al, 2004). To further aggravate the problem, the leaders and public authorities of the towns affected were caught unprepared for the tasks required by the extraordinary heat. In the absence of any previous experience, they had no really idea  what they were required to do. From the retrospect of a few years, the specialists analysing the events revealed that although it is true that extraordinarily high mortality was caused by the heat, good communication might have prevented the tragedy. By now, we all know that people on the periphery of society are hit hardest by heat waves, including in the first place those over 65, people with disease, physical or mental disabilities and the poor. Both memorable heat waves drew the highest number of victims from people with multiple disadvantages, in other words, the poor, the elderly and the sick. The reason for this is not simply their inability to look after themselves, but many other ones related to the absence of information and money. There were hardly any air conditioners in the suburbs of Chicago in the 90s and in fact, there had not even been ventilators to ease the sensation of heat in the homes of the deceased. To add to the problem, public safety has been deplorable in these districts, discouraging the elderly from going out in the streets in search of a cooler place. This was not a problem in Paris where the absence of air conditioners was. To go from bad to worse, air conditioning in those days was inadequate in public institutions and in many of the hospitals as well as in private homes. Both cities had a shortage of ambulances and hospital beds. In Paris, unfortunately, casualties also filled the morgues, creating a truly extraordinary situation for the town leadership.

Similar heat wave would probably be faced at an improved level of preparedness in the more highly developed big cities of the world holding out the hope that appropriate action plans and better communication might keep down the number of deaths caused by heat-related stress. However, there are also other dangers threatening areas other than human health. Among these, infrastructural problems are in the first place. Extreme heat might temporarily disable the railways  the consequence of whichcan paralyse public transport. Lasting heat may cause similar problems in major towns where temporary stoppages in tram or underground (subway) traffic may bring the public transport system to a complete standstill and that might also lead to complete blockages of the road traffic. The traffic situation will be further deteriorated by commuters travelling daily from the agglomeration surrounding all the major cities who, once the commuter's trains stop working, will all be forced to use their cars. Electricity might be another infrastructural problem. The spread of air conditioners has already significantly increased electric energy consumption in summer. Some big cities are already facing


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

capacity problems that might grow with the expected warming. As examples of the past few years have shown, in situation of narrow capacities, even a slight break-down in a period with outstandingly hot temperature might cause a blackout of entire districts or regions. Nuclear power plants, those otherwise reliable pillars of the electric energy network also become a source of potential danger. This is because nuclear reactors are usually built by rivers whose water provides adequate cooling for the reactor. The problem is that above a certain temperature the safety of this operation cannot be ensured and high temperature might necessitate a temporary shutdown. Long periods of dry and warm weather may cause the same problem by reducing the water level of certain rivers. This situation might be eased by the latest EU directive on energy, instructing members to rely as much as possible on the various renewable resources of energy, including, in the first place, solar energy, to meet the electric energy demands of the growing consumption of summer period.

Events triggered by heat wave that were surveyed so far represent but a few of all the possible problems. There are several issues on which we do not have enough information but assumed to be problematic. These are the security of drinking water supplies, the outburst of epidemics, reduced working ability, accidents induced by lack of concentration caused by the heat, etc. Our experiences justify the requirement to pay more attention to heat waves. We had embarked on this study in order to find out whether the frequency and intensity of heat waves change in the period examined.

## Definitions

What is a heat wave? One might be prompted to answer the question by saying that a heat wave is a hot spell of some length. True, but the question is how hot and what length? The answers may be as manyfold as the number of institutions or bureaus releasing studies on the issue. As an added complication, heat waves have meteorological or ecological consequences over and above the obvious humane and infrastructural impacts. So rather than accepting a general definition, we must consider the object of scrutiny. A more comprehensive approach is possible in the case of heat that might be harmful to human health, defined by the authorities as the „heat alarm threshold" in various countries.

In way of providing some kind of guideline, the World Meteorological Organization has come up with a definition by which we have a heat wave when the daily maximum temperature, over more than five consecutive days, exceeds by at least 5°C the average of the maximum daily temperatures of the same calendar days in the period between 1961-1990.

As a similar example, we might quote the Dutch definition by which a heat wave is an event when the daily maximum temperature over 5 consecutive days exceeds 25°C and for at least 3 days it reaches the 30°C mark.

The criterion for calling  a heat wave alarm is different in the various states of the US, but they also have a guideline with the definition by the National Weather Service which says that a heat wave stricken period is one in which the maximum temperature is over 32.2°C for at least three days. Heat waves are also classified by their degree of being dangerous, with various levels and action programmes established to provide the cornerstones of categorization. Here night-time maximum temperatures are also considered over and above the daily maximums. A more sophisticated concept than the temperature-based one is used in the form of a heat index, a derived quantity calculated from the values of temperature and humidity. The essence of this calculation is that it can express the human thermal sensation. Without doubt, in a human context, the heat index can be used with much greater accuracy than the temperature alone, for the current study however, we had no humidity data at our disposal, so we had to rely only on those of temperature. It should also be noted that the absence of data was not the only reason why we did not use a heat index. As discussed earlier, heat waves do not only hit people, they may also have an adverse effect on other beings, the infrastructure, economic performance, etc. Of all the negative effects of heat waves only those with a human implication can be analysed if we rely on thermal sensation in our investigation. Therefore we drew up analyses in which we distinguished among heat waves on the basis of their intensity as well as length. First, let us look at the official Hungarian definition - based on a study that has been a joint project of the National Institute of Environment Health of the National Center for Public Health - NCPH-NIEH (OKK-OKI)1, the Budapest Office of the National Public Health and Medical Officer Service – NPHMOS (ÁNTSZ) and the Hungarian Meteorological Service – HMS (OMSZ) - that points to days with an average temperature above the daily average temperature monitored at a 97% frequency (26.6ºC). By that, a heat wave is an event in which the daily average temperature is above 26.6º C on three consecutive days.

## Results

### *The frequency of heat waves on the basis of the official Hungarian definition*

Let us compare the distribution of the length of the heat waves by this definition in Budapest and Debrecen in the periods between 1901-2000 and 1970-2000. We need these two different time intervals to be able to decide which one to use as a base period for comparison in our subsequent enquiry.

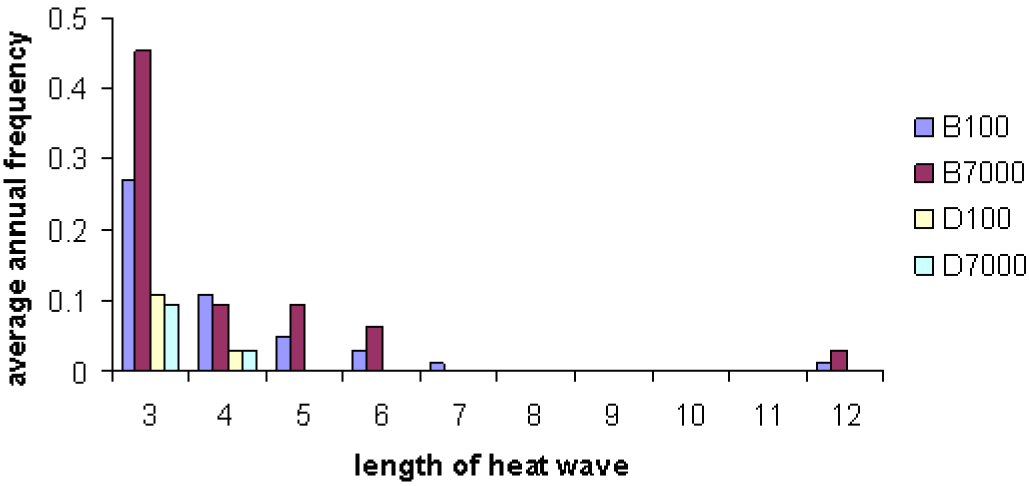



***Figure 1.*** *Distribution of heat waves in Budapest and Debrecen between 1901-2000, (B100, D100) and 1970-2000 (B7000, D7000)*

[1] The abbreviations of the Hungarian names of the institutes are given in brackets.

*Figure 1* shows that while the average annual frequency of heat waves increased in Budapest in the past 30 years compared to the interval of the past 100 years, it has remained practically unchanged in Debrecen. At the same time it is also obvious that heat waves are much more frequent and as a general rule, also last significantly longer in Budapest. The figure also shows that Budapest produced what by today's standard an „extremely" long is, a 12-day heat wave that, nevertheless, fades in proportion compared to the events of the entire period. In our enquiry we often came across with such remarkably outstanding yet infrequently occurring events which, notwithstanding, require attention because of their extreme values that are usually in the background of meteorological catastrophes.

Now let us examine the distribution of heat waves in the case of the scenarios of the three different model runs described earlier. *Figure 2* shows the distribution of the length of the heat waves – defined by the NPHMOS – with different lengths but of at least 3 days, in the case.

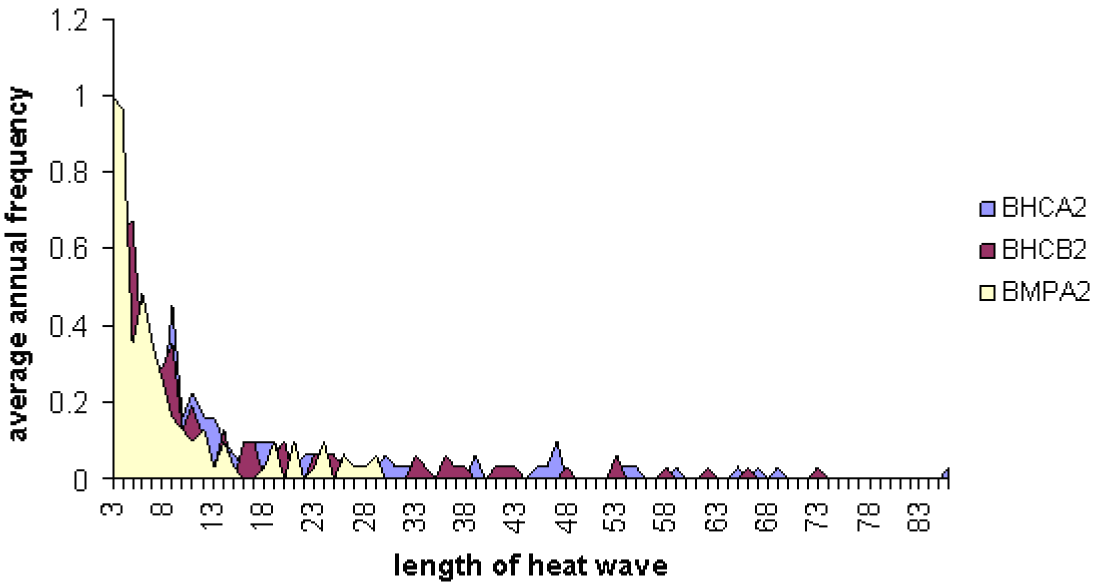



***Figure 2****.Distribution of heat waves in Budapest in 2070-2100 based on the NPHMOS definition (B-Budapest, HC-Hadley Center, MP-Max Planck Institute)*

The difference is remarkable. Heat waves are expected not only to be more frequent but they will also be extremely protracted in length. Against the historical data, a 12-day heat wave can be regarded as of extreme length, heat waves with length of 1-2, or even 3 months are relatively frequent in the HC runs. As a matter of fact, this means that in some of the modelled future years the whole summer is an only long heat wave. Although results of the MP appear to be essentially more steady, we should note that frequency values as well as the lengths of heat waves may double or in some cases even treble in the future. We come to similar result by examining the case of Debrecen (*Fig. 3*) The frequency values are very close to each another, however, the proportion of the occurrence of heat waves shows considerable growth. The same can be recognized in the length of heat waves. In both cases a tenfold growth may be reached and in some cases exceeded. A comparison of the diagrams of the cities reveals significant similarity in both the outstanding values and the values of great frequency.

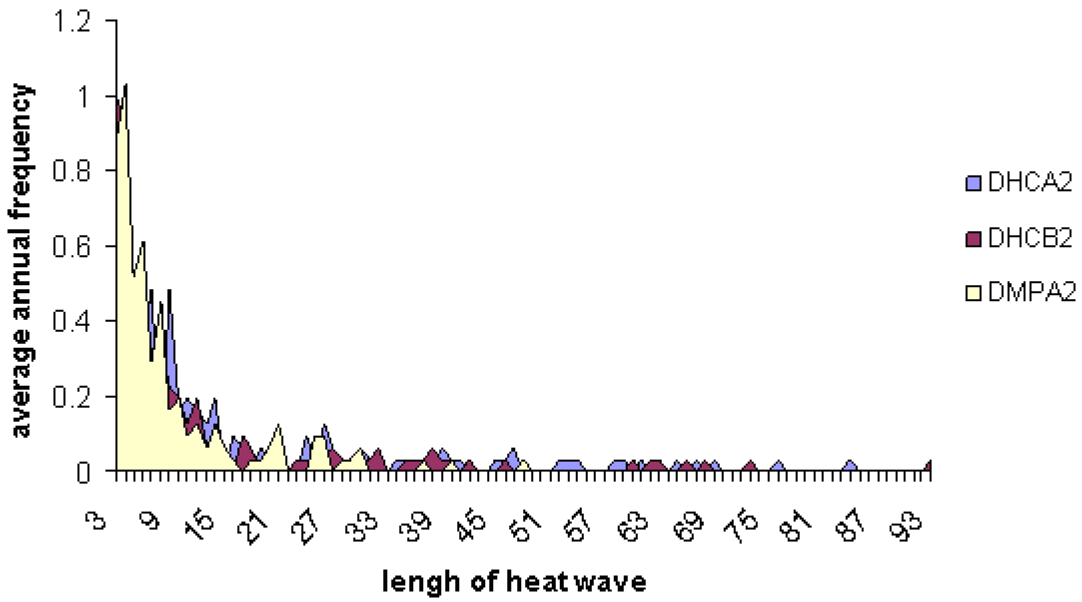



***Figure 3.*** *Distribution of heat waves by the NPHMOS definition in Debrecen in 2070-2100 (B-Budapest, HC-Hadley Center, MP-Max Planck Institute)*

This is presumably explained by the fact that the expected heat waves, rather than appearing as heat islands, will have a geographically large expansion. In other words, from the point of view of the extreme values the year under scrutiny is more important than the place of examination. To support this allegation let us look at two comparative figures for the model runs producing the highest and lowest frequencies (*Fig. 4 and 5*).

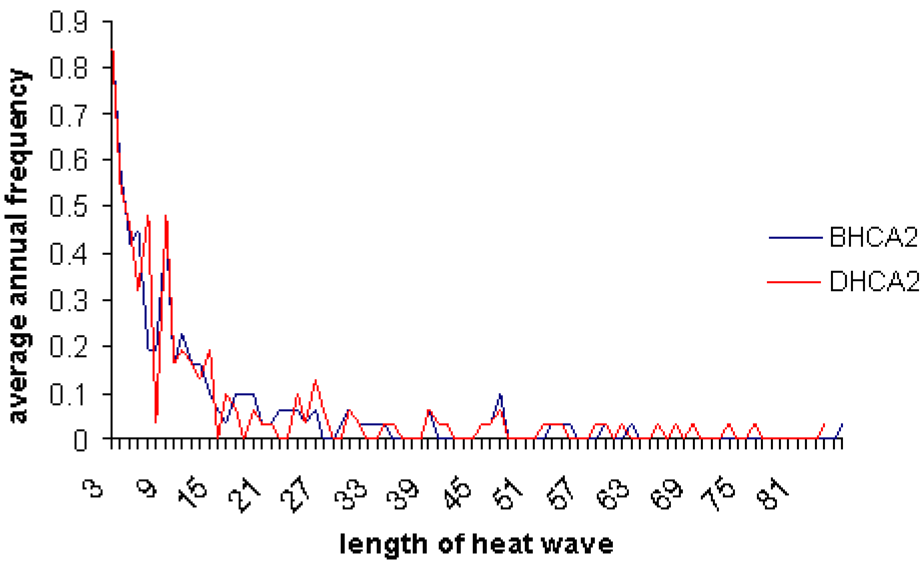



***Figure 4.*** *Distribution of heat waves in Budapest and Debrecen between 2070-2100 with the A2 model run of the Hadley Centeron the basis of the NPHMOS definition*

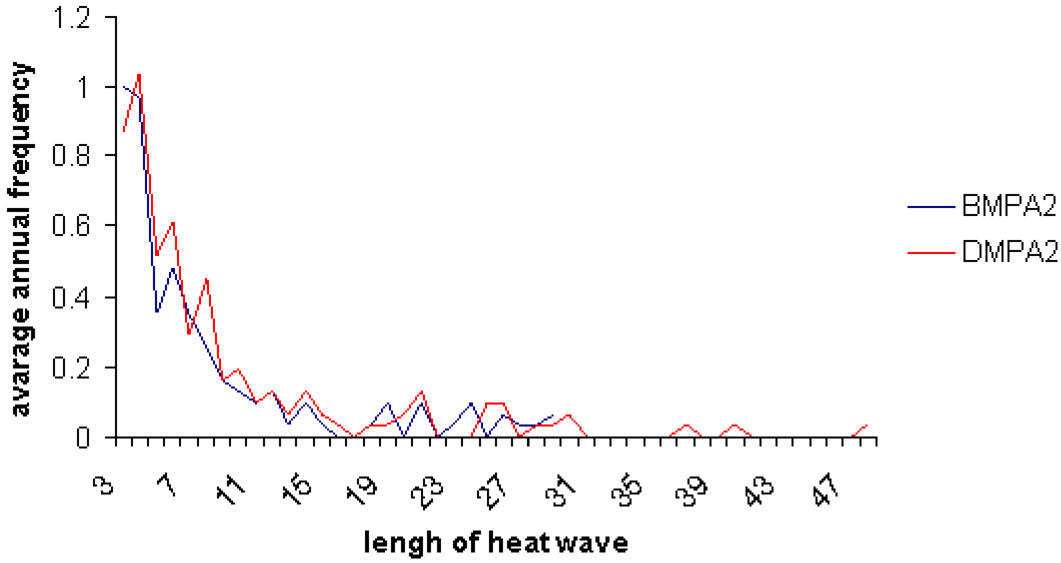



***Figure 5**. Distribution of heat waves in Budapest and Debrecen between 2070-2100 with the A2 model run by the Max Planck Institute based on the NPHMOS definition*

It can be seen in both figures that while the characters of the curves are identical, their values are also more or less the same regardless of which model run we consider. This, in essence, supports our presumption that heat waves depend much more on global meteorological conditions than on geographical distances. To prove this allegation it might be worth to examine several other towns, but in the absence of data, we need to delay this study.

Another question of interest is the average annual number of heat wave stricken days in the historical data and in the model runs. This is an important figure, because quite obviously, long but rarely occurring events must have a greater weight than shorter heat waves when considering risk factors. It can be seen that there is a dramatic rise in the number of heat wave stricken days regardless of what basis we select or which town we examine (*Fig. 6*). It can also be seen that the model runs influence the occurrence of events more than the scenarios themselves do, as in the case of both cities, the difference between scenarios A2 and B2 is smaller than the difference between the same scenarios of the two institutions. It is quite peculiar that in the case of the model runs, the value of standard deviation is around 20 days, although the mean value is between 40 and 80. The average values of Debrecen are just a little over those of Budapest which is all the more remarkable, as the values shown by the historical data are by and large „negligible" when compared to future values, yet, it can be seen that the situation used to be just the opposite in the past. Regarding the historical values, the uncertainty is reflected in the fact that the standard deviation exceeds the average value in every case, which makes clear that heat wave days in the past are connected to the „warmer years". In other words, in some years there were several heat waves, while in others there were none. The values generated by the model runs show nothing like that. Relative deviation is much smaller than in the case of the historical set of data, which clearly amounts to state that it is not possible to predict the exact number and length of heat waves in the various scenarios, while the number of heat wave days can be forecasted with „relatively great" accuracy.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

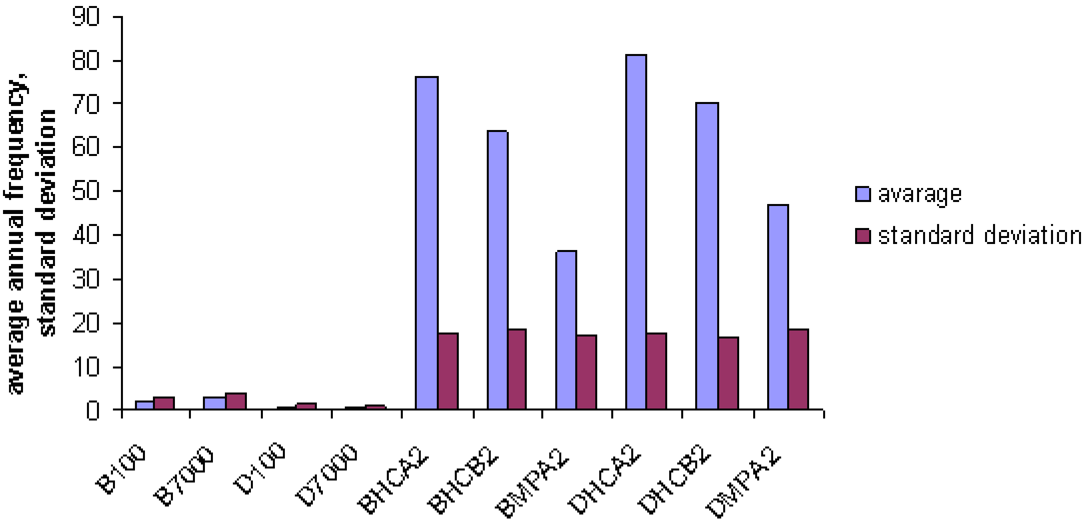



***Figure 6.*** *Average number of heat wave days and their standard deviation in the historical set of data and model runs based on the NPHMOS definition*

### *Examining the intensity of heat waves*

As mentioned earlier in my description of the relevant definitions, although heat wave is a term we can easily define from a human point of view and we can also safely say when a heat wave alarm should be called, the definitions contain no information whatsoever on the intensity of heat waves. But as the intensity of a heat wave might determine its varying effect on humans, animals, plants or the infrastructure and the economy, it is worth to examine the intensity as well as the length of each heat wave. Therefore we plotted the distribution of the outlier temperature values of the most typical three base periods used in climate research (1901-2000, 1960-1990, 1970-2000). In our first study we examined maximum temperatures instead of the usual average temperatures, as extremely high values stand out more clearly in this sample. *Figure 7* shows the distribution of the above mentioned three time intervals cumulated by temperature levels, revealing, in other words, in the  period the average annual number of „heat waves" lasting for t days and characterized by a temperature of at least T. In this classification we did not yet narrow down the definition of a heat wave to events that would last for at least three days.

Based on the chart it is difficult to draw a line of distinction between the three distributions. It can be seen that the highest values, surprisingly, are contained in the 100 year set of data; but its decreasing phase is steeper than in the case of the other two diagrams (this means that outstandingly warm periods occurred not only at the end of the 20th century but also before that, but the heat waves experienced by the end of the century were either warmer or longer than the earlier ones), although the difference is insignificant. As seen on the scales of the figures, the classification involves maximum temperature levels over 30°C, because this is roughly the level where the daily average also exceeds the threshold of heat wave alarm.

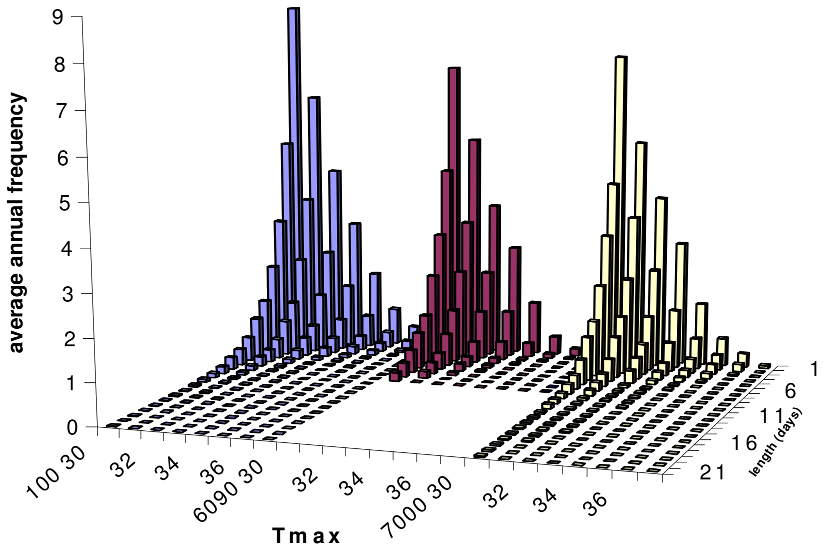



***Figure 7.*** *Distribution of the length and intensity of the maximum temperature "heat waves" for the three base periods, cumulated by temperature levels*

We carried out the same enquiry also for the three model runs (*Fig. 8*). The difference is too striking to need any further explanation.

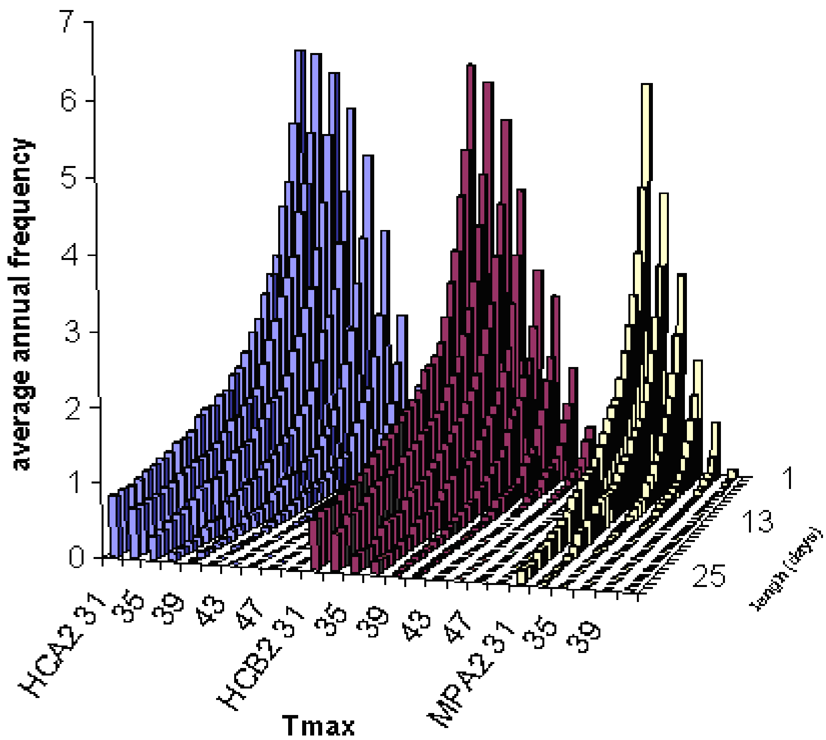



***Figure 8.*** *Distribution of the length and intensity of the maximum temperature "heat waves" of the three model runs in Budapest (2070-2100), cumulated by temperature levels*

All one might say is that the values have grown to such an extent that for technical reasons we could not represent frequencies in one and the same scale, as the 30°C value was accompanied by an extremely protracted length of time (even as it is, we can only show the values in a reduced scale), while on the other hand, we found we had such high temperature levels that in the interest of representation we had to desist from using a 1°C scale unit.

It can be clearly seen that of the three model runs frequency values were the lowest in the case of MPA2 and the highest with HCA2. To be able to compare the two HC scenarios, we drew up a figure of the differences of the frequencies (*Fig. 9*) which shows that with a slight exception, individual frequency values are higher in HCA2 than in B2.

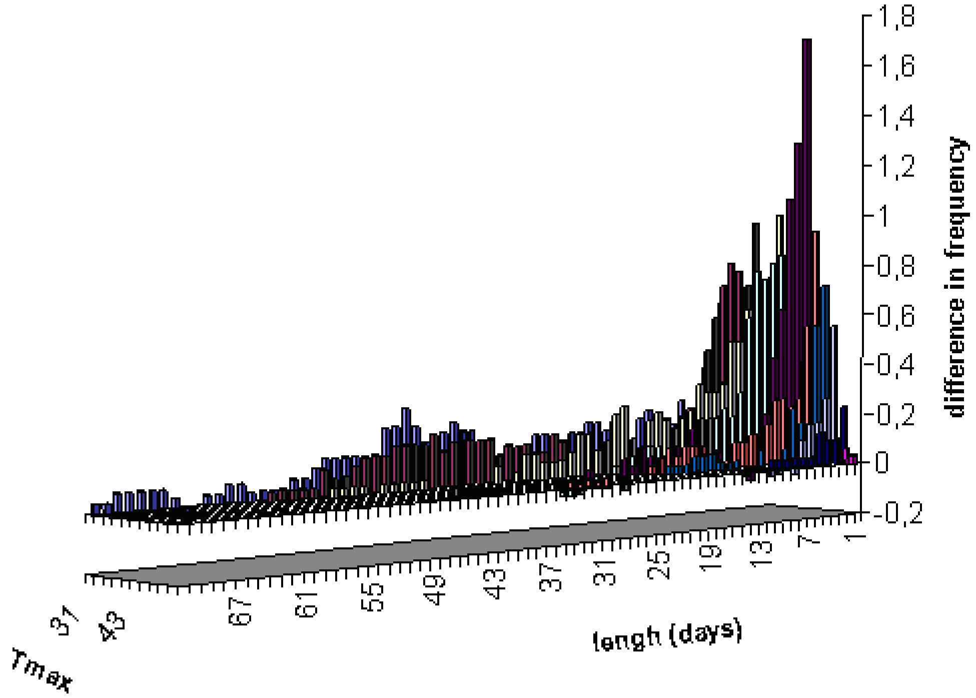



***Figure 9.*** *Differences in the frequencies of the HCA2 and HCB2 runs*

Yet, to be able to make some comparison, we produced a „best case" comparison, comparing the distribution of the highest frequency values (100 year) with the run of the model (MPA2) with the lowest values of frequency ( *Figure 10*). All its interpretation may require is to say that had we represented three-day events that are now regarded as standard, the heat waves of the historical data could practically not be seen in the Figure, being so small in size by comparison to the data of the scenario.

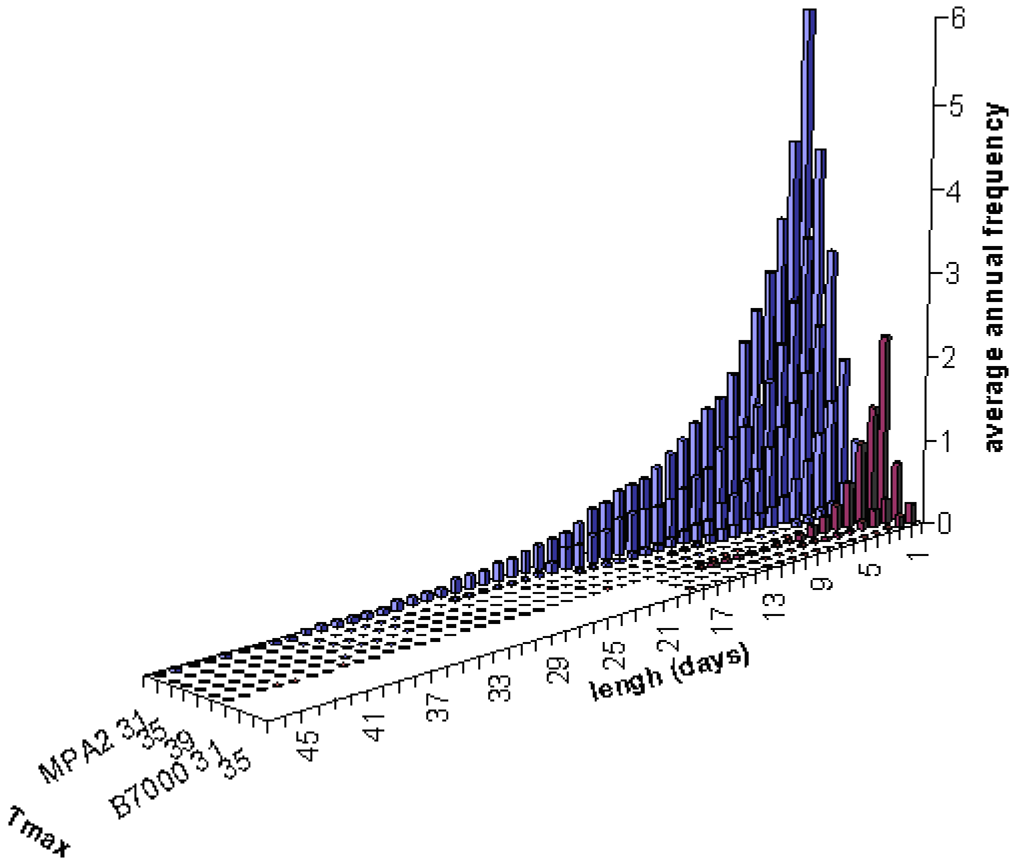



***Figure 10.*** *Comparison of the heat waves of MPA2 and the set of historical data from 1901-2000.*

Finally, here is a comparison of the numerical data of some past and expected "future" events:

- The longest 31°C maximum temperature heat wave we have had lasted for 18 days in the past and lasts for 87 days in the runs.
- In the case of heat waves lasting for at least three days the highest maximum temperature recorded was 37°C in the past while the runs envisage ones of 49°C.
- Past records show heat waves with a maximum temperature reaching or exceeding 31°C and lasting for at least 3 days lasting on average for 10.1 days, as opposed to some of the runs with an average reaching 92.5 days.

These are quite staggering figures. Considering these three data alone, they might mean that in case the scenarios come true, practically the whole summer will be one long heat wave, with its peaks higher by 12°C when we come to the period between 2070 and 2100. This appears unbelievable at first glance, for these scenarios envisage an average temperature rise of "only" 5-6°C at worst.

### *Average temperatures in Budapest*

To find out whether the rise of 12°C mentioned in the previous chapter is possible, we examined the succession of minimum, maximum and average temperatures in Budapest in the HCA2 and MPA2 model runs (that offer the two extremes in way of the data) and in the historical records (where we considered what the latest research also relies on, the period between 1970-2000). We made several comparisons, the most expressive of which are seen in *Figure 11*.

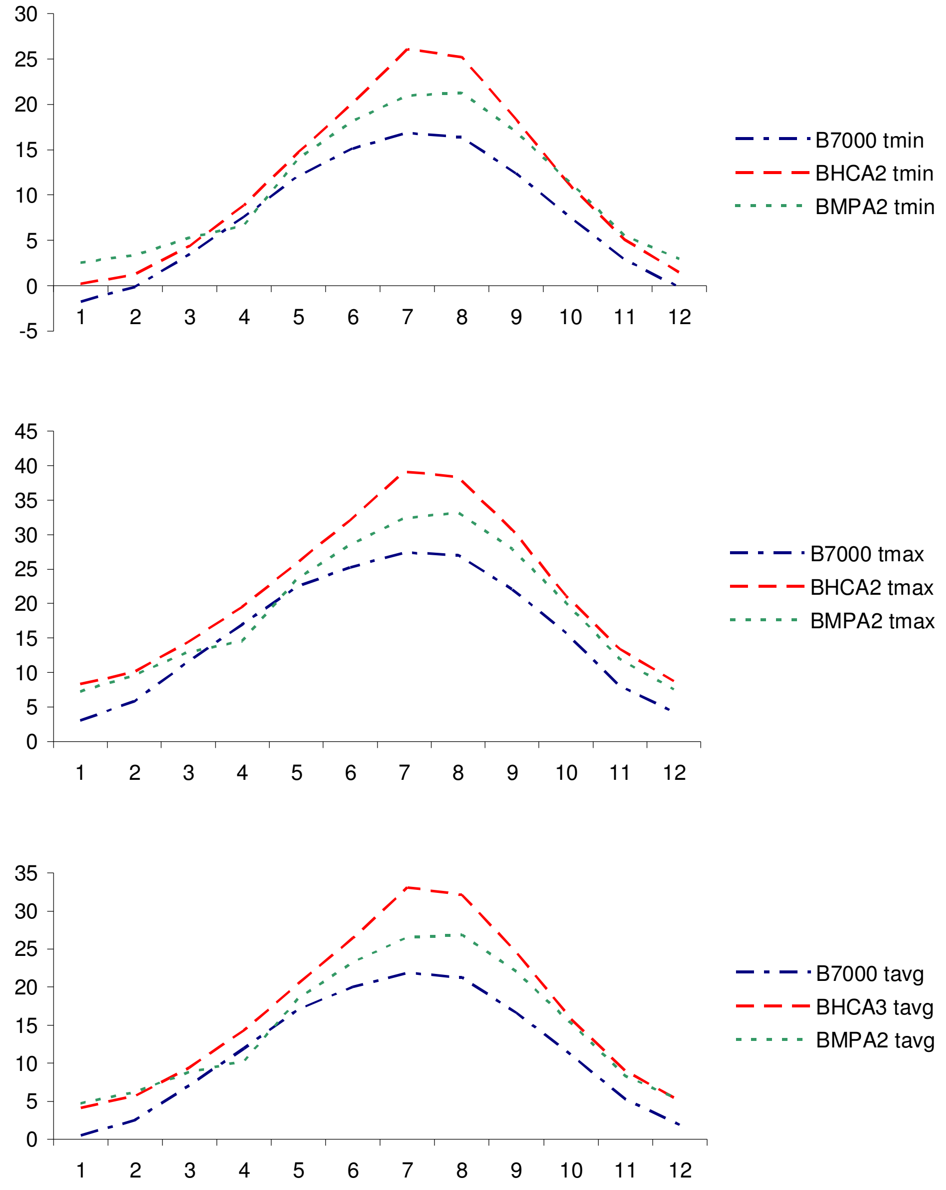



***Figure 11**. a, b, c: Monthly average of minimum, maximum and average temperatures in Budapest in the 1970-2000 period in case of historical data, and in the 2070-2100 period in the case of runs of the HCA2 and MPA2 models*

It is clear that with the exception of the figures for April, the historic time series data have always shown the lowest values. That was followed by the MPA2 run, as heat value highs appear in HCA2. In other words, the biggest differences appear between the set of historical data and HCA2. (*Tab. 1*)

***Table 1.*** *Difference between the 31 year average of monthly minimum, maximum and average temperatures of the HCA2 run and the 1970-2000 time series*

| | Tmin | Tavg | Tmax |
|---|---|---|---|
| **Januar** | 1,98 | 3,68 | 5,27 |
| **Februar** | 1,40 | 3,18 | 4,35 |
| **Mach** | 0,89 | 2,27 | 2,83 |
| **April** | 1,25 | 2,39 | 2,57 |
| **May** | 2,62 | 3,42 | 3,44 |
| **June** | 4,96 | 6,46 | 6,85 |
| **July** | 9,21 | 11,23 | 11,79 |
| **August** | 8,87 | 10,89 | 11,36 |
| **September** | 5,94 | 7,92 | 8,67 |
| **October** | 3,47 | 4,71 | 5,41 |
| **November** | 2,18 | 3,71 | 5,36 |
| **December** | 1,66 | 3,17 | 4,55 |
| **yearly** | **3,70** | **5,25** | **6,04** |

No deep-going analysis is required to find the solution. According to the HCA2 model run, the maximum temperature in July will be warmer by 11.8°C than the average of the last 31 years of the last century. It is no exaggeration to say that this is a dramatic value. Its appearance in real life stresses even perfectly healthy individuals while it is harmful for the diseased and it induces high ecological and economic risk. At the same time it can be seen that while winter would also be warmer, warming in spring might not be significant compared to the annual average. It is interesting, however, that the rise of the values is essentially smaller in the case of minimum temperatures, although the rise of 9.2°C in July is just as catastrophic as the value emerging in the maximum temperatures.

### *Minimum temperature heat waves*

In *Section* "Examining the intensity of heat waves" we discussed heat waves defined by maximum temperatures, Extreme events are of high risk on days with extreme hot noon hoursOn a day with extremely high maximum temperature the average cannot be low either, as in continental zone high fluctuations of temperature is not characteristic. On the other hand, one might ask: how cold are the nights of hot days? Do houses cool down enough for people to get the rest and recovery they need during the night? Naturally, this question can also be turned to form a statement: if nights are hot, presumably the days are hot too, and so you can also define a heat wave manifesting itself in high minimum temperatures which is just as unpleasant as those expressed in maximum temperatures. (Note that there is a significant overlapping between them.)

Analogously, we performed the same examinations with minimum temperature heat waves that we did with maximum temperature heat waves. In their tendencies, the results fully corresponded with earlier results. Admitthat the frequencies of the heat waves in the three model runs show larger differences than what we experienced in the case of maximum temperatures, but regarding frequency values we can set up the order of HCA2, HCB2 and MPA2 (*Fig. 12*) again. A comparison of the historical records and the most favourable MPA2 data also reveals differences in magnitude, even if those differences are somewhat smaller than in the case of maximum temperatures (*Fig. 13*).

Naturally, *Table 1.* explains why these differences are smaller in the case of the minimums than in that of the maximums.

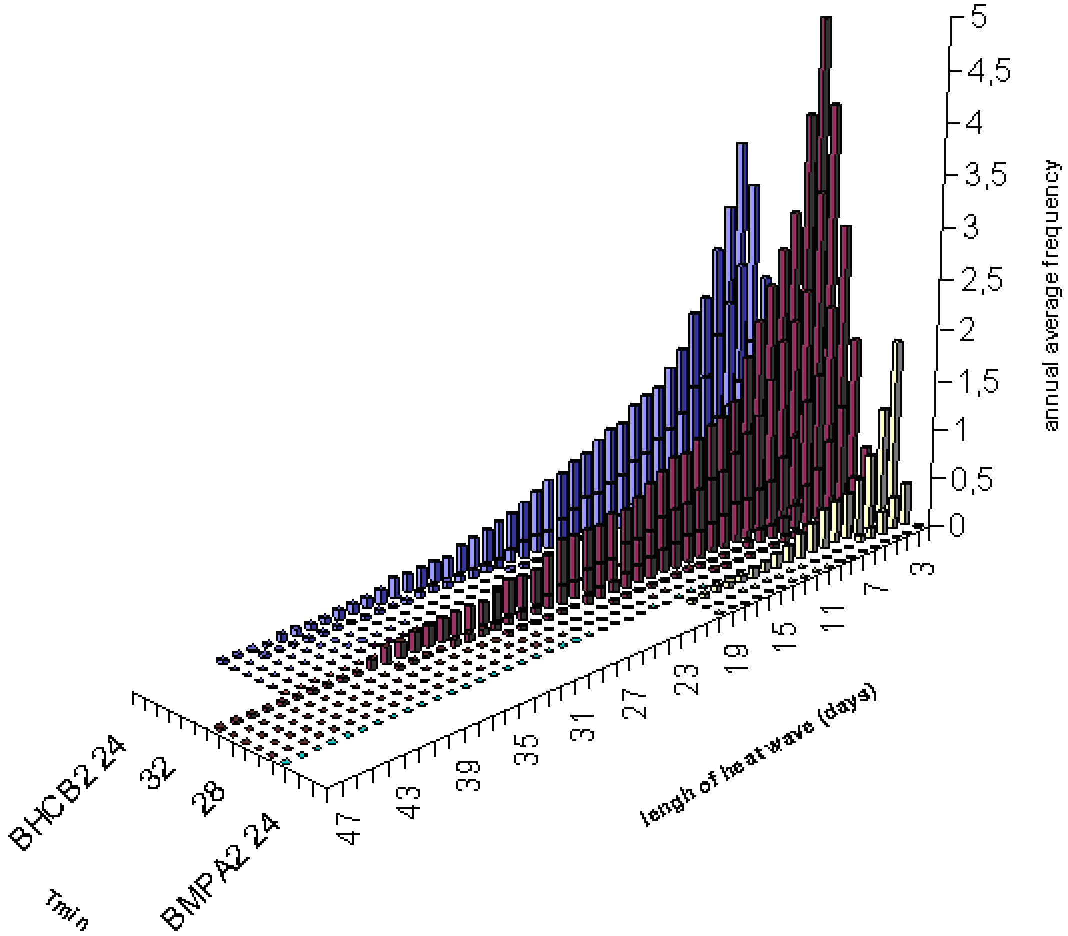



***Figure 12.*** *Distribution by minimum temperature levels of the heat waves considering minimum temperatures in Budapest in case of the three model runs*

In the minimum temperature category, we examined heat waves with a minimum temperature of over 24°C in the scenarios and those of over 18°C in the case of the historical data. We have chosen this value because it is agreed in scientific literature that it is difficult for the human body to regenerate above normal room temperature which would be 24°C, but because of the heat island effect of towns, the temperature in homes is warmer than air temperature by 5-6°C, therefore 18°C is not necessarily “pleasant” in a town. However, there was no point in examining this value in the model runs, because we would have arrived at heat waves of several months.

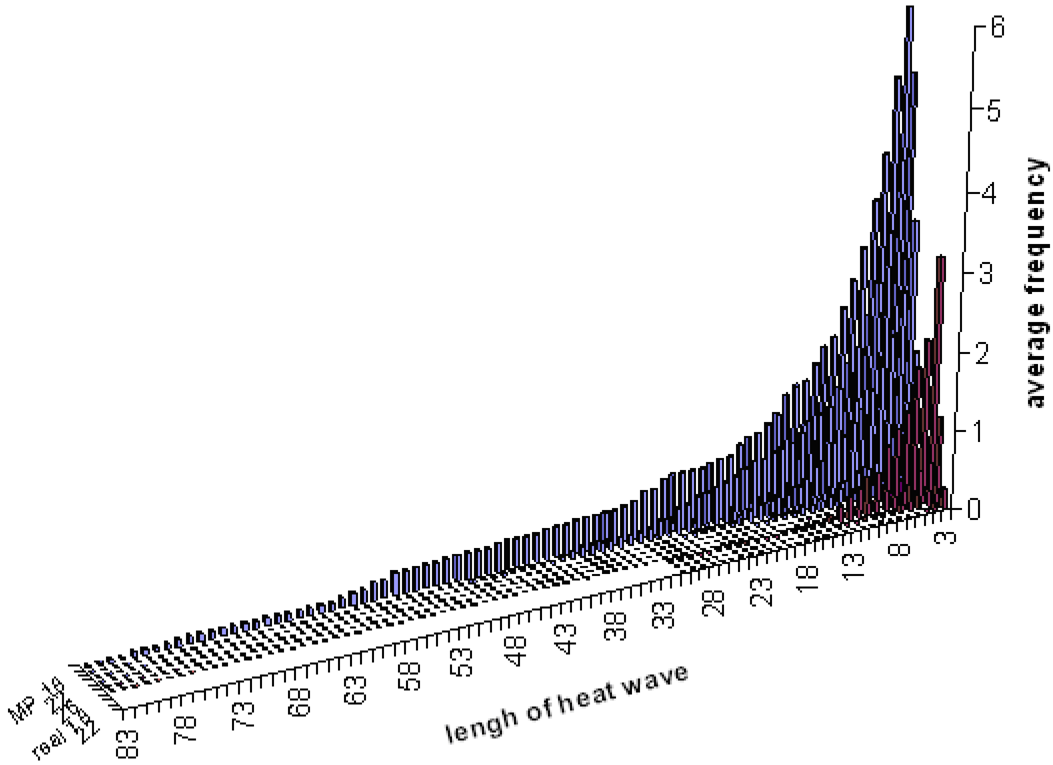



***Figure 13**. „Best case" comparison of the distributions cumulated by temperature levels of the heat waves considering minimum temperatures in Budapest using 1970-2000 and MPA2 data*

Finally, let us compare these heat waves, too, with some numerical data:

- The highest minimum temperature heat wave experienced was 21°C based on historical data, but model runs also predict ones of 34°C.
- The longest 18°C heat wave was one month long in the historical data. Even the most favourable scenario contained an 18°C heat wave lasting for 87 days.
- The number of heat wave days has also shown a drastic increase. This value is practically incomparable as in the historical data the minimum temperature was above 18°C for at least 3 days on an annual average of only 19 days, while the model runs contain spells of over 40 days when the minimum temperature does not go under 24°C.

I believe that the use of any of the above three heat wave definitions might substantiate the allegation made in the introduction, namely that the climate in Hungary will change and extreme events caused risks of all kinds will multiply if the scenarios we have studied and discussed become a reality. Heat waves are among the most dangerous of extreme meteorological events. Whichever definition we use, we can say that the length and intensity of heat waves will increase considerably with high possibility and it might entail unforeseeable consequences for several sectors.

## REFERENCES

[1] Beniston, M., Diaz, H.F.(2004): The 2003 heat wave as an example of summers in a greenhouse climate? Observations and climate model simulations for Basel, Switzerland. – Global and Planetary Change Volume 44, Issues 1-4, 73-81. pp.

[2] Harnos, Zs. (2007): Klímaváltozással összefüggő hazai kutatások: a VAHAVA folytatása. – „KLÍMA-21" Füzetek 2007.49.: 3-15. pp.

[3] Horváth, L., Gaál, M. (2006): Spatial analogies in service of climate change analysis – 6th Annual Meeting of the EMS / 6th ECAC 4 - 8 September 2006 Ljubljana, Slovenia abstract cd-rom.

[4] Horváth, L., Gaál, M., Solymosi N. (2007): Spatial analogues in climate change research – EFITA/WCCA 2 – 5 July 2007, Glasgow, Scotland, Paper CD ROM p22.

[5] IPCC (2007): Fourth Assessment Report "Climate Change 2007"

[6] Poumadère, M., Mays C., Le Mer, S., Blong, R. (2005): The 2003 Heat Wave in France: Dangerous Climate Change Here and Now. – Risk Analysis Volume 25 Issue 6. 1483-1494.pp.

[7] PRUDENCE (2007): Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects, http://prudence.dmi.dk.

[8] Schär C., Vidale, P.L., Lüthi, D., Frei, C., Häberli C., Liniger M.A., Appenzeller, C. (2004): The role of increasing temperature variability in European summer heat waves. – Nature 427, 332-336 pp.

[9] Solymosi, N., Maróti-Agóts, Á., Ózsvári, L., Könyves, L., Horváth L., Kern A. (2007): Region specific heat stress forecastfor cattleproduction based on climatechange. GISVET'07, Coppenhagen, 22-24 August 2007.

[10] Szenteleki K. (2007): A KKT programrendszer leírása – „KLÍMA-21" füzetek – impress

[11] Szenteleki K., Ladányi M., Erdélyi É., Horváth L., Hufnagel L., Révész A. (2007): A KKT klímakutatás adatbáziskezelő szoftver bemutatása – Georgikon Konferencia, Keszthely 5 pp.

[12] Szenteleki, K., Ladányi, M., Szabó, É., Horváth, L., Hufnagel L., Solymosi, N., Révész, A. (2007): Introducing the KKT climate research database management software – EFITA Conference, Glasgow.

[13] World Meteorological Organization, http://www.wmo.ch.

[14] Állami Népegészségügyi és Tisztiorvosi Szolgálat, http://www.antsz.hu.

[15] National Weather Service, http://www.nws.noaa.gov.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

# ANALYSIS OF CLIMATE CHANGE SCENARIOS BASED ON MODELLING OF THE SEASONAL DYNAMICS OF A DANUBIAN COPEPOD SPECIES

CS. SIPKAY[1] – L. HORVÁTH[1] – J. NOSEK[2] – N. OERTEL[2] – CS. VADADI-FÜLÖP[3] – E. FARKAS[3] – Á. DRÉGELYI-KISS[4] – L. HUFNAGEL[5]*

[1] *Department of Mathematics and informatics, Corvinus University os Budapest, H-1118 Budapest, Villányi út 29-33, Hungary (phone: +36-1-372-6261; fax: +36-1-466-9273)*

[2] *Hungarian Academy of Sciences, Institute of Ecology and Botany, Hungarian Danube Research Station, H-2131 Göd, Jávorka Sándor út 14, Hungary*

[3] *Department of Systematic Zoology andEcology, Eötvös Loránd University, H-1117 Budapest, Pázmány Péter sétány 1/c, Hungary*

[4] *Budapest University of Technology and Economics, Department of Chemical and Environmental ProcessEngineering H-1111 Budapest, Műegyetem rkp. 3, Hungary*

[5] *„Adaptation to Climate Change" Research Group of Hungarian Academy of Sciences H-1118 Budapest, Villányi út 29-43., Hungary* (phone: +36-1-482-6261; fax: +36-1-466-9273)

**Corresponding author*
*e-mail: leventehufnagel@gmail.com*

(Received 20th March 2008 ; accepted 14th October 2008)

**Abstract**. Climate change is one of the most crucial ecological problems of our age with great influence. Seasonal dynamics of aquatic communities are — among others — regulated by the climate, especially by temperature. In this case study we attempted the simulation modelling of the seasonal dynamics of a copepod species, *Cyclops vicinus*, which ranks among the zooplankton community, based on a quantitative database containing ten years of data from the Danube's Göd area. We set up a simulation model predicting the abundance of *Cyclops vicinus* by considering only temperature as it affects the abundance of population. The model was adapted to eight years of daily temperature data observed between 1981 and 1994 and was tested successfully with the additional data of two further years. The model was run with the data series of climate change scenarios specified for the period around 2070-2100. On the other hand we looked for the geographically analogous areas with the Göd region which are mostly similar to the future climate of the Göd area. By means of the above-mentioned points we can get a view how the climate of the region will change by the end of the 21st century, and the way the seasonal dynamics of a chosen planktonic crustacean species may follow this change. According to our results the area of Göd will be similar to the northern region of Greece. The maximum abundance of the examined species occurs a month to one and a half months earlier, moreover larger variances are expected between years in respect of the abundance. The deviations are expected in the direction of smaller or significantly larger abundance not observed earlier.

**Keywords:** *Cyclops vicinus, geographical analogy, hydrobiology, simulation modelling*

## Introduction

Climate change, the global warming can affect the aquatic ecosystems in a very sensible way (Straile 2005; Nováky and Bálint 2004). Therefore the research of the effect of climate variability on the aquatic ecosystems is an indispensable task.

One possible approach is the weather conditions depending simulation modelling of an appropriately chosen aquatic community. By the help of the simulation models we can predict the possible changes in the seasonal dynamics of the given aquatic community in the case of the alternative climate change scenarios, it is indeterminate though. Considering the errors and assumptions of the model, the most likely, possible scenarios of the effect of climate change can be achieved (Hufnagel and Gaál, 2005). For the modelling of the seasonal dynamics of population-collectives applying of extant model system is possible (Ladányi et al. 2003).

The seasonal dynamics of freshwater zooplankton communities is primarily influenced by climatic factors. Several authors have tried to describe and explore these connections (Bernot et al. 2004, Zelikman and Kamshilov, 1960, Hassel 1986, Villate et al. 1997). For modelling the seasonal dynamics complex approach is used generally: besides environmental factors, predator and prey terms are used as parameters (Broekhuizen et al. 1995, Angelini and Petrere 2000). However making comprehensive models requires many pieces of information, which could not be achieved at all times, as we are not able to measure the information for the parameters at the field. Therefore often so-called strategic models are set up, which focus on the essence of the process, hence many pieces of information are lost. Notwithstanding these models can be useful tools to understand the general function of the complex system. This is realized by stressing one factor considered as the most essential and neglecting the other factors.

Many authors draw attention to the relevance of temperature as the main regulating factor (Baranovic et al. 1993, Christou and Moraitou-Apostolopoulou 1995, Christou 1998, Dippner et al. 2000, Iguchi 2004, Meise-Munns et al. 1990, Viitasalo et al. 1990). We set up a discrete-deterministic simulation model which predicts the daily abundance of the investigated species by considering temperature as the main regulating factor and the abundance of population of the previous day. Our former studies were run on the seasonal dynamics modelling of the macroinvertebrate community in Lake Balaton (Sipkay and Hufnagel 2006, 2007) respectively of zooplankton and macroinvertebrate species in artificial water bodies (Vadadi and Hufnagel 2007). Present case study is made for modelling the seasonal dynamics of a Danubian copepod (Cyclopoida) species (Cyclops vicinus Uljanin, 1875) which is classed among the zooplankton.

The model was run with the data series of climate change scenarios that were specified for the period around 2070-2100, to answer the question, what changes could be expected concerning the seasonal dynamics of the species in question. What is more, we searched for the geographically analogous regions with similar climate as compared to the climate of the sampling site expected in the future, to demonstrate the climate change of the sampling site for the given period.


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

## Materials and methods

### *Data series used in study*

Quantitative data on copepods and cladocerans (ind/$m^3$) are available for the period of 1981-1994 (excepting the year 1990) based on the database of the Hungarian Academy of Sciences, Hungarian Danube Research Station. Sampling was conducted in the main arm of the Danube by Göd (1668 rkm) at a constant site near to the riverbank, filtering 200 liters of water with a plankton net (mesh size 75µm) from the surface at all times. Mostly samplings were performed weekly. Such frequent samplings adapt our data using for weather-dependent simulation modelling.

The meteorological data of the stations by Vác and Szentendre were applied, provided by the Hungarian Meteorological Office, as these two stations are near to the sampling site.

We used three data series of daily temperature for the period around 2070-2100, which are based on the A2 and B2 scenarios offered by the IPCC (2007). We used up the database of the PRUDENCE EU project (Christensen, 2005), namely the A2 and B2 scenarios of the HadCM3 climate change model run by the Hadley Centre (HC). Thirdly the running results of the Max Planck Institute (MPI) for the A2 scenario were applied. Daily data specified for the period around 2070-2100 are downscaled to the region of Budapest. Daily data series gained from running of the above-mentioned scenarios three times differently, are containing 31 years in each of the three cases.

For the geographical analogy the observed climatic data were obtained from the internationally accepted CRU TYN CL 2.0 database. This contains the mean monthly temperature and rainfall data for the period of 1961-1990 with a 10 minutes spatial resolution.

### *Geographical analogy*

One possible tool for analyzing climate change scenarios is the method of geographical analogy. This method is used for looking for regions that have similar climatic features currently, as compared to the examined area in the future (*Horváth, 2007*). The CLIMEX method (Sutherst et al., 1998) was used for analyzing the area of Göd, the grids of the TYN CL 2.0 (New et al., 1999, 2002) database were characterized on the basis of the climate related to a given grid, which has the greatest similarity with the data of scenarios. Regions can be regarded as analogous if their climatic similarity is greater than 90 %. Calculations were carried out based on the monthly temperature and rainfall values of all the 12 months.

### *Simulation modelling*

An all the year present, dominant species (*Cyclops vicinus*), often appearing in high abundance, was chosen for modelling from the investigated crustacean plankton. The model is based on the main hypothesis that temperature is the principal regulating factor, so thus the abundance pattern is determined by the minimum and maximum temperature, other effects (like trophic relations and other interpopulation interactions) can be realized as hidden or as integrated in the main effect. We suppose that the temperature reaction-curve must be the sum of optimum curves, since the temperature optimum-curves of the different developmental stages of the species in question or its distinct subpopulations, additionally every other biological phenomena determining the growth rate of the species can be added together in the reaction-curve. The seasonal dynamics of copepodits and adults of the chosen species were modelled separately. The individual numbers depend on the multiplier of minimum and maximum temperature ($^{o}$C) values according to the following formula:

$$N_t=R_T \cdot N_{t-1} \qquad \text{(Eq.1)}$$

Where $N_t$ is the individual number of the population (adult or copepodit) at the time „t”, $R_T$ is the value of the multiplier. Both of the temperature reaction-curves of minimum and maximum temperatures can be generated as the sum of two normal distributions. The parameters of the model consist of the standard deviations and means of the distributions, as well as an added constant, furthermore the constant values that were multiplied by the normal distributions. After all, the model for *Cyclops vicinus* is realized as the sum of the models run with the data of adults and copepodits. Parameters were optimalized with the Solver program of MS Excel.

From the data series for 10 years available for us, our model was fitted to 8 years of data. The remaining two years of data series (the year 1983 and 1987) were used for testing and validating the model.

The model was run with the daily data series of different climate change scenarios, beginning each year with an initial copepodit and adult abundance at the first day.

Statistical analysis of the results was performed using Past software (version 1.36, Copyright Hammer and Harper 1999-2005). The date of reaching of the maximum abundance was used as indicator, one-way ANOVA was used for checking if there is any difference between the scenarios regarding their prospective values. The post-hoc Tukey-test was performed to explore the significant differences between groups in pairwise comparisons; homogeneity of variance was checked with the Levene test.

## Results

### *Geographical analogy*

The present regions which have greater than 90 % similarity with the future climate of Göd are presented in *Figure 1.* Intense (above 95 %) analogy was not found in any cases. Analogous regions can be found most of all in Northern Greece.

| A2 | Similarity (%) | B2 |
|---|---|---|

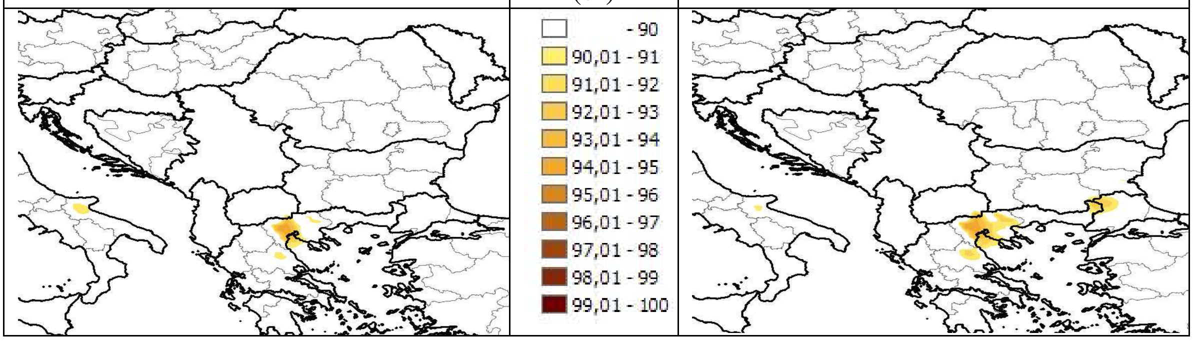



***Figure 1.*** *According to the A2 and B2 scenarios of the Hadley Centre, the climate of Göd in the period of 2070-2100 shows 90-93 % similarity with the present climate of the northern regions of Greece.*

### *Results of the simulation modelling*

The temporal changes of the observed and simulated abundance of Cyclops vicinus during the 10 years are presented in *Figure 2 a and b*. It can be seen that the model fits well to the observed values even in the case of the validating years (1983 and 1987).

The differences between the scenarios proved not to be significant (P= 0,07) based on the one-way ANOVA, performed for the date of supervention of maximum abundance in the model for the seasonal dynamics of *Cyclops vicinus*.

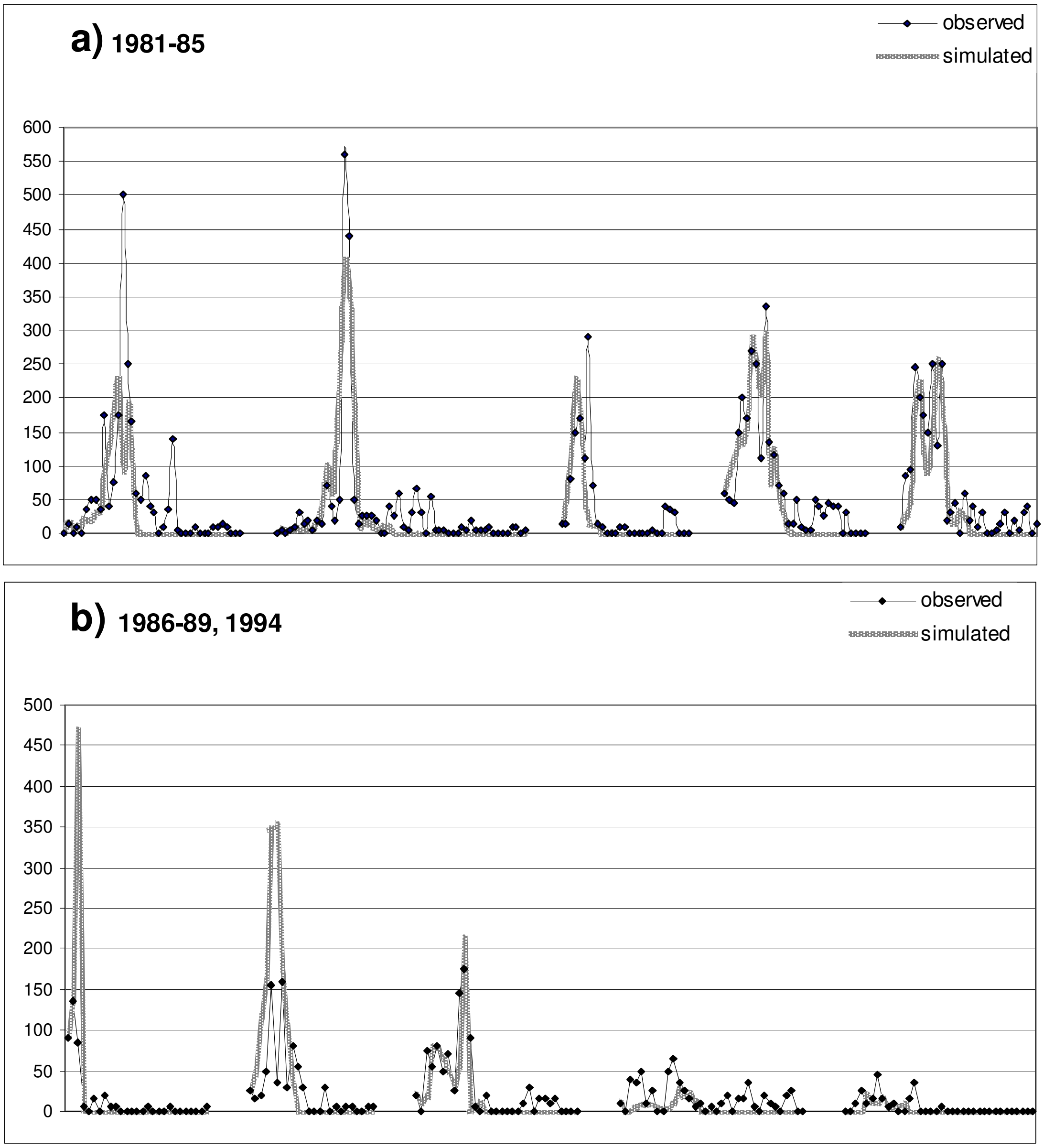



***Figure 2.*** *The seasonal changes of the observed and simulated individual numbers (ind/m3) of Cyclops vicinus in the years 1981, 1982, 1983, 1984, 1985 (a), as well as in 1986, 1987, 1988, 1989 and 1994 (b).*

According to the Levene test (p= 0, 17) the variances are homogeneous. No significant difference between the scenarios was detected by the Tukey-test based on pairwise comparisons. More intense similarity can be detected between the A2 and B2 scenarios of the Hadley Centre, than between the results of the two institute for the A2 scenario.

In the model fitted to the observed data (between the years 1981 and 1994), the maximum abundance occurs between the day 111 and 153, on the average at the day 137 (17 May). In contrast to the above-mentioned results, the maximum abundance occurs one respectively one and a half month earlier, on the average at the day 93 (A2, MPI), 98 (B2, HC) or 101 (A2, HC) regarding the scenarios, consequently between the 3 and 11 April.

No obvious increasing or decreasing tendency can be stated based on the maximum abundance and the yearly total abundance *(Table 1)*, but anyway a shift is expected compared to the examined state. According to the climate change scenarios in the period around 2070-2100, lower or markedly higher maximum abundance and yearly total abundance values are expected by greater chance, as compared to the period 1981-1994. Only on the basis of the A2 scenario of the Max Planck Institute can be stated that the abundance shifts around the higher values compared to the examined values. On the whole rather increasing abundance can be predicted based on the three scenarios, since the abundance values (maximum and yearly total abundance) proved to be so high on the basis of many years of model running, as could not be observed in the examined period. The results however must be handled watchful, since the simplicity of the model and also because the scenarios are outcomes of different models.

***Table 1.*** *The summary of the results of the model fitted to 10 years of observed data and to the data of A2 and B2 scenarios of the Hadley Centre (HC) and the Max Planck Institute (MPI) launched for 31 years. In the first column the categories of the supervention of the maximum abundance (which day of the year), maximum abundance and yearly total abundance are presented. In the other columns the proportions of the real data and scenarios are presented in percentage.*

| **Supervention of the maximum abundance** | **Real data** | **A2 (HC)** | **A2 (MPI)** | **B2 (HC)** |
|---|---|---|---|---|
| below 100 | 0% | 42% | 65% | 45% |
| 101-130 | 30% | 55% | 29% | 55% |
| 131-160 | 70% | 3% | 6% | 0% |
| above 161 | 0% | 0% | 0% | 0% |
| **Maximum abundance** | **Real data** | **A2 (HC)** | **A2 (MPI)** | **B2 (HC)** |
| below 100 | 20% | 39% | 16% | 45% |
| 101-400 | 50% | 23% | 10% | 13% |
| 401-800 | 30% | 3% | 3% | 6% |
| above 801 | 0% | 35% | 71% | 36% |
| **Yearly total abundance** | **Real data** | **A2 (HC)** | **A2 (MPI)** | **B2 (HC)** |
| below 3000 | 20% | 55% | 19% | 45% |
| 3001-6000 | 40% | 13% | 6% | 10% |
| 6001-20000 | 40% | 6% | 7% | 19% |
| above 20001 | 0% | 26% | 68% | 26% |

## Results

Neither similar climate to the expected climate of Göd for the end of the century along the Danube, nor intense similarity throughout Europe were found, supposedly owing to the large extent of changes due to happen by the end of the century. The regions with the greatest similarity are at a distance of about 400 km, which is in accordance with the data from literature.

We managed to set up a model predicting the seasonal changes of the abundance of *Cyclops vicinus* based on the daily maximum and minimum temperature values, it fitted well to the observed data and was validated. Even if we do not understand exactly the reason that the temperature is the main regulating factor, nevertheless we accept this fact; predictions can be made for the period around 2070-2100 regarding the abundance, by means of the model run with the data series of scenarios. From the A2 and B2 basic scenarios of the IPCC, the former predicts more drastic, the latter more moderate changes (*IPCC, 2007*). However our results show, that greater correspondence is between the outcome of the model run with the data series of the A2 and B2 scenarios of the Hadley Centre, compared to the results for the A2 scenarios run with the data of the two institutes. No significant difference was found between the scenarios. According to the former result, the change caused by the significant warming with different rate does not create notably different outcomes regarding the seasonal dynamics of the given species; the reaction to the warming can be regarded as uniform compared to the examined period (1981-1994).

According to the results the date of the supervention of maximum abundance shifts one respectively one and a half month earlier during the year. From the change in abundance predicted by the scenarios (namely shifting the maximum abundance and the yearly total abundance around the higher or lower values) may be concluded that, an unstable weather status may evolve in the period around 2070-2100 from the point of view of the examined species. Accordingly significantly greater fluctuations are expected in the abundance between the years due to global warming. On the other hand rather the increase of abundance can be made probable, which can be interpreted by physiological reasons. The shift of maximum abundance was observed around earlier dates by the cyclopoids and *Eudiaptomus zachariasi* in small artificial water bodies due to drastic warming, based on the simulation model in our former investigations (Vadadi and Hufnagel, 2007). However the zooplankton abundance showed distinct decline because of the drastic warming. Puelles et al. (2003) found the zooplankton abundance decreasing in a survey included 5 years, which was correlated with the global warming. This contradiction can be explained by the different physiological needs of the chosen species, or by the fluvial milieu.

Based on our zooplankton database the next step beyond the survey of species can be the research of guilds, moreover complex guilds within a food web. Nevertheless in the future it is worth investigating the relationship between the temperature of air and water, just as their potential changes owing to climate change.

## REFERENCES

[1] Angelini, R., Petrere, M. Jr. (2000): A model for the plankton system of the Broa reservoir, Sao Carlos, Brazil. – Ecological Modelling 126: 131-137.

[2] Baranovic, A., Solic, M., Vucetic, T., Krstulovic, N. (1993): Temporal fluctuations of zooplankton and bacteria in the middle Adriatic Sea. Marine Ecology Progress Series 92: 65-75.

[3] Broekhuizen, N., Heath, M. R., Hay, S. J., Gurney, W. S. C. (1995): Modelling the dynamics of the North Sea's mesozooplankton. Netherlands Journal of Sea Research 33 (3/4): 381-406.

[4] Christensen, J.H. (2005): Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects. Final Report. DMI, Copenhagen.

[5] Christou, E. D., Moraitou-Apostolopoulou, M. (1995): Metabolism and feeding of mesozooplankton at the eastern Mediterranean (Hellenic coastal waters). Marine Ecology Progress Series 126: 39-48.

[6] Dippner, J. W., Kornilovs, G., Sidrevics, L. (2000): Long-term variability of mesozooplankton in the Central Baltic Sea. Journal of Marine Systems 25: 23-31.

[7] Hassel, A. (1986): Seasonal changes of zooplankton composition in the Barents Sea, with special attention to Calanus spp. (Copepoda). J Plankton Res 2: 329-339.

[8] Horváth, L (2007): Földrajzi analógia meghatározásának néhány módszere és alkalmazásának lehetőségei. „Klíma-21” Füzetek 50: 54-61.

[9] Hufnagel L., Gaál M. (2005): Seasonal dynamic pattern analysis service of climate change research. Applied Ecology and Environmental Research 3(1): 79–132.

[10] Iguchi, N. (2004): Spatial/temporal variations in zooplankton biomass and ecological characteristics of major species in the southern part of the Japan Sea: a review. Progress in Oceanography 61: 213-225.

[11] IPCC (2007): The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the IPCC. Cambridge University Press, New York.

[12] Ladányi M., Horváth L., Gaál M., Hufnagel L. (2003): An agro–ecological simulation model system. Applied Ecology and Environmental Research 1(1–2): 47–74.

[13] Meise-Munns, C., Green, J., Ingham, M., Mountain, D. (1990): Interannual variability in the copepod populations of George Bank and the western Gulf of Maine. Marine Ecology Progress Series 65: 225-232.

[14] New, M., Hulme, M. and Jones, P.D., (1999): Representing twentieth century space-time climate variability. Part 1: development of a 1961-90 mean monthly terrestrial climatology. Journal of Climate 12, 829-856.

[15] New, M., Lister, D., Hulme, M. and Makin, I., (2002): A high-resolution data set of surface climate over global land areas. Climate Research 21:1-25.

[16] Nováky B., Bálint G. (2004): Éghajlatváltozás és a víz. Természet Világa, 135. évf.: 60–64.

[17] Puelles, M. L. F., Pinot, J.M., Valencia, J. (2003): Seasonal and interannual variability of zooplankton community in waters of Mallorca island (Baleric Sea, Western Mediterranean).- 1994-1999. Oceanologica Acta 26: 673-686.

[18] Sipkay Cs., Hufnagel L. (2006): Szezonális dinamikai folyamatok egy balatoni makrogerinctelen együttesben. Acta Biologica Debrecina Supplementum Oecologica Hungarica 14: 211–222.

[19] Sipkay Cs., Hufnagel L. (2007): Klímaváltozási szcenáriók összehasonlító elemzése balatoni makrogerinctelen együttes alapján. Hidrológiai Közlöny 87: 117-119.

[20] Straile, D. (2005): Food webs in lakes – seasonal dynamics and the impacts of climate variability. In: Belgrano, A, Scharler, U.M, Dunne, J & Ulanowicz, R.E.

[21] Sutherst, R.W. & Maywald, G.F. (1998). CLIMEX - A bio-geographical approach to entomology. In: Zalucki, M.P., Drew, R.A.I. & White, G.G. (Eds) Pest Management & Future Challenges. Proc. 6th Australasian Applied Entomological Research Conference. 2: 344-345. University of Queensland, Brisbane.

[22] Vadadi-Fülöp Cs., Hufnagel L. (2006): Klímaváltozási szcenáriók értékelése egy kerti tó zooplankton közösségének szezonális dinamikájának alapján. XLVIII. Hidrobiológus Napok, Tihany, 2006. (Abstract)

[23] Vadadi-Fülöp Cs., Sipkay Cs., Hufnagel L. (2007): Klímaváltozási szcenáriók értékelése egy makrogerinctelen faj (Ischnura pumilio Charpentier, 1825) szezonális dinamikája alapján. Acta Biologica Debrecina Supplementum Oecologica Hungarica 16: 211-219.

[24] Viitasalo, M., Vuorinen, I., Ranta, E. (1990): Changes in crustacean mesozooplankton and some environmental parameters in the Archipelago Sea (Northern Baltic) in 1976-1984. Ophelia 31: 207-217.

[25] Villate F., Moral M., Valencia V. (1997): Mesozooplankton community indicates climate changes in a shelf area of the inner Bay of Biscay throughout 1988 to 1990. J. Plankton Res 19: 1617 - 1636.
[26] Wu, L., Culver, D. A. (1994): Daphnia population dynamics in Western Lake Erie: regulation by food limitation and yellow perch predation. Journal of Great Lakes 20 (3): 537-545.
[27] Zelikman, E. A., Kamishilov, M. M. (1960): The long-term dynamics of plankton biomass in the southern part of the Barents Sea, and factors influencing it. Tr. Murm. Morsk Biol. Inst. 2: 68-113 (in Russian)


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

# THE DETERMINATION OF PARAMETERS OF MULTI-STEP ADSORPTION ISOTHERM BY SEQUENTIAL SIMPLEX OPTIMIZATION

L. TOLNER

*Department for Soil Science and Agricultural Chemistry, Szent István University*
*Pater Karoly street, H-2103 Gödöllő, Hungary*
*(phone: +36-30-581-0327; fax: +36-28-522-081)*

**Corresponding author*
*e-mail: tolner.laszlo@gmail.com*

(Received 25th October 2008 ; accepted 13rd December 2008)

**Abstract**. The nutrient and toxic compounds can be adsorbed on the surface of soil colloids. Investigating the adsorption of some pesticide compounds, instead of the simply asymptotic Langmuir isotherm multi-step isotherms can be obtained. In these cases a new layer is formed after the surface saturation, however, this mechanism can be described by using a new Langmuir-type isotherm. The adsorption of some compounds led to three superposition steps. The mathematical form is a nonlinear function with 8 parameters. The parameters were determined by a robust, direct optimum searching subroutine carried out by Visual basic macro made in Excel spreadsheet program which uses a simplex stepping procedure. The aim of the optimization is to minimize the residual sum of squares between measured and calculated values. The aim function can be calculated for any parameter series in the adequate dimension number. During the iteration the residual sum of squares decreases step by step, while the differences will be negligible.
**Keywords:** *Regression; model; adsorption; pesticide; soil*

## Introduction

The sorption on the solid matrix of the soil is one of the most important processes which control transport, persistence, bioavailability and degradation of organic pesticides on soil.

Many theories and models have been presented in the literature to describe the different types of sorption isotherms (Sposito 1984, Sparks 1999). Derivation of a scientifically based adsorption isotherm was first achieved by Langmuir (1918). The Langmuir isotherm model assumes monolayer adsorption on an energetically homogeneous surface, where the adsorption takes place only at specific localized sites and the saturation coverage corresponds to complete occupancy of these sites. Each site can accommodate only one molecule or atom and there is no interaction between neighbouring adsorbed molecules or atoms. Several more complex equations such as that of Brunauer, Emmett, and Teller (BET isotherm) have been proposed for multilayer adsorption (Brunauer 1938). Gregg and Sing have given a detailed discussion of the various models used to interpret each type of the isotherms (Greg, 1982). The most commonly used adsorption isotherm equations for organic contaminant on soil are the Langmuir and the Freundlich isotherms. In many cases the sorption of pesticides has been well described using these empirical models (Sparks 1993). These commonly used equations have the advantage of the possibility of linearization giving the adsorption parameters by the slope and intercept of the fitted line. These equations have been found to fit the adsorption data of some pesticide moderately well and have occasionally been used to estimate the capacity for adsorption. Using more realistic assumptions, modifications have been made to the Langmuir isotherm, which are summarized in the monographs of Ruthven (1984), Yang (1987), Adamson (1990), Rudzinski and Everett (1992).

Czinkota *et al.* (2002) derived a non-linear mathematical model – obtained from geometric series of modified Langmuir equation with the additional assumption that the actual location of the surface sites are covered either by one or more than one molecule, in the form of associated complex. Such complexes may result, for example, from the dispersion forces acting between the hydrophobic surfaces of the dissolved molecules. They assume formation of layers of associated complexes of different composition characterized by the association number ($n$), beginning with a single layer of the solute, continued with the layer of dimers ($n$=2), trimers ($n$=3) etc. The physicochemical interpretation of the theory is detailed below.

The following chemical equation means that the sorbent – soil in this case - can adsorb one or more than one molecule in form of associated complexes on its surface.

$$e + n\,c = q \qquad \text{(Eq.1)}$$

where

$e$ the possible maximum concentration of the substance on an empty surface area per unit mass [mg/kg]

$c$ the concentration of the dissolved, non associated substance in solution[mg/L]

$q$ the concentration of the substance on the covered area (occupied site) [mg/kg] – specific adsorbed amount

$n$ it is an integer, representing the degree of molecular association (association number)

The equilibrium constant of the reaction in (Eq.1):

$$k = \frac{q}{e \cdot c^n} \qquad \text{(Eq. 2)}$$

where

$k$ the equilibrium constant [(l/mg)$^n$]

If the adsorption area is finite, the following balance equation describes that the sum of the empty and covered area equal to total adsorption area:

$a = e + q$, in other form $e = a - q$

where

$a$ the total adsorption capacity [mg/kg]

We can use this function for describing the chemical equilibrium, in the following form:

$$k = \frac{q}{(a-q)\cdot c^n} \qquad \text{(Eq. 3)}$$

which after appropriate transformations, yields:

$$q = \frac{a \cdot k \cdot c^n}{1 + k \cdot c^n} \qquad \text{(Eq. 4)}$$

The calculation above is similar to the derivation of original Langmuir isotherm, the difference is just in the number of bounded molecules, and in the equation $n$ power number. Furthermore, a critical concentration of the substance on the surface depending on the adsorbate-surface interaction is assumed. Above this concentration, formation of a new adsorbed layer with different association number could be considered. In order to have good biological efficiency most of the pesticides consist of functional groups with


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

different hydrophobic character. These compounds, however, may form associates on the surface or in the solution. Using the limit concentration, the equation (Eq. 4) can be modified in the following way:

$$q = \frac{a \cdot k \cdot (c-b)^n}{1 + k \cdot (c-b)^n} \qquad \text{(Eq. 5)}$$

where

$b$ the concentration limit of associated compounds [mg/L]

In a physical approach, the function can be used only if $c > b$. Thus the equation must be modified using a new function, which equals to zero if the concentration of original compound is less than the critical concentration and in a higher concentration interval it is in linear function of the original compound concentration.

$$\left[\frac{(c-b) + abs(c-b)}{2}\right] = c - b, \qquad \text{if } c\text{-}b > 0\text{, and}$$

$$\left[\frac{(c-b) + abs(c-b)}{2}\right] = 0, \qquad \text{if } c\text{-}b \leq 0$$

Thus the (Eq.5) could be rewritten:

$$q = \frac{a \cdot k \cdot \left[\frac{(c-b) + abs(c-b)}{2}\right]^n}{1 + k \cdot \left[\frac{(c-b) + abs(c-b)}{2}\right]^n} \qquad \text{(Eq.6)}$$

After transformation (Eq.6) yields:

$$q = \frac{a \cdot k \cdot [(c-b) + abs(c-b)]^n}{2^n + k \cdot [(c-b) + abs(c-b)]^n} \qquad \text{(Eq.7)}$$

This mathematical formula describes the model of one step for any associates (any $n$).

In order to calculate the second and further steps the following interpretation could be used. There is a change in the accessible surface due to the coverage by the previous adsorption layer, which is function of original compound concentration, and this area can behave as a new adsorbent surface or it can form new associates. The common features of this theory are an adsorption equilibrium constant ($k$), an average association degree of the solute ($n$) and the saturation concentration of the layer ($a$) in question. The mathematical expression is the same in all cases.

Multi-step isotherms can be calculated additively from the adsorption isotherms of the individual "steps" (Eq.7). Let's call it Czinkota isotherm (Eq. 8).

$$q = \sum_{i=1}^{s} \left\{ \frac{a_i \cdot k_i \cdot [(c-b_i) + abs(c-b_i)]^{n_i}}{2^{n_i} + k_i \cdot [(c-b_i) + abs(c-b_i)]^{n_i}} \right\} \qquad \text{(Eq.8)}$$

where s the total number of steps on isotherms, dimensionless.

The Czinkota isotherm can be used for description of multilayer or associated materials adsorption (Konda *et al.* 2002, Földényi *et al.* 2004).

Using the derived function, the parameters of a given isotherm can be calculated by non-linear curve fitting, e.g. least squares method.

Sequential simplex optimization can be used for fitting non-linear models (Walters 1991). It was for this purpose that Nedler (1965) modified the fixed-size simplex of

Spendley (1962). The factors are the coefficients or parameters in the model and the response is the sum of squares of residuals ($SS_r$, Eq.9):

$$SS_r = \Sigma(y_{i,observed} - y_{i,calc})^2 \qquad \text{(Eq.9)}$$

Where $y_{i,calc}$ is the value predicted by the model at a given factor combination i, $y_{i,observed}$ is the value actually observed, and n is the number of data points. The object is to find the set of parameter estimates that gives the minimum sum of squares of residuals.

O'Neil (1971) was one of the first to use the simplex algorithm for regression, or model fitting. Caceci (1984) demonstrated how a PASCAL computer program could use the simplex algorithm for curve fitting. A PASCAL algorithm is also given by Press (1989). Jurs (1986) presented a FORTRAN computer program that used simplex for non-linear least squares or regression. The example given used the absorbance data of Deming (1973) and fitted the equation (Eq.10).

$$A = A_\infty(1 - e^{-kt}) \qquad \text{(Eq.10)}$$

Modelling adsorption phenomena in soils we use complex nonlinear functions. Sequential simplex optimization can be used to fit: the modelling kinetics of phosphorus adsorption in soils (Füleky 1980), the equilibrium of phosphorus adsorption in soils (Tolner 1987, 1995, 1996; Wahdan 2000, 2000a; Füleky 2006, 2006a), the equilibrium of copper adsorption in soils (Ioannou 2003), the respiration dynamics and microbial transforms in soils (Szegi 1988, Gulyás 1990).

## Materials and methods

In order to establish the sorption isotherms of six commonly used pesticides (acetochlor, atrazine, diazinon, carbendazim, imidacloprid and isoproturon) laboratory equilibrium studies were performed on brown forest soil with clay alluviation (Luvisol) using the batch equilibrium technique. The pesticide concentrations in the equilibrated liquid phase were quantified by high performance liquid chromatograph with UV detection. The sorption isotherms have been described by a new non-linear mathematical model – derived from the modified Langmuir equation – which well represents the single- and multi-step shaped adsorption profile detected for the investigated compounds.

## Results

We derived a non-linear mathematical model – obtained from geometric series of modified Langmuir equation with the additional assumption that the actual location of the surface sites are covered either by one or more than one molecule, in form of associated complex. Such complexes may be formed, e.g. by dispersion forces acting between the hydrophobic surfaces of the dissolved molecules. We assume formation of layers of associated complexes of different composition characterized by the association number ($n$), beginning with a single layer of the solute, continued with the layer of dimers ($n$=2), trimers ($n$=3) etc. The physicochemical interpretation of the theory is detailed in the Introduction according to Czinkota *et al.* (2002). To provide a physically sound interpretation consistent with the adsorption theory described in the literature, the following assumptions should be made: (1) the adsorption area of any kind of associated complexes, regardless of association number, should not differ significantly; (2) the distance of the active sites of adsorption on the surface should be greater than the size of any kind of associated complexes; (3) molecular interactions acting during adsorption and formation of associated complexes should involve different parts of the molecules, which means that adsorption and formation of associations are independent processes; (4) formation of associated complexes is considered irreversible thus their dissociation is not discussed here.

The mathematical equation detailed above (Eq. 8) has been applied to describe adsorption isotherms for all the examined compounds. We found that the experimental adsorption data could be simulated with single-step (Langmuir) model for acetochlor and carbendazim, two-step (Czinkota) model for diazinon, isoproturon, and atrazine, and three step (Czinkota) model for imidacloprid.

The three steps isotherm is presented in Eq. 11:

$$q=\frac{a_1\cdot k_1\cdot c}{1+k_1\cdot c}+\frac{a_2\cdot k_2\cdot[(c-b_2)+abs(c-b_2)]^2}{4+k_2\cdot[(c-b_2)+abs(c-b_2)]^2}+\frac{a_3\cdot k_3\cdot[(c-b_3)+abs(c-b_3)]^3}{8+k_3\cdot[(c-b_3)+abs(c-b_3)]^3} \quad \text{(Eq.11)}$$

The fitted adsorption isotherm of imidacloprid on soil can be seen in Fig. 1.

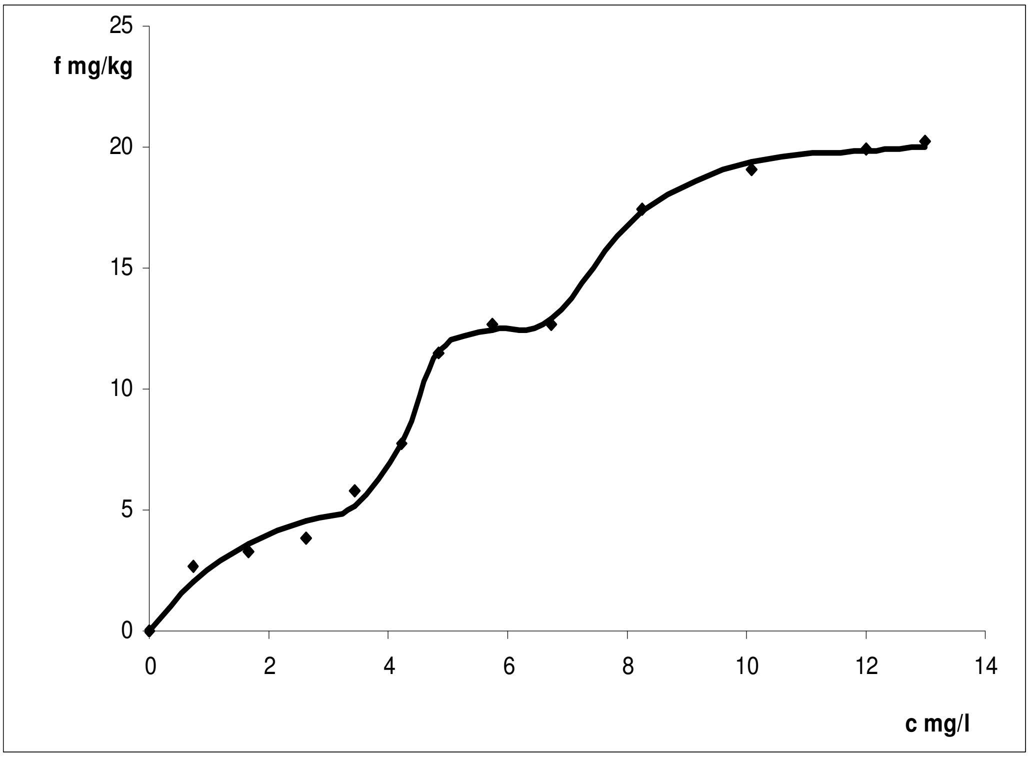



***Figure 1.*** *Adsorption of imidacloprid on brown forest soil. Points measured: the adsorbed imidacloprid in function of the equilibrium concentration. Continuous line: the fitted three-step isotherm.*

The model parameters ($a_1$, $k_1$, $a_2$, $k_2$, $b_2$, $a_3$, $k_3$, $b_3$) were determined by non-linear regression using sequential simplex optimization. Excel macro function was written in Visual Basic program language, and it was used as a fitting program.

The algorithm of non-linear regression calculation using sequential simplex optimization is interpreted here by means of the example of a two-parameter function


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

fitting (Eq. 12). As it is a two dimensional problem, it can be drawn in approximately two dimensional graph (the third dimension are the colours or level lines) (Fig. 2).

$$q = \frac{A \cdot k \cdot c}{1 + k \cdot c} \qquad \text{(Eq. 12)}$$

The measured data pairs are the equilibrium concentration ($c$) and the specific adsorbed amount ($q$). Parameters "$A$" and "$k$" will be determined by regression by the following method: the residual sum of squares between measured and calculated values ($SS_r$, as it is presented in Eq. 13) should be minimal in the given range (cf. Eq.9).

$$SS_r = \Sigma(q_{i,observed} - q_{i,calc})^2 \qquad \text{(Eq. 13)}$$

$SS_r$ is shown in function of "$A$" and "$k$" leading to the figure with line of levels (see Fig. 2).

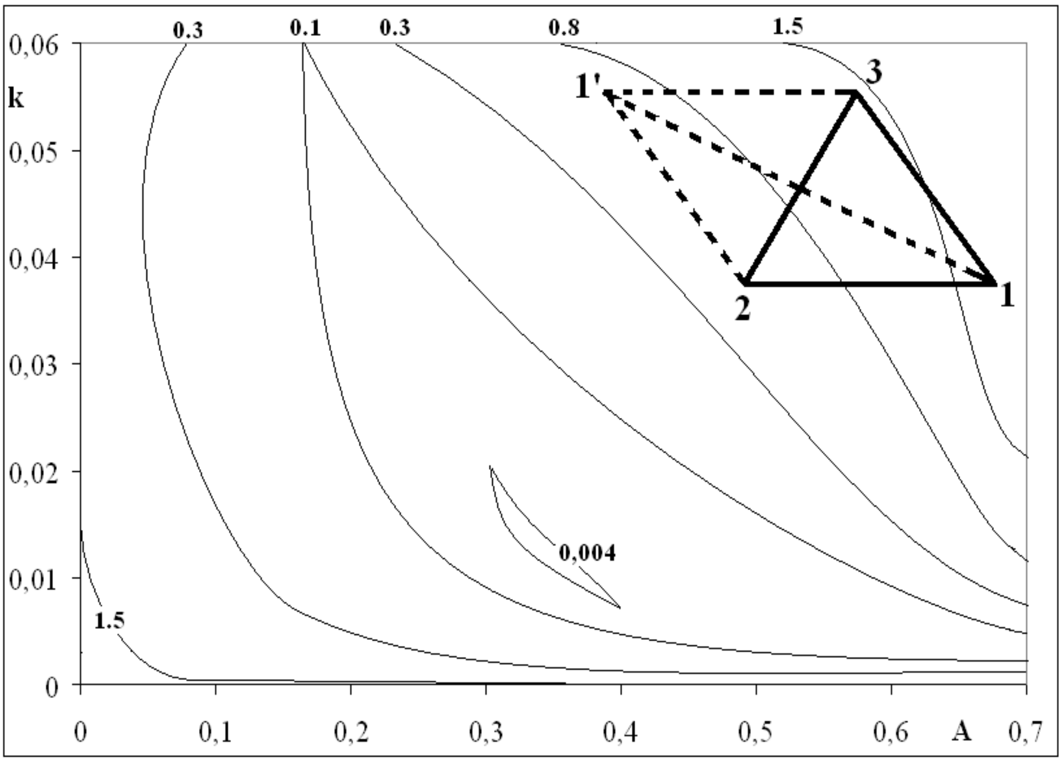



***Figure 2.*** *Sequential Simplex optimization in order to determine the parameters (A,k). 1. step.*

During the calculation the $A$ and $k$ values were determined by using the given 1, 2 and 3 marked points, and $SS_r$ values were calculated. Then the point having the highest $SS_r$ value was chosen, where the fitting is the least suitable. In our example this is the point 1. Mirroring this point on the half point of the line determined by the other two points, we can create the 1' point. The use of this point in a new calculation usually results in better fitting so we get less $SS_r$ value. Repeating this routine the optimum can be reached (Fig. 3.).


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

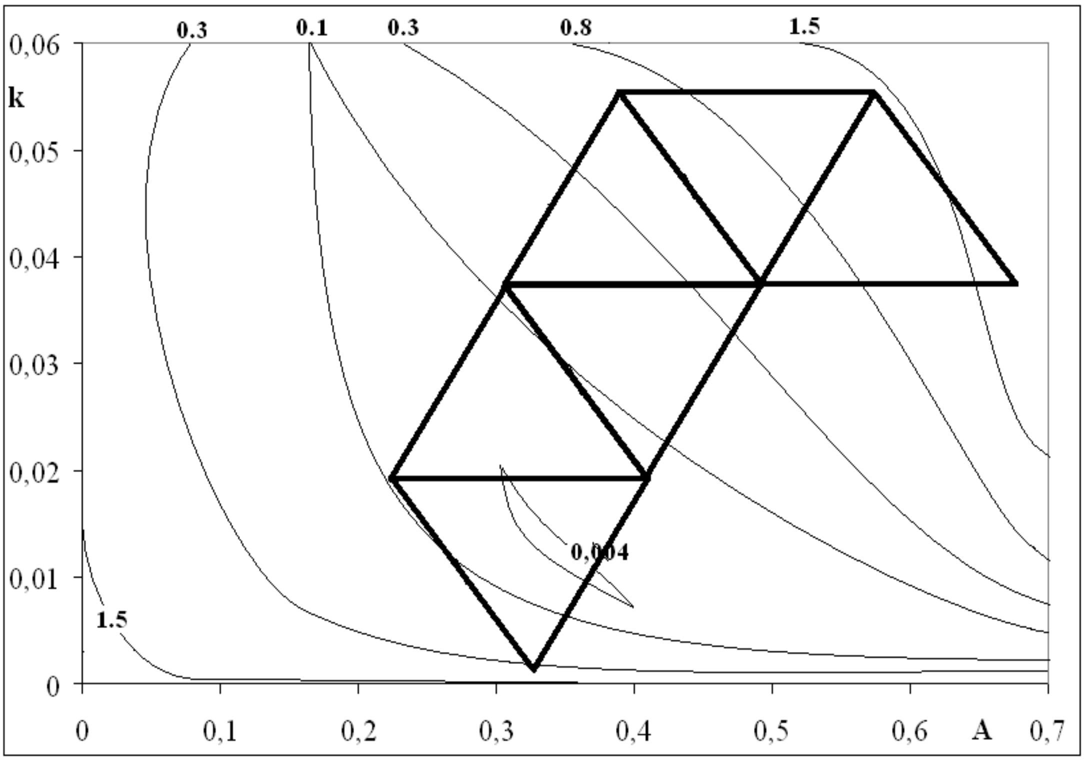



***Figure 3.*** *Sequential Simplex optimization in order to determine the parameters (A,k). 5 step.*

In order to approach the optimum more exactly this procedure can be continued by decreasing the size of simplex (in this case triangle).

When this procedure is applied to Czinkota isotherm in the case of imidaclopride adsorption, the values shown in Table 1 were calculated.

***Table 1.*** *Parameters and Variance table of Czinkota ishotherm for imidaclopride adsorption*

| $a_1$ | $k_1$ | $a_2$ | $k_2$ | $b_2$ | $a_3$ | $k_3$ | $b_3$ |
|---|---|---|---|---|---|---|---|
| 5,563 | 1,007 | 9,6269 | 0,45266 | 2,91358 | 5,34216 | 1,16231 | 7,09005 |

| Variance table | SS | DF | MS | F | $R^2$ |
|---|---|---|---|---|---|
| Total | 612,7557 | 12 | | | |
| Regression | 611,1635 | 7 | 87,309 | 274,2 | 0,9974 |
| Residual | 1,5921 | 5 | 0,3184 | | |

## Discussion

The sorption isotherms have been described by a new non-linear mathematical model derived from the modified Langmuir equation. It well represents the single- and multi-step shaped adsorption profile experienced in the case of the investigated compounds. The experimental adsorption data were well fitted by the proposed model. The physicochemical interpretation of the mathematical formula has been derived from chemical equilibrium consideration. The interpreted model allows the description of the


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

adsorption profile with great precision. The parameters calculated by means of the new equation provide an opportunity to estimate the extent of adsorption constant, adsorption capacity and concentration limit being characteristic to the measured stepwise isotherm in the studied soil-pesticide environmental system.

**Acknowledgements.** The financial support of Hungarian Scientific Research Foundation under grant No. T 32506 is gratefully acknowledged.

## REFERENCES

[1] Adamson, A. W. (1990): Physical Chemistry of Surfaces – Wiley Interscience, New York

[2] Brunauer, S., Emmett, P. H., Teller, E. (1938): Adsorption of gases in multimolecular layers. – J. Am. Chem. Soc. 60: 309-319.

[3] Caceci, M. S., Cacheris, W. R. (1984): Fitting curves to data. – Byte, 340-362.

[4] Czinkota, I., Földényi, R., Lengyel, Zs., Marton, A. (2002): Adsorption of propisochlor of soils and components equation for multi-step isotherms. – Chemosphere 48: 725-731

[5] Deming, S. N., Morgan, S. L. (1973): Simplex optimization of variables in analytical chemistry. – Anal. Chem. 45(3): 278A-283A.

[6] Földényi, R., Czinkota, I., Ertli, T. (2004): Presentation of multi-step isotherms formed at the adsorption of herbicides. Progress in Colloid and Polymer Science 125: 117–120.

[7] Füleky, Gy., Tolner, L., Dömsödi, J. (1980): Kinetics of phosphorus supply measured by anion exchange reson. [A talaj foszforszolgáltatása kinetikájának mérése anioncserélő műgyantával.] – Agrokémia és Talajtan 29: 273-280.

[8] Füleky, Gy., Tolner, L., Wahdan, A. (2006): Effect of acidification on recovery of fertilizer phosphorus with three water extraction methods. – Cereal Research Communications, 34: 183-186.

[9] Füleky, Gy., Tolner, L. (2006a): Determination of the phosphate content originally adsorbed on the soil by fitting an adsorption isotherm model. – Applied Ecology and Environmental Research, 4(2): 39-45.

[10] Greg, S. J., Sing, K. S. W. (1982): Adsorption, surface area and porosity – Academic Press, New York.

[11] Gulyás, F., Szili-Kováts, T., Szegi, J., Füleky, Gy., Tolner, L. (1990): Effect of NPK Fertilization and Organic Matter on the Respiration Dynamics and Microbial N Transformation Processes of the Soil. – Agrokémia és Talajtan 39. 423-429.

[12] Ioannou, A. Tolner, L., Dimirkou, A., Füleky, Gy. (2003): Copper adsorption on bentonite and soil as affected by pH. – Bulletin of the Szent István University, Gödöllő, 74-84.

[13] Jurs, P. C. (1986): Computer Software Applications in Chemistry. – John Wiley, New York, Chapter 9, pp. 125-140.

[14] Konda, L. N., Czinkota, I., Fuleky, G., Morovjan, G. (2002). Modeling of single-step and multistep adsorption isotherms of organic pesticides on soil. – Journal of Agricultural and Food Chemistry 50:7326-7331.

[15] Langmuir, I. (1918): The adsorption of gases on plane surfaces of glass, mica and platinum. – J. Am. Chem. Soc. 40: 1362-1403.

[16] Nelder, A., Mead, R. (1965): A simplex method for function minimization. – Comput. J. 7: 308-313.

[17] O'Neil, R. (1971): Function minimization using a simplex procedure. – Appl. Stat. 20: 338-345.

[18] Press, B. P., Flannery, B. P., Teukolsky, S. A. Wetterline, W. T. (1989): Numerical Recipies in Pascal. The Art of Scientific Computing, – Cambridge University Press, Cambridge.

[19] Ruthven, D. M. (1984): Principles of adsorption and adsorption processes. – Wiley Interscience, New York
[20] Rudzinski, W.; Everett, D. H. (1992): Adsorption of gases on heterogeneous surfaces. – Academic Press, London
[21] Sparks, D. L. (Ed.) (1999): Kinetics and Mechanisms of Chemical Reactions at the Soil Mineral/Water Interface in Soil Physical Chemistry. – 2nd Edition, Chapter 4, pp. 135-191, CRC Press
[22] Sparks, D. L., Scott, E., Fendorf, Peng-Chu, Zhang; Liya, Tang (1993): Kinetics and Mechanisms of Environmentally Important Reactions on Soil Colloidal Surface in Migration and Fate of pollutans in Soils and Subsoils – NATO ASI Series, Vol. G 32, Springer-Verlag, 141-168.
[23] Spendley, W., Hext, G. R., Himsworth, F. R. (1962): Sequential application of simplex designs in optimisation an evolutionary operation. – Technometrics 4: 441-461.
[24] Sposito, G. (1984): The Surface Chemistry of Soil. – Oxford Univ. Press, New York
[25] Szegi, J., Gulyás, F., Füleky, Gy., Tolner, L. (1988): Influence of NPK fertilization and cellulose application on the CO2 production of soils. – Ztbl. Mikrobiol., 143: 303-308.
[26] Tolner, L. Füleky, Gy. (1987): Availability of soil phosphorus by anion exchange resin. – Bull. of the Univ. of Agric. Sci. Gödöllő 1: 121-132.
[27] Tolner, L., Füleky, Gy. (1995): Determination of the Originally Adsorbed Soil Phosphorus by Modified Freundlich Isotherm. – Commun. Soil Sci. Plant Anal. 26: 1213-1231.
[28] Tolner, L., Wahdan, A., Füleky, Gy. (1996): A talajban adszorbeálódott foszfáttartalom többlépéses deszorpciójának modellezése. – Agrokémia és Talajtan 45: 295-306.
[29] Walters, Parker, Morgan, Deming (1991): Sequential Simplex Optimization. – CRC Press LLC, Florida.
[30] Wahdan, A., Füleky, Gy., Tolner, L. (2000): Recovery of sorbed fertilizer phosphorus by three water extraction methods. – Bulletin of the Szent István University. 1997-2000: Gödöllo, pp.75-81.
[31] Wahdan, A., Füleky, Gy., Tolner, L. (2000a): Phosphate sorption capacity of a calcareus soil influenced by acidification. – Bulletin of the Szent István University. 1997-2000: Gödöllo, pp.83-91.
[32] Yang, R. T. (1987): Gas separation by adsorption processes. – Butterworth Publishers, Boston


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

# THE ZOOPLANKTON OF THE RÁCKEVE-SOROKSÁR DANUBE: SPATIO-TEMPORAL CHANGES AND SIMILARITY PATTERNS

CS. VADADI-FÜLÖP[1,]* – G. MÉSZÁROS[2] – GY. JABLONSZKY[1] – L. HUFNAGEL[3]*

[1]*Eötvös Loránd University*
*H-1117 Budapest, Pázmány P. sétány 1/c, Hungary*

[2]*Szent István University*
*H-2100 Gödöllő, Páter K. út. 1., Hungary*

[3]*„Adaptation to Climate Change" Research Group of Hungarian Academy of Sciences*
*H-1118 Budapest, Villányi út 29-43., Hungary*
(*phone: +36-1-482-6261; fax: +36-1-466-9273*)

**Corresponding author*
*e-mail: vadfulcsab@gmail.com & leventehufnagel@gmail.com*

(Received 4th March 2008 ; accepted 12nd august 2008)

**Abstract.** The Ráckeve-Soroksár Danube has a great importance as it is the second largest side arm in the Hungarian section of the river Danube and many demands of exploitation are expected. The aim of this study is to analyse the spatial and temporal changes of the zooplankton (Copepoda, Cladocera) community in this river arm, moreover the similarity patterns of zooplankton communities in different Hungarian water bodies are presented in special consideration of the Ráckeve-Soroksár Danube. Basically this study is based on data from literature, however our data are also used for compiling the database for the spatio-temporal changes of the Ráckeve-Soroksár Danube. We put emphasis on the three typical sections of the side arm, as these are stressed due to hydromorphological aspects, but creating artificial borders are objectionable as well. The results show that both spatial and temporal changes are evident, what is more, the stagnant water character of the side arm should be underlined.
**Keywords.** *Copepoda, Cladocera, fauna, composition*

## Introduction

The Ráckeve-Soroksár Danube (hereafter abbreviated as RSD) is the second largest side arm in the Hungarian section of the river Danube, and is located between the 1642 and 1586 river kilometres. Geographically it is located on the Csepeli-sík, mostly south of Budapest, besides in north at Pesterzsébet, Soroksár and Dunaharaszti smaller segment of the arm assorts with the Pesti hordalékkúp-síkság (alluvium plain of Pest). RSD's area is a temperately warm, dry climated small-scene [28]. The river arm is 58 km long from which 11 km belongs to the area of Budapest. It is enclosed by the two estaurine works Kvassay- and Tass sluices, therefore water level is manageable. The current velocity is very low, 0,1-0,3 m/s. The shoreline is 120 km long, the shoreline length of the islands and side arms is 60 km, so the whole shoreline is altogether 180 km long, which is equal to that of lake Balaton [25]. The water level fluctuation is between 20-60 cm, the decline of water is between 10-30 cm. The catchment area is around 1800 km$^2$. Important waters connecting to the RSD are the Danube-Tisza canal, I. Árapasztó canal, Kiskunsági canal, Gyáli creek.

The Danube arm (*Fig 1.*) could be devided into three typical sections. The upper section (38-58 rkm) alters most dinamically that is caused by the large amounts of mud. Body of water is 4,5-6 million m$^3$, the river bed is shallow (2-3 m) and narrow (80-200 m), that is why the highest current velocity could be observed here. However this velocity is substantially lower as compared with the Danube, which has several effects. Primarily the floating matter settles here transported from the Danube and pollution is intense. The inadequate quality of water derived from the main arm has the severest effect here. In addition several sources of pollution coming from industrial establishments make the water quality even worse. Three islands are situated here: Molnár- , Czuczor- , and Dunaharaszti-Taksony-island , but their island-like character is hardly dominant because of the large amounts of mud. Next section (22-38 rkm) is deeper and wider (average bed width 350-400 m, water depth 2,5-3 m), body of water is 16-18 million$^3$. Extended reeds are characteristic of this stretch that extends between Szigethalom and Ráckeve. This section is of great importance in respect of spawning. In addition the unique floating bogs can be seen here. The lower section (0-22 rkm), located between Ráckeve and Tass sluice, has a bed width of 300 m, and water depth of 3,5-6 m. Body of water is 20-25 million $m^3$ that adds up to 50-55 % of the whole water body of the RSD. Reeds can be found only in the narrow shore zone. Current velocity is very low, it can be regarded as a stagnant water. Water quality is most favourable here, mostly suitable for fishing. This triple division must be kept in our mind as the spatial changes of the zooplankton community are based mainly on this phenomenon.

The three sections of the RSD show considerably distinct faces studying the anthroponetic environment of them. This feature is followed after the location of the river arm e.g. the three segments lie in a continuous, however geographically diversified milieu. This type of diversity is sensible both in physical and regional geographical points of view. Physical geographical aspects have already shown before [46]. Studying regional geograhical aspects a few essential parameters are necessary to be mentioned.

Approximately the half long of the upper section (situated between 38 and 58 rkm) belongs to the administrative area of the capital city of Budapest. This section is located in the mostly built-up area along the RSD comprising both industrial and residential zones, which esentially determinates certain ecological features. Especially from the 90s the residential function has started to escalate in this area while the significance of the industry has been reduced. Population density achieves the highest level along this section in the whole RSD.

The next section (22-38 rkm) is located in a transitional zone in regional geographical aspect. The town of Szigethalom existing in the northern edge of this segment belongs to the administrative conurbation existing round Budapest (together with Majosháza, which lies on the other side of the RSD, approximately 10 km to the southern direction). By this time Szigethalom was built together with the suburban town Szigetszentmiklós existing on the riverbank, accordingly the western side of the RSD has became fully built up around the mentioned area. Although other extensive built up riverbank areas are present around Szigetcsép, Majosháza and Szigetszentmárton, generally the lower part of this segment is traditionally unbuilt, despite a nearly continual immediate built-up strip along the RSD itself. Accordingly the population density is much lower in this segment than in the upper section shown before.

The largest settlement around the lower section of the arm (situated between 0 and 22 rkm) is Ráckeve, which lies directly adjacent to the RSD. Traditionally it was situated on Csepel Island, nevertheless it has already started to expand on the other bank of the arm as well. Also a notable settlement is Dömsöd located on the eastern side of the RSD, besides the mentioned narrow strip along the arm, mostly built up with


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

holiday houses. Population density is relatively low and the character of the sorroundings is defined by the growing distance from the capital.

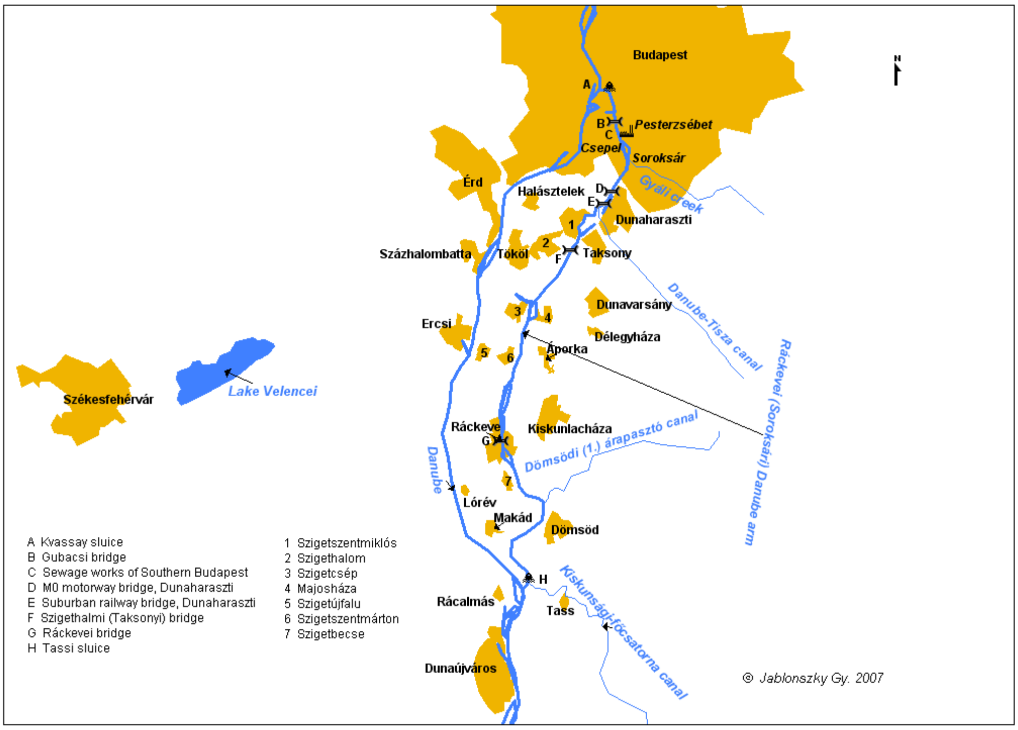



***Figure 1.*** *Map of the RSD with sampling sites, settlements and important works.*

The RSD is of great importance in the aspects of watering, industrial water usage, diversion of inland waters, water for fishponds, recreation, aquatic sports, fishing and the close position to the capital. Therefore the better understanding of the biota living here is crucial, including biological processes as well. Zooplankton is considered an important compartment of aquatic ecosystems for its role in the trophic chain. It represents the channel of transmission of the energy flux from the primary producers to the top consumers [1]. Hence it is of great interest to study planktonic Crustacea, including spatial and temporal changes of plankton communities. We are attempting to answer the question to what extent the zooplankton fauna is different in the externally well divided three river sections. We investigated the zooplankton components based on temporal changes because since the 1970s considerable effects – both positive and negative – have been modifying the fauna composition in the river. Our goal is not to create artificial borders but to demonstrate and analyse the existence of spatial and temporal changes with the help of statistical methods. One more aim is to compare the RSD to other essential Hungarian water bodies based on the zooplankton fauna. The stagnant water character of the river arm suggests that the RSD may have several similar features concerning its fauna to the lakes involved in the study.

## Review of literature

The first study concerning the zooplankton of the RSD was published in 1956 [2] which expressly deals with plankton crustaceans, respectively with the nutrition supply disposable for fishes. Notwithstanding that the surveys were carried out at a stretch of 2 kilometres (river km 20-22) and 3 sampling sites were designated, it counts as a fresh ground for RSD research. The individual numbers of plankton crustaceans were low throughout the year with the exception of June when the abundance was higher. The low abundance was interpreted by the permanent pollution. Present authors stated that the river arm as a considerably eutrophicated water deserves top interest. Based on the gut contents of fishes *Leydigia leydigi, Iliocryptus sordidus, Leptodora kindtii* and *Cyclops vicinus* were the main nutrients for fishes besides the chironomids.

Schiefner and Urbányi [42] performed also plankton surveys under complex hygiene examination of the river arm. They pointed out that the abundance of plankton organisms increased gradually from Pesterzsébet up to Tass, highest individual number was found in May. 17 Rotatoria species were identified, the water quality was beta-mesosaprobic based on saprobiological evaluation.

Bothár in her work, published in 1973 [3], analysed the zooplankton samples taken once in a fortnight, for one year, at 3 sampling sites (Soroksár, Dunaharaszti, Ráckeve). At each sampling site occured two peaks: end of May-early June respectively end of August-early September. The author set out that the upper river stretch (Dunaharaszti and Soroksár) has a similar fauna and low individual numbers as compared to the lower stretch, where more species occur and with higher abundance (abundance increased by 30-fold). Previous difference was explained by the pollution of the upper river stretch. The temporal variation of the copepod and cladoceran community was also presented. According to Bothár quantitative and qualitative differences exist among copepod and cladoceran standing stock. During the survey 38 Cladocera and 14 Copepoda species were recorded.

Gulyás and Tyahun [19] similarly investigated the Crustacea plankton of the RSD, samplings conducted between May and October 1970 from four sites (Szigethalom, Ráckeve, Dömsöd, Tass). The fauna of reedgrass vegetation was examined both quantitatively and qualitatively, additionally saprobity was estimated. However the authors came to the conclusion that the saprobiological evaluation based on crustacean led to unreal notion in the RSD (oligo-beta-mesosaprobic state). 28 Cladocera, 12 Copepoda and 2 Ostracoda species were identified from samples. In accord with the results of Bothár [3] both the abundance and species number increased around the lower river stretch. In the upper river stretch by Szigethalom, which is more polluted and muddy, are living common species with high level of adaptability. The quantitative and qualitative change of the Entomostraca fauna was identical along the whole section of the river arm. Copepods occur first in spring, their abundance decreases in summer and increases in autumn again. Contrarily cladocerans peaked in summer and autumn.

Győrbíró [20] dealt partly with cladocerans in his diploma work. Four sampling sites (Soroksár, Szigethalom, Ráckeve, Makád) were included in this research conducted between July and September. Results were compared to Berinkey-Farkas's [2] work. According to Győrbíró the abundance of plankton collected at Soroksár and Szigethalom were constantly decreasing during the survey, while at Ráckeve at first moderate then sharp increasing was followed by a sharp decreasing. It is worth mentioning the low number of Cladocera found by the writer.

Tyahun [44] announced data of Copepoda, Cladocera and Ostracoda from four locations (Szigethalom, Ráckeve, Dömsöd, Tass). In addition to the checklist, seasonal dynamics was also presented, namely copepods are among the first organisms inhabiting the reedgrass, they are characterized by spring and autumn peaks, cladocerans appear later with an abundance maximum in autumn, ostracods could reach the abundance of the order of one hundred thousand in August and September.

Bothár and Kiss [4] conducted phyto-and zooplankton investigations bimonthly at Ráckeve in 1983. They found less species than Bothár in 1970-71, and no other species turned up. The formerly dominant euplanktonic *Bosmina longirostris* occured rarely just as other Cladocera species characteristic previously. Summarized the results they came to the conclusion that the Ráckeve-Soroksár Danube arm has reached the eu-polytrophic state as compared to the meso-eutrophic, eutrophic state existing in 1970-71.

Gulyás [13] examined the Rotatoria and Crustacea plankton of the RSD and the main arm for one year. Rotifers were presented in the greatest abundance and also most species occured among Rotatoria. In the initial stretch of the river arm biomass and species composition were similar to the main branch, whereas 20-25 kilometres down increased the biomass notably. In the lower stretch biomass value characteristic for polytrophic stagnant water was measured.

Just et al. [21] dealt with comparing and co-ordinating the methods of water quality assessment used in Hungary and in Germany. In part of this study they carried out chemical, microbiological and faunistical examinations on the river Danube and on its side arm RSD. Five sampling sites were designated on the RSD (after Kvassay sluice, Dunaharaszti, Majosháza, Ráckeve, Dömsöd). The greatest zooplankton biomass was found at Ráckeve in June. Most zooplankton species occured among rotifers, 26 Copepoda and Cladocera species turned up in the river arm. Difference in species composition between the main branch and branch was interpreted by the different rate of flow (the lower stretch of the RSD has a character of stagnant water).

The qualitative and quantitative changes of Rotatoria and Crustacea plankton in the river Danube was published by Gulyás [15]. In this survey took part 10 researchers from different nations in order to examine the section of Danube between Neu-Ulm and Tulcea incorporating 2581 kilometres. Examinations trended not only to chemical water quality evaluation, but also following the ecological state of the water with attention, in tune with the Water Framework Directive. In the RSD high abundance and low number of species were found during the survey. Rotatoria and Crustacea species characteristic of polytrophic water bodies were presented. Present survey was also published as a summary report „Joint Danube Survey" [27].

The basis of this synthesis is the material compiled in our previous works [30, 45], a complex ecological review and evaluation of the RSD arm is also available [46]. *Table 1* shows the zooplankton surveys which have significant faunistic results.

***Table 1.*** *Overview of researches carried out in the RSD in faunistic point of view. Abbreviations: Pe — Pesterzsébet; Sor — Soroksár; Dh — Dunaharaszti; Szh — Szigethalom; Szsz — Szigetszentmiklós; Szcs — Szigetcsép; Kisk — Kiskunlanháza; Maj – Majosháza; Mak — Makád; Gub — Gubacsi bridge; Szm — Szigetszentmárton; Ráck — Ráckeve; Döm — Dömsöd; Tass — Tass.*

| Author | Sampling site | Sampling date | Number of taxa | | | |
|---|---|---|---|---|---|---|
| | | | Cladocera | Copepoda | Ostracoda | Rotatoria |
| *Berinkey and Farkas (1956)* | Ráck | 1953-54 | 14 | 6 | 4 | |
| *Schiefner and Urbányi (1970)* | Pe,Dh,Szsz,Maj,Kisk,Ráck,Döm,Tass | 1966-67 | | | | 17 |
| *Bothár (1973)* | Sor,Dh,Ráck | 1969-71 | 38 | 14 | | |
| *Gulyás and Tyahun (1974)* | Szh,Ráck,Döm,Tass | 1970 | 28 | 12 | 2 | |
| *Győrbíró (1974)* | Sor,Szh,Ráck,Mak | 1974 | 2 | 4 | | 10 |
| *Tyahun (1977)* | Szh,Ráck,Döm,Tass | 1970 | 23 | 11 | 2 | |
| *Gulyás (1997), Just et al.(1998)* | Kv,Dh,Maj,Ráck,Döm | 1995-96 | 17 | 9 | | 36 |
| *Mészáros (not published)* | Kv,Gub,Dh,Szh,Szcs,Szm,Ráck,Döm,Tass | 2005 | 30 | | | |
| *Vadadi-Fülöp (not published)* | Sor,Dh | 2006-07 | 10 | 4 | | |

## Materials and methods

Our examination is analysing the zooplankton fauna from the 1950s up to now. As few quantitative data are available this work is dealing only with qualitative data (presence – absence). We set up a zooplankton faunistic database based on data from literature and our measurements. We made charts of the data and classified them according to the time of sample taking (50-70s and 90-00s) and sampling sites: river sections (upper, middle, lower) and settlements.

There was no opportunity for a more precise classification since not all the publications have usable data. We have valuable information about the zooplankton fauna of the 1950s, 1960s and 1970s from the publications performed by Berinkey and Farkas [2], Bothár [3], Gulyás and Tyahun [19], Győrbíró [20] and Tyahun [44]. As for the 90-00s we used data from the publications presented by Gulyás [13], Just et al. [21]. In addition we could make good use of our own surveys (Mészáros 2005, Vadadi-Fülöp 2006-2007, not published). We decided on this classification because the data, we can use and evaluate, are mainly in accordance with these two aspects (spatial and temporal) and moreover they can be the basis for a clear comparison. While analysing we had to leave out the Rotatoria taxa because only one detailed survey of them was carried out in 1995-1996 [13, 21]. We have no ground for comparison though it was a comprehensive investigation as 36 taxa were found at 5 sampling sites. So only Copepoda and Cladocera are presented in the analyses. As for Copepoda fauna so far only two species of Harpacticoida suborder have been found in this section of the Danube, even so they are not described in the comparison as most of the studies do not deal with them. Ostracoda is also ignored for the same reasons.

The above-mentioned database was completed with the Copepoda and Cladocera fauna of some important Hungarian water bodies: the Danube (without Szigetköz), the Danube (with Szigetköz), the Tisza, the Rába, the Dráva, Lake Balaton, Lake Velence, Lake Fertő (*Fig. 2*). The Danube (without Szigetköz) means that the main arm of the Danube is considered and the water bodies of Szigetköz are neglected, respectively the Danube (with Szigetköz) includes the different water bodies of Szigetköz. Previous division seems to be necessary since in the Szigetköz region several rare species can be found without occurrence in the main arm. For these waters the database was compiled based on the works of Megyeri [29], Zánkai and Ponyi [48], Gulyás and Forró [17, 18], Ponyi [32, 36], Körmendi and Lanszki [26], Kiss [23], Zsuga et al. [49], Nedelkovics and Zsuga [31]. So altogether 126 species are included in the study.

Data were analysed with multivariate statistical methods (cluster analysis and ordination) performed with Past software (Hammer and Harper 1999-2005).

Characterization of the species is based on the following works: Einsle [5], Flössner [6], Forró and Gulyás [7], Kiefer and Fryer [22], Korovchinsky [24], Rylov [41], Smirnov [43], Gulyás and Forró [17, 18]. The taxonomic system of Gulyás and Forró [17, 18] was observed throughout the study, whereas saprobiological estimation is based on Gulyás's [14] work.

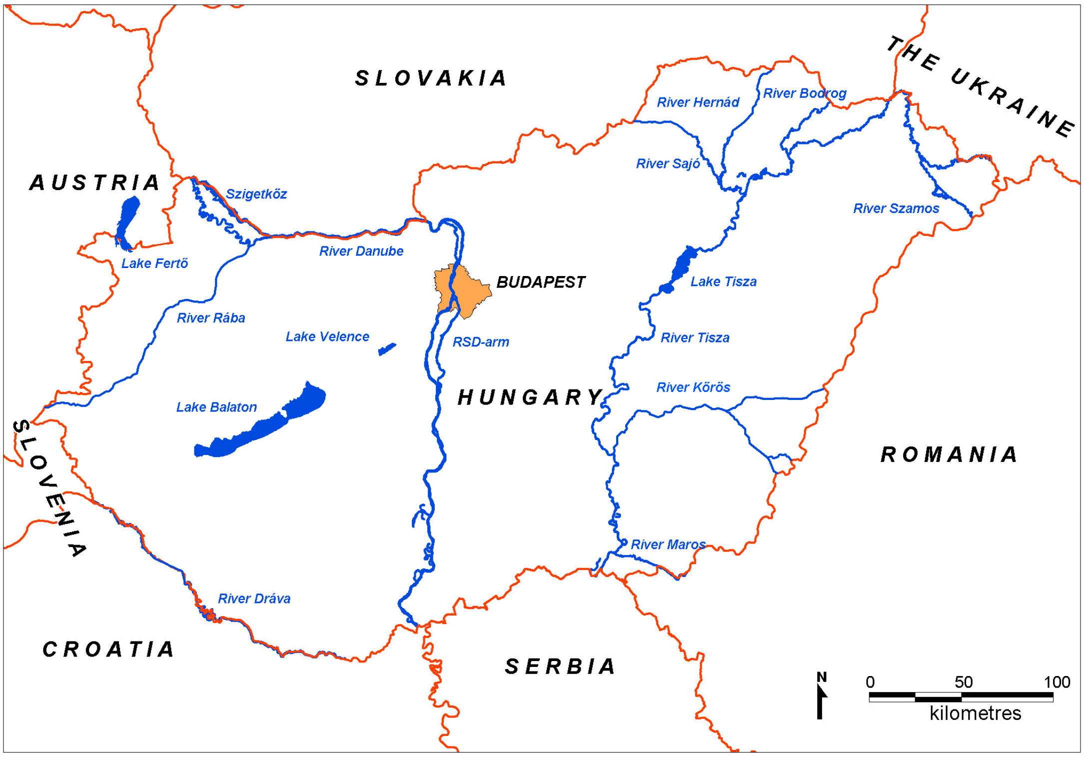



***Figure 2**. Map of the main water bodies in Hungary.*

## Results

### *Spatio-temporal changes of the zooplankton community*

In the RSD arm we managed to reveal 66 different Copepoda and Cladocera species on the basis of our examination and the data from literature we dealt with. Out of these species 61 can be found in the lower section located between Ráckeve and Tass, 37 species can be observed in the stretch extending between Szigethalom and Ráckeve. In the upper section, between Szigethalom and Kvassay sluice 41 species were described. Out of the 66 species in question 25 can be found in all the sections above. One of Copepoda species, *Graeteriella unisetigera* (Graeter, 1908) has not been found so far anywhere else in Hungary [18]. The habitat of this species is in subsoil waters, caves, wells, interstitial waters and it is highly abundant in Central Europe. In 1974 Győrbíró presented this species in all the three sections of the RSD arm but his results were not published. In *Table 2* we revised the species we investigated on the basis of literature and our data. Next to the species the years of their presence in the RSD arm can be seen. On the right the river sections where the species were described can be found.

***Table 2.*** *The zooplankton (Copepoda, Cladocera) fauna of the RSD and its spatio-temporal changes.*

| Taxa | 50-70s | 90-00s | lower | middle | upper |
|---|---|---|---|---|---|
| *Oxyurella tenuicaudis* (Sars, 1862) | + | | + | | |
| *Alonella exigua* (Lilljeborg, 1853) | | + | | | + |
| *Alonella nana* (Baird, 1850) | | + | | | + |
| *Anchistropus emarginatus* Sars, 1862 | + | + | + | | |
| *Bosmina longirostris* (O. F. Müller, 1785) | + | + | + | + | + |
| *Bosmina coregoni* Baird, 1857 | + | + | + | | + |
| *Camptocercus rectirostris* Schoedler, 1862 | + | + | + | + | + |
| *Leptodora kindtii* (Focke, 1844) | + | | + | | + |
| *Sida crystallina* (O. F. Müller, 1776) | + | + | + | + | |
| *Diaphanosoma brachyurum* (Liévin, 1848) | + | + | + | | + |
| *Daphnia cucullata* Sars, 1862 | + | + | + | + | + |
| *Daphnia hyalina* Leydig, 1860 | + | + | + | | |
| *Daphnia pulex* Leydig, 1860 | + | | + | | |
| *Daphnia longispina* O. F. Müller, 1785 | + | + | + | + | + |
| *Disparalona rostrata* (Koch, 1841) | + | + | + | + | + |
| *Eurycercus lamellatus* (O. F. Müller, 1785) | + | + | + | + | + |
| *Graptoleberis testudinaria* (Fischer, 1848) | + | | + | + | |
| *Simocephalus serrulatus* (Koch, 1841) | + | | + | | |
| *Simocephalus expinosus* (Koch, 1841) | + | | + | | |
| *Simocephalus vetulus* (O. F. Müller, 1776) | + | + | + | + | + |
| *Moina macrocopa* (Straus, 1820) | + | | + | | |
| *Moina micrura* Kurz, 1874 | + | + | + | + | + |
| *Moina brachiata* (Jurine, 1820) | + | | + | + | |
| *Monospilus dispar* Sars, 1862 | + | | + | | |
| *Ceriodaphnia quadrangula* (O. F. Müller, 1785) | + | + | + | + | |
| *Ceriodaphnia dubia* Richard, 1894 | + | + | + | + | + |
| *Ceriodaphnia laticaudata* P. E. Müller, 1867 | + | + | + | | + |
| *Ceriodaphnia pulchella* Sars, 1862 | + | | + | | |


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

| Taxa | 50-70s | 90-00s | lower | middle | upper |
|---|---|---|---|---|---|
| *Scapholeberis mucronata* (O. F. Müller, 1785) | + | + | + | + | + |
| *Macrothrix laticornis* (Fischer, 1848) | + | | + | | + |
| *Macrothrix hirsuticornis* Norman & Brady, 1867 | | + | | + | + |
| *Iliocryptus sordidus* (Liévin, 1848) | + | + | + | | |
| *Iliocryptus agilis* Kurz, 1878 | + | + | | + | + |
| *Acroperus harpae* (Baird, 1834) | + | + | + | + | + |
| *Pleuroxus truncatus* (O. F. Müller, 1785) | + | + | + | + | + |
| *Leydigia leydigi* (Schoedler, 1863) | + | + | + | | + |
| *Chydorus sphaericus* (O. F. Müller, 1776) | + | + | + | + | + |
| *Pleuroxus trigonellus* (O. F. Müller, 1785) | + | + | + | + | + |
| *Pleuroxus uncinatus* Baird, 1850 | + | + | + | | + |
| *Pleuroxus aduncus* (Jurine, 1820) | + | + | + | + | + |
| *Pseudochydorus globosus* (Baird, 1843) | + | + | + | + | |
| *Alona quadrangularis* (O. F. Müller, 1785) | + | + | + | + | + |
| *Alona affinis* (Leydig, 1860) | + | + | + | + | + |
| *Alona intermedia* Sars, 1862 | + | + | + | + | |
| *Alona guttata* Sars, 1862 | + | + | + | | |
| *Alona rectangula* Sars, 1862 | + | + | + | + | + |
| *Macrocyclops albidus* (Jurine, 1820) | + | + | + | + | |
| *Macrocyclops fuscus* (Jurine, 1820) | + | | + | | |
| *Eucyclops serrulatus* (Fischer, 1851) | + | + | + | + | + |
| *Eucyclops macruroides* (Lilljeborg, 1901) | + | | + | | |
| *Eucyclops macrurus* (Sars, 1863) | + | | + | + | |
| *Paracyclops fimbriatus* (Fischer, 1853) | + | + | + | | + |
| *Cyclops strenuus* Fischer, 1851 | + | | + | | + |
| *Cyclops vicinus* Uljanin, 1875 | + | + | + | + | + |
| *Graeteriella unisetigera* (Graeter, 1908) | + | | + | + | + |
| *Megacyclops viridis* (Jurine, 1820) | + | | + | + | |
| *Acanthocyclops vernalis* (Fischer, 1853) | + | | + | + | + |
| *Acanthocyclops robustus* (Sars, 1863) | + | + | + | + | + |
| *Diacyclops bicuspidatus* (Claus, 1857) | + | | | | + |
| *Cryptocyclops bicolor* Sars, 1927 | + | | + | | |
| *Mesocyclops leuckarti* (Claus, 1857) | + | | + | + | + |
| *Thermocyclops crassus* (Fischer, 1853) | + | + | + | + | + |
| *Thermocyclops oithonoides* (Sars, 1863) | | + | + | + | |
| *Eudiaptomus gracilis* (Sars, 1863) | + | + | + | | + |
| *Eurytemora velox* (Lilljeborg, 1853) | | + | + | | + |
| *Ectocyclops phaleratus* (Koch, 1838) | | + | + | | |

In the following we are describing the 3 RSD arm sections on the basis of Copepoda and Cladocera fauna and then on the basis of spatial and temporal changes.

### *The upper section*

According to our examinations and the data from literature 41 species can be identified in the upper river section. It is extremely remarkable that merely 3 of the 41 species can be regarded typical of this river stretch (*Alonella exigua, Alonella nana, Diacyclops bicuspidatus*). *Alonella exigua* can be described as a species closely confined to reedgrass and its sparse existence can be announced mainly in peaceful, hidden places and creek. There is no record of their presence in the RSD arm in the period of the 50-70s. In the meantime based on our survey we can say that *Alonella exigua* is relatively common both in the main and side arms at Dunaharaszti. *Alonella nana* is a resistant cladoceran and is presented in a large variety of waters. Its size makes the species capable of living in every place where detritus occurs. In spite of the fact that this section of the RSD arm has the most sources of pollution it must be mentioned that *Alonella nana* is announced to be sensitive to pollution. The third species, *Diacyclops bicuspidatus* prefers waters that are rich in organic substance.

Further species that can be found in this river section: *Bosmina longirostris* is a species of the highest abundance in small, eutrophic lakes, on the other hand it avoids polluted waters, commonly characteristic of beta-mesosaprobic waters. *Disparalona rostrata* lives in detritus accumulated in soft, deep mud. *Pleuroxus aduncus* is cosmopolitan and is the inhabitant of eutrophic waters. *Acanthocyclops vernalis* is a copepod of high abundance all over Central Europe. Upon these facts we can come to the conclusion that the upper river stretch of the RSD is the most polluted but the rate of pollution is not extreme as e.g. *Bosmina* and *Alonella* species avoid highly polluted waters.

According to the species described hereby the upper section is a moderately – highly polluted water where the signs of advanced eutrophication can be observed as the species described here like eutrophic waters. *Leydigia leydigi* must be mentioned as a species that has adapted so much to the circumstances with oxygen deficiency that even haemoglobin is present in its lymph.

If we take temporal changes into consideration when investigating Cladocera and Copepoda fauna, we can come to an interesting conclusion: based on the available data we can state the presence of 30 different species in the upper section and they were announced both in the 50s - 70s and 90s. There are only 7 species of them that were described only in the 60s in this section of the RSD arm, 5 species belong to Copepoda subclass and only 2 belong to Cladocera order. One of them is the rather scarce *Leptodora kindtii,* the only representative of Leptodoridae in Hungary. This species has considerable sizes (6-7 mm) that make it a real giant among Cladocera. Studying the needs and the habitats of these species we can see that they are the same more or less even nowadays. *Mesocyclops leuckarti* e.g. is the inhabitant of mainly eutrophic lakes, *Diacyclops bicuspidatus* likes waters rich in organic substance. *Macrothrix laticornis* lives mainly in the muddy bottom sediment of puddles and small lakes or among vegetation in moderately eutrophic waters. We have already described the needs and habitat of *Alonella exigua* and *Alonella nana*. In the 90s these two species were announced in the upper section just as *Macrothrix hirsuticornis* that can be described as the inhabitant of the shore zones of the most various waters. The occurrence of

*Thermocyclops oithonoides* is the most remarkable fact in this river section. It can be observed mainly in large stagnant waters, needs oxygen and shows meso-oligotrophy. In any case it is strange that an oxygen demanding species was stated in this river stretch.

On the whole if we examine the species presented above in accordance with temporal changes we cannot see considerable differences between the conditions of 50-70s and 90-00s. There are no significant changes in fauna composition. This fact is worth mentioning as numerous sources of pollution have ceased since the 60s and in addition the importance of transportation has declined on this waterway. So the water in the main arm of the Danube seems to determine the water quality in the upper section of the RSD arm just as 40 years ago.

### *The middle section*

In the middle section the number of species is the lowest (only 37 described species). It is interesting that there are no species exclusively characteristic of this section. All of the species here can be found either in the upper or the lower section and some species can be observed in both. This fact means the transient feature of the middle-section. It is conspicuous that *Ceriodaphnia quadrangula* can be observed in this river stretch as this species is sensitive to pollution and eutrophication. The occurrence of *Moina micrura* is pleasing. This species contrasted with the other *Moina* species exists in cleaner waters that are less polluted by organic substance. In spite of this fact it was described in the river section both in the 50-70s and 90-00s. These facts show that the effect of pollution is less dominating and self – purification process can be considerable in this section.

We can observe bigger differences in temporal examinations rather than in comparing the species composition of this section with that of the other two sections. There are 7 species described in the 50-70s but they are not presented in the 90s. In contradiction to this there are only 2 species present only in the 90s. *Eucyclops macrurus* lives sparsely and likes waters that are rich in vegetation. So in spite of the fact that this species was not identified in the 90s probably it has not vanished from the RSD arm as its vital conditions have not declined. *Grabtoleberis testudinaria* – also presented in the RSD arm in the 50-70s – is the inhabitant of the coastal phytoid zone of larger lakes and rivers. Its presence has been announced in many places but it likes mainly the acid, poor water of swamps. *Mesocyclops leuckarti* also can be found on the checklist of the 50-70s though it is the inhabitant of eutrophic waters while *Moina micrura* prefers cleaner waters. In spite of these facts both of them were described in the middle section of the RSD arm. It is worth mentioning that *Mesocyclops leuckarti* was presented in all the three sections in the 50-70s. We must remark that in 2007 during our investigations we could observe this species in a side-arm of the RSD arm. *Megacyclops viridis* was also presented only in the 50-70s. Though this species is cosmopolitan and common everywhere, in the 90s it was not described in the sections of the RSD arm. The tendency is similar as for *Graeteriella unisetigera*. The data from literature show its occurrence in the three sections of the RSD arm in the 50-70s but it was not announced in the 90s. It is really interesting that this species exists in subsoils and in the water of caves, wells i.e. in places where the water is rich in oxygen and gets little light. Probably its occurrence is unique and sparse. *Thermocyclops oithonoides* was described in the middle section only in the 90s. This species demanding oxygen prefers the extended, stagnant water and shows meso-oligotrophy. *Macrothrix hirsuticornis* is not confined to oxygen so much even it is a characteristic of sodic


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

waters. It is the inhabitant of a great variety of waters mainly in the coastal zone covered by vegetation or it occurs close to the river bed.

Based on the above mentioned facts we can state that the middle section cannot be sharply seperated from the other two river sections considering the fauna composition as there are not any species exclusively found in it. We must add that the middle section offers the most various habitats. Large, open body waters can be found here as well as hidden creeks and – as the shores are partly in the original state – a great variety of coastal vegetation extends. That is why all species can find their vital conditions in the middle river section.

If we examine temporal changes the situation is different. Seven species were described in the 50-70s and they were not in the 90s. Most of them are of high abundance. So we can come to the conclusion that some species have vanished not because the water quality has changed but because the other, less sensitive, cosmopolitan species have displaced them slowly.

### *The lower section*

According to the literature the lower section has the highest number of species. From the 50-70s 58 different species have been recorded. There are 15 species that exist or existed only in this section. This number can be regarded significant. *Anchistropus emarginatus, Monospilus dispar, Ectocyclops phaleratus* also belong to the group above. All the three species are scarce, so their presence in this river stretch is really special. *Ectocyclops phaleratus* lives mainly in small waters while *Anchistropus emarginatus* and *Monospilus dispar* like stagnant waters and waters with low current velocity. The former lives on hydras and feeds on their tissues. *Ceriodaphnia pulchella* likes clean, small waters that are free of pollution based on organic matter content. Eutrophication is the biggest problem in the RSD arm so the presence of *Ceriodaphnia pulchella* is very important as this species restricts eutrophication. The fact that the three species above and *Ceriodaphnia pulchella* can be found in the lower section means that the water quality is favourable.

*Daphnia hyalina* is reported as an inhabitant of deep, moderately calcareous lakes, reservoirs and shallow lakes with large surface.

*Alona guttata* was also presented exclusively in the lower section. This species is resistant and common so much that it was identified even in the collected water of hollow trees. In most cases however *Alona guttata* can be observed in the vegetation of reeds or in muddy circumstances with reedgrass. A lot of places of this kind can be found in the other two sections so its exclusive presence in the lower section is unusual. *Oxyurella tenuicaudis* likes habitat that is quiet and rich in vegetation, where the water is smaller, swamps are characteristic and lives in the submerged vegetation. Based on the data from literature its presence only in this river section is surprising.

So far *Cryptocyclops bicolor* and *Eucyclops macruroides* - the representatives of Copepoda – have been announced mainly in lakes and small waters.

Comparing the fauna composition in the lower section with those in the other two sections we can see remarkable differences as for the 15 species living only in the lower section. In addition there are scarce species among them and many of them like clean, unpolluted water. Moreover *Ceriodaphnia pulchella* is definitely described by literature as an eutrophication restrictive species. Another similarity of species is that most of them are the inhabitants of stagnant water or water of low current velocity. This reflects the present conditions entirely i.e. the lower section of the RSD arm can be regarded as a stagnant water.

When considering temporal comparison even more significant differences must be mentioned. In the 50-70s 20 species were pointed out and they were not described in the 90-00s. On the other hand only three species were described during the investigations in the 90-00s. All these three species (*Thermocyclops oithonoides, Eurytemora velox, Ectocyclops phaleratus* ) belong to Copepoda. *Eurytemora velox* definitely has been the member of the home fauna for 16 years. Its first occurrence was reported from Szigetköz in 1991. *Ectocyclops phaleratus* – scarce species, *Thermocyclops oithonoides* – oxygen demanding species, the inhabitant of bigger, stagnant waters, show meso – oligotrophy.

Going on with the analysis of Copepoda – based on literature – we can find 10 species described in the 60s in the RSD arm and not identified in the 90s. *Mesocyclops leuckarti* – presented mainly in eutrophic waters – has not been reported recently. *Megacyclops viridis* and *Acanthocyclops vernalis* are common species. Similary, it is surprising that *Alona guttata* was described in 50-70s and it has not been reported since then. *Graeteriella unisetigera* was described in the 50-70s in both the middle and lower section. Probably only few of them were found. *Cyclops strenuus* is very resistant and can adapt well to pollution and the changes of conditions. So probably the stock of them existing in this river section was not small yet their presence was not announced in the 90s. We must remark that the absence of some species does not mean that they have vanished but it may be a mistake when taking samples as scarce species do not always occur in samples. *Macrothrix laticornis* was the representative of Cladocera in the 50-70s. On the basis of literature it is the habitant of puddles, smaller lakes, dead arms, shallow water. This species – just as some others – may have been displaced from its habitat. Probably the some happened to *Ceriodaphnia pulchella*. It is the habitant of clean, smaller waters and restricts eutrophication. So the absence of this species is unfortunate. Whereas *Simocephalus serrulatus* was identified only in this river stretch. It lives in smaller waters (lakes, puddles, creeks, ditches) and prefers to stay in vegetation, where the water contains colloidal organic substance.

To sum up we can state that the lower section of the RSD arm is definitely from the other two ones as numerous species can be observed only in this river stretch. Although in the course of time the number of species has decreased it is still different from the middle and upper sections of the RSD arm.

In all the three sections the dominance of oligo-beta mesosaprobic species can be observed, especially regarding the lower section. However some species are characteristic of alfa-beta mesosaprobic or beta-mesosaprobic waters. Neither remarkable temporal nor spatial change in the saprobic state of the RSD could be stated based on Crustacea indicator species.

## Statistical analysis of the spatio-temporal changes

We attempted to explore the spatio-temporal changes of the zooplankton community with multivariate statistical methods. Cluster analysis and non-metric multidimensional scaling (NMDS) were performed using Euclidean distance in both cases. The results of the former methods were compared to verify their efficiency. We considered examining the spatial and temporal patterns meaningful simultaneously, thus we can answer whether the spatial or the temporal changes are larger. The similarity patterns of the main sampling sites were also carried out with the same methods.

The dendogram of the sections and the 50-70s respectively 90-00s is presented in *Fig. 3* based on the cluster analysis. For comparison the zooplankton fauna of the river Danube is represented with the water bodies of Szigetköz and without Szigetköz. It is evident that the river Danube isolated from the RSD. The result, that the fauna of the lower section is similar to the 50-70s likewise the fauna of the upper section is similar to the 90-00s is interesting. The middle section is near to the latter group. The transient character of the middle section was already apparent by the review of the species since no taxa were found existing only here. Particularly great similarity showed the 50-70s with the lower section on the grounds of their zooplankton fauna. The same result can be observed on the NMDS ordination (*Fig. 4*), the middle section is located between the other two sections. The fauna of the Danube without the water bodies of Szigetköz is closer to the RSD which can be interpreted by the species living in the Szigetköz area, namely there are many rare species not occurring in the RSD. *Fig. 5* shows the Shepard plot of the ordination.

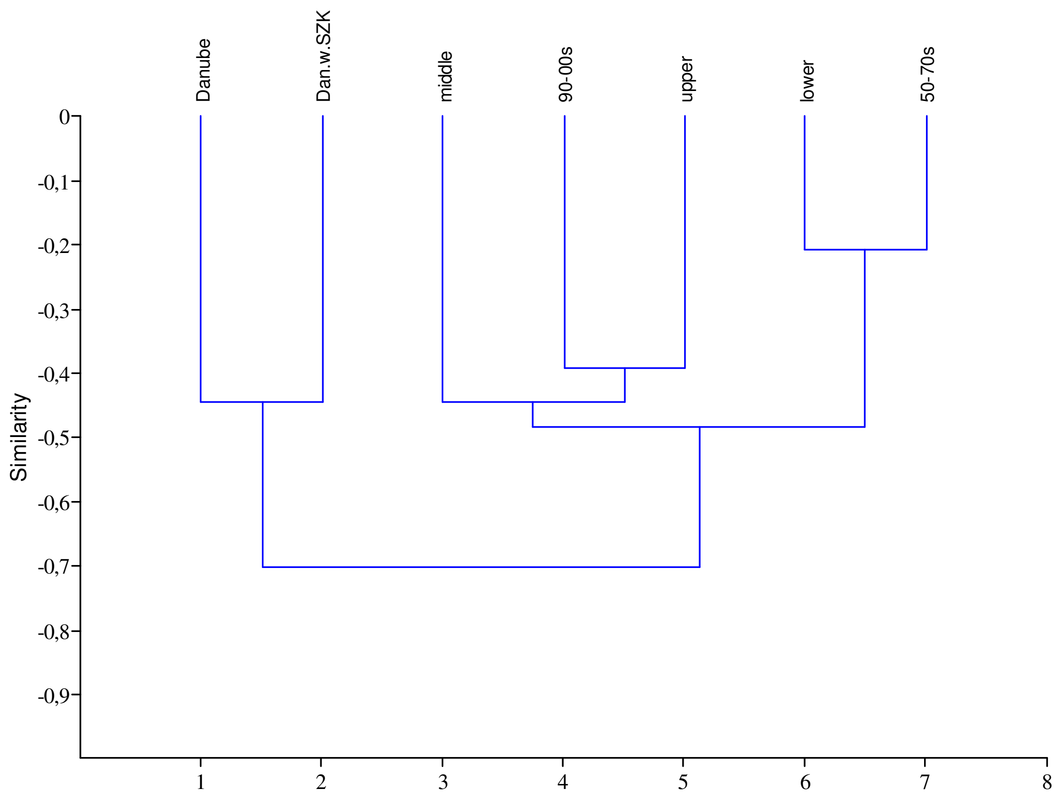



***Figure 3.*** *Dendogram of the sections and sampling dates (Euclidean distance).*

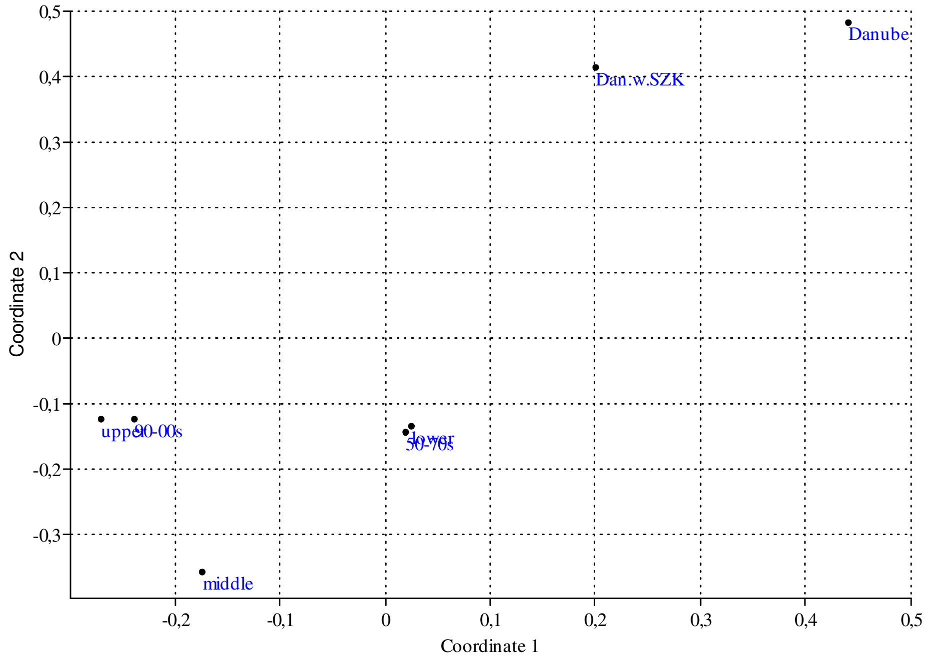



***Figure 4.** The NMDS ordination of the sections and sampling dates (Euclidean distance).*

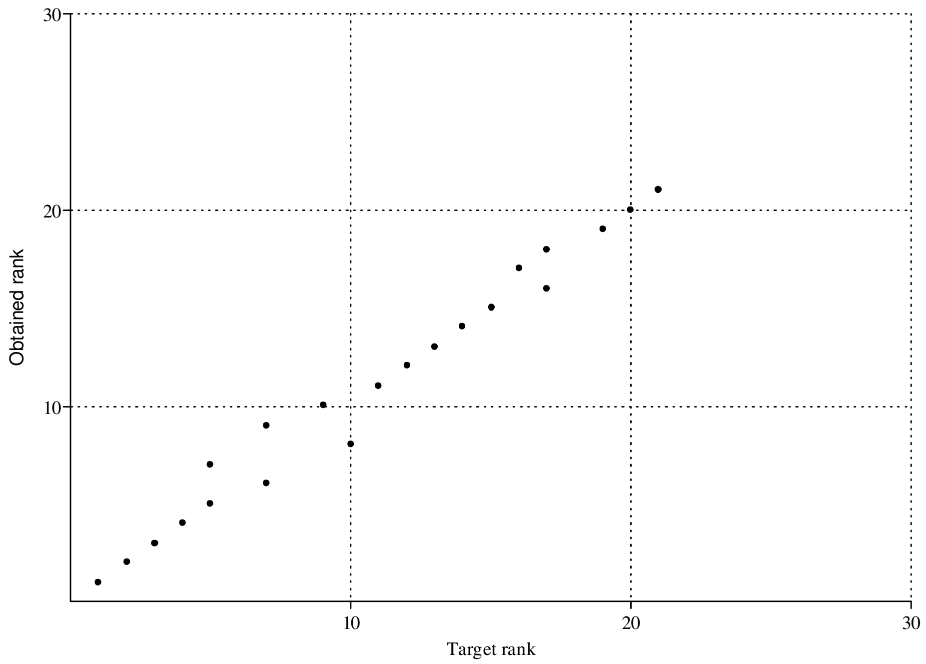



***Figure 5.** Shepard plot of the NMDS ordination of the sections and sampling dates (Stress: 0,07165).*

The main sampling sites, where sufficient number of surveys were conducted for making correct conclusions, were also classified. Sampling sites were the following: Kvassay sluice (Kv), Soroksár (Sor), Dunaharaszti (Dh), Szigethalom (Szh), Majosháza (Maj), Ráckeve (Ráck), Dömsöd (Döm), Tass (Tass). The fauna of the three sections are represented as references (*Fig. 6, Fig. 7, Fig. 8*). Our results showed that the fauna of the lower section is very similar to that of Ráckeve, which were sharply isolated from the other sampling sites and were characterized by the highest number of species. The sampling sites of Soroksár, Dunaharaszti and the upper section formed one group whit the associating Kvassay sluice and Majosháza, which from the ulterior belongs actually to the middle section. Majosháza is the bound of the upper and middle section, thus its position is not so surprising. Least species were found by Majosháza and Kvassay sluice and these were relative common species. Upper section is characterized by many common, pollution-resistant species. The third main group is the middle section, however it contains the sampling sites of Tass and Dömsöd as well. Neither several common species nor many rare species are living here. To sum up the statements the three typical sections seem to be isolated in point of the sampling sites, some deviation exist though.

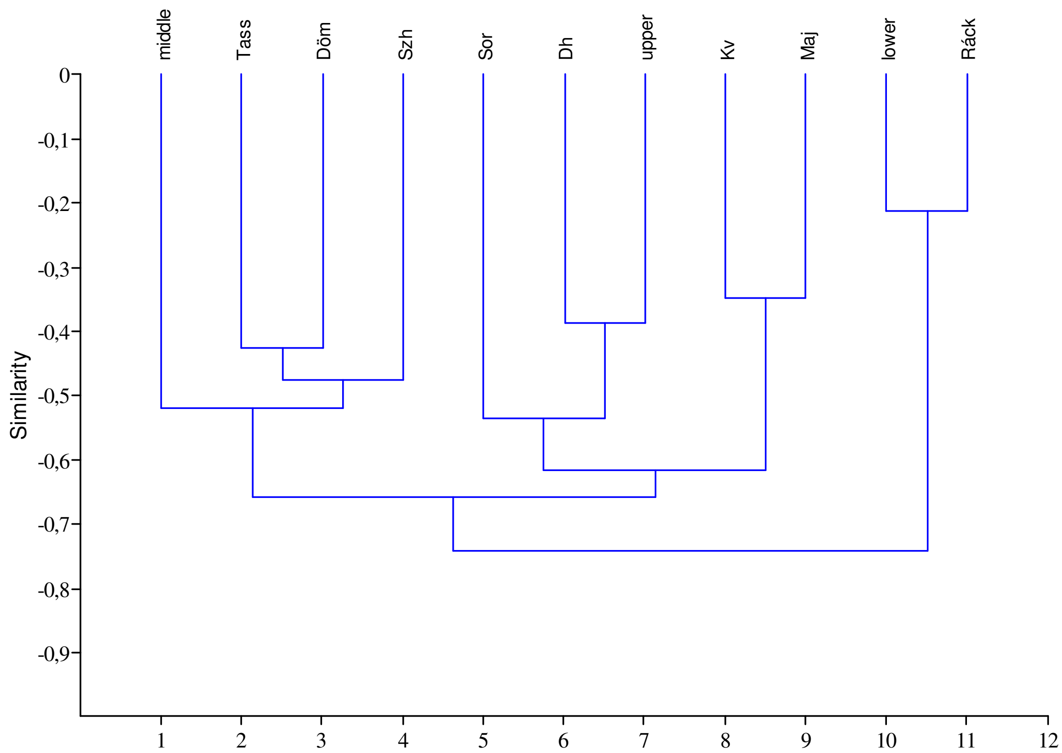



***Figure 6.*** *Dendogram of the sampling sites (Euclidean distance).*

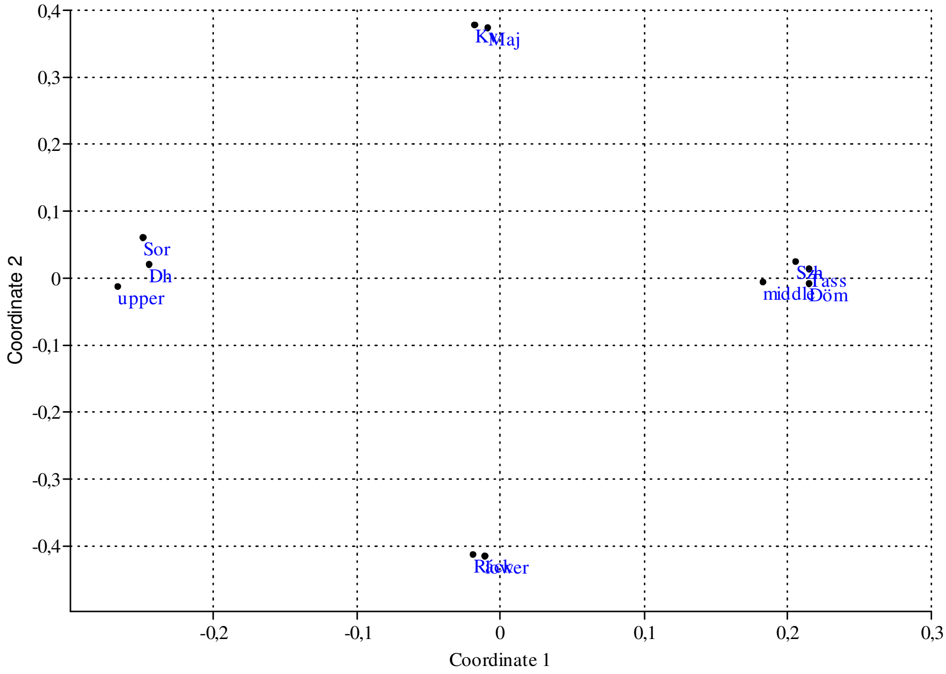



***Figure 7.*** *The NMDS ordination of the sampling sites (Euclidean distance).*

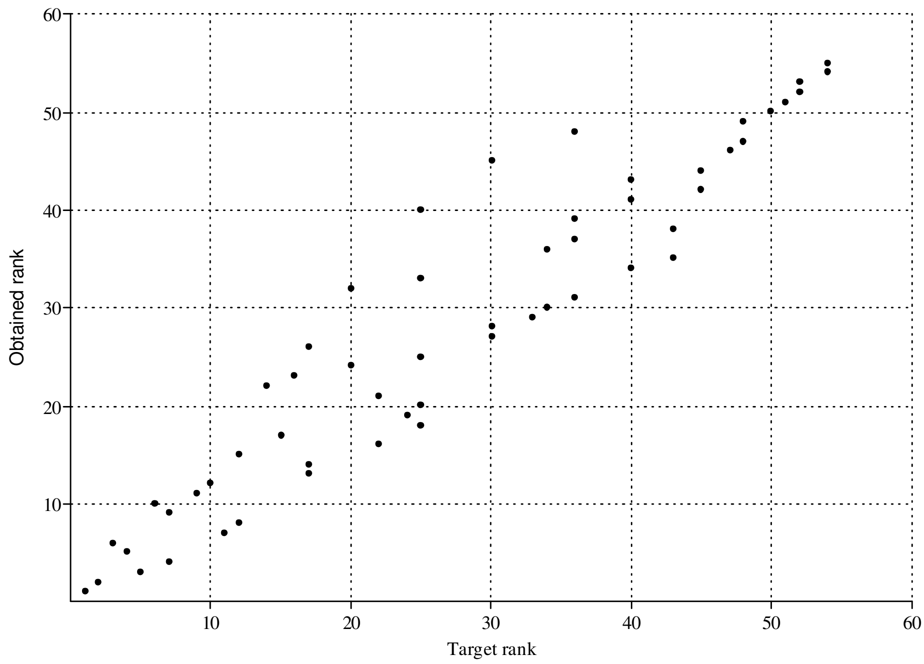



***Figure 8.*** *Shepard plot of the NMDS ordination of the sampling sites (Stress: 0,1624).*


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

### *Similarity patterns of crustacean assemblages in different Hungarian water bodies*

Altogether 9 water bodies (including also the RSD) were considered in order to compare their Copepoda and Cladocera fauna in special consideration of the RSD. These 9 water bodies are separable based on the copepod and cladoceran fauna. According to the cluster analysis (*Fig. 9*) the RSD takes up a place closer to the stagnant waters (Lake Balaton, Lake Velence, Lake Fertő). The Rába and the Dráva are separated, whereas the Danube and the river Tisza form one goup. The Danube represents one cluster in spite of the fact that the Szigetköz region has its own features with some rare species not occurring in the main arm. The results of the cluster analysis is supported by the outcome of non-metric multidimensional scaling. It seems that the „large rivers" (Danube, Tisza), „small rivers" (Rába, Dráva) just as the main lakes (Lake Balaton, Lake Velence, Lake Fertő) can be separated based on the crustacean fauna.

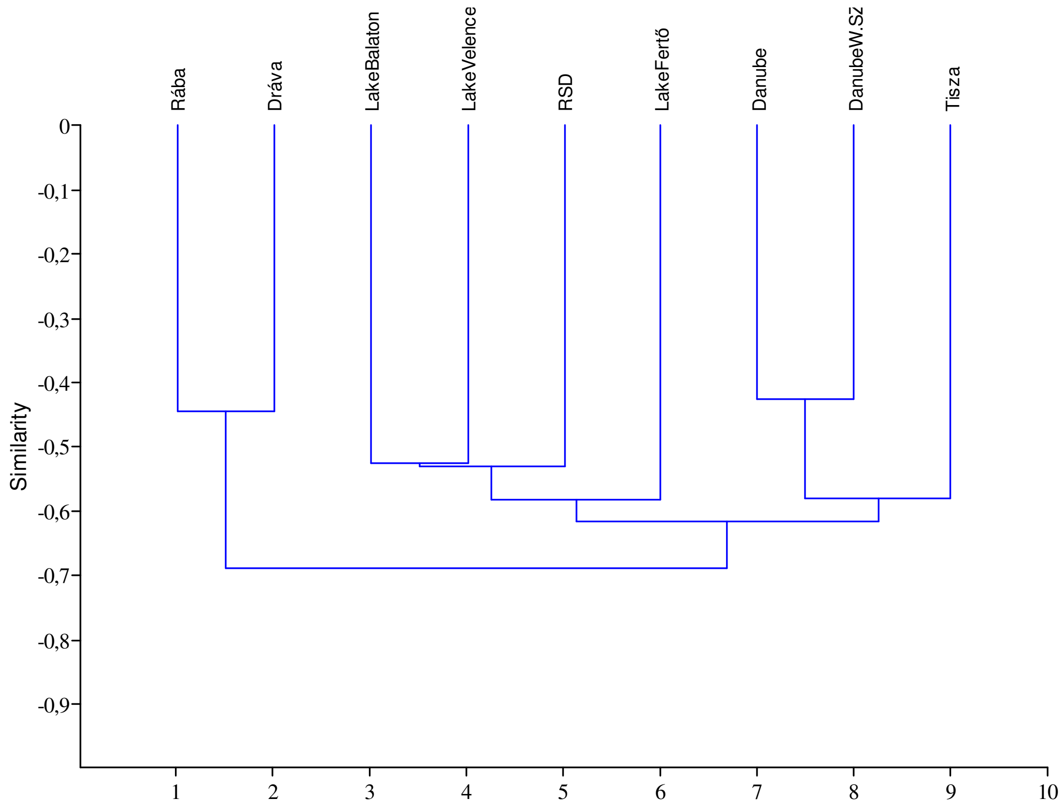



***Figure 9.*** *Similarity patterns of the examined water bodies based on the zooplankton (Copepoda, Cladocera) fauna (Euclidean distance).*

According to our database some groups are worthwhile to distinguish in order to get a better view of the waters in consideration. The first group is formed by the species detected only in the river Danube (some of them are living in the RSD as well): *Eurytemora velox, Cyclops furcifer, Megacyclops gigas, Simocephalus serrulatus, Holopedium gibberum, Bosmina longispina, Kurzia latissima, Chydorus gibbus, Daphnia similis, D. obtusa, D. parvula, Rhynchotalona falcata, Alona rustica, A. intermedia.* From the above-mentioned species *Daphnia obtusa, D. similis, Simocephalus serrulatus* and *Cyclops furcifer* are mainly the inhabitants of small waters. *Eurytemora velox* deserves attention as this copepod was first observed in Hungary in the year 1991 in the Szigetköz region. It is an euryhaline species, prefers the shoreline vegetation, and gets rarely into the zooplankton samples in the open water. The second group consists of the species of the large rivers, the following species were recorded only from the river Danube and Tisza: *Eudiaptomus graciloides, E. zachariasi, Diacyclops languidus, Metacyclops gracilis, Daphnia atkinsoni*, which from only *Eudiaptomus graciloides* can be regarded as euplanktonic. Crustacean species exclusively living in our great lakes (Lake Balaton, Lake Velence, Lake Fertő) and in the RSD are *Arctodiaptomus bacillifer, Diacyclops nanus, Diaphanosoma lacustris, D. mongolianum, Latona setifera, Daphnia cristata, Alona protzi, Anchistropus emarginatus* (we should note that not each of the listed organisms is living in every water in the group). The above-mentioned organisms are chiefly characteristic of stagnant waters, while *Arctodiaptomus bacillifer* prefers sodic waters. It should be noted that the following species have not been found in the Hungarian section of the Danube: *Diaphanosoma mongolianum, Ceriodaphnia rotunda, Metacyclops minutus, Mixodiaptomus kupelwieseri, Streblocerus serricaudatus.* These are rare species excluding *Ceriodaphnia rotunda*. Species that have been reported in all water bodies in question are the following: *Chydorus sphaericus, Bosmina longirostris, Daphnia longispina, Ceriodaphnia quadrangula, Scapholeberis mucronata, Alona rectangula, Megacyclops viridis, Acanthocyclops vernalis, A. robustus*. These organisms are frequent species and can be found in a large variety of waters without exception. (According to our investigations in the RSD *Bosmina longirostris*, *Acanthocyclops robustus* and *Alona rectangula* are dominant). Frequently occurring species are as well: *Cyclops strenuus, Paracyclops fimbriatus, Eucyclops serrulatus, Diacyclops bicuspidatus, Sida crystallina, Eurycercus lamellatus, Ceriodaphnia laticaudata, Macrothrix laticornis, M. hirsuticornis, Acroperus harpae, Simocephalus expinosus*. Although these taxa are not rare they have not been observed in the Rába and Dráva, nevertheless they may be living there. The last group is composed of the species that have been found in all water bodies in the study with the exception of one water: *Simocephalus vetulus, Pleuroxus aduncus, Alona quadrangularis, Macrocyclops albidus, Mesocyclops leuckarti, Thermocyclops crassus, Cyclops strenuus, Eucyclops serrulatus*. The absence of these taxa does not mean definitely that they are not existing in the water in question, rather further investigations are needed to explore them. The species and their occurrence are presented in the *Appendix*.

The listed groups do not ephasize the characteristic species, rather focus on the specific, rare species of the particular water bodies. To illustrate this point take e. g. *Eudiaptomus gracilis*, which is characteristic of Lake Balaton but is not mentioned by the stagnant waters because it is existing in many water bodies.

Although Harpacticoida copepods are not included in the study we feel it necessary to add some pieces of information about this suborder neglected unfairly. According to Ponyi [34] the figures are the following: Lake Balaton (9 species), Lake Fertő (2 species), the Danube (4 species), the Tisza (6 species). In the RSD 2 species of Harpacticoida were observed: *Attheyella trispinosa* (Brady, 1880), *Canthocamptus staphylinus* (Jurine, 1820) [2, 19]. Their small size, complicated identification and collection make it hard to investigate these copepods [34].


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

## Discussion

### *Spatio-temporal changes*

According to the statistical results there are differences between the sections and decades based on the zooplankton fauna, that is the fauna of the upper section is similar to the fauna of our days and recent past, whereas the lower section shows greater similarity to the 50-70s. One reason for this phenomenon may be that most species occur at the lower section and in the 50-70s more species were detected in the water, whereas numerous taxa were found only in that time at the lower section. Consequently the above-mentioned isolation of the lower section seems to be supported by statistics. To summarize the results we can appoint that greater difference is existing between the two temporal intervals respectively between the sections (spatial intervals), than between the spatio-temporal changes simultaneously based on the zooplankton community. It means that both spatial and temporal changes in the zooplankton assemblage are worthwhile considering.

If we take the settlements into consideration we can see a triple grouping, namely the main sampling sites form groups according to the sections. This phenomenon supports that the three sections are meaningful to distinguish. However some deviations must be kept in mind. One possible reason for this can be the sampling error, that is on the one hand the sampling in the field (catching efficiency), on the other hand the data from literature may not be satisfactory enough to make perfect statements and more researches are needed. However if we are aware of this fact, we can make watchful conclusions from the evaluation of the data and this is the goal of the present study.

If we are interested in the spatial changes, it is worth mentioning that in the Danube a longitudinal pattern stands out, namely increasing abundance- and species number can be observed downwards [11, 12, 15], whereas in the river Tisza several sections are distinguished based on the zooplankton composition [16]. These phenomena are similar to the spatial patterns of the zooplankton assemblages observed in the RSD.

### *Similarity patterns*

The stagnant water character of the RSD has manifested in the results. Most of all the lower section can be regarded as a stagnant water, nevertheless most species live here (from the 66 species living in the RSD 61 were recorded in the lower section), so it contributes to the results. The clusters are mainly due to the influence of the rare species, as the characteristic species are often common species living in many types of water bodies, so they are not able to distinguish the examined waters at all times. To illustrate this point, we present some basic information of the characteristic crustacaen communities in the examined waters. The characteristic species of the RSD are *Sida crystallina, Eurycercus lamellatus, Alona affinis, Pleuroxus truncatus, P. aduncus, Chydorus sphaericus, Bosmina longirostris, Macrocyclops albidus, Eucyclops serrulatus, Acanthocyclops vernalis, Megacyclops viridis, Mesocyclops leckarti* [19]. According to Bothár [3] *Eucyclops serrulatus, Acanthocyclops vernalis, A. robustus, Mesocyclops leuckarti, Thermocyclops crassus* and *Bosmina longirostris* were dominant, while Bothár and Kiss [4] found *Eucyclops serrulatus* and *Bosmina longirostris* to be abundant. Our investigations show the dominance of *Eucyclops serrulatus, Acanthocyclops robustus, Bosmina longirostris, Alona rectangula, Thermocyclops crassus.*


http://www.ecology.uni-corvinus.hu ● ISSN 1589 1623

Frequent species in the river Danube are *Bosmina longirosris, Acanthocyclops robustus, Diacyclops bicuspidatus, Mesocyclops leuckarti, Thermocyclops crassus* [11, 12, 13, 15], in the water bodies of Szigetköz *Bosmina longirostris, Chydorus sphaericus, Acanthocyclops robustus, A. vernalis, Mesocyclops leuckarti, Thermocyclops oithonoides, Eucyclops serrulatus, Alona rectangula, Pleuroxus aduncus, P. truncatus, Disparalona rostrata, Scapholeberis mucronata, Sida crystallina, Diaphanosoma brachyurum*, *Alona quadrangularis, Daphnia longispina, Macrothrix laticornis* are abundant [8, 9, 10, 23]. The most frequently occuring species are characteristic to the planktonic communities of eutrophic stagnant and slow-flowing rivers [11, 12, 15]. The zooplankton fauna of the Tisza is characterized by euplanktonic organisms, many of them are cosmopolitan, adaptable species, the endogenic plankton elements are *Bosmina longirostris, Daphnia longispina, Diaphanosoma brachyurum, Eucyclops serrulatus, Eudiaptomus gracilis* [16]. *Daphnia cucullata, Alona spp., Moina micrura, Cyclops spp., Thermocyclops spp., Leptodora kindtii* are also frequent [49]. Dominant species in the Rába are *Bosmina longirostris, Alona rectangula, Alona quadrangularis, Disparalona rostrata, Chydorus sphaericus, Moina micrura, Acanthocyclops robustus, Mesocyclops leuckarti*, indicating medium and slow flow velocities, with moderate nutrient contents [9, 10, 16]. Most of the crustacean species living in the Dráva are cosmopolitan, adaptable ones, also occuring in different waters in Hungary [26]. In Lake Balaton *Eudiaptomus gracilis, Cyclops vicinus, Mesocyclops leuckarti, Diaphanosoma mongolianum, Daphnia cucullata, Bosmina longirostris* [35, 39, 47, 48] are abundant. The dominant crustacean species of Lake Velence are *Bosmina longirostris, Ceriodaphnia quadrangula, Daphnia longispina, Diaphanosoma mongolianum, Mesocyclops leuckarti, Thermocyclops crassus, Cyclops vicinus* and *Arctodiaptomus bacillifer* [33, 40], whereas in Lake Fertő *Diaphanosoma brachyurum, Bosmina longirostris, Acanthocyclops vernalis, Arctodiaptomus spinosus, Alona rectangula, Simocephalus vetulus, Chydorus spp.* are frequent [37, 38].

Present analysis is based on the data of occurrence of altogether 126 species. This is the 80% of the Hungarian copepod and cladoceran fauna. In the RSD 65 from the above-mentioned species were observed. Actually it is 66 if we take *Diaphanosoma brachyurum* into consideration, so it is the 42% of the Hungarian fauna. The latter species was neglected in the analysis of similarity patterns because of its indefinite data of occurrence. Nevertheless its occurrence in the RSD is not questionable, so it is included in the evaluation of the spatio-temporal patterns. In the Hungarian section of the river Danube (without the water bodies of Szigetköz) 90 species were described, which from 60 were observed in the RSD as well, while 30 were only reported from the Danube and 4 exclusively from the RSD (*Graeteriella unisetigera, Anchistropus emarginatus, Moina brachiata, Oxyurella tenuicaudis*).

In the future more emphasis should be put on the research of the RSD, we should not neglect this side arm since it has a great importance in many aspects. More attention is needed in the case of the sampling methods in order to get valuable and comparable data for detecting long-term changes. Moreover there is a demand on the continuous monitoring of water quality by indicator organisms even if the zooplankton is not included in the Water Framework Directive.

**Acknowledgements.** We wish to express our gratitude to Katalin Zsuga, Pál Gulyás, Anita Kiss and VITUKI Kht (Environmental and Water Research Institute).

## REFERENCES

[1] Abrantes, N., Goncalves, F. (2003): The dynamics of Ceriodaphnia pulchella (Cladocera) in laboratory. – Acta Oecologica 24: 245-249.

[2] Berinkey, L., Farkas, H. (1956): Haltáplálék vizsgálatok a Soroksári-Dunaágban. – Állattani Közlemények 45: 45-58.

[3] Bothár, A. (1973): Crustacea-Planktonuntersuchungen im Donauarm von Soroksár. – Annales Universitas Scientiarum Budapestinensis de Rolando Eötvös Nominatae (Danubialia Hungarica LXV.) 129-144.

[4] Bothár, A., Kiss, K. T. (1984): Phyto-und zooplankton Untersuchungen im Donauarm Ráckeve. –24. Arbeitstagung der IAD. Szentendre. Ungarn. II. 85-88.

[5] Einsle, U. (1993): Crustacea, Copepoda: Calanoida und Cyclopoida. –In: Schwoerbel, J & P. Zwick (Eds): Süsswasserfauna von Mitteleuropa, Bd. 8, Heft 4, Teil 1, Gustav Fischer Verlag, Stuttgart: 1-208.

[6] Flössner, D. (1972): Krebstiere, Crustacea, Kiemen- und Blattfüsser, Branchiopoda, Fischlause, Branchiura. –In: Dahl, M., Peus, F. (ed.) Die Tierwelt Deutschlands, Gustav Fischer Verlag Jena.

[7] Forró, L., Gulyás, P. (1992): Eurytemora velox (Lilljeborg, 1853) (Copepoda, Calanoida) in the Szigetköz region of the Danube. –Miscellanea Zoologica Hungarica 7: 53-58.

[8] Gulyás, P. (1987): Tagliche Zooplankton-Untersuchungen im Donau-Nebenarm bei Ásványráró im Sommer 1985. –26. Arbeitstagung der IAD, Passau/Deutschland, 1987, Wissenschaftliche Kurzreferate 123-126.

[9] Gulyás, P. (1989): Rotatoria és Crustacea vizsgálatok a Szigetköz víztereiben. –Műhely 3: 1-10. Környezetminősítő és Számítástechnikai Osztály tanulmánysorozata, MTA Földrajztudományi Kutató Intézet, Budapest.

[10] Gulyás, P. (1994): Studies on Rotatoria and Crustacea in the various water-Bodies of Szigetköz. –In: Kinzelbach (ed.) Biologie der Donau (Limnologie Aktuell, Band 2.), Gustav Fischer Verlag, Stuttgart.

[11] Gulyás, P. (1994): Studies on the rotatorian and crustacean plankton in the Hungarian section of the Danube between 1848,4 and 1659,0 riv. km. –In: Kinzelbach (ed.) Biologie der Donau (Limnologie Aktuell, Band 2.), Gustav Fischer Verlag, Stuttgart.

[12] Gulyás, P. (1995): Rotatoria and Crustacea plankton of the River Danube between Bratislava and Budapest. –Miscellanea Zoologica Hungarica 10: 7-19.

[13] Gulyás, P. (1997): Untersuchungen des Rotatoria- und Crustacea-Planktons an der Donaustrecke unterhalb Budapest sowie im Donauarm Ráckevei-Soroksári Duna (RSD). –32. Konferenz der IAD, Wien-Österreich 1997. Wissenschaftliche Referate 265-270.

[14] Gulyás, P. (1998): Szaprobiológiai indikátorfajok jegyzéke. –In: Vízi Természet- és Környezetvédelem, 6. kötet, Környezetgazdálkodási Intézet: 1-95.

[15] Gulyás, P. (2002): A Rotatoria és Crustacea plankton minőségi és mennyiségi vizsgálata a Dunán. –Vízügyi Közlemények 84: 601-620.

[16] Gulyás, P., Bancsi, I., Zsuga, K. (1995): Rotatoria and Crustacea fauna of the Hungarian watercourses. –Miscellanea Zoologica Hungarica 10: 21-47.

[17] Gulyás, P., Forró, L. (1999): Az ágascsápú rákok (Cladocera) kishatározója, 2. bővített kiadás. –In: Vízi Természet- és Környezetvédelem, 9. kötet, Környezetgazdálkodási Intézet: 1-237.

[18] Gulyás, P., Forró, L. (2001): Az evezőlábú rákok (Calanoida és Cyclopoida) alrendjeinek kishatározója, 2. bővített kiadás. –In: Vízi Természet- és Környezetvédelem, 14. kötet, Környezetgazdálkodási Intézet: 1-198.

[19] Gulyás, P., Thyahun, Sz. (1974): Adatok a Ráckevei Duna-ág kisrák faunájához. – Hidrológiai Közlöny 54: 240-245.

[20] Győrbíró, T. (1974): A Ráckevei-Soroksári Duna halgazdálkodása. –Diplomadolgozat.

[21] Just, I., Schöll, F., Tittizer, T. (ed.) (1998): Versuch einer Harmonisierung nationaler Methoden zur Bewertung der Gewassergüte im Donauarm am Beispiel der Abwasser der Stadt Budapest. – Umweltbundesamt, Berlin.
[22] Kiefer, F., Fryer, G. (1978): Das Zooplankton der Binnengewasser, 2. Teil, Band 26. –In: Elster, H. J., Ohle, W. (ed.) Die Binnengewasser, Stuttgart.
[23] Kiss, A. (2004): Long-term changes of Crustacean (Cladocera, Ostracoda, Copepoda) assemblages in Szigetköz Floodplain Area (Hungary) 1991-2002. –Internat. Assoc. Danube Res. 35: 2-7. Novi Sad.
[24] Korovchinsky, N. M. (1992): Sididae and Holopedidae (Crustacea: Daphniiformes). –In: Dumont, H. J. F. (ed.) Guides to the identification of the microinvertebrates of the continental waters of the world, SPB Academic Publishing, The Hague.
[25] Kovács, J. Gy. (1973): Fővárosunk tava a ráckevei (soroksári) Duna. –Vízgazdálkodás 13: 215-220.
[26] Körmendi, S., Lanszki, J. (2002): A Duna-Dráva Nemzeti Park különböző vizes élőhelyeinek zooplankton vizsgálata II. A Crustacea (Cladocera, Copepoda) fauna kvalitatív vizsgálata. –Somogyi Múzeumok Közleményei 15: 113-121.
[27] Litheráthy, P., Koller-Kreimer, V., Liska, I. (2002): Joint Danube Survey. Technical Report of the International Commission for the Protection of the Danube River. – International Commission for the Protection of the Danube River, Vienna International Centre.
[28] Marosi, S., Somogyi, S. (ed.) (1990): Magyarország kistájainak katasztere. –MTA Földrajztudomány Kutató Intézet, Budapest, vol. I, pp. 38-43.
[29] Megyeri, J. (1971): A Tisza mezozooplanktonja. II. Entomostraca. –Szegedi Tanárk. Főisk. Tud. Közl. 10: 99-110.
[30] Mészáros, G., Vadadi-Fülöp, Cs., Udvari, Zs., Hufnagel, L. (2007): Analysis of spatial and temporal changes of the zooplankton fauna in the Ráckeve-Soroksár Danube arm. – Tájökológiai Lapok (in press).
[31] Nedelkovics, A., Zsuga, K. (2006): Áttekintés a Tisza zooplankton-kutatásának eredményeiről (1955-2004). –Hidrológiai Közlöny 86: 54-55.
[32] Ponyi, J. (1997): A Balaton Cladocera és Copepoda rákjai. –Állattani Közlemények 82: 69-80.
[33] Ponyi, J. (1999): A Velencei-tó meiobentosz faunájának vizsgálata 1998-ban. – Hidrológiai Tájékoztató 39: 26-28.
[34] Ponyi, J. (2001): Evezőlábú rákok (Copepoda) kevéssé ismert fajainak előfordulása Magyarországon. –Hidrológiai Tájékoztató 41:31-34.
[35] Ponyi, J. (2002): Nyíltvízi planktonrák-együttesek időbeli változása (1989-97 között) a Balatonban. –Hidrológiai Tájékoztató 42: 24-26.
[36] Ponyi, J. (2002): A Balaton rákfaunája (Crustacea) és változásai az elmúlt 100 évben. – Állattani Közlemények 87: 179-189.
[37] Ponyi, J., Dévai, I. (1977): A Fertő magyar területének rákjai (Crustacea). –Hidrológiai Közlöny 57: 262-270.
[38] Ponyi, J., Dévai, I. (1979): The Crustacea of the Hungarian area of Lake Fertő. –Opuscula Zoologica Budapest 16: 107-127.
[39] Ponyi, J., Péter, I., Zánkai, N. (1982): Az Eudiaptomus gracilis (G. O. Sars) (Copepoda, Calanoida) populációja szerkezetének és produkciójának naponkénti változása nyáron, a Balatonban. –Hidrológiai Közlöny 62: 260-266.
[40] Reskóné, M., Ponyi, J., Szító, A. (1999): A zooplankton, a meio- és a makrozoobentosz mennyisége, faji összetétele a Velencei-tóban. –Hidrológiai Közlöny 79: 369-371.
[41] Rylov, W. M. (1935): Das Zooplankton der Binnengewasser, Band 15. –In: Thienemann, A. (ed.) Die Binnengewasser, Stuttgart.
[42] Schiefner, K., Urbányi, A. (1970): A Soroksári Duna-ág komplex higiénés vizsgálata. – Hidrológiai Közlöny 50: 318-324.

[43] Smirnov, N. N. (1996): Cladocera: the Chydorinae and Sayciinae (Chydoridae) of the world. –In: Dumont, H. J. F. (ed.) Guides to the identification of the microinvertebrates of the continental waters of the world, SPB Academic Publishing, The Hague.
[44] Thyahun, Sz. (1977): Populatiodynamische Untersuchungen der Mesofauna in den Laichkrautbestanden des Donauarms von Soroksár. –Opuscula Zoologica Budapest 13: 83-106.
[45] Vadadi-Fülöp, Cs., Mészáros, G. (2007): A Ráckevei-Soroksári Dunával kapcsolatos zooplankton és makrogerinctelen kutatások áttekintése. –Hidrológiai Közlöny 87: 60-63.
[46] Vadadi-Fülöp, Cs., Mészáros, G., Jablonszky, Gy., Hufnagel, L. (2007): Ecology of the Ráckeve-Soroksár Danube –a review. –Applied Ecology and Environmental Research 5 (1): 133-163.
[47] Zánkai, N. (1987): A rákplankton összetétele és sűrűsége a Balaton nyílt vizében és partközelben. –Állattani Közlemények 74: 169-181.
[48] Zánkai, N., Ponyi, J. (1997): Nyíltvízi planktonrák-együttesek szerkezetének tér- és időbeli változása a Balaton két, trofitásban eltérő területén (Keszthelyi és Siófoki medence). –Állattani Közlemények 82: 87-108.
[49] Zsuga, K., Tóth, A., Pekli, J., Udvari, Zs. (2004): A Tisza vízgyűjtő zooplanktonjának alakulása az 1950-es évektől napjainkig. –Hidrológiai Közlöny 84: 175-178.

## APPENDIX

| Taxa | RSD | Tisza | Danube | Danube W.SZK | Lake Balaton | Lake Velence | Lake Fertő | Rába | Dráva |
|---|---|---|---|---|---|---|---|---|---|
| *Oxyurella tenuicaudis* (Sars, 1862) | + | + | + | | + | + | + | | |
| *Alonella exigua* (Lilljeborg, 1853) | + | + | + | + | + | | | | |
| *Alonella nana* (Baird, 1850) | + | + | + | + | | + | | | + |
| *Anchistropus emarginatus* Sars, 1862 | + | | | | + | | | | |
| *Bosmina longirostris* (O. F. Müller, 1785) | + | + | + | + | + | + | + | + | + |
| *Bosmina coregoni* Baird, 1857 | + | | + | + | + | | | | |
| *Camptocercus rectirostris* Schoedler, 1862 | + | + | + | + | + | + | | | + |
| *Leptodora kindtii* (Focke, 1844) | + | + | + | + | + | | | | |
| *Sida crystallina* (O. F. Müller, 1776) | + | + | + | + | + | + | + | | |
| *Daphnia cucullata* Sars, 1862 | + | + | + | + | + | | | + | + |
| *Daphnia hyalina* Leydig, 1860 | + | | + | + | + | + | | | |
| *Daphnia longispina* O. F. Müller, 1785 | + | + | + | + | + | + | + | + | + |
| *Disparalona rostrata* (Koch, 1841) | + | + | + | + | + | + | | + | |
| *Eurycercus lamellatus* (O. F. Müller, 1785) | + | + | + | + | + | + | + | | |
| *Graptoleberis testudinaria* (Fischer, 1848) | + | | + | + | + | + | + | | |
| *Simocephalus serrulatus* (Koch, 1841) | + | | + | + | | | | | |
| *Simocephalus vetulus* (O. F. Müller, 1776) | + | + | + | + | + | + | + | + | |

| Taxa | RSD | Tisza | Danube | Danube W.SZK | Lake Balaton | Lake Velence | Lake Fertő | Rába | Dráva |
|---|---|---|---|---|---|---|---|---|---|
| *Moina macrocopa* (Straus, 1820) | + | + | + | + | | | | | |
| *Moina micrura* Kurz, 1874 | + | + | + | + | | + | + | + | + |
| *Monospilus dispar* Sars, 1862 | + | | + | + | + | | | | |
| *Ceriodaphnia quadrangula* (O. F. Müller,1785) | + | + | + | + | + | + | + | + | + |
| *Ceriodaphnia dubia* Richard, 1894 | + | | + | + | | + | | | |
| *Ceriodaphnia laticaudata* P. E. Müller, 1867 | + | + | + | + | + | + | + | | |
| *Ceriodaphnia pulchella* Sars, 1862 | + | + | + | + | | + | | | |
| *Scapholeberis mucronata* (O. F. Müller, 1785) | + | + | + | + | + | + | + | + | + |
| *Macrothrix laticornis* (Fischer, 1848) | + | + | + | + | + | + | + | | |
| *Macrothrix hirsuticornis* Norman & Brady, 1867 | + | + | + | + | + | + | + | | |
| *Iliocryptus sordidus* (Liévin, 1848) | + | | + | + | + | | + | + | |
| *Iliocryptus agilis* Kurz, 1878 | + | + | + | + | + | + | | | |
| *Acroperus harpae* (Baird, 1834) | + | + | + | + | + | + | + | | |
| *Pleuroxus truncatus* (O. F. Müller, 1785) | + | + | + | + | | | | | + |
| *Leydigia leydigi* (Schoedler, 1863) | + | + | + | + | + | + | | | |
| *Chydorus sphaericus* (O. F. Müller, 1776) | + | + | + | + | + | + | + | + | + |
| *Pleuroxus trigonellus* (O. F. Müller, 1785) | + | | + | + | + | + | + | | + |
| *Pleuroxus uncinatus* Baird, 1850 | + | | + | + | + | | + | | |
| *Pleuroxus aduncus* (Jurine, 1820) | + | + | + | + | + | + | + | + | |
| *Pseudochydorus globosus* (Baird, 1843) | + | + | + | + | + | | | | |
| *Alona quadrangularis* (O. F. Müller, 1785) | + | | + | + | + | + | + | + | + |
| *Alona affinis* (Leydig, 1860) | + | + | + | + | + | + | | | |
| *Alona intermedia* Sars, 1862 | + | | + | + | | | | | |
| *Alona guttata* Sars, 1862 | + | | + | + | + | + | + | | |
| *Alona rectangula* Sars, 1862 | + | + | + | + | + | + | + | + | + |
| *Holopedium gibberum* Zaddach, 1855 | | | + | + | | | | | |
| *Daphnia magna* Straus, 1820 | | + | + | + | + | + | + | | |
| *Daphnia atkinsoni* Baird, 1859 | | + | + | + | | | | | |
| *Daphnia similis* Claus, 1876 | | | + | | | | | | |
| *Daphnia obtusa* Kurz, 1874 | | | + | | | | | | |
| *Daphnia curvirostris* Eylman, 1887 | | | + | + | + | | + | | |
| *Daphnia pulex* Leydig, 1860 | + | + | + | + | + | + | | + | |

| Taxa | RSD | Tisza | Danube | Danube W.SZK | Lake Balaton | Lake Velence | Lake Fertő | Rába | Dráva |
|---|---|---|---|---|---|---|---|---|---|
| *Daphnia parvula* Fordyce, 1901 | | | + | | | | | | |
| *Daphnia galeata* Sars, 1864 | | | + | + | + | | | | |
| *Simocephalus expinosus* (Koch, 1841) | + | + | + | + | + | + | + | | |
| *Ceriodaphnia reticulata* (Jurine, 1820) | | + | + | + | + | + | | | |
| *Ceriodaphnia megops* Sars, 1862 | | + | + | + | | + | | | |
| *Ceriodaphnia setosa* Matile, 1890 | | + | + | | | | | | |
| *Scapholeberis rammneri* Dumont & Pensaert, 1983) | | | + | + | + | + | + | | |
| *Megafenestra aurita* (Fischer, 1849) | | + | + | + | + | + | + | | + |
| *Lathonura rectirostris* (O. F. Müller, 1785) | | | + | | | | | | + |
| *Bunops serricaudata* (Daday, 1888) | | + | + | | | | | | |
| *Macrothrix rosea* (Liévin, 1848) | | | + | | | + | | | |
| *Bosmina longispina* Leydig, 1860 | | | + | + | | | | | |
| *Camptocercus lilljeborgi* Schoedler, 1862 | | + | + | | | | | | |
| Acroperus elongatus *(Sars, 1862)* | | | + | | + | + | + | | |
| *Kurzia latissima* (Kurz, 1875) | | | + | + | | | | | |
| *Tretocephala ambigua* (Lilljeborg, 1900) | | | + | + | + | | + | | |
| *Rhynchotalona falcata* (Sars, 1862) | | | + | | | | | | |
| *Leydigia acanthocercoides* (Fischer, 1854) | | + | + | + | + | + | + | | |
| *Alona costata* Sars, 1862 | | + | + | + | | + | | | |
| *Alona rustica* Scott, 1895 | | | + | | | | | | |
| *Dunhevedia crassa* King, 1853 | | + | + | | | | + | | |
| *Alonella excisa* (Fischer, 1854) | | + | + | | + | + | + | | |
| *Pleuroxus laevis* Sars, 1862 | | + | + | + | + | + | + | | |
| *Pleuroxus striatus* Schoedler, 1858 | | | + | | | + | | | + |
| *Chydorus gibbus* Sars, 1890 | | | + | + | | | | | |
| *Chidorus piper* Sars, 1862 | | | + | | + | | | | |
| *Chidorus ovalis* Kurz, 1875 | | | + | + | + | | | | |
| *Chydorus latus* Sars, 1862 | | | + | + | | | | + | + |
| *Polyphemus pediculus* (Linné, 1761) | | + | + | + | | | + | | |
| *Diaphanosoma mongolianum* Uéno, 1938 | | | | | | | + | | |
| *Diaphanosoma lacustris* Korinek, 1981 | | | | | + | | | | |
| *Latona setifera* (O. F. Müller, | | | | | + | | | | |

| Taxa | RSD | Tisza | Danube | Danube W.SZK | Lake Balaton | Lake Velence | Lake Fertő | Rába | Dráva |
|---|---|---|---|---|---|---|---|---|---|
| 1875) | | | | | | | | | |
| *Daphnia cristata* Sars, 1862 | | | | | + | | | | |
| *Moina brachiata* (Jurine, 1820) | + | + | + | | + | + | + | | |
| *Ceriodaphnia rotunda* Sars, 1862 | | | | | + | + | + | | + |
| *Streblocerus serricaudatus* (Fischer, 1849) | | | | | | + | | | |
| *Alona protzi* Hartwig, 1900 | | | | | + | | | | |
| *Graeteriella unisetigera* (Graeter, 1908) | + | | | | | | | | |
| *Macrocyclops albidus* (Jurine, 1820) | + | + | + | + | + | + | + | | + |
| *Macrocyclops fuscus* (Jurine, 1820) | + | + | + | + | | + | + | | + |
| *Eucyclops serrulatus* (Fischer, 1851) | + | + | + | + | + | + | + | | + |
| *Eucyclops macruroides* (Lilljeborg, 1901) | + | + | + | + | + | + | | | |
| *Eucyclops macrurus* (Sars, 1863) | + | | + | + | + | + | | | |
| *Paracyclops fimbriatus* (Fischer, 1853) | + | + | + | + | + | + | + | | |
| *Cyclops strenuus* Fischer, 1851 | + | + | + | + | + | + | + | | + |
| *Cyclops vicinus* Uljanin, 1875 | + | + | + | + | + | + | | | + |
| *Megacyclops viridis* (Jurine, 1820) | + | + | + | + | + | + | + | + | + |
| *Acanthocyclops vernalis* (Fischer, 1853) | + | + | + | + | + | + | + | + | + |
| *Acanthocyclops robustus* (Sars, 1863) | + | + | + | + | + | + | + | + | + |
| *Diacyclops bicuspidatus* (Claus, 1857) | + | + | + | + | + | + | + | | |
| *Cryptocyclops bicolor* Sars, 1927 | + | + | + | + | + | | + | | + |
| *Mesocyclops leuckarti* (Claus, 1857) | + | + | + | + | + | + | + | | + |
| *Thermocyclops crassus* (Fischer, 1853) | + | + | + | + | + | + | + | | + |
| *Thermocyclops oithonoides* (Sars, 1863) | + | + | + | + | | | | | |
| *Eudiaptomus gracilis* (Sars, 1863) | + | + | + | + | + | + | | | + |
| *Eurytemora velox* (Lilljeborg, 1853) | + | | + | | | | | | |
| *Ectocyclops phaleratus* (Koch, 1838) | + | + | + | + | + | + | | | |
| *Diaptomus castor* (Jurine, 1820) | | | + | | + | | | | |
| *Eudiaptomus vulgaris* (Schmeil, 1896) | | | + | + | | | + | | |
| *Eudiaptomus graciloides* | | + | + | + | | | | | |

| Taxa | RSD | Tisza | Danube | Danube W.SZK | Lake Balaton | Lake Velence | Lake Fertő | Rába | Dráva |
|---|---|---|---|---|---|---|---|---|---|
| (Lilljeborg, 1888) | | | | | | | | | |
| *Eudiaptomus zachariasi* (Poppe, 1886) | | + | + | + | | | | | |
| *Arctodiaptomus spinosus* (Daday, 1891) | | | + | | | | + | + | |
| *Macrocyclops distinctus* (Richard, 1887) | | | + | + | | + | | | + |
| *Eucyclops speratus* (Lilljeborg, 1901) | | + | + | + | | | + | | |
| *Eucyclops denticulatus* (Graeter, 1903) | | | + | + | + | | | | |
| *Paracyclops affinis* (Sars, 1863) | | | + | + | + | + | | | |
| *Cyclops furcifer* Claus, 1857 | | | + | + | | | | | |
| *Megacyclops gigas* (Claus, 1857) | | | + | + | | | | | |
| *Diacyclops languidus* (Sars, 1863) | | + | + | + | | | | | |
| *Microcyclops varicans* (Sars, 1863) | | | + | | + | | + | | |
| *Metacyclops gracilis* (Lilljeborg, 1853) | | + | + | + | | | | | |
| *Thermocyclops dybowskii* (Lande, 1890) | | + | + | | | | + | | |
| *Mixodiaptomus kupelwieseri* (Brehm, 1907) | | + | | | | | + | | |
| *Arctodiaptomus bacillifer* (Koelbel, 1885) | | | | | | + | + | | |
| *Paracyclops poppei* (Rehberg, 1880) | | | + | | + | | | | |
| *Diacyclops nanus* (Sars, 1863) | | | | | + | + | + | | |
| *Metacyclops minutus* (Claus, 1863) | | + | | | | | | | + |