ALGA KÖZÖSSÉGEK TÉR- ÉS IDŐBELI VÁLTOZÁSAI HOLTÁGAKBAN- ÉS VÍZFOLYÁSOKBAN

SPATIAL AND TEMPORAL PATTERN OF ALGAE ASSOCIATIONS IN OXBOWS AND RIVERS

Egyetemi doktori (PhD) értekezés

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Értekezés a doktori (Ph.D.) fokozat megszerzése érdekében
a Környezettudomány tudományágban
Írta: **Krasznai Enikő** okleveles Biológus-ökológus

Készült a Debreceni Egyetem **Juhász-Nagy Pál Doktori Iskolája**
(**Kvantitatív és Terresztris Ökológia** programja) keretében

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Az értekezés bírálói:
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elnök: ....
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Contents

1 Introduction

The dissertation focuses on algae associations of oxbows and lowland rivers in Hungary. The first part of the dissertation discusses pelagic phytoplankton in shallow oxbows. The second part is about phytoplankton patchiness in a sheltered, shallow oxbow. In the third part an evaluation of desmids is presented. In the fourth part characteristic types of the potamo-plankon are discussed. Finally, results and/or proposals regarding the riverine phytoplankton quality assessment is presented.

1.1 Oxbows

1.1.1 Phytoplankton of the oxbows

Large and medium-sized rivers, flowing across a flat area, are meandering. Over time, the meanders grow and develop into enormous loops. Eventually, during the flood periods, rivers break through the base of the loops (avulsion), cut off the meanders, and leave the curves behind as oxbow lakes. In addition to this natural process, man-made interventions can also result in the development of oxbows. The number of the oxbows created by the engineering and the natural processes exceeds 300 in the Carpathian basin (Pálfai 2003). These lakes undergo a gradual ageing process (frequently referred as hydroseries in succession studies) that ultimately converts them into wetlands and then to terrestrial biotops.

During the senescence of shallow basins the microflora undergoes considerable changes parallel with the macrophyte succession. Van den Berg et al. (1998) demonstrated the changes of the phytoplankton composition along a transect from the centre of a *Chara* stand to the open water.

Development of extended macrophyte stands results in a number of physical, chemical and biological changes. Macrophytes reduce nutrient concentrations, shade the water column, increase sedimentation rate (Hasler and Jones 1949), provide refuges for zooplankton grazers (Jeppesen et al. 1997) and release allelopathically active compounds (Gopal and Goel 1993; Gross 1999; Körner and Nicklisch 2002). These changes result in lower phytoplankton biomass and induce changes in the composition of the microflora. Additionally, macrophyte stands represent microhabitats and increase overall biodiversity (Borics et al. 1998, 2003).

Possible impacts of the macrovegetation on the phytoplankton are well documented in the literature (Scheffer 1998; Lau and Lane 2002; Takamura et al. 2003; Qin et al. 2006), however, the general features of the long-term succession of algae in shallow, rapidly ageing ecosystems has not been studied in details.

1.1.2 Small-scale heterogenity of phytoplankton

New techniques like in vivo fluorescence (IVF) of chlorophyll-a using submersible fluorometer, or the analysis of data from satellite-borne optical sensors provided strong evidence that horizontal distribution of phytoplankton is not homogeneous in the aquatic systems. This heterogeneity exists at a scale from a few centimetres to hundreds of kilometres. Lateral stirring with mixing events (Abbott et al., 1980), local upwellings (Salonen et al., 1999), or surface drifts (Wu et al., 2010) can also be responsible for patch generation in large lakes and in estuaries (Lucas et al., 1999). Irish and Clarke (1984) showed that in small waterbodies, differences in the horizontal distribution of larger, buoyancy-regulating algae can be expected. Besides the field observations modelling approaches like KISS theory (Kierstead and Slobodkin, 1953), 3-D computational fluid dynamics (CFD) model (Hedger et al., 1999), and flow field modelling (Schernewski et al., 2005) help us to understand the role of physical processes in the development of uneven distribution of planktonic organisms.

Physical measurement of the photosynthetic pigments is an easy and quick way to estimate phytoplankton biomass, but does not yield any information on the local dispersal of the different groups of algae. The study of the horizontal distribution of the various algal groups needs the microscopic investigation of large number of plankton samples. The other problem is that the accuracy of the traditional counting methods in most of the investigations is not sufficient to reveal existing differences in the distribution of planktonic elements. Counting of 400 units 10% accuracy can be achieved (Lund et al., 1958), but this accuracy refers to the total number of algae. The counting error of the less abundant taxa is much higher. Thus, the experienced differences for the rare taxa may not be realistic, just sampling artefacts produced by the investigator. Therefore, there is a high uncertainty as to whether, and to what extent uneven distribution of planktonic algae develops in the waterbodies. Knowledge of the properties of the small scale patchiness of algae can be important both theoretical and practical points of view.

Most of the oxbows in the Carpathian Basin are well sheltered and can be stratified stably in the growing season (Grigorszky et al., 2000, 2003; Teszárné-Nagy et al., 2003). Therefore, the oxbows are good objects of those investigations which focus on the small-scale spatial distribution of the planktonic algae, especially in calm and hot midsummer weather conditions which favour the development of small convection cells in the water and patch formation generated by algal mobility.

1.1.3 Desmids to assess natural value

Recently, the water quality assessments have been at the forefront of research (Rott et al. 2003, Gutowski et al. 2004, Padisák et al. 2006, Borics et al. 2007). During the last decades several methods were developed for the characterisation of the saprobic and trophic state of water bodies (Järnefelt 1952; Teiling 1955; Heinonen 1980; Rosén 1981; Hörnström 1981; Tremel 1996; Lepistö 1999). Most of these studies were aimed at classifying the various standing and running water types on the basis of their pollution levels, and rank them on an absolute scale without consideration of their natural characteristics. As a consequence, the evaluation of naturally eutrophic water bodies is usually problematic. It is conceivable that by taking into account biological features like the diversity of the macrophyte flora, and that of the reptile, fish and bird fauna, a more accurate assessment of the biological and ecological value of several of these habitats is possible. Typical representatives of these water bodies are oxbows, alkaline bog-lakes and marshlands which feature rich stands of macrophytes and benthic communities.

For an evaluation of the quality of these habitats, a study of the benthic algae seems appropriate. For practical reasons, mostly diatom based metrics have been developed in recent years (Descy 1979, Watanabe et al. 1986, Kelly et al. 1995, Schiefele & Schreiner 1991, Lenoir & Coste 1996). Nevertheless non-diatom algae can also been used as indicators of biological integrity (Fjerdingstadt 1965; Palmer 1969, Hill et al. 2000; Blinn & Herbst 2003) although a number of problems have to be faced. Species identification in several groups of algae is difficult, and to decide what constitutes an individual (in the case of filamentous or colonial forms) can also be problematic.

Desmids which are characteristic elements of epiphytic communities (John et al. 2002) can also be used in environmental assessments. Several species of this group are closely related to certain types of aquatic habitats, and may be used as indicators of changes of pH or nutrient supply (Coesel 1984, Borics 1998, Fehér 2003). On the bases of occurrence, rarity and maturity of desmid species a method was developed by Coesel (2001) for assessing the nature conservation value (NCV) (Coesel 1998) of aquatic habitats.

The Coesel method is presented for quantification of aquatic nature conservation value based on desmid assemblages present (Coesel 2001). Species richness (indicative of internal structural and functional differentiation of the ecosystem), the occurrence of rare taxa (often indicative of particular environmental conditions) and the presence of species indicative of ecosystem maturity are the parameters chosen to determine conservation value. For the sake of utility, schemes have been developed to transform the values scored for the various parameters to a simple scale ranging from 0 to 10, relative to regional and historical standards. During the first adaptation of this method for Hungary (Fehér 2007) the water qualities in the investigated lenitic waters were classified as oligotrophic to meso-eutrophic by trophic status based on desmid taxa. The applicability of the Coesel's method for Hungarian waters is necessary.

1.2 Rivers

1.2.1 Characteristic phytoplankton assemblages of rivers

The traditional multivariate statistical methods, like cluster analysis and ordination, are difficult to interpret and can not well present the information of very large data sets. Self Organizing Map (SOM) is a novel approach for the visualization of high-dimensional data. SOM converts complex statistical relationships between high-dimensional data items into simple geometric relationships on a low-dimensional display. Thus, it compresses information while preserving the most important topological and metric relationships of the primary data (Kohonen 2001). The main advantages of the SOM are the better data visualisation and noise reduction (Vesanto & Alhoniemi 2000). Mangiameli et al. (1996) compared SOM and several hierarchical clustering methods, and found SOM superior to hierarchical clustering in both robustness and accuracy. In addition, the two-level clustering approach (SOM neural network followed by K-means clustering) was developed and successfully applied to cluster data (Vesanto & Alhoniemi 2000, Beccali et al. 2004). SOMs are increasingly popular tools in diatom ecology, and have been used to describe bentic algal assemblages in France and Luxembourg (Gosselain et al. 2005, Rimet et al. 2005a, 2005b). The method however, has not been used so far to analyse riverine phytoplankton assemblages, although the biological monitoring of the waterways provided large datasets in several countries during the last decades.

The EC Water Framework Directive (2000) defines the minimal level for the ecological monitoring of surface waters in Europe. The importance of the use of macroscopic invertebrates and bentic diatoms as well-known indicator groups in rivers is emphasised, but it also indicates that the most relevant elements should be applied in the given situation. In the case of eutrophic rivers, the investigation of the phytoplankton is at least as important and informative as that of the other elements. The problem is that phytoplankton investigations alone are not equal with water quality assessment. In most cases, the phytoplankton of rivers is a mixed assemblage memorising the ecological conditions of the upper river segments. The phytoplankton assessment has to be based on the evaluation of the occurring species, or groups of algae, which groups can be created on the basis of their taxonomic relationship (genera, divisions), or on the basis of their similar ecological behaviour. The assessment method proposed by Borics et al. (2007) is based on the evaluation of the functional groups of algae (Reynolds et al. 2002, Padisák et al. 2006).

1.2.2 Riverine phytoplankton quality assessment

The increasing demand for developing new assessment methods for evaluating the ecological status of lakes and rivers has mainly been fuelled by the WFD (2000) in the recent years. The Directive doesn't deem necessary to investigate the phytoplankton in rivers which is not surprising, because the streams owing to the predominance of allochtonous organic material over the autochtonous primary production are naturally heterotrophic systems (Reynolds 2000). Nevertheless several investigations proved (Uherkovich 1971, Descy et al. 1988, Kiss 1994, Dokulil 1996, Skidmore et al. 1998) that the lower sections of the large, sluggish rivers (especially in lowland areas) can be characterised by highly eutrophic phytoplankton. Analysis of the Hungarian water quality database that contains more than 60.000 chlorophyll-a data for the Hungarian rivers (Vígh 2002) has also demonstrated the development of eutrophic, and even worse, hypertrophic situations in most of the lowland rivers in Hungary. Undesirable increment of the phytoplankton biomass is at least as problematic in riverine ecosystems as it is in lakes, because it may have deleterious effect on the other assemblages of the river, and it impairs water uses.

The basic characteristic of the rivers are, that during their course they change their trophic state from heterotrophy to autotrophy. In line with this, the philosophy of the river monitoring approaches, also have to change. Although the water quality monitoring of the streams are usually based on the composition of the macro-invertebrate fauna and the benthic diatoms, because of the above mentioned reasons, the investigation of the riverine phytoplankton for monitoring purposes is unavoidable. Methodology of the rheoplankton investigations (including the sampling, counting etc.) has been worked out in details for decades (Uherkovich 1971, Kiss at al. 1995, 1996). These are being applied as routine techniques by those organisations which are responsible for the water quality monitoring. Nevertheless phytoplankton based quality assessment of the rivers hasn't been elaborated yet, therefore in several countries the old saprobic systems (Pantle & Buck 1955) are in current use.

2 Objectives

The dissertation contains two sections. The aim of the first section is to describe the phytoplankton dynamics of oxbows. In the second section I deal with the characteristic phytoplankton assemblages of the rivers, and the phytoplankton based quality assessment. In the dissertation I answer the following questions:

Oxbows

Phytoplankton of the oxbows

(i) Do the oxbows have unique microflora? (ii) Does the macrophyte coverage have a large effect on the composition and biomass of the algal assemblages? (iii) Does the higher plants dominated state results in clear water conditions in the oxbows?

Small-scale heterogenity of phytoplankton

(i) Are there any differences in the horizontal distribution of algae along the longitudinal axis of the oxbow? (ii) How can the heterogeneity be characterized numerically? (iii) Which taxa, and to what extent are responsible for the heterogeneity? (iv) Do the differences exist at fine scale (1m)? (v) Which mechanisms are responsible for the development of algal patches? (vi) To what extent can the horizontal patchiness influence the results of the quality assessment?

Desmids to assess natural value

(i) Are desmids important elements of the microflora of shallow, alkaline, hypertrophic oxbows? (ii) What kind of NCV values characterise the Malom-Tisza oxbow? (iii) Do the NCV values change during the course of the summer? (iv) Are there any differences in the NCV values between the different substrates? (v) Do the NCV values change after applying Fehér's (2007) modified rarity values? (vi) What are the differences, if any, in the NCV values if different species enumeration methods are used?

Rivers

Characteristic phytoplankton assemblages of rivers

(i) How can be used the phytoplankton functional groups approach to describe characteristic phytoplankton assemblages in riverine ecosystems? (ii) What are the most frequent assemblage types based on this functional groups?

Riverine phytoplankton quality assessment

Is the invented new phytoplankton-based method for assessing the ecological state of the rivers?

3 Material and Methods

3.1 Study sites and sampling methods in oxbows

The investigated 13 oxbows are located in the Tisza valley, East Hungary (Fig. 3.1.1A). Some physical and chemical characteristics of oxbows are shown in Table 1 and Table 2 (Appendix).

For phytoplankton and water-chemical analyses samples were taken with a tube sampler at the deepest part of the lakes monthly (except

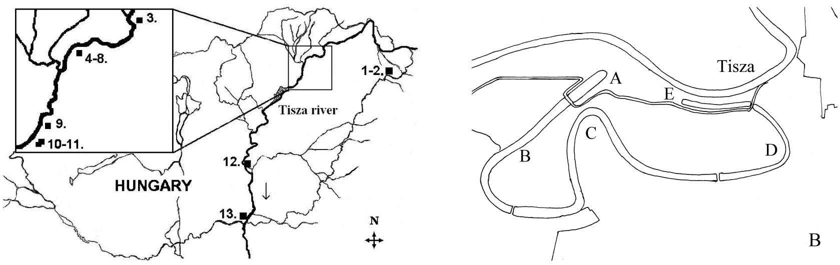


Fig. 3.1.1 A. Sampling sites: 1. Holt-Szamos Géberjén, 2. Holt-Szamos Tunyogmatolcs, 3. Szöglegelői-Holt-Tisza, 4. Szűcs-Tisza, 5. Malom-Tisza (pelagical part), 6. Malom-Tisza. part of floating island, 7. Falu-Tisza, 8. Darab-Tisza, 9. Miskafoki-Holt-Tisza, 10. Morotvaközi-Holt-Tisza, 11. Egyeki-Holt-Tisza, 12. Tiszaugi-Holt-Tisza, 13. Atkai-Holt-Tisza. Arrow shows the flow of the river. B. Map of the Tiszadob oxbow system. A - Darab-Tisza, B - Falu-Tisza, C - Malom-Tisza, D - Szűcs-Tisza, E - Felső-Darab-Tisza

Tiszaugi-Holt-Tisza, Holt-Szamos Géberjén and Tunyogmatolcs) from May 2005 to October 2008. In shallow oxbows (Zmax<2m) the whole water column was sampled, in the deeper ones we took samples from the epilimnion. All samples were collected from the unvegetated sites therefore differences in the illumination were negligible.

The Malom-Tisza oxbow was studied in detail, which lies in the middle section of the Tisza valley, East Hungary (48 01’14”N; 21 11’27”E). The eleven kilometres long oxbow is divided into five sections by embankments (Fig 3.1.1.B). The largest, middle section is the Malom-Tisza oxbow (length 4.2 km, average width 80m, surface area 30 hectares, average depth 3.5m, maximum depth 12.5m) and it is a eutrophic hard water lake. Most of the oxbow is a typical pelagic ecosystem; at the eastern section of the oxbow a unique macrophyte association is present which covers almost the entire eastern lake-basin. This association (Calamagrosti-Salicetum cinereae Thelypteridosum palustris using Braun-Blanquet's (1964) phytosociological terminology) is the result of the ageing process of water bodies and probably has always been a characteristic association of Hungary's shallow lakes.

For desmid assessment, water samples for physico-chemical analyses (Table 3, Appendix) were taken from the immediate surface layer at sampling points 1, 5 and 7 and for phytoplankton investigations at points 1-7 of the oxbow (Fig. 3.1.2) on 24 June and 25 August 2004. Phytoplankton samples were obtained by filtering 10L water through a plankton net (mesh size 20 µm). For the examination of the periphyton parts of macrophytes were collected. When different macrophyte species

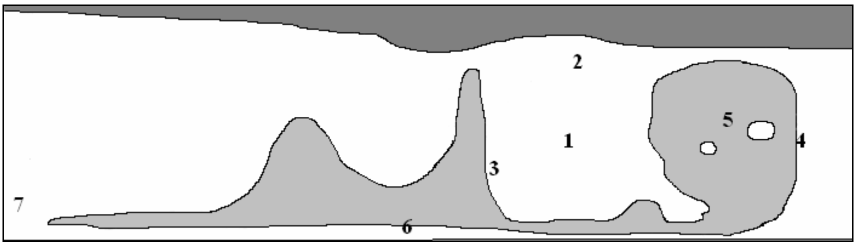


Fig. 3.1.2. Sampling locations in the Malom-Tisza oxbow on 24 June and 25 August 2004. 1 - bog-lake, 2 - north of bog-lake, 3 - margins of the Salici-Alnetum (floating islands), 4 - right side of the Salici-Alnetum (floating islands), 5 - pools in Salici-Alnetum (floating islands), 6 - lag-zone, 7 - at the shore of Malom-Tisza

of smaller size (Spirodela, Lemna spp., Riccia sp.) occurred in a small area, so-called "mixed samples" were also taken, pressing the water from the macrophytes by hand and filtered it through the net (Fig. 3.1.2). The samples collected and their attributes are shown in Table 4 (Appendix).

For the patchiness investigation samples were collected on 23 July 2007. For mapping the horizontal distribution of the phytoplankton 11 sample sites were selected along the longitudinal axis of the oxbow (Fig. 3.1.3). Using a tube sampler (length 2.5 m, diameter 0.06 m) three independent column samples were collected from the euphotic layer at each sample sites in the vertices of a triangle with one meter side length. The resulted 33 samples were preserved in acid Lugol's solution. For investigating the distribution of algae at smaller scale, a vertical grid sampling scheme was also implemented. Samples were collected along a transect in the middle part of the oxbow at site No. 8 perpendicular to the shoreline (Fig. 3.1.3). The length of the transect was 90 m, and the samples were taken at 15 m intervals. The sampling device was a hard plastic tube-sampler (length: 5 meters, built from two 2.5 meters long sections; diameter: 0.03 ms). The sampler has a bottom stopper and equipped with side valves at 0.25 ms intervals. To obtain the water samples from the different layers, the tube (with open bottom stopper and with closed side ports) was lowered vertically into water. After reaching the required depth the bottom stopper was closed, and the tube was slowly removed. When a side valve came above the water surface it was opened and the sample (0.25m water column) was poured into 250 mL glass bottles. Altogether 69 samples were collected from the vertical grid. Phytoplankton samples were kept in these bottles and preserved on the spot immediately after sampling. This technique enabled us to sample algae on a fine vertical scale. In this case the whole water column was sampled. To avoid disturbing the bottom sediment depth of the water was measured by fish sonar (Humminbird 350tx) at every sample sites. Samples taken by a 2-L Ruttner sampler were used to describe the vertical

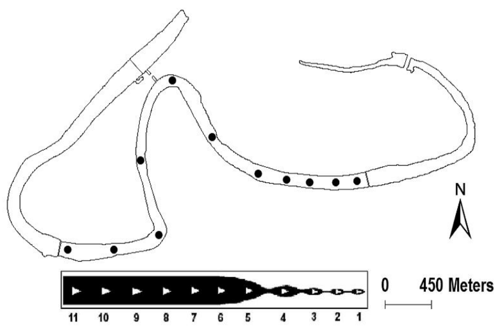


Fig. 3.1.3. Lake area map with the sampling sites (above) and the schematic view of the oxbow on 23 July 2007, illustrating the ratio of the open water (black) and the macrophyte covered regions (white).

temperature and oxygen profile at site 8. Samples were collected from surface to bottom at intervals of 1 m.

Water temperature, pH and conductivity were recorded in situ. Transparency was measured by a Secchi disc (Secchi disc visibility depth (Zsd)). Analyses of nitrate-nitrogen, nitrite-nitrogen, ammonium-nitrogen, soluble reactive phosphorus (SRP), total phosphorus (TP) and chlorophyll-a were carried out according the Hungarian national guidelines (MSZ ISO 7150-1:1992; MSZ 448-12:1982; MSZ 12750-17:1974).

3.2 Study sites and sampling methods in rivers

Data from 1897 phytoplankton investigations from 189 locations have been included in the analysis. The investigations were carried out in Hungarian rivers and rivulets by regional authorities and research institutions during the period 2000-2004.

The original database contained the relative abundance of the species. Since the analysis here is based on the relative biomass of the species, cell volume data from earlier measurements were used.

3.3 Samples analysis

Phytoplankton samples were fixed with Lugol's solution. In oxbows case phytoplankton samples were left to settle in 5 mL settling chambers for 48 h, and examined with Leica DMIL inverted brightfield microscope. For estimating the number of the larger forms (>40 μm) the whole area of the chamber was investigated at a magnification of 10×20. For giving the relative abundance of the smaller algae, a minimum of 400 settling units (cells, filaments or colonies) were counted in each sample at a magnification of 10×63. Using this magnification three transects of the counting chamber were investigated for giving the total number of smaller species.

Uncertainty in algae counting was estimated by 5 repeated investigation of a randomly selected sample. The variability was expressed by the coefficient of variation (CV) for each species.

In rivers samples case a minimum of 400 settling units per sample were counted with the Leica DMIL-inverted microscope (Utermöhl 1958).

The periphyton samples were shaken and allowed to settle in 100 ml cylinders. Two 20 μl droplets of the settled materials were investigated with Leica DMRB microscope equipped with brightfield, phase-contrast and Nomarski interference contrast optics. Two different enumeration methods were used to estimate the species richness of the samples: (i) counting up to 400 specimens, (ii) counting the whole volume of droplets. We also calculated the difference in the number of species based on the two enumeration methods

Phytoplankton biomass was calculated from biovolume data using appropriate geometric formulas, using Opticount programme (Opticount 2008). Functional groups were defined according to Reynolds et al. (2002) and Padisák et al. (2006, 2009).

3.4 Statistical methods

ESRI ArcMap Spatial Analyst program was used to illustrate the distribution of the selected algae taxa in the vertical profile of the oxbow. Data were smoothed by regularized spline interpolation with the parameters of weight=1 and points=8. Similarity of the samples was displayed by hierarchical cluster analysis using MSSQ fusion algorithm based on Bray-Curtis dissimilarity (Legendre and Legendre, 1998). The R environment for statistical computing and graphics (R Development Core team, 2010) was used for the calculations.

Kohonen's Self Organizing Map (SOM) was used to determine the typical algal assemblages (Kohonen 2001; Park et al. 2003). For its ecological applications we refer to Lek and Guegan (2000). SOM makes a projection of the data into a two-dimensional hexagonal map. Closely related communities are placed into neighbouring hexagons by their similarities, while samples with different communities are in distant hexagons. The SOM can display the groupings of samples and species together; therefore, each species can be evaluated by its importance. The SOM Toolbox was used to implement the SOM under a MATLABs environment; the numbers of virtual units were determined according to Vesanto (2000) as: $nVU = 5\sqrt{nS}$, where nVU: number of virtual units, nS: number of samples.

For clustering the SOM we used the K-means clustering technique, which is an algorithm to classify objects based on their attributes (in this case codon composition) into K number of group. The grouping is done by minimizing the sum of squares of distances between data and the corresponding cluster centroid as the square error of each data point is calculated and clusters reformed such that the sum of square errors is made to be minimum (Beccali et al. 2004).

The Structuring Index (SI) was originally developed to define species showing the strongest influence on the organization of the SOM map (Tison et al. 2008). Therefore, the set of species showing high SI (>~30) can be considered as indicator species (Park et al. 2005; Várbíró et al. 2007).

Numerical characterization of heterogeneity

A simple graphical display of the taxon numbers or biomass values is an illustrative approach, but can be misleading, especially in case of species of low relative abundance. Therefore, an index of heterogeneity

(IH) was proposed for each taxa as follows: IH = CVs / CVe, where CVs was the coefficient of variation of the algal counts among the column samples, CVe is the algal counting error. CVe was estimated by repeated counting on five counting chambers of 5mL which were filled with one of the phytoplankton samples. The whole area of the chambers was screened during the counting; to minimise the counting error only the large-size taxa were counted. Usually we counted approximately 500 specimens in the chambers. Based on the five repeated counting the coefficient of variation (CV) and means of the relative frequency of the enumerated taxa were calculated. The CV values of the taxa were plotted against the means of relative frequencies and a regression equation was fitted. For the small sized taxa we estimated the CVe using this regression equation. We received the following equation: $CVe = 43.22\ x^{-0.51}$, where x is the relative frequency of the taxon ($R^2 = 0.9683$). Both the large sized and the small sized taxa are randomly distributed in the counting chamber, thus their CVe can be estimated by this regression equation. This relationship between CVe and the mean relative frequency is an analogue of the Taylor's power law (Taylor and Taylor 1977).

Quantification method

The Coesel method is presented for quantification of aquatic nature conservation value (NCV) based on desmid assemblages present (Coesel 2001). Determination of the index requires the following data: number of desmids species observed (d, usually referred to as diversity), rarity (r) scores and maturity (m) scores of the desmid species. Rarity and maturity scores are based on expert judgement proposed by Coesel (2001). Depending on the pH-type of the water the Σr, Σm, and d scores are transformed to the so-called M, R and D scores based on the suggestion of Coesel (2001). The NCV is the sum of D (ranging from 1-3), R (ranging from 1-3) and M (ranging from 1-4); therefore the maximum of the D+R+M scores is 10.

It is evidence the nature conservation value elaborated in the Netherlands, is need to evaluation in other countries. On basis of detailed investigation of South-Hungarian water bodies' rarity values (r) of the desmid species have been modified by Fehér (2007). This study is the Coesel method very first evaluation for Hungary.

4 Results and discussion

4.1 Oxbows

4.1.1 Phytoplankton of the oxbows

Characteristic oxbow types

The 13 oxbow sampling sites were classified on basis of their location (outside or inside the dikes on the floodplain) and macrophyte coverage. The main types of the oxbows are the followings:

Type I - pelagial 1 type: macrophytes are found only in a narrow margin,

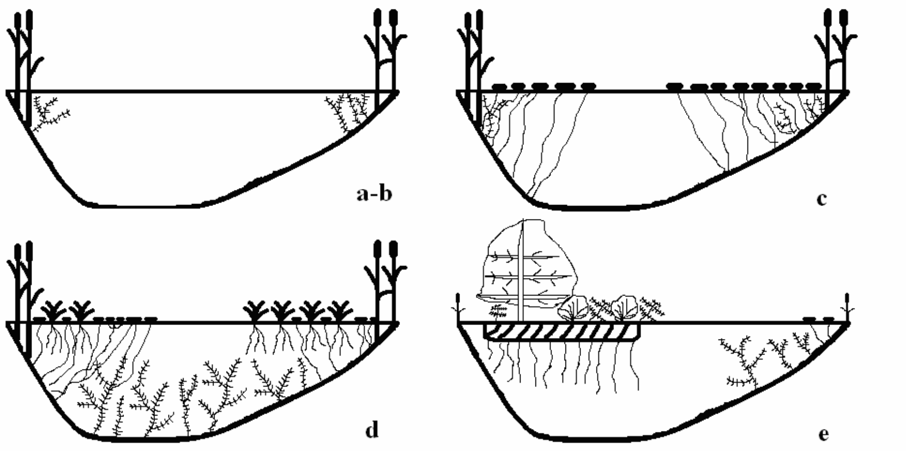


Fig. 4.1.1.1. Types of oxbows based on macrophyte coverage. a-b: Type I and Type II; c: Type III; d: Type IV and e: Type V. See type descriptions in the text.

the lakes are located on the floodplain (therefore the microflora can be influenced by phytoplankton of Tisza river) (Fig. 4.1.1.1a);

Type II - pelagial 2 type: macrophytes are only found in a narrow margin, located outside the embankments (therefore the river does not have a direct effect on them) (Fig. 4.1.1.1b);

Type III - floating-leaved type: *Trapa natans* L. or *Nymphaea alba* L. dominate the vegetation covering large portion of the surface of the oxbows (Fig. 4.1.1.1c);

Type IV - submerged-floating type: (*Ceratophyllum demersum* L. and *Stratiotes aloides* L. or *Nymphaea alba* L. are dominant in the water column, (Fig. 4.1.1.1d);
Type V - floating island type: floating islands of *Thelypteris* palus*t*ris Schott and *Salix cinerea* L. dominate the water, *Myriophyllum* spp. are

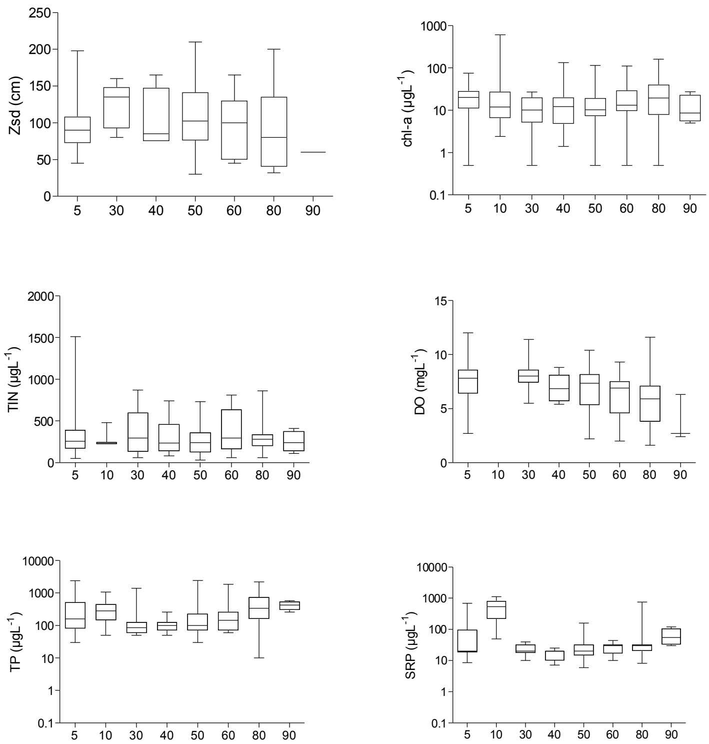


Fig. 4.1.1.2. Characteristic physical-chemical parameters along the different macrophyte coverage.

also present (Fig. 4.1.1.1e).

The percentage of the actual macrophyte coverage was estimated during sampling, along a transect perpendicular to the shoreline. The types listed above represent the stages of the ageing process (first phases of the hydroseries) of the oxbows. Most frequent order of stages are I→II→III→IV or I→II→III→V.

Taxonomic composition

A total of 646 species of algae were recorded in the oxbows over the study period. The microflora was dominated by chlorococcalean green algae (173), diatoms (114), euglenophytes (85), cyanophytes (70) and desmids (53). The ratio of the flagellated algae was high (31%). There are several chlorococcalean, euglenophyton and dinophyton species that are

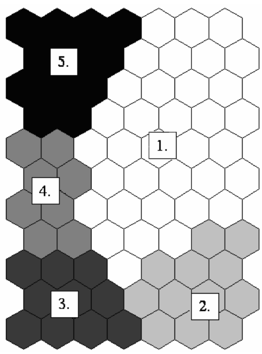


Fig. 4.1.1.3a

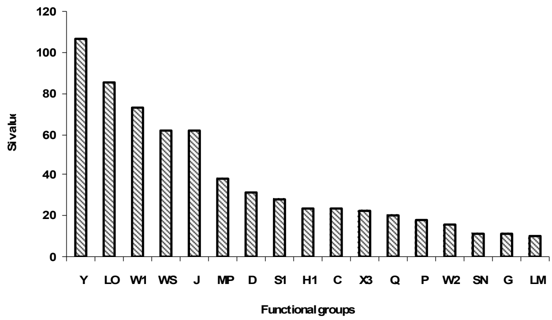


Fig. 4.1.1.3b

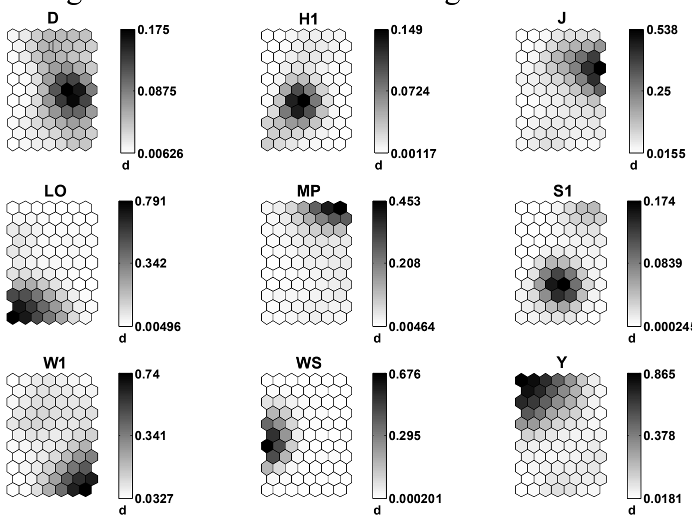


Fig. 4.1.1.3c

Fig. 4.1.1.3.a. Clusters of the SOM resulted by the K-means clustering. b. Coda with high structuring index (SI). The columns indicate the relative importance of each codon in determining the SOM patterns. c.Gradient distribution of important coda on the SOM.

known exclusively from oxbows in Hungary, like *Nephrochlamys willeana* (Printz) Korshikov, *Trachelomonas woycickii* Koczw. var. *pusilla* Drez. f. *pusilla*, *Ceratium furcoides* (Levander) Langhans, *Peridinium gatunense* Nygaard. Occurrence of *Peridiniopsis elpatiewskyi* (Ostenfeld) Bourrelly, *Cystodinium cornifax* (Schilling) Klebs, *Woloszynskia pascheri* (Suchlandt) Stosch, *Scenedesmus pannonicus* Hortob. and *Cosmarium kjellmanii* Wille has been reported in other types of waters in Hungary, but these can also be considered as typical oxbow-dwellers. Most of the species mentioned above occurred sporadically, but

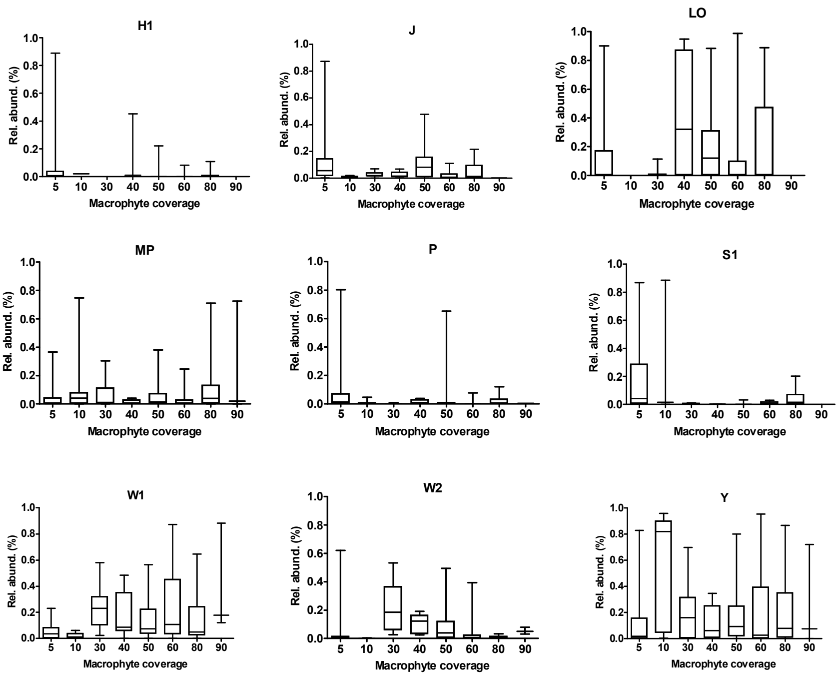


Fig. 4.1.1.4. Min., max., IQR data of relative biomass abundances of the relevant coda along the different macrophyte coverage.

the planktonic dinoflagellates were dominant members of the phytoplankton.

In case of those lakes where the number of samples is more or less similar (and relatively high, 18-20 samples), the flora consisted of more than 200 species (Table 1, Appendix). An especially rich microflora (308 species) characterised the Malom-Tisza oxbow (floating island-type) where two regions, the pelagic and littoral join.

The average number of taxa was almost identical in type I. (28), II. (32) and III. (33), but in type IV. it decreased considerably (23). The highest taxa number was found in case of type V. (46).

Physical and chemical characteristics

Changes of the relevant physical and chemical variables were investigated along the macrophyte coverage (Fig. 4.1.1.2.). None of the nutrients (TIN, TP, and SRP) showed close relationship with the coverage. Extremely high or low values occurred independently of oxbow types. It was also observed for the Secchi depth (Zsd) and the Chlorophyll-a concentration. Among the investigated variables, only DO showed consistent (decreasing) tendency towards the higher coverage.

Characteristic assemblages

The species were allocated into 32 coda. These were used to illustrate the phytoplankton assemblages in the different oxbow-types. The SOM and K-means clustering resulted in 5 different types of phytoplankton associations (Fig. 4.1.1.3a). These types were determined by the following coda with high structuring index **Y**, **L_O**, **W1**, **W_S** and **J**

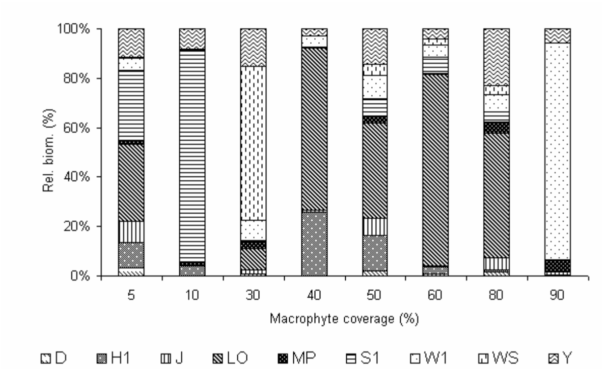


Fig. 4.1.1.5. Relative average biomass of the main coda along the different macrophyte coverage.

(Fig. 4.1.1.3b). Type 1 was dominated by **D**, **H1**, **J**, **MP**, **S1** coda. The most frequent phytoplankton assemblage was the **W1** in Type 2. **L_O** codon dominated Type 3. The characteristic functional group of Type 4 is **W_S**, while of Type 5 is the **Y** codon (Fig. 4.1.1.3c).

On basis of the SOM's results relative biomass abundances of the relevant coda were illustrated along the macrophyte coverage (Fig. 4.1.1.4.). Where the coverage was low (5-10%, oxbow types I-II.), **H1**, **J**, **L_O**, **MP**, **P**, **Y** and **W2** coda dominated the phytoplankton, of which the **Y** codon was notoriously dominating in some lakes. **L_O**, **W1**, **W2** and **Y** dominated assemblages were characteristic at 30-50% coverage (type III. and early stage of type IV.). In some of these oxbows the **H1**, **J**, **MP** and **P** coda could also attain relatively high share (40-50%) in the phytoplankton. In the macrophyte dominated lakes (coverage 60-90%, types IV-V.) the members of the **L_O**, **MP, W1** and **Y** coda were well represented. The abundances of euglenoids (**W1** codon) and dinoflagellates (**L_O** codon) was higher in the macrophyte covered oxbows, than in the pelagial-type oxbows. While the rate of the cryptomonads (**Y** codon) was relatively high in all oxbow types, it was independent from the macrophyte coverage (Fig. 4.1.1.5). Characteristic species of the main coda (based on the SOM) are shown in Table 4.1.1.1.

An interesting assemblage was found in one of the pelagial oxbow (Type I. oxbows, typical representative: Malom-Tisza). This is a deep, sheltered, consequently stably stratified lake, that was characterised by the dominance of actively buoyant species like *Limnothrix redekei* (Van Goor) Meffert (**S1**) and *Peridinium gatunense* (*Peridiniopsis elpatiewskyi*) (**L_O**). This plankton started to develop in June and was found even in September in every year of the investigations.

Nutrient-phytoplankton relationship

Relationship between physical and chemical variables and the relative frequency of the relevant coda has been analysed. Significant relationships were not found. It also applies for phytoplankton biomass. The Chl-a was not found to have a statistical relationship with the TP and TIN values.

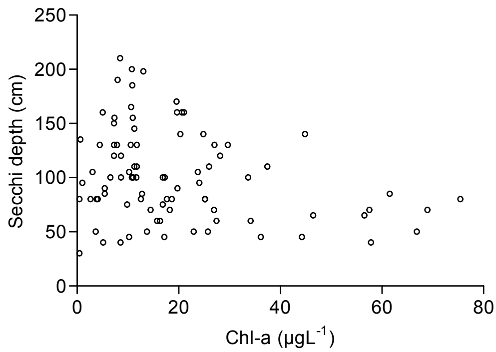


Fig. 4.1.1.6. Relationship between Secchi depths and Chlorophyll-a concentrations.

Turbid versus clear-water state

Secchi transparency (Zsd) and chlorophyll-a (Chl-a) data were used to investigate the turbid versus clear water state in the oxbows of different macrophyte coverage. At first, Zsd and Chl-a data were plotted against the percentages of macrophyte coverages. No statistically significant relationship was found between the variables ($p>0.05$). Descriptive statistics of the Zsd data (Fig. 4.1.1.2.) has also been analysed. The interquartile range (IQR) was almost identical in each lake type and somewhat lower values characterised the lakes with low coverage (Type I –II.). High (~200cm) and low (~30cm) values occurred in lakes with 5% and 80% coverage as well. As to the variation of Chl-a, the IQRs were shown to be also independent from the lake type. The high values indicated eutrophic state (Chl-a>75μgl^{-1}) even in lakes with 80% macrophyte coverage. An extremely high value (610μgl^{-1}) was found in one of the lakes (10% coverage) during late summer due to a *Cylindrospermopsis raciborskii* (**S_N** codon) bloom. Secchi transparency values were plotted against the Chlorophyll-a concentrations (Fig. 4.1.1.6). The relationship was not significant statistically ($p>0.05$). Nevertheless the arrangement of the points indicate, if the Chl-a concentration higher than 50μgl^{-1} the Zsd must be less than 1 meter. It might also be said that low Chl-a values do not necessarily result in high water transparency.

Discussion

The oxbows, similarly to other nutrient rich, productive ecosystems in the region, support various eutrophic assemblages (**C, D, J, S1,** and **H1**) (Grigorszky et al. 1998a, b; Borics et al. 2000). Comparison of the microflora with other occurrences published in the relevant literature (Uherkovich 1995; Németh 1997a, 1997b, 2005; Schmidt and Fehér 1998, 1999, 2001; Grigorszki et al. 1999) supported that there are some species known exclusively from oxbows in Hungary (Borics et al. 2002; Krasznai et al. 2008). The most interesting feature of the phytoplankton of the oxbows is that those assemblages that usually play minor role in other eutrophic lake types (**S, Y, Lo**) can dominate. The elements of the **W_S** codon (*Synura* spp.) obligately use carbondioxide as inorganic carbon source (Reynolds, 2006) and therefore avoid the eutrophic ecosystems with high pH. The members of this codon can prevail in macrophyte dominated oxbows (sometimes with *Gonyostomum semen* (Ehr.) Diesing). Cryptomonads (**Y**) that are susceptible to cladoceran filter feeding (Reynolds et al. 2002) can form stable populations in vegetated, as well as open water oxbows.

The ratio of the flagellated algae both in terms of the number of species and of the relative share in the biomass was surprisingly high. It can be explained partly by the large numbers of metaphytic elements (euglenophytes and several volvocalean green algae) characteristic in macrophyte dominated lakes (Borics et al. 2003), and partly by the fact that the oxbows are lentic habitats. In small forest lakes (most of the oxbows belong to this category) the wind shade, and consequently the lack of wind-induced turbulences can be a major environmental factor. Species that do not have the capability of active buoyancy regulation settle from the water column. (It might be the reason why dominance of larger diatoms has never been observed (Fig. 4.1.1.4). Dominance of cryptomonads or the dinoflagellates like *Peridinium gatunense* and the *Peridiniopsis elpatiewskyi* in the phytoplankton during summer indicates that due to their active vertical migration these organisms are successful competitors in this environment, where otherwise, dominance of elongated, cyanobacterial species possessing gas vacuoles are expected (Reynolds 2002).

The long lasting dominance of the actively buoyant species like *Limnothrix redekei* (**S1**) and *Peridinium gatunense* (*Peridiniopsis elpatiewskyi*) (**L_O**) in the deeper and stratified oxbows allows to conclude that the phytoplankton was in equilibrium state (Sommer et al. 1993; Naselli-Flores et al. 2003). Since the stable coexistence of these species was observed in every year, it cannot be considered as a simple mixture of the **L_O** and **S1** (**H1**) coda. Stable co-occurrence of the **L_O-H1** complex is characteristic also in Lake Balaton, and provided (a later unjustified, see Padisák et al., 2009) a reason to include some of the **H1** species to **L_O** (Hajnal and Padisák, 2008). If examples are accumulating, description as new codon would be useful.

The numbers of the occurring taxa (200-300) belong to the range considered characteristic for smaller lakes (Reynolds 2006). In ecosystems where the aquatic macroflora diverse and morphologically structured, many microhabitats may develop (Borics et al. 2003). In compliance with it, in our survey the richest microflora was found in those lakes where the ratio of the pelagial and littoral zone was more or less similar. Towards the pelagial type the number of metaphytic and benthic elements decreased, but towards the densely vegetated oxbows decrease of the euplanktic elements was observed.

Nutrients are considered to play a critical role in regulating the composition and biomass of the phytoplankton. Nevertheless their role in hypertrophic lakes is limited, because in these systems the concentrations of the nutrients highly exceed those that can be considered as limiting

(Sas 1989; Reynolds 2006). Since SRP and TIN values in the studied oxbows are considerably higher than the limiting values (Table 2., Appendix), it is not surprising that neither the composition, nor the biomass had significant relationship with the nutrients.

Table 4.1.1.1. Characteristic species of the main coda based on the SOM analysis

Codon	Characteristic species
D	*Discostella pseudostelligera* (Hustedt) Houk et Klee, *Discostella stelligera* (Cleve et Grunow) Houk et Klee, *Nitzschia acicularis* (Kütz.) W. Smith, *Stephanodiscus minutulus* (Kütz.) Cleve & Möller
H1	*Aphanizomenon aphanizomenoides* (Forti) Hortob. et Komárek, *Aphanizomenon issatschenkoi* (Usacev) Proshk.-Lavr.
J	*Crucigenia tetrapedia* (Kirch.) West et West, *Pediastrum tetras* (Ehr.) Ralfs, *Tetraedron minimum* (A. Braun) Hansgirg, *Koliella tenuis* (Nygaard) Hindák, *Scenedesmus quadricauda* (Turp.) Bréb.
L_O	*Merismopedia glauca* (Ehr.) Kütz., *Peridinium gatunense* Nygaard
MP	*Achnanthidium minutissimum* (Kütz.) Czarnecki, *Fragilaria crotonensis* Kitton, *Navicula radiosa* Kütz.
P	*Aulacoseira distans* (Ehr.) Simonsen, *Closterium acutum* (Lyngbye) Bréb., *Staurastrum tetracerum* (Kütz.) Ralfs
S1	*Limnothrix redekei* (Van Goor) Meffert, *Planktolyngbya limnetica* (Lemmerm.) Komárková-Legnerová et Cronberg, *Pseudanabaena limnetica* (Lemmerm.) Komárek
W1	*Chlorella* sp., *Euglena acus* Ehr., *Peridiniopsis elpatiewskyi* (Ostenfeld) Bourrelly, *Trachelomonas intermedia* Dangeard, *Trachelomonas planctonica* Svirenko
W2	*Trachelomonas volvocina* Ehr.
Y	*Cryptomonas erosa* Ehr., *Cryptomonas marssonii* Skuja, *Rhodomonas minuta* Skuja

Our results clearly demonstrate that among the investigated physical variables exclusively the macrophyte coverage influenced the composition of the phytoplankton assemblages. Where the coverage was higher than 40%, dominance of bloom-forming cyanobacteria (**S1, H1** coda) cannot be expected and in such environments dominance of the metaphytic **W1** species developed frequently (Fig. 4.1.1.4).

Due to the accumulating information on the shallow lakes during the last decades (Timms and Moss 1984; Van den Berg et al. 1998), and especially from the publication of Scheffer's excellent book (Scheffer 1998), it has become widely accepted that the eutrophic shallow lakes might be clear water lakes dominated by macrophytes, or phytoplankton dominated turbid lakes. In agreement with this, a clear relationship should exist between the macrophyte coverage and the Secchi transparency, moreover between macrophyte coverage and the chlorophyll-a concentration. Surprisingly our results did not support this theoretical consideration. In case of the pelagial lake types, the low chlorophyll-a and high Zsd values are explicable by the early sampling (May) and the early stage of phytoplankton succession, but he low Zsd and Chl-a values in case of the macrophyte dominated lakes are unusual and need more explanation. Because of the morphology (long, narrow) of the basin and the sheltering gallery forests, the fetch is very short in case of the oxbows. The wind induced mixing is minimal and in the pools isolated by the macrophytes dense algal assemblages (usually dominated by euglenophytes; **W1** codon) developed. Nevertheless low Zsd values were measured despite the low chl-a concentration. This phenomenon can be explained by the frequently occurring iron precipitation that coincided with the development of a planktonic assemblage dominated by iron bacteria. In these cases, the samples collected for phytoplankton analyses often contained ferritized cells of iron bacterium, *Ochrobium tectum* Perf.

In summary, the composition of the oxbow microflora is fairly similar to that of the other eutrophic lakes, but there are some rarely occurring species that are reported exclusively from oxbows. Species of the **S1** and $\mathbf{L_O}$ coda co-occur with high fidelity in oxbow lakes which may provide a reason to define a separate codon if such observations accumulate. During the transition from lake systems to landscape, the direction and the main stages of macrophyte succession can be foreseen, but our results proved that it is not exclusive for the macroflora. The macrophyte coverage has a great effect on the composition of the algal assemblages. Nevertheless in case of the oxbows, the macrophyte dominated state does not necessarily results in a clear water state.

4.1.2 Small-scale heterogenity of phytoplankton

Heterogeneity at the oxbow scale

The oxbow was characterised by a hypertrophic phytoplankton dominated by filamentous blue greens (*Limnothrix redekei* (Van Goor) Meffert, *Pseudanabaena limnetica* (Lemmerm.) Komárek, *Romeria*

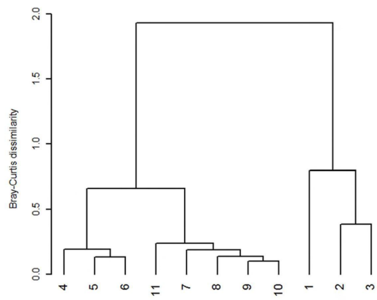


Fig. 4.1.2.1**.** Tree diagram of the sampling sites by MSSQ fusion algorithm and Bray-Curtis dissimilarity. Numeric codes of sample sites correspond to those in Fig. 3.1.3.

leopoliensis (Raciborski) Koczwara ex Geitler), and dinoflagellates (*Peridinium gatunense* Nygaard, *Peridiniopsis elpatiewskyi* (Ostenfeld) Bourrelly). There were considerable changes in the phytoplankton composition in the littoral region of the oxbow (site 1-3 (4)) (Fig. 4.1.2.1), where ratio of the chlorococcalean green algae (*Oocystis solitaria* Wittr. in Wittr. & Nordst., *Kirchneriella roselata* Hind., *Scenedesmus* spp.) was higher. An increasing tendency in algal biomass was observed from the

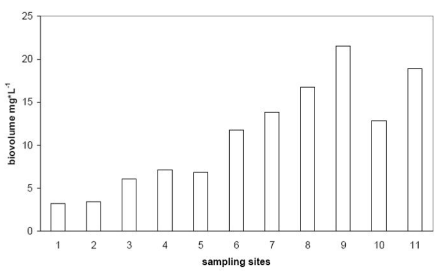


Fig. 4.1.2.2**.** Average biomass of algae (ind. ml^{-1}) in the 11 sample sites.

littoral to the pelagial part (Fig. 4.1.2.2.), indicating significant horizontal differences even in the pelagial part of the oxbow (5-11 sites), although this region has been considered previously as homogenous environment.

Small-scale heterogeneity

IH was calculated for each taxa, for all the 11 sites. Most of the values were in the range of 1-4, but several taxa had higher values than 4 (Table 4.1.2.1). In site1 where the macrophyte cover was the largest the data indicated extreme differences in the horizontal distribution of the planktonic *Ceratium hirundinella* (Levander) Langhans*, Peridinium gatunense*, and the metaphytic *Pannus* sp. Patchy distribution of some chlorococcalean green algae was observed in the littoral (1-3) sites. In case of site 4, where the intrusion of the eutrophic pelagial phytoplankton was experienced the flagellated algae showed heterogeneous horizontal distribution, among which the otherwise subdominant *Peridiniopsis elpatiewskyi* showed the most pronounced patchiness. In the pelagial parts (5-11) the uneven distribution of the frequent cyanobacteria were found in most of the sample sites, but occasionally flagellated algae were also characterised by high IH values.

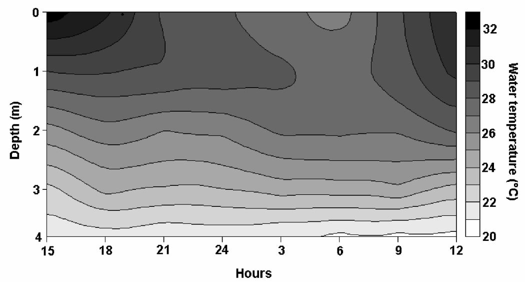


Fig. 4.1.2.3**.** Changes of the water temperature in the different layers of the oxbow (site 8; 23rd of July 2007, 14:00–15:00 hrs).

Visualisation of the vertical distribution of algae

Although the experienced horizontal differences might develop in a well mixed water column, the stratified layers provide better background for the patch formation. The temperature measurements showed (Fig. 4.1.2.3) that despite its absolute shallowness, the oxbow was stably stratified. Sharp decrease in the temperature of the deeper layers was observed in the day of sampling. Depletion of oxygen was also observed, indicating the development of an upper euphotic and a lower aphotic layers (Fig. 4.1.2.4.). These two layers were separated by the distribution of a blue-green alga, *Cylindrospermopsis raciborskii*

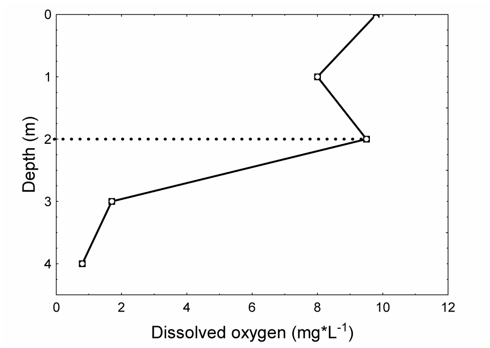


Fig. 4.1.2.4. Oxygen profile of the oxbow (site 8; 23rd of July 2007, 14:00–15:00 hrs). Dotted line indicates the depth of euphotic zone (2.5 × Secchi depth).

(Woloszynska) Seenaya et Subba Raju (Fig. 4.1.2.5a), and the purple sulphur bacteria *Thiopedia rosea* Winogr. (Fig. 4.1.2.5b).

We found that despite their similar ecological character there were great differences in the horizontal distribution of species, like *Cylindrospermopsis raciborskii* and *Aphanizomenon ovalisporum* Forti (Fig. 4.1.2.5c), or *Peridiniopsis elpatiewskyi* (Fig. 4.1.2.5d) and *Peridinium gatunense* (Fig. 4.1.2.5e). While the *C. raciborskii* was more or less evenly distributed in the photic zone, the *A. ovalisporum* showed distinct horizontal heterogeneities. The distribution of *Peridiniopsis elpatiewskyi* was also different from that of the *Peridinium gatunense*.

Effects on the quality assessment

Knowing the perplexing variety of distribution patterns and the rate of differences it is reasonable to assume, that these might influence the results of lake quality assessments. For estimating the possible impact of the horizontal differences on the final result of a phytoplankton based quality assessment, a simple Cyanobacteria Index (% of total biovolume) was calculated for all the samples taken in the pelagial part of the oxbow (Fig. 4.1.2.6). The width of the range of values covered almost 50%, which indicates high uncertainty in the quality assessment. Eliminating the small scale heterogeneity by averaging the values belonging to the same sites (Fig. 4.1.2.6), the range can be halved (26%) but still remained high.

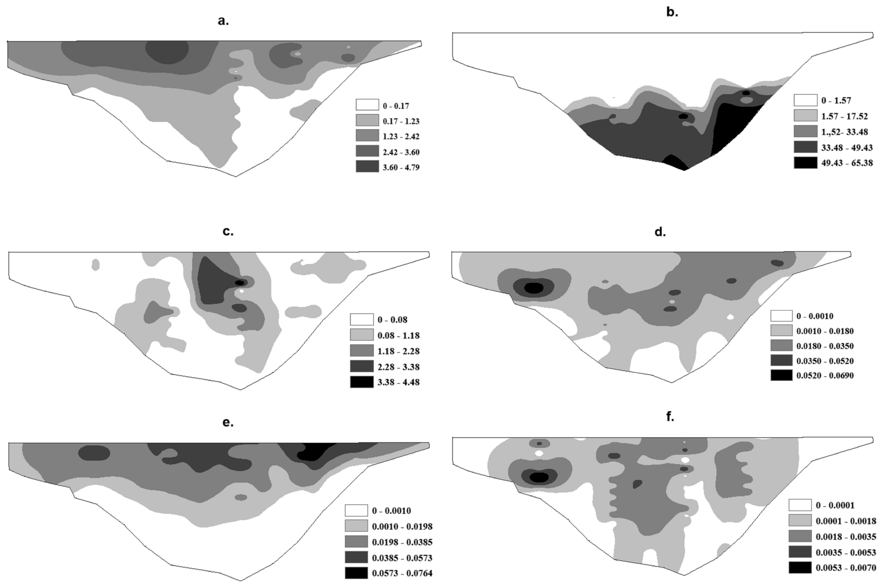


Fig. 4.1.2.5 Vertical distribution of algae and purple sulphur bacteria in the cross section of the oxbow (site 8; 23rd of July 2007, from14:00 to 15:00 hrs). (a: *Cylindrospermopsis raciborskii*, b: *Thiopedia rosea*, c: *Aphanizomenon ovalisporum*, d: *Peridinium gatunense*, e: *Peridiniopsis elpatiewskyi*, f: *Ceratium hirundinella*)

Discussion

Differences at horizontal scale

The observed differences of the phytoplankton biomass at the whole oxbow scale were in accordance with the findings of other, similar investigations (Van den Berg et al. 1997; Pełechaty and Owsianny 2003). Increasing abundance of aquatic macrophytes creates inhospitable milieu for the truly planktonic algae, and results in changes in the species composition and decrease in the algae biomass by reducing the light penetration, increasing the sedimentation rate (Van den Berg et al. 1997), providing habitat for grazers (Jeppesen et al. 1997), producing allelopathic substances (Hasler and Jones 1949; Körner and Nicklisch 2002). Consequently, the phytoplankton of the macrophyte dominated sites is not simply the low biomass version of the pelagial plankton but it is a different assemblage from phytocoenotic point of view (Pełechaty and Owsianny 2003). Although, the role of biotic interactions like allelopathy or prey selective grazing (Urabe 1990; Barker et al. 2010) cannot be

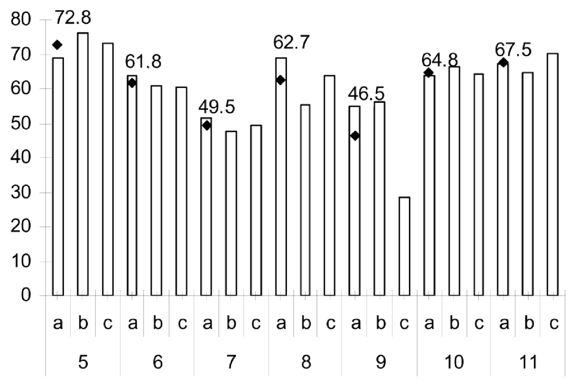


Fig. 4.1.2.6**.** Relative abundance (% of total algal biomass) of Cyanobacteria in the 5-11 (open water) sites. Columns indicate individual samples; the written values are site averages.

excluded especially at the macrophyte dominated sites, the role of physical processes in shaping the spatial distribution of algae seem more probable explanation. Due to the reduced mixing in regions of dense macrophyte cover, species with high specific gravity (like diatoms) settle out from the photic layer. The centric diatom *Cyclotella pseudostelligera* Hustedt that occurred in the pelagial sites of the oxbow in relatively large cell numbers, was completely absent in the 1-4 sites. Similar pattern was observed in case of all those species that do not have the capability of active locomotion. Nevertheless, as it was found in bog lakes (Borics et al. 2003), some euplanktic taxa (*Kirchneriella sp. Pannus sp.*) flourished in the metaphytic environment (site 1).

Besides the littoral versus pelagial differences, uneven distribution of algae was also characteristic for the open water (5-11) sites. Although these sites had larger similarity in overall species composition, the phytoplankton biomass appeared to be different and showed increasing tendency towards the western part of the oxbow (Fig. 4.1.2.2.).

Numerical characterisation of the heterogeneity

Knauer et al. (2000) proposed a formula for the heterogeneity of chemical substances in water bodies; it was used to characterize the horizontal differences of several variables in the Lago Maggiore (Bertoni et al. 2004). We tried to adapt this method for algae. Because of the differences between the measurement of chemical substances and the microscopy used for particle counting this formula was not especially useful for algae. The error of the algae counting is density dependent, i.e. the uncertainty of the cell counts' estimation increases towards the rarely occurring specimens. This has to be considered during the elaboration of a proper formula. In the formula proposed in our study the ratio of horizontal variability (CVs) and counting variability (CVe) was used (CVs/CVe). The index was useful in the quantitative characterization of the horizontal differences.

Fine scale heterogeneity

The IH values showed clearly that in case of some taxa (e.g. dinoflagellates, cyanobacteria and clorococcalean green algae) there were considerable differences in the biomass among the 3 neighbouring water columns, despite that the distance between them was only 1m. The distribution maps (Fig. 4.1.2.5.) depicting spatial variability of algae provided valuable clues about the different behaviour of the planktonic species. The well-known surface avoidance of dinoflagellates (Anderson and Stoltzenbach 1985; Galvez et al. 1988; Grigorszky et al. 2003; Heaney 1976) was not observed (Fig. 4.1.2.5.) d-f). It may be explained by the fact that the occurring species (*Peridinium gatunense, Peridiniopsis elpatiewskyi*) were capable of tolerating higher temperature and illumination. These taxa are characteristic members of the phytoplankton in warm, well-illuminated tropical waters (Borics et al. 2005). The dinoflagellates avoided the deeper layers, where due to lack of light and oxygen (Fig. 4.1.2.4.) both heterotrophic and autotrophic nutrition is impeded.

Our results also revealed that the similar buoyant properties do not necessarily result in similar spatial distribution. The cells of the dinoflagellate *Peridiniopsis elpatiewskyi* were present mainly in the immediate surface layer, while the *Peridinium gatunense* and *Ceratium hirundinella* showed contagious distribution. Investigating the spatial distribution of *Ceratium hirundinella* in Lake Balaton, Padisák (1985) assumed an active coastal avoidance of the species. Being one of the largest freshwater algae with active locomotion, *Ceratium* species are typical long distance movers in the world of algae. This species produced the largest IH value (20), i.e. showed the most striking horizontal difference at the first sampling site, in the still water of a small pool.

Pannus sp., that does not have the capability of active locomotion also showed distinct horizontal patchiness (IH: 16.9) at the same site. Therefore, it is reasonable to suppose, that other processes might also be responsible for the development of horizontal heterogeneities. Richerson et al. (1970) indicated that if the rate of mixing was slow enough relative to the reproductive rate of algae many different niches can develop and result in patchiness. In case of *Pannus sp.* a higher rate of cell proliferation can be hypothesized that may lead to patch formation in the lentic pool.

Mechanisms responsible for patch formation

Model results demonstrate (Webster 1990; Verhagen 1994) that both horizontal and vertical patchiness increases with the flotation velocity of the algae, and decreases if the strength of the horizontal currents is stronger than the strength of the circulation in the vertical plane. Investigating the role of Langmuir circulation in the spatial distribution of microscopic organisms Smayda (1970) and George and Edwards (1973) called the attention to the importance of the individual buoyant properties of the particles. Irish and Clark (1984), and Kousa (1988) also proved that the actively moving and passively drifting species show different horizontal distribution in lakes or coastal waters. Nevertheless it should be noted that at calm, windless weather the wind forced mechanisms are of lesser importance. The patchiness described in this paper developed under particular set of environmental conditions, i.e. small size of water body, irregular/elongated shape, wind shelter and stable stratification.

Horsch and Stefan (1988) proved by laboratory experiments that surface cooling creates currents in both horizontal and vertical directions and results in the exchange of water parcels in calm conditions. The temperature profile of the oxbow (Fig. 4.1.2.3) suggests that the surface cooling is a possible explanation for the observed patchiness. At the scale of the whole water column the stratification was stable and it is demonstrated by the spatial segregation of the *Thiopedia rosea* (Fig. 4.1.2.5b) (purple sulphuric bacteria) which cells were missing from the upper layers. The temperature of the immediate surface layer cooled down to that of the layer of two meters by 6 o'clock a.m. (Fig. 4.1.2.3) and this temperature decrease must have been large enough to generate convective currents, and to cause mixing in the upper two meters of the water column. This atelomixis (Barbosa and Padisák 2003) might result in patchy distribution of several phytoplankton taxa.

Effects on quality assessment

The EU and the member states initiated new legislative measures focusing on the ecological state of waters (WFD 2000), increasing attention has been paid to the monitoring of surface waters, including the smaller ones that were not important for the water managers in the previous years. The phytoplankton based assessment methods are the most popular tools to evaluate the ecological status of lakes (Padisák et al. 2006). The composition metrics are sensitive to the ratio of algal groups. Therefore, the high level of patchiness should be kept in mind during lake monitoring and assessment. The frequently used one sample/lake strategy may not satisfactory even in the case of a small waterbody like an oxbow, because of the high uncertainty of the state assessment. Although the number of samples can not be increased during a simple monitoring (very laborious), the confidence of our quality assessment can be achieved by reducing the inherent variability of the samples. This can be attained by improving the basic sample methodology, for example taking a larger volume of sample. This can be accomplished by using a larger sampler or collecting more samples and mixing them. Using this technique the uncertainty caused by the small scale horizontal heterogeneity can be minimized. When the large-scale heterogeneity is proved by exploratory investigations, designation of more sample site is needed.

Table 4.1.2.1. Taxa with high IH values (IH>4) from the different sample sites. Higher values indicate that in case of the given taxa there were large differences in the biomass among the three individual samples taken from the given site

	Sample sites										
	1	2	3	4	5	6	7	8	9	10	11
Aphanizomenon issatchenkoi								4.7			
Cyanogranis ferruginea			5.2						4.9		
Limnothrix redekei								5.4	4.7		
Pannus sp.	16.9										
Romeria leopoliensis							7.2	7.2			4.7
Kirchneriella lunaris			4.7								
Kirchneriella rostellata	6.1										
Monoraphidium contortum			4.7								
Monoraphidium minutum	5.4										
Quadrigula closterioides		4.6									
Cyclotella pseudostelligea				4.3							
Ceratium hirundinella	20.0										
Peridiniopsis elpatiewskyi				14.1	5.4	7.6					
Peridinium gatunense	11.8		6.8	4.5					15.0		
Peridiinium umbonatum				5.5							
Peridinium volzii		5.6		4.6							
Phacus glaber		5.0									
Phacus suecicus				5.7							
Phacus undulatus				4.6							
Cryptomonas reflexa										4.8	
Gonvostomum latum				6.3	7.1						

4.1.3 Desmids to assess natural value

Floristic composition

Altogether 247 taxa of algae were identified in 30 samples from the Malom-Tisza oxbow. The floristic compositions of the samples taken in June and August were slightly different (Table 5, Appendix). The species number of Cyanobacteria, Euglenophyta and Dinophyta doubled in August. The species number of Euglenophyta (4) in June was very low. The microflora was dominated by Chlorophytes (147 taxa) and Bacillariophyceae (39). The number of desmids was surprisingly high: 78 (Table 6, Appendix). Desmids that were present in at least 75% of the different habitats included *Cosmarium phaseolus* Bréb. ex Ralfs, *Cosmarium subprotumidum* Nordst. var. *pyramidale* Coes., *Sphaerozosma vertebratum* (Bréb.) ex Ralfs, *Staurastrum furcatum* (Ehr. ex Ralfs). Bréb., S. *polymorphum* Bréb., S. *tetracerum* Ralfs ex Ralfs, and *Xanthidium antilopaeum* (Bréb.) Kütz.

Conservation value of the oxbow

The differences in conservation values of the June and August samples were negligible (Figs. 4.1.3.1, 4.1.3.2). The average conservation values (NCV) were 6.3 in June and 6.5 in August (based on the whole droplets method). NCV values ranged between 2 and 8 in June, and between 3 and 10 in August. The theoretical maximum of the NCV (10) was found in the periphyton sample of *Utricularia vulgaris* L., taken from the north of the bog-lake (Fig. 3.1.2, map) in August. Differences of the NCV values between the samples are largely caused by the different R and M values, because D was almost constant (score 2) in every sample.

Habitat / Sampling areas

Due to the very low number of taxa observed, the NCV values of the open water proved to be very low too (NCV = 3). Higher values characterised the periphyton and the plankton net samples that were taken from small pools with a dense macrophyte vegetation. With respect to the number of observed species and the calculated NCV values, the periphyton sample of *Utricularia vulgaris* showed the highest scores (Fig. 4.1.3.1B).

Different sample enumeration methods

The two different sample enumeration methods (counting up to 400 specimens and analysis of the whole volume of the droplets) resulted in slight differences in the conservation values (Fig. 4.1.3.2). Approximately half of the samples showed an increase of one point. Nevertheless in the case of the *Utricularia vulgaris* sample in August, due to the more detailed microscopic analysis, a more substantial increase by 2 points was observed.

Calculation of the rarity values

Use of modified rarity values (Fehér 2007) did not significantly affect the value of the NCV-index (max. difference was ±1). Modification resulted in an increase of the NCV index by one point for those samples that originally had NCV values of 3 and 6. Samples that had very low and very high values were unaffected. A decrease of the NCV index was only found in sample SL06F, a periphyton sample from *Salvinia natans* (L.) All. taken in the lag-zone.

Discussion

The observed 247 algal taxa are indicative of a species-rich microflora in the Malom-Tisza oxbow. The relative share of the desmids was high (78 taxa). Only two Hungarian floristic accounts are available in which a larger number of species were reported, namely from a rice field (Kol 1954) and from Baláta, the largest Hungarian bog-lake (Borics 2001), respectively.

Several species that are considered to be acidophilic (e.g. *Cosmarium margaritiferum*, *Staurastrum furcatum*), acido-neutrophilic (e.g. *Cosmarium contractum*, *Xanthidium antilopaeum*), and prefer oligotrophic (e.g. *Cosmarium pyramidatum*, *Teilingia excavata*) or oligomesotrofic environments (e.g. *Cosmarium pseudoretusum*, *Staurodesmus dejectus*) were observed. It is not clear whether these unexpected findings are due to the limited knowledge about the tolerance of these species, or to the existence of ecotypes.

Contrary to expectations, the NCV values of the late summer samples compared to those taken in June were not significantly higher. Species that are characteristic for mature periphyton assemblages (Coesel 1998) (e.g. *Sphaerozosma vertebratum, Micrasterias crux-melitensis, Cosmarium regnessi, Desmidium swartzii*) were already present in June; thus, the maturity and rarity values were almost identical. Nevertheless it is worth mentioning that a possibly higher score of the NCV (10) was observed only in August.

Considerable differences in the NCV values of the microhabitats sampled were observed. The microhabitat of *Utricularia vulgaris* was characterised by the highest diversity and maturity values. Compared to other macrophytes like *Myriophyllum verticillatum, Ceratophyllum demersum* and *C. submersum*, the leave structure of *Utricularia vulgaris* is more delicate and provides an ideal habitat for periphytic assemblages. The plankton of pools with a rich vegetation are also characterised by high NCV values. Due to mechanical disturbances caused by the sampling procedure, a large number of desmids end up in the tychoplankton.

We observed considerable differences between the two species enumeration methods. Analysis of the total volume of the droplets resulted in an approximately 20% increase in the species number. Nevertheless this increase did not result in a change of the D value (Figs. 4.1.3.1, 4.1.3.2).

We calculated the NCV values also with the modified “r” values as suggested by Fehér (2007), but this resulted only in slight changes in the NCV values.

The Malom-Tisza oxbow had a high NCV value which demonstrates that naturally hypertrophic systems can be valuable habitats. Our results demonstrate that different sampling strategies and enumeration methods only result in small differences in the natural values (NCV scores). Coesel (2001) has suggested that the method should be based on species and that the use of lower taxa should be avoided, but there are cases where lower taxa (forms, varieties) have different ecological requirements or behaviour. Our opinion based on the field experience of this study is that forms or varieties, provided they can be identified reliably, may be considered in NCV assessment studies.

In conclusion, our results suggested that Coesel’s (2001) method was a useful tool for evaluating the NCV values of the Hungarian oxbow, but for wider acceptance of the method standardisation of the sampling and species enumeration procedures was needed.

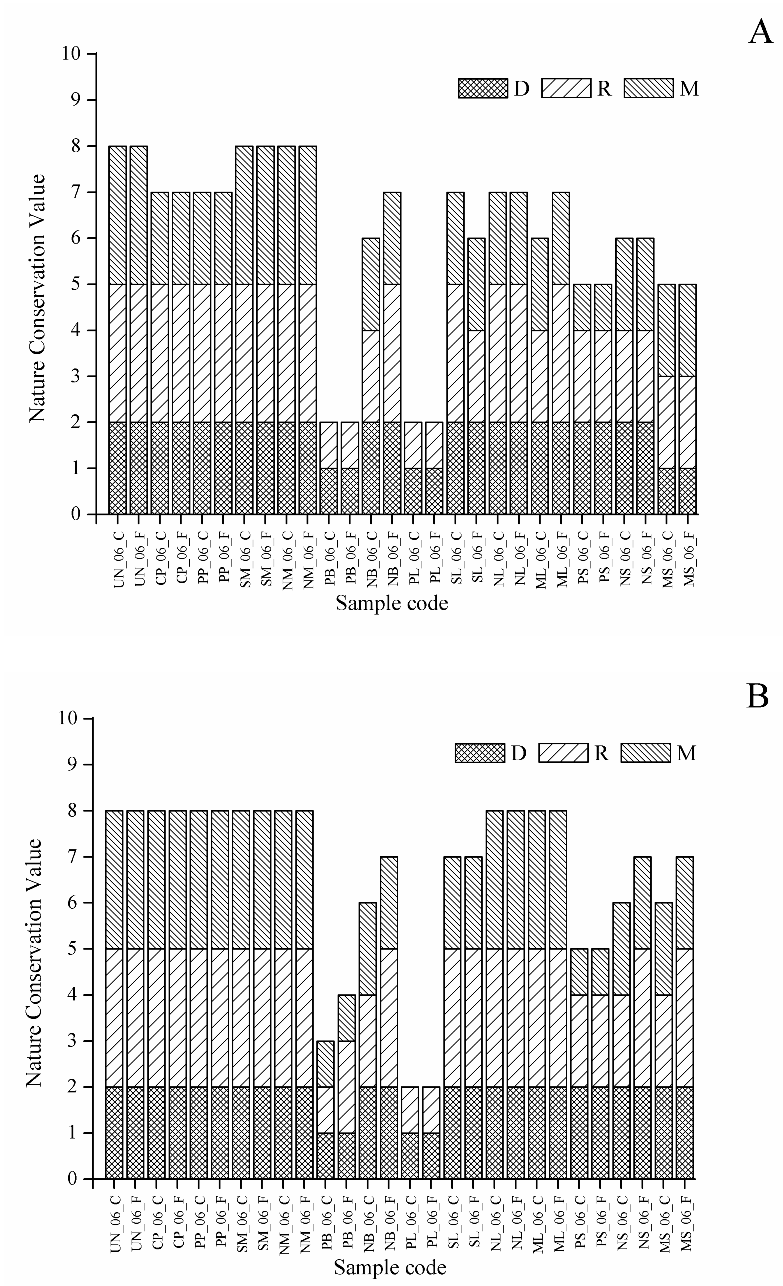
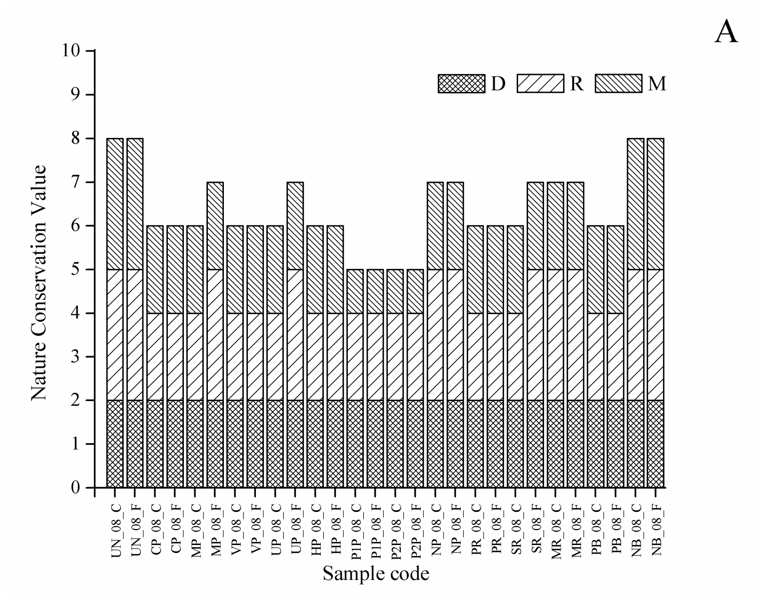


Fig 4.1.3.1. NCV scores of the July samples (sample codes as in Table 2). (A) up to 400 specimens counted, (B) whole droplets counted. C- NCV calculated by Coesel's method, F - NCV calculated by Fehér's method



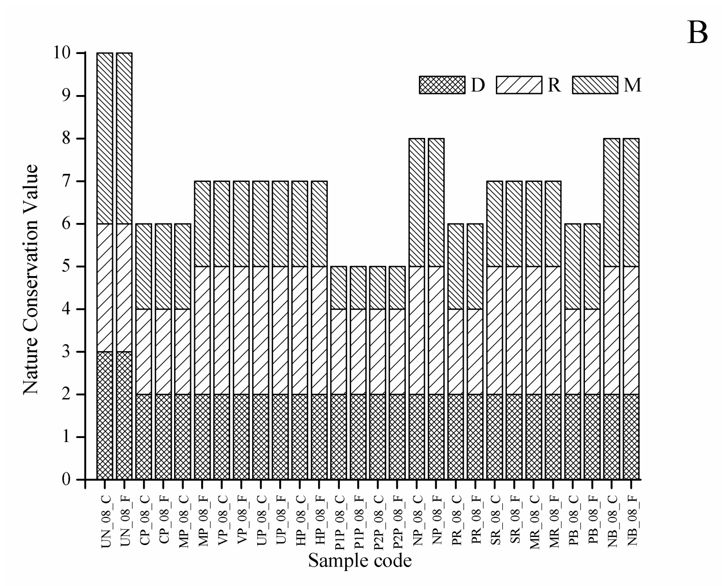


Fig 4.1.3.2. NCV scores of the August samples (sample codes as in Table 2). (A) up to 400 specimens counted, (B) whole droplets counted. C- NCV calculated by Coesel's method, F - NCV calculated by Fehér's method

4.2 Rivers

4.2.1 Characteristic phytoplankton associations in rivers

The application of SOM and the use of K-means clustering resulted in 8 different types of riverine phytoplankton association (Fig 4.2.2.1a-c). These types were determined by high structuring indexed coda such as **T_B, Y, W_0, D, J, C** and **W1** (Fig. 4.2.2.2., 4.2.2.3a.). Other coda, important in the riverine phytoplankton associations with their abundance of occurrence on the SOM map can be found in Fig 4.2.2.3b. After creating the SOM, we were able to count the number of samples belonging to a given virtual hexagonal map unit (Fig. 4.2.2.4), in this way the most frequent was the type I. in which 931 samples occurred.
The eight plankton associations can be defined as follows:

Type I. - This is the most frequent phytoplankton type which is representative for the upper section of rivers. The dominant codon is the **T_B** (bentic diatoms) with more then 70 % of the total biomass abundance (Fig. 4.2.2.5). This association has no seasonal preference. The most frequent taxa are *Nitzschia palea* (Kutz) W. Smith, *Nitzschia fonticola* Grunow, *Navicula capitatoradiata* Germain, *Surirella brebissonii* Krammer & Lange-Bertalot, *Diatoma vulgaris* Bory.

Type II. - Members of the **T_B** group are dominating Type II (Fig. 4.2.2.5) but the elements of the **W_0** and **W1** functional groups (*Chlamydomonas reinhardtii* Dangeard, *Euglena* spp.) indicate organic pollution. This type is also characteristic for upstream sections of rivers. Only a slight seasonal preference for early spring and autumn can be found.

Type III. - This is typical plankton of small rivers with the dominance of **T_B** and **D** (Fig. 4.2.2.5) coda. This assemblage occurs on those river sections where the retention time due to hydro morphological changes or upper stream reservoirs enables real phytoplankton to develop.

Type IV. - This association can be referred to as “Danube type” summer plankton. The most important coda are **D**, **J** and **C** (Fig. 4.2.2.5).

Dominant species of this association are *Stephanodiscus hantzschii* Grunow, *Cyclostephanos dubius* (Fricke) Round, *Skeletonema potamos* (Weber) Hasle, *Thalassiosira pseudonana* Halse & Heimdal and *Nitzschia acicularis* (Kütz.) W. Schmith from codon **D**, *Cyclotella meneghiniana* Kütz., *Cyclotella atomus* Hustedt from codon **C** and *Scenedesmus* species from codon **J**. However the favourable season of this type is the early summer (Fig. 5.6), certain species such as *Stephanodiscus invisitatus* Hohn & Hellermann, which belongs to codon **D**, could bloom, in the Danube during winter (Kiss and Genkal 1993).

Type V. - A type could be mainly found on the lower section of the river Tisza with the dominance of **Y** codon (Fig. 4.2.2.5). *Cryptomonas reflexa* (Marsson) Skuja, *C. marssonii* Skuja, C. *rostratiformis* Skuja, *Rhodomonas minuta* Skuja become dominant in this section. Development of this association is absolutely independent from the seasons (Fig. 4.2.2.6).

Type VI. - The characteristic functional group of type VI is $\mathbf{W_0}$ (Fig. 4.2.2.5). The dominance of this group is due to very strong organic pollution. *Chlamydomonas* spp., *Euglena viridis* Ehr., *Polytoma uvella* Ehr., *Spermatozopsis exultans* Korsch. are typical elements of this assemblage. This type of plankton is usually dominant in winter and early spring (Fig. 4.2.2.6.).

Type VII. - This type is a mixture of a very divers association with the presence of relatively rare groups like $\mathbf{L_0}$, **H1**, $\mathbf{L_M}$, $\mathbf{S_N}$ (Fig. 4.2.2.5). The occurrence of this type is expected in slow flowing channels and small rivulets in late winter and summer.

Type VIII. - The dominant codon of this type is the **W1** (Fig. 4.2.2.5) which is according to Reynolds is characteristic for small organic pools. Frequent taxa are the metaphytic *Phacus* and *Trachelomonas* spp. This type is typical in slow-flowing rivulets and channels which are under the risk of organic pollution and have rich macrophyte vegetation. Development of this type is expected in summer.

The seasonal distribution of the defined plankton types (Fig. 4.2.2.6) shows, that several of them have affinity to a certain period of the year. Type IV and VIII develop usually in summer. Type VI occurs in late winter and early spring. Type VII has got a special bimodal character with a late winter and mid summer peak.

Discussion

The Danube river basin is the second largest system in Europe. Flow regulation and river fragmentation has crated hundreds of impoundments in its catchment. These lentic habitats, depending on their altitude, depth, trophic state and residence time, provide different ecological conditions for the development of specific algal assemblages. It is no exaggeration to say that the diversity of habitats (lakes, impoundments) enables the development of almost all of the functional groups of algae, but survival and further development down stream is rather different. With the implementation of Self Organizing Map and k-means clustering eight significant algal assemblages were defined and described by their relative contribution of algal functional groups (Reynolds 2002). Since some of the functional groups are closely related to certain types of environmental pressure (organic pollution $\mathbf{W_0}$,**W1**; high nutrient status **Y, H1, J**; impounding $\mathbf{L_0}$, $\mathbf{L_M}$) it is possible to highlight those river sections or periods which are impacted by human activities. Evaluation of the dataset validated the separation of the $\mathbf{W_0}$ from the Reynolds' **W1** group. The establishment of the $\mathbf{W_0}$ group enables the description of the worst status of the rivers with serious organic pollution. This status usually occurs in late winter and early spring, because mineralization is slow due to low temperatures. Our results demonstrate that the abundance of the $\mathbf{W_0}$ decreases with elevated water temperature, but the occurrence of the **W1** shows an increasing tendency (Fig. 4.2.2.6, VI).

In our dataset, the most frequent algal assemblage was the type I, dominated by bentic diatoms (Fig. 4.2.2.3). This can be explained by the short residence time of the water bodies in question.

The bimodal character of the type VII is cause by the $\mathbf{L_0}$ functional group. This plankton type frequently occurs in the summer epilimnion of lakes (Reynolds 2002). Several Dinophytes however can be important members of the winter phytoplankton (Grigorszky et al. 1998). Therefore it would be necessary to separate certain oligotherm *Peridinium* taxa from the $\mathbf{L_0}$ codon.

The application of functional groups in lake quality assessment has been proved by Padisák et al. (2005). Further studies have been start for the application of this approach on riverine phytoplankton quality assessment see Borics et al. (2006).

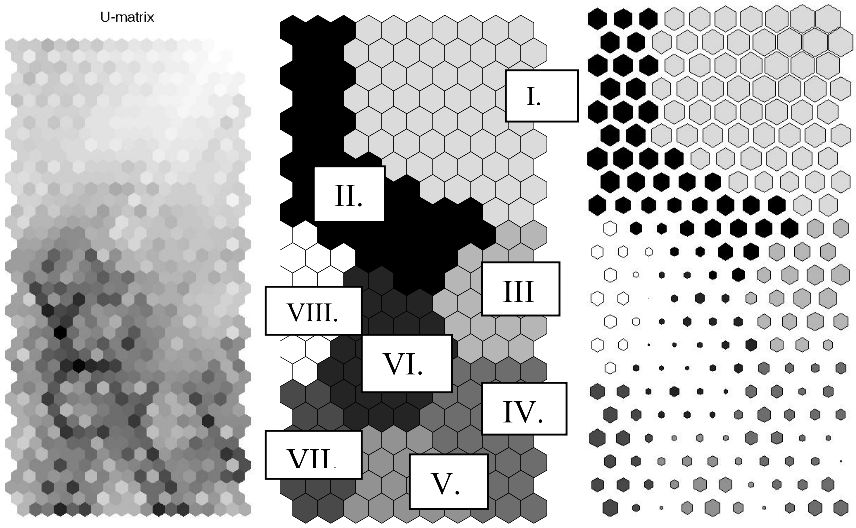


Fig 4.2.2.1.a. Fig 4.2.2.1. b. Fig 4.2.2.1. c.

Fig 4.2.2.1a. U-matrix of the SOM, darker cells indicate more distance between neighbouring cells. 4.2.2.1b. Clusters of the SOM resulted by the K-means clustering. Roman letters means the different clusters. 4.2.2.1c. SOM histogram of samples - the larger the hexagons are the larger numbers of samples belong to that given virtual map unit, colours are according to the clusters indicated in Fig 4.2.2.1. b.

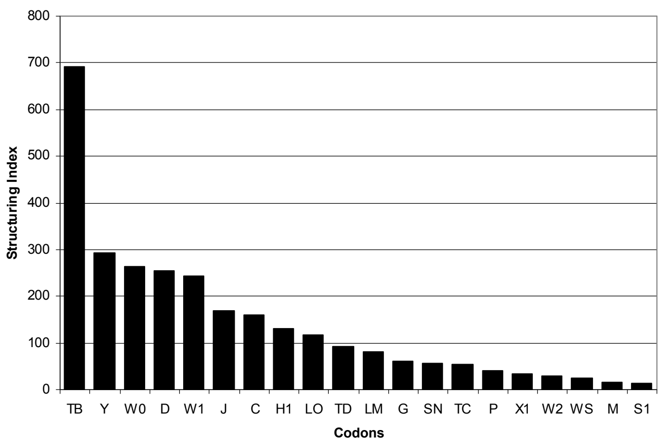


Fig 4.2.2.2. Coda with high structuring index. The values indicate the relative importance of each coda in determining the SOM patterns.

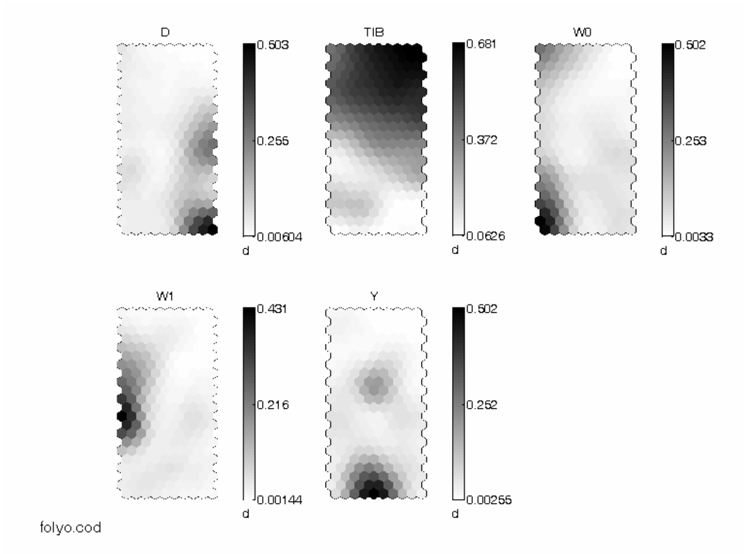


Fig 4.2.2.3.a. Gradient distribution of the most important coda on the SOM. Darker cells mean higher abundance of the codon in the hexagonal unit.

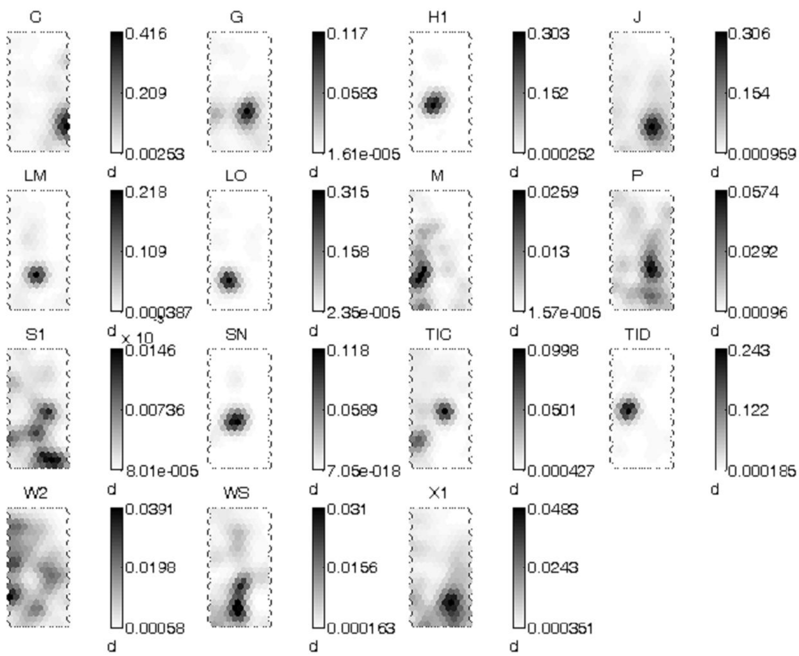


Fig 4.2.2.3.b. Gradient distribution of important coda on the SOM. Darker cells mean higher abundance of the codon in the hexagonal unit. Scale bar refers relative percentage.

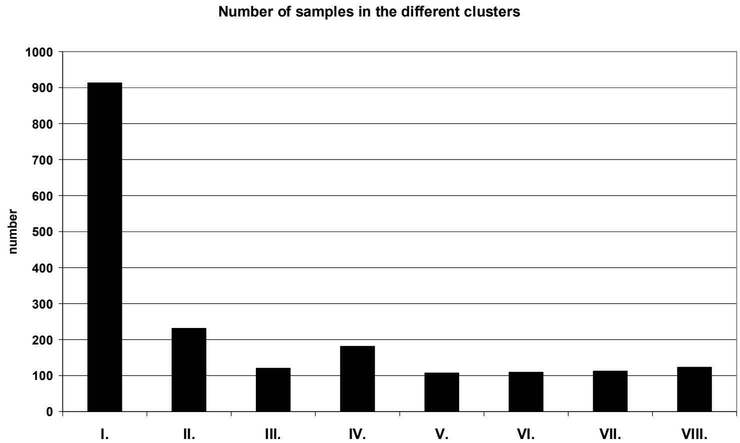


Fig 4.2.2.4. The number of the samples belongs to the different cluster groups. Roman letters refer to the cluster numbers.

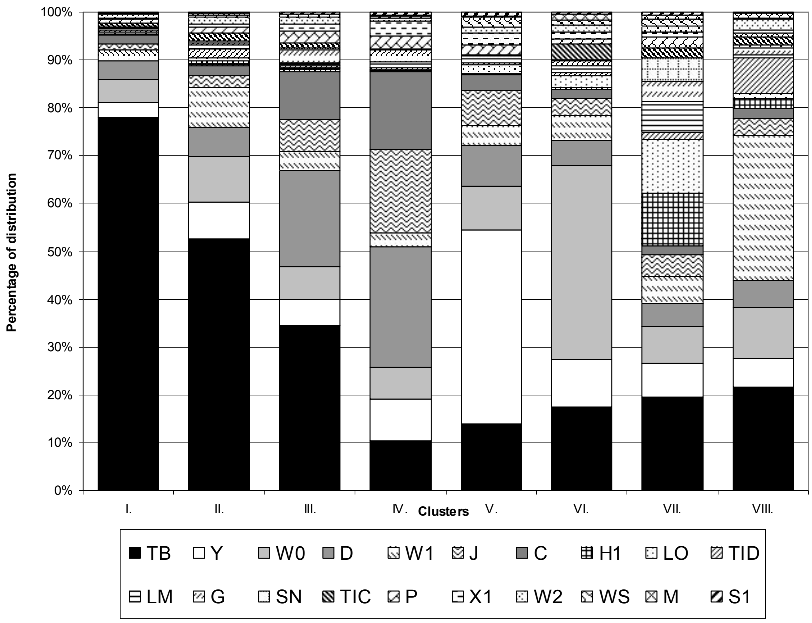


Fig 4.2.2.5. Percentage distribution of the different coda according to the SOM clusters. Roman letters refer to the cluster numbers.

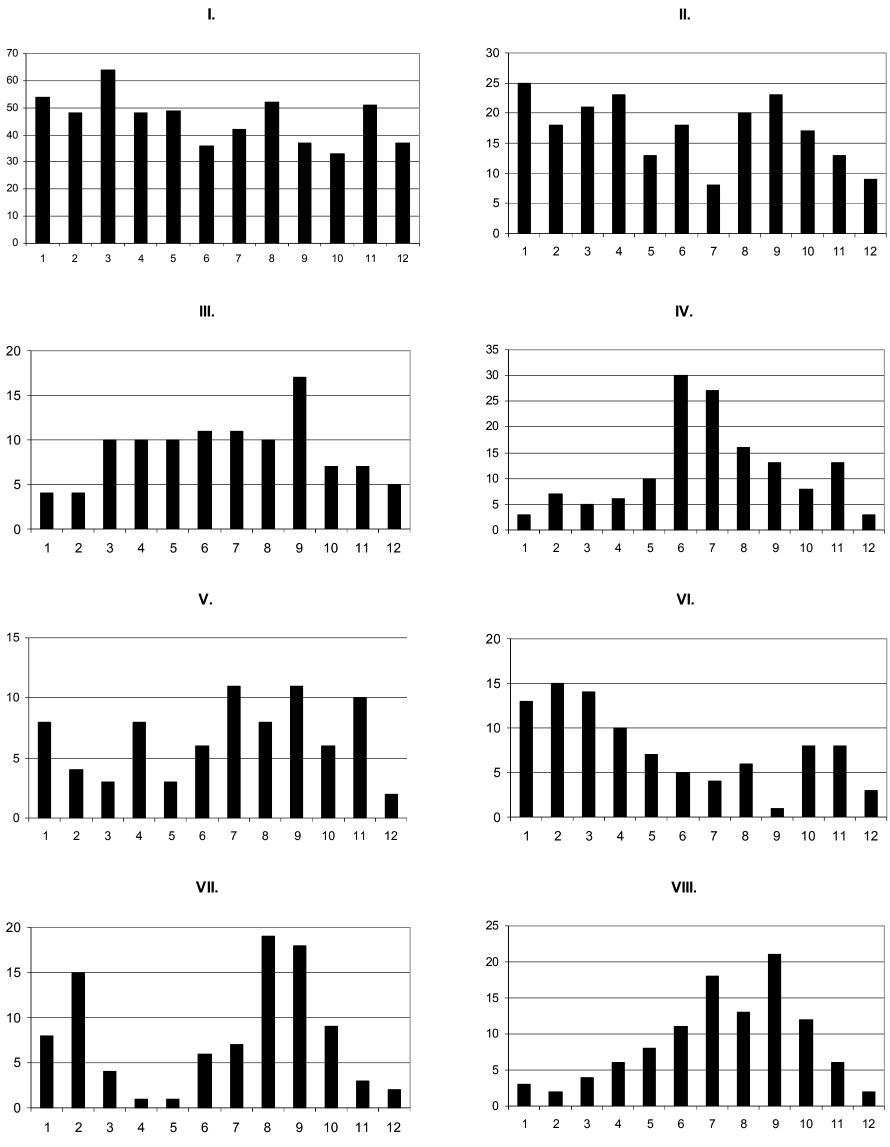


Fig 4.2.2.6. Seasonal distribution of the algal assemblage types. Roman letters means the cluster numbers, horizontal axis represents the months, while vertical axis the number of samples belonging to that given month.

4.2.2 Riverine phytoplankton quality assessment

Evaluation of the assemblages

Elaboration of a phytoplankton based quality assessment method needs the evaluation of phytoplankton associations in rivers. Therefore we evaluate here the occurrence of the elements of the phytoplankton assemblages (Reynolds et al. 2002, Padisák 2003) by estimating how far, or rather, how close these limnetic assemblages are to those types that can be considered as reference algal assemblages of rivers. We focus on those environmental elements that are specific for rivers (short residence time), or important from the environmental point of view (trophic state, toxic algae). We also consider that the phytoplankton of the rivers is quite similar to those of the shallow, turbid lakes (Reynolds et al. 1994). Finally, the assemblage is characterised numerically by a compound factor (F) estimated from the following components.

Each functional group of algae (Reynolds et al. 2002) was assigned to trophic state, turbulence and residence time on a scale from 0 to 5, on the basis of:

1. trophic state: (hypertrophic 0; eutrophic 1; mesoeutrophic 2; mesotrophic 3; oligo-mesotrophic 4; oligotrophic 5),
2. turbulence character: the habitats of the coda were scored by their turbulence preference (totally standing waters like pools among macrophytes 0, lentic 1, slightly lotic (mixed epilimnion) 2, medium lotic (mixed layers) 3, lotic 4 (well mixed layers), highly lotic 5),
3. residence time, needed for the development of the given assemblage. Lower values were given to those assemblages that need relatively long time for their development. (We can conclude to this from the biomass of the algal species belonging to the assemblage. Species of large biovolume usually can be dominating in the late stage of succession, whereas small celled, invasive species are mostly the members of young, pioneer associations. During the estimation of this number the succession sequence of the coda (Reynolds 2002, Padisák 2003) was also considered. (climax assemblages 1, pre-climax assemblages 2, transitional assemblages 3, pioneer assemblages of lakes and rivers 4, benthic coda 5),
4. As a highly subjective element, we also estimated, how the occurrence of the given assemblage in the riverine ecosystem is

“undesirable”, that is, indicates pollution, or may be toxic. Higher values were given to the lower risk.

The designated values of each element were summed and on the basis of this, on a scale ranging from 0-5 the assemblages were classified (Table 4.2.1.1.). A high value of the factor (F) indicates that the occurrence of this functional group in the riverine phytoplankton can be considered as natural.

Table 4.2.1.1 Calculation of the F numbers

Sum of the points	Factor number
0-3	0
4-6	1
7-10	2
11-14	3
15-17	4
18-20	5

The list of the functional groups (Reynolds et al. 2002) and its updated version (Padisák 2003) has to be augmented with those groups that are characteristic elements for the potamoplankton. Tychoplanktic elements that contain originally benthic species have been inserted into the assemblages. These species can be dominant even in low discharge periods.

Three tychoplanktic groups have been established

- The $\mathbf{T_B}$ group contains benthic Bacillariophyceae species.
- The $\mathbf{T_D}$ group consists of benthic Desmidiales
- The $\mathbf{T_C}$ group contains benthic Cyanobacteria

Already Reynolds et al. (2002) noted that the **W1** and **W2** groups need to be refined. In harmony with this, a new functional group $\mathbf{W_0}$ has been created, in which those organisms were collected, those prefer waters of extremely high organic content and are capable of surviving even under septic conditions. The natural representatives of these habitats are the shallow oxbows on the floodplain, while the artificial ones are the sewage treatment ponds. Because of this new functional group some alterations were necessary in the species pool of the **W1**, and **W2** groups. Details of the functional groups are shown in Table 7 (Appendix).

For the assessment of the ecological state of the rivers, an assemblage index (Q) has been developed. Calculation of the Q index follows the suggestions by Padisák et al. (2005).

$$Q = \sum_{i=1}^{n} p_i \times F_i$$

where pi is the relative share of the i-th functional group equal to ni/N where n1 is the biomass of the i-th group and N is the total biomass), and F is the factor number from Table 7 (Appendix). The theoretical maximum of Q is 5, the minimum is 0.

Relationship between Q and the different river types

River typology based on hydro-geology and geochemistry in Hungary revealed 26 types (Kvvm 2005). The results of a nationwide ecological survey of the Hungarian waters (Arcadis Euroconsult 2005) suggest that several of the 26 types can be amalgamated. Surprisingly,

Table 4.2.1.2. Proposed river types and Ecological Quality Ratio (EQR=Q/5) values for different water quality classes

River type	Code of the type	Stream order[1]	Residence time (day)	EQR				
				excellent	good	moderate	poor	bad
Brooks and small streams	1	1-5	<2	1	**0.99**	0.97	0.95	<0.95
Streams	2	3-6	2-4	0.99	**0.97**	0.95	0.90	<0.90
Small rivers (lowland streams)	3	4-7	4-8	0.95	**0.9**	0.8	0.7	<0.7
Rivers	4	6-9	8-12	0.9	**0.8**	0.7	0.6	<0.6
Large rivers	5	7-11	12-16	0.8	**0.7**	0.6	0.5	<0.5
Very large rivers	6	> 10	16<	0.7	**0.6**	0.5	0.4	<0.4

[1]Depending on local conditions

this proved to be true even for the macro-invertebrates, although this group is quite sensitive to small differences between the physical characteristics of riverine habitats. It also holds for those biological elements - like phytoplankton – which are more or less independent from the quality of the substrate. The species composition of the rheoplankton depends primarily on the inocula present at the upper river-segment, the light climate and the residence time. Consequently, the number of the river types, based on the characteristic phytoplankton assemblages, will be much smaller than those made on the basis of hydro-geological and geochemical characteristics.

In case of a pristine river, phytoplankton assemblages that can be considered as reference depend primarily on the residence time.

Table 4.2.1.3. Relative share (%) of the assemblages belong to the functional groups F= 5; 4; 3; and 2, and the calculated Ecological Quality Ratio (EQR) values. This table contains example distribution of the different functional groups

5	**4**	**3**	**2**	**EQR**
100	0	0	0	1
95	5	0	0	0.99
85	15	0	0	0.97
75	25	0	0	0.95
50	50	0	0	0.9
0	100	0	0	0.8
0	50	50	0	0.7
0	0	100	0	0.6
0	0	50	50	0.5
0	0	0	100	0.4

Residence time however, is not constant at the given point, but changes with the actual current velocity, therefore must be considered when defining the reference assemblages. In general, the $\mathbf{T_B}$ functional group can be considered as a reference assemblage in the upper river segments and along the river it is enriched with other phytoplankton elements, in natural rivers mainly with those, that have high factor number (F=4). The value of the Q index decreases downstream.

On basis of the residence time 6 main river types are proposed that are more or less in accordance with Meybeck's (1996) system. These types and the recommended Ecological Quality Ratio (EQR) values are shown in Table 4.2.1.2. Boundary values would be preferably derived from detailed analysis of large data sets. This approach is not feasable here because of the lack of data and the heterogeneity of the existing datasets. Therefore, the boundary values have been extracted from the theoretical contribution of the assemblages that belong to F = 5, 4, 3 or 2 categories (Table 4.2.1.3.) in the phytoplankton. These example distributions explain the relatively high EQR values in certain river types.

Case studies

The new assessment method has been tested by using different data sets from Hungarian rivers that contain phytoplankton data against the Pantle-Buck index (Pantle & Buck 1955), which is the officially accepted qualification method in Hungary and several other countries in Europe. Some of the databases had to be supplemented with biovolume data. In such cases cell-volumes from earlier investigations were used.

Data from the following rivers were considered: River Kösely at Hajdúszovát), River Tisza at Tiszalök), and River Danube near Göd). The two methods are in accordance when their values move to opposite direction.

River Kösely at Hajdúszovát, riv. km 46,0

Lowland, calcareous, small river with yearly average water discharge 1.0 m^3 s^{-1} in East Hungary (type 3 in Table 4.2.1.3). This small

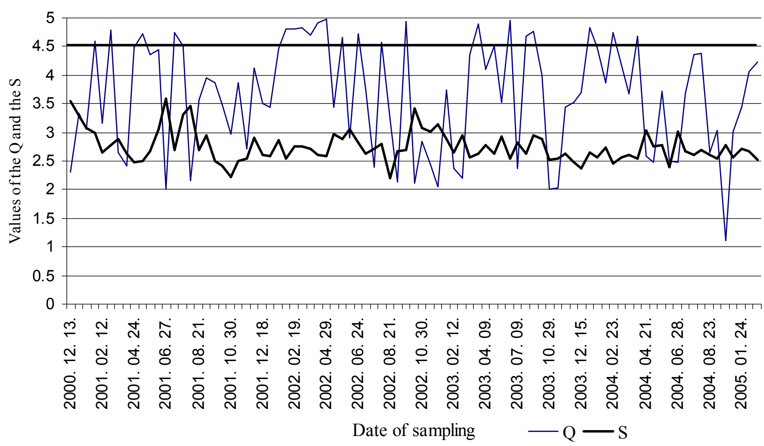


Fig. 4.2.1.1. Quality assessment of the River Kösely on basis of the Q and S (PANTLE-BUCK 1955). The thick line at 4.5 indicates the good-moderate boundary

streamlet carries the effluent of the sewage treatment plant of the city of Debrecen (average wastewater load 50.000 m^3 day^{-1}) and it is one of the most polluted rivers in this region with high organic content, but with relatively small hydromorphological alterations.

Compared to the saprobic index, the Q values exhibit a much wider range (Fig. 4.2.1.1). The Q values indicated better quality in several cases, when the saprobity was α-mesosaprobic or α-β-mesosaprobic. This can be explained by the frequently occurring pennate diatoms, *Navicula rhyncocephala* Kütz. and *Nitzschia palea* (Kütz.) W. Smith, belonging to the $\mathbf{T_B}$ group, which have the highest factor value (F = 5) in the new assessment system while these species were considered as α-mezosaprobic indicators in the saprobic system. The $\mathbf{T_B}$ group will have to be refined again on the basis of the pollution tolerance.

River Tisza at Tiszalök, riv. km 518,2

This is a lowland, calcareous, large river with yearly average water discharge 540 m^3s^{-1} (type 4 in Table 4.2.1.3). Sampling point is just upstream of the Tiszalök barrage, which is situated at the upper part of the middle river-segment. Compared to the Pantle–Buck index, the Q values

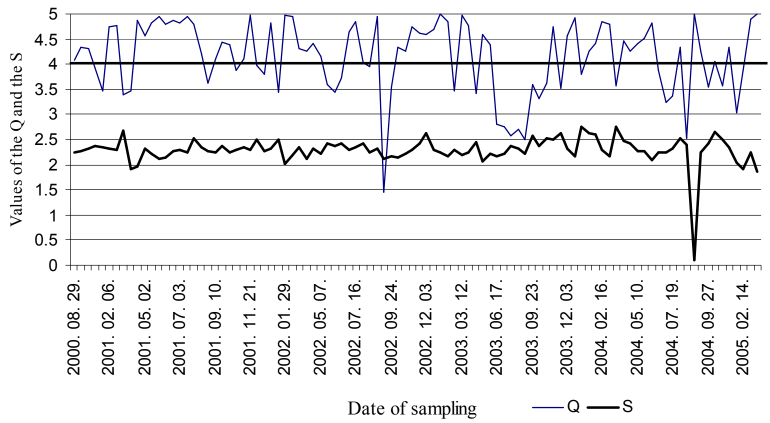


Fig. 4.2.1.2 Quality assessment of the River Tisza on basis of the Q and S (PANTLE-BUCK 1955). The thick line at 4.0 indicates the good-moderate boundary

fluctuate at a much larger scale (Fig. 4.2.1.2). In situations when water-quality is worse both methods coincide, because those phytoplankton groups that have low F numbers have usually high S values in the saprobic system. Since the highest factor number (F=5) was given exclusively to the representatives of the **T_B** group, the Q values higher than 4, refer to the dominance of benthic diatoms. The large number of Q values that exceed 4 indicate, that this section has frequently been in good ecological state despite impounding which increases residence time). The Q index however, indicates bad quality situations in several cases when the saprobic index points to favourable water quality. The reason is that some groups, like cyanobacteria, have low saprobic values, and consequently, refer to relatively good water quality. In the present method they have low values as well (F=0, or F=1), but here they indicate undesirable water quality situations.

River Danube at Göd, riv. km 1669)

Lowland, calcareous, large river with average discharge 2300 $m^3 s^{-1}$ at Göd (type 5 in Table 4.2.1.3). Sampling was carried out at the middle part of the Hungarian river section. The Q values (Fig. 4.2.1.3) indicate that the phytoplankton of the river consists primarily of euplanktic species during the vegetation period. The estimated residence time at the sampling point of >20 days at low discharge allows the

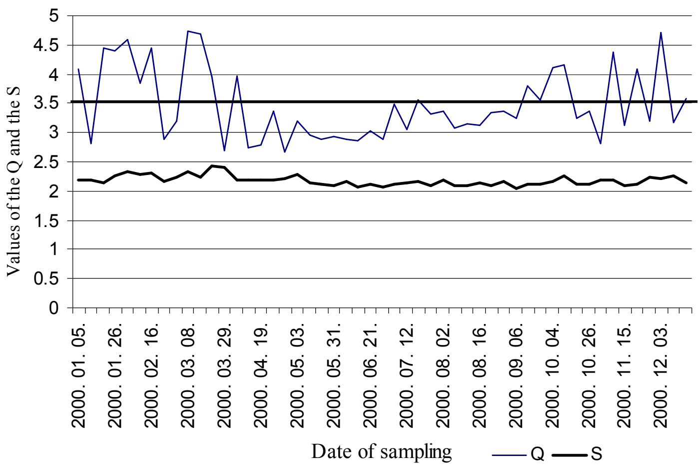


Fig. 4.2.1.3 Quality assessment of the River Danube on basis of the Q and S (PANTLE-BUCK 1955) The thick line at 3.5 indicates the good-moderate boundary

development of assemblages **B**, **C**, and **D**, which are dominated mainly by centric diatoms (F=4). The values lower than 4 indicate the dominance of **P** and **F** assemblages. The saprobic index proved to be insensitive during the whole investigation period.

Supposedly, the residence time was long enough for the development of characteristic riverine phytoplankton in the large and very large rivers even in the earlier, pristine situation, but the stream regulations by damming and impounding at the upper river basin considerably reduced flow rate and increased residence time. The composition of the phytoplankton under pristine conditions is therefore difficult. Re-investigation of samples collected from the River Danube in the late 1950s proved, that several taxa that now are considered as "new and dominant" elements of the algal flora (e.g. *Skeletonema potamos* (Weber) Hasle), were present in the plankton (Kiss, 1986). Although the ratio of these euplanktic elements must have been lower in the past than nowadays, we have the opinion that the phytoplankton of large pristine rivers consisted of these elements during low discharge periods. The meso-eutrophic state must have been a natural characteristic of the very large pristine rivers. Probably large European rivers were potentially eutrophic in the middle of the last century, but their actual trophic state was mesotrophic as a result of high concentration of the suspended solids (Kiss 1985, 1997).

Discussion

Monitoring of the naturally occurring algal communities in rivers provide data on species composition, species number, diversity, or quantitative occurrence of the algae. Experts of administrative institutions who are responsible for water quality management need simple numerical values rather than species lists or scientific evaluation of the assemblages. Much of the monitoring activities concentrated on bentic Bacillariophyceae species in the recent years, and numerous indeces have been developed for characterising the quality of the rivers (Descy 1979, Coste in Cemagref 1982, Watanabe et al. 1988, Kelly and Whitton 1995, Schiefele and Schreiner 1991, Lenoir and Coste 1996, Rott et al. 1997). These methods became widely used in the last decades, but their applicability in large, deep, slow-flowing rivers (because of the lack of appropriate substrate) is problematic. Nevertheless this type of the rivers is usually enriched with nutrients and - pending the hydro meteorological situations - can be characterised by highly eutrophic phytoplankton. High phytoplankton biomass may occur in smaller water currents as well, consequently the phytoplankton as a tool in the water quality assessment should not be ignored. Since up to now, little attention has been attended to the application of the phytoplankton for evaluation of ecological state of the rivers, the present study aims to show a new assessment method. The method is based on the functional group of algae represented in the potamoplankton and provides a single index number (Q). The index has been tested on phytoplankton data of different rivers, and proved to be more sensitive than the earlier used saprobic index. After calculating the Q, the Ecological Quality Ratio (expected by the WFD) could also be given.

Conclusions

As an evaluation it is worth mentioning the strengths and weaknesses of the method.

Strengths of the method:

- has been elaborated on the basis of the fundamental hydrological characteristics of the rivers,
- applicability is not restricted to a geographic region,
- it is sensitive
- it is capable of indicating different anthropogenic impacts (organic pollution, impoundment, occurrence of toxic elements),
- it can be computerised easily

Weaknesses of the method:

- it is difficult to define those river stretches where the given associations expected to be occur or to be dominant (supposing natural conditions),
- efficiency of the lentic areas as the “cradles” of the euplanktic species is not known,
- it is also not known how much the „dead zones„ (Reynolds et al. 1991, Reynolds 2000) enlarge the residence time,
- the factor numbers have been given by expert judgement,
- those species that have not been mentioned in the Reynolds’ system (Reynolds et al. 2002) are sorted into the groups on the basis of expert opinion,
- during the testing average biomass data were used,
- in case of a water bloom, the method may indicate good or excellent ecological state,
- the boundaries cannot be set by analysing the variation of the given biological indicator (Q) along a pressure gradient (as it

suggested by the Ecostat (2005) document), therefore the boundary setting is subjective.

The method has been tested with hundreds of phytoplankton samples, it is simple, and after applying to a phytoplankton database it can be computerised easily.

5 Conclusion

Oxbows

Phytoplankton of the oxbows

(i) *Do the oxbows have unique microflora*?
Comparison of the microflora with other occurrences published in the relevant literature supported that there are some species known exclusively from oxbows in Hungary.

(ii) *Does the macrophyte coverage have a large effect on the composition and biomass of the algal assemblages*?
During the transition from lake systems to landscape, the direction and the main stages of macrophyte succession can be foreseen, but our results proved that it is not exclusive for the macroflora. The macrophyte coverage has a great effect on the composition of the algal assemblages

(iii) *Does the higher plants dominated state results in clear water conditions in the oxbows*?
In case of the oxbows, the macrophyte dominated state does not necessarily results in a clear water state.

Small-scale heterogenity of phytoplankton

(i) *Are there any differences in the horizontal distribution of algae along the longitudinal axis of the oxbow*?
Horizontal sampling within a lentic oxbow demonstrated the uneven distribution of algae at both large and small scale

(ii) *How can the heterogeneity be characterized numerically*?
An index of heterogeneity (IH) was proposed to characterize the fine-scale horizontal patchiness, which was defined as the ratio of the coefficient of variation among samples and the algae counting error.

(iii) *Which taxa, and to what extent are responsible for the heterogeneity*?
Most of the patches were formed by those species that have good buoyancy-regulating mechanisms (blue greens, dinoflagellates)

(iv) *Do the differences exist at fine scale (1m)*?
In case of some taxa (e.g. dinoflagellates, cyanobacteria and clorococcalean green algae) there were considerable differences in the biomass among the 3 neighbouring water columns, despite that the distance between them was only 1m.

(v) *Which mechanisms are responsible for the development of algal patches*?
Atelomixis caused by surface cooling can be the explanation of the heterogeneity.

(vi) *To what extent can the horizontal patchiness influence the results of the quality assessment*?
The anisotropic horizontal distribution of the phytoplankton could cause high uncertainty in lake quality assessment, therefore to improve the accuracy, composite sampling is needed.

Desmids to assess natural value

(i) *Are desmids important elements of the microflora of shallow, alkaline, hypertrophic oxbows*?
Desmids are important elements of the microflora of an shallow, alkaline, hypertrophic oxbow. Only two Hungarian floristic accounts are available in which a larger number of species were reported.

(ii) *What kind of NCV values characterise the Malom-Tisza oxbow*?
The Malom-Tisza oxbow characterized by the highest NCV score (10).

(iii) *Do the NCV values change during the course of the summer*?
The NCV values of the late summer samples (10) compared to those taken in June (8) were not significantly higher.

(iv) *Are there any differences in the NCV values between the different substrates*?
Considerable differences in the NCV values of the microhabitats sampled were observed.

(v) *Do the NCV values change after applying Fehér's (2007) modified rarity values*?
The use of modified rarity value calculations as recently proposed by Fehér did not significantly affect the conservation value.

(vi) *What are the differences, if any, in the NCV values if different species enumeration methods are used*?
Different enumeration methods (up to 400 speciments counted, or whole droplets counted) to quantify the floristic diversity did result in different conservation values.

Rivers

Characteristic phytoplankton assemblages of rivers

(i) *How can be used the phytoplankton functional groups approach to describe characteristic phytoplankton assemblages in riverine ecosystems*?
We identified the different algal communities which characterise different river types. The algal communities were described as different ratios of algal functional groups.

(ii) *What is the most frequent assemblage types based on this functional groups*?
The most frequent phytoplankton type is representative for the upper section of rivers and is dominanted by the $\mathbf{T_B}$ (bentic diatoms) functional group.

Riverine phytoplankton quality assessment

Is the invented new phytoplankton-based method for assessing the ecological state of the rivers?
The phytoplankton-based new method is a useful tool for assessing the ecological state of the rivers.

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8 Appendix

Table 1. Physical characteristics of the 13 studied oxbows

Name	Geographic coordinates	Surface area (ha)	Mean depth (m)	Max depth/ depth of sampling point	Type	Macrophyte's cover (%)	Species number/ sample number
Miskafoki-Holt-Tisza	47 43 14 N 20 59 53 E	25	0.9	1/0.5	I	~10	124/9
Atkai-Holt-Tisza	46 22 58 N 20 11 50 E	83	3.5	2	II	~10	99/14
Falu-Tisza	48 01 15 N 21 11 10 E	23	3.6	4/2	II	~5	237/20
Holt-Szamos Géberjén	47 56 02 N 22 28 07 E	100	1.5	2/2	II	~5	152/7
Holt-Szamos Tunyogmatolcs	47 56 52 N 22 25 49 E	125	3.1	3.5/2	II	~5	159/7
Malom-Holt-Tisza (pelagical part)	48 01 14 N 21 11 27 E	30	3.5	10/2	II	~5	230/19
Tiszaugi-Holt-Tisza	46 51 46 N 20 03 10 E	50	2.3	2	II	~10	50/4
Darab-Tisza	48 01 18 N 21 11 17 E	9	1.7	2.5/1	III	~50	260/21
Egyeki-Holt-Tisza	47 38 32 N 20 52 19 E	40	1.5	2/1	IV	~80	172/22

Szűcs-Tisza	48 01 17 N 21 13 26 E	10	2.0	2/1	IV	~60	248/18
Morotvaközi-Holt-Tisza	47 39 51 N 20 56 57 E	71	1.4	2/1.4	IV	~80	127/16
Szöglegelői-Holt-Tisza	48 04 16 N 21 27 38 E	20	1.0	1.5/1	IV	~90	97/6
Malom-Holt-Tisza (part of floating island)	48 00 44 N 21 12 29 E	8	2.0	2/1	V	~80	308/19

Table 2. Chemical characteristics of the 13 studied oxbows.

Name	Secchi depth (m)		Chlorophyll-a (μgL^{-1})		TIN (μgL^{-1})		TP (μgL^{-1})		SRP (μgL^{-1})	
	Min-Max	Mean	Min-Max	Mean	Min-Max	Mean	Min-Max	Mean	Min-Max	Mean
Miskafoki-Holt-Tisza	-	-	-	-	200-330	260	-	-	50-60	55
Atkai-Holt-Tisza	-	-	2.4-49	13.8	220-380	245	60-1070	340	-	-
Falu-Tisza	0.5-1.6	0.91	3.9-75.5	26.0	50-950	330	40-9450	692	3-50	20
Holt-Szamos Géberjén	0.6-0.9	0.72	14.5-62.5	35.0	50-1510	370	190-1660	557	20-270	140
Holt-Szamos Tunyogmatolcs	0.45-1.2	0.89	9.4-38.3	23.7	110-380	280	290-1510	654	110-690	361
Malom-Holt-Tisza (pelagical part)	0.8-2.5	1.34	4.1-70.2	19.8	50-990	320	30-2290	318	8-340	34
Tiszaugi-Holt-Tisza	-	-	41.0-610.0	390.0	220-480	290	50-460	287	50-140	87
Darab-Tisza	0.6-1.5	1.0	1.4-114.6	16.2	30-870	280	30-2160	320	7-160	25
Egyeki-Holt-Tisza	0.32-1.05	0.65	1.1-154.1	33.7	120-700	330	50-1860	507	10-130	33
Szűcs-Tisza	0.6-1.9	1.3	4.5-133.8	22.7	50-760	240	50-2430	236	3-100	21
Morotvaközi-Holt-Tisza	0.3-1.35	0.56	0.5-160.6	27.8	180-860	410	10-4140	712	11-750	63

Szöglegelői-Holt-Tisza	0.6-0.7	0.65	1.5-27.5	10.5	110-760	320	60-580	331	30-120	62
Malom-Tisza. part of floating island	1.0-2.1	1.46	2.3-44.9	17.4	60-650	260	40-1360	240	8-350	35

Table 3. Chemical parameters of the Malom-Tisza oxbow at sampling points 1, 5 and 7 (cf. Fig. 2) on 24 June and 25 August 2004

	June			August		
	1	5	7	1	5	7
Temperature (^oC)	21.2	21.3	21.2	22.4	22.6	22.4
pH	7.93	7.51	8.56	7.61	7.33	7.39
Conductivity (µS cm^{-1})	283	289	287	299	297	295
Chlorophyll a (µg L^{-1})	10.7	2.2	2.3	5.5	5.3	7.6
NH_4^+ (mg L^{-1})	0.2	0.17	0.18	0.17	0.24	0.23
NO_2^-(mg L^{-1})	0	0	0	0	0	0.01
NO_3^-(mg L^{-1})	1.9	2.1	2.1	2.5	2.4	2.4
PO4-P (µg L^{-1})	40	30	40	60	70	60
COD-Mn (mg L^{-1})	10.6	9.3	9.8	8.9	8.6	10.7

Table 4. List of samples and their attributes of Malom-Tisza oxbow on 24 June and 25 August 2004. Sampling location designations 1-7 as in Fig. 2

Code	Type of the sample	Sampling location	Date
UN_06	*Utricularia* periphyton	2	24.06.2004.
CP_06	*Calliergonella* periphyton	5	24.06.2004.
PP_06	plankton	5	24.06.2004.
NM_06	netplankton	3	24.06.2004.
SM_06	*Salvinia* periphyton	3	24.06.2004.
PB_06	plankton	1	24.06.2004.
NB_06	netplankton	1	24.06.2004.
PL_06	plankton	6	24.06.2004.
SL_06	*Salvinia* periphyton	6	24.06.2004.
NL_06	netplankton	6	24.06.2004.
ML_06	mixed periphyton	6	24.06.2004.
PS_06	plankton	7	24.06.2004.
NS_06	netplankton	7	24.06.2004.
MS_06	mixed periphyton	7	24.06.2004.
UN_08	*Utricularia* periphyton	2	25.08.2004.

CP_08	*Calliergonella* periphyton	5	25.08.2004.
NP_08	netplankton	5	25.08.2004.
MP_08	mixed periphyton	5	25.08.2004.
VP_08	*Myriophyllum* periphyton	5	25.08.2004.
UP_08	*Utricularia* periphyton	5	25.08.2004.
HP_08	*Hydrocharis* periphyton	5	25.08.2004.
P1P_08	plankton	5	25.08.2004.
P2P_08	plankton	5	25.08.2004.
PR_08	plankton	4	25.08.2004.
SR_08	*Salvinia* periphyton	4	25.08.2004.
MR_08	mixed periphyton	4	25.08.2004.
PB_08	plankton	1	25.08.2004.
NB_08	netplankton	1	25.08.2004.
PS_08	plankton	7	25.08.2004.
NS_08	netplankton	7	25.08.2004.
MS_08	mixed periphyton	7	25.08.2004.

Table 5. Number of observed taxa of Malom-Tisza oxbow on 24 June and 25 August 2004.

number of taxa			
	June	August	Total
CYANOBACTERIA	15	20	26
HETEROKONTOPHYTA			
Chrysophyceae	4	4	4
Bacillariophyceae	33	33	39
Xanthophyceae		2	2
CHLOROPHYTA			
Chlorococcales	44	48	60
Desmidiales	64	67	78
Volvocales	5	4	5
Other Chlorophyta	3	4	4
EUGLENOPHYTA	4	14	15
DINOPHYTA	6	11	11
CRYPTOPHYTA	3	1	3
Total	181	208	247

Table 6. Desmidiales flora of the Malom-Tisza oxbow on 24 June and 25 August 2004. * rare taxa in Hungary (FEHÉR 2007). Sampling location designations 1-7 as in Fig. 2

	Sampling locations						
Tax**on**	1	2	3	4	5	6	7
**Actinotaenium turgidum* (Bréb.) Teil.			+	+	+		
Closterium aciculare T.West			+			+	
Closterium acutum Bréb.					+		+
Closterium acutum var *variabile* (Lemm.) Krieg.						+	
Closterium dianae Ehr.	+	+	+	+	+		+
Closterium ehrenbergii Menegh.		+					
Closterium incurvum Bréb.					+		+
Closterium moniliferum (Bory) Ehr.					+		
Closterium sp. 1		+		+	+		
Closterium sp. 2					+		
Closterium venus Kütz. ex Ralfs	+	+	+	+	+	+	+
Cosmarium botrytis Menegh.	+	+	+	+	+		+
**Cosmarium connatum* Bréb. in Ralfs	+	+			+	+	+
Cosmarium contractum Kirch.	+	+	+		+	+	+

Cosmarium contractum Kirchn. var. *contractum* West et West					+		
Cosmarium contractum Kirchn. var. *ellipsoideum* (Elfv.) W. et G.S. West	+			+	+		
Cosmarium contractum Kirchn. var. *retusum* (W. et G.S. West) Krieg. et Gerl.				+			
Cosmarium contractum Kirchn. var *rotundatum* Borge	+			+	+		
Cosmarium crenulatum Näg.		+	+	+	+		+
Cosmarium depressum (Näg.) Lund				+			
**Cosmarium fastidiosum* W. et G. S. West cf.					+	+	
Cosmarium formosulum Hoff in Nordst.				+			+
Cosmarium granatum Bréb. in Ralfs	+	+		+	+	+	+
Cosmarium humile (Gay) Nordst.		+	+	+			+
Cosmarium margaritiferum Menegh. ex Ralfs	+		+				
Cosmarium moniliforme (Turp.) ex Ralfs	+	+			+		+
**Cosmarium notatum* (Grönbl.) Coes.					+		
Cosmarium phaseolus Bréb. ex Ralfs	+	+	+	+	+	+	+
Cosmarium portianum Arch.					+		
**Cosmarium pseudoretusum* Ducell v. *inaequalipellicum* (W. et G. S. West) Krieg. et Gerl.						+	
**Cosmarium pseudoretusum* Ducell. var *pseudoretusum* Krieger et Gerloff					+		
Cosmarium punctulatum Bréb. cf.				+			
Cosmarium pygmaeum Arch. cf.		+					
**Cosmarium pyramidatum* Arch. cf.					+		

Cosmarium regnellii Wille						+	
Cosmarium regnellii Wille var. *minimum* Eichl. et Gutw.		+		+	+		+
Cosmarium regnellii Wille var. *regnellii*		+	+	+			
**Cosmarium regnesi* Reinsch var. *montanum* Schmidle			+			+	+
Cosmarium reniforme (Ralfs) Arch.	+	+	+	+	+	+	+
Cosmarium subprotumidum Nordst. var *pyramidale* Coes.		+	+	+	+	+	+
Cosmarium subprotumidum Nordst. var *subprotumidum* West et West		+					+
Cosmarium subtumidum Nordst.						+	
Cosmarium subundulatum Wille						+	
**Cosmarium tetraophthalmum* Bréb. in Ralfs		+			+	+	+
Cosmarium turpinii Bréb.	+	+	+		+	+	+
Desmidium aptogonum Bréb. ex Kütz.			+			+	
Desmidium swartzii (C. A. Ag.) C. A. Ag. ex Ralfs	+	+	+	+	+	+	+
Euastrum denticulatum Gay		+	+		+	+	+
**Euastrum germanicum* (Schmidle) W.Krieg.		+	+	+		+	+
Heimansia pusilla (Hilse) Coes.	+	+	+	+			+
Micrasterias crux-melitensis (Ehr.) Hass ex Ralfs	+	+			+	+	+
Pleurotaenium trabecula var. *trabecula* (Ehr.) Näg.		+	+	+	+	+	+
**Sphaerozosma laeve* (Nordst) Thom.		+	+				
**Sphaerozosma vertebratum* (Bréb.) ex Ralfs		+	+	+	+	+	+

Spondylosium planum (Wolle) W. et G. S. West	+	+		+	+	+	
Staurastrum anatinum Cooke et Wills			+				
**Staurastrum bieneanum* Rabenhorst	+	+	+	+	+		+
**Staurastrum boreale* W. et G. S. West			+		+	+	
**Staurastrum boreale* W. et G. S. West var. *quadriradiatum* Kors.	+						
**Staurastrum furcatum* (Ehr. ex Ralfs). Bréb.	+	+	+		+	+	+
Staurastrum furcatum (Ehr. ex Ralfs). Bréb. (4 arms)							+
Staurastrum gladiosum W.B.Turner	+	+	+		+		+
Staurastrum hystrix Ralfs						+	
Staurastrum lunatum Ralfs						+	
Staurastrum manfedtii Delponte	+	+	+	+	+	+	+
Staurastrum orbiculare (Ehr.) Ralfs ex Ralfs			+				
Staurastrum polymorphum (Ehr. ex Ralfs). Bréb.	+	+	+	+	+	+	+
**Staurastrum quadrangulare* Ehr. ex Ralfs	+	+			+		
**Staurastrum smithii* G.M.Smith							+
**Staurastrum subavicula* (W. West) W. et G. S. West		+	+		+	+	+
Staurastrum teliferum Ralfs		+			+	+	+
Staurastrum tetracerum Ralfs ex Ralfs	+	+	+	+	+	+	+
Staurodesmus cuspidatus (Bréb. ex Ralfs) Teil.		+	+		+		+
Staurodesmus dejectus (Bréb. ex Ralfs)	+	+	+		+	+	+

Staurodesmus dejectus (Bréb. ex Ralfs) v. *apiculatus* (Bréb.) Teil.	+			+	+		
**Staurodesmus glaber* (Ehr. ex Ralfs) Teil.	+	+	+				
Xanthidium antilopaeum (Bréb.) Kütz.	+	+	+	+	+	+	+
**Xanthidium variabile* (Nordst.) W. et G. S. West					+		

Table 7. Evaluation of the functional groups of algae. The first three columns were elaborated by Reynolds et al (2002) and Padisák (2003)

Codon	Characteristic species	Habitat	Nutrient status	Turbulence	Time sufficient for the development of the given assemblage	Risk (inverse scale)	Sum of the points	Factor number (F)
A	*Urosolenia (Rhizosolenia), Cyclotella comensis, C.glomerata*	Clear, often well-mixed, base poor, lakes	4	4	4	5	17	**4**
B	*Aulacoseira subarctica, A. islandica, Stephanodiscus neoastraea, S. rotula, Cyclotella comta*	Vertically mixed, mesotrophic, small-medium lakes	3	4	4	5	16	**4**
C	*Asterionella formosa, Aulacoseira ambigua, Stephanodiscus rotula, Cyclotella meneghiniana, C. stelligera*	Well mixed, eutrophic small-medium lakes and rivers	1	5	4	5	15	**4**
D	*Synedra acus, Nitzschia* spp., *Stephanodiscus hantzschii, Cyclotella ocellata, C. pseudostelligera*	Shallow, enriched turbid waters, including rivers	1	5	4	5	15	**4**
T_C	*Epiphytic cyanobacteria Oscillatooria, Phormidium, Lyngbya, Rivularia*	Enriched standing waters, or slow-flowing rivers with emergent macrophytes	1	1	5	3	10	**2**

T_D	*Benthic (epiphytic) desmids and filamentous green algae,*	Enriched standing waters, or slow-flowing rivers with emergent macrophytes	2	1	5	4	12	**3**
T_B	*Benthic diatoms Nitzschia spp., Navicula,, Gomphonema, Didymosphaenia, Fragilaria, Achnanthes, Surirella,*	Highly lotic environments including rivers and rivulets	3	5	5	5	18	**5**
N	*Tabellaria, Cosmarium, Staurodesmus, Xanthidium*	Mesotrophic epilimnia	3	3	1	4	11	**3**
P	*Fragilaria crotonensis, Aulacoseira granulata, Staurastrum pingue, S. chaetoceras*	Eutrophic epilimnia	2	3	1	5	11	**3**
T	*Pediastrum duplex, P. simplex, Coelastrum spp. Geminella, Mougeotia, Tribonema, Planctonema, Closterium aciculare C acutum v. variabile*	Deep, well-mixed epilimnia	2	4	3	4	13	**3**
S1	*Planktothrix agardhii, Limnothrix redekei, L. planctonica, Pseudanabaena limnetica, Planktolyngbya limnetica, P. contorta*	Mixed layers	0	2	1	0	3	**0**
S2	*Spirulina, Arthrospira, Raphidiopsis*	Shallow, mixed layers	0	2	1	0	3	**0**
S_N	*Cylindrospermopsis, Anabaena minutissima*	Warm slightly mixed layers	0	2	1	0	3	**0**
Z	*Synechococcus,*	Clear, mixed	4	3	4	3	14	**3**

	Pseudodictyosphaerium, Choriocystis Single celled prokaryotic pikoplankton	layers						
X3	*Koliella, Chrysococcus, eukaryotic pikoplankton*	Shallow, clear, mixed layers	2	3	4	4	13	**3**
X2	*Plagioselmis (Rhodomonas) Chrysochromulima*	Shallow, clear, well mixed layers in meso-eutrophic lakes	3	4	4	4	15	**4**
X1	*Ankyra, Monoraphidium*	Shallow well mixed layers in enriched conditions	1	4	4	4	13	**3**
Y	Large microflagellates, *(Cryptomonas)*	Usually, small, well mixed, enriched lakes	1	4	4	4	13	**3**
Y_{Ph}	*Phacotus*	Small, Ca- rich alkaline lakes	1	2	3	3	9	**2**
E	*Dinobryon, Mallomonas, Synura*	Usually small, oligotrophic, basepure lakes or heterotrophic ponds	3	2	3	4	12	**3**
F	Colonial Chlorococcaleans *(Botryococcus, Pseudosphaerocystis, Coenochlorys, Oocystis), Elakatothrix*	Clear epilimnia	4	2	2	4	12	**3**
G	*Volvox, Eudorina*	Short, nutrient-rich water	1	0	1	2	4	**1**

		columns, small pools among macrophytes						
J	*Scenedesmus, Golenkinia, Tetrastrum, Crucigenia, Actinastrum, Micractinium stb.*	Shallow, enriched lakes, pnds and rivers	2	3	3	2	10	**2**
K	*Aphanothece, Aphanocapsa*	Short, nutrient-rich columns	2	2	3	2	9	**2**
H1	*Anabaena flos-aquae, Aphanizomenon flos-aquae*	Dinitrogen fixing Nostocaleans	1	2	1	1	5	**1**
H2	*Anabaena lemmermannii, Gloeotrichia echinulata*	Dinitrogen-fixing Nostocaleans of larger mesotrophic lakes	3	1	1	1	6	**1**
U	*Uroglena*	Summer epilimnia	4	1	1	2	8	**2**
L_O	*Peridinium, Woronichinia, Merismopedia*	Summer epilimnia in mesotrophic lakes	3	1	1	2	7	**1**
L_M	*Ceratium, Microcystis*	Summer epilimnia in eutrophic lakes	1	1	1	2	5	**1**
M	*Microcystis, Sphaerocavum*	Daily mixed layers of small, eutrophic, law latitude lakes	0	2	1	0	3	**0**
R	*Planktothrix rubescens, P. mougeotii*	Metalimnia of mesotrophic, stratified lakes	3	2	1	0	6	**1**
V	*Chromatium, Chlorobium*	Metalimnia of eutrophic, stratified lakes	0	0	3	0	3	**0**

W0	*Chlamydomonas, Spermatozopsis, Pyrobotrys, Chlorella, Polytoma, Oscillatoria chlorina, Beggiatoa alba,*	Small ponds of extremely high organic content	0	1	3	0	4	**1**
W1	*Euglena, Phacus, Lepocinclis, Gonium pectorale, G. sociale(Pandorina morum)*	Small, organic ponds	1	2	2	1	6	**1**
W2	*Trachelomonas, Strombomonas, Dysmorphococcus spp. Small dinoflagellates Peridinium, Glenodinium, Gymnodinium, other metaphytic species*	Shallow, mesotrophic, well mixed lakes	2	4	3	4	13	**3**
W_S	*Synura*	Small, mesotrophic, mixed lakes, pH neutral	3	3	2	4	12	**3**
Q	*Gonyostomum*	Small, humic lakes	2	2	1	1	6	**1**

9 List of publications

Publications (in English)

1. Borics G., Abonyi A., **Krasznai E.**, Várbíró G., Grigorszky I., Szabó S., Deák Cs. & Tóthmérész B. (2011): Small-scale patchiness of the phytoplankton in a shallow oxbow. *Journal of Plankton Research* 2011. doi: 10.1093/plankt/fbq166 (IF: 1.612)
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4. **Krasznai E**., Fehér G., Borics G., Várbíró G., Grigorszky I. & Tóthmérész B. (2008): Use of desmids to assess the natural conservation value of a Hungarian oxbow (Malom-Tisza, NE-Hungary). *Biologia* 63: 924-931. (IF: 0.406)
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7. **Krasznai E**., Borics G., Várbíró G., Deák Cs., Abonyi A., Tóthmérész B., Padisák J. (2010): A fitoplankton vertikális mintázata egy sekély holtágban. *Hidrológiai Közlöny* 90: 81-83.
8. Abonyi A., **Krasznai E**., Padisák J. (2010): Néhány produktív mély bányató fitoplanktonja és bevonatlakó kovaalgái. *Hidrológiai Közlöny* (kézirat)
9. Borics G., **Krasznai E**., Abonyi A., Várbíró G. (2010): Miként befolyásolja a fitoplankton horizontális mintázata az ökológiai állapotértékelés eredményét egy holtág esetén? *Hidrológiai Közlöny* (kézirat)

10. Borics G., Várbíró G., Szabó S., **Krasznai E**. (2009): Milyen mértékben határozzák meg a hidromorfológiai sajátságok sekély tavaink trofitását? *Hidrológiai Közlöny* 89: 96-98.

11. **Krasznai E.**, Borics G., Várbíró G., Tóthmérész B. (2009): Cianobaktérium dinamika egy sekély holtágban. *Hidrológiai Közlöny* 89: 138-140.

12. Abonyi A., **Krasznai E.**, Borics G., Várbíró G., Grigorszky I., Tóthmérész B., Padisák J. (2009): Két tisza-menti holtág rétegződési sajátságai. *Hidrológiai Közlöny* 89: 196-198.

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1. Abonyi A., **Krasznai E.**, Padisák J. (2010): Néhány produktív mély bányató fitoplanktonja és bevonatlakó kovaalgái. LII. Hidrobiológus Napok, Tihany.

2. Borics G., **Krasznai E.**, Abonyi A., Várbíró G., Tóthmérész B. (2010): Miként befolyásolja a fitoplankton horizontális mintázata az ökológiai állapotértékelés eredményét egy holtág esetén. LII. Hidrobiológus Napok, Tihany.

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4. Krasznai E. (2010): Jellegzetes fitoplankton társulások sekély holtágainkban. Magyar Hidrológiai Társaság, Hajdú-Bihar megyei Területi Szervezet, Debrecen.

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