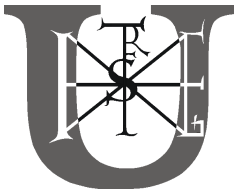

SZENT ISTVÁN UNIVERSITY

Comparative macrophyte survey and monitoring of running waters in Germany and Hungary

Theses of Ph.D. dissertation

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BACKGROUND AND OBJECTIVES

The presence or absence of aquatic plants, their quantity and condition reflects the changes taking place in the habitat. The continuous observation of them is necessary for exploration of state and for long-term monitoring of the changes in watercourses as in habitats. The survey of their population, monitoring and evaluating the changes has become particularly timely with the introduction of the EC Water Framework Directive (WFD) (2000/60/EC Directive), because the WFD (contrary to the former water usage centered view) always considers ecological viewpoints first in order to determine and to preserve the good state and potential of natural and man-made water habitats. Therefore the importance of biological elements in determining water quality is more emphasized as it has been so far and so their significance has been elevated to the same level as the chemical elements. In consequence of this situation new methodical problems have arisen during the planning and realization of the monitoring required by the WFD in addition to the double requirement of the scientific thoroughness and cost effectiveness.

In Hungary the rules for observation and status evaluation of surface waters are governed by regulation 31/2004. (XII. 30.) KvVM, with modifying regulation 34/2008 (XII. 31.) KvVM. The standard MSZ EN 14184:2004 is applicable for the field surveying of macrophytes (aquatic plants visible to the naked eye) in running waters which allows us a wide range of alternatives to choose the fitting method. The standard only puts down the principles, such as an easily repeatable survey method, which should be independent of the person conducting it, and that which can only contain minimal chance for mistakes. Further cardinal principle is the quantitativeness of the data, which serves as a basis for calculation of different indexes and for the final evaluation as well. However we even have no international and widely standardized protocol for this realization of the quantitative statistical analysis. So the intercalibration of national protocols will be essential for the united interpretation of the data in the European Union.

On the watercourses of the Friedberger Au in Germany continuous river macrophyte mapping has been carried out since 1972 (repeated every 4-5 years), which means this is one of the longest running long-term macrophyte monitoring in Europe. These watercourses are one of the model areas where Kohler (1978) has improved his section mapping method. In the course of my work together with my supervisor I had the opportunity to join this macrophyte survey that was being carried out for the seventh time in 2001 and familiarise myself with the proper application of the method. Following this we have conducted the survey independently in 2005 on the four watercourses of the Friedberger Au. The first application of the method in Hungary took place in 1990 during the macrophyte mapping program of the IAD (Internationale Arbeitsgemeinschaft Donauforschung), where different sections of the Danube by Vác (Ráth 1994) and in the Szigetköz (Pall et al. 1996) have been surveyed.

To carry on and extend this survey the IAD works within the frame of the Multifunctional Integrated Study Danube: Corridor and Catchment (MIDCC) Program to make the first, uniform and quantitative description of the macrophytes in the River Danube and its tributary, moreover to determine the reference for the different ecological states declared by the WFD and to create a database necessary to the statistical analysis that is available for all the member-states (Pall et al. 2004, Schütz et al. 2005). Partly connected to the aims of the MIDCC program we used the Kohler-method also in the Tisza Project lead by the VITUKI Non-profit Ltd. the goal of which was to help the protection of ecological values by using and developing integrated hydrological tools in the oxbows of the River Tisza.

The section mapping method has been first tested on artificial watercourses in Hungary in 1998 by Sipos (2001), on three members of the Danube-Tisza Mid-region canal system: the Harmincas and Apaji Canals and a section of the Danube-valley Main Canal near Szabadszállás. In her work she emphasizes the key role these formerly botanically less researched canals play in the ecological network of the area, therefore their ecological evaluation is of great importance in spite of their anthropogenic origin. But on the basis of former exploratory vegetation mappings of the aquatic habitats of the Danube-Tisza Mid-region only little information is available. Sipos (2001) informs us about diverse habitats where significant divergence could be observed in the flora of the three connected canals and there was difference in the amount of the species as well. Additionally these canals (being under strong anthropogenic effect) are better supporting the spreading of invasive plants and because an extensive population of the invasive *Cabomba caroliniana* (Gray) had been discovered, Sipos has suggested that in addition to surveying additional areas, the vegetation of canals should be continuously monitored. After entering the research, we have advised the mapped areas to be extended with additional four canals and canal sections having different roles and sizes. In 2001 the Sós-ér was added, followed by the Danube-Tisza Canal, and the Dabas, Akasztó, and Baja sections of the Danube-valley Main Canal in 2002. I have repeated the surveying of the macrovegetation on all previously mapped areas (152 km) in 2008, with it starting the systematic monitoring of the canals of the area.

Aims and scope:

The goal of this dissertation is to evaluate the results of the macrophyte surveys conducted using the section mapping method on water bodies belonging to the catchment area of the Danube, on the watercourses of the Friedberger Au, and on the members of the Danube-Tisza Mid-region canal system, and to compare the results of the two survey years per each watercourse. Regarding the planning of regulations and execution of the surveys the WFD has an integrated view on the level of catchment areas. This approach can be followed in the present work examining and evaluating of macrophytes in different watercourses which altogether belong to the catchment area of the River Danube.

I. General aims:

1. Repetition of previous macrophyte surveys with section mapping method.
2. Description of the flora of the watercourses, detection of the changes and specification of the causes.
3. Evaluation of the changes in the vegetation between the former and present surveys.
4. Verification of disturbances and anthropogenic influences, and finding out how they correlate with the changes in the aquatic vegetation.
5. Determining of influencing factors of the macrophytic vegetation in artificial watercourses.
6. Searching for new evaluation method to be able to analyse the huge volume of data coming from the section mapping integrally and in a well-arranged way.

II. Regional aims on the Friedberger Au research area:

1. To create the conditions for comparison between previous and our surveys (2001 and 2005) and to continue the long-term monitoring being carried out since 1972 in the watercourses.
2. Determination of the stands of protected and invasive plant species occurring in the researched area and detection of their changes between the two mapping years.

III. Regional aims on the Danube-Tisza Mid-region research area:

1. Floristic assessment of the artificial canal system in the Danube-Tisza Mid-region.
2. Complex representation of the vegetation of the investigated canals with GIS methods, and creation of widely usable attributes and database.
3. Preparation of the first and actual vegetation map of the canals.
4. Determination of the stands of protected and invasive plant species occurring in the research area and detection of their changes between the two mapping year.

MATERIALS AND METHODS

Location of the research areas

The investigated watercourses of the Friedberger Au plain in Germany, the Friedberger Ach, Forellenbach, Höhgraben and Hörgelaugraben are situated in the southern part of Bavaria, northward from Augsburg on the Lech-Wertach Plain which was formed by two alpine rivers Lech and Wertach. In the four watercourses wide stands of the protected and red listed *Potamogeton coloratus* Hornem. can be found. The macrophyte survey with section mapping method developed by Kohler (1978) has been running since 1972, with surveys repeated every 4-5 years with unchanging section division of the watercourses over a total sampling length of 44km. The vegetation mapping was widened with particular laboratory and field replanting research as well to define the indicator value of the plant species in connection with the investigated area (Kohler 1975, 1976, 1982; Kohler et al. 1974), and the plant species were divided into five groups in according to their sensitivity to the trophic state. Joining to this long-term monitoring, we conducted the survey in 2001 and 2005.

The second survey area with five investigated canals can be found in the Danube-Tisza Mid-region in Hungary. The Danube-Tisza Canal, which was mapped in its total length, has its source directly from the Ráckevei-(Soroksári) Danube-Arm and flows continuously into the Danube-valley Main Canal which is the principal element of the canal system and was only mapped in four subsections at Dabas, Szabadszállás, Akasztó and Baja. Altogether with the further three investigated canals: the Harmincas Canal (XXX. Canal), the Sós-ér (V. Canal) and the Apaji Canal (XXXI. Canal) the total length of the survey units is 152 km long. The field survey and evaluation of data was made for all the survey units in two different years in each case. The first survey was made by Sipos (2001) on the Harmincas Canal, Apaji Canal, and Danube-valley Main Canal at Szabadszállás in 1998. The second survey was carried out together with Sipos (Falusi et al. 2004) on the Sós-ér in 2001 and in the Danube-Tisza Canal and in the Danube-valley Main Canal (Dabas, Akasztó, Baja) in 2002. I have repeated the mapping of the macrophytes on all sections of the afore-mentioned canals in 2008.

Field survey method

The actual survey is done by Kohler's section mapping method (Kohler 1978) by splitting the length of the watercourse into sections and the total water body of each section was taken into consideration. The borders of sections are defined by the changes in the ecological attributes determining the spreading of the macrophytes, so each section can be considered a homogenous habitat. On the Friedberger Au research area the section borders which were marked during the previous mappings were used in present surveys as well and similarly on the Danube-Tisza Mid-region where the sections were stated in 1998, 2001 and 2002.

During the field survey we marked the section borders on topographical maps with 1:25 000 scale and GPS measuring was even made which data was used for digitalization of maps and for creation of a GIS database with the Arc View 3.1 software.

During the field survey on the Friedberger Au research area the macrophytes were measured while going upstream on foot, in case of the Danube-Tisza Mid-region canal system the water depth made it necessary to do the mapping from a boat. The definition macrophyte is not a classification with taxonomical basis. All aquatic plants visible to the naked eye (without any optical aid) are classed among macrophytes, so vascular hydrophytes, amphiphytes and helophytes moreover mosses and macroalgae as well are included (Casper and Krausch 1980 and 1981). After the survey, we have estimated the amount of each species in the sections on a 1 to 5 scale defined by Kohler (1978), where the meaning of the values are the following: 1=rare, 2= occasional, 3=frequent, 4=abundant, 5=very abundant. Not only the presence and estimated value of the plant species in each survey section was noted down into the recording sheet but also the physical parameters influencing the distribution of macrophytes: depth and width of the watercourse, the speed and turbidity of the water, the shadiness of the water surface, the sediment type, the vegetation of the banks and the land use type of the surroundings.

Indexes used during the evaluation

During the index calculation process for the characterization of the vegetation in the watercourses only the hydrophytes and amphiphytes were taken into consideration from the field data. All the calculations were made on the basis of the statement of Melzer (1988), whereas the connection between the estimated plant mass and the real plant mass is not a linear function but can be described with the function $F_{(y)}=x^3$, which hypotheses was proved with measurements by Janauer and Heindl (1998).

We have determined different spread indicators, which had been defined by Kohler (1978) and were later refined by Kohler and Janauer (1995). To evaluate the spread pattern, we have used the relative distribution length (Relative Arealänge, Lr), and the average quantity indexes (Mittleren Mengenindices, MMT, MMO). The relative plant mass (Relative Pflanzenmenge, RPM) gives useable information about the dominance relations of the plants in the watercourses, as it shows the proportion of the plant mass of the individual species in comparison to the total plant mass of all the species present.

The distribution diagram made for each watercourse and each survey year combines the species list and the sections together with the estimated plant mass per section, thus it can be considered a vegetation map of the watercourse.

For our statistical analysis we used the freely accessible R software environment, the first version of which was developed by Ihaka and Gentleman (1996). Additionally to visualize the data on the distribution, we have introduced a so called heat map analysis as a new method in macrophyte research. In this we have displayed the spread data in graphical form with the help of cluster analysis (Figure 1). The presence and quantitative data of species was represented together by the rotation of clusters so in the rows and columns the similar values get into closer clusters (Sneath 1957). The first software using cluster heat map in the course of visualization was the SYSTAT as a high resolution colour image and its algorithm was developed by Gruvaeus and Wainer (1972). So during the graphical visualization of the field data of the watercourses hierarchical cluster analysis was made. The dendrogram on the X-axis shows the connections among the plant species and the dendrogram on the Y-axis shows the connections among the sections. In case we expand the meaning of the sections with full knowledge of the ecological parameters it represents the relations between the vegetation and habitat types. In the rectangle-shaped matrix bordered by the two dendrograms different colours indicate the possible variations of the estimated plant mass (0, 1-5), thereupon a combined characterization will be possible compared with the former ones. Previously the classification of the sections according to their similar or different vegetation happened with the analysis of the distribution diagrams with the naked eye. This newly introduced statistical analysis was applied retrospectively to both research area and for each investigation period.

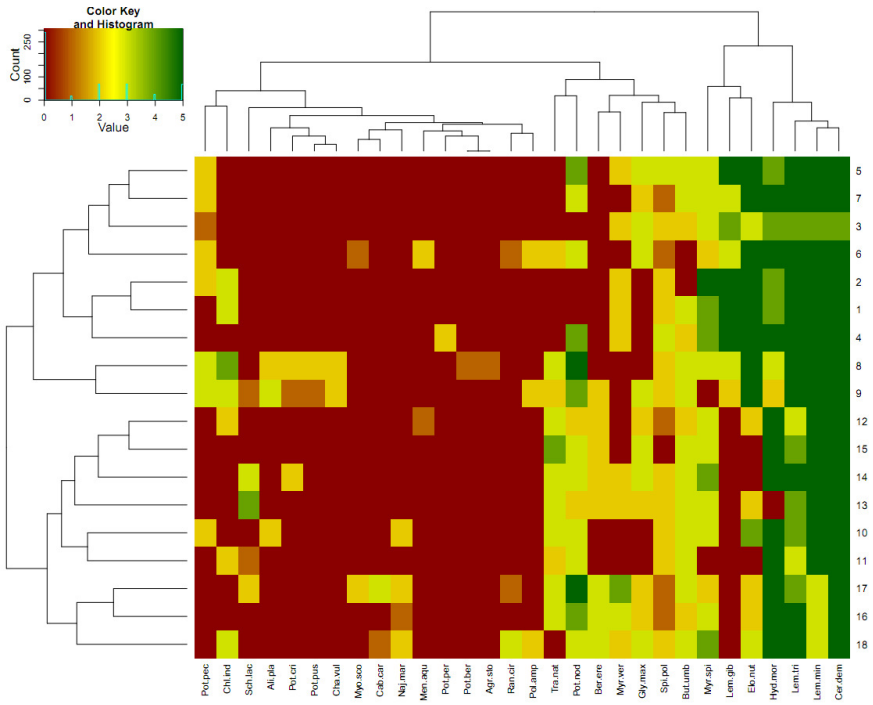

Figure 1 Heat map of the Apaji Canal generated from the data of the survey in 1998

RESULTS AND DISCUSSION

Floristic results of the watercourses of the Friedberger Au

On the basis of our research and the long-term survey of the area it can be stated that the stands of the *Potamogeton coloratus* Hornem red list species showed a lightly but continuously decreasing tendency. That is why it was so important that in 2001 we could extend the survey area with a new distribution section of the species in the source area of the Friedberger Ach. In consequence of the increasing shading along the Hörgelaugraben the presence of the *Potamogeton coloratus* could not be proved in 2005 and the *Apium repens* (Jacq.) Lagasca could not be found in its distribution section either.

Out of the hydrophytic invasive *Elodea* species generally present in this area only the *Elodea canadensis* (L.) C. Rich. was absent and solely from the Höhgraben. Since 1992 the *Elodea nuttallii* (Planchon) St. John) and the helophytic *Impatiens glandulifera* Royle form wide-spread stands but only along the Friedberger Ach so far.

Results of the vegetation mapping of the watercourses of the Friedberger Au

By 2005 in spite of the stable stands of the *Potamogeton coloratus* the drastic decrease of the estimated plant mass in case of the *Juncus subnodulosus* indicated eutrophication, furthermore the growing dominance of the *Elodea canadensis* (from 0,1% to 2,3%) showed increasing disturbance in source area of the **Friedberger Ach**. Along the middle flow of the river a regeneration process of the macrophytes could be observed since 1974, the year when the waste water inflow at city Friedberg had been stopped. Besides the high plant mass of *Myriophyllum spicatum* the growing stands of *Myriophyllum verticillatum* (from 1,8% to 7,7%) and the appearance of the *Groenlandia densa* in 2001 showed a change for the better. It can be stated that this part of the watercourse which was under high nutrient load and which was free from macrophytes in the past has diverse vegetation nowadays. On the lower sections of the Friedberger Ach species typical for eutrophic watercourses such as the *Zannichellia palustris* have been dominating since 1996. The ecological state of the Friedberger Ach was negatively affected by the colonization of the adventive *Elodea nuttallii* in 1992.

In the case of **Forellenbach** it can be generally stated that it has originally oligotrophic water, which state was preserved as indicated by the vegetation surveys during the years, such as the stable – with same relative distribution length and estimated plant mass – stands of *Potamogeton coloratus* and *Juncus subnodulosus*. On the other hand the doubled relative plant mass and increasing distribution length of the *Elodea canadensis* was in connection with the increasing anthropogenic disturbances caused by the construction of a motorway cutting through the area. During the survey of 2001 a totally dried up spring area was found. It has gotten some water supply by 2005 but it was not enough for hydrophytes to appear anew.

In the **Höhgraben** the distribution sections of the *Potamogeton coloratus* were halved thus it was present only in 13% of the watercourse. The *Elodea canadensis* is present in the area of the Friedberger Au since 1972 but the Höhgraben is the only watercourse from the four investigated ones in which it was not occurring. The vegetation was dominated mainly by amphiphytes (*Berula erecta, Mentha aquatica, Phalaris arundinacea*).

New hydrophytes expanded the species list of the Höhgraben in 2001 (*Lemna trisulca*, *Nitella opaca*, *Fontinalis antipyretica)*, out of which the *Lemna trisulca* was never found in any of the surveyed running waters of the area before. In 2001 due to the drying process in the area new amphiphytes have appeared (*Myosotis scorpioides* and *Veronica anagallis-aquatica*).

In 2001 the group of species indicating oligotrophic water was represented by the *Potamogeton coloratus* present only in the spring area of the **Hörgelaugraben** but its stands could not be discovered in any of the sections in 2005. Parallel to it the *Juncus subnodulosus* – an amphiphyte indicating less nutrient load in the water – that previously had stable stands during the long-term survey had extremely decreased estimated plant mass during the mapping in 2005.

According to our observations the hydrological conditions of the Hörgelaugraben have changed considerably. This process has started in 1996 with the drying up of the lower parts of the watercourse which had an effect on 3 km long area (Veit et al. 1997). We found the same condition in 2001 and the dried sections expanded by 2005 and reached a length of 5 km. This change was clearly reflected by the shift in the proportion between the amphiphytes and hydrophytes with advantage for the hydrophytes. One of the causes of the sinking water level could be the infrastructural development and constructions in the surrounding area. Also the habitat island of the *Veronica anagalloides* was destroyed due to a building. In 2005 not only the number of the noted species has fallen drastically but also the estimated plant mass has been lower on average than it was before. Besides the sinking of the water level the increasing shading due to the shrub and forest belt caused the decreasing diversity of the macrophytic vegetation in the Hörgelaugraben.

Floristic results of the canal system of the Danube-Tisza Mid-region

The *Ceratophyllum demersum* was the most frequent species of the canals and occurred almost in all surveyed sections. The estimated plant mass of the *Myriophyllum spicatum,* the *M. verticillatum* and the *Potamogeton nodosus* was high among the submerse macrophytes. Compared to the previous surveys of the canals new species present were the adventive *Pistia stratiotes* and the protected *Salvinia natans* in 2008.

An important output of the survey is that it has been proven that the canal system could provide suitable habitat to protected species (13/2001. (V. 9.) Gov. order) such as the *Nymphaea alba* and the *Trapa natans.* The *Salvinia natans* appeared in the Sós-ér and in the Danube-valley Main Canal at Baja in 2008. The *Acorus calamus* is rare regarding the Great Plain but it was found in two places during our survey in the Danube-Tisza Canal and the Danube-valley Main Canal at Baja. Besides the protected species the *Cyperus longus* L., a rare species for Hungary, could be found in each year in the Danube-valley Main Canal at Baja.

During our surveys four adventive species occurred in the mapped members of the canal system. One of them, the alien Central American *Cabomba caroliniana* (A. Gray.), spread aggressively in the canals directly connected with Danube water (Danube-Tisza Canal, Danube-valley Main Canal, Harmincas Canal). It lives through the winter with non-leafy stem parts buried in the sediment and usually spreads in the vegetation period with broken down stem or rhizome pieces as well. The shoot pieces can survive floating in the water for up to 6-8 weeks that is why it helps the spread even more if the waterweeds are harvested regularly. It has no terrestrial form but it tolerates the fluctuation of the water-level therefore it adapted properly to the water-level conditions of the canal system.

During the first survey in 1998 the invasive *Elodea nuttallii* (Planch.) H. St. John. had already a distribution length of 84% in the Apaji Canal which species had been first reported in Hungary from the Szigetköz. It was present in the canals with high plant mass at places cleared and continuously disturbed by anglers. It prefers shallow water. The species was present in each surveyed canals of the area in both survey years.

A new adventive species the *Pistia stratiotes* has appeared during the survey in 2008 in the Danube-Tisza Canal, entering the canal system from the Ráckevei (Soroksári)-Danube-Arm where based on oral reports its high cover caused difficulties in 2007 (Fishing Society ex verb.).

Along the Sós-ér and the Apaji Canal that are flowing across areas with saline soil greater stands of the *Typha laxmannii* Lepech could be found which species was first brought in to the Tiszántúl with the rice cultivation where it builds wider stands in rice fields and along the connected canals.

Results of the vegetation survey on the canal system of the Danube-Tisza Mid-region

In case of the **Danube-Tisza Canal** the hydrophytes dominated but most of all the *Ceratophyllum demersum.* In 2002 it had 36%, in 2008 already 60% share in the relative plant mass and was present with 100% relative distribution length. In the background of the decreasing tendency of the estimated plant mass in case of amphiphytes (*Sparganium erectum, Glyceria maxima*) and the tightened distribution of certain helophytes (*Rumex hydrolapatum*, *Typha angustifolia*) by 2008 first of all the dredging operations carried out in 2004 could be discovered. It can be stated that four years after the management the *Sparganium erectum* has lost the most from its distribution length and the *Phragmites australis* has regenerated almost completely. The *Lemna gibba* was absent from the canal in 2002. The appearance and 47% relative distribution length of this species indicated that the nutrient load of the water had become more acute in 2008. The appearance of the *Zannichellia palustris* confirmed this process as well. Among the invasive species occurring in the canal the *Elodea nuttallii* and the *Cabomba caroliniana* were present in connection to the continuously cleaned angling places. Beyond that the appearance of *Pistia stratiotes* could be also declared as a consequence of human intervention. The stands of the protected plant species occurring in the canal were constant (*Acorus calamus, Nymphaea alba*).

In the **Danube-valley Main Canal at Dabas** the *Ceratophyllum demersum* dominated likewise as in the Danube-Tisza Canal. In 2002 the vegetation showed homogeneous distribution in all of the sections. But in the slowly flowing sections of the canal a wide *Lemna gibba* "carpet" covered the water surface in 2008 until the connection with the Harmincas Canal which made the mapping more difficult. The spreading of amphiphytes (*Sagittaria sagittifolia, Berula erecta, Mentha aquatica*) has been enabled not only by the slow flow but also by the possible support provided by the thick carpet of floating macrophytes. The image of the vegetation has changed a lot due to the decreasing estimated plant mass of the floating hydrophytes when the canal got water supply from the Harmincas Canal. While the *Cabomba caroliniana* was connected to these opened surfaces the *Elodea nuttallii* had its stable stands in the sections closer to the Danube-Tisza Canal.

The formerly (1998) heterogeneous macrophytic vegetation in the **Danube-valley Main Canal at Szabadszállás** changed a lot by 2008 and significant decreasing could be observed in case of all the generated indexes. The number and distribution of species has significantly decreased and the estimated plant mass has fallen back also. The formerly high estimated plant mass and 100% relative distribution length of *Cabomba caroliniana* had been halved. In 2008 great flowering stands of it with floating leaf could only be observed in the upper sections but only in areas where the floating macrophytes had less covering. The vegetation profile of this canal was determined by the confluence with the Harmincas Canal and the slower flow dynamic caused by the flotsam blockade that existed in the section 113-114.

In case of the upper sections of the **Danube-valley Main Canal at Akasztó** the vegetation was formed by the cattle coming to drink from the widely extended pastures along the canal. The vegetation dominated by hydrophytes (*Ceratophyllum demersum, Cabomba caroliniana, Lemna minor*) in the survey of 2002 have been changed by 2008 because of the growing mass of amphiphytes (*Berula erecta, Sparganium erectum*) due to the gently sloping banks formed by the continuous trampling of the cattle. The so evolved inlets with steady water served as ideal habitats for the *Trapa natans* and its distribution area increased with 30% compared with the results in 2002. In these sections the increasing tendency of the nutrient load because of the effect of the animals was indicated by the immediately high (67%) relative distribution length of the only in 2008 appeared *Lemna gibba*. After the area at Akasztó lot of angling places could be found along the canal due to the closeness of the settlement, and these places preserved the stable stands and distribution of the *Elodea nuttallii*.

In the vegetation of the **Danube-valley Main Canal at Baja** besides the *Ceratophyllum demersum* and *Potamogeton nodosus* the submerse forms of the *Sparganium erectum* and *Sagittaria sagittifolia* were dominating. In the flattened inlets of this southern part besides the *Nuphar lutea* protected species could settle down also, like the *Trapa natans* and the *Nymphaea alba*. In the section 68 the *Salvinia natans* appeared as a new and protected species in 2008. Its further spread can be expected under advantageous conditions.

In case of the **Sós-ér (V. Canal)** the steep riverside and the often 2 meter wide reed belt pushing out into the water along both sides gave no advantage to the distribution of amphiphytes. We could come through this reed belt only occasionally at places cleared by anglers. On the basis of the results it can be stated that in both survey years four species dominated considering the value of the RPM and MMT/MMO indexes in the Sós-ér: *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Potamogeton nodosus* és a *Hydrocharis morsus-ranae*. The appearance and dispersion of the protected *Salvinia natans* from section 11 specifies the direct connection between the Kiskunsági Main Canal and the Sós-ér. It is important to establish that the aggressively spreading *Cabomba caroliniana* had its distribution dominance in bigger canals connected directly or indirectly with the water of the Danube. According to the data from 2008 this invasive species could not be found not even in the mouth sections of the Sós-ér and the Apaji Canal which justified the statement of Sanders (1979) as the *Cabomba caroliniana* does not like alkaline water. On the other hand the *Typha laxmannii* appeared in more sections in the bank vegetation of the Sós-ér especially due to this habitat parameter.

In the records of the **Harmincas Canal (XXX. Canal)** resulting from the survey of 1998 the stands of the *Hydrocharis morsus-ranae,* the *Spirodela polyrhiza*, the *Ceratophyllum demersum*, the *Myriophyllum spicatum* and the *Cabomba caroliniana* were characteristic with high (4-5) plant mass estimates. In 2008 considerable recession could be detected regarding to the number, the relative distribution length and the estimated plant mass of the species. In the same survey year in consequence of the 100% reed cover the survey could not be completed in some parts of the canal. In 2008 the dominating plant was the *Ceratophyllum demersum* with a very high RPM value (46,7%). The *Cabomba caroliniana* that was present on 82% of the canal during the last survey has now lost nearly 60% from the relative distribution length (Lr). Protected species present in the canal were the *Trapa natans* and the *Nymphaea alba* with gently increasing stands in comparison of the two survey data.

We have found that the sections of the **Apaji Canal (XXXI. Canal)** at Alsószenttamás had stagnant water and it was covered by floating macrophytes with high relative plant mass (4-5). After these sections the water supply of the canal was dependent on the water level of the confluence with the Kígyós-ér. As a consequence of the little bit stronger current only the *Ceratophyllum demersum* reached higher plant mass estimates further on and on the basis of the relative plant mass (RPM) gave 31,6% of the total plant mass in 2008. The other change in the vegetation of the canal was given by the grayish-white muddiness of the water in the sections of the watering-place of the Hungarian grey cattle. The vegetation was missing over hundreds of meters along the left bank. The *Cabomba caroliniana* could not keep its formerly (1998) stand near the mouth to the Harmincas Canal so it is not present in the mapped sections of the Apaji Canal similarly to the Sós-ér. Regarding the protected species the *Trapa natans* had lost from its formerly high estimated plant mass, but its relative distribution length increased with 13%. In 2008 the *Nymphaea alba* has joined the species list of the canal.

Heat map evaluation of the vegetation in the watercourses of the Friedberger Au

The heat map generated from the data of all sections of the Friedberger Ach mapped in 2001 gave the same section grouping and classification which ecological zones were also determined by Veit et al. (1997) on the grounds of ecological parameters and anthropogenic impacts of the sections. On the basis of the data from 2005 this classification was not so evident in consequence of the anthropogenic influences occurred in the area. In the Forellenbach the total lack of hydrophytes separated the spring area dominated by the amphiphytic *Nasturtium officinale* et *microphyllum* from the middle sections characterized by the *Potamogeton coloratus* and the *Mentha aquatica*. In the heat map of the Höhgraben and the Hörgelaugraben both the grouping of the species and the classification of the section groups was determined by the plant mass and distribution conditions of the amphiphytic *Veronica anagallis-aquatica*, the *Mentha aquatica*, the *Phalaris arundinacea* and the *Berula erecta.*

Evaluating together the changes and degree of relationship of the species in the indicator groups used by Kohler (1982) in the Hörgelaugraben a close connection was detected between the *Potamogeton coloratus* and the *Chara hispida* on the basis of the data from 2001. In the Forellenbach the *Mentha aquatica* and the *Potamogeton coloratus* showed close relations in addition to their focus of distribution in each survey year so they had parallel changing tendency. This close connection was only proved in the case of Forellenbach. Only in the Friedberger Ach was present the *Zannichellia palustris*, a species from the class 5 (plants occurred in eutrophic water) and always together with *Potamogeton pectinatus* that is considered indifferent. Distribution pattern showed close relationship in both years. This situation gives basis to the statement that the *Potamogeton pectinatus* is non-sensitive against the nutrient load.

Heat map evaluation of the vegetation in the canal system of the Danube-Tisza Mid-region

During the evaluating of the heat maps generated from the data of the surveyed canals of the Danube-Tisza Mid-region canal system the estimated plant mass and dispersion of *Ceratophyllum demersum*, *Hydrocharis morsus-ranae*, *Lemna minor* and *Spirodela polyrhiza* determined the classification of the section groups. The amphiphytes were pushed into the background and among them the *Sparganium erectum* and the *Sagittaria sagittifolia* reached higher values but only with presence in submerse form.

In case of the sections of the Danube-valley Main Canal at Dabas the heat map separated such sections statistically as well that were not different from each other during the evaluating of the distribution diagram with the naked eye. Consequently it can be stated that the heat map evaluation is suitable and has enough sensitivity for the quantifiable following of the changes in the vegetation pattern of the canals having homogenous vegetation.

New scientific results

1. **New floristic results for the Friedberger Au research area:**

   a. In spite of the long-term series of explorations four new species have been found or precisely stated in the researched area during the survey of 2001 carried out on the watercourses of the Friedberger Au. Since 1972 the first recognition of the *Lemna trisulca* L. in case of the Höhgraben and of the *Veronica anagalloides* Guss. in case of the Hörgelaugraben have been registered.

   b. The helophytic *Agrostis gigantea* Roth was detected in large amounts on the banks of the Forellenbach, although it had not been noticed previously. Presumably the former notes about *Agrostis alba* partly related to the *Agrostis gigantea* taxon. Likewise the data about the *Glyceria fluitans* could possibly refer to the *Glyceria notata* Chevall /G. *plicata/*) which species had not been detected in the research area beforehand.

   c. Newly found stands of the all over Europe decreasing *Potamogeton coloratus* were discovered, this new unit in the spring area of the Friedberger Ach had been involved into the survey in 2001. The since 1992 not detectable stands of *Groenlandia densa* could be proved as well after a long while in 2001 and it was present in 2005 as well but not with such a high estimated plant mass.

2. **New results of the comparable characterization with the classical distribution indexes of the watercourses on the Friedberger Au:**

   a. During our survey in 2001 a vegetation state similar to the former (1996) mapping of the four surveyed watercourses was verified. The distribution sections and estimated plant mass of the species had no significant changes in comparison with the last survey only the precise statement of the taxon (see point 1) caused difference between the two mapping period.

   b. The minor, not even significant changes detected during the survey in 2001 have been amplified by the time of the survey in 2005 and the increasing dominance of the amphiphytes and the general decrease of the estimated plant mass indicated the drastic sinking of the water level. At several points of the watercourses a decreasing tendency of the plant species sensitive to disturbances and to the nutrient load could be detected and parallel with it an increasing tendency of invasive plant species could be discovered which changes are mainly caused by the expansion of the settlements and by their infrastructural development.

3. **New results of the heat map analysis of the vegetation in the watercourses of the Friedberger Au:**

   a. The heat map analysis that was newly introduced into the evaluation process applied to the mapped sections of the watercourses on the Friedberger Au outlined in 2001 the same section groups and ecological zones which were separated by Veit et al. (1997) on the basis of the ecological parameters and anthropogenic influences. Differences were present only in case of minor subclasses, so the heat map analysis turned out to be more sensitive in the classification and determination of ecological zones considering the vegetation changes.

   b. On the basis of the two surveys of the Friedberger Au (2001, 2005) if we evaluated the changes of the trophic state indicating species which were defined during the former field and laboratory examinations then a close connection could be only proven in some cases. For the exploration of the real connections and for preparation of statistically reliable indicator grouping the heat map analysis should be completed to all the former investigation periods as well.

4. **New floristic results of the Danube-Tisza Mid-region research area:**

   a. We found four protected plant species (*Nymphaea alba*, *Trapa natans*, *Salvinia natans, Acorus calamus*) in the examined area, their spreading area was determined as well. Stable stands of the *Cyperus longus* L. (a species rare in Hungary) have been proven to exist.

   b. During the exploration of adventive and invasive species significant stands of *Cabomba caroliniana* Gray were detected in case of canals connected directly with Danube water (Danube-Tisza Canal, Danube-valley Main Canal, Harmincas Canal). The *Elodea nuttallii* (Planch.) H. St. John appeared in areas continuously cleared by anglers in the case of all canals. In 2008 new invasive species, the *Pistia stratiotes* came to the species list of the Danube-Tisza Canal, the position of it was considered as the area endangering new invasive species. A spreading area of *Typha laxmannii* was determined along the Sós-ér and the Apaji Canal.

5. **New results of the comparable characterization of the canal system on the Danube-Tisza Mid-region with the classical distribution indexes:**

   a. The first comparable evaluation of the vegetation changes with section mapping method was carried out in artificial watercourses in Hungary. It has been proven by quantifiable distribution indexes that in case of the canals typically the morphology of the river bed and the permanently changing conditions joined with the actual demands of the water management (mainly the continuously variable flow dynamics) have the strongest influence on the quantifiable parameters of the vegetation.

6. **New results of the heat map analysis of the vegetation in the canal system of the Danube-Tisza Mid-region:**

   a. In case of the canal system of the Danube-Tisza Mid-region the heat map analysis determined that the estimated plant mass and the distribution pattern of dominating species such as the *Ceratophyllum demersum*, *Hydrocharis morsus-ranae*, *Lemna minor* and *Spirodela polyrhiza* plays one of the significant roles in the separation of the section groups. Besides them the angle of the bank slope has concrete influence in the canal system and connected to this parameter the presence and increasing estimated plant mass of the amphiphytes indicates statistical different habitat on the basis of the vegetation.

   b. During the evaluation of data that resulted from the survey of the typically homogenous sections of the canals in the Danube-Tisza Mid-region the classical evaluation of the distribution diagrams and the distribution indexes with the naked eye was a particularly challenging scientific task. With the application of the newly introduced heat map analysis such section groups have been statistically differentiated which showed no any dissimilarity compared to the former evaluation of the distribution diagrams. It can be stated that the heat map analysis shows adequate sensitivity for the reliable and quantifiable follow-up of the changes happening in vegetation patterns seemingly homogenous at first sight.

7. **Floristic database and vegetation attributes of the canal system of the Danube-Tisza Mid-region:**

   a. From the data for further monitoring and planning processes a useful digitized map and attribute store has been established with the Arc View 3.1 software, based on this a dispersion map of any plant species present in the surveyed parts of the Danube-Tisza Mid-region canal system can be prepared and visualized together with the estimated plant mass.

CONCLUSIONS AND SUGGESTIONS

In 2001 and 2005 by joining the long-term mapping series carried out on the Friedberger Au we extended the further application chances of the Kohler-method in other research areas. The results of the new steps of the long-term monitoring had enabled that after the testing stage this section mapping method could become a part of the valid standard (MSZ EN 14184:2004) concerning the field survey of the macrophytes in watercourses.

The applicability of the section mapping method for artificial canals of the Danube-Tisza Mid-region was proven by Sipos (2001) during the surveys in 1998. The present data resulting from the widening and repetition of previous unit mapping surveys contribute also to a better body of knowledge about indicating relations between living beings and changes in their environment and emphasizes the connections between vegetation changes and environmental parameters in the German and the Hungarian areas as well.

The development of the aquatic vegetation definitely indicates the parameters of the water regime and the drying processes of an area. Consequently they are suitable for the explanation of local effects and for the forecasting of changes evolving due to climatic conditions in the future. The anthropogenic influences and disturbances were unambiguously outlined by the macrophytic vegetation in both German and Hungarian survey areas. Additionally our surveys provide help in the protection against invasive species that are typically spreading with the help of anthropogenic influence, because the section mapping conducted not at sampling points shows where the appearance and spreading of invasive species can be anticipated, making the fight against them more efficient.

From cost effectiveness point of view the section mapping method by Kohler and its possibilities for evaluation are suitable for determining the basic state of watercourses and for marking the characteristic and endangered sections, and also for status monitoring in longer 5 year intervals. For the evaluation of the changes between the survey years the diagram of the average quantity indexes (Mittleren Mengenindices MMT/MMO) showed adequate sensitivity among the classical distribution indexes.

The heat map analysis that was newly introduced into the evaluation process applied to the statistical evaluation of data resulting from the section mapping turned out as proper evaluation method and gave sufficient reliability for the separation of different habitats of the canals having at first sight homogenous ecological parameters and vegetation. The heat map analysis used in case of former surveys gives an opportunity for the verification of the connections between the ecological parameters of the watercourse and the distribution of macrophytes and for the clear determination of the indicator value in case of individual species.

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