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Classification of the Oxbow Lakes of the Hármas-Körös River and Determination of Ways for Further Exploiting the Various Water Regions in the Light of the Water Framework Directive

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Abstract. Hármas-Koros river lies between the mouth of the Tisza and the city Békés. In the nineteenth century, the work of regulatory her bed was made, which resulted in 44 oxbow lakes were created, of which 36 still exist till today. In presented work 14 oxbow lakes was selected and the following objectives were carried out:
1. The classification of oxbow lakes based on selected criteria: the manner and intensity of water exchange, sediment thickness, redox potential, usage, ichtiofouna.
2. The assessment of the state of spawning and its impact on ichtiofauna.
3. Determination the best methods of water management in particular types of oxbow lakes, which could stop their further degradation.
The obtained results led to the following conclusions:
- Tested oxbow lakes belong to different categories
- Anthropogenic factors had a negative effect on the conditions of fish reproduction and survival of their juvenile stages.
- The management of fisheries was not a factor differentiating the individual water regions, but had an impact on the ecological status.
- For the maintenance and/or improvement of the natural environment of the individual oxbow lakes significant impact may have fishery management, carried out in the following years.

Keywords: environmenatl protection, fishery management, Hungary, oxbow lakes classification, spawning areas.

Conference topic: Environmental protection.

Introduction

Hungary, due to its geographical location, is a country poor in natural water resources. The main aquatic ecosystems of Hungary is a system of lowland rivers, whose sources are located outside the country. Morphometry of this system has changed substantially in the predominant extent as a result of regulatory activities, not natural changes in river beds and river courses (Pálfai 2002). Regulation of the three largest Hungarian rivers – Danube, Tisza and Körös generated hundreds of oxbow lakes. Inventory of that aquatic ecosystems was made in Hungary not before 1962 by the Research Institute of Water Management – 287 oxbow lakes and among them 160 with an area of over 5 ha was recorded (Vituki 1962). Currently, the volume of these reservoirs is 119.4 million m^3, of which 87.2 million m^3 is a capacity of oxbow lakes located outside the flood dikes and the rest is in the overflow-arm of rivers (Pálfai 2002). The value of these natural ecosystems has been underestimated for a long time. During their utilization economic profit was a priority, which often resulted in deterioration of the ecological status. Due to improper use and neglect, more than half of Hungarian oxbow lakes ceased to exist in the last hundred years. The disappearance and degradation of these ecosystems alarmed scientists, also outside Hungary. The tendency to disappearance and the degradation of small water reservoirs in the second half of the twentieth century had already a global dimension. Hungary's accession to the European Union forced to change this situation, because it came into force the Water Framework Directive. The Water Framework Directive requires Member Countries duty to follow recommendations the specified in the methods of water management and evaluation of habitats and water. The aim of these actions is to maintain the specified criteria of water quality and, if possible, improvement of water quality. The Directive also indicates the necessity of registering of protected areas, but does not address the specifically to the problem of oxbow lakes as a specific local problem of Hungary. Therefore, in Hungary there is now an urgent need to develop a "rapid methods" classification of individual oxbow lakes into one of three specified categories, and determine how to further exploitation of the various water regions.

In the south-eastern part of Hungary flow several rivers named Körös: Fekete, Fehér, Sebes, Kettős, Hármas, whose waters flow into the river Tisza. Their basin has a total area of 20,000 km^2 and its geographical catchment area is between 38–40 ^{0}E and 46–47.5 ^{0}N. Half of them are located in mountainous areas.

Hármas-Koros river lies between the mouth of the Tisza and the city Békés (Fig. 1). In the nineteenth century the last century, the work of regulatory her bed was made, which resulted in 44 oxbow lakes were created, of which 36 still exist today.

In work 14 oxbow lakes (Table 1, Fig. 2) was selected and the following objectives were carried out:

1. The classification of oxbow lakes based on selected criteria (the manner and intensity of water exchange, sediment thickness, redox potential, usage, ichtiofouna).

2. The assessment of the state of spawning and its impact on ichtiofauna.

3. Determination the best methods of water management in particular types of oxbow lakes, which could stop their further degradation.

Material ant methods

Research was conducted in 1992 and 2006. Location of sampling was determined by the instrument navigation type GARMIN GPS III plus. The results of the spatial information system were visualized on a map using ArcView 3.0. and archived on a computer.

Classification oxbow lakes based on the way of water exchange

Depending on the way of water supplementation, the oxbow lakes were classified to one of three groups. The first group – parapotamonic – oxbow lakes that have at least one end permanently connected to the riverbed. The second group – paleopotamonic – objects beyond the flood embankments and having no connection with the riverbed, and are supplied only with rainwater or groundwater. The third group – semipaleopotamonic – objects, where it is possible to supplement or replace the water, taken from the river using technical solutions.

Assessment of thickness of sediment (sediment accumulation)

The thickness of the layer of soft sediment, was determined using a sediments' probe. Measurements were performed on cross sections of designated oxbows. Their number depended on the morphometric traits of individual reservoirs. The cross-sections of seven wells were performed in each case, the water depth measured at the measuring point and the thicknesses of the total sludge, sediment soft and hard sediment. In the cross-sections for every time seven bore-holes were performed. The water depth at the measuring point and the thicknesses: of the total sediment, soft sediment and hard sediment, were measured.

Fig. 1. The geographical location of the oxbow lakes of the Hármas-Körös river (source: Pálfai 2001)

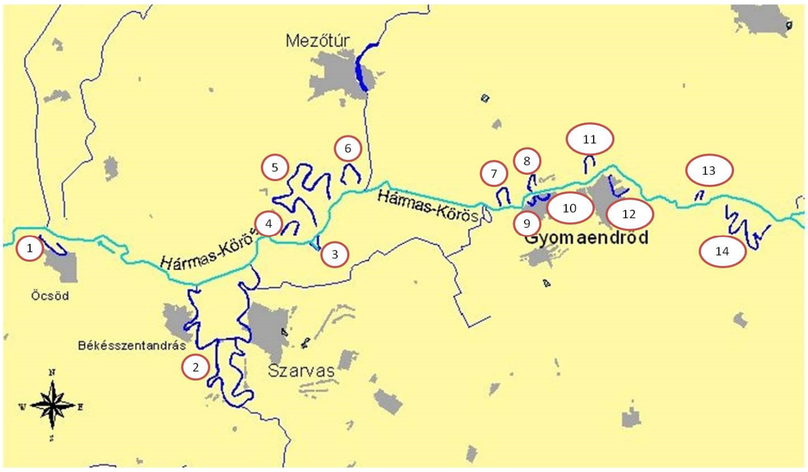

Fig. 2. The geographical location of studied oxbow lakes (source: own study)

Table 1. Characteristics of selected parameters in studied oxbow lakes (source: own study)

No.	The name of the oxbow lake	The length (km)	The width (m)	The area (ha)	The depth (m)	Legal protection
1	Álomzugi	2.8	80	22	1.5	
2	Kákafoki (Szarvas-Békésszentadnrási)	30.2	71	207	2.2	
3	Aranyosi	1.6	60	10	4	X
4-5-6	Halásztelek-Túrtő-Harcsás	18.7	90	168	2	
7	Bónomzugi	2.2	50	11	1.5	
8	Templomzugi	2	51	10	1.7	
9	Révzugi	1	65	6	2.3	
10	Csókási	1.2	46	6	2	
11	Németzugi	2	60	12	2	X
12	Hantoskerti	2.3	60	14	2.5	
13	Kecsegészugi	1.3	50	7	29	
14	Félhalmi	9	44	40	2.7	
Total		**74.1**		**517**		

The measurement of redox potential in the sediment

It was assumed that below – 140 mV, degradation of organic matter run anaerobically, in the range of – 140 to + 325 mV facultative anaerobic, whereas above + 325 mV under aerobic conditions.

Measurements were performed on a sample taken from the middle point of the surveyed sections using a pH / mV meter type Cole-Parmer 59002-60.

The assessment of spawning areas

The assessment of spawning areas were performed in three oxbow lakes (Álomzugi, Kákafoki and Aranyosi), where low water level in winter allowed lead inspection and assessment of the potential areas of various types of substrates at the banks. The characteristic features of the morphology of the shore were determined with an accuracy of five meters by walking in the middle of a frozen riverbed along the oxbow lake. Sections suitable or unsuitable for spawning and fulfilling the role of hiding places for juvenile were distinguished.

Assessment of fishery management in the years of intensive stocking of herbivorous fish (1980–1986) and the fishing management (1998–2005)

For evaluation of the fisheries management, information on stocking and harvesting in two periods were collected. In 1980–86 all studied oxbow lakes were utilized by the Cooperative Fishermen in Viharsarok. Data from that period, was obtained on the basis of records and protocols of stocking and harvesting.

In the years 1998–2005 the users of surveyed oxbow lakes were mostly associations of anglers. Data were obtained with the consent of the relevant associations of anglers, from the National Fisheries Database. The collected materials were used to analyze stocking and harvesting. For the analysis the summarized biomass, recalculated per unit area (kg/ha), divided into predators, herbivores and native cyprinids were taken.

Statistical analysis

The compliance of the attribute distribution with normal distribution was checked using Kolmogorov-Smirnov test. Tested oxbow lakes were characterized by the mean value and standard deviation of the measured parameters. In order to estimate a set of environmental characteristics, discriminant analysis was performed. For the calculations Statistica program was used.

Results and discussion

Classification oxbow lakes based on the way of water exchange

Due to the way of water exchange one oxbow lake classified as parapotamonic (Aranyosi), four typical paleopotamonic (Álomzugi, Révzugi, Csókási and Hantoskerti) and nine semipaleopotamonic (Kákafoki, Halásztelki, Túrtői, Harcsási, Bónomzugi, Templomzugi, Németzugi, Kecsegészugi and Félhalmi).

Thickness of sediment

Oxbow lakes are sensitive to strong sedimentation and accelerated eutrophication. The increase of anthropopressure in oxbow lakes catchments leads to increased inflow of biogenic elements and allochtonous matter. The consequence of this fact is an increase in primary production, as a result of growth of phytoplankton. Intensive sedimentation of the dying plankton results in accumulation of fertile bottom sediments. According to the literature, describing the state of the river Hármas-Körös before regulation, riverbed at the time had a very small decline and the midstream was slow. For one kilometer of the original length drop of trough was averaged only 15 mm (Gallacz 1896). On the basis of this fact, it can be assumed that the hard sediments in the studied oxbow lakes were dated back to this period, when through lateral erosion of the river their deposition occurred in the trough. This statement is confirmed by the results of observations conducted by the Institute of Geography of the Hungarian Academy of Sciences (Schweitzer 2003).

After analyzing the data, it can be stated that the order of values of the ratio W/SS (water / soft sediment), calculated for semipaleopotamonic oxbow lakes is reversed than the ratio W/TS (water / total sediment). This order reflects the real state of degradation and indicates a correlation between the thickness of the soft sediment and the state of the environment. It can be concluded, that the amount of sediment depends on the intensity of water exchange. Due to damming of water, four from oxbow lakes, ie. Halásztelki, Félhalmi, Túrtői and Kákafoki have constant possibility of gravitational water exchange (Józsa *et al.* 1996). In the case of other oxbow lakes, it is possible only by pumping – because of the costs, they are “refreshed” only occasionally or in emergency situations (Table 2).

Measurements of the redox potential in the sediment

Redox potential is one of the most critical factors of the aquatic environment, because it affects on a number of biological processes and chemical. Manipulation of this factor may serve as the cheapest way to improve the environment of a water ecosystem. There is a correlation between the values of redox potential and biological processes. Below – 140 mV, degradation of organic material take place anaerobically. In the field of anaerobic sulfur ion it is formed. In the range of from – 140 to + 325 mV optionally anaerobic decomposition takes place, and over +325 mV only under aerobic conditions. During the facultatively anaerobic conditions, in the range +75 + 150 mV disappears NO^{3-}, in the range of +325 to +100 mV NO^{3-} acts as an oxidant. In aerobic condition (from +325 to +375 mV) O_2 disappears and above 375 mV a significant amount of Mn^{2+} ions and Fe^{2+} are formed (Jorgensen 1989). Scale of nitrification is dependent on redox potential and at low levels of oxygen can occur denitrification. At low values of this potential the part of the bound phosphorus may be released from the sediment. Therefore dominance of anaerobic degradation in sediment can affect the rate of water eutrophication. Ranking of oxbow lake in terms of the measured redox potential value of sediments in both years are shown in Table 3. It was found that in the paleopotamonic group the redox environment has improved in the: Kecsegészugi, Németzugi and Bónomzugi oxbow lakes (reservoirs lying among farmlands). The environment has not changed significantly in the: Templomzugi, Hantoskerti and Révzugin oxbow lakes (one side of the border with the built-up areas). While the deteriorated state of the environment was observed in the Álomzugi oxbow lake, which is polluted by municipal wastewater and Harcsási oxbow lake, situated among areas of intensive crops. In the oxbow lakes belonging to the semipaleopotamonic group an inverse trend was observed. Clearly deteriorated state of environment was observed in the Halásztelki oxbow lake.

Assessment of spawning areas

In the case of oxbow lakes belong to parapotamonic type, still about 43% of waterside are covered with roots, which are a suitable substrate for fish spawning, and approximately 15% of the length of the waterside is covered with underwater branches, making these sections as good hiding places for juvenile fish. Unsuitable for spawning are primarily sections without vegetation and watersides, which are overgrown with reeds (about 10%).

In the case of oxbow lakes belong to paleopotamonic type, an average of only about 5% of waterside is useful as spawning grounds. It can be argued that this type of waters drastic decline in spawning places mainly due to the overgrowing waterside thick reeds. Anthropogenic impact is noticeable only in a fragmented sections without reeds. Percentage share of fragments unsuitable for spawning is the same as before. The sections differ only in the type of coverage the waterside.

The quantity and quality of spawning areas and hiding places largely determines of the species composition of the fish fauna of the ecosystem. Only in a few works, data on the species composition of fish in the Hármas- Körös river basin can be found (Györe, Oláh 1988; Györe 1993; Józsa 1994; Sallai 1995).

In the oxbow lakes, in which rated the status of spawning areas, the number of species of fish was 14 (Aranyosi, Álomzugi) and 20 (Kákafoki), and in the Hármas- Körös river – 29 (Györe, Sallai 1998). Large variations were found in the species composition of the fish fauna of each oxbow lakes. Species from stagnophilic group (mainly of the litophilic reproductive group) dominated in parapotamonic Aranyosi oxbow lake. It was also found one reophilic species *(Leuciscus cephalus)* and one invasive *(Pseudorasbora parva).* In the paleopotamonic Álomzugi oxbow lake and semipaleopotamonic Kákafoki oxbow lakeit was found four invasive species: *Pseudorasbora parva, Ictalurus nebulosus, I. melas* and *Lepomis gibosus.* Based on pooled data the impact of human on the decrease in the number of spawning areas, could not be clearly demon strated. In addition, building over waterside reduced area of potential hiding places for juvenile stages, and negatively affected their survival (Józsa, Oláh 1996).

Table 2. The ration of soft sediment cumulation in selected oxbow lakes (source: own study)

The name of oxbow lake	W/SS ratio	Ranking based on W/SS ratio	W/TS ratio	Ranking based on W/TS ratio
The parapotamonic oxbow lakes				
Aranyosi	9.00	1	1.74	1
The paleopotamonic oxbow lakes				
Csókási	2.64	1	0.86	1
Hantoskerti	2.30	2	0.71	2
Álomzugi	2.08	3	0.58	3
Révzugi	1.46	4	0.38	4
The semipaleopotamonic oxbow lakes				
Halásztelki	10.18	1	0.93	9
Félhalmi	9.07	2	0.98	8
Túrtői	7.17	3	1.03	7
Kákafoki	6.55	4	1.18	6
Harcsási	5.83	5	1.21	5
Templomzugi	4.74	6	1.27	4
Németzugi	3.98	7	1.52	3
Bónomzugi	3.34	8	1.85	2
Kecsegészugi	3.09	9	1.86	1

Table 3. Comparative classification of studied oxbow lakes in terms of redox potential of sediment (RPS) value in 1992 and 2006. (source: own study)

The name of oxbow lake	The mean value of RPS [mV]		Classification		The change direction
	1992	2006	1992	2006	
The paleopotamonic oxbow lakes					
Harcsási	61	107	1	7	+
Álomzugi	50	–59	2	8	-
Templomzugi	–16.5	64.5	3	4	+
Hantoskerti	–104	–21	4	5	+
Bónomzugi	–110	38	5	3	+
Németzugi	–129	73	6	2	+
Kecsegészugi	–171	79	7	1	+
Révzugi	–185	–153	8	6	+
The semipaleopotamonic oxbow lakes					
Halásztelki	116	87	1	4	–
Túrtői	66	105	2	3	+
Kákafoki	61	124	3	2	+
Félhalmi	–50	179	4	1	+

Optimal fishery management

On the Hungarian oxbow lakes intensive fishery management started in the sixties of the last century, it was continued till the nineties, and all this time it was conducted in a very similar way. During this period, oxbow lakes were fish stocked in very similar way to those used in the fishery farm, in which were the rearing of carp in polyculture with Asian herbivorous fish (Antalffy, Tölg 1968). In this technology, the percentage of silver carp stocking was 66%, 29% carp and grass carp 4%; while the share of prey species (catfish, pike, perch, eel) accounted for less than 1%. This way of farming resulted in the elimination from the composition of the fish fauna of oxbow lakes the native fish species and the further acceleration the process of eutrophication. The negative effects of such specifically conceived fishery management, affected not only small reservoirs, as oxbow lakes, but even Lake Balaton, in which indigenous species were dominated by silver carp (Tátrai *et al.* 2002, 2003, 2004, 2005). In the catches on the oxbow lakes exploited by the Fishing Cooperative regularly occurred 14 species of fish. Percentage of dominant species in the catches was slightly lower than in the case of stocking (carp of 40.3%, 6.4% carp, grass carp 0.6%). It follows that the fishery management in the oxbow lakes relied primarily on cheap production of silver carp, at the expense of native species. When assessing the stocking and catches in 1998–2005 it can be seen that the manner of exploitation depended not so much on economic expectations, but on the financial possibilities of the user. Mistakes in the fishery management consisted not only on the revaluation of production capacity and excessive stocking, it were not taken into account the environmental requirements and too much emphasis was placed on indicator of biomass of catched fishes. In carp dominated the stocking, but still it was too small proportion accounted for predatory fish. In this way effect "bottom up" was reinforced and it was adjusted to the deterioration of water quality (Mátyás *et al.* 2004). When planning stocking, the operation of bio manipulation were not used to improve water quality (Prejs 1978, Benndorf 1995, Tátrai *et al.* 1998, Dawidowicz *et al*. 2002). It should be noted that the level of stocking, especially predatory fish, was in contrary to the principles of rational fisheries management. Currently, the first period of contracts for the use of oxbow lakes is ending. During new adjudication by tender should be preferred offers that take into account both the needs of anglers, as well as the requirements of environmental protection, especially in those areas that do not have extreme degradation. In the stocking it should take into account the conduct of rational fisheries management, with the participation of predatory fish in the tank should be in the range of 20 ÷ 30%, while reducing the share of carp and preferences for its wild varieties (Tátrai *et al*. 1997). Only in this way it can maintain or improve the quality of water in these valuable aquatic ecosystems.

Conclusions

The obtained results led to the following conclusions:

- Tested oxbow lakes belong to different categories, they were classified not only on the basis of morphological features, but also based on how water exchange.
- Anthropogenic factors had a negative effect on the conditions of fish reproduction and survival of their juvenile stages.
- The fishery management was not a factor differentiating the individual water regions, but had an impact on the ecological status.
- Statistical analysis of data showed that the abiotic factor which differentiating environment of oxbow lakes is the redox potential of sediment.
- Measurements of redox potential in sediments conducted every few years, allows to predict the direction of environmental changes in the oxbow lakes.
- For the maintenance and / or improvement of the natural environment of the individual oxbow lakes significant impact may have fishery management, carried out in the following years.
- On the basis of the factors presented at this paper, a quick "grading" of each oxbow lakes in Hungary can be probably made.

Disclosure statement

Authors declare that they have not any competing financial, professional, or personal interests from other parties.

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