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The muddy bottom sediments of the old river beds of the lower Vistula

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Abstract: The main objective of this study was to characterize the muddy bottom sediments of three hydrologically different old river beds of the lower Vistula, located in the vicinity of Toruń: Port Drzewny, Martwa Wisła and Przybysz. Samples were taken at monthly intervals from April to November 2015 from two (Martwa Wisła and Przybysz) or three sampling sites (Port Drzewny) located in the central parts of the reservoirs. The bottom sediments of these water bodies were characterized by a low water content and organic matter content expressed as a percentage of dry weight, high organic matter content expressed in units of weight, as well as a high sediment oxygen demand. The most distinct reservoir was Martwa Wisła, most likely due to the lack of a connection with the River Vistula.

Key words: old river beds, bottom sediments, water content, organic matter content, sediment oxygen demand

Introduction

Old river beds are small water bodies, located in a river valley, connected permanently, periodically or completely separated from the riverbed (Żmudziński et al. 2002), created in a natural way by cutting the neck of a meander of a river or in an artificial way, as a result of hydrotechnical activities (Jezierska-Madziar 2005).

In terms of morphometric features old river beds are similar to shallow lakes; however, the reservoirs under study are characterized by a greater variability of environmental conditions (Obolewski and Glińska-Lewczuk 2011). This particularly concerns old river beds connected with the river, but also the reservoirs isolated from waters of the river which become flooded when the water level in the watercourse is high. Therefore, the functioning of these water bodies to a very large extent is dependent on the degree of connection with the river. Isolated oxbow lakes create a completely different type of aquatic environment in comparison to the river, in turn, old river beds permanently connected to a watercourse constitute a kind of intermediary between the river and the lake (Malard et al. 2000).

Bottom sediments and processes occurring in their surface layer – the exchange of substances between the sediments and water – play an extremely important role in the functioning of aquatic ecosystems. In oxbow lakes and other shallow water bodies, these processes are much more important than in deep lakes. This is due to their polimictic character which facilitates the flux of nutrients in both: sediment-water interface, as well as throughout the whole water column, contributing to the increase of productivity of these reservoirs. The degree of connection to the watercourse also has a great impact on these processes in the old river beds and generally contributes to the increase of water dynamics. Hydrological connectivity with the river is therefore one of the key factors shaping the environment of old river beds (Junk et al. 1989; Ward et al. 2002; Gallardo et al. 2012).

The role of oxbow lakes in the functioning of river ecosystems has been long undervalued by scientists (Koc et al. 2009). This neglect is quite surprising because they are very specific water bodies, characterized by considerable dissimilarity, depending on their connection to the river. Therefore, studies on their abiotic environment, including bottom sediments that play a special role in the aquatic ecosystem would seem to be very important since they offer the chance to enhance our understanding of the functioning of these water bodies, as well as the assessment of habitat conditions for aquatic organisms.

Thus, the main objective of this work was to analyze the physico-chemical parameters of the muddy

bottom sediments in three hydrologically different old river beds of the lower Vistula River: Port Drzewny, Martwa Wisła and Przybysz.

It was assumed that a connection with the river would significantly affect the measured parameters of the bottom sediments, and that Martwa Wisła should show the greatest differences among the studied reservoirs and should also most resemble a shallow lake, perhaps due to its lack of any connection with the River Vistula.

Methods

Samples were taken at monthly intervals from April to November 2015 at two (Martwa Wisła and Przybysz) or three sampling sites (Port Drzewny) located in the central parts of the reservoirs. However, in Przybysz, the sampling in October was abandoned, due to the very low water level (< 0.2m). Selected parameters of the muddy bottom sediments were measured in their surface layer (0–5 cm) taken by means of a Kajak core sampler with a catching area of 10 cm^2.

It was assumed that one of the factors that may have a significant impact on the physico-chemical properties of the sediments may be the amount of light reaching the bottom of the reservoir. In order to determine this parameter the product of the vertical attenuation coefficient of light under water (E) and the depth of the sampling site (D) was calculated. Attenuation coefficient was calculated according to the following equation (Scheffer 1998):

$$E = \frac{ln(I_0/I_z)}{z}$$

where: I_0– light intensity just under the water surface [lx], I_z – light intensity at a depth z [lx], z – depth of measurement [m].

This index $E \times D$ allows the light conditions at the bottom to be defined, regardless of the changes in the intensity of light reaching the water surface. The higher value, the less light on the bottom (darker).

The water content of the bottom sediments was determined by oven-drying to a constant weight at 104°C. This was calculated from the difference in weight of the sediments before and after drying.

The organic matter content in the sediments was measured by igniting dried sediments at 550°C for 2 hours. This parameter was presented as the percentage of dry weight of sediments and the amount of dry weight of organic matter in milligrams per unit of fresh sediment volume (10 cm^3). The difference between these two quantities is related to the water content in the sediments. If the organic matter content expressed as a percentage of the sediment dry weight is similar, the sediments with lower water content always have more organic matter (in milligrams).

Sediment oxygen demand (*SOD*) was estimated by adding 300 ml of 100%-oxygen saturated tap water to a special dark glass dish (preclusive of the photosynthesis of the phytoplankton) containing 10 cm^3 of fresh sediments. The measurements were performed at a constant temperature (20°C) for one hour using an oxygen probe placed in the neck of the dish, to prevent the exchange of oxygen between the bottle and the environment. In order to sustain the water flow around the membrane of the oxygen sensor, a magnetic stirrer was used.

The relationship between the studied physico-chemical parameters of bottom sediments was determined by the Pearson correlation coefficient.

Study area description

The study was conducted in three old river beds of the lower Vistula River, located in the vicinity of Toruń: Port Drzewny, Martwa Wisła and Przybysz. They are quite shallow and young reservoirs, created after the regulation of the river in the nineteenth century (Dembowska and Napiórkowski 2012). During the research the water level in the Vistula was declining gradually, resulting in strong, successive shallowing of the analyzed reservoirs (significantly lower in Martwa Wisła, which has no connection with the river) (Table 1).

Port Drzewny is the largest of the analyzed water bodies (Table 1), located 6 km to the West of Toruń, permanently connected with the Vistula. In the direct catchment woodlots, grasslands and agricultural areas dominate. The area to the north of the old river bed is developed and used recreationally. This reservoir has the highest water dynamics among the water bodies

Table. 1. Morphometric data of the water bodies under study

Water body	Surface area [ha]	Maximum length [m]	Maximum width [m]	Depth [m]		
				1	2	3
Port Drzewny	64	1800	350	0.5–2.6	0.6–2.6	0.4–2.5
Martwa Wisła	2	640	50	1.7–2.3	1.2–1.6	–
Przybysz	1	160	50	0.2–1.9	0.2–1.9	–

1, 2, 3 – No. of the sampling stations.

under study due to its large surface area and parallel arrangement in relation to the direction of prevailing winds in Poland. In mid-summer, during the research, there was an intensive development of submerged macrophytes at the bottom of the old river bed as a result of a significant decline in the water level in the Vistula. At sampling station No. 3 (which was least under the influence of the river) submerged vegetation overgrew almost the whole water column. In turn, helophytes were very poorly developed.

Martwa Wisła is located in Toruń, completely cut off from the influence of the Vistula waters, surrounded by century-old trees. Its small area, weak exposure to wind action and lack of connection with the river, result in the low dynamics of its waters. Relatively high water transparency enables the development of submerged vegetation. During the research, in the vicinity of sampling station No. 2 a large part of the bottom was covered with elodeids. The banks of the reservoir are also abundantly overgrown by emergent vegetation.

Przybysz is a small reservoir, also located in Toruń, close to Martwa Wisła. It connects periodically with the river by means of a channel with a relatively large surface area. However, there is no connection with the Vistula when the water level in the river is low . This situation prevailed from June to the end of the research, when the water level in the river did not exceed 2m. The banks of the reservoir are quite high, covered largely by deciduous trees. On the north side, a large area of the catchment is occupied by allotments. Przybysz has little exposure to wind action and its small size limits the mixing of the water. In the summer the low water level in the River Vistula enabled the development of submerged vegetation in the reservoir, but their density was relatively small. However, there was no emergent vegetation.

Results

Light conditions at the bottom were determined on the basis of the index $E \times D$. The average values of this parameter for the studied old river beds ranged from 2.7 (Port Drzewny and Przybysz) to 3.1 (Martwa Wisła), while the limit above which the light did not reach the bottom of the analyzed reservoirs in a sufficient amount to provide a positive net photosynthesis was $E \times D = 4.4$. This indicator showed clear horizontal differences in the water bodies: Martwa Wisła and Port Drzewny.

The bottom sediments of the studied old river beds differed significantly in respect to water content (WC) (Fig. 1). The highest value of this parameter was observed in Martwa Wisła (average – 84.3%), while the lowest in the Przybysz reservoir (77.4%). There were no

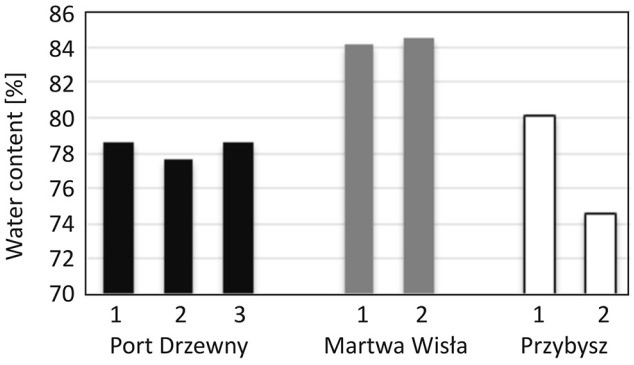

Fig. 1. Sediment water content in percentages at the studied sampling stations (average values)

significant horizontal changes in water content of bottom sediments in Port Drzewny and Martwa Wisła.

Similarly to water content, clear differences in organic matter content expressed as a percentage in the sediments between old river beds were found (Fig. 2). The highest values of this parameter were observed in Martwa Wisła (average – 14.3%), while the lowest in Przybysz (average – 10.7%). There were no significant horizontal differences (with the exception for Przybysz).

The organic matter content expressed in milligrams of dry weight per unit of fresh sediment volume also showed clear differences between the old river beds (Fig. 2). The lowest values of this parameter were found in Martwa Wisła (241 mg), and the highest in Port Drzewny (292 mg). The organic matter content expressed in this way showed smaller horizontal differences in the studied water bodies than the organic matter content expressed as a percentage.

In the case of the sediment oxygen demand (*SOD*) significant differences between the old river beds were also observed (Fig. 3). The highest quantities of oxygen were consumed by sediments of Przybysz (average – 16.3 mg O_2 dm^{-3} h^{-1}). Much lower values of

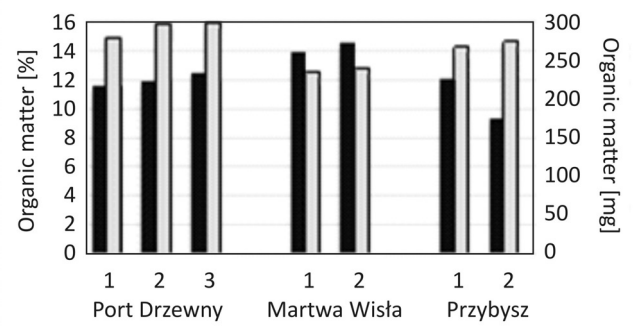

Fig. 2. Organic matter content expressed as a percentage (black bars) and in milligrams (grey bars) at the studied sampling stations (average values)

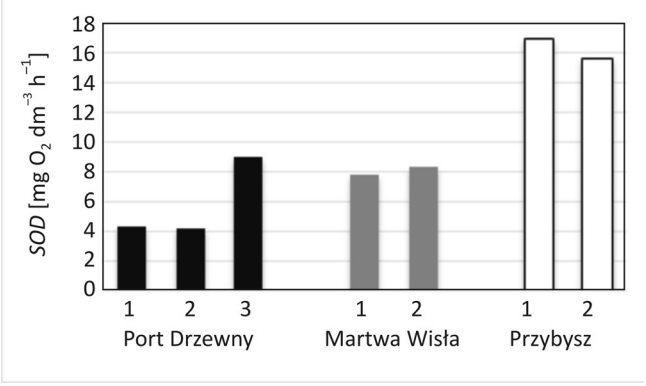

Fig. 3. Sediment oxygen demand [mg O_2 dm^{-3} h^{-1}] at the studied sampling stations (average values)

this parameter were found in Martwa Wisła (8.0 mg O_2 dm^{-3} h^{-1}) and in Port Drzewny (5.8 mg O_2 dm^{-3} h^{-1}). Significant differences between the sampling stations were observed only in Port Drzewny.

The amount of light at the bottom ($E \times D$ index) positively correlated with the organic matter content, both expressed as a percentage ($r = 0.36$; $p = 0.0129$) and in milligrams ($r = 0.30$; $p = 0.041$), while it correlated negatively with *SOD* ($r = -0.33$; $p = 0.0268$).

The water content of bottom sediments showed a positive correlation with the organic matter content expressed as a percentage ($r = 0.78$; $p < 0.0001$), and a negative correlation with the organic matter expressed in milligrams ($r = -0.56$; $p < 0.0001$).

There were no correlations between the organic matter content expressed as a percentage and in milligrams ($r = 0.06$; $p = 0.6887$), which justifies the legitimacy of presenting data in two ways.

There was also a negative correlation between *SOD* and organic matter content expressed in units of weight ($r = -0.30$; $p = 0.0453$).

Discussion

Based on the $E \times D$ index, it was found that light reached the bottom in a sufficient amount to provide a positive net photosynthesis at all sampling sites (except for the first sampling date). There were clear horizontal changes of this index in Port Drzewny and Martwa Wisła which resulted from variations in water transparency (Port Drzewny) and differences in depth (Martwa Wisła) at the different sampling sites.

The water content of bottom sediments in the reservoirs under study was not very high (77.4–83.4%). Analogous values in the shallow lakes studied by Żbikowski (2011), showing a strong resemblance in terms of morphometric features to the old river beds, were significantly higher (93.9–98.3%). The reason for the relatively low water content of sediments in the studied water bodies is most likely to be a low organic matter content in the sediments, expressed as a percentage of dry weight. The confirmation of this relationship is a strong, positive and significant correlation between these parameters.

The organic matter content in the muddy sediments of the studied old river beds, expressed as a percentage of dry weight was quite low (10.7–14.3%) compared to the shallow lakes (33.3–77.3%) (Żbikowski 2011). This situation is surprising because old river beds are shallow, eutrophic reservoirs with high biological production and a large amount of poorly decomposed autochthonous matter reaches their bottom (Cornett and Rigler 1987; Ellis and Stefan 1989). The explanation for the low values of this parameter may be an intense mineralization of organic matter, which can be inferred from the high temperature of the sediments in the growing season and good oxygenation of the near bottom layer of water (Mimier unpubl. data), as well as the high values of the sediment oxygen demand. There is a strong possibility that a connection with the river also played a key role, as the river waters, rich in inorganic matter, are able to enter old river beds (Dembowska 2002).

Also somewhat surprising were significant horizontal differences of the organic matter content in the sediments, expressed as a percentage, in the Przybysz reservoir. Unfortunately, on the basis of the present study it is difficult to identify the cause of this situation. The positive, statistically significant correlation between this parameter and the $E \times D$ index shows that the highest organic matter content in the sediments was observed when a small amount of light reached the bottom, which suggests a slower mineralization of organic compounds under these conditions. This hypothesis is not confirmed in the literature, which suggests that the limiting factor for the decomposition of organic matter could be light, not its absence. This is due to the reduction of fungi activity on the illuminated bottom, which is more important in the mineralization of organic matter than bacteria (Denward et al. 2001).

In the studied old river beds the organic matter content, expressed in milligrams of dry weight per unit of fresh sediment volume, was significantly higher (241–292 mg) than in the shallow lakes (106–240 mg) (Żbikowski 2011). This parameter showed a negative correlation with water content of the bottom sediments.

Presenting the amount of organic matter in sediments in two ways (in percentage and in units of weight) seems to be reasonable because each of them provides other information about the conditions in the reservoir. This is confirmed by the lack of relationship between these two quantities. The organic matter content expressed in units of weight allows for a better

assessment of the availability of food for benthic organisms as it shows the real amount of organic matter in the sediments, while the share of organic matter expressed as a percentage of dry weight informs only about the quality of material contained in these sediments. Thus, the choice of the method of presentation of the data depends on the main purpose of the study.

The values of the sediment oxygen demand in the old river beds (5.8–16.3 mg O_2 dm^{-3} h^{-1}) were very high compared to the shallow lakes (1.1–6.0 mg O_2 dm^{-3} h^{-1}) (Żbikowski 2011). It is worth noticing that bottom sediments of analyzed reservoirs differed significantly from each other in terms of this parameter. The highest quantities of oxygen were consumed by sediments of the Przybysz reservoir, indicating a very intense mineralization of organic matter in this reservoir (Żbikowski unpubl. data). The confirmation of the relationship between the intensity of decomposition of organic compounds and the sediment oxygen demand may be a significant, negative correlation between sediment oxygen demand and the organic matter content expressed in milligrams. The results also suggest that the higher the water dynamics, and as a consequence probably more frequent resuspension of sediments, the lower the value. It is likely that in Przybysz, due to its small size and low exposure to wind action, the resuspension occurred with low intensity and frequency. This may explain the high values.

Clear horizontal changes of the sediment oxygen demand were observed only in Port Drzewny, which showed large differences in the coverage of the bottom with macrophytes at the different sampling sites. The values of the sediment oxygen demand were two-fold higher at the sampling station, where the submerged vegetation overgrew almost the whole water column. However, more detailed studies are necessary to find out the exact mechanism of the effects of macrophytes on sediment oxygen demand.

It is possible that other factors, which are not studied in this work, influenced such high values of oxygen uptake by the sediments. According to Wiśniewski (1989) the loss of oxygen in the water is the sum of chemical and biological processes; but in shallow reservoirs this parameter depends mainly on the chemistry of the sediments (Wang 1980).

Conclusions

In terms of morphometric features the old river beds are similar to shallow lakes; however, there are differences in bottom sediments between these reservoirs. The sediments of the reservoirs under study compared to the sediments of lakes with a similar depth differed in: lower water and organic matter content expressed as a percentage and higher organic matter content in milligrams, as well as higher values of the sediment oxygen demand. On the basis of the analyzed parameters the reservoir the most resembling a shallow lake is Martwa Wisła, perhaps due to the lack of a connection with the River Vistula.

References

Cornett R.J., Rigler F.H., 1987, Vertical transport of oxygen into the hypolimnion of lakes, Can. J. Fish. Aquat. Sci. 44: 852–858.

Dembowska E., 2002, Fitoplankton Zbiornika Włocławskiego w latach 1994–2000 (Phytoplankton of the Włocławek Reservoir during the years 1994–2000) [PhD thesis], Zakład Hydrobiol. UMK, Toruń (in Polish).

Dembowska E., Napiórkowski P., 2012, Dlaczego warto chronić starorzecza? (Why do we have to protect old river beds?) Kosmos 61(2): 341–349 (in Polish, English summary).

Denward C.M.T., Anesio A.M., Graneli W., Tranvik L., 2001, Solar radiation effects on decomposition of macrophyte litter in a lake littoral, Arch. Hydrobiol. 152(1): 69–80.

Ellis C.R., Stefan H.G., 1989, Oxygen demand in ice covered lakes as it pertains to winter aeration, Water Resour. Bull. 25(6): 1169–1176.

Gallardo B., Espanol C., Comin F. A., 2012, Aquatic metabolism short–term response to the flood pulse in a Mediterranean floodplain, Hydrobiologia 693: 251–264.

Jezierska-Madziar M., 2005, Wstęp (Introduction), [in:] Jezierska-Madziar M. (ed.), Starorzecza jako istotny element ekosystemu rzecznego (Oxbow lakes as a significant element of a river ecosystem), Wydaw. ARPoz., Poznań: 9–10 (in Polish).

Junk W. J., Bayley P. B., Sparks R. E., 1989, The flood pulse concept in river-floodplain systems, Proc. of the International Large River Symposium (LARS), Can. Spec. Publ. Fish Aquat. Sci. 106: 110–127.

Koc J., Kobus Sz., Glińska-Lewczuk K., 2009, The significance of oxbow lakes for the ecosystem of afforested river valleys, J. Water Land Dev. 13a: 115–131.

Kuehn K.A., Lemke M.J., Suberkropp K., Wetzel R.G., 2000, Microbial biomass and production associated with decaying leaf litter of the energent macrophyte *Juncus effuses*, Limnol. Oceanogr. 45(4): 862–870.

Malard F., Tockner K., Ward J. V., 2000, Physico-chemical heterogeneity in a glacial riverscape, Landsc. Ecol. 15: 679–695.

Obolewski K., Glińska-Lewczuk K., 2011, Effects of oxbow reconnection based on the distribution and structure of benthic macroinvertebrates, Clean – soil, air, water 39(9): 853–862.

Scheffer M., 1998, Ecology of shallow lakes, Chapman and Hall, London, 357 pp.

Ward J. V., Tockner K., Arscott D. B., Claret C., 2002, Riverine landscape diversity, Freshwat. Biol. 47(4): 517–539.

Wiśniewski R., 1989, Sediment oxygen demand in the Włocławek Dam Reservoir and in two different trophy lakes: role of resuspension, [in:] Salanki J., Herodek S. (eds), Conservation and Management of Lakes, Akad. Kiadó, Budapest: 177–185.

Wang W., 1980, Fractionation of sediment oxygen demand, Water Res. 14: 603–612.

Żbikowski J., 2011, Makrozoobentos centralnych części płytkich jezior nizinnych różnych typów na tle wybranych parametrów abiotycznych wody i osadów dennych (Macrozoobenthos of central parts of shallow lowland lakes of different types against a background of selected abiotic parameters of water and bottom sediments), Wydaw. Nauk. UMK, Toruń, 206 pp. (in Polish, English summary).

Żmudziński L., Pęczalska A., Korzeniewski K., 2002, Słownik hydrobiologiczny. Terminy, pojęcia, interpretacje (Hydrobiological dictionary. Terms, concepts, interpretations), Wydaw. Nauk. PWN, Warszawa, 287 pp. (in Polish).