Hydromorphological assessment of the anastomosing section of the Narew River after restoration

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Abstract: Five parallel channels of the Narew River (NE Poland) were hydromorphologically assessed with the River Habitat Survey (RHS) method. Four out of the five studied channels were partly separated from the functioning system of the anastomosing river by a dike for more than 20 years, and were subjected to gradual overgrowing and shallowing. In the 1990's and in 2002, a number of renaturation measures were implemented, restoring sufficient discharge for the channels to make them active again. The Habitat Modification Score (HMS) obtained as a result of the survey only classifies the fragment ecologically to the third class of streams with high HMS value in the case of the current main channel of the Narew River (largely formed in an artificial manner). This suggests substantial anthropogenic changes in the river channel and its vicinity. The aggregate values of the Habitat Quality Assessment (HQA) index suggest the preservation of numerous environmentally valuable elements at all of the five studied sites of the anastomosing Narew River system. This even concerns channels which remained almost separated and functioned as oxbow lakes for more than 20 years. The highest HQA values were recorded in the case of the channel constituting the main channel before the regulation, and a neighbouring regulated channel currently fulfilling the function of the main water course in this cross-section. In spite of long-term negative changes, the studied fragment of the ecosystem of the anastomosing river is distinguished by high resistance to "anthropogenic stress", and high capacity for spontaneous restoration of a state close to the natural one. Although lotic ecosystems constitute elements of the natural environment particularly sensitive to anthropopressure, they retain the ability to regenerate for a long time, under the condition of providing them with relevant hydrological and ecological conditions.

Key words: river habitat survey, anastomosing river, restoration

Introduction

The issue of progressing degradation of riverine environments in Europe is still valid, and the Water Framework Directive forces corrective measures to be undertaken, including restoration projects (Moss 2004). In Poland, attempts at the renaturation of small rivers have been undertaken (Jędryka 2003; Zieliński et al. 2008), but large transit rivers or anastomosing rivers have not been subject to renaturation before, mainly due to lack of relevant resources. Costs incurred for renaturation depend on the size of the river, catchment management, and largely on the degree of preservation of natural elements of the channel and valley. If the river flows through scarcely populated areas, and thus its valley is located in such an environment, then restoration requires fewer resources due to the high degree of

preservation of the original state of the river (Żelazo and Popek 2002). Such an example is the Narew River, still with a high degree of naturalness, with a large part of it under national park protection. The Narew River represents a specific type of river, namely the anastomosing river. It flows in a number of channels which often divide and connect, developing an irregular river network. The channels of the Narew River usually have low inclination and varied depth. A specific feature of anastomosing rivers is the fact that their channels are composed of organic formations, are usually stable, and their position rarely changes (Banaszuk 2004a). However, in many places, particularly in the channel bed sediments, the proportion of organic material is insignificant, because the sediments here are mainly composed of loose sand and other mineral fractions. The slow current of the river and richness of peat habitats

determined the development of a specific, rich fen habitat, unique on the European scale, constituting the life environment of waterfowl. In the 1970's, regulation of the Narew River commenced, involving the construction of an entirely new channel from the confluence of the Narew and Biebrza Rivers up the river course. Advanced melioration works were discontinued in the 1980's at the stage of digging a new Narew River channel in the vicinity of the Rzędziany village (the area subject to this study). The effect of the newly constructed channel on the water regime of the anastomosing valley was very destructive. Within the range of direct influence of the new channel of the Narew River, mire habitats seriously declined, and are still partly degrading. The restoration of the original state from before melioration was not possible any more due to a change in cultivation, change in ownership relations, irreversible losses resulting from fires, and more than 20 years of draining by the new and relatively deep river channel. However, important interference was still possible, involving the restoration of side channels which took over a significant role in water transport in the area.

The comparison of the hydromorphology of five parallel channels involved the application of the River Habitat Survey (RHS) method (EA 2003). The method is among the most popularised methods in Europe (Szozkiewicz et al. 2006). It has been applied on a large scale in Great Britain since the early 1990's (Logan 2001), and

became popular among others in Germany, Sweden, Denmark, the Czech Republic, Latvia, and in a modified version also in Italy, Greece and Portugal. In Poland, the method has been used since the second half of the 1990's. So far, it has been applied in the analysis of several hundred sections of rivers throughout the country. This constituted the basis for evidencing the possibility of the application of the RHS system in the hydromorphological assessment of rivers as defined in the Water Framework Directive (Szozkiewicz et al. 2007).

In the current hydromorphological studies in Europe there is a lack of assessment on anastomosing rivers. Therefore, the objective of the paper was the assessment of the degree of transformation and level of preservation of five parallel channels of the anastomosing Narew River at the boundary of the Narew National Park with varied intensity of hydrotechnical measures implemented in the past.

Study area

The field RHS research was conducted in the growing season in late spring 2011. The study area is located in the buffer zone of the Narew National Park, at its northern boundary. The research cross-sections were distributed on five parallel channels of the anastomosing system of the Narew River, in the vicinity of the Rzędziany-Pańki dike (Fig. 1, Tab. 1).

Fig. 1. Map of the buffering zone of Narew National Park with the location of the River Habitat Survey sites

Table 1. Location of RHS sites on the anastomosing Narew River with selected river channels characteristic, and dominating flow types: SM – smooth, RP – rippled, NP – no perceptible

River channel number	GPS location		Water width [m]	Water depth [m]	Dominant type of water flow
	check spot No 1	End of site			
1	N 53°09'08.8" E 22°52'32.6"	N 53°09'06.0" E 22°53'01.8"	11	3.2	SM 80% RP 20%
2	N 53°08'31.0" E 22°52'32.1"	N 53°08'29.9" E 22°52'58.3"	28	3.5	RP 60% SM 40%
3	N 53°08'44.4" E 23°09'93.5"	N 53°08'26.6" E 22°52'37.1"	3	1.5	NP 100%
4	N 53°08'17.7" E 22°52'50.1"	N 53°08'20.5" E 22°52'53.3"	5	1.7	NP 80% SM 20%
5	N 53°08'04.2" E 22°52'38.2"	N 53°08'10.2" E 22°52'55.8"	7	2.2	NP 40% SM 40% RP 10%

In this area, restoration of the valley was conducted, involving increasing the water stage and increasing the flow capacity of channels earlier flowing through small pipelines under the dike. The Narew River valley between Suraz and Żółtki is currently largely under legal protection, and was still fully natural in the 1960's (Banaszuk 2004a). During that time, two zones were distinguished – wetland and paludificated – with insignificant differences in hydrological-vegetation terms, determined by natural factors (Banaszuk 2004b). After the regulation works commenced in the 1970's, involving among others digging a new channel from the confluence of the Narew and Biebrza Rivers to Rzędziany village, water relations in the valley drastically deteriorated, and substantial drainage of the wetlands and side channels of the Narew River occurred (Banaszuk 1996). The occurring climatic changes and annual precipitation total decreasing in the latest years (Górniak 2000) additionally worsened the specific hydrological conditions of the valley. The regime of water outflow from the catchment was changed in 1990 as a result of the construction of the Siemianówka reservoir in the upper part of the river catchment (Górniak and Piekarski 1999; Grabowska and Mazur-Marzec 2011). After the construction of the reservoir, spring floods below the reservoir occur very seldom. In order for the state of the environment to improve, quite a radical change in the water relations was required. The specific hydrological regime of the valley, mainly expressed in long floods and intensive inundation with groundwaters, was clearly disturbed. The concepts of restoration of the Narew River valley below the Rzędziany-Pańki dike were already developed in the 1980's (Okruszko 1989). In 1993, the North Podlasie Society of Bird Protection (later Polish Society of Bird Protection)

together with the European Nature Heritage Fund, Euronatur, initiated an undertaking called the Narew River Project. Its main assumption was nature protection in the region of the Wetland Narew River Valley with special consideration of hydrological conditions, and an integrated programme of economic development of the area, based on its environmental values (Suchowolec 2012). Since 1996, simultaneously with the construction of dams to raise the water level, also works related to unclogging and clearing of overgrown oxbow lakes were conducted (Mioduszeński 1999). They involved cutting out bushes and trees from the channel beds and scarp banks. As a result of the restoration, more than 14 km of current river channels were restored. The most important measure involved connecting the water system of the Narew National Park with the restored oxbow lakes of the buffer zone through the construction of three water passages on the line of the Rzędziany-Pańki dike. Bridges and passages related to the renaturalisation works conducted were located outside the described fragments of channels on which RHS study sections were located. Reclamation works on meadows and pastures were simultaneously conducted, involving removal of trees and bushes (Suchowolec 2012).

Methods

The River Habitat Survey is a system of valuation of habitat character and quality of rivers mainly based on the assessment of the hydromorphological structure. The study is based on the description of a river section of 500 m, and it is implemented in two stages (EA 2003). The first stage involves the description of the basic morphological features of the channel

and banks in 10 cross-sections distributed every 50 m. It considers physical parameters (recorded in a cross-section with a width of 1 m) such as the predominant type of discharge, bed and banks substrate, level of erosion of river banks, manner of sedimentation, type of flow, and technical reinforcements of scarps and the channel. Additionally, in cross-sections with a width of 10 m, the aquatic and bank vegetation structure as well as bank management is determined. The second stage of the study involves a synthetic description of the entire 500 m section of the river subject to RHS analysis. It considers all the morphological formations and transformations not registered at the previous stage. The synthetic description is supplemented with the description of the valley, dimensions of the channel (height of the banks, width and depth of the channel), riffles, sedimentation material, number of water constructions, etc. (Szozkiewicz et al. 2007). The tree cover of the banks is estimated for each of the banks separately. Additionally, other elements of the environment related to tree stands are described, such as the occurrence of underwater roots, fallen trees, or strong reduction of the flow capacity of the channel due to wood debris (Szozkiewicz et al. 2007).

The RHS method permits the determination of approximately 400 parameters describing the hydromorphological conditions of a studied section. The ordered system of control cross-sections provides extensive possibilities of application of various statistical techniques (Raven et al. 1998). An advantage of the RHS system is also the complexity of the description of the river together with its river valley at a distance of 50 m from the channel.

After data processing, synthetic indices are calculated, constituting a resultant of many single basic parameters permitting the assessment of hydromorphological parameters of the river in a numeric form. They include the following:

- Habitat Modification Score (HMS), determining the scope of transformations in the river morphology,
- Habitat Quality Assessment (HQA), based on the occurrence and diversity of natural elements of a river and river valley.

For synthetic indices HMS and HQA, threshold values of five classes of hydromorphological state were determined (Walker et al. 2002, Szozkiewicz et al. 2009). For the HQA index, the following ranges of particular classes were proposed: I: 109-135, II: 82-108, III: 55-81, IV: 28-54, V: 0-27. For the HMS index, the

following ranges of particular classes were proposed: I: 0-2, II: 3-8, III: 9-20, IV: 21-44, V: >45. Low HMS value suggests a lack of anthropogenic transformations of a river, and a high value indicates their high number. A high HQA value suggests the occurrence of numerous and varied elements of natural landscape in the vicinity of the river, and a zero result means a total lack of natural elements (Szozkiewicz et al. 2009).

Results and discussion

In the region of the Rzędziany-Pańki dike, the Narew River has no obvious valley sides and a flat bottom with an extensive flood terrace with a width of approximately 2 km. Among the five studied channels, the so-called main channel of the Narew River was distinctive (site 2). It was artificially shaped, and provided with an additional embankment. Significant straightening and deepening was observed in the channel (Table 1). In all five studied channels, no occurrence of water constructions was recorded which could greatly decrease the value of the Habitat Quality Assessment. Due to the typically lowland character of the river, the studied channels were distinguished by slow laminar flow not disturbing the water surface. The study revealed the predominance of three types of discharge: smooth, rippled and no perceptible (Table 1). The last of the discharge types mentioned occurred along the entire 500 m section of the river, at site No. 3. Unnoticeable water discharge in the channel permitted intensive development of macrophytes within the channel, and favoured the development of structural algae. At sites No. 1, 2, and 5, where rippled discharge was recorded, side bars and point bars appeared. However in the analysed fragments of the anastomosing section of the Narew River, no occurrence of vegetated bars was recorded, i.e. point or side bars which could have developed shortly before the survey. Vegetated point and side bars were numerous on the investigated Narew section. A single riffle appeared in the main channel of the Narew River (site 2) transporting the majority of the water of the system. Numerous pools were observed in all the channels except for channel No. 3 with practically stagnant water.

The Habitat Modification Score (HMS) reached high values only for the main channel of the Narew River (site 2; Fig. 2). Based on the recorded value of HMS = 41, the result classifies this fragment of the Narew River to the fourth ecological class of streams in the case of the hydromorphological assessment.

Fig. 2. Values of habitat modification score (HMS) and habitat quality assessment (HQA) on five different survey sites of the anastomosing Narew River

Such an HMS value suggests significant anthropogenic transformations both within the river and the surrounding valley. The synthetic HMS index reflects a very significant transformation of this part of the Narew River valley which was artificially shaped as a result of regulation conducted in the 1980's (Banaszuk 1996). High HMS values for the Narew River are also recorded in the further course of the river, where earlier studies showed the HMS value for the Narew River at the level of 38.3 (Szozkiewicz et al. 2009). The river is a specific ecosystem, where various features, including hydrochemical ones, can be subject to substantial changes along the river course (Zieliński et al. 2003). Therefore, the HMS for rivers should not be only based on the average value for the entire river, but rather on point or linear measurements. In many cases, a single high HMS value can obscure the good state of a river, e.g. in the case of the Mała Panew River – at one site HMS=32, and at the remaining four assessment points the values were close to zero (Czerniawska-Kusza and Szozkiewicz 2007). A similar situation occurs in the case of the anastomosing system of the Narew River. In the cross-section of the valley, the artificial river channel (site 2) considerably inflates the value of the entire system. Mean HMS for all the channels amounts to 9, and the mean excluding this site amounts to only 1. High HMS values of more than 20

are typical of anthropogenically transformed rivers, and those subject to, among others, hydrotechnical or urban development. In the case of the Biała River, a mean HMS value of 20.8 was recorded (Zieliński et al. 2012). The second class of ecological state concerns channel No. 3 of the Narew River (Fig. 2). This section of the river is located in the vicinity of the main channel of the Narew River, and its numerous anthropogenic elements considerably affect the neighbouring fragments of the valley. Values close to those obtained in the case of untransformed channels of the Narew River were recorded in the Słoja River (HMS=3.7) (Szozkiewicz et al. 2009). The remaining channels do not show signs of anthropogenic transformations, and are included in the first class in the HMS classification. Such HMS values have not been recorded in the rivers of Podlasie so far (Szozkiewicz et al. 2009). This suggests scarce anthropogenic modifications in the buffer zone of the Narew National Park in spite of quite considerable human interference since the 1970's.

The aggregate values of the Habitat Quality Assessment suggest the occurrence of a number of environmentally valuable elements in individual channels of the anastomosing system of the Narew River (Fig. 2). The highest HQA values were recorded for site No. 1, fulfilling the function of the main channel before regulation. The artificial channel of the Narew

River, currently transporting the highest amounts of water (site No. 2), has high HQA values due to the appearance of many natural morphological elements of the river which developed over more than 30 years of its functioning after the completion of the regulation works (Fig. 2). Moreover, substantial water discharge in comparison to the remaining analysed side channels positively affects the number of original, natural morphological elements of the channel and banks, such as point and bank bars, or lateral erosion formations in the channel. Somewhat lower HQA values calculated for sites 3, 4, and 5 are not related to their anthropogenic transformations, but rather result from the uniformity of the terrain, and lower velocity, which worsens the morphological features (Fig. 3). In the southern channels analysed, the following are almost identical: channel bed, discharge type, vegetation types and structure, both directly in the channels and in their vicinity (Fig. 2). As a result of the discontinuation of extensive agricultural management in the

valley, they were subject to homogenisation and decession (Banaszuk 2004). The obtained synthetic values of the HQA index in the analysed part of the Upper Narew River valley classify the channels analysed to the fourth class in the HQA hydromorphological classification. Those values are high in comparison to results obtained in other rivers of Podlasie region, particularly in the lower course of the Narew River (HQA=29.0) (Szozzkiewicz et al. 2009). The rivers of Podlasie are distinguished by a high level of naturality expressed in HQA values, e.g.: the Supraśl River – 34.5; the Słoja River – 43.9 (Szozzkiewicz et al. 2009). In an urban area river (the Biała River), mean HQA value amounted to as much as 31.1 (Zieliński et al. 2012) owing to the seminatural source and mouth sections. The HQA index is the synthetic sum of a number of elements of the environment related to the course of the river to which numerical values are ascribed. The components affect HQA values to various degrees (Fig. 3). The channel substrate, uniform in terms of

Fig. 3. Components of Habitat Quality Assessment of analysed parallel Narew river channels.

values, determined HQA values in an uneven manner (Fig. 3). Features of the channel were very variable in the analysed fragments of the anastomosing river (Fig. 3). Consideration of only natural elements of the channel morphology resulted in a decrease in the importance of this component for the HQA index in the main channel of the Narew River (site 2), artificially developed in the 1980's. The period from the profiling of the banks, and the activity of the current (increasing the discharge rate) caused a considerable increase in the importance of features of banks for the HQA value at site No. 2 (Fig. 3). In all of the southern channels of the Narew River (sites: 3, 4, and 5), the importance of features of banks as a component of HQA is considerably lower. Bank vegetation is very important for the Habitat Quality Assessment value. The low contribution of this parameter to HQA values of the southern channels is related to the abandonment of extensive agricultural management in the area, and predominance of large reed fields (Fig. 3). An important restoration task possible to implement in the area is increasing the diversity of structural vegetation on the banks through mowing of reeds and restoring sedge habitats natural for this area. Interchannel vegetation had the predominant effect on HQA values (Dawson and Szoszkiewicz 1999) (Fig. 3). The amount and typological richness of plant assemblages mainly determined high HQA values recorded in RHS. Land management in the direct vicinity of the river banks

plays the most substantial role in the development of HQA values in the southern channels of the Narew River (Fig. 3). The current and habitats predominating in the vicinity of the studied channels with variable humidity, fens, and transitional bogs, considerably increase the values of channels in the RHS classification (Raven et al. 1998, 2000). In the River Habitat Survey system, tree stands at the banks and the accompanying morphological elements are of great importance. The first channel and the main channel of the Narew River (site 2) obtained the highest HQA (Fig. 1), mainly due to the presence of trees (Fig. 3). Other features environmentally valuable from the point of view of RHS did not occur only in the main channel of the Narew River (site 2) (Fig. 3). In the remaining channels of the anastomosing system of the Narew River, they constitute a significant component of the HQA index (Fig. 3). The highest variation of the HQA index in individual control cross-sections occurs in the main channel of the Narew River (site 2) (Fig. 4). Such a high diversity of the habitat in the short RHS section (500 m) is unnatural in the case of lowland rivers. The application of the River Habitat Survey method confirms the unnatural character of the channel. The remaining channels, in spite of obtaining varied numerical index values, are distinguished by relatively high uniformity along the entire RHS section. This is a phenomenon typical of lowland rivers with high degree of naturalness (Fig. 4).

Fig. 4. Changes in habitat quality assessment (HQA) along the river channel course on 10 investigated control check points of the anastomosing Narew River profile

Our results suggest that even 30 years of anthropogenic transformations in the valley does not result in total degradation of the riverine environment. This suggests high resistance of the ecosystem to "stress". The hydrotechnical development, abandonment of mowing of valley meadows, and exclusion of a fragment of the valley from functioning definitely impoverished the morphological and hydrological diversity of the river, but it permitted the preservice of its environmentally valuable elements. Moreover, based on the example of the studied main channel of the Narew River, even a river transformed to a large degree, if transporting a sufficient amount of water and retaining its current rate at an appropriate level, is able to increase its hydromorphological values, and improve its ecological state, provided it is free from excessive human interference. Potential renaturalisation works can undoubtedly improve the intensity of environment rehabilitation to a state close to natural or semi-natural.

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References

- Banaszuk H., 1996, Paleogeografia, naturalne i antropogeniczne przekształcenia Doliny Górnej Narwi (Paleogeography, natural and anthropogenic transformations of Upper Narew Valley), Wyd. Ekonomia i Środowisko, Białystok, p. 213 (in Polish).
- Banaszuk H., 2004a, Geomorfologia doliny Narwi (Geomorphology of the Narew valley), [in:] Banaszuk H. (ed.), *Przyroda Podlasia. Narwiański Park Narodowy – monografia przyrodnicza* (Nature of Podlasie. Narew National Park – nature monograph), Wyd. Ekonomia i Środowisko, Białystok: 42-69 (in Polish).
- Banaszuk P., 2004b, Gleby i siedliska glebotwórcze Narwiańskiego Parku Narodowego (Soils and soil-forming habitats of Narew National Park), [in:] Banaszuk H. (ed.), *Przyroda Podlasia. Narwiański Park Narodowy – monografia przyrodnicza* (Nature of Podlasie. Narew National Park – nature monograph), Wyd. Ekonomia i Środowisko, Białystok: 141-155 (in Polish).
- Czerniawska-Kusza I., Szoszkiewicz K., 2007, Biologiczna i hydromorfologiczna ocena wód płynących na przykładzie rzeki Mała Panew (Biological and hydromorphological assessment of running waters based on the example of Mała Panew), Sindruk, Opole, p. 67 (in Polish).
- Dawson F.H., Szoszkiewicz K., 1999, Relationship of some ecological factors with the associations of vegetation in British rivers, *Hydrobiologia* 415: 117-122.
- [EA] Environment Agency, 2003, River Habitat Survey in Britain and Ireland. Field Survey Guidance Manual: 2003, Environment and Heritage Services, Warrington, p. 140.
- Górniak A., 2000, Klimat województwa podlaskiego (Climate of Podlaskie Voivodeship), IMGW, Białystok, p. 119 (in Polish).
- Górniak A., Piekarski M.K., 1999, Hydrologiczne aspekty funkcjonowania zbiornika Siemianówka (Hydrological aspects of the functioning of the Siemianówka reservoir), *Gosp. Wod.* 2: 52-55 (in Polish).
- Grabowska M., Mazur-Marzec H., 2011, The effect of cyanobacterial blooms in the Siemianówka Dam Reservoir on the phytoplankton structure in the Narew River, *Oceanol. Hydrobiol. Stud.* 40: 19-26.
- Jędryka E., 2003, Renaturyzacja małych cieków nizinnych (Restoration of small lowland streams), IMUZ, Falenty, p. 76 (in Polish).
- Logan P., 2001, Ecological quality assessment of rivers and integrated catchment management in England and Wales, *J. Limnol.* 60: 25-32.
- Mioduszewski W., 1999, Koncepcja renaturyzacji doliny Narwi na odcinku Żółtki-Rzędziany. Aktualna problematyka ochrony mokradeł (Narew valley restoration concept on the Żółtki-Rzędziany section. Current problems of wetland protection), Seminar Proc. 43, IMUZ, Falenty (in Polish).
- Moss T., 2004, The governance of land use in river basins: prospects for overcoming problems of institutional interplay with the EU Water Framework Directive, *Land Use Policy* 21: 85-94.
- Okruszkó H., 1989, Dokumentacja i koncepcja zagospodarowania doliny Narwi na odcinku Żółtki-Rzędziany; stanowiąca podstawę do projektu technicznego melioracji i zagospodarowania (Documentation and development concept of the Narew valley section Żółtki-Rzędziany; the basis for the technical project of melioration and management) [manuscript], IMUZ, Falenty, (in Polish).
- Raven P.J., Holmes N.T., Dawson F.H., Everard M., 1998, Quality assessment using River Habitat Survey data, *Aquat. Conserv.* 8: 477-499.
- Raven P.J., Holmes N.T., Naura M., Dawson F.H., 2000, Using river habitat survey for environmental assessment and catchment planning in the UK, *Hydrobiologia* 422: 359-367.
- Suchowolec A., 2012, Renaturalizacja strefy buforowej Narwiańskiego Parku Narodowego (Restoration of the buffering zone of the Narew National Park), [in:] Suchowolec A. (ed.), *Ocena efektów renaturalizacji strefy buforowej Narwiańskiego Parku Narodowego* (Assessment of restoration effects in the buffering zone of Narew National Park), PTOP, Białystok: 10-11 (in Polish).

- Szoszkiewicz K., Buffagni A., Davy-Bowker J., Lesny J., Chojnicki B. H., Zbierska J., Staniszewski R., Zgoła T., 2006, Occurrence and variability of River Habitat Survey features across Europe and the consequences for data collection and evaluation, *Hydrobiologia* 566: 267-280.
- Szoszkiewicz K., Zgoła T., Giełczewski M., Stelmaszczyk M., 2009, Zastosowanie metody River Habitat Survey do waloryzacji hydromorfologicznej i oceny skutków planowanych działań renaturyzacyjnych (Application of River Habitat Survey method for hydromorphological assessment of rivers and for evaluating potential restoration efforts), *Nauka Przyr. Technol.* 3: 1-9 (in Polish, English summary).
- Szoszkiewicz K., Zgoła T., Jusik Sz., Hryc-Jusik B., Dawson F.H., Raven P., 2007, Hydromorfologiczna ocena wód płynących (Hydromorphological assessment of running waters), *Bogucki Wyd. Nauk., Poznań-Warrington*, p. 134 (in Polish).
- Walker J., Diamond M., Naura M., 2002, The development of physical habitat objectives, *Aquat. Conserv.* 12: 381-390.
- Zieliński P., Górniak A., Bralski M., 2012, Ecological status assessment of the urbanized river applying hydromorphological features, *Inż. Ekol.* 29: 246-256 (in Polish, English summary).
- Zieliński P., Górniak A., Suchowolec T., 2003, Changes in water chemistry along the course of two rivers with different hydrological regimes, *Pol. J. Environ. Stud.* 12: 111-117.
- Zieliński P., Jekatierynczuk-Rudczyk E., Górniak A., 2008, Changes in dissolved organic carbon concentration in renaturalized lowland river, *Limnological Papers* 3: 69-77.
- Żelazo J., Popek Z., 2002, Podstawy renaturyzacji rzek (Basis of river restoration), *SGGW, Warszawa*, p. 319 (in Polish).