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Original Research

Changes in the Meandering Upper Odra River as a Result of Flooding Part I. Morphology and Biodiversity

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Abstract

Several changes have been observed in the meandering river channel of the Upper Odra River as a result of the many floods in its drainage basin that have occurred since 1903. In 1966 and 1997 the high stages, velocities, and flow rates caused the waters to break through the banks of two meanders on the Polish-Czech border in the vicinity of Chałupki (Poland) and Bohumin (Czech Republic). New distributaries were thus created. River erosion combined with the settling and sedimentation of deposits contributed to silting up of the original meanders, cutting them off and forming two oxbow lakes. In 2008 the site was acknowledged to be unique because of the presence of rare natural habitats and fauna and flora species. Consequently, it was entered into the Natura 2000 network. After the floods in 1997 and 2010 the valley of the meandering Odra underwent further morphological and biodiversity changes.

Keywords: Odra River, meanders, floods, morphology, biodiversity

Introduction

Channel changes in meandering rivers have been observed among by Ollero [1], among others. Spain's middle Ebro River has witnessed substantial changes in channel morphology, gravel bars, riparian vegetation, and floodplain uses over the last 80 years. Growth in its sinuosity, migrations, and meander cutoffs were frequent before 1981. Since 1927 the middle course of the Ebro has witnessed significant changes along its channel and mainly in the land use on the floodplain and in the extension of gravel accumulation areas and riparian vegetation. In the Aragonese sector of the middle Ebro, relevant changes have been found in 81 locations since 1927. The main changes recorded are: increase of the meander, bends, and migration downstream and, less importantly, cut-offs that result in abandoned channels (oxbow lakes), known locally as "galachos." The horizontal activity of a river consists in the changes to the course of its channel and valley.

Because of centrifugal force, the winding course of a river makes the current shift towards the concave (outer) bank. This bank is steep because it is being undercut by water of higher velocity, causing in-depth and sideward erosion [2]. Bend instability is most often, though not invariably, convective at both a linear and nonlinear level. Moreover, the group velocity of perturbations changes sign as the width-to-depth ratio of the channel crosses some threshold value (the resonant value of Blondeaux and Seminara). They discussed the implications that these findings have on the morphological characteristics of meandering rivers (in particular, the sense of skewing of meander bends and the direction of meander migration). Zolezzi et al. [3], and Cox et al. [4] have explored the possible scenarios originating from the mutual feedback between

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changes of the reach averaged hydraulic and geometric characteristics and channel axis deformation (based on a wide dataset for single-thread, gravel bed rivers). Results indicate the range of parameters where transitions between morphodynamic regimes are more likely to occur; in this respect, the most frequent of these transient behaviors is from the super- to the sub-resonant regime.

Calculations on the development of the bed of alluvial meandering streams have been performed by many researchers [5, 6]. Using dimensional and physical considerations, it was found that the duration of bed development is proportional to the square of the flow width and inversely proportional to the channel-averaged bed-load rate. The proportionality factor was found to be a function of the initial deflection angle.

Lonsdale and Hollister studied cut-offs at an abyssal meander south of Iceland [7]. They found that a crevasse at the outside of the bend may cause channel avulsion, that chute cut-off isolated a scroll bar, and that the 8-km-wide meander neck was dissected by narrow spillways and by "mega-flutes" as much as 1 km wide and 30 m deep.

Głosińska and Lechowski [8] described the changes in the land cover and management of floodplains in towns located on Poland's Odra River. They also estimated flood risk and how it has been changing in the towns of Kostrzyn and Krosno Odrzanskie, and how these changes have affected the environment for the period of 1995-2010. The former lies in the lower course of the Odra and the latter in its middle section. The research indicates that flood risk has risen due to the continuous development of urbanized areas (both unbuilt and built-up) that used to be exploited as arable land. That had a negative effect on the environment, as well.

Lewandowski [9] presented results of an analysis conducted on the basis of the findings of all studies of the hydromorphological status of Polish rivers conducted and published in 1995-2008. From 2.202 km of watercourses, in which scoring was applied for select quality elements, a total of 1.588 km (uniform in terms of methodology) were selected from 35 rivers. Statistical analysis determined the distribution of results for analyzed quality elements, constituting the foundation for a new method of hydromorphological monitoring of rivers, adapted to the requirements of the Water Framework Directive.

During floods of particularly high energy a river can break through the meander banks, make a shortcut and leaving the old river channel, which is eventually cut off. Gradually the old arm is filled with slime and overgrown with vegetation, forming a unique oxbow lake. Thus new habitats are created in the valleys of meandering rivers. New species appear and both fauna and flora flourish.

For example, the technical regulations for the lower Vistula River made in the 19th century created a number of shallow reservoirs, which can be permanently connected to or disconnected from the main channel of the river. In May 2010 the flood that occurred on the Vistula flooded all the investigated reservoirs and influenced the zooplankton community. Napiórkowski and Napiórkowska [10] compared the results of zooplankton investigations before and after the 2010 flood, which destroyed submerged plants and brought suspension, which changed abiotic conditions of life in the floodplain lakes.

The flood waters caused a decrease in the number of species and rebuilt the structure of zooplankton species in the reservoirs. The increase of rotifer species at the expense of crustaceans was observed at different sites. There was also a several-fold increase in the abundance of zooplankton. The largest changes of zooplankton after the flood were recorded in the floodplain lakes that were rich in submerged vegetation (before the flood).

Grabowska et al. [11] studied the fate of phytoplankton communities in different hydrological and hydrochemical conditions in the middle basin of Poland's Biebrza River. Their results showed that hydrological connectivity significantly influenced phytoplankton abundance in floodplain lakes: minimal abundance was stated in lotic and maximal in lentic waterbodies. Phytoplankton diversity and species richness were related to changes in water levels. During the low-water phase, phytoplankton biodiversity was the lowest in lentic and the highest in lotic lakes. High water levels promoted exchanges in species among waterbodies and the river, which increased biodiversity indices. The isolation of any floodplain lake from the river channel deteriorates its trophic conditions. The decrease in phytoplankton biodiversity in floodplain lakes should be regarded as an indirect feedback of the hydrobionts on hydrological factors.

Among all the Natura 2000 sites, river valleys play a special role and are of particular importance. The Upper Odra Valley with its unique meanders is now entered into the Natura 2000 list as Graniczny Meander Odry (GMO, or the Border Reach Odra Meander) [12-14]. The site is rich in habitats, fauna, and flora, and is part of an ecological corridor.

Research on the Odra in the region of the Polish-Czech meanders has been carried out by several authors. Hydrological, hydraulic, and morphodynamic measurements and analyses of the river channel and valley have been performed by Kasperek et al. [15]. They determined, among others things, the extent of the required engineering works (in the form of a technical solutions concept for this area), including the selection of the Odra reaches on which engineering structures should be built and maintained in future in order to prevent bank erosion.

Konca [16] and Szczepański [17] made an inventory of trees (trees, bushes, and shrubs) on the Polish side of the meandering Odra reach and of the fauna, with particular emphasis on the presence of *Cucujus cinnaberinus* and the *Osmoderma eremita* (the hermit beetle). One of the goals was also to verify the possible presence of protected beetle species from the Cerambycidae and Lucanidae families. Kowalska analysed the distribution and condition of *Cucujus cinnaberinus* habitats in the GMO Natura 2000 site [18]. Matyjaszczyk made a forest land survey, drew up a wildlife conservation program, and prepared a forest development plan for the GMO [19]. Pielech and Świerkosz [20] carried out the regeneration of riparian forests at the GMO and drafted general guidelines for the conservation and management of riparian forests in this area. Koszela and Tokarska-Guzik [21] implemented a counter knotweed program aimed at allowing for the natural succession of vegetation to take place. They also monitored the changes occurring in the GMO vegetation.

Botanical investigations confirmed the existence of 363 vascular plant species, including 95 species of alien origin. The participation of archaeophytes was 12%, kenophytes 10%, and diaphytes 4%. The high participation of these groups of species was noted in habitats transformed by human activities, such as fields, roadsides, and hedges, as well as in natural ones, such as steep escarpments and gravel sandbanks shaped by the dynamic flow of the river. Similar work was carried out by Kłos et al., who investigated the concentrations of micro- and macro-elements accumulated in lichens, mosses, and soils in the Opole area [22].

Herczek has issued an expert zoological opinion for the purpose of making a conservation task plan for the investigated Odra area [23].

The Upper Odra Valley is a potential habitat of riparian forests. Due to long-term human impact the area has been considerably transformed, but nonetheless its natural assets retain a huge potential for regeneration. On the Polish side six types of habitats listed in Annex I to the Council Directive 92/43/EEA are confirmed to be present. Moreover, two invertebrate species from Annex II to the same directive, including the hermit beetle and other rare and endangered invertebrates, are present in the area.

Materials and Methods

Floods on the Upper Odra

The months of high flood risk in the Odra basin are July and August. The highest flood risk is caused by precipitation exceeding 70 mm a day. In the 20 and 21st centuries the biggest water surges and floods on the Upper Odra took place in 1903, 1960, 1965, 1966, 1970, 1972, 1977, 1985, 1996, 1997, and 2010. During the catastrophic flood in 1997, when meander M1 was broken through, the maximum flow rate was 2,160 $m^3 \cdot s^{-1}$ and the flood wave at Chałupki was 705 cm high. The latest flood occurred in 2010, with a flood wave of 650 cm and maximum flow rate of 1,040 $m^3 \cdot s^{-1}$. The flood was caused by very heavy and long rainfall over a wide area in May and June. Rainfall in mid-May 2010 resulted in the first flood wave on the Odra, which at the end of May and beginning of June caused the second surge. Overall, the total monthly precipitation in May 2010 was the highest observed in May since 1951. All other extreme floods on the Odra – namely in 1903, 1966 (breaking through meander M3), and 1985 – had very similar characteristics.

Engineering Structures on the River and Fluvial Processes

The 7-km-long reach of the Upper Odra runs between the villages of Chałupki (Poland) and Bohumin (Czech Republic) (Fig. 1), from km 21.0 to the Olza-Odra confluence at km 28.0 (Silesian province, Raciborski District, the commune of Krzyżanowice). This river reach is partly protected by embankments and is built up with three bridges: B1, B2, and B3. Over the investigated Odra reach there are altogether six curves (meanders), the locations of which are shown in Fig. 1. These meanders are labelled M1, M2, M3, M4, M5, and M6. The Odra reach being investigated spreads between the bridges and is unique in its hydrological regime due to the high variation of stages and flows and the sudden surges. Its location and the river's regime result in intensive fluvial erosion, sediment transport, and sedimentation of solid particles.

The flow of surface waters through the inter-embankment zone of the Odra causes intensive bottom/downward and bank/sideward erosion. As a result, the bottom and bank materials create various channel forms. According to Radecki-Pawlik [24], the following channel forms can be distinguished in rivers: meander point bars, alternate bars, mid-channel bars, downstream-of-obstruction bars, upstream-of-obstruction bars, high-flow bar deposits, irregular bars, and braided bars.

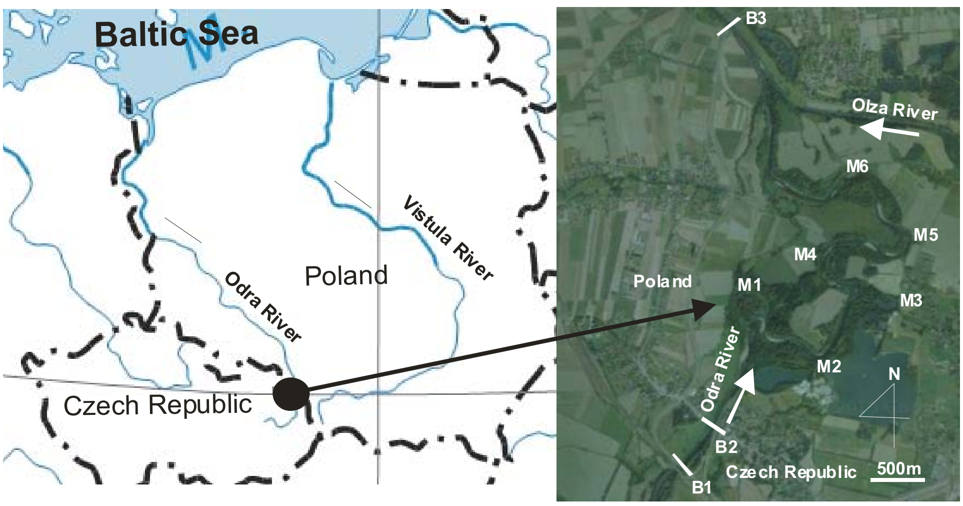

Fig. 1. Location of the Polish-Czech meanders of the Odra River.

Research Methods

This work aims to analyse the fluvial processes occurring on the Polish-Czech meandering reach of the Odra, with particular emphasis on the influence of historical floods. The author has conducted years-long site measurements of the meander areas. These measurements included the Odra channel and valley inventorying. Several calculations and comparative analyses were also conducted, allowing the status of the river channel and valley to be assessed. The author has analysed both his own and the earlier measurements, and additionally satellite photographs from 2004-12. A comparison was made of the Odra River channel and valley in the area of meander M1, which was broken through in 1997.

Results and Discussion

Morphological Transformations

Over the last years in the channel and valley of the Upper Odra between the Chałupki-Bohumin railway bridge and the Olza-Odra confluence, many new river arms, water reservoirs, outwashes, islands, and bank breaches have been formed as result of the intensive morphodynamic processes after the floods 1997 and 2010:

- The outwash-island by the left Polish bank, right up- and downstream of the old railway bridge on the Chałupki-Bohumin route (km 20.530)
- Breaches on the right Czech bank on the reach right upstream of meander M1 (km 21.200-21.300)
- The new channel in meander M1 formed during the flood in 1997 (km 21.500) joins the present channel at km 22.200
- The new central river outwash in the new channel of meander M1 where the new and the old channels meet (km 21.680)
- Meander M1 channel was cut off in 1997, starting at km 21.500
- The breach on the left Polish bank in the new channel of meander M1 (km 21.600)
- Outwash on the right Czech bank in the new channel of meander M1 (km 21.600)
- Meander M3 channel was cut off in 1966 (km 23.370)
- Breaches on the right Czech bank on the reach just upstream of meander M3 (km 23.500-23.050)
- The island at km 24.200-24.300 (meander M4)
- Breaches on the left Polish bank (downstream of meander M6, km 26.000-26.450).

During floods road bridge B2 concentrates and suppresses the stream, increasing the flow velocity downstream. As a result, bottom erosion takes place and considerable amounts of rubble are outwashed. This rubble is transported down the river and forms natural obstacles, such as sand and gravel outwashes, that deteriorate the hydraulic conditions and hinder the flow of flood waters. Apart from the B2 bottleneck, there are no embankments on the Polish or Czech sides of the entire meandering reach of the Odra. This leads to sudden outflows of water carrying bottom sediments onto the flooded terraces, and flow velocity decreases in the entire inter embankment zone. This results in increased sedimentation of solid particles at the entrance to the meandering zone and contributes to the formation of outwashes and islands. The observations and measurements made by the authors over the last dozen or so years show that these outwashes and islands intensively develop upstream of the river, on the reach from the entrance to meander M1 to the border bridges B1 and B2 at Chałupki and Bohumin.

As shown in Fig. 2 (2004 – after the 1997 flood but before the 2010 flood; 2012 – after the 2010 flood; both to the same scale), the outwashes and islands in the left part of the channel in meander M1 confirm the high dynamics of fluvial processes. For example, in 1997-2004, just upstream of meander M1 an outwash of almost 300 m in length and almost 70 m in width was formed. Over the years 2004-12 the same outwash has considerably developed and today measures 570×72 m. The average yearly length increase over the period of 1997-2012 was as much as 38 m/year. The sand, gravel, and pebbles being deposited have greatly narrowed the main channel, causing the main, high-velocity current of the river to deviate and move toward the right bank. As a result, no flow exists in the higher left part of the channel over the greater part of the year, and consequently the channel becomes overgrown with bushes and trees (poplars, birches, alders). The right bank on the Czech side, on the other hand, is exposed to washing away, erosion, and breaching. The old channel (A) is now completely filled with slime, overgrown, and cut off from the flowing water. Since the new channel (B) allows water to flow throughout the year, its left bank and bottom are being intensively eroded and damaged. Also, outwashes 2 and 3 have grown in size. Moreover, additional outwashes (4 and 5) have begun to appear in the new arm B of this meander.

As a result of the floods that have occurred over the last 45 years on the meandering reach of the Odra, meanders M1 and M3 have been broken through twice, causing the river course to shorten by 1,200 m and its slope to increase from 0.7 to 1.6%. This caused mean flow velocity to rise approx. 1.5 times. At medium flows (approx. 44 $m^3 \cdot s^{-1}$) the velocity increases from 0.8 m/s to 1.2 $m \cdot s^{-1}$, while for high water flows (e.g., over 150 $m^3 \cdot s^{-1}$), the velocity rises from 1.5 $m \cdot s^{-1}$ to 2.3 $m \cdot s^{-1}$. The flow measurements were performed using an acoustic Doppler current profiler. The author estimated the water flow conditions in the meander M1 area of the Odra channel during the extreme recent floods in 1997 and 2010 and assessed their influence on fluvial processes. The flood in 1997 was characteristic of the historically highest wave height of about 7.05 m, which corresponded to a water flow rate of aprox. 2,160 $m^3 \cdot s^{-1}$. In 2010 the flood wave reached 650 cm in height with a flow rate of 1,040 $m^3 \cdot s^{-1}$. The flow velocities corresponding to the above wave parameters for the 1997 and 2010 floods were about 3-4 $m \cdot s^{-1}$. This led to the bottom sediments to be washed out and the bumps to appear on the Odra reach downstream of the Chałupki-Bohumin road bridge.

Researchers from Turkey and Finland [25] have performed similar studies. Morphological changes on meander point bars associated with flow structure at different discharges were examined using an acoustic Doppler current profiler at three flow stages. The results indicated that a meander point bar both affects and in turn is itself modified by the flow at different discharges. The lower flow stages also have a significant effect on point bar morphology, especially on deposition over the bar head. Investigations of these authors confirm that the three-dimensional flow structure has a major effect on point bar morphology, and flow structure seems to depend on how the point bar affects the flow trajectory which, in turn, depends upon flow stage. The shape of the bend and the grain size distribution control the impacts of the flow structure, leading to divergent morphologies of point bars with certain generic features.

Odra Meander Ecosystem and Biodiversity

Over the last several decades, the factors that intensified the development of natural habitats, fauna, and flora on the Polish-Czech border meanders reach of the Odra and contributed to its conservation and triggered its entering the Natura 2000 network include: the breaking through of the left bank of meander M3, the breaking through of the right bank of meander M1, and fluvial processes (i.e., erosion of the river bottom, transport of river rubble, and settling of sediments).

For many years scientists, environmentalists, the World Wildlife Fund (WWF), and Regional Directorate for Environmental Protection (RDOŚ; Katowice, Poland) have been carrying out research on the changes occurring in the Odra meanders ecosystem and its biodiversity. Several unique natural habitats have formed and several species of importance for the EC have developed in this area. These include, among others: oxbow lakes and eutrophic reservoirs, fresh meadows, willow-poplar and alder riparian forests, two species of protected fish, three species of protected amphibians, two species of protected reptiles, 11 species of protected birds, and four species of protected invertebrates. The following natural habitats can be distinguished in the Odra meanders area: oxbow lakes and natural eutrophic water reservoirs with *Nympheion* and *Potamion* communities; tall herb communities of the mon-

Fig. 2. Evolution of Odra meander M1 during 2004-12.

tane level (*Adenostylion alliariae*) and riverside tall herb communities (*Convolvuletalia sepium*); extensively used fresh meadows, both lowland and of the montane level *Arrhenatherion elatioris*; riparian willow, poplar, alder, and ash forests (*Salicetum albo-fragilis*, *Populetum albae*, *Alnenion glutinoso-incanae*, *Cardamino amare-Alnetum*); and riparian oak-elm-ash forests (*Ficario-Ulmetum*).

In the Odra meanders area an invasion of knotweed (*Reynoutria*) and Himalayan balsam (*Impatiens glandulifera*) has already been observed for many years; these species can present a significant threat for other plant species. In 2005 a counter knotweed program was launched (RDOŚ, Katowice) that continues today. Knotweed shoots are being mowed or sprayed. It should be added that the knotweed invasion has no adverse impact on the biodiversity of the Odra meanders area. This regards both the flora in the communities of *Salicetea purpureae* and the riparian ash-elm forests (*Ficario-Ulmetum*). Recent research indicates that no native species are driven out by the knotweed from the area under study.

Varied natural habitats in the Odra meanders area create favourable conditions for many fauna species, many of which are legally protected. In recent years the presence of the following species has been confirmed:

- 20 mammal species among the vertebrates, two of which are listed in Annex II to Council Directive 92/43/EEA
- 19 fish species, including two listed in Annex II
- Nine amphibian species, including three from the Annex II list
- Two reptile species and several dozen bird species, 11 of which are listed in Annex I to Council Directive 79/409/EEA
- 15 invertebrate species, four of which are listed in Annex II to Council Directive 92/43/EEA

Below is a summary of the animal species present in the Odra meanders area:

- Invertebrates: sand wolf spider (*Arctosa cinerea*), wasp spider (*Argiope bruennichi*), banded demoiselle (*Calopteryx splendens*), giant peacock moth (*Saturnia pyri*), old world swallowtail (*Papilio machano*), purple emperor (*Apatura Iris*), lesser purple emperor (*Apatura ilia*), poplar admiral (*Limenitis populi*), dusky large blue (*Maculinea nausithous*), large copper (*Lycaena dispar*), hermit beetle (*Osmoderma eremita*), Schindler's ground beetle (*Carabus scheidleri*), Ullrich's robust ground beetle (*Carabus ullrichi*), Cucujus cinnaberinus (*Cucujus cinnaberinus*), and painter's mussel (*Unio pictorum*)
- Fish: ide (*Leuciscus idus*), common minnow (*Phoxinus phoxinus*), amur bitterling (*Rhodeus sericeus*), and weatherfish (*Misgurnus fossilis*)
- Amphibians: smooth newt (*Triturus vulgaris*), great crested newt (*Triturus cristatus*), fire-bellied toad (*Bombina bombina*), yellow-bellied toad (*Bombina variegata*), common toad (*Bufo bufo*), green toad (*Pseudepidalea viridis*), marsh frog (*Rana ridibunda*), European frog (*Rana esculenta*), and European tree frog (*Hyla arboreta*)
- Reptiles: sand lizard (*Lacerta agilis*) and grass snake (*Natrix natrix*)
- Mammals: European beaver (*Castor fiber*), European otter (*Lutra lutra*), and European hamster (*Cricetus cricetus*)
- Birds: white-tailed eagle (*Haliaeetus albicilla*), western marsh-harrier (*Circus aeruginosus*), common sandpiper (*Actitis hypoleucos*), common whitethroat (*Sylvia communis*), northern lapwing (*Vanellus vanellus*), song thrush (*Turdus philomelos*), great spotted woodpecker (*Dendrocopos major*), grey-headed woodpecker (*Picus canus*), lesser spotted woodpecker (*Dendrocopos minor*), greenfinch (*Carduelis chloris*), garden warbler (*Sylvia borin*), red-backed shrike (*Lanius collurio*), hawfinch (*Coccothraustes coccothraustes*), sand martin (*Riparia riparia*), northern goshawk (*Accipiter gentiles*), rude kite (*Milvus milvus*), and Eurasian blackcap (*Sylvia atricapilla*)

Conclusions

Dynamic fluvial processes are observed on the meandering border reach of the Odra. These processes are related to erosion, transport, and sedimentation of rubble. Sand, gravel, and stone washouts are being formed here, new islands appear, and unique natural habitats are created. Over the last 45 years two Odra meanders have been broken through, leading to the formation of oxbow lakes, which are now vividly developing fauna and flora habitats.

The investigated Odra reach in the meanders area undergoes continuous morphodynamic transformations. The research carried out between 2004 and 2012 showed that both degradation and aggradation of the river channel take place. The first phenomenon is related to the intensive erosion of the Odra banks and the second consists of the sedimentation of rubble in the old river channel, in particular in meanders M1 and M3.

References

1. OLLERO A. Channel changes and floodplain management in the meandering middle Ebro River, Spain. Geomorphology **117**, 247, **2010**.
2. LANZONI S., SEMINARA G. On the nature of meander instability. J. Geophys. Res. **111**, (F4), **2006**. DOI: 10.1029/2005JF000416
3. ZOLEZZI G., LUCHI R., TUBINO M. Modeling morphodynamic processes in meandering rivers with spatial width variations. Rev. Geophys. **50**, (4), **2012**. DOI: 10.1029/2012RG000392
4. COX R.T., LUMSDEN D.N., VAN ARSDALE R.B. Possible relict meanders of the pliocene Mississippi River and their implications. J. Geol. **122**, (5), **2014**. DOI: 10.1086/676974, 609
5. DA SILVA A.M.F., BINNS A.D. On the time of development of the bed of alluvial meandering streams. In: Proceedings of XXXII IAHR Congress 1-6 July, Venice, Italy, **2007**.

6. WILLIAMS G.P. River meanders and channel size. J. Hydrol. **88**, 147, **1986**.
7. LONSDALE P., HOLLISTER C.D. Cut-offs at an abyssal meander south of Iceland. Geology **7**, (12), **1979**. DOI: 10.1130/0091-7613
8. GŁOSIŃSKA E., LECHOWSKI Ł. Changes in land cover and management of floodplains located in towns along the Odra River in the context of flood risk assessment. Pol. J. Environ. Stud. **23**, (1), 73, **2014**.
9. LEWANDOWSKI P. Polish investigations on river hydromorphology. Pol. J. Environ. Stud. **21**, (4), 957, **2012**.
10. NAPIÓRKOWSKI P., NAPIÓRKOWSKA T. The impact of catastrophic flooding on zooplankton. Pol. J. Environ. Stud. **23**, (2), 409, **2014**.
11. GRABOWSKA M., GLIŃSKA-LEWCZUK K., OBOLEWSKI K., BURANDT P., KOBUS SZ., DUNALSKA J., KUJAWA R., GOŹDZIEJEWSKA A., SKRZYPCZAK A. Effects of hydrological and physicochemical factors on phytoplankton communities in floodplain lakes. Pol. J. Environ. Stud. **23**, (3), 713, **2014**.
12. DECISION OF THE MINISTER FOR THE ENVIRONMENT of 13 April 2010 on habitats and species of interest for the Community and on the selection criteria for areas qualifying for the Natura 2000 site status. J. Law No. 77, Item 510, **2010** [In Polish].
13. GŁOWSKI R., KASPEREK R., PARZONKA W., WIATKOWSKI M. Estimation of morphological changes of the Odra River valley in meandering sector between Chałupki and the Olza River mouth after 1997 flood. Arch. Environ. Prot. **33**, (1), 67, **2007**.
14. OBRDLIK P. Oder border meanders – experience from the countries of transition. 3rd European Conference on River Restoration, RIVER RESTORATION 2004, Zagreb, Croatia, 17-21 May 2004, 255, **2004**.
15. KASPEREK R., PARZONKA W., BARTNIK W., STRUŻYŃSKI A. Characteristics of the river bed processes of the border reach of the river Odra around the interrupted meander no I. Infrastruktura i Ekologia Terenów Wiejskich **4**, (2), 263, **2007** [In Polish].
16. KONCA B. Inventorying and assessment of health of the trees growing in the Odra River Meanders area from km 20+500 to km 22+320. Report, Katowice, **2009** [In Polish].
17. SZCZEPAŃSKI W., SZCZEPAŃSKI W. Appendix to the monograph entitled "Inventorying and assessment of health of the trees growing in the Odra River Meanders area from km 20.500 to km 27.800." The presence of selected beetle species in the "Odra River Meanders" area. Report, Katowice, **2009** [In Polish].
18. KOWALSKA A. Analysis of presence and of degree of preservation of the *Cucujus cinnaberinus* habitat in the Natura 2000 sites: the Widawa River Valley, the Odra River Border Reach Meander, the Forest in the Area of Tworków. Report, Wrocław, **2012** [In Polish].
19. MATYJASZCZYK M. Forest land survey description and inventorying, including a wildlife conservation programme and draft development plans for the Odra River Border Reach Meanders forest in the Krzyżanowice commune of the raciborski district. Report, Brzeg, **2009** [In Polish].
20. PIELECH R., ŚWIERKOSZ K. Land use plan for the riverside areas in "The Odra River Border Reach Meanders" landscape protection park. Report, WWF Poland, Wrocław, **2006** [In Polish].
21. KOSZELA K., TOKARSKA-GUZIK B. Alien plant species in the protected landscape area of the Odra River meanders: habitat preferences and threats. Biodiv. Res. Conserv. **9-10**, 73, **2008**.
22. KŁOS A., RAJFUR M., WACŁAWEK M., WACŁAWEK M. Application of enrichment factor (EF) to the interpretation of results from the biomonitoring studies. Ecol. Chem. Eng. S. **18**, (2), 171, **2011**.
23. HERCZEK A. Zoological opinion for the purpose of making a conservation tasks plan for the Special Nature Conservation Area Natura 2000 "The Odra River Border Reach Meander" in the śląskie province. Report, Katowice, **2012** [In Polish].
24. RADECKI-PAWLIK A. Hydromorphology of rivers and mountain streams. Selected sections. Kraków, pp. 288, **2011** [In Polish].
25. KASVI E., VAAJA M., ALHO P., HYYPPÄ H., HYYPPÄ J., KAARTINEN H., KUKKO A. Morphological changes on meander point bars associated with flow structure at different discharges. Earth Surf. Proc. Land. **38**, (6), 577, **2013**.