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Biodiversity of Macroinvertebrates in Oxbow-Lakes of Early Glacial River Basins in Northern Poland

Krystian Obolewski
Pomeranian University in Słupsk, Department of Aquatic Ecology
Poland

1. Introduction

River basins are very complex systems which include both abiotic and biotic elements. Such a high number of components results in a situation that normal functioning of river with adjacent areas depends on a set of hydrological and geological processes. They influence biological diversity observed in river basins (Arscott et al., 2005; Marshall et al., 2006). Proper assessment of a lotic system should include not only the main watercourse but also wetlands flooded in spring and autumn. The diversity of habitats in natural river valleys increases biological diversity of aquatic ecosystems and thus the quality of environment (e.g., Boulton et al., 1992; Clausen & Biggs, 1997; Tockner et al., 1999; Gibbins et al., 2001; Sheldon et al., 2002; Arscott et al., 2003; Robinson et al., 2003, 2004; Arscott et al., 2005; Whiles & Goldowitz, 2005; Gallardo et al., 2008; Reese & Batzer, 2007; Obolewski, 2011a; Obolewski & Glińska-Lewczuk, 2011).
Each meandering, lowland River is forming its riverbed constantly. Often after rapid floods it turns out that a river flows in new riverbed and the cut-off fragments transform into oxbow-lakes (Amoros & Roux, 1988). They can be filled up during river rises and undergo succession (Junk et al., 1989; Tockner et al., 2000). Due to the diversity of river rise intensity, the connectivity between an oxbow-lake and a river can vary. Therefore, we distinguish lentic, semi-lotic and lotic oxbow-lakes. The first type is supplied by river waters under high water table level or by ground waters while the two remaining types are partly or totally connected to a river. Limited exchange of water in a river valley as well as its agricultural use causes that oxbow-lake drainage area often undergoes anthropopression which leads to quick eutrophication and massive phytoplankton blooms. As a result, water contains considerable amounts of biogenes, mineral salts but low oxygen content. Additional unfavourable factors are hydromorphological features of oxbows, i.e. small area (between a few hundreds squared meters and a few hectares) and depth which usually does not exceed 3 meters. As a result oxbows quickly react to changes in temperature and thanks to that they are perfect objects for the research on climate changes even in the global depiction (Klimaszyk, 2004).
The structure and functioning of wetland ecosystems, including oxbow-lakes, are directly and indirectly connected with the fluctuations in water table level of rivers during floods or flow pulsations (Junk et al., 1989; Tockner et al., 2000). According to Amoros & Roux (1988),

hydrological connectivity determines the processes that take place both in a river and adjacent wetland systems. That concerns the transport of dissolved or suspended elements and organisms, environment reorganization, productivity and biodiversity of aquatic and land ecosystems (Amoros & Roux, 1988; Junk et al., 1989; Poff & Ward, 1989; Heiler et al., 1995; Ward & Stanford, 1995; Poff et al., 1997; Ward et al., 2002; Tockner et al., 2000). Limited hydrological connectivity as well as hydrotechnical appliances located on rivers of moderate river slope result in hydrological changes which can lead to the loss of many valuable ecosystems, including oxbow-lakes (Poff & Ward, 1989; Dynesius & Nilsson, 1994; Heiler et al., 1995; Poff et al., 1997; Tockner et al., 1999; Ward et al., 2002; Thorns & Sheldon, 2000). Consequently, the flora and fauna migration in a river valley occurs only during the periods of water exchange between wetlands and the main river channel, which deteriorates the river ecosystem biodiversity and functioning (Amoros & Roux, 1988; Heiler et al., 1995; Walker et al., 1995). Those changes can be observed by the monitoring of a selected hydrobiont group and its changes in terms of qualitative and quantitative structure that reflect the ecological state of a river valley.

Among various hydrobiont groups, benthic invertebrates are particularly attractive research objects, because their life cycles are short and they also easily adapt to environmental conditions due to, for instance, their shape and dispersion (Gasith & Resh, 1999). High abundance of benthic macroinvertebrates allows using them as indicator organisms in the monitoring of aquatic ecosystem quality (e.g. Boon, 1988; Obolewski et al., 2009). Moreover, some groups of macroinvertebrates periodically reach their maximum abundance and diversity in relation to spatial and environmental variables, however those phenomena have not been fully understood so far (e.g., Van der Brink et al., 1991; Tockner et al., 1999; Heino, 2000; Griffith et al., 2001; Arscott et al., 2005; Monaghan et al., 2005).

This study investigates the relationships between macrozoobenthos communities and the level of hydrological connectivity between wetlands and the main river channels in the river valleys of three lowland rivers located in northern Poland: Słupia, Łyna and Drwęca. The studied wetlands were selected according to the hypothesis, that the level of hydrological contact between oxbow-lakes and rivers influences the qualitative and quantitative structure of benthic macroinvertebrates inhabiting wetlands.

2. Study area

2.1 Characteristics of the studied river valleys in northern Poland

The study area covered the wetlands of middle Łyna, Pasłęka, Drwęca and Słupia rivers. They were chosen because of geomorphologic and hydrological similarities. They are also located in areas of similar climatic conditions and shows hydrological regime typical of lakelands.

Łyna River Valley

The studied oxbows are located in the middle section of the Łyna River Valley- the largest tributary of Pregoła which flows into the Zalew Wiślany reservoir. The drainage area of Łyna reaches 7126 km^2 and 5773 km^2 is within the territory of Poland while the lower part of drainage area with the estuary are located in Russia. Total length of the river is around 290 km. Łyna is characterized by varied, natural and valuable landscape of its valley thanks to polygenetic processes that occurred during ice-sheet recession in the Baltic glaciation (Michniewska – Szczepkowska & Szczepkowski, 1969). The river begins its course at the elevation about 160 m.a.s.l., north-east from Łyna village, by the western edge of Lasy Napiwodzkie and 10 km to the north of Nidzica. The spring of Łyna is fairly abundant due to the presence of impermeable Pliocene loam. Spring streams formed a deep and branch ravine. Łyna flows through many lakes (Persing, Kiernoz Wielki and Kiernoz Mały, Łańskie, Ustrych), among which the Łańskie Lake is the largest. At the latitude of Kiernoz Wielki one of the largest tributaries- Marózka- flows into the Łyna River. Further course of Łyna is diverse in terms of its direction through morainic elevation and rich with numerous meanders. Just below the city of Olsztyn Łyna joints with the second largest tributary- Wadąg- which is 20 km long and with drainage area of 1218 km^2. The average slope of the upper course of the Łyna River is at the level of 1- 2 ‰.

In the middle course of the river, between Dobre Miasto and Lidzbark Warmiński, Łyna reveals the features of a meandering river, washes away river banks and transports considerable amounts of fine sediments. In the vicinity of Sępopol the river joints with such tributaries as Sunia and Kirsna, located in the area of the studied oxbows as well as Symsarna (drainage area of 276 km^2), Ekna (drainage area of 301 km^2) and Guber (length of 73 km, drainage area of 1682 km^2). Passing Sępopol the river crosses the border near Znamieńsk and flows into Pregoła at the altitude of 4 m.a.s.l. The slope in its lower course is around 0.4 ‰. The mean annual flow near the border is 38.5 m^3/s while the spread of water stages reaches about 4 m.

Parameter	Unit	River – gauging station		
		Łyna-Smolajny	Drwęca-Rodzone	Słupia-Słupsk
No. of kilometres (from estuary)	km	172.0	126.7	31.6
Drainage area	km^2	2290	2725	1450
Mean annual river flow SSQ	m^3 s^{-1}	14.7	11.2	15.0
$WQ_{10\%}$	m^3 s^{-1}	50.5	46.1	49.0
$NQ_{10\%}$	m^3 s^{-1}	4.49	4.50	6.02
Mean low river flow SNQ	m^3 s^{-1}	6.45	6.30	7.45
Flow coefficient *cv*	-	0.439	0.442	0.450
Oscillation of water stages	cm	207	191	171
Watercourse slope	m km^{-1}	0.32	0.30	0.18
Width of valley-bottom zone	m	372	618	315
River sinuosity	-	1.36±1.82	1.66±2.40	1.21±2.13
Mean number of oxbows per1 km of river valley length	no/1km	3	10	4

Table 1. Characteristics of the studied rivers at sections with meandering riverbed: Łyna (Smolajny), Drwęca (Rodzone) and Słupia (Słupsk)

The most interesting section of the Łyna River Valley is its middle part, rich with oxbow-lakes, which was included in this study. The mean annual flow over years 2007-2009 at the cross-section located in Smolajny (172 km) reached 14.7 m^3 s^{-1} while the mean low river flow was almost 6.5 m^3 s^{-1} (Table 1). Moreover, the highest water stage amplitudes were observed there comparing to the remaining rivers studied in this investigation.

Drwęca River Valley

The Drwęca River is a right-side, large tributary of Vistula, with the length of 207.2 km and drainage area of 5343.5 km^2. The spring of Drwęca is localized at the northern foot of the Dylewskie hills, to the south of Drwęck. The river flows into Vistula near Złotoria (vicinity of the city of Toruń). The upper section of the riverbed is a ravine, 20-30 m deep and 8 km long, called the "Czarci Jar". First the river flows to north-west as a small stream in a valley covered with forest and surrounded by agricultural areas, crosses the Ostrowin Lake and then joins with its tributary- the Grabiczek River. Further, the river changes its direction into west and flows into the Drwęckie Lake. Passing that lake the river is regulated and flows to south-west, receiving the waters of Poborska Struga, Gizela, Elszka (left-sided tributaries), Ruda and Iławka (right-sided tributaries). In the town of Bratian Drwęca joins with its largest tributary- the Wel River.

Starting from the town of Bratian the river is meandering and flows in a deep valley. After joining with the left-sided tributary- the Brybica River- Drwęca flows to north-west direction. Near Brodnica the river joins with its tributary- Skarlanka, then Rypienica and Struga Wąbrzeska. In the vicinity of Młyniec the river changes its characteristics. After building a dam in 1997 in Lubicz the river formed a reservoir with the area of 50 ha, where the water flow decreased to 0.2-0.3 m^3 s^{-1}. In the lower section of the Drwęca River the most important tributaries are: Struga Kowalewska, Struga Rychnowska and Struga Lubicka. After passing the town of Nowa Wieś the river turns to north-west and flows into the Vistula River in Złotoryja (Mileska, 1992).

The drainage area of Drwęca is localised on clay, sand and gravel of glacial origin with peatlands in depressions. It was formed during the Baltic glaciation in the Toruń-Eberswald pra-valley. The studied part of valley is located 127 km from the estuary on ground moraine and 6 km wide. Typical of this section is a considerable number of oxbow-lakes (Table 1). The river flow of Drwęca is relatively stable thanks to the retention ensured by numerous lakes and forests. In general no catastrophic floods or low water stages are observed in the valley (Bralczyk, 1996). The average annual river flow in years 2007–2009 at Rodzone (127 km) was 11.2 m^3 s^{-1} while the low water flow slightly exceeded 6 m^3 s^{-1} (Table 1).

The Drwęca River Valley is under various forms of legal protection. In 1961 the whole river with lakes Drwęckie and Ostrowin, some of the tributaries and 5 m wide strip of river bank became a reserve in order to protect breeding ground for salmon fish. Moreover, the Area of Protected Landscape in the Lower Drwęca River Basin has been created with the area of 17 472.4 ha as well as the Area of Protected Landscape of the Upper Drwęca River Valley (area 8 039.5 ha). It is planned to include the river with some of its tributaries (area of 2 162.1 ha) to the European Ecological Network Nature 2000.

Słupia River Valley

The Słupia River flows into the Baltic Sea. The whole river basin is located in the Pomeranian Voivodeship. It borders the Wieprza River Basin (west), the Brda River Basin (south) as well as the Łeba and Łupawa river basins (east). The length of Słupia is 138.6 km (according to the „Hydrographic division of Poland", IMGW, 1983) while its basin covers the area of 1310 km^2. The spring of Słupia is in the Kaszuby Lake District near Sierakowska Huta at the height of 178 m.a.s.l. The river estuary is in Ustka and its average slope is around 1.3 per mill.

The characteristic features of Słupia formed around 15 000 - 10 000 lat BP. Melting ice-sheet created a net of sub-glacial gullies, marginal and riverine valleys. The Słupia's tributaries are strongly meandering water-courses. In the upper section the river flows through lakes Tuchlińskie, Pręgożyno, Skrzynka, Trzebocińskie, Gowidlińskie, Węgorzyno, Żukowskie.

The tributaries of the Słupia are asymmetrical, mostly located on the left side of the river (Skotawa- the largest tributary, Glaźna, Gnilna). On the right side there are Parchowska Struga, Stropna, Bytowa, Kamienica, Brodek, Kamienna, Żelkowa Woda, Kwacza.

Hydrological characteristic of the Słupia River is typical of the Pomeranian Region:

- domination of ground water supply (70-75% according to Paszczyk, 1976);
- even annual outflow determined by climatic conditions (stable precipitation, mild winters) and physiographic conditions (large forest area and flow-through lakes);
- low amplitude of water stages.

The average outflow in spring constitutes around 130-180% of average monthly outflow. The lowest outflow occurs in summer (mainly July). The floods are small, mostly in December, January or March and connected with melting snow. The ice phenomena in the Słupia River basin start in late November or early December. Due to the presence of fast currents the ice covers only part of the river (channels, still water bodies) and melts between 15 and 20 of March.

Numerous oxbow-lakes are located in the middle part of the Słupia River and they were mainly formed after river regulation at the beginning of XXth century. Nowadays they are within the borders of "Dolina Słupi" Landscape Park. Its area is the lowest but water outflow is the highest (Table 1).

2.2 Selected oxbow-lakes located in lowland river basins of northern Poland

The research covered 14 oxbow-lakes (four in the Drwęca river valley, five in Łyna and five in the Słupia river valleys)- 8 of them were cut-off, 4 were open and 2 were semi-open reservoirs. Those oxbows differed in habitat conditions and morphometric features (Table 2).

The oxbow-lakes in the Drwęca river valley were formed during regulation works and all of them are cut off from the main river channel (lentic). OLD 1, OLD 2 and OLD 4 are located on the right side of the river while OLD 3 is situated on the left side (Fig. 1). Their length varies from 140 to 1200 m (Table 2). The main shape of those reservoirs is determined by one river bend of sinuosity S around 5.5. In the valley there are also oxbows almost parallel to the riverbed (S=1.5) as well as better developed (S=9.8). Water table area of the studied reservoirs ranges from 0.1 to 1.2 ha and their volume from 5.3 to 16.7 thousand m^3 (in relation to the Drwęca water level H=100 cm on the watermark in Rodzone). Morphometric features change over time for each reservoir individually. The flat fragment of the river valley in the vicinity of Bratian does not limit the changes in water table level. The fluctuations in Drwęca water level cause that the volume and area of oxbows can be twofold different.

The oxbow-lakes in the Łyna river valley are located near the Smolajny village and were also formed as a result of regulation works. Three of them (OLŁ 2, OLŁ 3 and OLŁ 5) are connected with the river on both sides (lotic) and OLŁ 1 through one arm (semi-lotic) while OLŁ 4 is cut off from the river (lentic). The length of those reservoirs ranges from 420 to 700 (Table 2) but most of them reach 200-400 m (43% of all objects). Their main shape is determined by one bend of sinuosity S around 3.0. In the valley there are also oxbows almost parallel to the riverbed (S=1.2) as well as better developed (S=9.5). The area of oxbows varies between 0.3 and 1.5 ha while their volume between 2.2 and 25.3 thousand m^3 (in relation to the Łyna water level H=100 cm on the watermark in Smolajny). Morphometrical features change over time for each reservoir individually. Steep and high banks reduce the range of changes in water table area. The fluctuations in Łyna water level cause that the volume of oxbows can be 4-fold different while the area only 1.9-fold different.

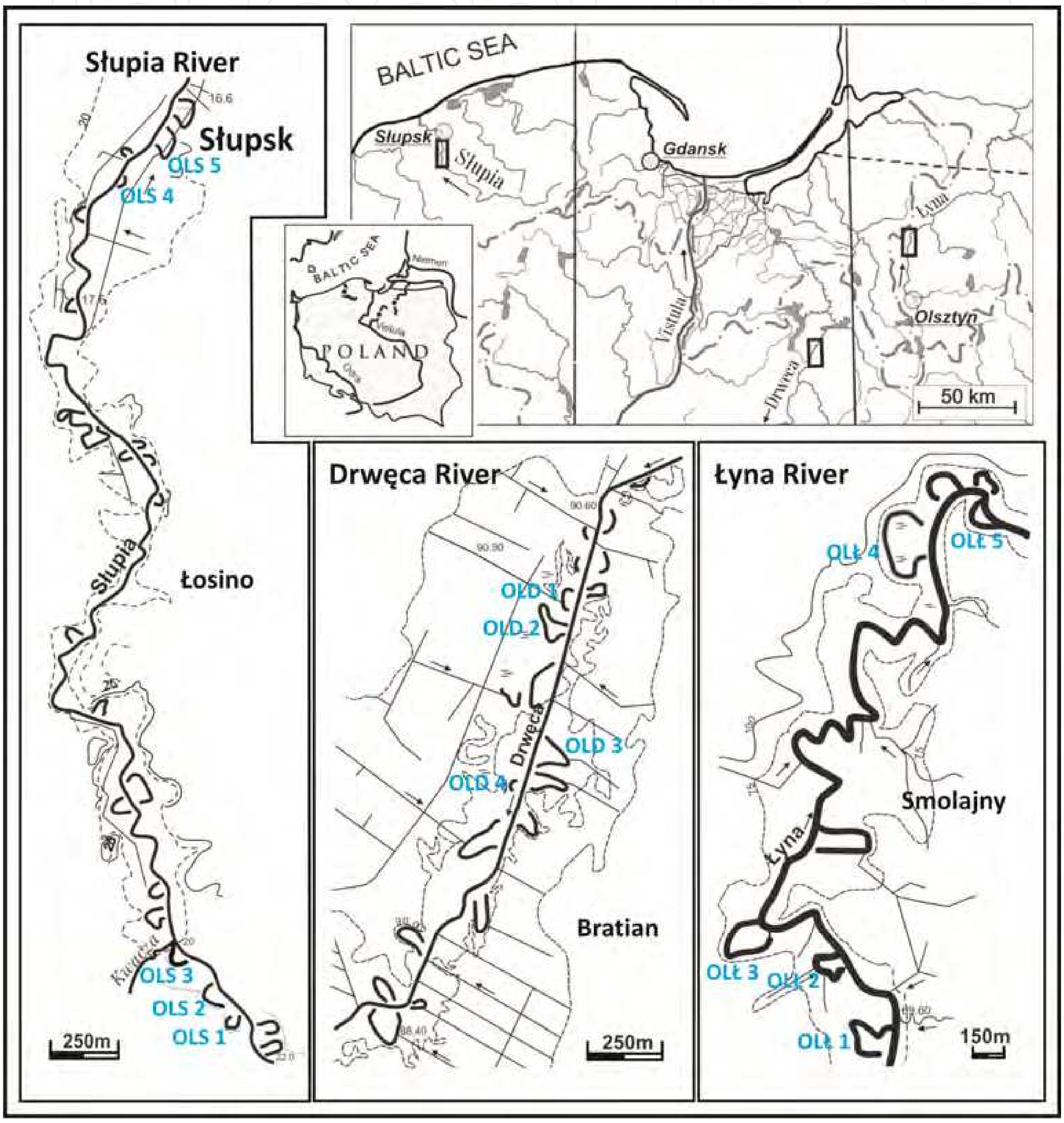

Fig. 1. Localisation of sampling sites

The studied oxbow-lakes in the Słupia river valley are located within the 15 km long river section. Three of them (OLS 1, OLS 2 and OLS 3) are near Kwakowo in the area of "Dolina

Oxbow-lake	River	Geographical coordinates	Type of connection with river	Length D [m]	Width S [m]	Area A [ha]	Sinuosity S=D/a-c [-]	Distance between arms a-c [m]	Distance from river:			Width		Depth		Volume
									Upper arm [m]	Lower arm [m]	Max. [m]	River S_{rz} [m]	River valley WWW S_{dol} [m]	$h_{śr}$ [m]	h_{max} [m]	$V_{śr}$ [thou m³]
OLD-1	Drwęca	N 53°28′06.61″ E 19°35′56.96″	LE	481	11.2	0.49	9.8	49	37	26	237	11.1	296	1.07	3.11	5.29
OLD-2	Drwęca	N 53°27′51.98″ E 19°36′18.11″	LE	144	15.2	0.20	1.5	95	34	25	100	12.2	231	0.95	3.20	1.89
OLD-3	Drwęca	N 53°27′53.98″ E 19°36′34.16″	LE	1210	14.0	1.51	6.4	190	22	11	462	10.9	425	1.12	2.27	16.88
OLD-4	Drwęca	N 53°28′50.20″ E 19°36′04.74″	LE	347	19.2	0.60	4.3	80	44	14	193	14.0	434	1.16	1.71	6.92
OLŁ-1	Łyna	N 54°01′17.14″ E 20°24′00.39″	SLO	424	15.1	0.92	5.4	79	23	0	180	17.0	462	1.16	2.60	10.70
OLŁ-2	Łyna	N 54°01′38.33″ E 20°24′15.23″	LO	464	16.5	0.79	6.7	69	15	0	198	16.0	227	1.25	2.40	9.90
OLŁ-3	Łyna	N 53°57′49.68″ E 20°25′04.45″	LO	713	25.0	2.64	1.2	594	100	100	200	15.0	200	0.11	0.90	2.90
OLŁ-4	Łyna	N 54°05′40.38″ E 20°26′18.53″	LE	560	31.0	1.74	2.6	219	38	22	342	16.2	409	1.45	1.80	25.30
OLŁ-5	Łyna	N 54°05′26.41″ E 20°26′14.52″	LO	320	22.7	0.26	8.0	30	0	0	159	19.9	200	0.85	2.30	2.20
OLS-1	Słupia	N 54°23′07.31″ E 17°02′25.38″	LE	333	9.8	0.36	5.8	57	82	66	209	14.9	160	0.58	1.25	2.06
OLS-2	Słupia	N 54°23′14.57″ E 17°02′15.94″	LE	329	10.3	0.35	1.8	183	103	35	180	15.7	190	0.63	1.62	2.19
OLS-3	Słupia	N 54°23′25.62″ E 17°01′59.16″	SLO	143	10.5	0.14	1.1	131	124	0	118	12.4	217	0.6	1.30	0.82
OLS-4	Słupia	N 54°26′45.21″ E 17°01′38.70″	LO	125	9.1	0.13	1.6	77	16	23	59	15.2	374	0.88	1.82	1.14
OLS-5	Słupia	N 54°26′52.99″ E 17°01′58.41″	LO	512	10.3	0.71	2.8	186	37	22	180	14.5	308	0.79	1.65	5.51
Mean	-	-	-	**436.1**	**15.7**	**0.8**	**4.2**	**145.6**	**48.2**	**24.6**	**201.2**	**14.6**	**295.2**	**0.9**	**2.0**	**6.7**

Table 2. Morphological characteristics of the studied oxbow-lakes (LO –lotic, SLO- semi-lotic, LE-lentic)

Słupi" Landscape Park while OLS 4 and OLS 5 are situated near Słupsk (Fig. 1). OLS 1 and OLS 2 are cut off from the main river channel (lentic), OLS 3 is connected by one arm (semi-lotic) and the remaining two oxbows (OLS 4 and OLS 5) are connected to the river by pipes or melioration ditches (lotic). The Słupia oxbow-lakes are reservoirs of length ranging from 125 to 500 m (Table 1). Most of them are oxbows of not large width (around 10m). Their main shape is determined by one bend of sinuosity S around 3.0. In the valley there are also oxbows almost parallel to the riverbed (S=1.1) as well as moderately developed (S=5.8). The oxbow areas are similar and range from 0.1 to 0.7 ha while their volume from 0.8 to 5.5 thousand m^3 (in relation to the Słupia water level H=100 cm on the watermark in Słupsk). Morphometrical features change over time for each reservoir individually. The fluctuations in Słupia water level cause that the volume and area of oxbows can be 4-fold different.

3. Material and methods

In order to investigate the biodiversity of macroinvertebrates we chose 12 oxbow-lakes located in the valleys of three lowland rivers- Drwęca, Łyna and Słupia. The oxbows were classified into three types: lotic, semi-lotic and lentic. The sampling was performed in years 2007-2009 through four seasons (winter, spring, summer, autumn). Three sampling sites were locates in each oxbow-lake- in the middle of the reservoir and in both arms. Bottom sediments with macrozoobenthos were sampled using the Ekman's grab sampler (surface 225 cm^2) three times at each site and related to the bottom area of 1 m^2. The sediments were sieved through a 1 mm mesh size sieve and fixed in 4% formalin. Then, macrozoobenthos was separated from sediments in a laboratory and identified to taxonomic units. Further analysis consisted of the calculations of biocenotic indices.

The constancy of occurrence of the identified taxa was calculated according to the following formula (1):

$$C = N_a/n \cdot 100\% \quad (1)$$

where: N_a – number of samples with a given taxon

n – total number of samples

The index of constancy of occurrence is mostly used as the parameter which indicates the level of connection between a taxon and the environment. According to Tichler the index is classified as follows:

C_4 – euconstants (75.1 – 100%),

C_3 – constants (50.1 – 75.0%),

C_2 – accesoric taxa (25.1 – 50.0%),

C_1 – accidental taxa (<25.0%).

The domination index in terms of density is defined by the formula (2):

$$D_A = A/A_{av} \cdot 100\% \quad (2)$$

where: A – average density of a given taxon

A_{av} – total average density for the whole reservoir

It was classified after Biesiadko & Kowalik (1980) into:

eudominants (abundance above 10%),

dominants (5.01-10%),

subdominants (2.01-5%),

recedents (1-2%),
subrecedents (below 1%).
The ecological importance index Q was calculated according to the formula (3)

$$Q = \sqrt{C \cdot D} \tag{3}$$

where: D – domination index (in terms of density)
C – constancy of occurrence.
The following classification was applied in this study:
Q5 – very high >30.00%,
Q4 – high 15.01-30.00%,
Q3 – moderate 10.01-15.00%,
Q2 – low 5.01-10.00%,
Q1 – very low <5.00%.
The next parameter used in this investigation was the Shannon diversity index (4):

$$H' = -\sum_{i=1}^{s} p_i \log_2 p_1 \quad \text{where:} \quad p_i = \frac{n_1}{N} \tag{4}$$

where: n_i – species abundance
N – total density of taxonomic groups
S – number of taxonomic groups in the studied samples.

4. Results and discussion

4.1 Qualitative structure of benthofauna in the studied oxbow-lakes

4.1.1 Łyna River basin

Macrozoobenthos in the oxbows of the Łyna River was represented by 41 taxa belonging to 12 taxonomic groups. Benthofauna was predominated by Diptera of *Chaoborus* genus (Table 3). They were particularly abundant in lentic oxbow-lakes where they constituted over 50% of the total macrozoobenthos abundance and were classified as constants. In OLŁ1 they were accesoric species. That situation indicates a bad condition of the OLŁ1-OLŁ3 ecosystems (Glińska-Lewczuk, 2009). The share of Diptera of *Chaoborus* genus was much lower in the two remaining oxbow-lakes (OLŁ4 and OLŁ5). As for the other taxa, they were relatively abundantly observed in OLŁ1. Oligochaeta, Chironomidae larvae and Bivalvia reached there the status of accesoric species. Oligochaeta also predominated the bottom of OLŁ5, being a constant species.

The qualitative composition of benthofauna in the oxbows of the Łyna River indicated their considerable degradation through succession (Kajak, 1988, 2001). As a result the benthic invertebrates are eliminated (Lapmert & Summer, 2007) with stenobionts in particular because their adaptability to changing environmental conditions are very limited (Allan, 1995). As bioindicators they belong to accesoric species.

The pattern of benthofauna constancy of occurrence was similar in all the oxbow-lakes of the Łyna River. Extreme values were reached in OLŁ2 and OLŁ3, which was connected with the concentration of Diptera larvae represented by *Chironomus* sp. (Fig. 2). The median of benthofauna constancy of occurrence for 80% of the Łyna oxbow-lakes was equal to zero, probably because of the presence of many occasional species. Only the OLŁ1 oxbow lake differed in terms of median and no predominant species were observed there.

Taxa	Oxbow-lakes					average	classification
	OLŁ 1	**OLŁ 2**	**OLŁ 3**	**OLŁ 4**	**OLŁ 5**		
Chaoborus sp.	38.9*	20.8	58.6**	8.3	0.0	25.3	**C_2**
Oligochaeta	27.8*	9.0	2.2	8.3	52.9**	20.0	**C_1**
Chironomus sp.	27.8*	13.9	10.4	16.7	9.9	15.7	
Procladius sp.	44.4*	5.7	4.7	8.3	0.0	12.6	
Pisidium sp.	44.0*	0.0	0.0	8.3	5.1	11.5	
Erpobdella sp.	22.2	8.1	2.3	16.7	1.9	10.2	
Viviparus viviparus L.	22.2	6.7	3.4	8.3	10.5	10.2	
Sialis fuliginosa Pictet	22.2	9.3	1.7	8.3	0.0	8.3	
Asellus aquaticus L.	22.2	2.3	0.0	0.0	14.4	7.8	
Valvata pulchella Studer	0.0	0.0	0.0	25.0	0.0	5.0	
Glossiphonia sp.	22.2	0.0	1.7	0.0	0.9	5.0	
Bezzia sp.	5.6	5.4	7.5	0.0	0.2	3.7	
Cyrnus sp.	0.0	7.0	1.7	8.3	0.0	3.4	
Valvata piscinalis O.F. Müller	16.7	0.0	0.0	0.0	0.0	3.3	
Potamopyrgus antipodarum Gray	6.0	0.0	0.0	8.3	0.0	2.9	
Anodonta anatina L.	11.1	2.1	0.0	0.0	0.4	2.7	
Lymnaea stagnalis L.	11.1	0.0	0.0	0.0	1.5	2.5	
Limnephilus sp.	0.0	1.5	1.7	8.3	0.0	2.3	
Sphaerium sp.	11.0	0.0	0.0	0.0	0.0	2.2	
Dytiscus sp.	0.0	0.0	0.0	8.3	0.0	1.7	
Notonecta sp.	0.0	0.0	0.0	8.3	0.0	1.7	
Sergentia sp.	0.0	0.0	0.0	8.3	0.2	1.7	
Valvata cirstata O.F.Müller	5.6	0.0	0.0	0.0	0.0	1.1	
Galba truncatula O.F.Müller	5.6	0.0	0.0	0.0	0.0	1.1	
Anodonta cygnea L.	5.6	0.0	0.0	0.0	0.0	1.1	
Lepidostoma sp.	5.6	0.0	0.0	0.0	0.0	1.1	
Ecnomus tenellus Rambur	5.6	0.0	0.0	0.0	0.0	1.1	
Goera sp.	5.6	0.0	0.0	0.0	0.0	1.1	
Hydropsyche sp.	5.6	0.0	0.0	0.0	0.0	1.1	
Psychomidae	5.6	0.0	0.0	0.0	0.0	1.1	
Mochlonyx culiciformis Degeer	5.6	0.0	0.0	0.0	0.0	1.1	
Polypedilum sp.	5.6	0.0	0.0	0.0	0.0	1.1	
Limoniidae	5.6	0.0	0.0	0.0	0.0	1.1	
Helobdella stagnalis L.	0.0	1.5	1.7	0.0	0.0	0.6	
Chironomus sp. pupa	0.0	0.0	2.3	0.0	0.0	0.5	
Lestes sp.	0.0	2.1	0.0	0.0	0.0	0.4	
Epitheca bimaculata Charpentier	0.0	1.5	0.0	0.0	0.0	0.3	
Phryganaidae	0.0	0.0	0.0	0.0	1.5	0.3	
Dreissena polymorpha Pall.	0.0	1.5	0.0	0.0	0.0	0.3	
Caenis sp.	0.0	1.5	0.0	0.0	0.0	0.3	
Cloëon sp.	0.0	0.0	0.0	0.0	0.2	>0.1	

Table 3. Constancy of occurrence (C, %) of benthofauna representatives in the oxbow-lakes of the Łyna River with the classification of consecutive taxa (* - C_2, **- C_3)

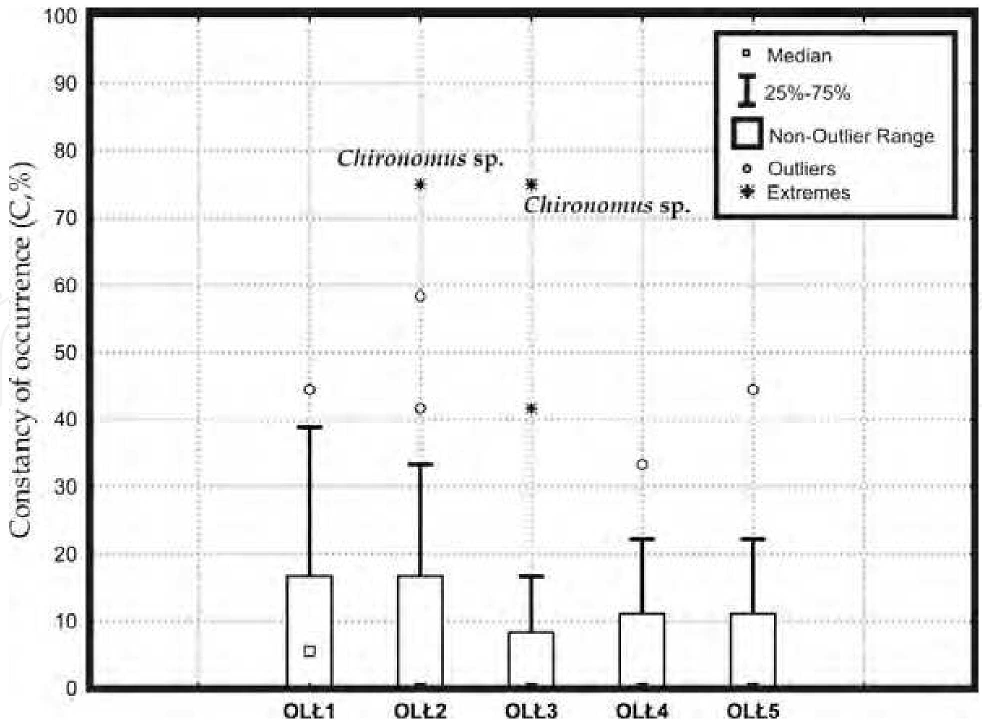

Fig. 2. Benthofauna constancy of occurrence (C, %) in the oxbow-lakes of the Łyna River

4.1.2 Drwęca River basin

Only 13 benthofauna taxa belonging to 7 taxonomic groups were observed in the oxbow-lakes of the Drwęca River. The most abundant were *Chaoborus* sp. representatives with very high constancy of occurrence (constant species, Table 4) reaching even 100% (euconstants).

Taxa	Oxbow-lakes				Mean	Classification
	OLD 1	**OLD 2**	**OLD 3**	**OLD 4**		
Chaoborus sp.	33.3*	100.0***	66.7**	33.3*	58.3	**C_3**
Chironomus sp.	8.3	75.0**	50.0*	66.7**	50.0	**C_2**
Erpobdella sp.	8.3	8.3	25.0	50.0*	22.9	**C_1**
Procladius sp.	8.3	33.3*	16.7	0.0	14.6	
Chironomus sp. pupa	0.0	25.0	33.3*	0.0	14.6	
Oligochaeta	0.0	25.0	16.7	0.0	10.4	
Bezzia sp.	0.0	8.3	8.3	0.0	4.2	
Cloëon sp.	8.3	0.0	8.3	0.0	4.2	
H. stagnalis	0.0	0.0	0.0	8.3	2.1	
Glossiphonia sp.	0.0	0.0	8.3	0.0	2.1	
Sergentia sp.	0.0	0.0	8.3	0.0	2.1	
A.aquaticus	8.3	0.0	0.0	0.0	2.1	
Cyrnus sp.	0.0	8.3	0.0	0.0	2.1	

Table 4. Benthofauna constancy of occurrence (C, %) in the oxbow-lakes of the Drwęca River with the classification of consecutive taxa (* - C_2, **- C_3, *** - C_4)

The second abundant were the larvae of *Chironomus* sp., being between accesoric and constant species. Considerable number of taxa were occasional species which occurred in some oxbow-lakes with higher abundance. Among accesoric species that situation particularly concerned leeches *Erpobdella* sp., which in OLD4 were present in half of the samples. That situation was caused by the abundance of Diptera larvae (Turoboyski, 1979). In OLD2 and OLD3 apart from the larvae of *Choborus* sp. and *Chironomus* sp., equally frequent were predatory *Procladius* sp. and chrysalis of *Chironomus* sp.

The oxbow-lakes of the Drwęca River were the most degraded ecosystems, which functioning depended on periodical floods (Tockner et al., 1999). The domination of migrating species indicated oxygen depletion in the bottom zone of those reservoirs. That suggests the need of reconnecting those oxbows to the river (Bornette et al., 1998; Gallardo et al., 2007; Ward & Stanford, 1995; Ward et al., 2002).

The constancy of occurrence of benthofauna varied between 0 and 50% (Me<10%). The only oxbow with more favourable conditions to invertebrates was OLD3 (Fig. 3). There was only one taxon which was the most often identified in each reservoir (*Chaoborus* sp.) and extreme values of constancy of occurrence were noted in OLD4.

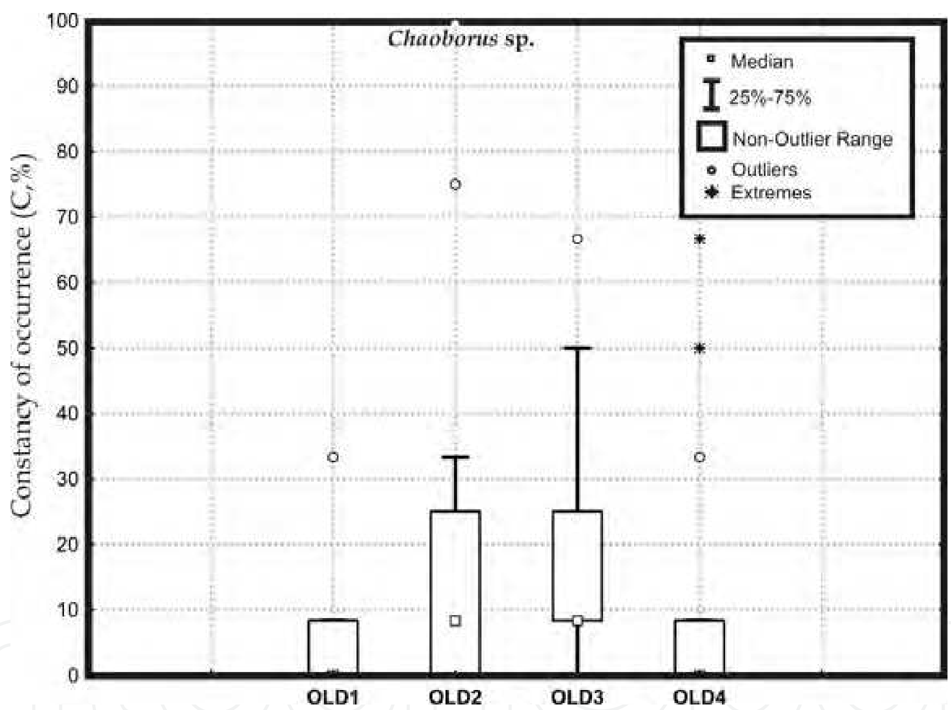

Fig. 3. Benthofauna constancy of occurrence (C, %) in the oxbow-lakes of the Drwęca River

4.1.3 Słupia River basin

31 benthofauna representatives belonging to 13 taxonomic groups were identified in the oxbow-lakes of the Słupia River (Table 4). The highest diversity of macrozoobenthos was noted in those reservoirs, probably due to regular spates connected with the functioning of hydro-power stations (Obolewski, 2011a).

The most frequently present were Crustaceans represented by *A. aquaticus* as well as Hirudinea represented by *Erpobdella* sp. (constant species). Both in the Łyna and Drwęca river basins those taxa were occasionally observed. The presence of *A. aquaticus* indicates β-mezosaprobic waters polluted with organic substances (Turoboyski, 1979). High abundance of *Erpobdella* sp. was caused by the presence of *A. aquaticus*, which they feed on. The representatives of Oligochaeta, Hirudinea, Insecta and Bivalvia were accessoric taxa. That taxonomic diversity was favoured by pulsating floods of the Słupia River (Junk et al., 1989; Tockner et al., 2000).

Taxa	Oxbow-lakes					Mean	Classification
	OLŁ 1	**OLŁ 2**	**OLŁ 3**	**OLŁ 4**	**OLŁ 5**		
A.aquaticus	58.3**	58.3**	58.3**	67.7**	83.3**	65.2	**C_3**
Erpobdella sp.	66.7**	66.7**	66.7**	42.0*	66.7**	61.8	
Oligochaeta	50.0*	58.3**	50.0*	16.7	67.0**	48.4	**C_2**
Procladius sp.	50.0*	58.3**	58.3**	41.7*	33.3*	48.3	
Chironomus sp.	33.3*	66.7**	33.3*	25.0	41.7*	40.0	
Sphaerium sp.	41.7*	33.3*	33.3*	41.7*	16.7	33.3	
Glossiphonia sp.	33.3*	8.3	58.3**	0.0	50.0*	30.0	
S.fuliginosa	8.3	33.3*	33.3*	58.0**	8.3	28.2	
Limnephilus sp.	33.3*	8.3	16.7	42.0*	33.3*	26.7	
Cloëon sp.	50.0*	25.0	8.3	8.3	25.0	23.3	**C_1**
H.stagnalis	25.0	25.0	58.3**	0.0	0.0	21.7	
Sergentia sp.	0.0	25.0	25.0	16.7	0.0	13.3	
Corixa sp.	16.7	8.3	16.7	8.3	16.7	13.3	
Gammarus sp.	0.0	0.0	16.7	33.3*	8.3	11.7	
Chaoborus sp.	8.3	0.0	8.3	25.0	8.3	10.0	
Lestes sp.	25.0	0.0	0.0	0.0	25.0	10.0	
A.grandis	8.3	0.0	0.0	8.3	25.0	8.3	
Dytiscus sp.	16.7	8.3	8.3	0.0	8.3	8.3	
V.viviparus	16.7	8.3	0.0	0.0	8.3	6.7	
Cyrnus sp.	0.0	0.0	0.0	17.0	8.3	5.1	
Piscola geometra L.	0.0	0.0	0.0	0.0	25.0	5.0	
Bezzia sp.	0.0	8.3	0.0	0.0	8.3	3.3	
Chironomus sp. pupa	0.0	0.0	8.3	8.3	0.0	3.3	
Platambus sp.	0.0	8.3	0.0	8.3	0.0	3.3	
E.bimaculata	0.0	0.0	0.0	8.3	0.0	1.7	
Ephemera sp.	0.0	0.0	8.3	0.0	0.0	1.7	
Notonecta sp.	0.0	0.0	0.0	0.0	8.3	1.7	
Libellula sp.	0.0	0.0	0.0	8.3	0.0	1.7	
Hydrovatus sp.	0.0	0.0	0.0	8.3	0.0	1.7	
Nepa cinera L.	0.0	0.0	0.0	8.3	0.0	1.7	
Tabanus sp.	8.3	0.0	0.0	0.0	0.0	1.7	

Table 5. Benthofauna constancy of occurrence (C, %) in the oxbow-lakes of the Słupia River with the classification of consecutive taxa (* - C_2, **- C_3, *** - C_4)

The pattern of constancy of occurrence was similar in all the oxbow-lakes of the Słupia River (Fig. 4). The medians were at the level of 10% which indicated that there were many occasional species present only during some seasons.

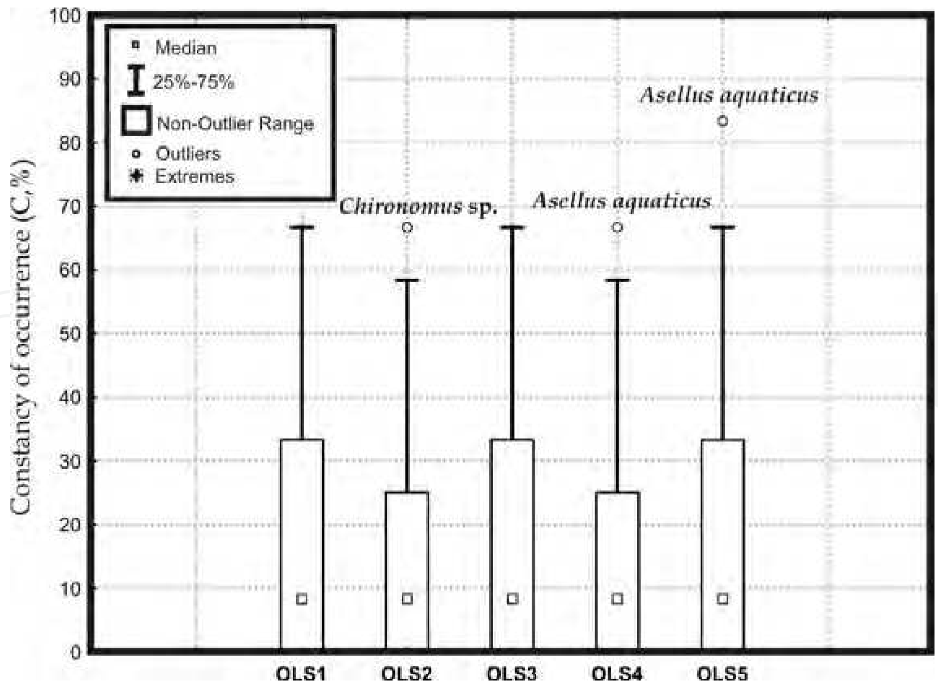

Fig. 4. Benthofauna constancy of occurrence (C, %) in the oxbow-lakes of the Słupia River

Collating the data from the studied river basins one can conclude that the most frequent were *Chironomus* sp. larvae, although they did not place the first position in any of the river basins (Table 6). *Erpodbella* sp. ($C_{av.}$=32%), *Chaoborus* sp. ($C_{av.}$=31%) and Oligochaeta ($C_{av.}$=26%) were also important elements of benthofauna structure. None of the identified invertebrate representatives reached the status higher than accesoric taxon.

Taxa	River basin		
	Łyna	**Drwęca**	**Słupia**
Chironomus sp.	15.7 (3)	50.0 (2)	40.0 (5)
Erpobdella sp.	10.2 (6)	22.9 (3)	61.8 (2)
Chaoborus sp.	25.3 (1)	58.3 (1)	10.0 (14)
Oligochaeta	20.0 (2)	10.4 (6)	48.4 (3)
Procladius sp.	12.6 (4)	14.6 (4)	48.3 (4)
A.aquaticus	7.8 (8)	2.1 (9)	65.2 (1)
Glossiphonia sp.	5.0 (9)	2.1 (9)	3.0 (7)
Cloëon sp.	0.1 (40)	4.2 (7)	23.3 (10)
Bezzia sp.	3.7 (11)	4.2 (7)	3.3 (19)

Table 6. Benthofauna constancy of occurrence (C, %) and their ranks in the studied river basins

4.2 Qualitative structure of benthofauna in oxbow-lakes with various type of connection to the main river

4.2.1 Lentic oxbow-lakes

The oxbow-lakes with limited hydrological connection to the main river were inhabited by 27 taxa. The most abundant were Chironomidae larvae (*Chironomus* sp. and *Chaoborus* sp.) as well as leeches of *Erpobdella* genus (Table 7). Those taxa are characterized by considerable adaptability to environmental conditions and therefore are common in various aquatic ecosystems, including oxbows (Galardo et al., 2008, Obolewski, 2011a). However, they were only accesoric taxa and their constancy of occurrence did not exceed half of the samples.

Taxa	Drwęca River Basin				Łyna River Basin	Słupia River Basin		Mean
	Oxbow-lakes							
	OLD 1	**OLD 2**	**OLD 3**	**OLD 4**	**OLŁ 4**	**OLS 1**	**OLS 2**	
Chironomus sp.	8.3	75.0	50.0	**66.7**	16.7	33.3	**66.7**	45.2
Chaoborus sp.	**33.3**	**100.0**	**66.7**	33.3	8.3	8.3	0.0	35.7
Erpobdella sp.	8.3	8.3	25.0	50.0	16.7	**66.7**	**66.7**	34.5

Table 7. Constancy of occurrence with classification of the most frequent benthofauna taxa ($C_{av.}$ > 25.0 %) in lentic oxbow-lakes

Both leeches and Diptera larvae are often observed in reservoirs polluted with organic substances, where the concentration of oxygen is low and limits the existence of other aquatic invertebrates. The remaining representatives of benthic fauna were classified as accidental taxa. The frequency of 5 taxa, including *Procladius* sp. larvae and Oligochaeta representatives, exceeded 10%,

The comparison of constancy of occurrence between the studied river basins gives interesting observations. The oxbow-lakes of the Drwęca River are closed and the refreshment of waters takes place during spring and autumn spates. Macrozoobenthos was represented there by 12 taxa and predominated by Diptera larvae (*Chironomus* sp., *Chaoborus* sp.), classified as constant taxa (OLD1) or euconstants (OLD2-OLD3). Particularly low macrozoobenthos diversity was observed in OLD1, where dense pleustonic fauna limited the mixing of waters and decreased the oxygenation (Glińska-Lewczuk, 2009). In the Łyna River Basin there was only one cut-off oxbow-lake, in which 14 taxa were observed and 85% of them occurred once. The most frequent was *V. pulchella* but it was still classified as accidental taxon (C<25%). The two closed oxbow-lakes in the Słupia river basin were rich with 20 macrozoobenthos taxa. 35% of them were constant taxa. Comparing to the oxbow-lakes of Drwęca and Łyna, *Erpobdella* and *A. aquaticus* occurred the most frequently in the Słupia river basin. No *Chaoborus* sp. larvae were observed which indicated good water oxygenation (Kajak, 2001).

4.2.2 Semi-lotic oxbow-lakes

Semi-open oxbow-lakes are hydrologically classified between cut-off and open reservoirs. They form environmental conditions favourable to fauna typical of both lotic and lentic ecosystems. The total number of taxa identified in the studied semi-lotic oxbow-lakes was equal to 40 which was reflected by the qualitative structure of benthofauna (Table 8)

The most frequent taxa in the oxbow-lake of the Łyna River were predatory larvae *Procladius* sp., bivalves *Pisidium* sp. and *Chaoborus* sp. larvae. However, the last two taxa were classified as accesoric, similarly to Oligochaeta and *Chironomus* sp. The remaining taxa were accidental. Different situation was observed in the oxbow-lake located in the Słupia River Basin, where the highest constancy of occurrence reached *Erpobdella* sp., *Procladius* sp., *A.*

aquaticus, *H. stagnalis* and *Glossiphonia* sp. (constant taxa). Oligochaeta, *Chironomus* sp., *S.fuliginosa* and *Sphaerium* sp. were accesoric taxa and the remaining were accidental.

Taxa	Łyna River Basin	Słupia River Basin	Mean
	Oxbow-lakes		
	OLŁ1	**OLS 3**	
Procladius sp.	**44.4**	58.3	51.4
Erpobdella sp.	22.2	**66.7**	44.4
A. aquaticus	22.2	58.3	40.3
Glossiphonia sp.	22.2	58.3	40.3
Oligochaeat	27.8	50.0	38.9
Chironomus sp.	27.8	33.3	30.6
H. stagnalis	0.0	58.3	29.2
S. fuliginosa	22.2	33.3	27.8

Table 8. Benthofauna constancy of occurrence with classification of the most frequent taxa ($C_{av.}$ >25.0 %) in semi-open oxbow lakes

4.2.3 Lotic oxbow-lakes

The most frequent taxon in lotic oxbow-lakes was *Chironomus* sp. which was classified as euconstants (C>50%). Quite often occurred *Erpobdella* sp., *A. aquaticus,* oligochaetes and *Chaoborus* sp. (Table 9).

Taxa	Łyna River Basin			Słupia River Basin		Mean
	Oxbow-lakes					
	OLŁ 2	**OLŁ 3**	**OLŁ 5**	**OLS 4**	**OLS 5**	
Chironomus sp.	**75.0**	**75.0**	**44.4**	25.0	41.7	52.2
Erpobdella sp.	41.7	16.7	33.3	42.0	66.7	40.1
A.aquaticus	16.7	0.0	22.2	**67.7**	**83.3**	38.0
Oligochaeta	41.7	16.7	44.4	16.7	67.0	37.3
Chaoborus sp.	58.3	**75.0**	0.0	25.0	8.3	33.3

Table 9. Benthofauna constancy of occurrence and classification of the most frequent taxa ($C_{av.}$ > 25.0 %) in lotic oxbow-lakes

The frequency of occurrence of other benthofauna representatives differed between the river basins. The open oxbow-lakes of the Łyna River were predominated by *Chironomus* sp. ($C_{av.}$=60%, euconstant taxon). The larvae of *Chaoborus* sp. also occurred quite often ($C_{av.}$=44%) but they were not present in OLŁ5. It was the youngest of the studied reservoirs while *Chaoborus* sp. prefers stagnant waters and therefore was absent in the discussed oxbow-lake (Kajak, 2001). The qualitative structure of benthofauna in the oxbows of the Łyna River Basin indicated decreased importance of *A. aquaticus* which was not observed in OLŁ3. This species is typical of oxbow-lakes in northern Poland (Obolewski, 2011a; Obolewski & Glińska-Lewczuk, 2011) rich with organic matter. They are absent in reservoirs which are uncovered or with high flow velocity washing out organic substances (Stańczykowska, 1986). Lotic oxbow-lakes of the Słupia River were predominated by *A. aquaticus* ($C_{av.}$=76%) and *Erpobdella* sp. ($C_{av.}$=54%) which were classified as euconstants.

4.3 Quantitative structure of benthofauna in oxbow-lakes of the studied river basins

4.3.1 Łyna River basin

The oxbow-lakes of the Łyna River were predominated by *Chaoborus* sp., Oligochaeta and *Chironomus* sp. which jointly constituted 66% of the total benthofauna abundance. They were classified as eudominant taxa (Table 10).

As for the other macrozoobenthos representatives, *V. viviparus* reached the status of dominant taxa and six taxa belonging to Crustacea, Hirudinea and Insecta were subdominants. Relatively large group of taxa was observed with low density which is typical of degraded aquatic ecosystems (Kajak, 2001).

The average density in the studied reservoirs was low and did not exceed 200 indiv. m^{-2}. However, each oxbow-lake was predominated by one taxa- OLŁ1-OLŁ3 by *Chaoborus* sp. (maximum density 1400 indiv.m^{-2}) and OLŁ4-OLŁ5 by Oligochaeta (maximum density 2600 indiv.m^{-2}), (Fig. 5).

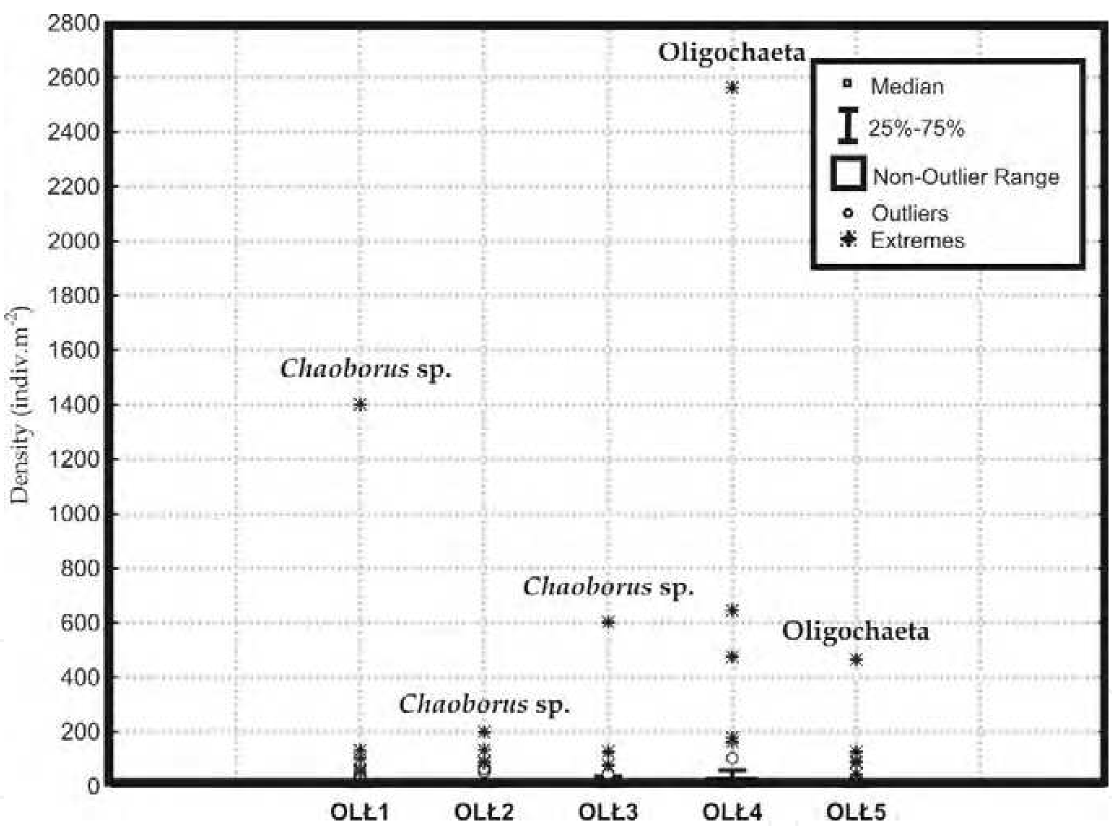

Fig. 5. Benthofauna density (indiv. m^{-2}) in the oxbow-lakes of the Łyna River

Such high abundance was reflected by the values of domination index (D, %). The share of *Chaoborus* sp. varied between 70% in OLŁ1 to 20% in OLŁ2, where they were eudominants. In OLŁ1 their domination was so high that no other taxa exceeded 10% of the total density. That situation indicates OLŁ1 as the most degraded reservoir which needs revitalization (Obolewski et al., 2009). The level of Oligochaeta domination in two oxbow-lakes was around 50-60% (Table 10).

Taxa	Oxbow-lakes					Mean	Classification
	OLŁ 1	**OLŁ 2**	**OLŁ 3**	**OLŁ 4**	**OLŁ 5**		
Chaoborus sp.	**69.1**	**20.8**	**58.6**	0.3	0.0	29.8	**ED**
Oligochaeta	6.5	9.0	2.2	**58.3**	**52.9**	25.8	
Chironomus sp.	2.3	13.9	10.4	14.7	9.9	10.2	
V. viviparus	3.7	6.7	3.4	1.3	10.5	5.1	**D**
A. aquaticus	2.2	2.3	0.0	0.0	14.4	3.8	**SD**
Limnephilus sp.	0.0	1.5	1.7	10.8	0.0	2.8	
Erpobdella sp.	1.0	8.1	2.3	0.8	1.9	2.8	
Bezzia sp.	0.0	5.4	7.5	0.0	0.2	2.6	
S. fuliginosa	0.6	9.3	1.7	0.3	0.0	2.4	
Procladius sp.	0.1	5.7	4.7	0.7	0.0	2.2	
Cyrnus sp.	0.0	7.0	1.7	1.0	0.0	1.9	**R**
Pisidium sp.	3.1	0.0	0.0	0.3	5.1	1.7	
M. culiciformis	5.9	0.0	0.0	0.0	0.0	1.2	
Dytiscus sp.	0.0	0.0	0.0	4.0	0.0	0.8	**SR**
Glossiphonia sp.	1.0	0.0	1.8	0.0	0.9	0.7	
Notonecta sp.	0.0	0.0	0.0	3.7	0.0	0.7	
H. stagnalis	0.0	1.6	1.7	0.0	0.0	0.7	
A. anatina	0.3	2.1	0.0	0.0	0.4	0.6	
Sergentia sp.	0.0	0.0	0.0	2.5	0.2	0.5	
Chironomus sp. pupa	0.0	0.0	2.3	0.0	0.0	0.5	
Lestes sp.	0.0	2.1	0.0	0.0	0.0	0.4	
L. stagnalis	0.5	0.0	0.0	0.0	1.5	0.4	
E. bimaculata	0.0	1.5	0.0	0.0	0.0	0.3	
Phryganaidae	0.0	0.0	0.0	0.0	1.5	0.3	
D. polymorpha	0.0	1.5	0.0	0.0	0.0	0.3	
Caenis sp.	0.0	1.5	0.0	0.0	0.0	0.3	
V. pulchella	0.0	0.0	0.0	0.9	0.0	0.2	
Polypedilum sp.	0.9	0.0	0.0	0.0	0.0	0.2	
V.piscinalis	0.4	0.0	0.0	0.0	0.0	0.1	
P. antipodarum	+	0.0	0.0	0.4	0.0	0.1	
V. cirstata	0.3	0.0	0.0	0.0	0.0	0.1	
A. cygnea	0.3	0.0	0.0	0.0	0.0	0.1	
E. tenellus	0.4	0.0	0.0	0.0	0.0	0.1	
Goera sp.	0.5	0.0	0.0	0.0	0.0	0.1	
Psychomidae	0.4	0.0	0.0	0.0	0.0	0.1	
G. truncatula	0.2	0.0	0.0	0.0	0.0	+	
Sphaerium sp.	0.4	0.0	0.0	0.0	0.0	+	
Lepidostoma sp.	0.2	0.0	0.0	0.0	0.0	+	
Hydropsyche sp.	+	0.0	0.0	0.0	0.0	+	
Limoniidae	+	0.0	0.0	0.0	0.0	+	
Cloëon sp.	0.0	0.0	0.0	0.0	0.2	+	

Table 10. Domination index (D, %) of benthofauna in the oxbow-lakes of the Łyna River with classification (ED – eudominants, D – dominants, SD – subdominants, R – recedents, SR – subrecedents) +<0.1%

4.3.2 Drwęca River basin

Macrozoobenthos in the oxbow-lakes of the Drwęca River was predominated by Diptera larvae: *Chaoborus* sp., *Chironomus* sp. and *Procladius* sp. which jointly constituted 76% of the total density. *Chaoborus* sp. was the most abundant in OLD1 and OLD4 while *Chironomus* sp. in OLD2 and OLD3 (Table 11). The increase in *Chironomus* sp. density was accompanied by higher abundance of predatory *Procladius* sp. but they were not observed in the reservoirs predominated by *Chaoborus* sp. In terms of domination, larvae of *Chironomus* sp.

Taxa	Oxbow-lakes				Mean	Classification
	OLD 1	**OLD 2**	**OLD 3**	**OLD 4**		
Chaoborus sp.	**37.3**	26.5	22.6	**68.3**	38.7	ED
Chironomus sp.	14.5	**46.3**	**30.2**	19.4	27.6	
Procladius sp.	4.8	17.1	18.7	0.0	10.2	
Erpobdella sp.	24.1	1.4	2.0	9.8	9.3	D
A. aquaticus	14.5	0.0	0.0	0.0	3.6	SD
Glossiphonia sp.	0.0	0.0	8.7	0.0	2.2	
Cloëon sp.	4.8	0.0	2.6	0.0	1.9	R
Oligochaeta	0.0	2.7	3.9	0.0	1.7	
Sergentia sp.	0.0	0.0	6.1	0.0	1.5	
Chironomus sp. pupa	0.0	1.8	3.5	0.0	1.3	
Bezzia sp.	0.0	1.5	1.7	0.0	0.8	SR
Cyrnus sp.	0.0	2.7	0.0	0.0	0.7	
H. stagnalis	0.0	0.0	0.0	2.5	0.6	

Table 11. Benthofauna domination index (D, %) in the oxbow-lakes of the Drwęca River with classification (ED – eudominants, D – dominants, SD – subdominants, R – recedents, SR – subrecedents)

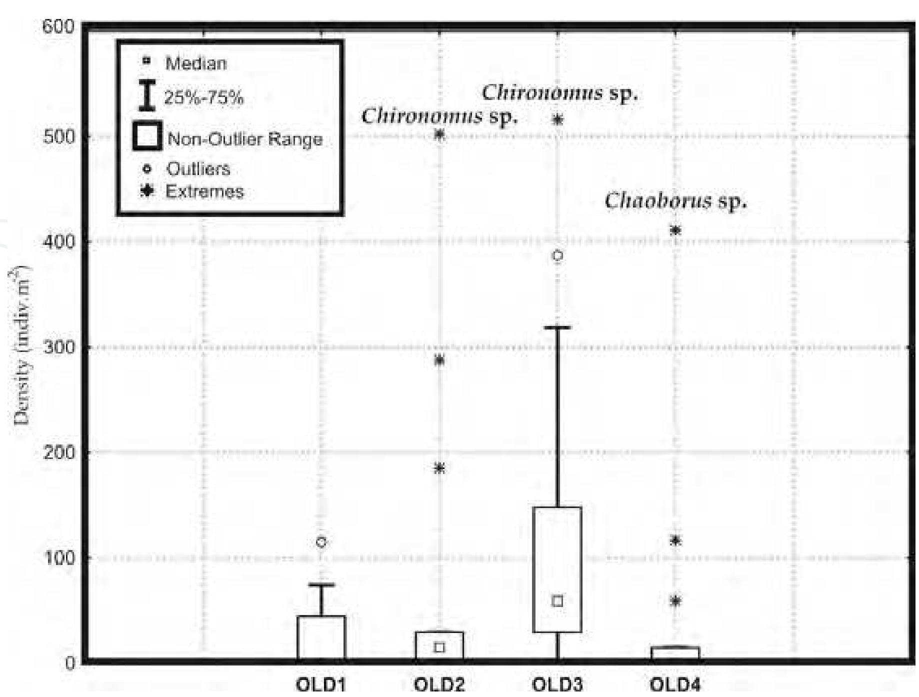

Fig. 6. Benthofauna density (indiv. m^{-2}) in the oxbow-lakes of the Drwęca River

predominated and reached even 70% of benthofauna (OLD4) while *Chironomus* sp.- 30-50% (OLD2-OLD3). The only exception was OLD1 where leeches of *Erpobdella* sp. as well as *Chironomus* sp. appeared (Table 11).

The density of benthofauna did not exceed the average value of 50 indiv.m^{-2} and more abundant macrozoobenthos was observed only in OLD3 (Fig. 6). The larvae of *Chironomus* sp. appeared massively (density above 500 indiv.m^{-2}) in that reservoir as well as in OLD2. OLD4 seems to be the most degraded oxbow-lake in the Drwęca River Basin due to low benthofauna density and the predomination of *Chaoborus* sp. (density above 400 indiv.m^{-2}). The only reservoir with no predominant taxa was OLD1 and represented different zoocenotic type.

4.3.3 Słupia River Basin

The oxbow-lakes in the Słupia River Basin were abundantly inhabited by taxa belonging to Oligochaeta, Crustacea and Insecta (Table 12). They constituted 70% of benthofauna and the share of *A. aquaticus* reached 40%. That species predominated in three oxbows (D=30-36%). *A. aquaticus*, particularly large individuals are typical of β-mezosaprobic waters (Turoboyski, 1979). Almost half of benthofauna density in OLS1 constituted the larvae of *Chironomus* sp. but their share was lower in the remaining reservoirs. In turn, the density of Oligochaeta was similar in all the oxbows (Table 12).

Quite atypical domination structure was observed in OLS5, where benthofauna was predominated by *Cloëon* sp. (25% of total density). That taxon is regarded as bioindicator and its presence is a sign of good environmental conditions, particularly high water oxygenation (Turoboyski, 1979).

Average macrozoobenthos density in the oxbow-lakes of the Słupia River was at the level of 100 indiv.m^{-2} with the domination of *A. aquaticus* (density between 400 and 700 indiv.m^{-2}), *Chironomus* sp. (maximum density over 1500 indiv.m^{-2}) or *Cloëon* sp. (1600 indiv.m^{-2}), (Fig. 7).

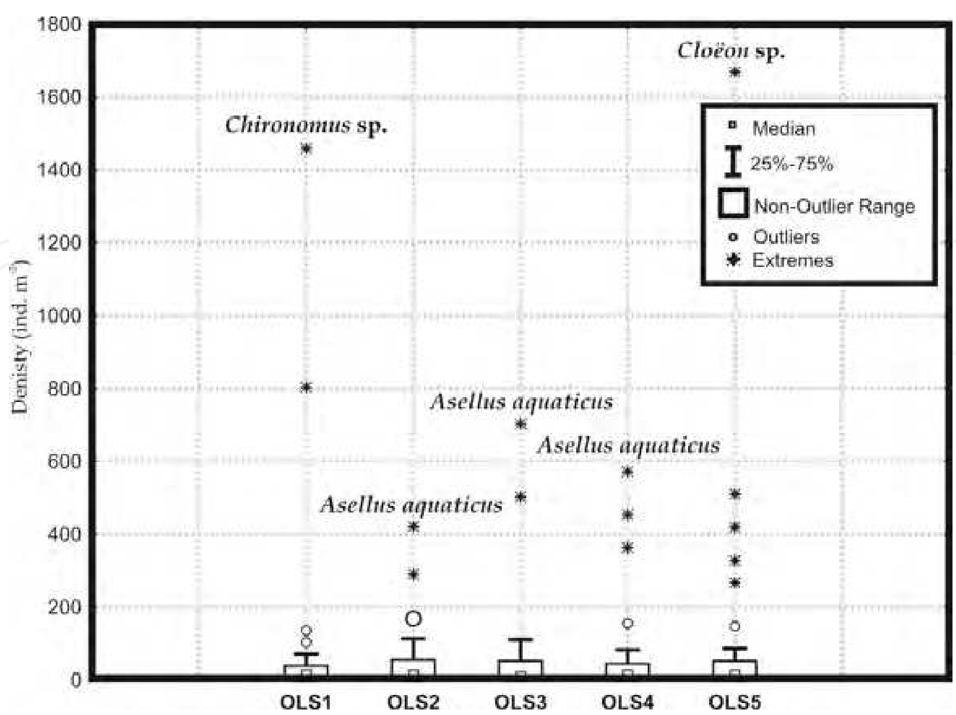

Fig. 7. Benthofauna density (indiv. m^{-2}) in the oxbow-lakes of the Słupia River

The comparison of averaged domination indices and ranks of the consecutive taxa in the studied river basins shows the frequent occurrence of *Chaoborus* sp. larvae which predominated in the oxbow-lakes of Drwęca and Łyna (Table 13). Its importance was lower in the Słupia River Basin. Opposite situation was observed in case of *A. aquaticus* and *Cloëon* sp. which were not abundant in the Drwęca and Łyna river basins but constituted the most importand quantitative component of macrozoobenthos in the Słupia River Basin. High ranks were also reached by *Chironomus* sp. and Oligochaeta.

Taxa	Oxbow-lakes					Mean	Classification
	OLS 1	**OLS 2**	**OLS 3**	**OLS 4**	**OLS 5**		
A. aquaticus	27.1	**29.0**	**36.3**	**29.3**	11.4	26.6	**ED**
Chironomus sp.	**49.2**	11.6	4.3	23.3	0.7	17.8	
Oligochaeta	2.4	19.9	26.1	7.9	13.5	14.0	
Cloëon sp.	3.5	7.8	0.4	0.8	**44.1**	11.3	
Procladius sp.	4.6	7.6	2.1	4.4	1.4	4.0	**SD**
Gammarus sp.	0.0	0.0	0.8	18.1	0.4	3.9	
Erpobdella sp.	1.3	1.8	2.4	1.5	8.6	3.1	
S. fuliginosa	2.3	4.6	3.8	2.4	0.4	2.7	
Sphaerium sp.	2.3	3.8	1.5	3.8	0.8	2.4	
Limnephilus sp.	1.2	2.0	4.8	1.3	1.1	2.1	
Corixa sp.	0.7	1.0	0.5	0.8	7.3	2.1	
Sergentia sp.	0.0	1.7	5.7	2.4	0.0	2.0	
Glossiphonia sp.	0.7	1.0	3.2	0.0	2.3	1.4	**R**
V. viviparus	0.7	4.2	0.0	0.0	0.4	1.1	
Bezzia sp.	0.0	1.0	0.0	0.0	3.9	1.0	
H. stagnalis	0.7	1.0	2.7	0.0	0.0	0.9	**SR**
Chaoborus sp.	0.5	0.0	0.4	1.6	0.6	0.6	
Dytiscus sp.	0.5	1.0	0.4	0.0	0.9	0.6	
Hydrovatus sp.	0.0	0.0	1.9	0.0	0.0	0.4	
Lestes sp.	0.8	0.0	0.0	0.0	0.8	0.3	
Tabanus sp.	1.0	0.0	0.0	0.0	0.0	0.2	
Cyrnus sp.	0.0	0.0	0.0	0.8	0.4	0.2	
Chironomus sp. pupa	0.0	0.0	0.4	0.8	0.0	0.2	
Platambus sp.	0.0	1.0	0.0	0.0	0.0	0.2	
E. bimaculata	0.0	0.0	0.0	0.8	0.0	0.2	
Ephemera sp.	0.0	0.0	0.8	0.0	0.0	0.2	
Notonecta sp.	0.0	0.0	0.0	0.0	0.5	0.1	
Libellula sp.	0.0	0.0	0.0	0.4	0.0	0.1	
P. geometra	0.0	0.0	0.0	0.0	0.5	0.1	
A. grandis	0.5	0.0	0.0	0.0	0.0	0.1	
N. cinera	0.0	0.0	0.4	0.0	0.0	0.1	

Table 12. Benthofauna domination index (D, %) in the oxbow-lakes of the Słupia River with classification (ED – eudominants, SD – subdominants, R – recedents, SR – subrecedents)

Taxa	River basin		
	Łyna	**Drwęca**	**Słupia**
Chaoborus sp.	29.8 (1)	38.7 (1)	(0.6) 17
Chironomus sp.	10.2 (3)	27.6 (2)	17.8 (2)
Oligochaeta	25.8 (2)	1.7 (8)	14.0 (3)
A.aquaticus	3.8 (5)	3.6 (5)	26.6 (1)
Procladius sp.	2.2 (10)	10.2 (3)	4.0 (5)
Erpobdella sp.	2.8 (6)	9.3 (4)	3.1 (7)
Cloëon sp.	0.1 (36)	1.9 (7)	11.3 (4)
Glossiphonia sp.	0.7 (15)	2.2 (6)	1.4 (13)
Bezzia sp.	2.6 (8)	0.8 (11)	1.0 (15)
Sergentia sp.	0.5 (19)	1.5 (9)	2.0 (12)

Table 13. Domination index (D, %) and ranks of benthofauna representatives in the oxbow-lakes of consecutive river basins

4.4 Qualitative structure of benthofauna in oxbow-lakes with various type of connection to the main river

4.4.1 Lentic oxbow-lakes

Limited hydrological connectivity between cut-off oxbow-lakes and the river causes that those reservoirs are predominated by taxa belonging to eurybionts (Kajak, 2001). The main components of benthofauna in the studied lentic oxbows were Diptera larvae (*Chironomus* sp. and *Chaoborus* sp.), Oligochaeta and Isopoda (*A. aquaticus*) – 8 taxa in total. They formed the group of eudominants and constituted 71% of benthofauna abundance (Table 14). They were accompanied by predatory larvae of *Procladius* sp. as well as leeches *Erpobdella* sp. (dominants). As for the other benthofauna representatives, the presence of *Cloëon* sp. *Limnephilus* sp. should be noticed.

Benthofauna structure in lentic oxbow-lakes depended on the specific features of consecutive river basins. In the Drwęca River Basin the inflow of fresh water occurs during floods and therefore benthofauna was predominated by taxa resistant to low oxygen concentration in water- some of the Diptera larvae (Mikulski, 1974; Stańczykowska, 1986). The cut-off oxbows of Łyna and Słupia are additionally refreshed by regular, twenty-four

Taxa	Oxbow-lakes							Mean	Classification
	OLD 1	**OLD 2**	**OLD 3**	**OLD 4**	**OLŁ 4**	**OLS 1**	**OLS 2**		
Chironomus sp.	14.5	**46.3**	**30.2**	19.4	14.7	**49.2**	11.6	26.6	**ED**
Chaoborus sp.	**37.3**	26.5	22.7	**68.3**	0.3	0.5	0.0	22.2	
Oligochaeta	0.0	2.7	3.9	0.0	**58.3**	2.4	19.9	12.5	
A.aquaticus	14.5	0.0	0.0	0.0	0.0	27.1	**29.0**	10.1	
Procladius sp.	4.8	17.1	18.7	0.0	0.7	4.6	7.6	7.6	**D**
Erpobdella sp.	24.1	1.4	2.0	9.8	0.8	1.3	1.8	5.9	
Cloëon sp.	4.8	0.0	2.6	0.0	0.0	3.5	7.8	2.7	**SD**
Limnephilus sp.	0.0	0.0	0.0	0.0	10.8	1.2	2.0	2.0	

Table 14. Domination index of the most import ant benthofauna representatives (mean D>2 %) in lentic oxbow-lakes with classification (ED – eudominants, D – dominants, SD – subdominants)

hour oscillation of water level caused by the work of hydroelectric power stations (so called effect of Intensive Flood Pulse IFP) (Obolewski, 2011b). As a result, benthofauna abundance is higher with the domination of Oligochaeta and Crustacea.

4.4.2 Semi-lotic oxbow-lakes

Semi-open oxbow lakes were predominated by the larvae of *Chaoborus* sp. which were accompanied by *A. aquaticus* and Oligochaeta. They formed the group of eudominants and constituted 70% of total benthofauna density (Table 15). Other important macrozoobenthos components were 6 taxa belonging to Insecta (Diptera, Trichoptera, Megaloptera) and Hirudinea.
The structure of benthofauna domination in Łyna and Słupia river basins was specific. The diversity of lotic and lentic habitats causes that those biocenosis are unique biological systems (Tockner et al., 1999; Obolewski, 2011a). *Chaoborus* sp. and *M. culiciformis* predominated in the oxbow-lake of the Łyna River, opposite to the Słupia River Basin. That indicates possible differences in the level of water refreshment. Moreover, water currents may wash away *Chaoborus* sp. (Mikulski, 1974) but favour the presence of *A. aquaticus* thanks to the inflow of organic matter carrying by water. As for other taxa, *Limnephilus* sp. and leeches *Glossiphonia* sp. were classified as subdominants. Their occurrence indicates β-mezosaprobic waters (Turoboyski, 1979).

Taxa	Oxbow-lakes		Mean	Classification
	OLŁ1	**OLS 3**		
Chaoborus sp.	**69.1**	0.4	34.7	**ED**
A. aquaticus	2.2	**36.3**	19.2	
Oligochaeta	6.5	26.1	16.3	
Chironomus sp.	2.3	4.3	3.3	**SD**
Sergentia sp.	0.0	5.7	2.9	
M. culiciformis	5.5	0.0	2.8	
Limnephilus sp.	0.0	4.8	2.4	
S.fuliginosa	0.6	3.8	2.2	
Glossiphonia sp.	1.0	3.2	2.1	

Table 15. Domination index of the most import ant benthofauna representatives (mean D>2 %) in semi-lotic oxbow-lakes with classification (ED – eudominants, SD – subdominants)

4.4.3 Lotic oxbow-lakes

Lotic oxbow-lakes are reservoirs with constant inflow of fresh water which intensity depends on water flow in the river (Ward et al., 2002). The studied open oxbows were predominated by Oligochaeta, Diptera larvae and Crustacea. Their share in benthofauna qualitative structure reached 56% (eudominants). The higher was hydrological connectivity the lower was the percentage share of eudominants but higher number of important benthofauna components. Regardless the level of contact between oxbows and rivers, the same taxa prevailed. However, the importance of Oligochaeta increased and they were the most abundant in OLŁ5 (Table 16).
The domination structure also depended on hydrological connectivity. The oxbow connected with the main river by melioration ditches was predominated by *Cloëon* sp.- bioindicator of oligotrophic waters.

Taxa	Oxbow-lakes					Mean	Classification
	OLŁ 2	**OLŁ 3**	**OLŁ 5**	**OLS 4**	**OLS 5**		
Oligochaeta	9.0	2.2	**52.9**	7.9	13.5	17.1	**ED**
Chaoborus sp.	**20.8**	**58.6**	0.0	1.0	0.4	16.2	
Chironomus sp.	13.9	10.4	9.9	23.3	0.7	11.6	
A.aquaticus	2.3	0.0	14.4	**29.3**	11.1	11.4	
Cloëon sp.	0.0	0.0	0.2	0.8	**44.1**	9.0	**D**
Erpobdella sp.	8.1	2.3	1.9	1.2	8.6	4.4	**SD**
V.viviparus	6.7	3.4	10.5	0.0	0.4	4.2	
Gammarus sp.	0.0	0.0	0	18.1	0.4	3.7	
Bezzia sp.	5.4	7.5	0.2	0.0	3.9	3.4	
Procladius sp.	5.7	4.7	0	4.2	1.4	3.2	
S.fuliginosa	9.3	1.7	0	2.4	0.4	2.8	
Cyrnus sp.	7.0	1.7	0	0.8	0.4	2.0	

Table 16. Domination index of the most import ant benthofauna representatives (mean D>2 %) in lotic oxbow-lakes with classification (ED – eudominants, D – dominants, SD – subdominants)

4.5 Assessment of benthofauna diversity

4.5.1 Diversity of benthofauna in oxbow-lakes of the studied river basins

Łyna River Basin

The Shannon diversity index for the Łyna River Basins varied between 0.148 and 0.438 with average value equal to 0.293 (Table 17). Considerable standard deviations indicate the instability of habitat conditions (Ward, 1998). The highest average value of H′ was observed in semi-lotic OLŁ2 and the lowest in cut-off OLŁ5.

Oxbow-lakes				
OLŁ 1	**OLŁ 2**	**OLŁ 3**	**OLŁ 4**	**OLŁ 5**
0.388±0.220	**0.438**±0.246	0.316±0.209	0.174±0.234	0.148±0.147

Table 17. Average values of Shannon diversity index (H′± SD) for benthofauna in the oxbow-lakes of the Łyna River

The index of ecological importance reached the highest values for *Chaoborus* sp. (Table 18). Oligochaeta and *Chironomus* sp. were also important components of benthofauna in the Łyna River Basin. The ecological importance of many taxa was low.

Drwęca River Basin

The Shannon diversity index for the oxbow-lakes in the Drwęca River Basin varied between 0.06 and 0.29 (0.152 on average) (Table 19). High standard variations, often exceeding mean values indicate unstable habitat conditions (Ward, 1998). The highest H′ value was observed in OLD2 and the lowest in OLD1.

The analysis of ecological importance indicated *Chaoborus* sp. and *Chironomus* sp. as the most important taxa (Table 20). Among other taxa, the role of *Procladius* sp. and *Erpobdella* sp. should be noticed.

Taxa	Oxbow-lakes					Mean	Classification
	OLŁ 1	**OLŁ 2**	**OLŁ 3**	**OLŁ 4**	**OLŁ 5**		
Chaoborus sp.	**51.8**	**34.8**	**66.3**	1.9	0.0	31.0	Q5
Oligochaeta	13.4	19.3	6.0	**25.4**	**48.5**	22.5	Q4
Chironomus sp.	8.0	32.3	30.4	18.0	21.0	22.0	
V. viviparus	10.9	13.0	7.7	3.9	10.8	9.3	Q1
Erpobdella sp.	5.8	18.3	6.0	4.3	4.6	7.8	
Bezzia sp.	0.5	13.4	17.7	0.0	1.4	6.6	
A. aquaticus	7.8	6.2	0.0	0.0	17.9	6.4	
Pisidium sp.	11.8	0.0	0.0	1.9	15.0	5.7	
Procladius sp.	0.7	11.9	6.0	2.7	0.0	4.3	
S. fuliginosa	4.2	8.8	3.5	1.9	0.0	3.7	
Limnephilus sp.	0.0	3.6	3.5	10.9	0.0	3.6	
Cyrnus sp.	0.0	10.8	3.5	3.3	0.0	3.5	
A. anatina	1.4	7.2	0.0	0.0	2.9	2.3	
Phryganaidae	6.8	0.0	0.0	0.0	4.1	2.2	
Glossiphonia sp.	0.0	0.0	4.9	0.0	3.2	1.6	
M. culiciformis	7.5	0.0	0.0	0.0	0.0	1.5	
Lestes sp.	0.5	7.2	0.0	0.0	0.0	1.5	
V.piscinalis	2.1	0.0	0.0	5.6	0.0	1.5	
H. stagnalis	0.0	3.6	3.5	0.0	0.0	1.4	
Notonecta sp.	0.0	0.0	0.0	6.4	0.0	1.3	
L. stagnalis	2.3	0.0	0.0	0.0	4.1	1.3	
Dytiscus sp.	0.0	0.0	0.0	6.7	0.0	1.3	
Sergentia sp.	0.0	0.0	0.0	5.1	1.4	1.3	
Chironomus sp. pupa	0.0	0.0	6.0	0.0	0.0	1.2	
E. bimaculata	0.0	3.6	0.0	0.0	0.0	0.7	
D. polymorpha	0.0	3.6	0.0	0.0	0.0	0.7	
Caenis sp.	0.0	3.6	0.0	0.0	0.0	0.7	
P. antipodarum	0.5	0.0	0.0	1.9	0.0	0.5	
Polypedilum sp.	2.2	0.0	0.0	0.0	0.0	0.4	
Goera sp.	2.0	0.0	0.0	0.0	0.0	0.4	
Sphaerium sp.	1.6	0.0	0.0	0.0	0.0	0.3	
Cloëon sp.	0.0	0.0	0.0	0.0	1.4	0.3	
V. pulchella	0.0	0.0	0.0	0.9	0.0	0.2	
Lepidostoma sp.	0.8	0.0	0.0	0.0	0.0	0.2	
Psychomidae	0.8	0.0	0.0	0.0	0.0	0.2	
G. truncatula	1.0	0.0	0.0	0.0	0.0	0.2	
V. cirstata	0.3	0.0	0.0	0.0	0.0	0.1	
A. cygnea	0.3	0.0	0.0	0.0	0.0	0.1	
E. tenellus	0.7	0.0	0.0	0.0	0.0	0.1	
Limoniidae	0.5	0.0	0.0	0.0	0.0	0.1	
Hydropsyche sp.	0.1	0.0	0.0	0.0	0.0	<0.1	

Table 18. Index of ecological importance (Q, %) for benthofauna representatives in the oxbow-lakes of the Łyna River and its classification (Q5 – very high, Q4 – high, Q1 – very low)

Oxbow-lakes			
OLD 1	**OLD 2**	**OLD 3**	**OLD 4**
0.056±0.157	**0.293**±0.164	0.166±0.216	0.092±0.131

Table 19. Average values of Shannon diversity index (H'± SD) for benthofauna in the oxbow-lakes of the Drwęca River

Taxa	Oxbow-lakes				Mean	Classification
	OLD 1	**OLD 2**	**OLD 3**	**OLD 4**		
Chaoborus sp.	**35.3**	49.8	**38.9**	**47.7**	42.9	Q5
Chironomus sp.	11.0	**57.0**	**38.9**	35.9	35.7	
Procladius sp.	6.3	23.1	17.6	0.0	11.8	Q3
Erpobdella sp.	14.2	3.3	7.0	22.2	11.7	
Chironomus sp. pupa	0.0	6.5	10.8	0.0	4.3	Q1
Oligochaeta	0	8.0	8.1	0	4.0	
Glossiphonia sp.	0.0	0.0	8.5	0.0	2.1	
Cloëon sp.	6.3	0.0	4.7	0.0	2.7	
Sergentia sp.	0.0	0.0	7.1	0.0	1.8	
Bezzia sp.	0.0	3.3	3.8	0.0	1.8	
A.aquaticus	6.3	0	0	0	1.6	
Cyrnus sp.	0.0	4.6	0.0	0.0	1.2	
H. stagnalis	0.0	0.0	0.0	4.5	1.1	

Table 20. Index of ecological importance (Q, %) for benthofauna representatives in the oxbow-lakes of the Drwęca River and its classification (Q5 – very high, Q3 – moderate, Q1 – very low)

Słupia River Basin

Benthofauna diversity in the Słupia River Basins was the highest among the studied basins (0.412 on average) (Table 21). Low values of standard deviations indicate more stable habitat conditions which favour taxonomic diversity (Ward, 1998; Gallardo et al., 2008; Obolewski, 2011a; Obolewski & Glińska-Lewczuk, 2011).

Oxbow-lakes				
OLS 1	**OLS 2**	**OLS 3**	**OLS 4**	**OLS 5**
0.354±0.163	0.377±0.291	**0.488**±0.207	0.377±0.232	0.464±0.180

Table 21. Average values of Shannon diversity index (H'± SD) for benthofauna in the oxbow-lakes of the Słupia River

The analysis of Q index indicated *A. aquaticus* as the most important component of benthofauna in the Słupia River Basin. High Q values were reached by Oligochaeta and *Chironomus* sp. while moderate by *Procladius* sp., *Cloëon* sp. and *Erpobdella* sp. (Table 22). Such ecological structure, with the presence of oligotrophic water bioindicators (*Cloëon* sp., *Gammarus* sp., *Ephemera* sp.) is a sign of good environmental conditions (Lapmert & Summer, 2007; Turoboyski, 1979).

Taxa	Oxbow-lakes					Mean	Classification
	OLS 1	**OLS 2**	**OLS 3**	**OLS 4**	**OLS 5**		
A.aquaticus	39.8	**41.1**	**46.0**	**44.2**	30.4	40.3	Q5
Oligochaeta	11.0	34.1	36.0	11.5	30.0	24.5	Q4
Chironomus sp.	**40.5**	27.8	11.9	24.1	5.4	22.0	
Procladius sp.	15.1	21.0	11.1	13.3	6.8	13.5	Q3
Cloëon sp.	13.2	14.0	1.8	2.5	**33.2**	12.9	
Erpobdella sp.	9.4	10.9	12.1	6.7	24.0	12.6	
Sphaerium sp.	9.8	11.3	7.1	12.3	3.6	8.8	Q2
S.fuliginosa	4.1	12.4	11.3	11.5	1.8	8.2	
Limnephilus sp.	6.5	4.1	9.0	6.7	6.0	6.4	
Glossiphonia sp.	5.0	2.9	13.6	0.0	10.7	6.4	
Gammarus sp.	0.0	0.0	3.6	24.9	2.6	6.2	
Corixa sp.	3.5	2.9	2.9	2.5	13.8	5.1	
Sergentia sp.	0.0	6.5	12.0	6.2	0.0	4.9	Q1
H.stagnalis	4.1	5.0	12.5	0.0	0.0	4.3	
V.viviparus	3.5	5.8	0.0	0.0	1.8	2.2	
Chaoborus sp.	2.0	0.0	1.8	5.0	1.8	2.1	
Dytiscus sp.	2.9	2.9	1.8	0.0	2.6	2.0	
A. grandis	2.0	0.0	0.0	2.5	4.4	1.8	
Lestes sp.	4.6	0.0	0.0	0.0	4.4	1.8	
Bezzia sp.	0.0	2.9	0.0	0.0	5.7	1.7	
Platambus sp.	0.0	2.9	3.1	0.0	1.8	1.6	
Cyrnus sp.	0.0	0.0	0.0	3.6	1.8	1.1	
P. geometra	0.0	0.0	1.8	0.0	3.6	1.1	
Chironomus sp. pupa	0.0	0.0	1.8	2.5	0.0	0.9	
Hydrovatus sp.	0.0	0.0	4.0	0.0	0.0	0.8	
Tabanus sp.	2.9	0.0	0.0	0.0	0.0	0.6	
E.bimaculata	0.0	0.0	0.0	2.5	0.0	0.5	
Ephemera sp.	0.0	0.0	2.5	0.0	0.0	0.5	
Libellula sp.	0.0	0.0	0.0	2.5	0.0	0.5	
Notonecta sp.	0.0	0.0	0.0	0.0	1.8	0.4	
N. cinera	0.0	0.0	1.8	0.0	0.0	0.4	

Table 22. Index of ecological importance (Q, %) for benthofauna representatives in the oxbow-lakes of the Słupia River and its classification (Q5 – very high, Q4 – high, Q3 – moderate, Q2 –low , Q1 – very low)

The comparison of average values of ecological importance index Q between river basins with the classification of consecutive taxa shows, that the most important role was played by *Chironomus* sp. larvae (Table 23). Its average ecological importance reached $Q_{av.}$=27%, similarly to *Chaoborus* sp. larvae ($Q_{av.}$=25%). Oligochaeta and *A. aquaticus* also revealed considerable ecological importance ($Q_{av.}$ equal to 17% and 16%, respectively). It is interesting, that the importance of *Chaoborus* sp. is very high in the Łyna and Drwęca river basins but very low for Słupia oxbow-lakes.

Taxa	River basin		
	Łyna	**Drwęca**	**Słupia**
Chironomus sp.	22.0 (3)	35.7 (2)	22.0 (3)
Chaoborus sp.	31.0 (1)	42.9 (1)	2.1 (16)
Oligochaeta	22.5 (2)	4.0 (6)	24.5 (2)
A.aquaticus	6.4 (7)	1.6 (11)	40.3 (1)
Procladius sp.	4.3 (9)	11.8 (3)	13.5 (4)
Erpobdella sp.	7.8 (5)	11.7 (4)	12.6 (6)
Cloëon sp.	0.3 (31)	2.7 (8)	12.9 (5)

Table 23. Index of ecological importance (Q, %) for benthofauna representatives in the studied river basins and their ranks

4.5.2 Diversity of benthofauna in oxbow-lakes with various type of connection to the main river

Benthofauna diversity changed depending on hydrological connectivity (Fig. 8). The Shannon index for closed oxbow-lakes did not exceed 0.7 ($H'_{av.}$=0.217±0.194). In case of semi-lotic reservoirs H' values ranged from 0.8 in the Łyna River to 1.1 in the Słupia River Basin with 0.438±0.214 on average. Higher diversity comparing to closed oxbow is caused by more often fresh water inflow (Amoros & Bornette, 2002; Obolewski et al., 2009). Full hydrological connectivity did not increase considerably benthofauna diversity. In open oxbow-lakes the Shannon index reached 0.349±0.203 on average, which is 1.2-fold less than in semi-lotic oxbows and 1.6-fold higher than in lentic reservoirs. One can conclude, that

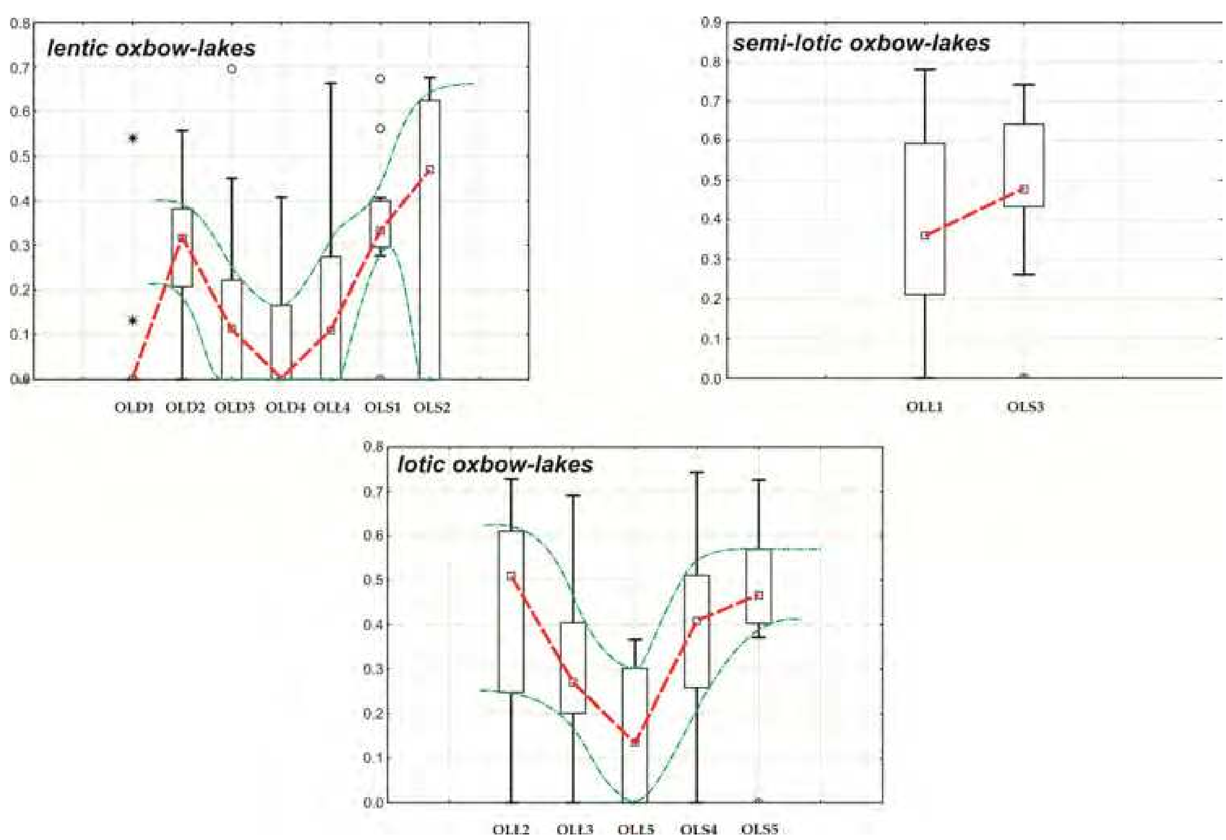

Fig. 8. Shannon diversity index (H') in oxbow-lakes with different types of connection to the main river course

semi-lotic oxbow-lakes are optimal habitat for macrozoobenthos in terms of diversity (Gallardo et al., 2008; Obolewski, 2011a and b).
The analysis of ecological importance (Q) for consecutive hydrodynamic types of oxbow-lakes indicates that it evens out for higher hydrological connectivity (Table 24). A unimodal pattern with the domination of *Chironomus* sp. was observed in cut-off reservoirs while in semi-lotic oxbows three taxa were important (*Chaoborus* sp., *A. aquaticus* and Oligochaeta). Lower frequency of occurrence for *Chironomus* sp. there is caused by fish foraging (Penczak et al., 2007). In lotic oxbow-lakes the ecological importance of main benthofauna components was at similar level. Four taxa reached high values (Oligochaeta, *Chironomus* sp., *Chaoborus* sp. and *A. aquaticus)* while only for *Erpobdella* the Q level was moderate. The role of Oligochaeta increases with hydrological connectivity, opposite to *Chaoborus* sp. due to washing out by water movement (Stańczykowska, 1986) and ichthyofauna pressure.

Taxa	Oxbow-lakes		
	lentic	**semi-lotic**	**lotic**
Chaoborus sp.	28.18	**28.65**	23.20
Chironomus sp.	**34.64**	10.05	24.65
Oligochaeta	16.78	25.14	**25.24**
A.aquaticus	13.40	28.20	20.83
Erpobdella sp.	14.26	8.43	13.28

Table 24. Index of ecological importance ($Q_{av.}$>10.01%) for benthofauna representatives in oxbow-lakes with different types of connection to the main river course

5. Conclusions

This study confirms that hydrological connectivity between the main river and its wetlands strongly influences benthofauna composition and abundance. Limited hydrological connection as well as hydrotechnical buildings on rivers of moderate slope cause permanent hydrological changes. As a result many valuable aquatic ecosystems may be degraded because water exchange is sporadic. Recreation of hydrological connectivity in river basins favours its protection and revitalization as well as protection against rapid floods. Reconstruction of biodiversity after such events is initiated in wetlands where diverse habitats favour benthofauna survival and further recolonization.
Regardless of the distinguished hydrodynamic types of oxbow-lakes those reservoirs are important ecological centres (so called “hot spots”) within a river valley or even a region which form various habitats for many fauna and flora species. Relationships between the main water-course and the rest of valley include production, decomposition and consumption which depend on periodical floods and oscillations of water table level. According to the theory of Junk et al. the alternating flood and low water stage periods increase the decomposition and nutrient circulation which trigger biological diversity and productivity. Those processes may be reinforced by intensive flood pulses caused by hydroelectric power stations and therefore river valleys with hydrotechnical buildings show higher benthofauna diversity.

6. Acknowledgments

I would like to thank Katarzyna Glińska-Lewczuk, Szymon Kobus and Paweł Burand for their help in morphometric studies (Dept. of Land Reclamation and Environmental

Management, University of Warmia and Mazury) as well as Ernest Murza for his help in collecting and preparation of biological material (Dept. Aquatic of Ecology, Pomeranian University in Słupsk). This study was supported financially by the Polish Ministry of Education and Science. grant no. NN 305 3247 40.

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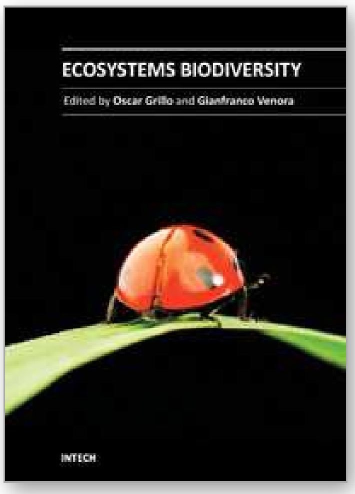

ISBN 978-953-307-417-7
Hard cover, 464 pages
Publisher InTech
Published online 16, December, 2011
Published in print edition December, 2011