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RESULTS OF FLOODPLAIN FORESTS PROTECTION IN THE UROCZYSKO WARTA, THE WIELKOPOLSKA REGION, POLAND

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Abstract

The Uroczysko Warta is one of the most important riparian forest areas in Poland. The construction of the Jeziorsko reservoir resulted in changes in the Warta river hydrological regimes. This in turn led to a reduction in the floodplain area and flooding frequency, which as a consequence has had a dramatically detrimental effect on the floodplain forests in that wilderness. Riparian forests are among the richest and most beautiful forest ecosystems. Unfortunately, river regulation and flood control measures result in their degradation. In Poland only 0.2% total area is covered by riparian forests. The Uroczysko Warta is one of the most important groups of these habitats not only in Poland, but also on the European scale. It was assumed that the implementation of simple land and water system restoration systems – gates, barrages, culverts with backwater valve gates – may promote recreation of advantageous hydrological relations.

This study presents results of water monitoring in the Uroczysko Warta Wilderness and the volume of deadwood formed as a consequence of hydrometeorological conditions. The paper provides a detailed description of climate characteristics (air temperature and precipitation) in the 30-year period of 1988-2017, i.e. after the commissioning of the Jeziorsko reservoir along with the hydrological characteristic of the wilderness area in the years 2009-2017 (water stages in the Warta river and in the Lutynia river, water stages in oxbow lakes and groundwater tables) and the volume of deadwood formed in the years 2006-2014. Water stages in the Warta and the Lutynia as well as water levels in oxbow lakes and groundwater tables show considerable mutual correlations. This indicates efficient operation of constructed land reclamation systems. The volume of formed deadwood shows no evident trends, only a close relationship with climatic conditions.

Thus it may be hypothesised that the concept for the protection of floodplain forests in the Uroczysko Warta, consisting in the buffer supply of oxbow lakes at high water stages in the Warta and the Lutynia is appropriate, particularly since waters supplying the wilderness area do not stagnate, but they move within the ground.

Keywords: floodplain forest, deadwood, small water retention, oxbow lake, the Uroczysko Warta

INTRODUCTION

Riparian or floodplain forests are some of the richest deciduous forest ecosystems in Poland. Although in our country according to the potential vegetation map riparian forests cover almost 9% total area, in the structure of forest sites in Poland the forest site types corresponding to riparian or floodplain forests account for as little as 0.7% area, of which 0.2% are floodplain forests (Danielewicz 1993). A major factor determining the occurrence and health of riparian forests as well as ecosystems associated with oxbow lakes, naturally found in river valleys, is connected with their periodical inundation by flood waters. Absence of flooding leads to degradation of riparian forest sites, referred to as their transformation into oak-hornbeam forests, while in the case of oxbow lakes the processes of their overgrowing and shallowing are accelerated. The most adverse factors influencing these ecosystems are related with the reduction of inundation zones due to the construction of flood embankments and changes in the hydrological regime of river waters caused by the construction of large water reservoirs (Cieśla 2009, Kurowski 2007, Miler 2015).

In many cases protection of wetlands is limited to passive methods, such as monitoring of anthropopressure and climate change in the ecosystems (Greger 1998, Haase and Gläser 2009, Klimo and Hager 2001, Greco *et al.* 2007, Kramer *et al.* 2008).

An important aspect in the preservation of habitats in river valleys is connected with their active protection. Protection of wetland sites is a complex problem and requires individualised solutions (Rohde *et al.* 2006). This is also true of monitoring the adopted solutions (Syrbe *et al.* 2007). We need to search for compromise solutions between the development of technical infrastructure and simultaneous realisation of environmental protection aims (Larsen *et al.* 2007, Buijs 2009, Oswalt and King 2005, Ollero 2010, Moradkhani *et al.* 2010, Pawlaczyk *et al.* 2002, Kupfer *et al.* 2010, Küßner 2003).

In the case of the Uroczysko Warta, where as a result of changes in the natural hydrological regime of the Warta the inundated area and flooding frequency were reduced (among other things due to the construction of the Jeziorsko reservoir – Miler 2015), good results may be provided by the application of simple land and water system restoration measures, facilitating restoration of advantageous hydrological conditions, e.g. by increasing storage of oxbow lakes.

The aim of this paper is to present results of water monitoring in the Uroczysko Warta, including consequences of water shortage manifested in the formation of deadwood.

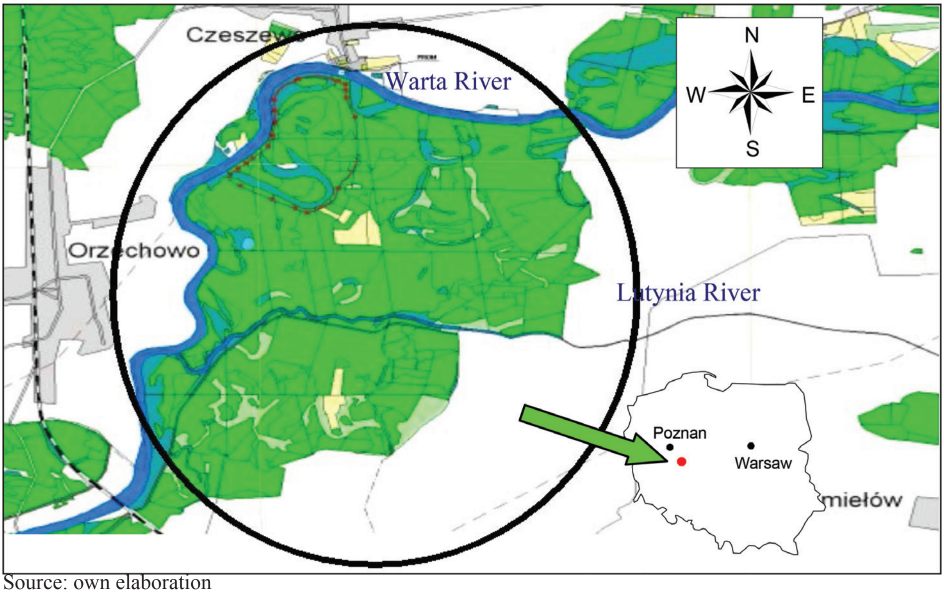
CHARACTERISTICS OF THE UROCZYSKO WARTA AREA

The Uroczysko Warta is a forest complex located in the floodplain of the left bank Warta River, between 332 and 337.5 km its course and the outlet stretch of the Lutynia (0 to 3.2 km). In terms of administrative division the entire area is located in the Wielkopolskie province, with the largest part of the Uroczysko situated in the Miłosław commune (the Września county), while only the eastern part is located in the Żerków commune (the Jarocin county).

The area is administered by the Jarocin Forest District. The total area of the complex is 772.44 ha, of which 634.99 ha are forests; the rest is covered by forest meadows, oxbow lakes and marshes. Soils are mainly alluvial soils (82.2%), rusty soils (9.3%) and lessive soils (5.7%). Rusty and lessive soils were formed in areas located outside the inundation zone. Other soils found sparsely include ground-gley, brown, muck, pseudogley, alluvial-muck soils as well as forest black muck and poorly developed soils (Pawlaczyk *et al.* 2002).

From the hydrological point of view the climatic conditions prevalent in the analysed area as well as the entire catchment of the Warta are not advantageous. This results from two reasons: relatively low precipitation compared to the neighbouring regions and high evapotranspiration (Woś 1994).

In the wilderness area 10 oxbow lakes of the Warta river may still be found (starting from the east: Musiółka, Czaple, Szaniec, Łojewo, Mała Starucha, Wielkie, Zaskrzęcie, Długie Zaskrzęcie, Dębiński Rów, Podkowa) as well as several overgrown channels – remnants of former oxbow lakes. The Czeszewski Las reserve of 222.62 ha is located in the eastern part of the Uroczysko (Fig. 1 and 2). The entire wilderness area is situated within the boundaries of the Żerkowsko-Czeszewski Landscape Park of 15640 ha in area (Jarocin State Forest Division 2009).



Source: own elaboration

Figure 1. Location of the Uroczysko Warta (Jarocin State Forest Division 2009)

Source: the author's photo

Figure 2. View of Uroczysko Warta (photograph taken by a drone)

The Uroczysko Warta is a complex of oak-hornbeam forests and ash-elm floodplain forests with a considerable proportion of old growths, located in the lowest floodplain of the Warta river, with preserved oxbow lakes and their typical vegetation. The wilderness area comprises also phytocenoses of reed canary grass, great manna grass, yellow iris and sedge reeds, as well as fragments of meadows associated in their floristic composition to Cnidium meadows typical of large river valleys. A part of the reserve is regularly flooded by the Warta during early spring water stages. Floodplain forests of the Uroczysko Czeszewo, together with forests extending along the Warta below Czeszewo (to the Dębno reserve) comprise the largest and best preserved complex of floodplain forests in the Wielkopolska region and probably also in Europe (Jarocin State Forest Division 2009).

A major effect on discharge in the Warta is exerted by the Jeziorsko reservoir, with total capacity of 203 million m^3, located in the middle stretch of the river and commissioned in 1987 (Miler 2015). In the early spring period prior to 1987 a part of the Uroczysko Warta was regularly flooded by waters of the Warta and partly the Lutynia. Thanks to co-financing by the EkoFundusz foundation in the project "Comprehensive protection of biodiversity in the Uroczysko Warta in the Żerkowsko-Czeszewski Landscape Park" e.g. in the years 2004-2005 the barrage damming waters of the Lutynia, 4 culverts with backwater valve gates (Fig. 3) and 2 flashboard valves were constructed (Kamiński *et al.* 2010, 2011).

Source: the author's photo

Figure. 3. A culvert with a backwater valve gate

METHODS

In 2008 the Uroczysko Warta was equipped with the monitoring system for surface and underground waters. A total of 26 hydrogeological test wells were drilled ranging in depth from 4 to 26 m below ground level (Zieliński and Niemczyński 2008). In the drilling sites piezometers are installed, which in the beginning of 2009 were equipped with devices automatically recording underground water tables. The gauging system is supplemented with 7 staff gauges installed in oxbow lakes and the Lutynia (Fig. 4). Surface water levels were observed using standard staffs, while groundwater tables were measured automatically using Divers and next the data were analysed with the Diver-Office 2008 software (data provided by the Jarocin Forest District).

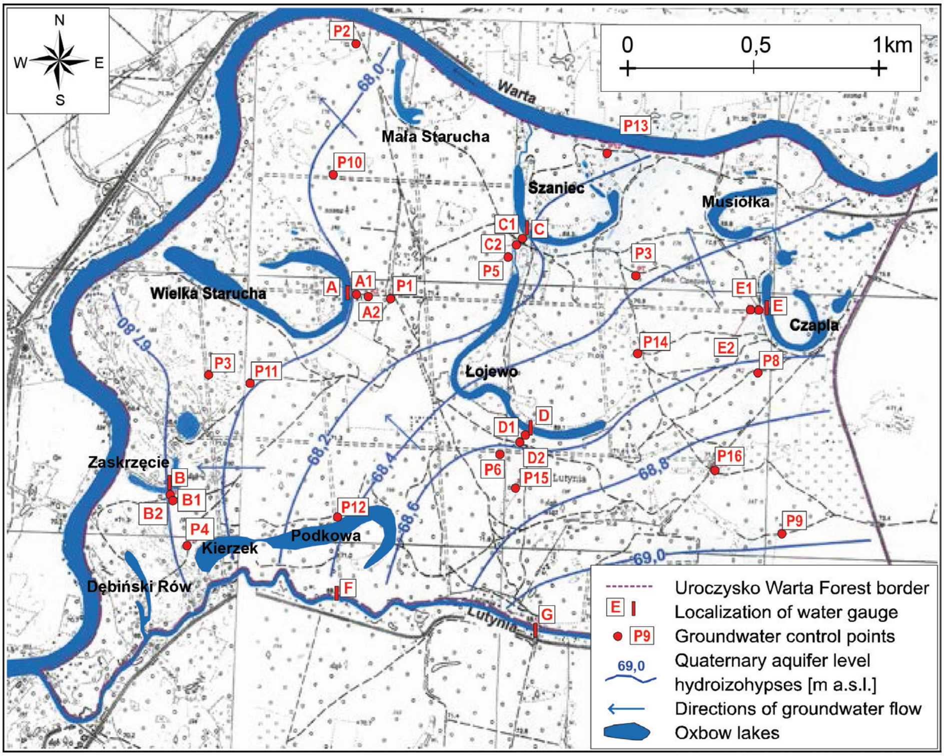


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Figure 4. Plan of the Uroczysko Warta Forest (Zieliński, Niemczyński 2008)

Weather data were obtained from the Institute of Meteorology and Water Management, the National Research Institute (IMGW PIB) for the stations in

Nowa Wieś Podgórna (precipitation) and in Kórnik (air temperature). Similarly (from IMGW PIB) hydrological data were obtained, i.e. water stages in the Warta river in the Nowa Wieś Podgórna section.

In the years 2006, 2007, 2009, 2011, 2012, 2013 and 2014 employees of the Jarocin Forest District conducted an inventory of deadwood found in the former reserves of Lutynia (45.85 ha) and Czeszewo (26.37 ha), which are at present included in the Czeszewski Las reserve. Deadwood is not removed from the reserve, thus the increment in deadwood in the period between the inventories is calculated based on the difference in the volumes inventoried at the end and the beginning of a given period. After 2014 no inventory of deadwood was performed due to storms, which had caused wind-broken trees and windthrows; as a consequence it was impossible to separate natural deadwood from damage caused by these storms.

In order to assess time trends for changes in air temperature, precipitation, surface and groundwater the adopted methodology was based on the Mann-Kendall non-parametric test (Gilbert 1987), which is used e.g. to assess trends in hydrological and climatic parameters (Hirsch and Slack 1984; Chiew and McMahon 1993; Yue *et al.* 2002; Khambhammettu 2005; Banasik *et al.* 2013). Values of statistic *S* in the test were determined using the following formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\,(x_j - x_k) \quad (1)$$

where: $sgn\,(x_j - x_k) = \begin{cases} 1\ for\ (x_j - x_k) > 0 \\ 0\ for\ (x_j - x_k) = 0 \\ -1\ for\ (x_j - x_k) < 0 \end{cases}$

x_j, x_k – values of data in time *j* and *k*,
n – length (size) of the data set.

Values of data x_i were compared in relation to all successive data values. The initial value of Mann-Kendall statistic *S* was assumed as 0 (no trend). If the value of the next element in the series was greater that the preceding value, then *S* was increased by 1. On the other hand, if the value of the next element in the series was lower than the preceding value, then *S* was reduced by 1. As a result of these calculations the final value of *S* was obtained. Calculations of variance *S* (*Var(S)*) were made taking into consideration adjustments concerning the number of data in the series over 40 with repeated values in the group of data (Gilbert 1987):

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p - 5)}{18} \quad (2)$$

where:
n – length (size) of the data set,
g – number of groups of data with repeated values,
t_p – number of repeated values of data in the group.

Probability connected with test statistic Z was obtained using normalised test statistic Z calculated from equation:

$$Z = \begin{cases} \dfrac{S-1}{[(Var\ (S)]^{1/2}} & dla\ S > 0 \\ 0 & dla\ S = 0 \\ \dfrac{S+1}{[(Var\ (S)]^{1/2}} & dla\ S < 0 \end{cases} \qquad (3)$$

It is assumed that a trend is downward when Z is less than zero and probability is lower than the assumed significance level α=0.05. At the same time, a trend is considered to be upward when Z is greater than zero and probability is analogous as above.

RESULTS

Climatic conditions

Climate change is assessed based on long series (30 years according to WMO and IPCC) of direct observations. Such series are available for the Uroczysko Warta e.g. for the period 1988-2017.

In the 30-year period (1988-2017) climatic conditions in the investigated period did not change significantly (Figs. 5 and 6). Mean annual air temperature was 9.2 ^{0}C, while mean precipitation total was 531 mm. For the vegetation season months (IV-X) it was 14.5 ^{0}C and 354 mm, respectively. The regression coefficient for air temperature was 0.023 ^{0}C·year^{-1}, while for precipitation it was – 0.188 mm·year^{-1}. Both these values are statistically non-significant at α=0.05.

Climate change in the Uroczysko Warta is distinguished by relatively significant stationarity expressed e.g. by parameters of air temperature and precipitation dynamics.

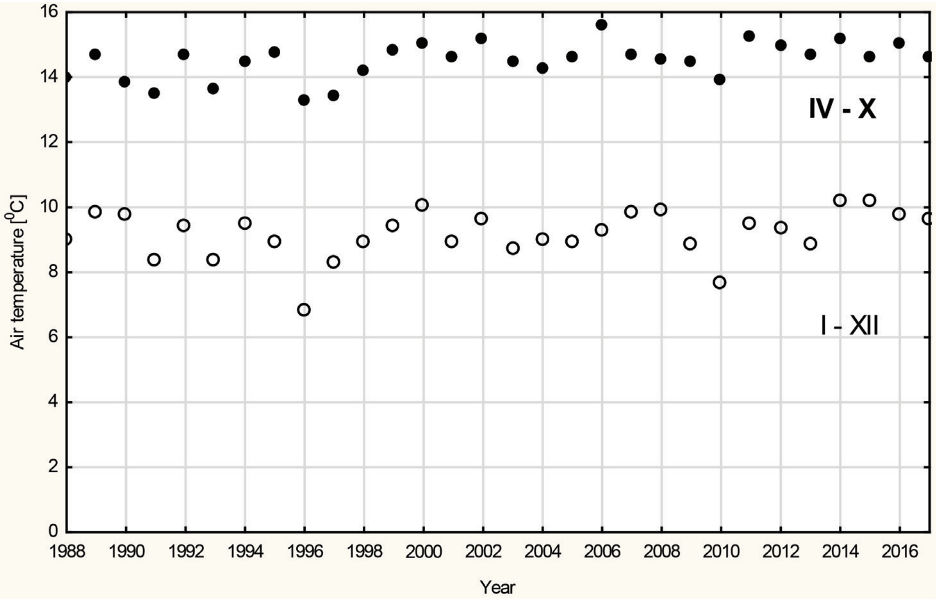

Figure 5. Time series of air temperature in the period of 1988-2017

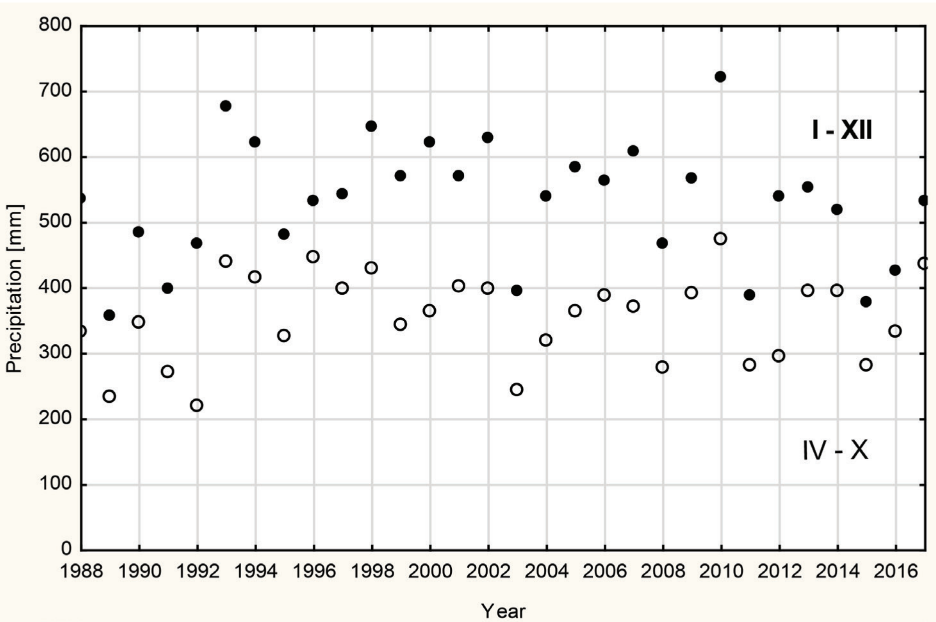

Figure 6. Time series of precipitation in the period of 1988-2017

Surfcae water levels

Based on the daily water stages in the Warta at the Nowa Wieś Podgórna section using 2nd stage characteristic values it was calculated that the mean water stages range from 225 to 298 cm.

Figure 7 shows the course of monthly water stages in the Warta at that section in the monitoring period, i.e. 2009 to 2017.

The range of variation of water level in the Warta River is 154÷496 cm, median 236 cm and standard deviation 66 cm.

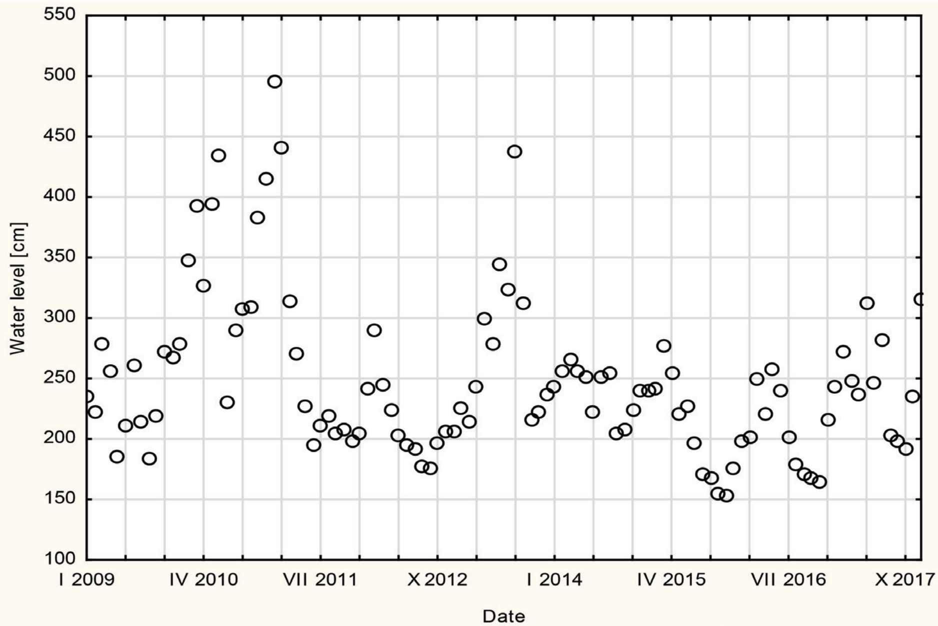

Figure 7. Time series of monthly water levels in the Warta River at the cross section of Nowa Wieś Podgórna in the period of 2009-2017

Monthly water stages in the Lutynia at the Nowy Most section are presented in Fig. 8.

The range of variation of water level in the Lutynia River is 30÷220 cm, median 85 cm and standard deviation 40 cm.

In turn, Fig. 9 gives averaged monthly water stages in oxbow lakes.

The range of variation of water level in oxbow lakes is 47÷248 cm, median 116 cm and standard deviation 48 cm.

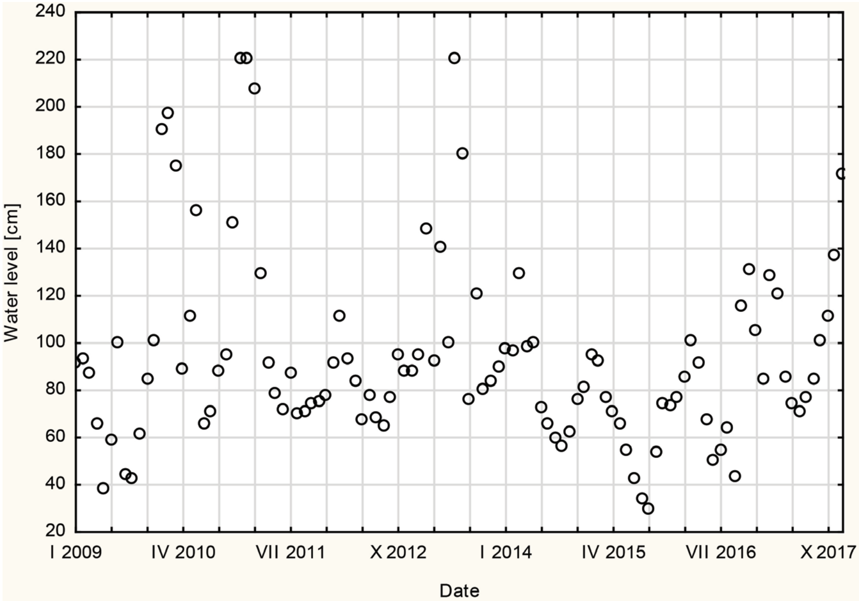

Figure 8. Time series of monthly water levels in the Lutynia River in the cross section of Nowy Most in the period of 2009-2017

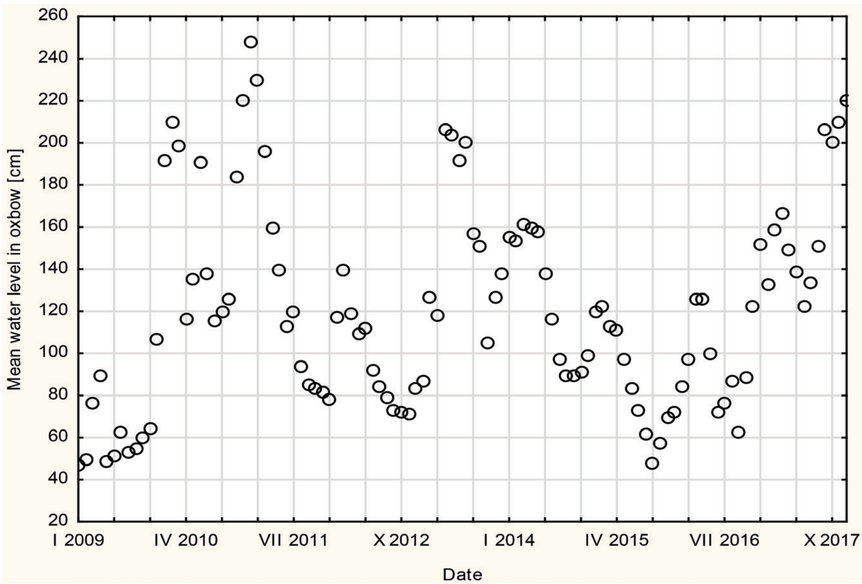

Figure 9. Time series of monthly water levels in oxbow lakes in the period of 2009-2017

Groundwater tables

Groundwater tables are very similar in terms of the swelling and subsidence periods, which was also shown in an earlier study (Okoński, Miler 2013). Thus values of all the piezometers were averaged. Figures 10 presents these averaged groundwater tables.

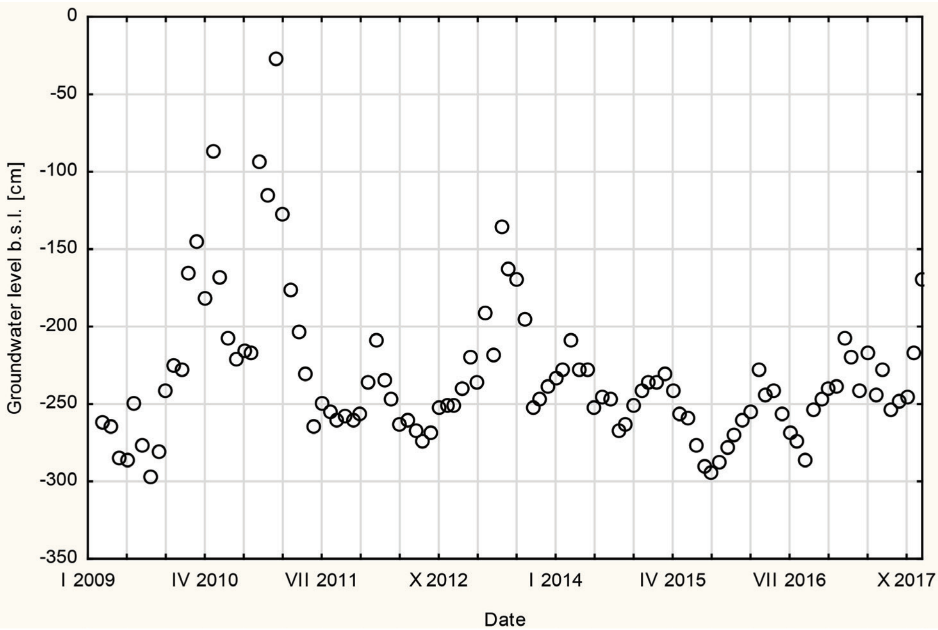

Figure 10. Time series of monthly groundwater levels in the period of 2009-2017

The range of variation of groundwater level is (-297)÷(-28) cm, median – 243 cm and standard deviation 46 cm.

Results of deadwood inventory

Tables 1 and 2 give inventoried amounts of deadwood in the years 2006-2014 for its volume and mass, respectively, calculated for the identified species: oak, ash, linden, hornbeam, birch, maple and elm.

Figure 11 presents the volume of deadwood formed in the years 2006-2014.

Table. 1. Inventory results of deadwood volume in the Lutynia and the Czeszewo reserves in the period of 2006-2014

Date	Lutynia reserve 45.85 ha		Czeszewo reserve 26.37 ha		Weighted mean
	m^3	m^3/ha	m^3	m^3/ha	m^3/ha
11-12.04.2006	1 260	.	315	11.9	21.7
23-25.04.2007	1 934	42.2	596	22.6	35.0
14-15.04.2009	2 273	49.6	1 034	39.2	45.8
25-27.05.2011	2 481	54.1	1 536	58.2	55.6
08.05.2012	3 243	70.7	1 868	70.8	70.7
18.11.2013	3 568	77.8	2 119	80.4	78.7
22-31.12.2014	4 018	87.6	2 327	88.2	87.8

Table. 2. Inventory results of deadwood mass in the Lutynia and the Czeszewo reserves in the period of 2006-2014

Date	Lutynia reserve 45.85 ha		Czeszewo reserve 26.37 ha		Weighted mean
	kg	$kg \cdot ha^{-1}$	kg	$kg \cdot ha^{-1}$	kg/ha
11-12.04.2006	1 160 000	25 316	285 150	10 813	20 020
23-25.04.2007	1 549 750	33 800	536 950	20 362	28 893
14-15.04.2009	2 023 550	44 134	888 030	33 675	40 315
25-27.05.2011	2 202 750	48 042	1 322 810	50 163	48 816
08.05.2012	2 911 480	63 500	1 605 430	60 880	62 543
18.11.2013	3 211 990	70 054	1 830 980	69 434	69 828
22-31.12.2014	3 618 250	78 914	2 001 930	75 916	77 819

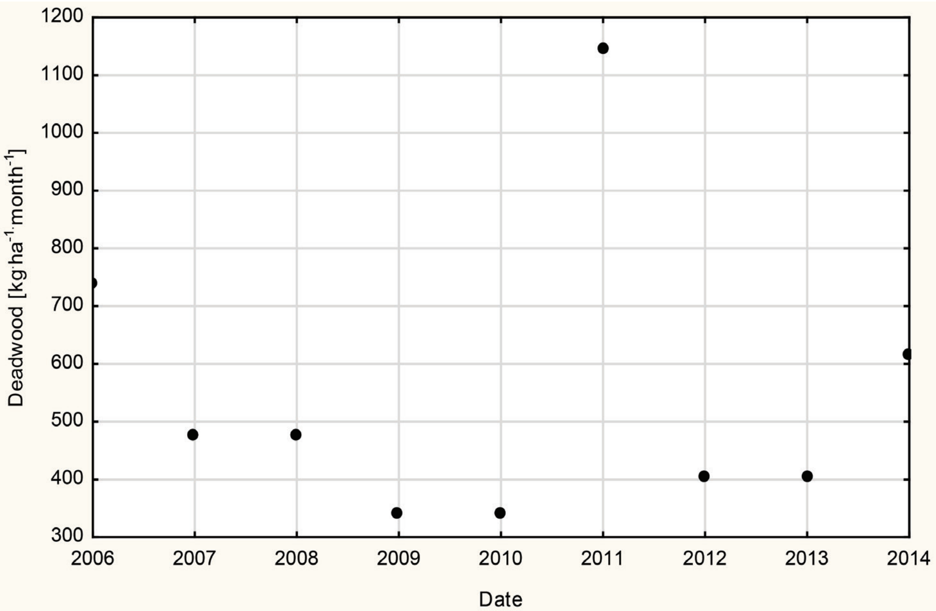

Figure 11. Time series of deadwood in the period of 2006-2014

DISCUSSION

Synthetically the concept for the protection of floodplain forests in the Uroczysko Warta consists in the buffer supply of oxbow lakes at high water stages in the Warta and the Lutynia. Oxbow lakes due to their high numbers and hydrogeological conditions of the Uroczysko advantageously regulate water relations in soils of floodplain forests at additional water supply and increased retention capacity of these objects (Kowalczak *et al.* 2006, Puźniak 2008, Zieliński and Niemczyński 2008, Kamiński *et al.* 2010, 2011, Okoński and Miler 2013). This concept was positively verified in this study. Monthly water stages in the Warta and the Lutynia, as well as water levels in oxbow lakes and groundwater tables are significantly correlated at $\alpha = 0.05$ (tab. 3).

In the monitoring period (2009-2017) the following years were observed: a cool year (2010), two warm years (2014, 2015), one wet year (2010) and three warms years (2011, 2015, 2016). The values, which did not differ from the mean by more than ±10% were assumed as standard average values.

Increased formation of deadwood in 2011 may be explained by a cool and wet year of 2010 and a very dry and relatively warm year of 2011. Annual precipitation in 2011 was as low as 387 mm and it amounted to 72.8% mean. In turn, air temperature was 9.5 ^{0}C. Also the vegetation season of IV-X 2011 was characterised by precipitation below the average value (281 mm) and higher air temperature (15.2 ^{0}C). A higher air temperature obviously results in an increased evapotranspiration. High and very high water stages recorded in 2010 in the Warta at the Nowa Wieś Podgórna section causing inundation during the vegetation season may have also contributed to an increased formation of deadwood.

Table. 3. Correlation coefficients between levels in oxbow lakes, in the Warta River, in the Lutynia River and groundwater levels.

	Level in oxbow lakes	**Level in the Warta River**	**Level in the Lutynia River**	**Groundwater level**
Level in oxbow lakes	1			
Level in the Warta River	0.687	1		
Level in the Lutynia River	0.817	0.694	1	
Groundwater Level	0.780	0.909	0.813	1

RECAPITULATION AND CONCLUSIONS

Water stages in oxbow lakes and groundwater tables in the Uroczysko Warta show high correlation with water stages in the Warta and the Lutynia. This indicates close hydraulic connections of surface waters and groundwater of the Uroczysko with the rivers flowing within its boundaries.

Monitoring results for surface water and groundwater levels confirm that the adopted concept for the protection of floodplain forests in the Uroczysko Warta using damming systems of the hydraulic structures is appropriate. Water retained in oxbow lakes obviously contributes to the maintenance of groundwater tables in the Uroczysko.

The appropriate operation of the land reclamation structures is also confirmed by a lack of any recorded positive trend for the increment of formed deadwood. The reported incidental increase in deadwood volume in 2011 needs to be connected with the climatic conditions observed in the years 2010-2011.

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