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Diversity of water level fluctuations in degraded Baltic raised bogs

Zróżnicowanie wahań poziomu wody na zdegradowanych torfowiskach bałtyckich

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Abstract
The aim of paper is to present the diversity of water level fluctuations in degraded Baltic raised bogs. An attempt was made to answer the question how strong the diversity of fluctuations is both within each object and between two objects situated close to each other. Moreover, speed and value of the response of water level to atmospheric precipitation were analysed. The spatial scope of the paper covers two Baltic raised bogs in the lower part of the Łeba river valley: Czarne Bagno and Łebskie Bagno. The time scope covers years 2012–2014. The study found that both analysed bogs were a high dynamic in variation of groundwater level. Annual amplitudes of fluctuations in the water table was in the range of 28.4 to 77.9 cm (Łebskie Bagno) and of 45.6 to 105.0 cm (Czarne Bagno). It has been observed that lowering the water level on both peatlands always been recorded in the summer months, whilst the increase in the autumn, which lasted until spring. Retention and the water level on peatlands influenced primarily precipitation. Extreme meteorological conditions that make it less conspicuous is the variation resulting from factors such as location in different parts of the bog or type of degradation.

Streszczenie
Celem pracy jest przedstawienie zróżnicowania wahań poziomu wody na zdegradowanych torfowiskach bałtyckich. W jego ramach podjęto próbę odpowiedzi na pytanie na ile silne jest zróżnicowanie wahań zarówno wewnątrz każdego obiektu, jak i pomiędzy dwoma obiektami położonymi w niewielkiej odległości od siebie. Ponadto przeprowadzono analizę prędkości i wielkości reakcji poziomu wody na opad atmosferyczny. Zakres przestrzenny pracy obejmuje dwa torfowiska bałtyckie w dolnej części Pradoliny Łeby: Czarne Bagno i Łebskie Bagno. Zakres czasowy obejmuje lata 2012 – 2014. W pracy stwierdzono, że na obu analizowanych torfowiskach obserwuje się dużą dynamikę zmienności poziomu wód podziemnych. Roczne amplitudy wahań poziomu zwierciadła wody, mieściły się w zakresie od 28,4 cm (Łebskie Bagno) do 105,0 cm (Czarne Bagno). Zaobserwowano, że obniżenie się poziomu zwierciadła wody na obu torfowiskach zawsze rejestrowane było w miesiącach letnich, zaś wzrost jesienią, który trwał do wiosny. Na wielkość retencji i poziom wody na torfowiskach wpływ miał przede wszystkim opad atmosferyczny. Skrajne warunki meteorologiczne powodują, że mniej widoczne jest zróżnicowanie wynikające z takich czynników jak: położenie w różnych częściach torfowiska, czy rodzaj degradacji.

1. INTRODUCTION

Raised bogs are formed in the presence of a high water level and domination of atmospheric supply, which is a necessary condition for ombrophilous peat-forming vegetation and for the formation of a raised bog layer [Okruszko 2009]. Their habitat is closely dependent on the moist and cool climate near the Baltic Sea [Herbichowa 2003]. According to Lipka and Stabryła [2012], raised bogs are the most typical wetlands. For the peat layer in raised bogs to increase, it is essential that water level remains high, with small seasonal variations. Good conditions for the growth of peatmosses occur when the water table is at a depth of about 1–22 cm below the ground level [Tuittila et al. 2004].

The raised bogs that occur in Poland are divided into Baltic raised bogs, continental raised bogs and kettle bogs [Żurek, Tomaszewski 1996]. The range of occurrence of Baltic raised bogs is limited to the area of southern Baltic coastlands and lakelands. The distinguishing feature of Baltic raised bogs is a clearly convex shape, called a dome [Gore 1983].

Baltic raised bogs were formed in various locations, most often in hollows in the ground: on plateau or in the vicinity of alluvial plains. Yet, raised bogs in river valleys are a special case. They were formed in those fragments of emersion zone of the valley (the zone beyond the maximum scope of flood waters) [Oświt 1973] that were characterised by a lower ground water level. Such conditions occurred, for example, in water divides of the main watercourse and tributaries or on the edges of river valleys. This allowed clusters of vegetation of transitional bogs to form, followed by those of raised bogs, as a result of a longer-lasting saturation of the terrain with low-mineralised precipitation waters.

River valley bottoms in the area of south Baltic coastlands and lakelands were subject to intensive anthropogenic pressure already in the early Middle Ages. An intensification of transformations became noticeable from the late eighteenth and early nineteenth centuries [Ilnicki 2002]. Human pressure was exerted mainly on low bogs in river valleys, where together with ongoing melioration to intensify meadow use, peat was extracted mainly for fuel. Transformations also covered Baltic raised bogs, none of which has completely natural water relationships any more [Herbichowa 1998].

The aim of this paper is to present the diversity of water level fluctuations in degraded Baltic raised bogs. An attempt was made to answer the question how strong the diversity of fluctuations is both within each object and between two objects situated close to each other. Moreover, speed and value of the response of water level to atmospheric precipitation were analysed.

The spatial scope of the paper covers two best preserved Baltic raised bogs in the lower part of the Łeba valley streamway: Czarne Bagno and Łebskie Bagno (Fig. 1). They are covered by protection as reserves and their fragments are qualified by botanists, according to Appendix I to Habitats Directive, as 7120 – Degraded raised bogs still capable of natural regeneration. The time scope covers years 2012–2014 from which measurement data concerning water level fluctuations and monthly precipitation sums come.

Łeba ice marginal valley was remodelled during the last glacial period, but its origin is earlier. The transformation of ice marginal valley in the Holocene due to fluvial processes was relatively small. During the Holocene the bottom of the valley was filled with peat.

Origin of a large part of the Czarne Bagno is associated with lake transformation. Lake genesis was a result of melting of dead-ice block in the bottom of valley. It remained after the withdrawal of the ice sheet. It melted when Łeba River was already flowing at the current level of the mineral bottom of the valley. Therefore, in this section of the valley, the river flows closer to its west edge [Rachocki 1992].

Part of Łebskie Bagno was also formed as a result of transformation of the lake lying next to the edge of the plateau [Pietruszyński, Duda 2016].

On both sides of valley are morainic plateaus. The upper part is made up of up to several meters thick layer of clay. There are sands under the clays, involving some amount of glaciofluvial gravel and silt. Morainic plateaus are cut by relatively narrow tunnel valleys and melt waters valleys, which reach below the bottom of the clays. Sands below glacial clays are in connection with a sandy bottom of the valley, under the peat [Morawski 1990].

Anthropogenic degradation on the Czarne Bagno and Łebskie Bagno was caused by the artificial draining and exploitation of peat. At the end of the eighteenth century, Kanał Łebski was dug, east of Łebskie Bagno (Fig. 1). In the 19th century, were dug deep ditches surrounding the central parts of the two peat bogs and shallow ditches within the bogs. Ditches within the bogs were filled or plugged during the active protection works in the early 21st century.

The first evidence of the exploitation of peat on the Czarne Bagno come from the 19th century [Reymann's Topographische Special-Karte ca. 1838]. It was continued with different intensity in the 20th century. Total area of manually exploited parts was approx. 17.8 ha. At the end of the 80s. the western part of the bog was exploited by machine: using an excavator (7.6 ha) and by peat milling (9.2 ha). In total, exploitation covered the 33.6% of the present reserve 'Czarne Bagno' area and other 5.8% was drained [Duda et al. 2016].

Manual, extensive extraction of peat on Łebskie Bagno lasted at least 100 years (the first half of 19th century - the first half of 20th century). Area of the reserve is 1.11 km^2. Approximately 80-90% covered the exploatation [Duda et al. 2015]. Thickness of the removed peat layer on both bogs ranged from 1 to no more than 2 meters.

2. MATERIAL AND METHODS

The paper is based on the measurement results from hydrological monitoring networks functioning on the analysed objects. They include 25 piezometers in Czarne Bagno and 13 piezometers in Łebskie Bagno. The piezometers are equipped with sensors (MiniDiver) for automatic measurement and recording of water level. They were programmed for measurement with an 8-h interval.

To demonstrate the diversity of water level fluctuations in 2012–2014, six measurement points were selected – three for each reserve (Fig. 2). The choice was based on the criterion of location with reference to the present morphology of the analysed bogs. Points A and D are located in non-exploited fragments of the central topmost parts of the domes of Czarne Bagno and Łebskie Bagno; points C and E are located in fragments where peat used to be extracted in the past. Points B and F are located near girdling ditches – they cover the edges of present hydrological systems of raised bogs. The analysis covered water table levels in three subsequent hydrological years: 2012–2014.

In order to present the value of precipitation, measurement data from two types of devices were used. For years 2012–2013, the measurement results from two meteorological stations (Davis Vantage Pro) installed in the central parts of both bogs were used. At the end of 2012, in Redkowice (3 km from the eastern border of Czarne Bagno, 2.9 km from the southern end of Łebskie Bagno), a disdrometer (Thies Clima LPM) was installed. Measurement results from the disdrometer were contrasted with those from pluviometers of 2013. Owing to the failures of meteorological stations, precipitation sums for 2014 were obtained only from the disdrometer. Because data from standard pluviometers without heaters were used in the first year, the results obtained in winter months may be underestimated.

3. RESULTS AND DISCUSSION

In the period 2012–2014, the annual amplitudes of water table fluctuations in the analysed bogs ranged from 28.4 (Łebskie Bagno) to 105 cm (Czarne Bagno). Water table level is observed to decrease in summer months. In 2012 and 2013, after a summer decrease, the water table gradually returned to a state close to initial up to autumn. The year 2014 was characterised by a deeper and longer-lasting decrease in water level (from February to May) in comparison to previous two years. An increase in water level started as late as in the second half of September (Figs. 3 and 4). The highest mean annual water table level in Czarne Bagno was observed in 2013. The highest states were recorded in point A, where mean annual water table levels ranged from 1 to 15 cm below the ground level (Table 1). The high mean values of water table levels in 2012 and 2013 were influenced by a long-lasting period of high water stages from August 2012 to June 2013 (Fig. 3).

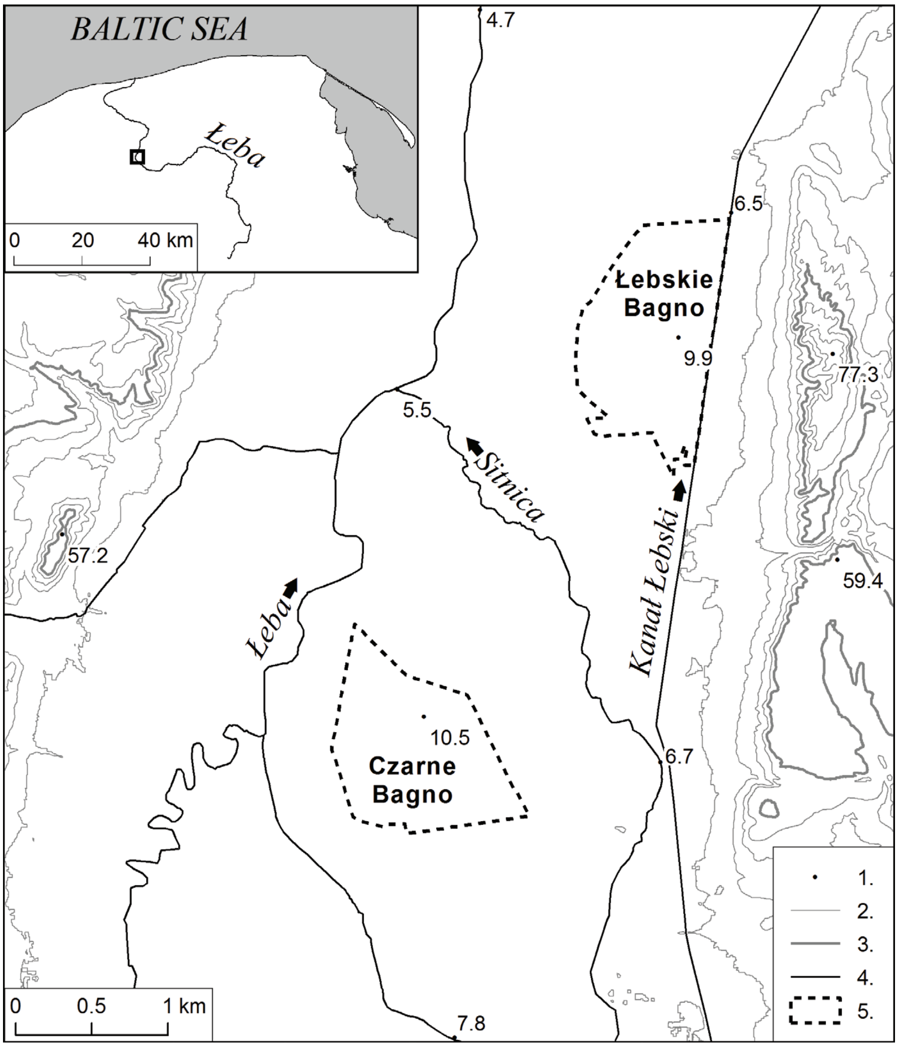

Figure 1. Location of Czarne Bagno and Łebskie Bagno in the fragment of the lower part of the Łeba valley: (1) altitude point: m a.s.l, (2) isohypse: 10 m interval, (3) isohypse: 50 m a.s.l., (4) rivers, (5) nature reserve border.

Figure 2. Present hydrographic network in Czarne Bagno (I) and Łebskie Bagno (II). (1) Measurement points, (2) ditches and canals, (3) ditches and canals divided with weirs, (4) water reservoirs and (5) reserve boundary.

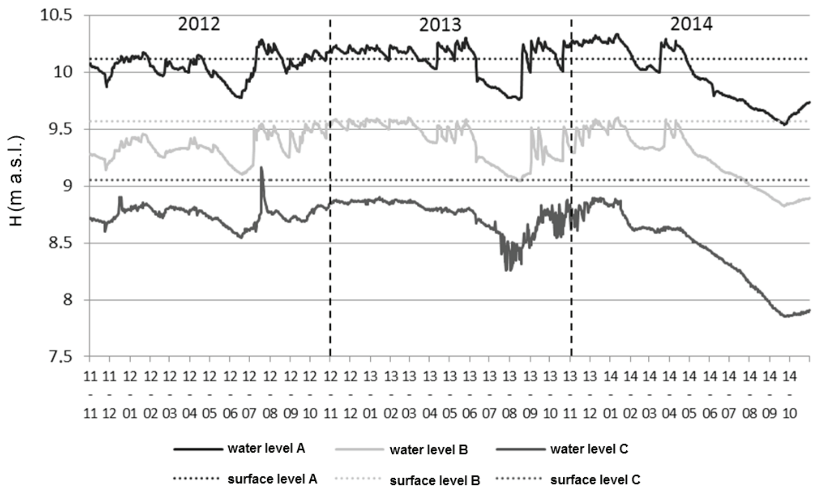

Figure 3. Changes in water level in Czarne Bagno in 2012–2014.

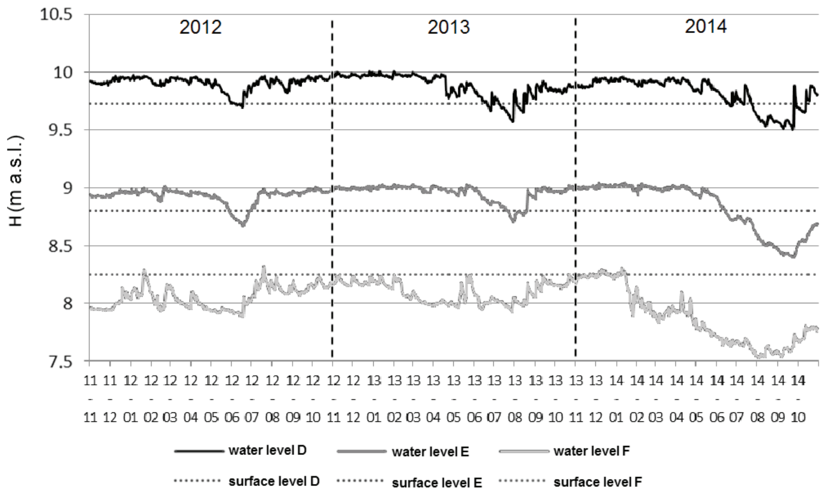

Figure 4. Changes in water level in Łebskie Bagno in the years 2012–2014.

Table 1. Mean annual water levels in Czarne Bagno in 2012–2014.

	A		B		C	
	m above sea level	m above ground level	m above sea level	m above ground level	m above sea level	m above ground level
2012	10.05	- 0.07	9.34	- 0.23	8.74	- 0.31
2013	10.11	- 0.01	9.40	- 0.17	8.74	- 0.31
2014	9.97	- 0.15	9.24	- 0.33	8.43	- 0.62

In 2013, an increase in retention (comparing the beginning and end of hydrological year) in the analysed points was, on average, 17 cm. In the following year, water level was observed to decrease by, on average, 10 cm. The year 2014 was considerably different – mean retention decrease was 58 cm (43 cm in point B, 50 cm in A and 82 in C).

The occurrence of the lowest values of water level in all the analysed points is strongly correlated with each other. They occurred in the first decade of June in 2012, at the end of July and beginning of August in 2013 and at the end of the first decade of September in 2014. High water stages in measurement points also occur in similar periods. Because they are long lasting (several months), there is no single culmination. The lowest amplitudes of water level fluctuations are observed in points A and B in 2012. In 2013, the amplitudes are slightly higher than those in the previous year. In 2014, they are considerably higher than those in the two preceding years – on average, by about 50% than that in the first of the analysed years (Table 2).

The water level in points located in Łebskie Bagno was generally higher than that in Czarne Bagno. Mean annual water table level in points D and E was above the ground level for each year, whilst in point F, it was from 15 to 38 cm below the ground level (Table 3).

Water level fluctuations in 2012–2014 in Łebskie Bagno are presented in Fig. 4. Minimum values of water level were very strongly synchronised amongst points D, E and F: they occurred on 18 June 2012 and 28–30 July 2013 in all these points at the same time. In 2014, they occurred on 3 August in point F and on 23 and 25 September in points D and E, respectively. The amplitudes of fluctuations increased further away from the non-exploited part of the bog. The year 2013 was an exception when the decrease was the strongest in point D located in the non-exploited fragment of the bog (Table 4). Small water level fluctuations in point F in 2013 result from a temporary blockage of outflow in a nearby girdling ditch by tree branches felled by beavers.

Formation and development of raised bogs is conditioned by a positive climatic water balance (domination of atmospheric precipitation over evaporation) throughout most of the year [Morrison 1955]. In transformed bogs, the proportion of atmospheric precipitation that is retained, and thus an increase in water level, may be smaller because of an increased surface runoff from the area (melioration network). Moreover, because of an increase in diversity within objects (including artificial elements of hydrographic network and changes in land relief because of peat extraction), the response of water level to atmospheric precipitation (or lack of it) may be different in particular parts of a given object. Many authors, amongst others, Pawlaczyk [2007] and Wołejko et al. [2004], indicate that the progressive spread of trees (especially birch) on hilltops bogs is a factor that contributes to increased evapotranspiration: both transpiration from the plants themselves in the vegetation and surface evaporation associated with penetrating ground peat by root systems. According to a research from the Canadian transpiration, birch trees on degraded peat bogs may constitute two-third of the total evapotranspiration from the test unit surface area [Fay and Lavoie 2009].

Table 2. Annual amplitudes of water level fluctuations (m) in Czarne Bagno in 2012–2014.

	A	B	C
2012	0.503	0.456	0.616
2013	0.542	0.556	0.644
2014	0.793	0.773	1.045

The analysed years were classified according to Kaczorowska's criteria (1962), contrasting annual precipitation sums with the mean sum of the period 1961–2000, that is, 688 mm [Fac-Beneda 2005] from the station in Lębork situated 9 km south-east of the edges of the bogs. According to the adopted criteria, the year 2012 was very wet (Łebskie Bagno) and wet (Czarne Bagno), 2013 was dry and 2014 was very dry.

High precipitation sums in the second half of 2012 (541 mm in Czarne Bagno, 608 mm in Łebskie Bagno), especially very wet July (Fig. 5), contributed to the retention of a considerable quantity of water. High water stages remained till May 2013. Owing to a smaller precipitation sum in 2013, after the summer period, water table was at a slightly lower level than that in spring (second half of 2013: 455 mm, Redkowice). The decrease in water level in summer 2014 was deeper. The precipitation sum in the second half of 2014 was by 160 mm lower than that in the second half of the previous year. Owing to low precipitation sums, the water table level did not return to the previous state.

The temporal distribution and range of fluctuations of water level in 2012–2013 is similar to the mean values observed in the least meliorated parts of raised bogs in northern Germany (Köningsmoor bog). The changes in water level in 2014 (points B, C, E, F) are closer to those observed in heavily meliorated bogs [Ingram 1983].

The highest mean water level, the smallest recorded depth and the lowest amplitude of fluctuations are observed in points A and D, situated in the eastern parts of Czarne Bagno and Łebskie Bagno. Peat was not extracted in their direct vicinity. The above hydrological parameters confirm that they represent parts of bogs with conditions close to those of the top of the natural dome.

The measurement results of water table from the central parts of Czarne Bagno and Łebskie Bagno, in sites of original tops of their domes (points C and E) are characterised by a lower mean water level and higher amplitudes than those in the above-mentioned non-exploited fragments. This is in contradiction to the outlines of the water table system with respect to land relief in raised bogs presented in literature of the subject, where it is close to the ground level in the central part and becomes lower at the edges [Ivanov 1953, Ingram 1982]. The discrepancy is also visible in a comparison of the obtained results with the results of measurements carried out in Baltic raised bogs in Poland, for example, Wieliszewo Peat bog [Pacowski 1967], as well as in raised bogs of Western Europe, including Dun Moss in Scotland [Ingram 1983]. This indicates the significant role of transformations of the analysed bogs. Changes in land relief as a result of peat extraction lead to a considerable change in the spatial diversity of water conditions within the analysed bogs.

Table 3. Mean annual water levels in Łebskie Bagno in 2012–2014.

	D		E		F	
	m above sea level	m above ground level	m above sea level	m above ground level	m above sea level	m above ground level
2012	9.91	0.18	8.93	0.13	8.05	- 0.20
2013	9.88	0.15	8.96	0.16	8.10	- 0.15
2014	9.82	0.09	8.83	0.03	7.87	- 0.38

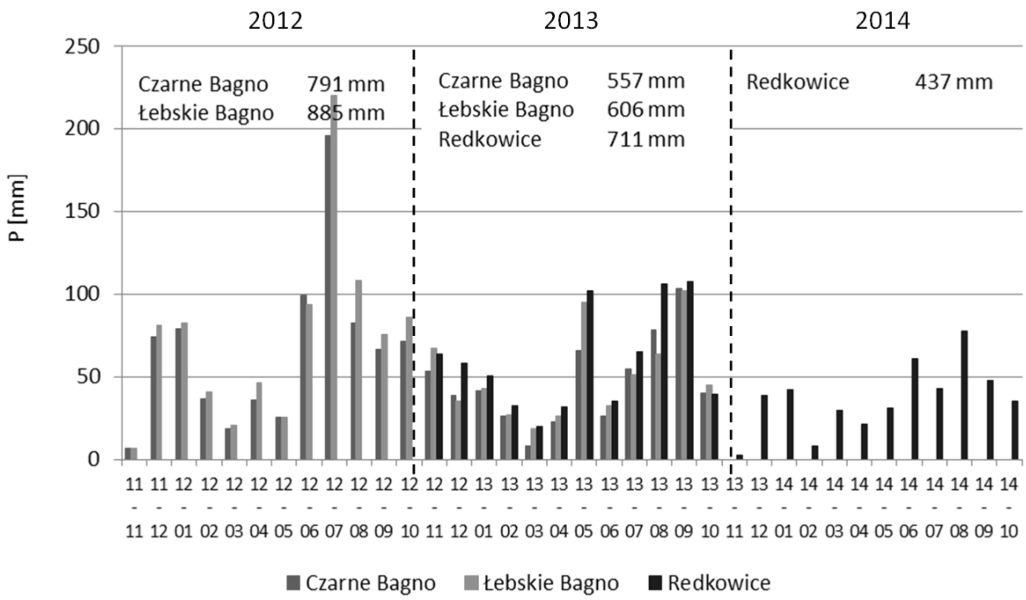

Figure 5. Monthly precipitation sums in Czarne Bagno and Łebskie Bagno in 2012–2014.

Table 4. Annual water level fluctuations (m) in Łebskie Bagno in 2012–2014.

	D	E	F
2012	0.284	0.339	0.440
2013	0.437	0.332	0.326
2014	0.460	0.644	0.779

Taking into consideration the maximum depth of water table appropriate for the development of peatmosses, given by Finnish authors (22 cm below ground level, Eeva-Stiina et al. 2004), the water conditions in both exploited and non-exploited fragments of both bogs can be appropriate for the development of peatmosses (and thus for peat formation) for most of the year. This concerns the wet year and the following dry year (2012–2013). In the very dry year 2014, only in the non-exploited part of Łebskie Bagno (point D), the water level did not fall below the value 22 cm below ground level. In the remaining points, water level below that value remained for between 2 (point E) and 9 (point C) months.

Keep in mind that the most important factor in determining the main characteristics of peat bogs is their location in the geographic space and hydrological conditions [Mitsch, Gosselink, 2007], which is applied to human activity and has a significant impact on the formation of water in these areas. Economic interest in wetlands is documented in Europe since the Middle Ages [Charman 2002] and in Poland as the beginning of their use is given the seventeenth and eighteenth centuries [Ilnicki 2002]. As a result of human activity in recent centuries, they were drying and dehydration [Dembek et al. 2004], which led to a decline in overall retention [Okruszko 1968]. According Pietrucień [1993], weight loss of water from Polish peat bogs as a result of land reclamation in the twentieth century is about 160 million m^3. Changes that occur in wetlands (bogs) not only apply to north Poland, where the number of these objects is the greatest [Churski, 1993], but also slightly covered with peat bogs in south Poland, where the best is examined in this respect bog of the Orawsko-Nowotarska valley [Łajczak 2002, 2013]. Łajczak [2013] stated that two-third of the amount of retained water in the peat bogs of the Carpathians collects residual dome raised bog, mostly in Podhale and Orava. Losses resulting from their operation described it at 79 million m^3.

4. CONCLUSION

On the basis of the obtained results, it can be stated that both examined peat bogs seen very dynamic variation of groundwater level. Annual amplitude of fluctuations in the water table is in the range of 28.4 (Łebskie Bagno) to 105.0 cm (Czarne Bagno). The water level in points located on Łebskie Bagno was generally higher than that located on the Czarne Bagno.

Lowering of the water level on both peatlands was always recorded in the summer months, whilst the increase was recorded in the fall and lasted until spring. In the years 2012 and 2013, on both peat bogs after a decline in the summer, the autumn water level returned to a state similar to the original. Year 2014 stood out against the background of the previous two years, the duration of the said reduction of the water level (February–May) and the depth of the water level. The rebound in the water level began in the second half of September. This confirms that the main source of supply for these bogs is precipitation. During the three years of measurement, the influence of the size of the retention of extremely low precipitation was very clear in 2014 (total rainfall in the second half of 2014 was about 160 mm lower than that in the second half of the preceding year). During this period, it seems to be the most important factor determining the level of water in peat bogs. Extreme weather conditions that make it less visible are the variation resulting from the factors such as location in different parts of the bog or type of degradation; which it also affects the changes in the level of underground water.

The response of the water table in bogs to changes in meteorological conditions is strong. In a dry year, the water table may remain below the favourable level for peatmosses growth for longer periods, despite protective measures aimed at retaining water in the bog. However, because of the short study period of three years, an attempt at evaluating the effectiveness of undertaken works is groundless. Drawing conclusions is also hindered by a shortage of objects for comparisons of ongoing transformations – Baltic raised bogs of a similar size and location, both fully natural and transformed ones.

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