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INFLUENCE OF HUMAN ACTIVITY ON THE FUNCTIONING OF THE RAISED BOG ON THE EXAMPLE OF THE ŻARNOWSKA PEATLAND (IN NORTHERN POLAND)

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Abstract

The paper discusses changes in groundwater relations in the Żarnowska Peatland in northern Poland. It examines changes in water content in the studied peat bog between the beginning of drainage works and the present time as well as describes attempts to restore optimal water conditions designed to facilitate the growth of peat moss. The study period ranges from 2006 to 2016. The period starts with the beginning of active protection in the study area. The paper is focused on the interpretation of key changes in water levels in different parts of the peat bog (i.e. cupola, logged zone) based on data provided by Słowiński National Park, where the study area is located. Interpretations were based on changes driven by bog drying via drainage ditches and the results of active protection efforts. A positive effect was detected in the study area, although one that is still incomplete. The water levels are increasing and overall water retention is improving gradually. However, there still exist sites where uncontrolled water loss from the bog is detected. Positive changes denoted in the bog area are often interrupted by anomalous climate phenomena.

Keywords: Słowiński National Park, raised cupola bog, active protection, groundwater level, ecosystem

1.INTRODUCTION

Peat bogs represent water-land systems that accumulate organic matter via an overproduction of biomass in relation to its decomposition. This process requires special environmental conditions: an abundance of water, limited access to oxygen, low microbiological activity, and low temperature. In other words, the formation of raised bogs depends on: positive climatic water balance, guaranteeing high water levels for the greater part of the year, small seasonal fluctuations of water levels and the way of water circulation in cupola (Morrison 1995, Tuittila at al., 2004, Whitefield at al. 2006). In addition, raised bogs have a high biological value (McLeod et al., 2011). Peat bogs are covered with vegetation that likes an abundance of light. Only 4% of the area of Poland is covered with peat bogs, which concentrate first and foremost in Young Glacial areas in the north of the country. Peat bogs also occur in the valleys of larger rivers. Raised cupola bogs are found in some areas along the Baltic coastline, and cover 0.06% of the area of Poland. Almost 84% of peatlands in Poland (10,540 ha) are damaged due to water loss and extraction.

The study site is a partially dried peat bog called the Żarnowska Peatland, which covers an area of 300 hectares. It is part of a wetland known as Wielkie Bagno, which covers an area of about 630 ha. It is currently part of Słowiński National Park (SNP). Wielkie Bagno and the Żarnowska Peatland form the northeastern part of a larger complex of bogs formed along the southern shore of the coastal lake Łebsko, which is located in the Łeba drainage basin situated across the Gardno-Łeba Lowland (Figure 1).

The purpose of the paper is to discuss the functioning of the Żarnowska Peatland ecosystem during the period after the deactivation of its economic purpose, and the introduction of steps designed to reduce its surface drainage in 2006. The primary focus of the paper is on the abiotic element of the studied ecosystem (biotope), as expressed by changes in water levels over time and spatially. The key findings of this study represent the background for an international project pursued by the Naturalist Club since 2017: Life Peat Restore 15 CCM/DE/000138; title: *"Reduction of CO_2 emissions by restoring degraded peatlands in the Northern European Lowland."* The purpose of the project is to restore the right water levels in the bog in order to trigger peat-formation processes, which would increase CO_2 binding by developing peat and wetland vegetation.

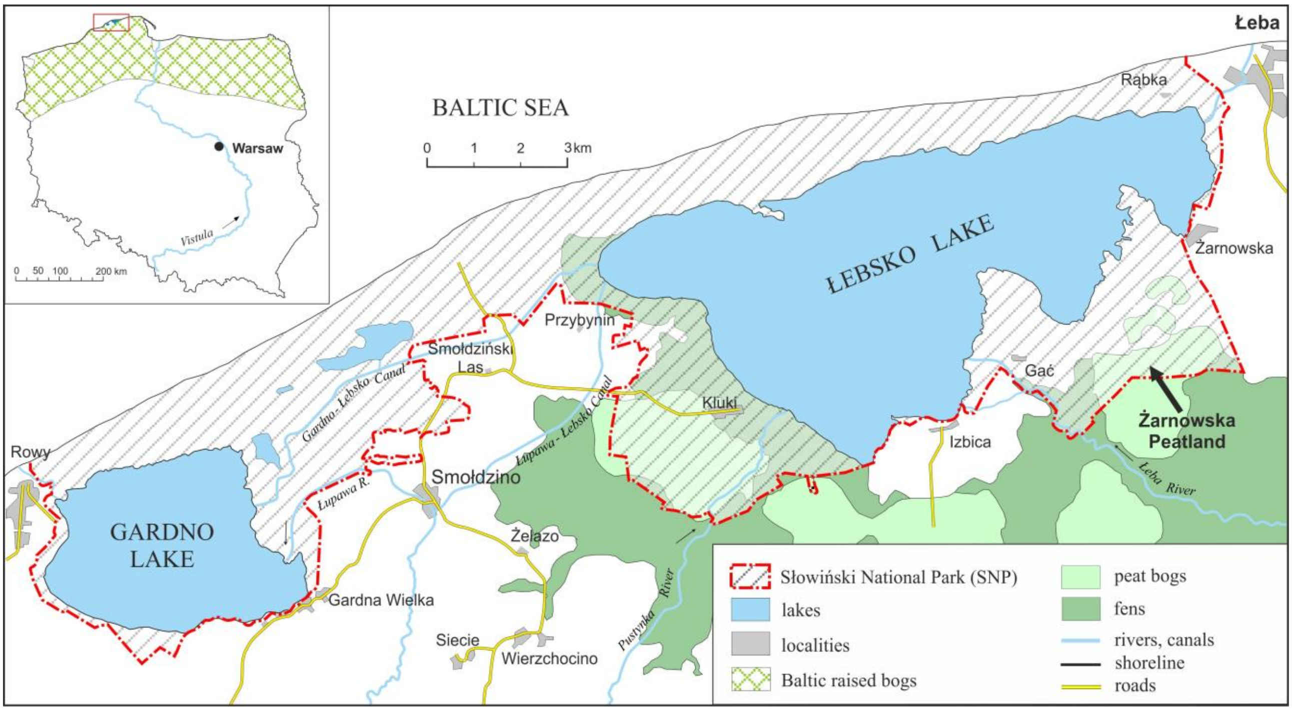

Figure 1. Study area

2.MATERIALS AND METHODS

The paper is based on hydrographic interpretation and additionally uses previously published reconstruction results for major changes in the hydrographic network found across the Gardno-Łeba Lowland. The study period covers the most recent 200 years and uses cartographic materials (Chlost 2010; Chlost, Sikora 2015). The study consisted of a review of published materials and field mapping in order to help assess water relations of the Żarnowska Peatland. Data obtained from Słowiński National Park were also processed and interpreted. These included information on protection efforts such as the installation of wooden barriers in drainage ditches, selective logging, and installation of gauges to measure groundwater levels. For the purpose of this paper, the most useful information consisted of the number, location, and type of water level gauges, and the data generated by these gauges.

The most botanically valuable part of a cupola raised bogs, also known as a Baltic type raised bogs, is uplifted plateau, which is surrounded by a water-logged zone. Thus, the study sites were selected for monitoring purposes based largely on this particular feature. The observation network included traditional piezometers, where the observer performs water level readings once a week, and two automated water level gauges. In light of the incompleteness of the recording time for the automated gauges, their data was not used in the present study. Changes in groundwater levels were analyzed using point data obtained from eight piezometers. Their location was planned according to the following scheme: piezometers PZ1 to PZ6 were focused on the uplifted section of the bog and situated along a specific transect, while piezometers PZ7 and PZ8 were situated in the surrounding fringe zone. The piezometers were arranged in pairs: even numbers indicate shorter piezometers – reaching about 120 cm of depth, while odd numbers indicate longer piezometers – reaching about 180 cm of depth. This type of arrangement makes it possible to show the relationship between the acrotelm or the surface layer of the peat bog (loose, living vegetation) responsible for precipitation water management and the catotelm or the deeper, dead part of peat bogs, where water flow is slowed down by the compacted nature of the peat bog. Piezometers PŻ1, PŻ2, and PŻ8 were installed in areas characterized by peat extraction as deep as one meter. The study also uses data from a staff gauge installed in a ditch draining the fringe zone of the northern part of the studied bog. Data obtained from piezometers and the staff gauge were analyzed for the period 2006 – 2016.

3.RESULTS AND DISCUSSION

The evolution of the Żarnowska Peatland occurred without any major disruptions over the course of centuries. This changed with the introduction of the first drainage ditches in the second half of the 18th century. This change was associated with human settlement and manmade development across the Gardno-Łeba Lowland (Chlost 2010). Engineering work occurred in stages depending on the exact technology used (manual or mechanized) and the needs of the local residents whose decisions were driven largely by economic considerations: manual peat extraction for fuel and forest management purposes, mechanical transformation of bog surfaces into meadows and pastures, peat extraction on an industrial scale for gardening purposes. A total of seven stages of change were identified, and this depended on the rate of change (Table 1).

Table 1. Changes in local water conditions across the Gardno-Łeba Lowland and the Żarnowska Peatland since the late 18th century (Chlost 2012)

Stage	Period	Characteristics
I	1750-1800	first regulation and drainage works
II	1800-1840	intermission in works due to lack of funds
III	1840-1880	period of reconstruction and maintenance of existing sites
IV	1880-1945	accelerated rate of drainage works
V	1845-1965	neglect and lack of maintenance of existing sites due to frequent political changes in Poland
VI	1965-1993	reconstruction and maintenance of existing sites and new investment
VII	since 1993	adaptation of existing drainage network to current needs, increasing role of SNP in wetland rehabilitation

Stages of accelerated drying were intertwined with periods of stagnation triggered by the political or economic situation of Poland. The Żarnowska Peatland came to experience a period of rapid change in terms of water levels in the late 19th century and first half of the 20th century. This period of change was driven by the construction of canals and ditches driving increased surface water loss from the bog (stages 4 and 6). The construction of this network upset the natural water levels present in the area for centuries. Groundwater levels decreased in order to satisfy the increasing number of surface channels and ditches (Chlost, Sikora 2015) (Figures. 2, 3). Thus, the Żarnowska Peatland hydrographic network came to consist of numerous drainage ditches, periodically wet mud flats, and a number of post-extraction pits and ponds.

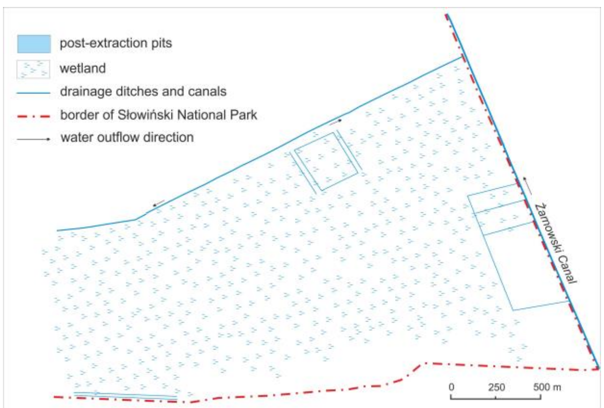

Figure 2. Picture of water networ on Żarnowska Peatland in the early 19th century

Figure 3. Picture of water networ on Żarnowska Peatland at the end of the 20th century

One outcome of bog drying was a lowering of the groundwater level, which led to additional negative consequences for the entire ecosystem. A change in plant habitat conditions occurred from an open bog to an area covered with wetland forest. The natural succession of common pine (*Pinus sylvestris*) and moor birch (*Betula pubescens*) as well as logging and planting of new trees led to an expansion of tree root systems, which then led to increased access to oxygen in the bog. The result was accelerated organic matter decomposition and mineralization, which then caused a gradual collapse of peat deposits at selected locations. The peat formation process halted, and the most valuable plant communities of the raised bog represented by peat moss and cross-leaved heath (*Erico-Sphagnetum medii* complex) began to decline. Peat vegetation, especially that found in former extraction pits, was gradually replaced with a number of expansive species, mostly heather (*Calluna vulgaris*) and purple moor-grass (*Molinia caerulea*), and less often common rush (*Juncus effusus*). The new plant communities began to gradually push out wetland vegetation that thrives on moisture and light (Bociąg et al. 2017). Research has also shown the presence of foreign species at selected sites: American cranberry (*Oxycoccus macrocarpa*), American blueberry (*Vaccinium corymbosum*), yellow azalea (*Rododendron luteum*), and dwarf mountain pine (*Pinus mugo*). Peat extraction at the studied bog ended in the 1990s (stage 7). Some of the drainage ditches became overgrown with vegetation or filled with mud. This new stage allowed for the right conditions for peat formation. Today, the bog consists of a mosaic of embankments and extraction pits with regenerating areas of moss vegetation (Figure 4).

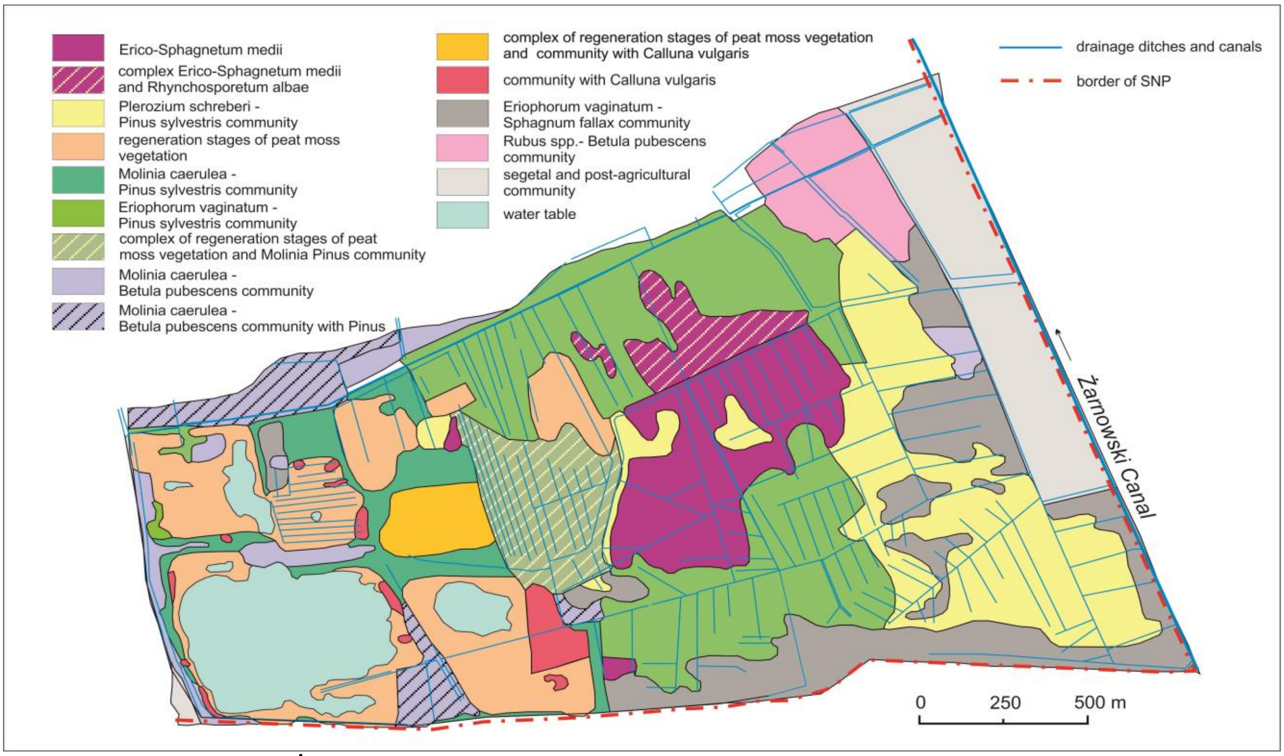

Figure 4. Vegetation of Żarnowska Peatland (Bociąg at al. 2017)

The process of species restoration occurred very slowly – and needed to be supported by effective human action. In 2006 the bog became the subject of active protection in the form of loss reduction work associated with water loss via drainage ditches and limits on transpiration. This was accomplished thanks to the blockage of main ditches via a system of 24 barriers and the felling of 30 hectares of pine trees. The second step consisted of the installation of a groundwater level gauging network in order to evaluate the effects of the bog protection efforts. This procedure had already been successfully implemented at other peat bogs across Poland (Pikunas, Kobielas 2007) and throughout Europe and the world (Komulainen et al. 1999; Price et al. 2003; Schuman and Joosten 2008).

The steps described above produced positive outcomes in the form of increased water levels in the studied peat bog (Figure 5). The bog groundwater level increased, and permanent wetlands formed in some parts of the bog, which led to the demise of trees. Yet, the restoration of plant communities remains incomplete. Hence, the Life Peat Restore project assumes additional logging work in order to remove shade trees (2018) and the construction of barriers across drainage ditches (2019).

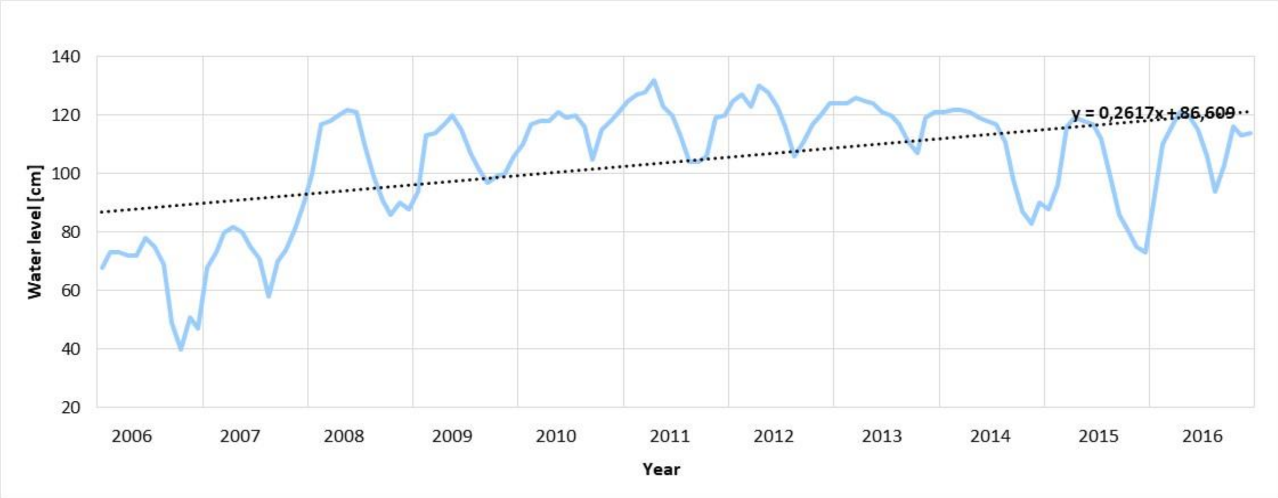

Figure 5. Water levels in a drainage ditch (staff gauge) in the period 2006 – 2016

In the period 2006 – 2016, the groundwater level in the studied peat bog was stabilized at an average of 20 cm below ground. Its depth ranged from 13 cm in 2010 to 35 cm in 2015 (Figure 6). Water was found at greater depths in longer piezometers (PŻ1, PŻ3, PŻ5, PŻ7) installed in the dead part of the peat deposit (catotelm). This indicates that the water stored therein was being lost horizontally at a greater rate – in the direction of fringe area ditches – via less decomposed low bog material forming the bottom layer. Faster water loss was also suggested by larger variances in water depths up to 90 cm. Groundwater was detected closer to the surface in the acrotelm or the living (surface) layer of the bog (short piezometers: PŻ2, PŻ4, PŻ6, PŻ8) (Figure 7). However, this layer experiences the effects of the weather and is also susceptible to periodic water loss via ditches that may or may not be passable (mud-filled, partly overgrown). This is due to the general properties of peat, which tends to be characterized by difficult infiltration, which is only exacerbated by its reduced ability to collect and channel water due to antecedent water loss and partial decomposition. While fluctuations are a little smaller, they are not less significant: average of 30 to 40 cm, extreme cases reaching 80 cm.

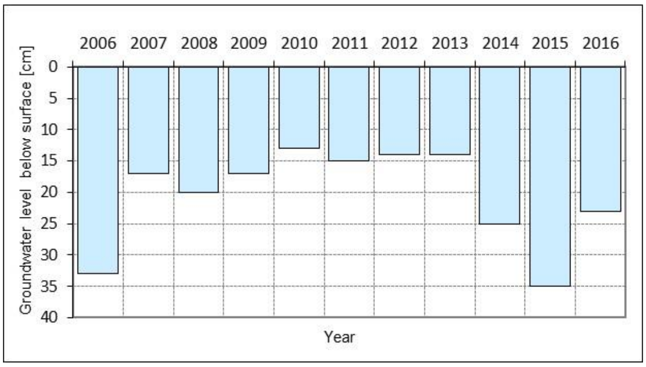

Figure 6. Yearly mean grounwater level in the Żarnowska Peatland, 2006-2016

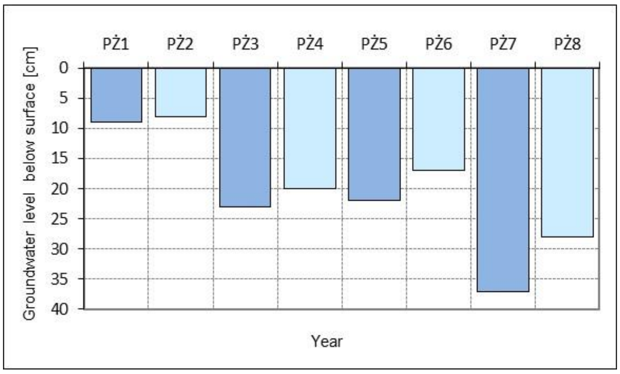

Figure 7. Yearly mean grounwater level in piezometers, 2006-2016

Research has also shown clearly seasonal fluctuations and spatial fluctuations in groundwater levels. A systematic increase in the water level was noted until 2013 both in the cupola section of the bog and across its fringe area (Figure 8). The rate of increase ranged from an average of about 1 cm per year (PŻ1, PŻ2, PŻ6) to almost 4 cm per year (PZ8). The research results suggest that the protective procedures in effect in recent years are producing positive results – and even more positive results are expected in terms of increasing water content across the studied bog. Unfortunately, for reasons independent of man, the water content of the bog decreased in 2014 and 2015.

Research has shown (Chlost et al. 2018) that these two years were extremely warm and dry. These anomalies led to a negative climate balance – precipitation less evaporation. The water deficit was calculated for hydrologic years as 54 mm (2014) and 159 mm (2015). It caused a major reduction in water retention throughout the bog. Water levels eventually stabilized at the level recorded prior to active protection efforts reaching mean annual values of 14 to 43 cm below ground level. Hence, the previous increase in water levels was halted and turned into a decrease at all piezometers, with the exception of PZ8 (Figure 8). The staff gauge used in the study recorded a stable, albeit small positive trend in water levels for one of the drainage ditches in the bog fringe area in the period 2006 – 2016. This shows that this ditch still serves as a drainage channel despite the extensive presence of mud as well as a compact layer of water surface vegetation. In addition, fluctuations in groundwater levels as well as overall trends measured at piezometers PZ7 and PZ8 prove that the bog fringe zone provides higher water content than does the cupola section.

Figure 8. Fluctuations in groundwater levels in the Żarnowska Peatland in the period 2006 – 2016

The cupola was characterized by variable moisture conditions in the period 2006 – 2016. At some locations, the mean annual groundwater table was found directly underneath the surface of the Earth (PZ2), while at other locations it was found deeper (PZ5) (Figs. 9, 10). Variances depended on the location of the piezometer in relation to drainage ditches and the ability of the ditches to help channel water. Extremely low water depths were reached most often in the summer, often in excess of 50 cm or the established boundary between permanent and periodic wetlands.

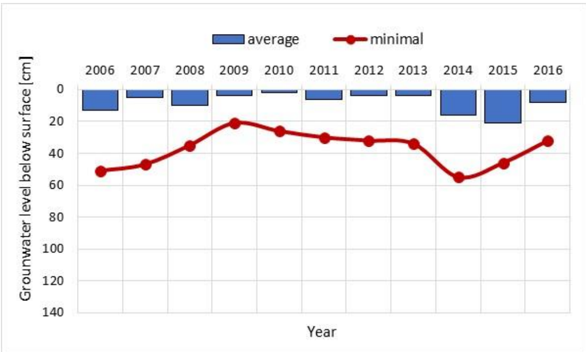

Figure 9. Yearly mean and minimal grounwater level in piezometer PŻ2, 2006-2016

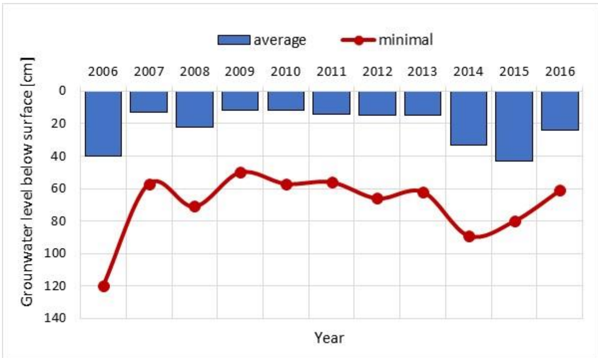

Figure 10. Yearly mean and minimal grounwater level in piezometer PŻ5, 2006-2016

The entire study period, and especially the years 2014 and 2015, were characterized by major differences in water retention in summer and winter. Water would normally stagnate on the surface in the cooler months of the year (Dec. – Mar.) and fill concave spaces in the valley-type relief of the bog or create local flooding and wetlands. In the vegetation season in summer (Jul. – Aug.), the water would fall below ground level and stabilize at depths from 25 to 55 cm. However, in extremely dry years such as 2014 and 2015, the water deficit occurred in most months of the year. Minimum water levels occurred in September in both years, with the mean monthly water level in the cupola section at 80 to 90 cm below ground level. This large decrease was due to low precipitation and high evaporation or the main components of vertical exchange in the water balance. The largest precipitation shortages were noted in June, July, and August (Figs. 11, 12), with peak values recorded in July 2014 (71 mm) and August 2015 (81 mm).

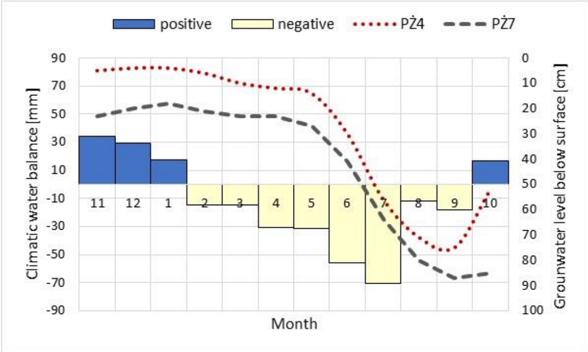

Figure 11. Water shortage and monthly mean grounwater level in the piezometers PŻ4 and PŻ7 in 2014

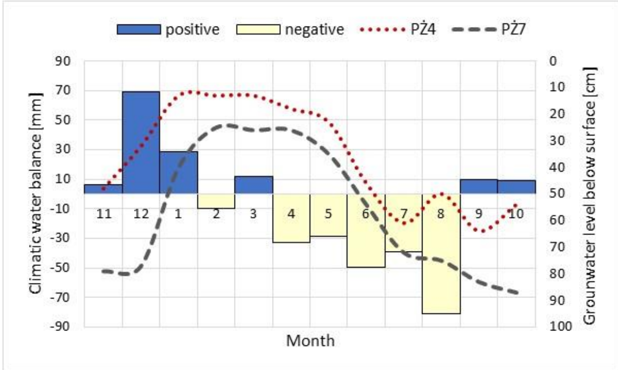

Figure 12. Water shortage and monthly mean grounwater level in the piezometers PŻ4 and PŻ7 in 2015

The water resources of the Żarnowska Peatland are determined by climate conditions and manmade hydrographic networks constructed over the last several centuries in the peat bog area. As in other ombrogenous bogs, water influx is determined almost exclusively by atmospheric precipitation. The seasonal pattern of precipitation and evaporation in the studied bog yields a pattern of decreasing water levels in the summer. Research has shown that the degree of bog water saturation is driven by spring retention rates. When the water table remains close to ground level from April to June due to the occurrence of intense precipitation or late snowmelt events triggered by persistently lower air temperatures, the water level in the summer also remains high and does not fall below 50 cm under the surface of the Earth. This is even true of years with less than average summer precipitation. This relationship was noted in the years 2010 and 2013.

The bog's retention of water is also affected by drainage via ditches and canals channeling any excess water away. This process occurs despite the use of barriers and dams on selected ditches and despite the relatively advanced clogging of the ditches. Bog water loss occurs mainly in the autumn, winter, and spring. It is also sporadically detected in the summer following intense rainfall. Fieldwork has shown a number of water loss pathways for the bog, which channel water away in all directions. Most ditches channel water away in the eastern direction towards the Żarnowski Canal, while some channel water north in the direction of Lake Łebsko. Water is also lost in the western direction due to the Gać pumping station, and in the southern direction towards the Łeba River. Some of the ditches are not covered by the 2006 active protection plan due to flood protection measures for one nearby village and the dirt road connecting the village with a seaside resort. For this very reason, barriers on some of the ditches are equipped with a spillway that enables the outflow of excess water (Figure 13). In selected cases, water pressure has washed out material from underneath the barriers/dams, and this leads to the loss of water sideways. Initial measurements, part of the Life Peat Restore project, indicate an estimated rate of water outflow ranging from several liters to more than 300 liters of loss of water per second depending on the time of year and current bog water content. In periods with a water deficit, the outflow stops, and water stagnates in the drainage ditches.

Figure 13. Water outflow from the Żarnowska Peatland towards the Żarnowski Canal via a spillway in a dam (Photo. I. Chlost March 24, 2018)

4.CONCLUSIONS

Raised peat bogs form ecosystems especially sensitive to changes in environmental conditions resulting from natural conditions such as climate change and human impact. The groundwater level changes are considered the most important cause of peatland degradation (Sharitz 2003, Frieswyck and Zedler 2007). Many years of human impact have disrupted the water equilibrium of the Żarnowska Peatland, triggering water deficits in the bog leading to the demise of rare hydrophilic species and the invasion of bushy plants and trees. The end of peat extraction in the late 20th century did not immediately improve the condition of the bog. It was the introduction of active bog protection in 2006 that led to a gradual increase in groundwater levels. This stage may be considered a key stage (8th stage) in the history of changes in water content in the Żarnowska Peatland. This is the ecosystem renaturalization stage. However, this process occurs very slowly. Despite the use of barriers/dams at some locations, water deficits are still detected in the bog water content pattern, especially in the warmer months (Apr. – Oct.). In this warmer season, water levels decrease below 0.5 m and sometimes even below 1 m below ground level. The fringe zone of the bog retains much more water than the cupola part whose water content varies. The protection of the bog is bringing a limited amount of success. The water level is gradually rising, as manifested by a number of high water stages and the decline of pine and spruce stands and bog birch in the northern part of the bog. However, the opposite trend may be deduced from the mean annual water increase pattern for the period 2006 – 2016. This trend is negative (-0.2 cm/yr). However, it must not be associated with human impact, but with anomalous warm and dry periods in the years 2014 and 2015.

The change pattern most likely to be realistic is that provided by the staff gauge on a drainage canal. The trend here is one of an increase of 0.26 cm/yr, although this increase was larger until 2013 reaching between 0.6 and almost 4.0 cm per year depending on site. Fieldwork has shown that even this type of large increase is not sufficient for the central part of the bog. Pine trees are once again invading the area, even after having been felled previously. In addition, it has been observed that the old drainage network remains periodically useful in the channeling of water away from the bog, even though it is partly damaged or overgrown. Outflow starts at high water stages in the winter and after heavy rainfall in the summer. This is also true of ditches without barriers/dams and in some cases of ditches with dams that have been washed under and are experiencing lateral outflow.

The active protection effort in the study area has produced some useful ecological effects, but overall remains unsatisfactory, even though it is true that peat-formation processes cannot be fully triggered by man. However, the current water content of the studied bog suggests that protection be continued. This will make it possible to complete the Life Peat Restore project, which will further aid in the stoppage of outflow and the sealing of water outflow pathways. In the final analysis, this will be a positive step in the improvement of water retention conditions in the studied peat bog.

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