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Effects of environmental and anthropogenic determinants on changes in groundwater levels in selected peat bogs of Slowinski National Park, northern Poland

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Abstract

The present study focuses on two Baltic-type peat bogs in Slowinski National Park, namely that at Żarnowskie and at Kluki, located in the Lake Łebsko catchment and both characterised by a centrally located dome with a very marshy fringe area featuring an emerging marshy coniferous forest (*Vaccinio uliginosi-Pinetum*). The Żarnowskie bog is under active protection. A total of 24 flow barriers were installed in drainage ditches during the years 2006 and 2007. The purpose of these barriers was to put a halt to water outflow. In addition, 30 hectares of young pine forest were cleared in order to decrease loss of water via evapotranspiration.

Kluki peat bog is only partially protected by Polish law. The lack of efforts to prevent outflow via the canal is due to the fact that the canal is utilised to drain meadows in the vicinity of the village of Łokciowe outside of the national park. Peat formation no longer occurs in this peat bog. The hydrological condition of the bog is catastrophic as a result of its main canal, referred to as Canal C9, which is 2.5 to 3.0 m deep and 10 m wide in places.

Both peat bogs are monitored for fluctuations in groundwater. Research has shown that changes in water levels fluctuate based on season of the year and geographical location, which is illustrated quite well using the two studied peat bogs.

The water retention rate of the Żarnowskie peat bog may be considered fairly high and is likely to improve due to protective measures enabled by Polish environmental laws. The water retention rate of the bog is consistently improving thanks to these measures, fluctuations in water level are small and the water level does not drop under 0.5 m below ground level even under extreme hydrometeorological conditions. This yields optimum conditions for renewed peat formation in this area. One potential threat is the Krakulice peat extraction facility, which is located in the southern part of the bog close to the boundary with the national park.

Key words: wetland, retention, piezometer, drainage system, protection

1. Introduction

Wetlands are extremely important in view of their retention potential, numerous hydrological functions and, primarily, biological values (i.e., a large variety of species) (Oertli et al., 2005). Together with their catchments, wetlands often comprise geographically isolated areas. At the same time, due to natural or anthropogenic changes they may, together with other hydrographic objects in the area, create entire hydrographic systems linked via hydraulic bonds (Tiner, 2003). Their existence, as well as the composition of species occurring in wetland habitats, have always been associated with water resources and circulation, which is why it is important to know and reconstruct the water budgets in their area. This offers an opportunity to explore changes in the environment that have occurred in wetlands (Leider et al., 2013). Unfortunately, due to irresponsible human activity the surface area of wetlands across the globe has drastically decreased, which has led to a distortion of the existing water circulation, not only on a local or regional scale, but on a global scale as well, i.e., declining water resources across the world (Rijsberman, 2006). This is due to attempts to use the land for agricultural purposes (Muller et al., 2013).

One area characteristic of the southern Baltic coastline is Slowinski National Park (SNP), which is located between two fairly large lakes: Gardno and Łebsko (Fig. 1). Hydrogenic land ecosystems play an important role in the circulation system of Slowinski National Park. This is especially true of the water retention capacity of the park, approximately 25% of which is covered by such ecosystems. These include peat bogs whose origin is associated with changes in climate and vegetation during the Holocene (Tobolski, 1972, 1975, 1989; Tobolski et al., 1997).

Peat ecosystems in the park are classified as Atlantic-type and are characterised by advanced degradation, as manifested by decomposition and mineralisation of the peat mass. In effect, the structure of the bog is slowly collapsing. This process has been observed for more than 200 years due to intense drainage works designed to regulate and adapt peat bogs to the needs of agriculture as well as for the purpose of peat extraction. Human impact has produced a situation in which large areas are overgrown with peat-forming plant communities, but peat is no longer formed in any of these areas.

These peat-forming plant communities currently exist and function exclusively due to the fluctuation of groundwater levels. The purpose of the present paper is to discuss changes in groundwater level in selected peat bogs of Slowinski National Park. The paper also aims to determine the impact of selected geographical determinants, including protective measures, on groundwater fluctuation in peat bogs in the park.

Water research in Slowinski National Park has been performed for more than 130 years. However, research of groundwater in the park did not start until the late 1960s. A study by Drwal (1968) determined groundwater levels and their effects on water circulation along the Baltic Sea coastline between the Lake Gardno and Lake Bukowo. In more recent years, Braun and Chlost (2008) analysed the functioning of the Żarnowskie peat bog system based on groundwater levels as well as other determinants.

Cieśliński et al. (2014) discussed the effects of changes in groundwater level on the development of selected plant communities in Slowinski National Park. Furthermore, in 2015 Chlost and Sikora outlined the effects of human activity on water levels across the Gardno-Łebsko Lowland. Hence, the number of research papers on groundwater levels in Slowinski National Park is small, while work on the relationship between groundwater level in the park and local plant communities is not available yet.

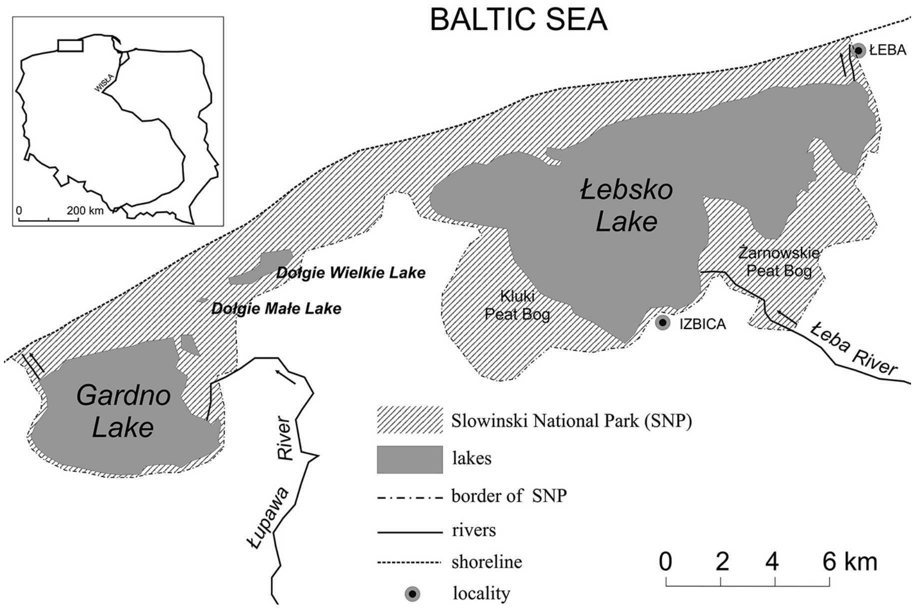

Fig. 1. Slowinski National Park.

2. Methods

Our research consisted of hydrographic surveys of selected peat bogs in order to observe anthropogenic changes and produce a static portrayal of bodies of water, circulation patterns and hydrotechnical structures. Data collected in the course of our fieldwork were supplemented with a review of primary source materials, including groundwater level data from a monitoring site in Slowinski National Park. The present study focused on two Baltic-type peat bogs in Slowinski National Park, Żarnowskie (part of Wielkie Bagno) and Kluki (its part named the Bórbagno Kluki).

These peat bogs differ in terms of measures employed to protect it, although both are located in the Lake Łebsko catchment and both are characterised by a centrally located dome with a very marshy fringe area featuring an emerging marshy coniferous forest (*Vaccinio uliginosi-Pinetum*).

The Żarnowskie peat bog was analysed using eight manual piezometers, with readings once per week (Fig. 3). The piezometers were deployed in pairs – mixed long and short piezometer pairs – in such a way that a transect of the central part of the bog was acquired. The following piezometer pairs were installed across the dome of the bog: PŻ1-PŻ2, PŻ3-PŻ4 and PŻ5-PŻ6. Three of these are long piezometers (PŻ1, PŻ3 and PŻ5), which reach about 180 cm or the abiotic part of the bog featuring significant water content, but a more compacted mass (base mass).

Even-numbered piezometers (PŻ2, PŻ4 and PŻ6) were short, reaching only 120 cm. These were installed in the bottom section of the upper layer of the peat bog. This section is characterised by loose turf and relatively high porosity whose water content depends on current atmospheric conditions. The fringe area of the peat bog was analysed using two piezometers (PŻ7 and PŻ8). It is important to note that piezometers PŻ1, PŻ2 and PŻ8 were situated in an area affected by extraction; down to a depth of one metre peat has been removed here.

The peat bog was also analysed using two automated water level gauges collecting data once per hour (Fig. 2). Gauge no. 1 recorded fluctuations in the water level in the fringe area of the peat bog, and was situated close to a drainage ditch that ringed the bog, while gauge no. 2 was installed on the top of the dome of the bog.

Six manual piezometers were employed to measure groundwater levels across the Kluki peat bog (Fig. 3). The piezometers were distributed according to the following scheme: (1) the PK1/PK2 pair was located at the edge of the bog near a road, (2) the PK3/PK4 pair was placed in the central part

Fig. 2. Location of piezometers across the Żarnowskie peat bog.

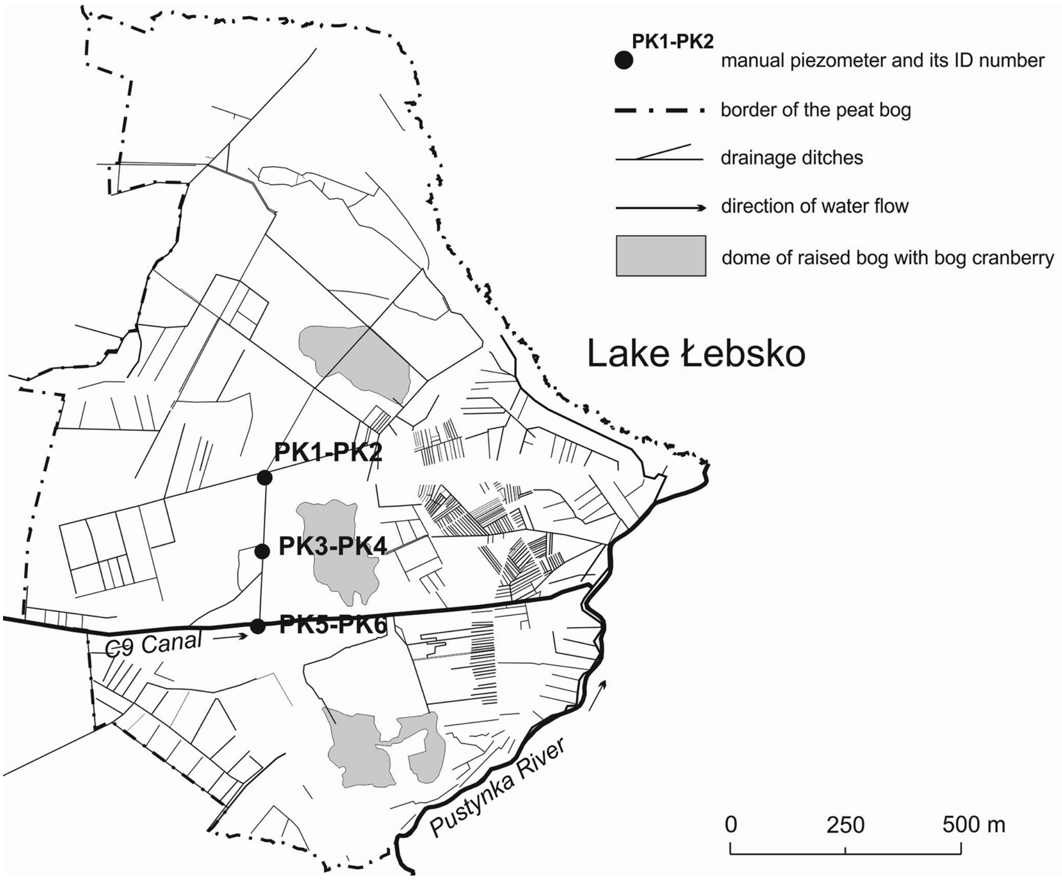

Fig. 3. Location of piezometers across the Kluki peat bog.

of the bog, and (3) the PK5/PK6 pair near Canal C9. In addition, water levels were monitored using four automated water level recorders. However, the data produced by these devices were deemed not very credible and thus were not included in the analysis.

3. Geological and hydrogeological characteristics of study area

The peat bogs studied are grouped in a geomorphological classification unit known as the Gardno-Łebsko Lowland unit. The hydrogeological conditions found in this lowland needed to be analysed within the context of its complex local geology and parent material. This local geology is also linked to the location of a series of terminal moraines of the Gardno phase, which clearly mark the margins of the lowland on the east, south and west. According to Borówka & Rotnicki (1995), the evolution of the basin of the Gardno-Łebsko Lowland in a form that resembles its contemporary form may have been linked with both erosional and shearing depression formation during the late Warthe glacial period.

This depression later became filled with sediment of varying origin. Initially these were fluvioglacial formations as well as river and lake formations associated with the recession of ice sheets. Later these included Late Glacial fluvial and glaciolacustrine deposits. These formations are overlain by Holocene units, up to 15 m in thickness and consisting of fluvial accumulation sediments (sand, silt, gravel) that line the valleys of the rivers Łeba, Pustynka and Łupawa. The next layer consists of sediments laid down during marine incursions as well as lake deposits.

Marsh formations are a special feature of the geology of this lowland. These originated from a physical complication in overland flow to the sea at the moment of the formation of the long Łeba Sandbar, dated at 4,100 to 3,600 years BP (Rotnicki, 2009). The formation and ongoing collection of peat mass in local depressions was facilitated by a cool and moist climate as well as a high level of groundwater, associated with a Holocene-Pleistocene aquifer. Many bogs formed as a result of the disappearance of water surfaces, which can be inferred from the presence of limnic sediments – represented by gyttja – across the bottom layer of peat (Tobolski et

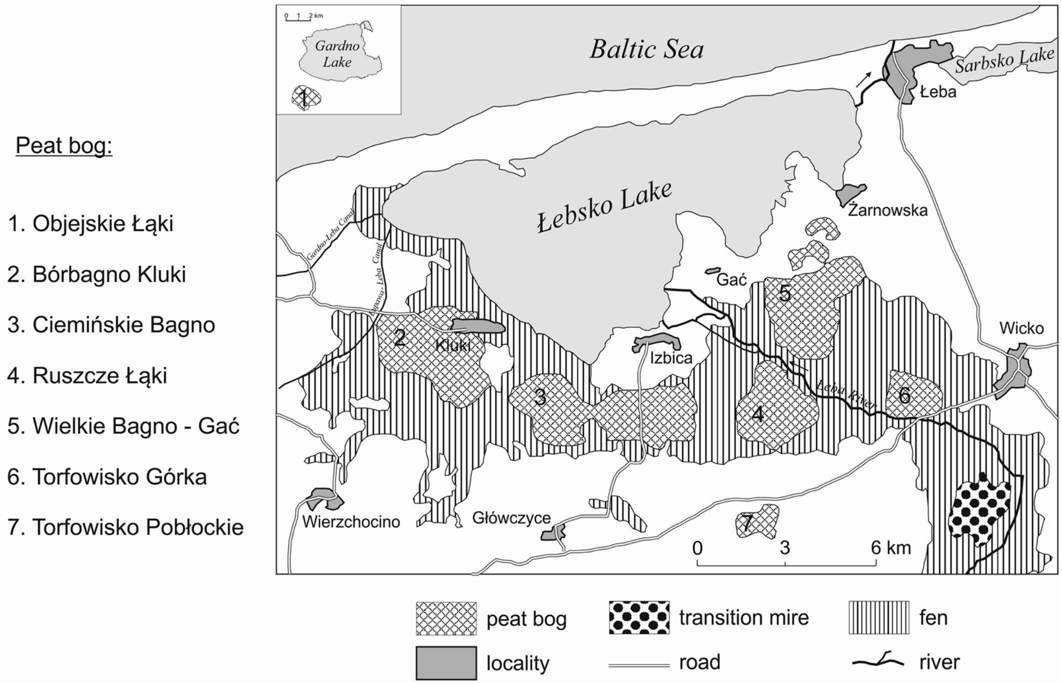

Fig. 4. Location of peat bogs in the valley of the River Łeba (Jasnowski, 1978).

al., 1997). Today, the most extensively studied peat bogs are found in the valley of the River Łeba (Fig. 4), while the studied lowland is a region with 13 to 20% peat coverage (Jasnowski, 1978, 1990).

Hydrogeological relationships detected across the Gardno-Łebsko Lowland and Slowinski National Park confirm its function in local and regional water drainage systems (Fig. 5). This lowland constitutes a key erosional basis for all local and regional water tables including the Cretaceous horizon (Kozerski & Sadurski, 1985), while the surrounding moraine hills function as water recharge areas. Lidzbarski (2004) identified three types of water flow: (1) local flow, including Pleistocene-Holocene, palaeovalley and inter-moraine aquifers, (2) transitional flow, occurring in lower Pleistocene and Quaternary aquifers, (3) regional flow, occurring in the Cretaceous aquifer.

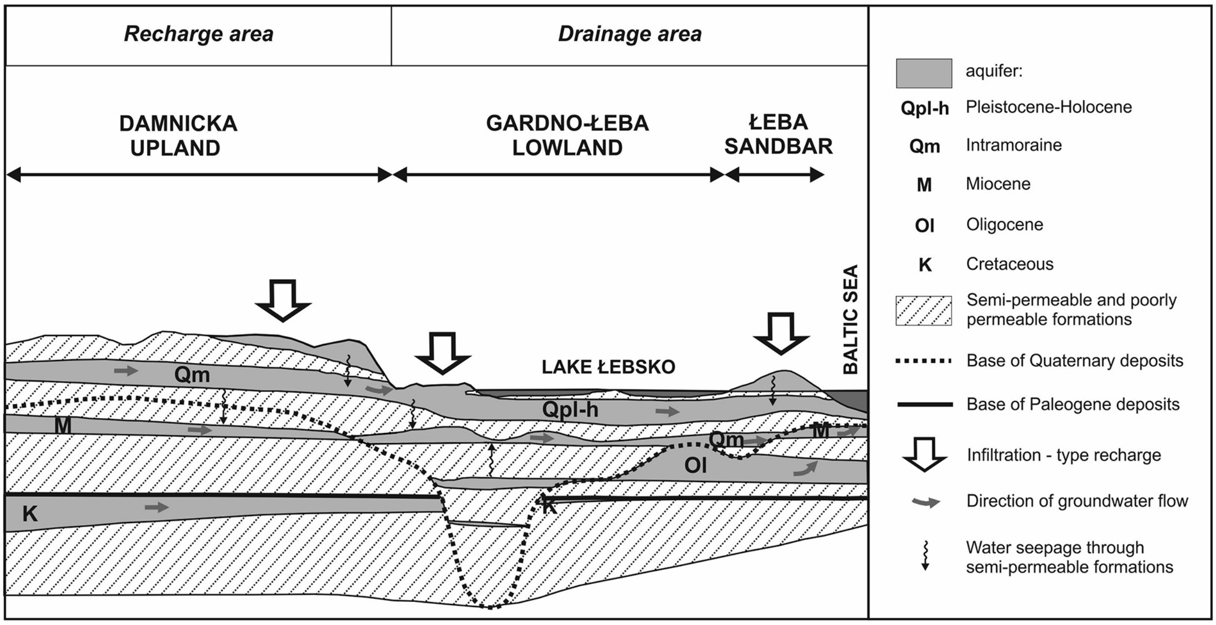

Fig. 5. Recharge and drainage areas in Slowinski National Park (www.psh.gov.pl).

Research has shown that local groundwater flow in the study area is recharged first and foremost by precipitation infiltration. This is particularly important in the case of the sandbar and coastal dunes studied. Other important sources of recharge are lateral influx and vertical influx of water from deeper-water tables. Transitional flow occurs in the form of exchange with shallower-water tables. Water exchange and supply, especially that via lateral influx, occur in the fringe area within all water-bearing aquifers and tables.

Alluvial plains along the Polish Baltic coast are characterised by a very diverse system of hydrogeological structures. This pattern yields a well-defined first shallow aquifer found at a depth of 1 to 2 metres. Its capacity is low thanks to its relatively thin water-bearing formations. Nevertheless, this particular aquifer may reach as deep as 10 metres (Drwal, 1968). Cenozoic levels, on the other hand, can store a significantly larger quantity of water, which is often held in place by pressure.

Virtually the entire Lake Łebsko catchment is covered with a compact collection of organic formations, with the exception of coastal dunes as well as the Izbica region (upland outcrop). The top of the main aquifer is found at a depth of 5 metres or less. The sandbar studied is characterised by stagnant waters, which are cut off from infiltration recharge by various glaciolacustrine deposits. The basin of Lake Łebsko is situated in an area covered by sand and silty sand, while the top of the primary water table is not less than 1.6 metres below the surface. The Pleistocene-Holocene horizon detected across the alluvial plain is directly joined with water-bearing formations of the palaeovalley series (Kreczko, 2000). In this case, the horizon is recharged by infiltration of atmospheric precipitation as well as the lateral influx of water from the upland area. The surface of the water table is found no deeper than 3 metres above sea level.

4. Results

Both peat bog complexes are characterised by large areal extent and great thickness reaching 7 metres (average: 4 m). It is important to note that the peat deposits are distributed unevenly and include several biogenic accumulation basins. Mineral deposits are also intertwined with peat deposits at selected sites. Fringe areas consist of transitional bogs and low bogs. The predominant peat types in the study area are reed and sedge peat. Both are excellent indicators of change in aqueous environment and ecosystems formed in such settings. Woodland plant communities, marshy coniferous forests in particular, emerge across any dried portions of peat bog. Improved water conditions lead to a collapse of tree stands and a return to an open bog.

The Żarnowskie bog covers an area of 300 hectares and is characterised by a dense network of drainage ditches. The eastern boundary of the bog runs along the Żarnowski Canal, while the western part of the bog includes former extraction pits, with the raised bog layer between 1 and 1.5 metres thick. Today the bog consists of a mosaic of dikes and post-extraction pits along with regenerating peat vegetation as well as the surface of the former peat dome with the remainder of an *Erico-Sphagnetum medii* phytocoenosis. However, it is just a fraction of its former extent. Predominant habitats in the area comprise coniferous forests as well as an admixture of pine and birch marshland areas. The eastern region of the bog is covered with segetal and nitrophilous vegetation due to the close proximity of Żarnowski Canal, which carries waters subject to eutrophication linked with upstream agricultural areas. Former extraction pits are flooded and form reservoirs that bear only locally recognised names.

Parts of other sections of the bog were also subject to peat extraction. The bog's northern boundary runs along the local Gać-Żarnowska road, which is also lined with a drainage ditch that directs water away from the bog via an underground pipe leading to Lake Łebsko. The bog is protected by Polish law as a conservation area. A total of 24 flow barriers were installed in drainage ditches in 2006 and 2007. The purpose of these barriers was to put a halt to water outflow. In addition, 30 hectares of young pine forest were cleared in order to decrease loss of water via evapotranspiration. The southern part of the bog includes a peat extraction area – the Krakulice facility (Fig. 6). Once peat deposits are exhausted and drainage systems are no longer in working condition, national park authorities take over former extraction areas. In addition, former extraction areas are classified as Nature 2000 protection areas, the purpose of which is to help them regenerate peat.

The Kluki peat bog is located near Lake Łebsko, atop a local drainage divide. It can be described as having a well-developed network of drainage ditches, mostly on the left bank of the River Pustynka. The central part of the dome is relatively poorly drained. The hydrological condition of the bog is catastrophic as a result of its main canal, referred to as Canal C9, which is 2.5 to 3.0 m deep and 10 m wide in places (Fig. 7). It features steep, virtually vertical banks. The water level in the canal is 2.5 m below the surface of the peat bog.

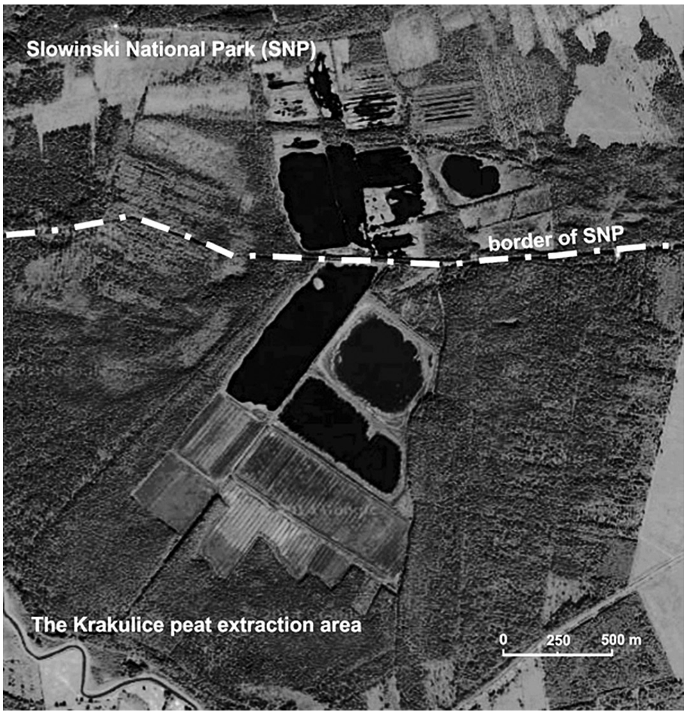

Fig. 6. Peat extraction area along the southern boundary of Slowinski National Park.

The peat bog is only in part protected by Polish law. The lack of efforts to preclude outflow via the canal is due to the fact that the canal is utilised to drain meadows in the vicinity of the village of Łokciowe outside of the national park. Peat formation no longer occurs in this peat bog. Both raised bog and transitional deposits remain completely overgrown with woodland vegetation. Decreasing water shortages have produced a tree stand succession. Local habitats classified as marshland (coniferous) forests are really closer to Molinia meadows that invade dried areas with a layer of decaying matter tens of centimetres thick. In places with a better water supply, mixed pine and birch marshes gradually encroach upon and eventually replace pine forests. Non-forest vegetation has emerged along the fringes of the bog, close to the lake. This also includes rush-type plants, meadow vegetation and herbs. The southern part of the bog consists of large fringe areas featuring nitrophilous vegetation.

The Żarnowskie and Kluki peat bogs are classified as ombrogenous due to local water outflow conditions and water sourcing patterns. Both bogs are recharged almost exclusively via atmospheric precipitation and formed in areas characterised by difficult outflow conditions, where precipitation exceeded evapotranspiration and excess water was stored in the peat mass. The proper functioning of these bogs was shifted off-balance due to changes in water flow patterns caused by an artificial lowering of the groundwater level due to ditches that helped drain the bogs for the purpose of peat extraction.

This led to decay and, in extreme cases, mineralisation of the surface layer of peat as a result of excess drying, which is manifested by the significant presence of *Cladonia* lichens, common heather (*Calluna vulgaris*) and tussock cottongrass (*Eriophorum vaginatum*). These new elements of the bogs led to the disappearance of the characteristic clump and depression structure of bog habitats. In addition, peat-forming oligotrophic vegetation dies off including bogmoss (*Sphagnum magellanicum*, *Sphagnum rubellum*). The lowering of water levels has produced a change in habitat conditions and has enabled the succession of common pine (*Pinus sylvestris*) and birch (*Betula pubescens*), both of which had given rise to marsh-type forests as well as sub-

Fig. 7. The C9 Canal in the Kluki peat bog.

stitute vegetation dominated by common heather (*Calluna vulgaris*) and purple moor grass (*Molinia caerulea*) across post-extraction areas.

A total of 24 flow barriers were installed in drainage ditches surrounding the Żarnowskie peat bog in 2006 and 2007. The purpose of these barriers was to impede uncontrolled water outflow. Furthermore, 30 hectares of young trees were cleared to counter loss of water via evapotranspiration from the bog surface (Braun & Chlost, 2008). Similar protective measures have been successfully implemented in other raised bogs in northern Poland (Herbichowa et al., 2007) and in Scandinavian countries (Komulainen et al., 1999). Once drainage systems were disassembled in the western part of the bog, post-extraction pits became filled with water. These reservoirs were given local names such as Babidół Wielki, Babidół Mały and Jelenie.

The Żarnowskie and Kluki peat bogs are classified as ombrogenous marshland areas due to their recharge type. However, the bogs phytosociology includes peat-forming, oligotrophic bogmoss (*Erico-Sphagnetum medii*) featuring a large quantity of protected cross-leaved heath (*Erica tetralix*) (Jasnowski, 1990). Both plants bear a close resemblance to natural vegetation found in bog areas.

Mean monthly fluctuation data obtained for groundwater levels for the Żarnowskie peat bog for the period 2006–2011 indicate that fluctuation patterns are associated with oceanic characteristics (Chełmicki, 1991). This means that water levels change on a seasonal basis in the sense that high water levels are recorded in colder months, from November to April. During these months, water stagnates at ground level, while in the warmer months, it infiltrates up to 0.5 m below the surface of the ground. Minimum water levels usually are recorded in July and August (Fig. 8). These two months are also the period of the highest atmospheric precipitation, which, however, does not compensate for the loss of water due to evaporation and plant transpiration.

Research has shown that the mean water level in the bog gradually increases over time resulting in a higher bog water content (Fig. 9).

The mean annual groundwater level increased in the period 2006–2011 from about 1.0 cm per year (PŻ1 and PŻ6) to about 5.0 cm per year (PŻ8). This change indicates that protective measures employed in this case were successful. However, studies have also demonstrated that it is vital to consider the hydrometeorological conditions for each analysed period or year, as these can substantially affect water level fluctuations. Two examples of this include a long harsh winter and an exceptionally hot and dry July in 2006 (Braun & Chlost, 2008). These events effectively changed established patterns and resulted in the lowest water levels in the study period (2006–2011).

Research has also shown a significant synchroneity between groundwater levels and the influx of pluvial water via a short and long cycle. This means that groundwater levels are very sensitive to short-lived changes in hydrometeorological conditions, but this response is also delayed and its magnitude varies depending on the magnitude of precipitation. The delay may last from several days (PŻ2, PŻ4 and PŻ6) to a month or longer (PŻ8) depending on the

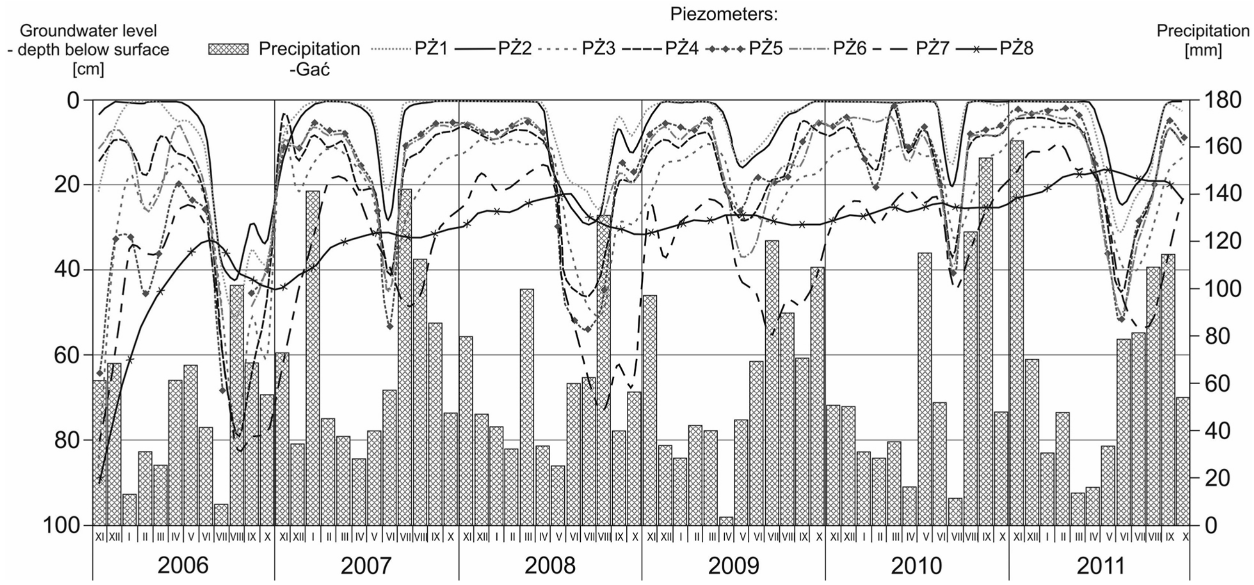

Fig. 8. Mean monthly fluctuations in groundwater levels in the Żarnowskie bog in the period 2006–2011.

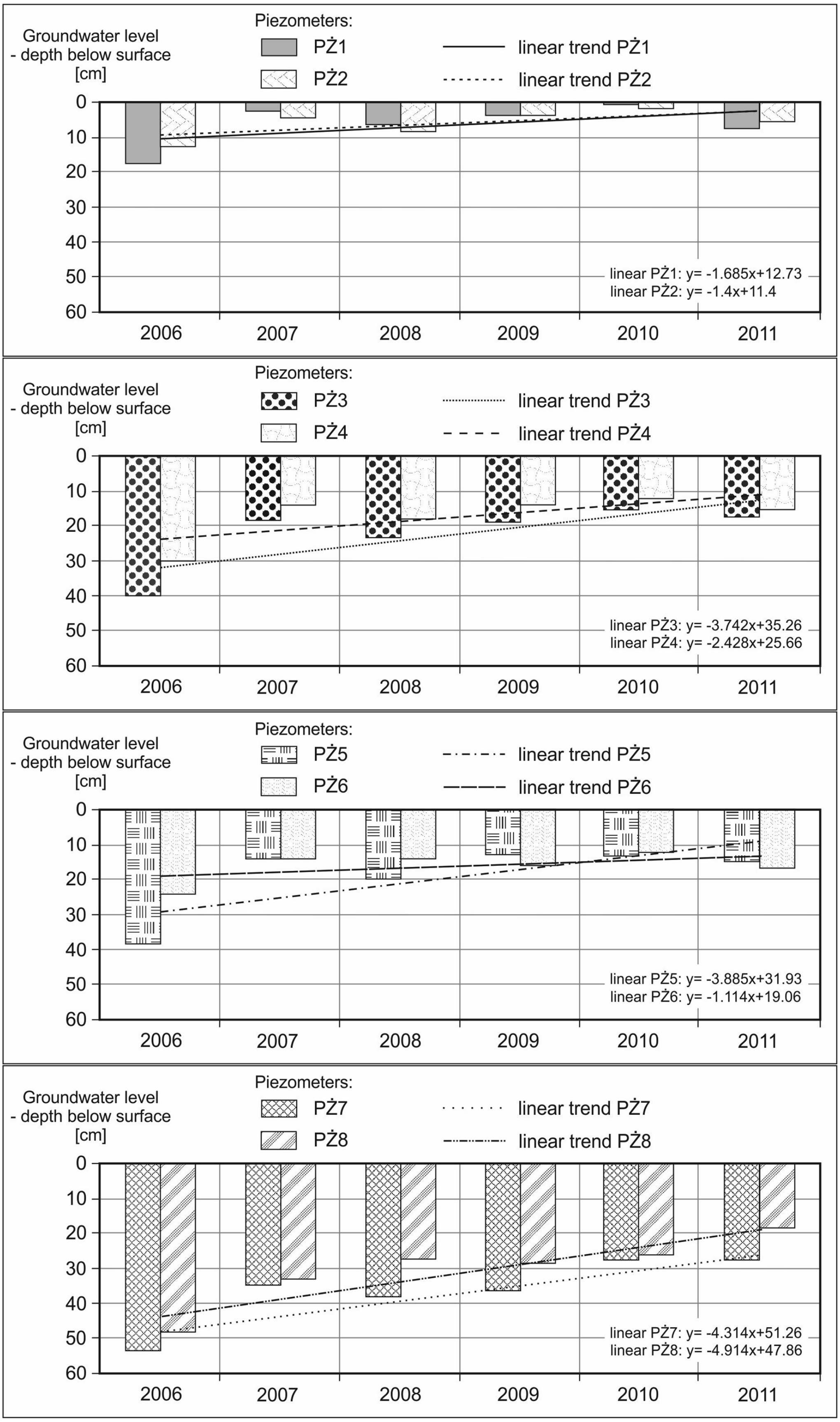

Fig. 9. Groundwater level growth pattern for the Żarnowskie peat bog.

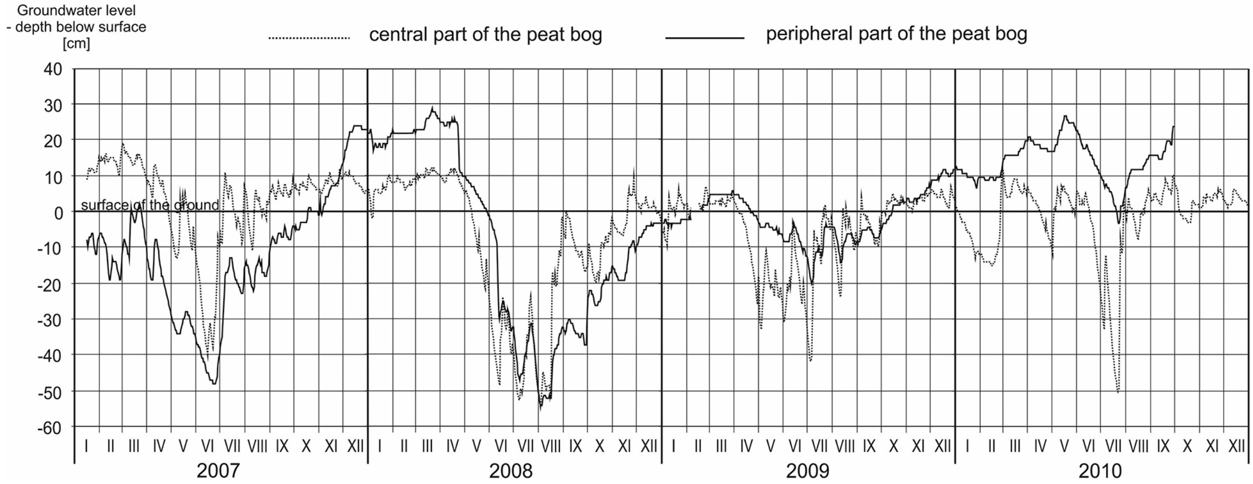

Fig. 10. Daily fluctuations in groundwater levels in the Żarnowskie peat bog in 2007–2010 .

structure of the bog and the depth at which piezometers are installed. In the former, these are piezometers at shallow depths, installed in the porous acrotelm layer, which is responsible for the pattern of water distribution within a bog. In the latter, the delay is the result of infiltration of pluvial waters through the structure of settled (compacted) peat.

Research in the period 2006–2011 has shown that bog water levels in the summer are determined not so much by the magnitude of atmospheric precipitation as by the magnitude of spring retention. If the water level in April, May and even June remains high or stagnant on the surface of the ground due to hydrometeorological conditions, then water levels in the summer do not drop under 0.5 m below the surface, even in the case of little precipitation. One example of a year when this actually occurred was 2010 when the total precipitation in July was a mere 11.4 mm.

What is important is the water level fluctuation pattern obtained for the cross section of the bog. Water level fluctuation data obtained from manual piezometers show that the largest fluctuations occurred in the dome section of the bog and reached about 1.0 metre (PŻ5 and PŻ6). On the other hand, fluctuations noted by divers indicate large fluctuations in the central and fringe areas of the bog. These inconsistent results are due to a different deployment of manual and divers. However, it is important to note that the water level divers noted does not decrease substantially below the boundary value of 0.5 m below ground level (Fig. 10).

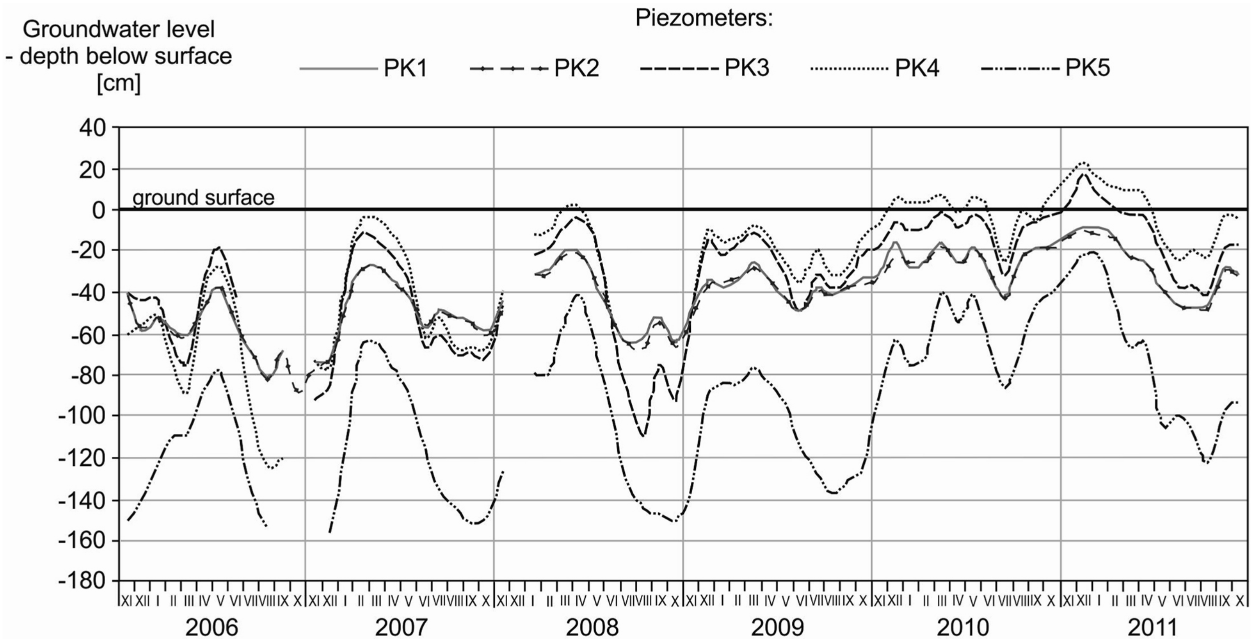

Fig. 11. Mean monthly groundwater fluctuations in the Kluki peat bog in 2006–2011.

Water level patterns are somewhat different for the Kluki peat bog – a natural area not receiving the type of protection available to the Żarnowskie peat bog. Mean monthly data show that groundwater levels at most piezometers fall below 5.0 m below ground level (Fig. 11). This is especially true during the warmer months of the year. In the case of some piezometers, weekly data show decreases reaching 1.5 m. Data on extreme hydrometeorological situations in the summer show that these piezometers dry up – the part of the piezometer installed under the ground ranges between 1.0 and 1.6 m in length. This refers to piezometers PK5 and PK6, respectively; both were located close to Canal C9 (about 10 m away). The two piezometers were situated in an area affected by human impact, atop a base material formed of matter accumulated in the course of canal construction. This area is also the highest part of the bog studied – and its base includes old drains that direct water away from the body of the bog. Hence, these two piezometers record the lowest water levels during the year, which confirms the drainage role of the canal.

The correlation between groundwater level fluctuations for the Kluki peat bog and the C9 Canal can be inferred from water level changes for virtually all piezometers used in the present study (Fig. 12). Changes in water levels in the C9 Canal depend on beaver activity and work done to dredge the canal by the Department of Drainage and Water Management in the city of Słupsk. Once dredging is complete, water levels in the canal fall to 60 or 70 cm, while beaver activity leads to increased water levels of 100 centimetres or more.

Piezometers PK1, PK2, PK3 and PK4 were installed in a part of the bog not subject to human impact. The mean groundwater level for PK1 and PK2 for the period 2006–2011 was 40 cm below surface. The largest decreases (more than 0.5 m) were noted in the months from June to October, and sometimes even December. The highest water levels, in most cases, were noted from January to April. Research did not reveal any stagnation of water on the surface of the ground. This may be due to the location of the piezometers – close to a road lined with drainage ditches. The road was constructed on a natural sandy dune belt cutting the bog across from west to east. Drainage ditches serve to secure the road from flooding at high water stages.

Piezometers PK3 and PK4 were installed in the lowest area of the bog – the dome area – which had collapsed to some extent due to high water content. This is an area with the shallowest groundwater levels, which seasonally yield pools of water on the surface, especially during the wet months of the year (January, February) and during snowmelt season (March, April).

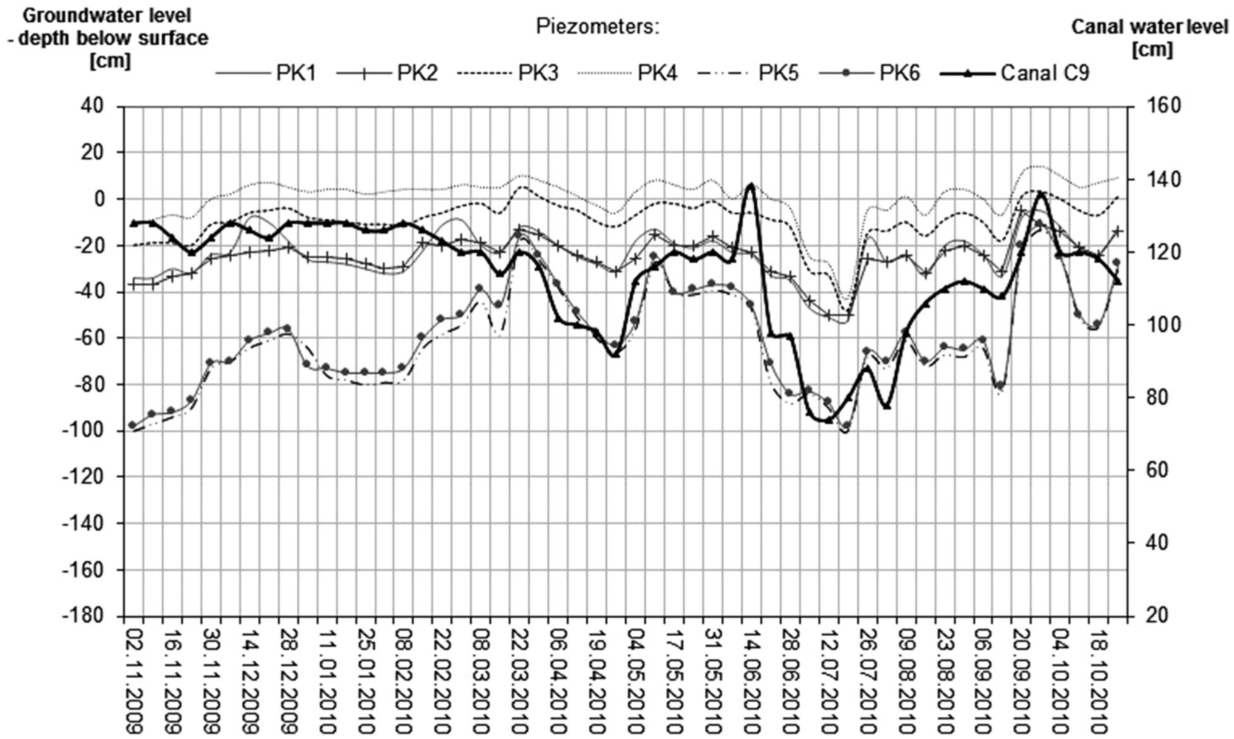

Fig. 12. Dependence of groundwater level fluctuations in the Kluki bog on water levels in the C9 Canal, illustrated by the 2010 hydrological year.

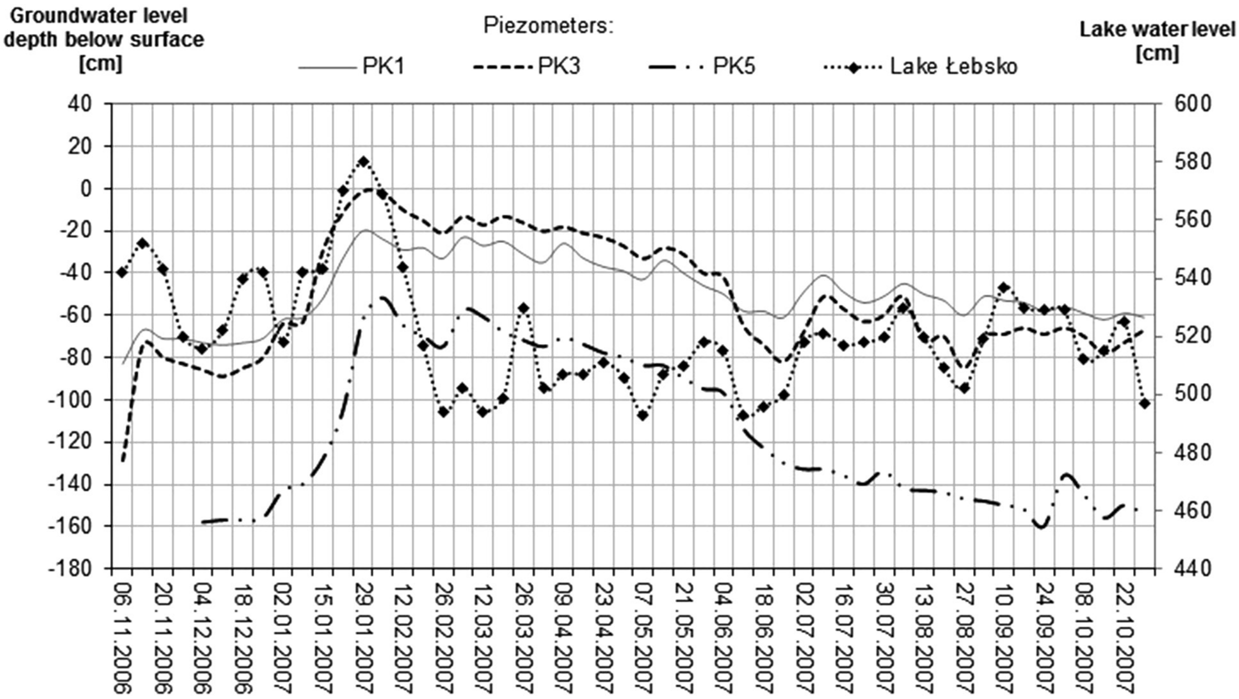

Fig. 13. Fluctuations in groundwater levels for the Kluki peat bog and Lake Łebsko, exemplified by the 2007 hydrological year.

The location of the bog in the close proximity of Lake Łebsko leads to hydraulic contact between the bog and the lake (Fig. 13). This linkage manifests itself primarily in the effect of the lake's water level on groundwater levels; however, it is only possible to observe this effect during extreme rises or drops in lake water levels. It is important to note that water levels in the lake fluctuate very dynamically in line with changes in water levels in the Baltic Sea. The coefficient of correlation for fluctuations in these two bodies of water is R^2=0.9 (Chlost, 2012).

Research has shown that the bog is slowly storing a larger amount of water due to the overgrowth of drainage ditches with vegetation, clogging of old drains and the construction of beaver dams in the C9 Canal, which make water levels in the canal rise and consequently reduce the loss of groundwater from the bog.

5. Final discussion and conclusions

Invariably, the main factor causing changes in plant habitats is water. Therefore, any change in the manner and intensity of swamp water supply affects the vegetation. Drainage of peat deposits is considered the most important reason for changes in swamp habitats. The consequence is a change in vegetation (Ilnicki, 2002). Additionally, the supply of significant quantities of biogenic compounds and their transformation have a significant impact on plant habitat change (Jahangir et al., 2013; McPhillips et al., 2015).

Research has shown that changes in water levels fluctuate based on season of the year and geographical location, which is illustrated quite well using the two peat bogs studied. The main factors that impact the dynamics of water level changes include atmospheric precipitation and physical linkages between the bogs and lake studied. Human impact is yet another important determinant of change. In effect, changes in groundwater levels determine the water retention rate of each studied peat bog, which further determines their proper functioning.

The water retention rate of the Żarnowskie peat bog may be considered fairly high and is likely to improve due to protective measures enabled by Polish environmental laws. The water retention rate of the bog consistently improves thanks to these measures, fluctuations in water level are small and the water level does not fall below 0.5 m below ground level even in extreme hydrometeorological conditions. This yields optimum conditions for the renewal of peat formation in this area. One potential threat is the Krakulice peat extraction facility, which is located in the southern part of the bog close to the boundary with the national park.

The facility includes a pumping station that serves the Żarnowskie peat bog with the aim to drain part of the peat extraction area. Drainage work occurs from May to September when atmospheric precipitation is at an all-year low. The artificial removal of water thanks to this pumping station abruptly lowers the groundwater level across the bog. One man-made feature that tends to limit loss of groundwater is the post-extraction pond. Many of these form in post-extraction areas and serve as means to retain water.

On the other hand, the water content of the Kluki peat bog needs improvement. The bog is threatened primarily by the drainage effects of two local canals – C9 and a seasonal canal that drains the bog in section 77 – as well as the drainage effects of roadside ditches along the road to the village of Kluki. This problem is exacerbated by the fact that most drainage ditches and canals begin outside of Slowinski National Park and empty into coastal lakes in the park. This means that they cannot be deleted, as this would threaten a rise in water levels in meadows found adjacent to the park.

The most basic problem in this case is the conflict between environmental protection goals and the proper functioning of drainage canal C9, which causes excessive fluctuations in the groundwater level across the bog. This leads to excessive drying of the bog and consequently the succession of trees and bushes. Substantial fluctuations in the bog's water level may also be linked with the hydraulic connection between the bog and Lake Łebsko, which is in turn affected by dynamic changes in water levels in the Baltic Sea. In the case of the Żarnowskie bog, this connection is limited due to the isolation of the bog from the lake by a belt of dunes.

In 2015, a plan to rebuild drainage systems in order to help renaturalise the Kluki bog and prevent its further damage (www.zmiuw.gda.pl) was put forward. The plan involves Slowinski National Park and the Provincial Environmental Protection and Water Management Fund of Gdańsk as well as the Department of Drainage and Water Management at Gdańsk. The plan calls for a redirection of water from the upstream section of Canal C9 using a pumping site in the village of Łokciowe towards Smoldzinski Canal. Once this is accomplished, it will be possible to close down the canal and stop water loss from the bog. The project is set to start in the months to come. According to Zedler (2003) in the United States, as a result of drainage of wetlands for agricultural purposes, their area has decreased by 60%. Mitsch & Day (2006) estimated the reduction of this surface at about 80–90%. However, according to Kath et al. (2010), since 1900 the surface area of wetlands decreased globally by 50%, which is primarily associated with agricultural activities. It is important to take all measures seeking to renaturise wetlands. It is particularly important to reduce the impact of human activity on the lowering of the groundwater level. Worldwide research shows that the size of the retention wetlands depends on the circulation of elements, chemicals compounds and the preservation of peat-forming processes. Many peat bogs seemingly untouched by drainage and cultivation are influenced by a diffuse sum of man-made environmental changes, such as atmospherical nitrogen deposition that mask general patterns in species richness and functional group responses along resource gradients (Kleinebecker et al., 2010). According Kleinebecker et al. (2008) species richness in peat bogs shows strong linear correlations to peat chemical features and a general regression model resulting in three major environmental variables (water level, total nitrogen and NH_4Cl soluble calcium), altogether explaining 76% of variance.

Finally, climate change also impacts fluctuations in groundwater levels in both bogs. Similar observations have been made around the world (Rouse, 2002). As a result, the number of extreme hydrological and meteorological events have increased in recent years. For the national park, the larger number of heavy rainfall events is less important than the larger number of hydrological droughts, as these cause a drop in the amount of water both on and below the ground. According to Dale (1997), climate change is one of the two most important factors influencing not only the evolution of the surface area of wetlands but also water circulation in such areas. This is important, since the main water source for wetlands, also in the analysed area, is just precipitation and their hydrology results from the vertical water exchange (precipitation – evaporation). In the event of a 10% drop in the summer rainfall, the durability and severity of the water deficit on wetlands, which could be particularly well observed during dry years, will probably increase.

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