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1. INTRODUCTION. CLIMATE PROBLEMS

There is no doubt that the Earth's climate is changing and the weather is more and more often unusual, difficult to predict and often violent. In Poland, warm and wet winters, prolonged heat waves in summer, episodic but catastrophic wind storms are increasingly affecting nature and people's lives. The causes of these episodes can be seen in changes of atmospheric circulation as well as currents and sea oscillations, which are the result of disturbing the Earth's energy balance and increasing the temperature of its atmosphere. In other places around the world, waves of catastrophic droughts and heat, but also the appearance of extreme tropical cyclones, are becoming more frequent. Glaciers disappear, the Arctic ice does not renew during winter, the permafrost melts, entire ecosystems disappear before our eyes.

Although the Earth's climate has been always changing, over the past few decades we have been observing its warming at an unprecedented pace.

All data indicate that the source of this disturbance is caused by changes in the composition of the atmosphere caused by human activity - excessive emission of so-called greenhouse gases, primarily carbon dioxide (CO_2). The current concentration of this gas in the Earth's atmosphere, amounting to about 415 ppm in volume (= 0.415 ‰) is the highest in three million years, and has increased abruptly to this level in a short, 100-year period coinciding with the development of industry and intensive agriculture. There has always been a correlation between the concentration of CO_2 in the atmosphere and its temperature in the geological history of the Earth - now also manifesting itself in a constant increase in average temperature with an increase in carbon dioxide concentration. We seem to understand the basic mechanism of this correlation: even small amounts of CO_2 in the atmosphere make it permeable for short-wave solar radiation towards the Earth, but it inhibits the radiation of energy through the Earth in the form of infrared radiation, and this effect is proportional to the concentration of this gas. This phenomenon is analogous to the heating of a greenhouse or a car left in the sun - hence it is often called the greenhouse effect, and the gases causing it - greenhouse gases. Some other gases also work similarly: water vapor, methane, nitrous oxide. However, since the concentration of carbon dioxide has been increasing very rapidly lately, this gas is widely considered to be the main cause of the current increase in the average atmosphere temperature. Consequently, the increase in temperature, and thus the energy of the atmosphere, is the cause of complex, interacting and propelling each other, not entirely predictable changes in atmospheric circulation, changes in sea icing, circulation of sea currents and others. These changes result in episodes of extreme weather conditions and a widespread impression of a disruption in the Earth's climate system.

There is no bigger doubt that people and their activities are responsible for this. Increased CO_2 emissions are mainly due to the massive combustion of fossil fuels. The greenhouse gas emissions generated by intensive agriculture (e.g. from the decomposition of organic matter in the soil) also contribute significantly to this.

We do not know what will happen next. However, there is something to be afraid of. If climate change continues, and even more so when it accelerates, large parts of the land can be flooded with sea water, and large areas can become hostile to life because they are too dry and hot, for example. It is not possible to preserve the forests that we know today, nor the agricultural crops that we use today. We do not know what will happen to the wildlife around us, which we are happy with today, but we do know that the ecosystems, plants, animals and fungi that surround us are even more sensitive to change than we are. And the climate catastrophe will certainly get worse if we continue to emit greenhouse gases. At most, we have a chance, perhaps a few dozen per cent, to reduce its impact - but only if we do everything we can to reduce greenhouse gas emissions almost immediately and to remove at least part of the carbon that is already in the atmosphere.

Photo 1. Dry peat on the Wielkie Bagno peat bog in the Słowiński National Park - the result of the heat and drought period in 2018. Photo by P. Pawlaczyk.

2. PEATLANDS AND GREENHOUSE GASES BALANCE

The so-called carbon cycles are key for the balance of carbon dioxide in the atmosphere. The basic cycle is that the vegetation in the process of photosynthesis absorbs carbon dioxide and incorporates it in the form of organic compounds into its biomass. All living organisms use organic compounds in their breathing (respiration) processes, which is connected with the release of carbon from them, emitted in the form of CO_2 back into the atmosphere.

Peatlands are unique ecosystems in which part of the biomass of plants under marshy, anaerobic conditions transforms into peat, which means that the carbon contained in the biomass is excluded from this cycle. Peat in a natural, hydrated mire may remain unchanged for millennia; peat-forming vegetation on the surface of the mire will accumulate further layers of peat. In our climatic zone, thickness of peat deposits reach up to a few or even several metres. Carbon constitutes about 50% of peat mass, so peatlands withdraw significant amounts of this element from circulation for a long time. Although the process of carbon accumulation itself is not very intensive (usually about 0.5 tons of carbon per hectare per year), it builds a significant carbon reservoir in the long term. Researchers estimate that peatlands, occupying only about 3-5% of the world's land area, accumulate in total over 600 billion tons of carbon, i.e. about 25-30% of the carbon reserves accumulated in all terrestrial ecosystems. This is twice as much as the amount of carbon in the biomass of all the world's forests. Peatlands are the second largest reservoir of this element in the world after the ocean. The amount of carbon stored there, and thus withdrawn from the fast cycle, is estimated to correspond to 60-75% of the carbon stock in the atmosphere. These data may even be underestimated due to under-estimation of the surface and volume of so far poorly researched tropical and subtropical peatlands.

Some climatologists are even inclined to the hypothesis that it is the accumulation of carbon in peatlands at the beginning of the Holocene (when climatic conditions were exceptionally favourable), together with oceanic mechanisms, that has significantly contributed to the decrease of CO_2 concentration in the atmosphere and the start of ice ages.

Nowadays, as during almost whole the Holocene, peatlands still act as carbon sinks. All over the world they accumulate about 100-200 million tons of carbon annually (equivalent to absorbing 370-740 million tons of CO_2).

The carbon accumulated in peatlands remains in there only as long as the peatlands are saturated with water. Dehydration of peat causes its oxidation, so called decaying, as a result of which organic matter is decomposed and carbon

Photo 2. In the boreal zone, peatlands are much larger than in Poland, they occupy thousands hectares, they also accumulate proportionally more carbon. Photo by J. Kujawa-Pawlaczyk.

dioxide is emitted to the atmosphere. This process is usually much faster than the accumulation of peat - from a hectare of dry peatland is emitted from several to dozen or so tons of CO_2 per year - this is approximately the same order of magnitude as the entire annual emission "*per capita*", i.e. per one inhabitant of the Earth.

According to the estimates of the international organization Wetlands International, the global CO_2 emission from degraded peatlands amounts to about 2×10^9 tons per year (in other sources there are estimates of 1.3 - 5×10^9 tons per year, however, there is consensus as to the order of magnitude), with the trend of growth of about 2% per year. The area of degraded, requiring restoration peatlands on Earth is estimated to be at least 0.5 million km^2. Emissions of carbon dioxide from anthropogenically degraded peatlands are estimated at approx. 5-6% of total anthropogenic emissions of this gas, and approx. 30% of emissions from land use and land use changes (LULUCF).

The reason for the drainage of peatlands is usually the willingness to use them for agricultural purposes, although sometimes also as wood production or to peat mining. In Europe, more than 90% of regional CO_2 emissions from agriculture come from degraded peatlands used for agricultural purposes, although they account for only 3% of arable land.

In Poland the area of peatlands is estimated at 1211 thousand ha (=12.11 thousand km^2), but over 90% of them are degraded and dry. Most often it is a result of drainage, carried out on a mass scale in order to improve conditions for agricultural production (mainly meadows) on fens; sometimes it is also a result of drainage in bog forests and peat exploitation. Water drainage from peatlands is still ongoing, e.g. under the pretext of "increasing hay yields", "enabling hay crops", "restoring stands after felling", "preventing flooding of meadows, fields and forests", "preventing flooding of roads and buildings" (notwithstanding the fact that these roads and buildings were thoughtlessly located).

Based on the area of forested and agriculturally used peatlands and average emission factors, Wetlands International estimated the annual CO_2 emission from all degraded peatlands in Poland at 25.8 million tonnes, i.e. 7.5% compared to the emission from burning fossil fuels. This would place Poland in the group of the 10 largest global CO_2 emitters from degraded peatlands.

This simplest model already shows that in order to limit the increase in CO_2 concentration in the atmosphere, it is important to prevent the release of carbon already accumulated in peatlands, which requires preventing their drying up and degradation. Potentially important is also maintaining or restoring their ability to capture carbon dioxide from the atmosphere, accumulate carbon in peat and thus exclude it from circulation.

Admittedly, the model presented above is a significant simplification. First of all, peatlands also emit methane and nitrous oxide, which are also greenhouse gases, and their impact on the climate is much stronger than carbon dioxide.

Photo 3. Any drainage of the bog will cause decay of the peat releasing CO_2. The function of peatlands as a carbon sinks cannot be reconciled with their forest or agricultural use that usually requires at least partial drainage. Photo by P. Pawlaczyk.

Methane emission processes are typical of natural, well hydrated peatlands and, unlike carbon dioxide emissions, are inhibited in dry and degraded peatlands. Emissions of nitrous oxide is highest from dry peatlands. Apart from the emission of gases, the degradation of the peatland as a result of dehydration also causes leaching with water the so-called dissolved organic carbon (DOC), which in the waters is largely oxidized to CO_2. The carbon balance of a specific peatland is, as a consequence, complicated.

Despite the complications in balancing carbon sequestration and emissions of different forms of carbon on peatlands, measurements and studies show that, *per saldo*, well preserved natural peatlands are still greenhouse gas absorbers and thus have a cooling effect on the climate. This means that the impact of CO_2 absorption outweighs the impact of methane emissions. On the other hand, desiccated and dry peatlands, usually as a result of human activity, become "climate bombs", i.e. significant emitters of greenhouse gases. These emitters operate on a large scale, because most peatlands are drained and degraded, and are still maintained in this state. If all peatlands in the world were effectively drained, such destruction would introduce as much greenhouse gases into the atmosphere as about 100 years of burning coal at the current rate. This would completely destroy all the chances of limiting the effects of the current climate crisis.

Worse still, there are fears that climate change alone will degrade peatlands and switch them from carbon sinks to greenhouse gases emitters. The warmer the Earth is, the warmer the peatlands are, and this increases the activity of microorganisms that decompose peat, CO_2 emissions from ecosystem respiration and methane emissions. Winter cooling of peat has so far limited the rate of peat decomposition, and in circumstances of warming the climate this process can be switched off. Repeated droughts can initiate peat decay as well as artificial desiccation. Droughts may hinder the living conditions of peat-forming vegetation, especially mosses, and accelerate the expansion of vascular plants that facilitate peat decomposition, including shrubs and trees, whose transpiration deepens drying. Finally, droughts and drying of peat can lead to more frequent fires. If the global warming in the 21st century turns out to be sudden and significant (and all points to it), then peatlands may be subject to processes that are impossible to predict today. Then, degrading peatlands, instead of cooling down the climate, may additionally contribute to its heating.

For a long time, as nature conservation actions, we have been trying to rewet some drained peatlands. Blocking the ditches draining water from the mire has already become a standard on protected areas and sometimes in forests. The effects of such activities on the ecosystem are usually better, the less degraded it is. On mires relatively recently drained, with the remains of typical vegetation still preserved, sometimes it is possible to reverse the effects of desiccation. It takes a long time for the results to be achieved on a peatlands that are deeper drained, and usually it does not mean the restoration of the original vegetation, but the formation of some other wetland ecosystems. Completely decayed peat cannot be saturated with water again.

Despite significant uncertainties, most studies lead to the conclusion that the restoration of a degraded peatland, if successful, can restore its natural role in the greenhouse gas balance, and certainly can protect from decomposition those carbon stocks that are already accumulated in peat. On this basis, it is widely advocated throughout the world that the protection and renaturalization of peatlands should also be taken into account as part of climate change mitigation measures. Such restitution of peatlands to conserve their accumulated carbon stock and restore their carbon accumulation processes is in synergy with the protection and restoration of peatlands as valuable ecosystems and biodiversity sanctuaries.

How is this measured?

There are research techniques that directly measure CO_2 absorption and CO_2, methane and nitrous oxide emissions on the mire's surface, i.e. the intensity of the emitted and absorbed gas fluxes. One of them is the so-called *eddy covariance method* analyzing changes in the concentration of individual gases depending on local air turbulence and enabling calculation of such gas fluxes on the mire surface. The second, more often used is the so-called *chamber method*, consisting in measuring the dynamics of changes in gas concentrations under the chamber laid down on the mire surface and comparing the situation of ongoing photosynthesis with the situation of simulated obscuration (such a measuring point also operates on one of the peatbogs in the Słowiński National Park, see Photo 4). Both methods give a result referring only to a specific point on the mire's surface.

Such measurements are expensive, require specialized equipment, but provide interesting results. In several places in Poland, such measurements are carried out, sometimes additionally simulating e.g. reduction of precipitation or temperature increase. From such experiments it can be concluded how the greenhouse gas balance on peatlands can change as a result of climate change.

Simplified methods of estimating carbon accumulation / emissions from peatlands have also been proposed, based on easier to study features of their structure, e.g. vegetation. It is assumed that certain types of peatland vegetation reflect a specific balance of greenhouse gases on a surface covered with such vegetation and based on the coefficients measured in a given type of vegetation at various places in the world, an estimated balance is calculated for the entire mire.

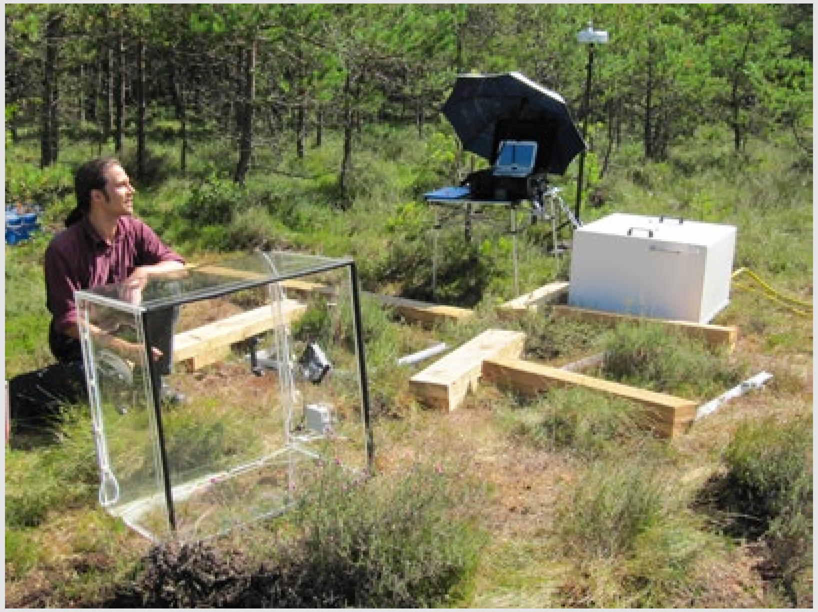

Photo 4. Measurement of greenhouse gas balance by chamber method on moss bog in the Słowiński National Park. Photo by J. and P. Pawlaczyk.

Photo 5. A technically advanced automatic greenhouse gas balance measurement station and for experiments with changing rainfall and temperature, on the Rzecińskie mire in the Notecka Forest in Greater Poland. Photo by J. and P. Pawlaczyk.

3. MIRES OF SLOVINCIAN COAST AND THE SŁOWIŃSKI NATIONAL PARK

3.1. Occurrence in the landscape

The mires of Gardno-Łebsko Lowland have already started to develop around 10,000 years ago, i.e. shortly after the continental glacier disappeared. Small fens emerging as the first, as the organic deposit grew, joined together into larger complexes. Within them, transitional mires and raised bogs began to form. The latter developed here in the form of so-called Baltic raised bogs, i.e. those whose central part forms a raised dome.

As a result of their growth, the entire area between Łebsko Lake and the moraine plain south of it, and the final stretch of the Łeba river valley became peatlands. The creation of mires in the Gardno-Łebsko Lowland was supported by a positive water balance resulting from a cool and humid climate, as well as the stagnation of surface and groundwaters due to geomorphological factors related to the creation of the Łebska Spit. Initially, after the Scandinavian glacier disappeared, the lowland area remained open from the north, which ensured free outflow to the Baltic Sea of waters flowing in from the land. However, its level and remoteness changed as a result of consecutive sea transgression and regression. Over time, at the end of the litorine period, as a result of the accumulation of marine sediments and wind activity, a barrier in the form of a sand spit gradually formed, which, rising towards the east, cut off the lagoon from the sea. Gradually further sedimentation processes contributed to the complete isolation of the formed basin, which was divided into smaller reservoirs (lakes). The spit, in the form in which it currently is, was formed around 4,000 years ago. The creation of the spit complicated the filtration conditions of the lowlands by cutting off contact of sea waters with inland waters and hindering the outflow of the latter. In this way, excellent conditions for water accumulation arose in the Gardno-Łebsko Lowland, as its inflow (together with precipitation) exceeded the losses associated with outflow and evaporation. Water stagnating in the concavities of the terrain has become a place for the formation of swamps and mires, also around gradually overgrowing coastal lakes. So the bottom of the lowland became a place of accumulation of organic sediments concentrated in several sedimentary basins.

The formation and deposition of peat in the lowland meant that it currently belongs to areas of Poland with a high rate of peat soils. According to research conducted by prof. M. Jasnowski in the 1990s, this rate amounts to 13-20%, and the best researched mires are located in the Łeba river valley and around the Łebsko lake, to which the river flows.

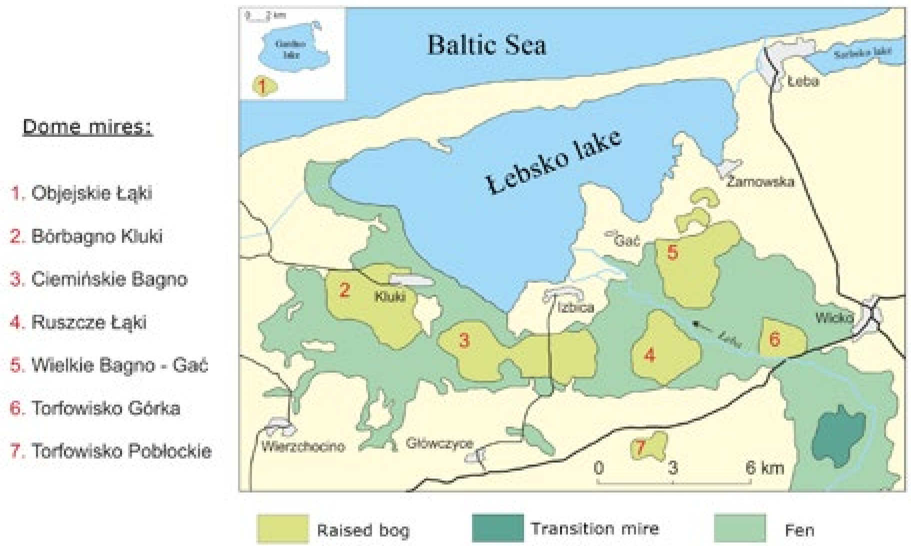

Fig. 1. Distribution of peatlands in the Łeba valley, according to M. Jasnowski (1990). The original peatland names were retained.

The natural development of mires associated with climate change and the shifting of the sea shoreline has been overlapped by anthropogenic pressure, particularly strong in the last two centuries. The peatlands of the Gardno-Łebsko Lowland, including a part of it currently located within Słowiński National Park, has been intensively drained for over 200 years. A network of canals and drainage ditches has been operating here since 1750s. Part of the area was converted into meadows and pastures, and peat has been exploited in other mires since the 19th century for heating purposes and as animal litter. Intensification of drainage on a large scale was carried out in the first decades of the 20th century. The fens were converted into meadows, pastures and arable fields. The drained surfaces of transitional mires and raised bogs were also partly afforested for wood production purposes. The expansion of trees into the originally open mires is associated not only with the planting of trees, but also their spontaneous entry into over-dried peat soils. Peat was commonly mined here. On the largest, industrial scale, this happened in the area of Wielkie Bagno, where peat mine still operates.

3.2. Former and current vegetation

Despite the transformations made, the spatial mosaic of moss (fen), transitional and raised peats on Gardno-Łebsko Lowland is still legible on maps of soil types or peat deposits. On the other hand, the vegetation underwent very strong changes and only partly retained its natural, mire-type nature.

Fens were originally created here by sedge and reed rushes, acidic moss fens, willow and bog myrtle *Myrica gale* thickets (typical only for the coastal zone) and bog alder forests (alders). Such vegetation has survived to this day only in the lakeside area of Ciemińskie Błota peat bog in Słowiński National Park. In the rest of the Lowland it was transformed into meadows, pastures and arable land. In some places, former arable land is currently under secondary succession, and regeneration of fen vegetation is regenerating in such places. Raised bogs and transitional mires were originally open woodless- or forest areas, depending on the degree of hydration. In heavily hydrated areas, they were overgrown by non-forest moss vegetation, (i.e. Sphagnum moss and low herbaceous plants and shrubs), and in areas with less hydration, pine bog forests or bog birch forests developed. The moss vegetation mainly covered central raised domes, while forest communities were found in their peripheral parts, or they also entered more strongly overdried domes.

Due to the mild coastal climate, the moss bog vegetation of the Lowland had its specific character, its distinguishing feature was, among others very numerous occurrence of cross-leaved heath *Erica tetralix* (hence the name of the community - heath moss bog). The human activity discussed earlier contributed to its high degradation. As a result of drainage and other forms of anthropogenic pressure, the area of open moss mires shrunk over time, and the area occupied by degraded bog forest increased.

Currently, the vegetation of raised bogs and transitional mires of Gardno-Łebsko Lowland is mainly of forest nature. Of the forest communities, only those located in the better hydrated areas of peatlands still retained the features of pine bog forests or birch bog forests. A significant, often surface-dominating type of forest are overdried pine, birch-pine and birch stands. As a result of planting trees (especially pine, sometimes spruce), such surfaces have an unnaturally dense stand. Young birch forests originating from self-seeding are similarly dense. In many places, bog forests have a heavily changed surface due to peat extraction. Often, trees only grow on former dikes, while the former peat-cut pits are occupied by regenerative moss vegetation or the initial forms of bog woodland and forests. Today, a large part of the bog forests originate from plantings. The introduced species were not always compatible with the habitat, sometimes even alien species, e.g. spruce, were also planted. Periodic water level fluctuations and insect gradations occurring in the last few decades have caused in many places (e.g. Kluki peat bog and Wielkie Bagno) the dying of older, planted pine or spruce stands formed in conditions of a lower and more stable water level.

The bog pine forests of Gardno-Łebsko Lowland, depending on the groundwater level, develop in various forms. Currently, typical, well-preserved patches of bog pine forest, with sphagnum-rich moss-subshrub undergrowth, as already mentioned, is not much. Its forms with the herbaceous undergrowth dominated by the purple moor-grass *Molinia caerulea* are more common. Strongly degraded pine forests are also common, with only a small share of peat vegetation in the undergrowth, and with a predominance of species typical of moist coniferous forests. It also happens that only peat substrates reveal their old, moorland nature. The trees are tall, slender; most often they originates from plantings. In places where old pines have died down, there is no natural regeneration of this species. Depending on the current hydration, such areas are transformed into non-forest or secondary forest communities. The former are either moss communities, with Sphagnum moss and cotton grass, or patches dominated by tussock-forming grass - purple moor-grass, sometimes also by tall flagellum fern - bracken *Pteridium aquilinum*. In the case of succession towards forest communities, the regeneration of birch dominates, in such places these forests acquire the character of overdried bog birch forests.

Well-hydrated bog birch forests, typical for transitional mires, in the area under discussion are characterized by undergrowth with Sphagna and a large proportion of hare's-tail cottongrass, common cottongrass and purple moor-grass. The latter often dominates in herbaceous undergrowth, especially in places slightly dried or with fluctuating water levels. On the heavily desiccated surfaces, in the undergrowth, the typical for bog forests blueberry is found in large numbers, sometimes the undergrowth is dominated by dense, low blackberries with an admixture of purple moor-grass. Such forests, like extremely dry forests, no longer have peat-forming character.

In the vicinity of bog birch forests, a birch-oak forest develops. This type of forest is commonly found especially in Kluki peat bog, where it constitute a peripheral zone around birch forests and pine forests. It is distinguished by the constant presence of oaks in the undergrowth layer and young trees. Old specimens of oaks are rare, but they are important as a source of seeds. Depending on the degree of soil moisture and fertility, the undergrowth in such forests varies: from strongly referring to bog forests (with moor-grass and mosses) to rich in herbaceous species (blackberries with a small share of mosses). This last, drier and more fertile forest variant refers to the acidic birch-oak forest (in the Pomeranian zone (but on a mineral substrate)) and is sometimes classified as such. Future humidity and climatic conditions will decide whether the oak's share in these places will prove permanent.

In Klucki Las peatland, on a very shallow peat or on moist mineral soils, another non-peat-forming type of forest is found - an oak-beech forest. It is formed by an old stand of beech and oak, with very poorly developed undergrowth. Most of the forest floor is occupied by dead beech and oak leaves.

Bog forests, despite their currently poor conservation status, play an important role in the peatlands of Gardno-Łebsko Lowland. First of all, they protect the peat deposit from further degradation and are refuges for species of plants, animals and fungi typical for such habitats. In the pine bog forest grows relict species - cloudberry *Rubus chamaemorus* and bog myrtle *Myrica gale* is seen in the pine and birch bog forests. Birds of prey nest on old trees. Conservation of bog forests in this area must primarily consist of improving their hydration. In selected places where the stand died out spontaneously, efforts should also be made to recover previous non-forest moss mire communities. The non-forest vegetation of raised bogs and transitional mires in the Gardno-Łebsko Lowland has, as already mentioned, a specific character. The raised bog moss vegetation common in Poland is replaced by the heath moss communities here. It is distinguished by the constant presence of the cross-leaved heath *Erica tetralix*, it is also the deergrass *Baeothryon caespitosum* and a few rare species of Sphagnum associated with the coastal climate in Poland. This type of bog moss vegetation has been preserved in this area mainly in over-dried and degraded form. In many places (especially in Bagna Izbickie, neighboring Słowiński National Park) it transformed into a moist heathland with cross-leaved heath and only a small share of Sphagnum mosses. Drying of such places causes that they are overgrown by trees - pines and birches. The lack of the possibility of a radical increase in the water level means that without the removal of trees, the permanent existence of treeless bog moss or heath vegetation is not possible. Due to the thick and still preserved peat deposit, such moist, cross-leaved heath heaths should still be considered as raised bogs, but already degraded. Both in Słowiński National Park and in the adjacent Bagna Izbickie nature reserve, active conservation measures are currently underway, involving the removal of trees. The predominant surface of the Lowland non-forest peatlands are areas where peat has been mined in the past. Depending on the depth of its extraction and the current water level, these are highly dry, well hydrated or even flooded surfaces. The most desiccated woodless areas (e.g. in Bagna Izbickie or Wielkie Bagno) are occupied by the heaths with cross-leaved heath discussed above and dense clumps of moor-grass. This type of vegetation no longer has peat-forming properties.

The post-peat-mining areas, which are dry in summer and wet in other seasons, are occupied by regenerative moss vegetation dominated by feathery bogmoss *Sphagnum cuspidatum*, common cotton-grass *Eriophorum latifolium* and purple moor-grass *Molinia caerulea*. Places that are well hydrated throughout the year are covered by communities formed by other species of Sphagna, cotton-grasses and subshrubs from the *Ericaceae* family. In the oldest, around 100-year-old peat-cut pits, even heath-moss communities develop in some places. It has an initial form in such places, with a small share of heath, but with a significant share of transitional mire species.

Photo 6. Degraded raised bog covered with moist heath with cross-leaved heath, in Bagna Izbickie neighboring Słowiński National Park. Photo by J. Kujawa-Pawlaczyk.

The former excavation basins, which are filled with water, are characterized by poorly developed vegetation. On the oldest of them, in Wielkie Bagno peat bog, there is floating mat of moss vegetation on the water starting to overgrow the basin from the side of the dyke. Younger, decades old, shallow and very extensive excavation basins have only a narrow strip of vegetation at the very edge. It consists of emerged shoots of sedges, cotton-grasses and Sphagna submerged or floating on the surface. Brown, acidic water in the rest of the excavation basin is not inhabited by vascular plants or bryophytes.

Preservation or restitution of non-forest moss vegetation of Gardno-Łebsko Lowland requires intensive and permanent active conservation measures. Even heavily degraded areas, e.g. with extensive peat-cut areas, are valuable from the conservation point of view as convenient habitats for rare species of plants and animals, or e.g. as a stepping stones during bird migration. For example - in Wielkie Bagno in former peat-cut pits a large population of *Drosera intermedia* appeared in recent years.

3.3. Water supply

Large peatlands complexes in Gardno-Łebsko Lowland are characterized by the fact that their central parts are of raised-bog-domes character and the marginal parts are transitional mires. Mires of this type have a specific type of hydrological supply. In the case of non-degraded raised bogs and transitional mires, the water balance is primarily shaped by the atmospheric phase of the water cycle through precipitation and evaporation. In addition, the essence of their proper functioning is the limited or complete lack of outflow. Drainage of peatlands carried out in the 19th and 20th centuries resulted in a complete change in the conditions of supply and drainage of these sites, expanding the water balance with new elements. These include, on the one hand, water supply carried out additionally by the inflow of water from the outside, and on the other - more important and destructive for the persistence of peatlands - escape (outflow) of water outside the given site. At the same time, the proportions between rainfall and evaporation were disturbed, as the losses due to evaporation increased resulted from open water surfaces in canals and drainage ditches as well as post-mining excavations.

Despite the fact that since the establishment of Słowiński National Park, the drainage network has not been maintained and some ditches have overgrown, some of them still drain surplus water beyond the boundaries of the sites, deteriorating their water balance. Their location in the surface drainage system, and therefore in the vicinity of Łeba river, Pustynka and Łebsko Lake, is of great importance in shaping the retention of large peatlands in the Park. Their influence is particularly affected by those fragments that are connected with rivers and the lake by drainage ditches. In the Park there are (apart from the above-mentioned complexes) several smaller raised bogs, occupying outflowless depressions between mineral elevations. These small sites are relatively well preserved and currently occupied by moss vegetation. Their condition indicates a favorable water balance for their functioning.

4. PEATLANDS WITHIN LIFE PEATRESTORE PROJECT

Three mires in Gardno-Łebsko Lowland, located in Słowiński National Park, have become pilot sites on which - in full synergy with nature conservation - we are trying to stop peat degradation processes and related greenhouse gas emissions, and ultimately also at least partially restore the peat-forming process, i.e. CO_2 absorption. It is part of the international project "Reduction of CO_2 emissions by restoring degraded peatlands in Northern European Lowland", whose aim is demonstrative, pilot restoration of several peatlands in five Baltic countries (Germany, Poland, Lithuania, Latvia, Estonia). The Nature and Biodiversity Conservation Union (NABU) from Germany is the coordinator of activities planned for 2016-2021. The ecological NGO Klub Przyrodników is responsible for the implementation of the Polish part of the project, cooperating in this respect with Słowiński National Park - land manager of peatlands in question. The main funding body is the EU LIFE financial instrument under its climate subprogramme; hence the project is referred to as the LIFE PeatRestore project. Activities in each of beneficiary countries are additionally co-financed from other sources - the Polish part is co-funded by Regional Fund for Environmental Protection and Water Management in Gdańsk and the Baltic Sea Conservation Foundation in Greifswald.

The project is carried out on peat bogs (Fig. 2): Kluki (also known as Bórbagno Kluki), Ciemińskie Błota (also known as Ciemińskie Bagna) and Wielkie Bagno (also known as Wielkie Bagno-Gać, Żarnowska or Krakulice; cf. Fig. 1). The first stage of the project was to identify the water conditions and current vegetation of these peat bogs. As part of hydrological monitoring, 80 measuring points have been established, where since 2017 water levels have been recorded daily. Once a quarter, hydrologists map backwaters and water flows with all ditches. Such observations show what are the main current directions of drainage of these peatlands. At the same time, a description and maps of current vegetation were made. Further on, we will present a detailed description of these sites, which are the effect of these studies. The implemented and planned conservation measures, the need for which has been identified, are the subject of chapter 5.

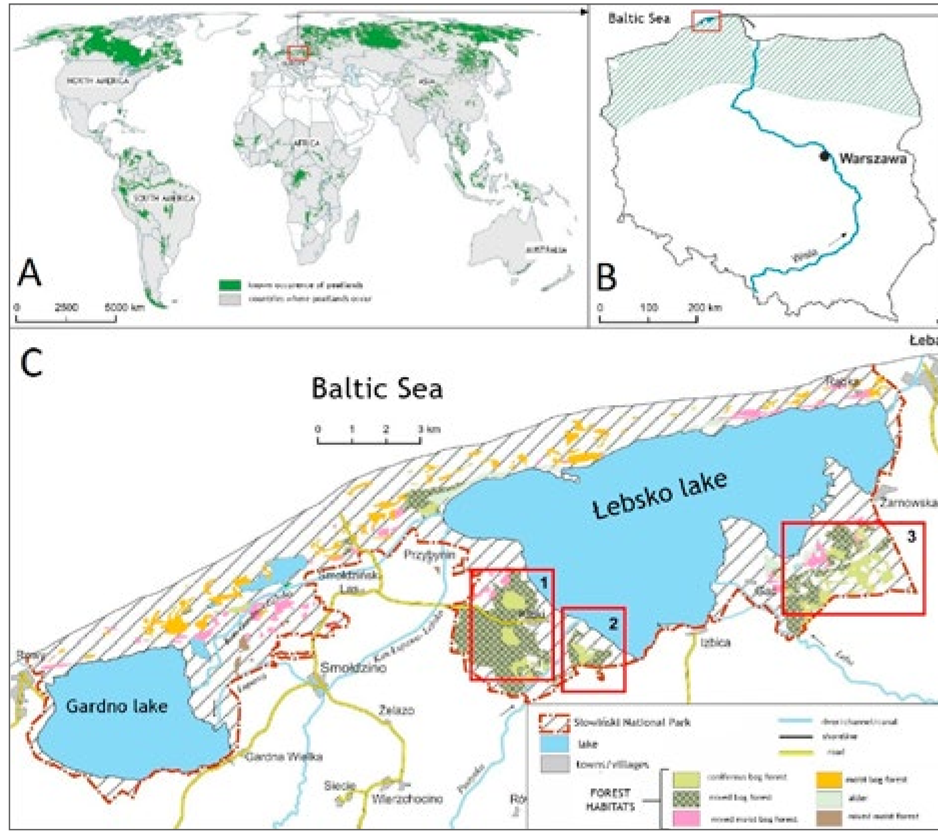

Fig. 2. A: Occurrence of peatlands in the world. B: Zone of the highest peatlands concentration in Poland. C: Peatlands covered by the LIFE PeatRestore project against the background of Słowiński's National Park borders. 1 - Kluki, 2 - Ciemińskie Błota, 3 - Wielkie Bagno.

4.1. Kluki peat bog

4.1.1. Location, stratigraphy, history

Kluki peat bog (Bórbagno Kluki) is located on the southwestern shore of lake Łebsko, west of the village of Kluki. It covers an area of about 900 ha. The peat bog consists of two sedimentary basins separated by a dune belt, differentiated in terms of age and thickness. The history of the southern part of the bog dates back to around 10,000 years ago, and the peat deposit is thicker and reaches up to 8.5 m. The layer of raised peat covers about 1.3 m. The northern part of the peat bog is younger (about 6,000 years) and shallower (thickness up to 2.5 m and in some places 0.4 m). Within the entire complex, the processes of desiccation and decay are strongly marked. In the eastern and southern parts peat was cut off and part of its eastern margins were used for agriculture.

4.1.2. Water conditions

The Kluki peat bog area is characterized by a dense network of canals and drainage ditches. The peat bog's water conditions are shaped by Łebsko lake, which is closely located and constitutes the main drainage base, and is drained by Pustynka river (Klukówka) flowing along the eastern border of the peat bog. The artificial hydrographic network is represented by a dense network of ditches and drainage canals, whose development peak occurred at the turn of the 19th and 20th centuries. The largest facilities of this type include Gardno-Łebsko Canal and Łupawa-Łebsko Canal, running north of the bog. Both canals were created to lower the water level in the lakes located in Gardno-Łebsko Lowland (Gardno and Łebsko lakes). The main channel that passes through the central part of the bog and causes its strong drainage is the so-called Canal C9. In addition, it is drained through a girdling ditch in the north-eastern part of the peat bog, which drains water directly to Łebsko lake. Water outflow from the peat bog through the C9 Canal is over 84%, and through the girdling ditch about 16% of all surface waters. This is because, near Kluki bog, there is a polder with an area of 184 ha, which drains water to Łebsko lake, collecting them among others from Canal C9. Therefore, it is responsible for the catastrophic water conditions of the peat bog itself and in the peat bog vicinity. The size and extent of the C9 Canal drainage is affected by its parameters: depth, which ranges from 2.5 to 3.0 m, and a width reaching in some places up to 6-8 meters. The banks of the canal are steep, practically vertical, and the water level stabilizes at a depth of 2.5 m below the bog surface. This value also reflects the depth of drainage of the peat deposit and the water deficit in the neighborhood. This canal though may periodically also play a supplying role. This is due to the fact that it originates far beyond the borders of the site, in agricultural areas, and flows through the peat bog. However, the waters it supplies have a different chemical composition and properties than those attributed to raised bog waters.

Kluki peat bog retention is characterized by high seasonal variation, which results from unequal hydrometeorological conditions throughout the year. This is well illustrated by the variability of water levels observed in different months. The highest retention is recorded after spring thaws, and then in autumn, after heavy rainfall. In the spring, the hydrographic network is expanded, and many areas in the peat bog are flooded with water (groundwater stagnates on the surface of the peat bog). Alternately, during the summer, due to high air temperatures and increased evaporation, and water intake for vegetation, there is a water deficit in the peat bog. At this time, there are few active drainage ditches and canals, most are dry, as is the bog dome.

Water outflow from the bog is conditioned by the scale of atmospheric supply. Even in summer (with low retention) during and immediately after heavy rainfall there is possible a short-term low-intensity drain. It mainly results from difficult infiltration conditions. The drain stops when the rain stops. The outflow increases with increasing retention in the autumn and winter. Research carried out in 2017-2018 indicates that the volume of monthly outflow from the peat

Photo 7. Drainage depth of the C9 Canal at Kluki peat bog. Photo by I. Chlost.

bog ranges from nearly 38,000 m^3 in summer to 572,000 m^3 in autumn. This affects the water level fluctuations in the peat deposit. The range of variability on the bog's dome is about 100 cm (from 0 cm a.g.l to -100 cm b.g.l), while in the bog's margins about 120 cm (from +20 to -98 cm b.g.l). Łebsko lake also influences the groundwater level fluctuations in the bog, which manifests itself in the relationship between the groundwater level of the points closest to the lake, and fluctuations in water levels in the lake itself (Fig. 3). In the western part of the bog the ditches were blocked by beavers in several places. Although such overflooding may impedes the tourist trail availability, it is a blessing for the bog.

Fig. 3. The course of the change in water levels in the Łebsko lake and selected point on Kluki peat bog.

4.1.3. Vegetation

Kluki peat bog is dominated by bog forests with different conservation status, there are almost no raised moss bogs (Fig. 4). Due to the centuries-old history and scale of drainage conducted here, at the time of Słowiński National Park establishment, i.e. in the 1960s, the forestless, moss bog nature had only the central part of the northern raised bog dome and small fragments in the area of the southern dome (but in this area peat has been cut-off in the past). Since then, the surface of the moss bog part on the peat bog has diminished even more because the open moss bog vegetation on the northern dome have completely disappeared: today its entire peak is overgrown by low bog coniferous forest. The enclave of moss bog in the southern part are kept in a forestless state thanks to active conservation measures. The first such measures were taken by Słowiński National Park about 10 years ago. They had good results: they allowed to preserve the above-mentioned enclaves of the moss bog vegetation, in addition, it was possible to restore the heath moss vegetation on low dikes in one of the former peat-cut-off areas. As part of the LIFE PeatRestore project, such activities have been undertaken in the following areas.

The bog forests of Kluki peat bog vary and their character has changed quite significantly over the past 50 years. In the central, highest part of the northern basin of the peat bog, the bog forest replaced moss bog. Patches of typical bog forest are also found in some of the former peat-cut-off areas in the southern part of the bog. On the other hand, the form of bog coniferous forest with the dominance of the purple moor grass in Kluki bog is more common, as well as its even more degraded form, with a negligible share of bog-type species in the undergrowth, and the dominance of species typical of moist coniferous forest. In bog forests on all three raised bog domes of Kluki peat bog cloudberry *Rubus chamaemorus* occurs. It grows dispersed in the vicinity of the northern and central dome, on the southern dome has only single stands.

Occurring in the 1980s, insect gradations and water level fluctuations meant that some of the old pine stands, as well as spruce plantings, began to die off enormously. This took place mainly in the northern and central part of the peat bog dome. The new generation of trees that appeared in their place consists mainly of birch, sometimes with an admixture of oak. As a result, these surfaces became similar to the surrounding domes of birch bog forests and birch-oak forests. In some places, after the fall of the old stand, the gaps retain a forestless nature and are overgrown by patches of purple moor grass or bracken.

Birch bog forest patches have a diverse undergrowth, which is related to the degree of their hydration. A common species among them is the purple moor grass. In wet places there are numerous Sphagnum species and both species of cotton grass. In desiccated places, the share of bryophytes is negligible, while many blueberries appear. On dry and decayed peat, blackberry with an admixture of moor grass and abundant herbaceous plants abound in the undergrowth. In drier areas, birch-oak forest develops on decayed peat. The undergrowth in such a forest, in the least hydrated and relatively fertile places, is relatively rich in species, often with a large proportion of blackberries. On the other hand, in moist and less fertile places in the undergrowth, the purple moor grass dominates. In the vicinity of the birch-oak forest, in the northern part of the complex, there are small patches of the beech-oak forest with very scanty undergrowth, growing in shallow young stages of bog-type vegetation on peat.

- A public and marked tourist trail ‘Klucki Las’, about 5 km long, leads through the northern part of Kluki peat bog. It starts at the road to Kluki, just before entering the village. Initially, it goes through degraded forests on peat, leading to the bog coniferous forest on the northern dome of the peat bog and cloudberry stands. Further on, it leads near the shore of Łebsko lake, next to the observation tower, along the edge of alders and dry birch bog forests, to the old beech and oak forest “Klukowe Buki”, and then along the western edge of the forest to the road near Łokciowe (town). In the wet periods of the year, the path can be muddy, although there are wooden footbridges in the wettest places.

- On the eastern edge of the peat bog there is a yellow-marked tourist trail (open to pedestrians and bicycles) from Kluki to the Pustynka river and further to Izbica. One cannot see the most characteristic elements of the peat bog vegetation, but you can see the landscape of bog forests and shrubberies, and beaver dams. In wet periods of the year, the trail is muddy and hard to access. Wooden footbridges, made by the Naturalists’ Club in consultation with Smołdzino Municipality, were laid down through the most wet places as part of the LIFE PeatRestore project.

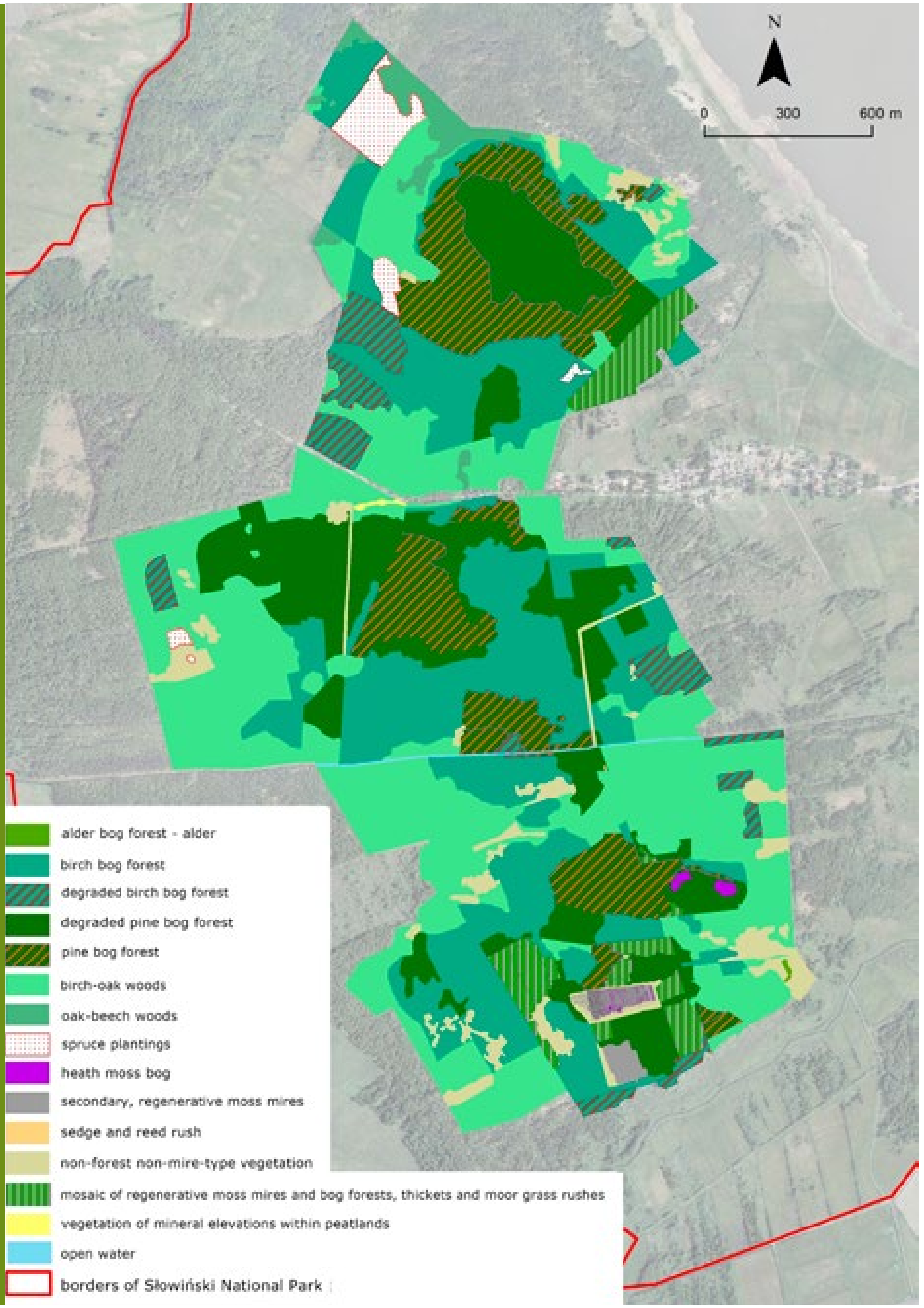

Fig. 4. Current vegetation map of this part of Kluki peat bog included in the project.

Photo 8. Pine bog forest on Kluki peat bog. Photo by K. Bociąg.

Photo 9. Young birch forest on Kluki peat bog replaced the old, died off pine stand. Photo by K. Bociąg.

Photo 10. Birch bog forest with a moor grass in undergrowth. Photo by K. Bociąg.

Photo 11. Degraded birch bog forest with undergrowth dominated by blackberries (Kluki). Photo by K. Bociąg.

Photo 12. Degraded form of pine bog forest. Photo by K. Bociąg.

Photo 13. Birch-oak forest on the margins of Kluki peat bog. Photo by K. Bociąg.

Photo 14. Beech and oak forest "Klukowe Buki" on moist mineral soils on the margins of the complex. Photo by P. Pawlaczyk.

4.2. Ciemińskie Błota peat bog

4.2.1. Location, stratigraphy, history

Ciemińskie Błota (Ciemińskie Bagna) peat bog is the northern part of the extensive raised bog complex located south of Łebsko lake, covering a total area of approx. 1,200 ha. It is located between Pustynka river in the west and the gridling ditch in the east. The most elevated, southwestern part of the complex is protected as Izbickie Bagna nature reserve, but this part is outside the borders of Słowiński National Park. A fragment of the peat bog belonging to the Park, with an area of about 180 ha, is separated from the reserve with a section of the bicycle path connecting Izbica and Kluki. The peat deposit in the entire complex is characterized by considerable thickness and ranges from 4.8 m to 9.0 m, while the layer of raised peat reaches about 0.5-1.0 m.

4.2.2. Water conditions

Ciemińskie Błota is characterized by an extensive network of ditches and drainage channels, which are concentrated in the western and south-eastern parts of the site. The axis of the drainage system is a transit channel meridional to Łebsko lake, which cuts the peat bog into the western part - the more hydrated and the eastern part - with worse humidity parameters. Smaller canals and ditches flow into the channel, and among them the most important drainage role is played by the parallel channel in the central part of the site. Here, there is also a division due to different water conditions, because north of the canal (towards the lake), the peat bog is almost permanently waterlogged (except in extremely dry periods), while south of the canal the retention varies.

Ciemińskie Błota shows the best water conditions among the studied peat bogs of Słowiński National Park. As in the previously described sites, water resources are subject to seasonal changes, from surpluses of water in winter and spring (thaws) and autumn (rainfall), with stagnant water on the ground surface, to summer deficits, when a reduced hydrographic network is observed as a result of ditch drying and lowering the level of groundwater (Fig. 5). The ditches and canals existing within the site are largely overgrown and obstructed. This also applies to the transit channel, which currently no longer flows directly into Łebsko lake. A measurable outflow from the bog starts only during a high retention period in the cold season and takes place not through the entire cross-section, but only the upper part of the ditch or channel, creating a shallow surface stream. This causes that in winter, during freezing temperatures, a thin layer of water freezes easily forming ice. Then the water outflow is stopped. When there is a high level of retention on the peat bog and there are no ice, overflow of water through the road located on a dyke separating from the south Ciemińskie Błota with Bagna Izbickie is observed. The overflow occurs in the form of numerous, chaotic streams. The monthly volume of outflow from the bog is estimated from 17,000 m^3 to nearly 182,000 m^3 of water - on the basis of measurements carried out. The inflow periodically initiated by the transit channel or streams supplying the peat

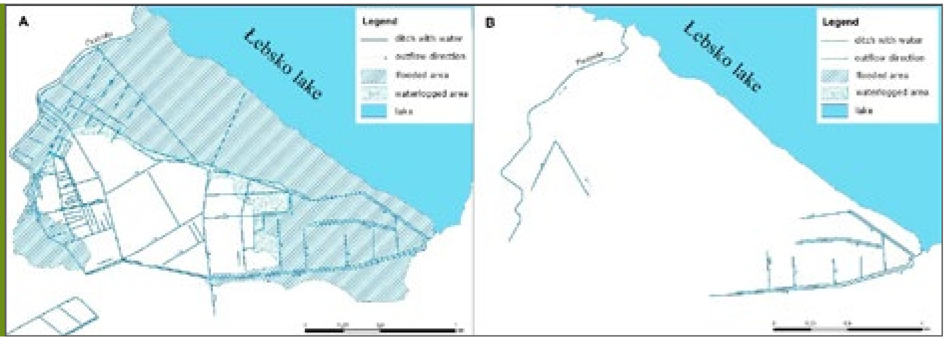

Fig. 5. State of retention of Ciemińskie Błota in 2018: A - in spring (March) and B - in summer (August).

bog from the side of Bagna Izbickie is lower and ranges from nearly 4,000 m³. of water to approximately 53,000 m³.

In the south-eastern part of the site, along the aforementioned road, retention is supported by beaver activity. In the northern part, good water conditions are associated with the vicinity of the lake. On the other hand, the grindling ditches constituting the eastern border of the bog play the key draining role.

Photo 15. Water outflow from Ciemińskie Błota during the high retention period (in autumn): water overflowing from a gridling ditch. Figure and photo by I. Chlost.

Changes in the groundwater level in the peat deposit are diversified. Fluctuation amplitudes are smaller in the central, dome part of the peat bog, and slightly higher in the lagg zone. However, they do not exceed 100 cm, reaching a maximum of about 90 cm. On the dome, water appears on the ground in the cold season and stagnates for six to seven months. In some zones on the bog perimeter, groundwater behaves in a similar way, however, it reacts more dynamically to atmospheric conditions (precipitation, temperature). Current observations (2017-2018) show that minimum water levels were recorded, as in other sites, in September 2018.

The water level recordings in the transit channel are characterized by high stability of fluctuations. The range of variation reaches only 15 cm both at the entrance to and exit from the channel. Only in summer does the water level drop, causing the amplitude of fluctuations to increase to approx. 40 cm.

4.2.3. Vegetation

The vegetation of Ciemińskie Błota (within the scope of the LIFE project) shows a specific zonation resulting from the location near the lake. Its northern part, from the side of Łebsko lake, is of fen character and is well hydrated. Shrubberies, alder bog forests (fertile alders) and small patches of reed dominate here (Fig. 6). In addition to typical, well-developed alders with mature stands, their initial stages consisting of low, young trees with a large share of willows. This demonstrates the high dynamics of vegetation in this region and the ongoing succession. Scrub vegetation consists of willow and alder-willow thickets. The participation of young birches and bog myrtle *Myrica gale* is frequent. The latter species sometimes forms compact single-species shrubberies. They are distinguished as a bog myrtle shrub community specific for the coastal zone. These shrubberies are the botanically most valuable component of the fen vegetation of this site.

The southern part of the bog is much less fertile. The vegetation here is of transitional mire and raised bog nature. The first type is represented mainly by birch bog forests and regenerative vegetation in peat cut-off areas, while the second type is represented by bog pine forests and heath moss bog. Birch bog forests are located in peripheral parts, while the central part of the peat bog is occupied by bog pine forest and moss bog. The stand in the bog forests of Ciemińskie Błota is younger than on Kluki peat bog, and their conservation status is diversified. There are few well-preserved and typically developed birch forests or pine bog forests. Overdried patches with a scarce share of bog-type species in the undergrowth predominate. Many patches have a young, compact stand, which additionally inhibits the presence of bog-type species that are photophilic. The plant that often dominates in the undergrowth is the purple moor grass. On the peripheral zones there are also fragments of a birch forest with undergrowth dominated by blackberries. In their vicinity, small patches of birch-oak forest are also found. In contrast to Kluki bog, in Ciemińskie Błota this type of forest is rare and occupies a neglectable surface.

Well-developed bog forests occupy a small area in Ciemińskie Błota and are adjacent to the open moss bog. Much more frequent here are overdried forests with a young, compact stand, where the bog-type undergrowth is poorly developed or dominated by moor grass. A significant area is occupied by degraded bog forests, whose undergrowth is extremely poor and free of bog-type species. Despite the poor condition, bog forests in this part of the Park are an important refuge for the relict species, cloudberry *Rubus chamaemorus*. A unique fern was also found here - the royal fern *Osmunda regalis*. Open moss bog on the site in the form of well-hydrated, young stages of moss bog communities in the central part and in the form of small desiccated enclaves surrounded by degraded bog forest. The succession of trees is observed in all patches, which is why within the framework of LIFE PeatRestore active conservation measures - removing trees - are repeated and previously have already been performed by the national park.

The peat bog is a biotope of the unique butterfly, common ringlet *Coenonympha tullia*. In comparison with Kluki peat bog or Wielkie Bagno, Ciemińskie Błota has been much less exploited in the past. There are only small peat-cut-off pits, traces of manual peat digging. Regenerative vegetation has, depending on their location on the peat bog, the nature of an oligo- or mesotrophic moss bog.

Located outside the Park, the southern part of the peat bog lies within the boundaries of the Izbickie Bagna nature reserve, is strongly desiccated and vegetation is highly degraded, however, extensive open heath has been preserved here with cross-leaved heath and still with some participation of Sphagnum mosses.

- Through Ciemińskie Błota, more or less along the border between Słowiński National Park and Bagna Izbickie nature reserve, runs the yellow-marked touristic trail from Izbica to the bridge on Pustynka river and further to Kluki. From the trail you can see bog pine and birch forests, and in the western part also reeds and ditches dammed by beavers, while no open moss bog can be seen. Along the trail you can see a few bushes of bog myrtle *Myrica gale* and royal fern *Osmunda regalis*. In the wet periods of the year the trail is muddy and sometimes very difficult to access. Wooden footbridges were laid down through the most waterlogged places.

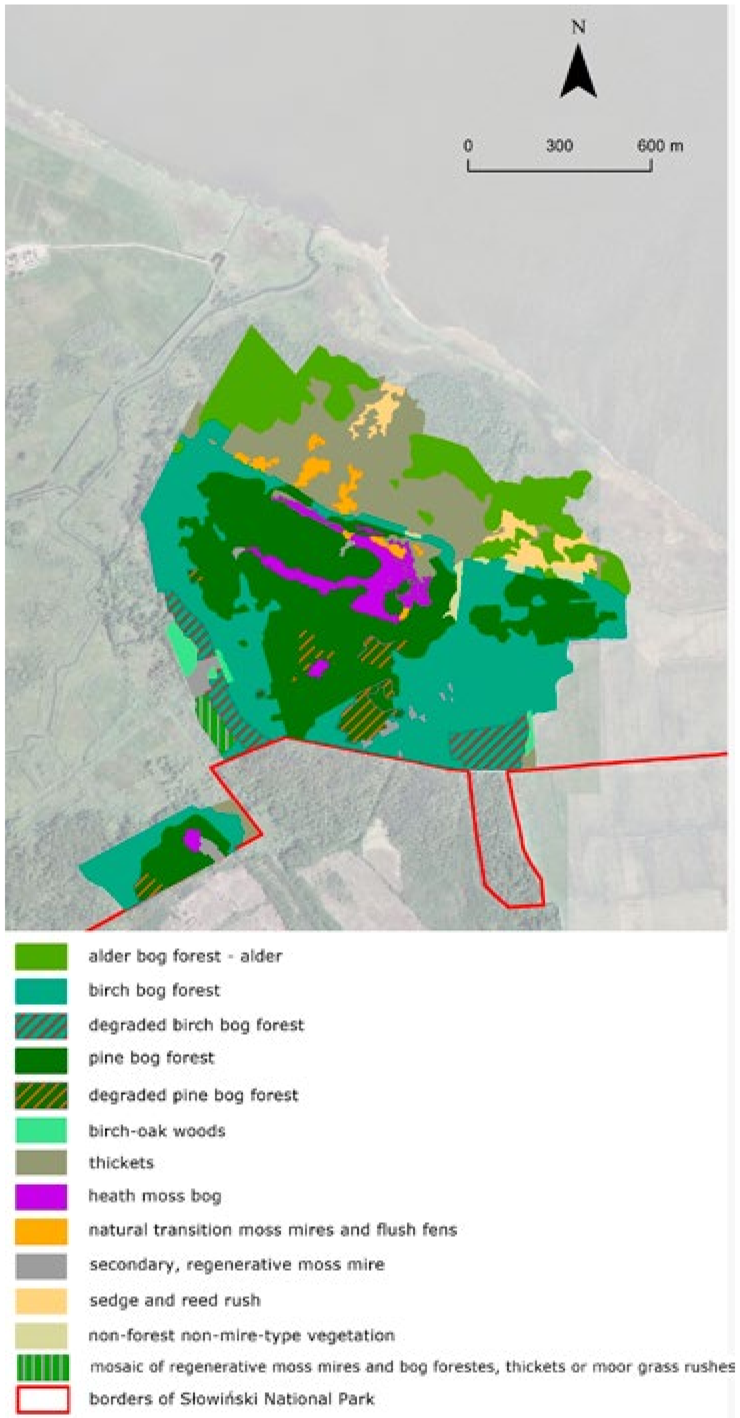

Fig. 6. Map of vegetation in the Ciemińskie Błota within the site covered by the LIFE project.

Photo 16. Cross-leaved heath Erica tetralix.
Photo by K. Bociąg.

Photo 17. Bog myrtle Myrica gale.
Photo. K. Bociąg.

Photo 19. Heath moss bog community with bog myrtle in Ciemińskie Błota.
Photo by K. Bociąg.

Photo 18. Cloudberry Rubus chamaemorus. Photo by P. Pawlaczyk.

Photo 20. Alder in the northern part of Ciemińskie Błota. Photo by K. Bociąg.

4.3. Wielkie Bagno peat bog

4.3.1. Location, stratigraphy, history

Wielkie Bagno (also called Żarnowska, Krakulice, Wielkie Bagno-Gać) is a peatland located between the mouth section of the Łeba river in the west, the southern shore of lake Łebsko in the north and the Żarnowski Canal in the east. The southern border of the site constitutes the bend of the Łeba river, while the northern boundary is in fact the inland dunes along the Gać-Żarnowska dirt road. The entire complex covers a total of approx. 1600 ha, of which less than 40% (630 ha) is within Słowiński National Park The thickness of the peat deposit varies and ranges from 0.5 to 8.0 m. The layer of raised peat (in regions that have not been exploited) is estimated at about 1.0 m. The western part of the site is occupied by former excavations after peat exploitation, in which the organic layer of the raised bog was cut-off to a depth of 1 to 2.0 meters. The peat bog is cut through a dense network of drainage ditches. This peat bog has long been exploited. Large-scale peat mining began in the northern part, where there are extensive old peat-cut-off basins. On the west side, after cutting off the top layer of peat, it was used by local people as arable land, later abandoned and overgrown with forest. In the post-war period, the industrial exploitation of peat in the central part of the peat bog was moving from east towards west. At the end of the 20th century, abandoned areas after exploitation were incorporated within the national park borders. However, peat extraction was started south of Słowiński National Park's borders. Since the 1970s, peat extraction by milling method (iteratively cutting off the surface layer of peat) has been carried out in the southern part of the bog. In 2004 and 2009, the areas after this exploitation were gradually handed over to the national park. They were largely occupied by shallow, but extensive water basins created in the excavations. Currently, the last areas are legally (under concession) exploited. Peat is transported by narrow-gauge industrial railway to the processing plant in Krakulice east of the site. The exploitation is to be completed in 2026.

Areas subjected to drainage and exploitation show varying levels of hydration. Within the unexploited parts of the peat bogs, the processes of decay are strongly marked as a result of their desiccation. Retention of post-mining areas is diversified, some of them are also desiccated, and some are water reservoirs. During the autumn gatherings, thousands of crane flocks gather on the Wielkie Bagno, and during the autumn migration flocks of plovers, ducks and swans are also observed. Unique species of butterflies, such as the cranberry blue *Plebejus optilete* and the common ringlet *Coenonympha tullia*, were also found.

Photo 21. Peat exploitation in the southern part of Wielkie Bagno, outside the national park borders. Photo by J. and P. Pawlaczyk.

Photo 22. Industrial narrow gauge railway of the peat mine at Wielkie Bagno, on the border of the national park. Photo by J. and P. Pawlaczyk.

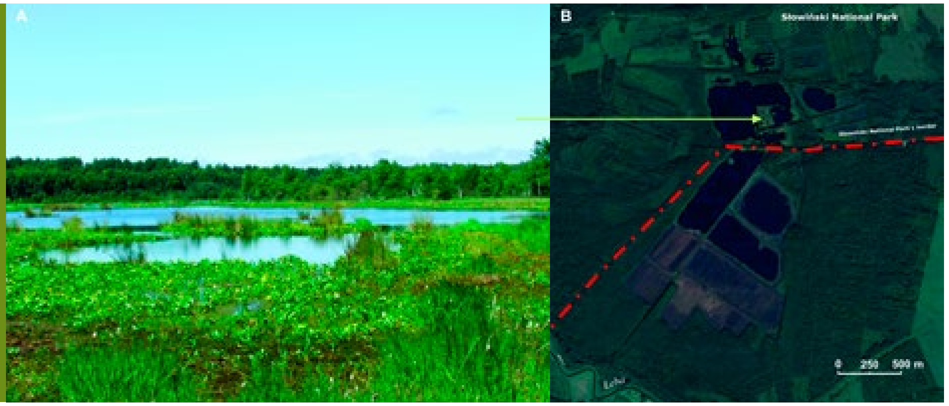

Fig. 7. Excavations after peat exploitation: A - old, overgrowing (Photo by I. Chlost), B - present.

4.3.2. Water conditions

The network of the drainage ditch of Wielkie Bagno is constructed in such a way that water drainage takes place in all directions. Water flows out of the site south towards the Łeba river, then west to Gać pumping station serving the polder of same name, further north through an underground pipe draining water to Łebsko lake and finally to the east, where the drainage base is Żarnowski Canal. The network of ditches inside the site is characterized by varying degrees of patency. As a rule, these are partially overgrown ditches, with variable throughput, depending on the season and weather conditions. Transit and grindling ditches show better patency. The location of Wielkie Bagno in the duneland causes that, apart from hydrometeorological factors, the shape of the peat is determined by the terrain. The presence of surfaces with cut-off peat or turf removed is also of great importance, as well as the places where as a result of drainage the deposit has settled and the aforementioned ditch patency. The highest state of retention

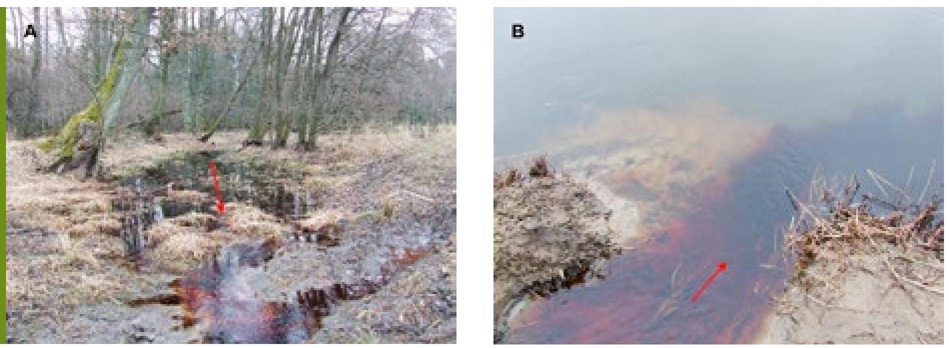

Photo 23. Water outflow from Wielkie Bagno: A - towards Łeba river, B - contrast between peat bog waters and river waters. Figures and photos by I. Chlost.

in Wielkie Bagno is observed during periods of high rainfall and low evaporation, i.e. at the beginning of winter and after spring thaws. During this time, the hydrographic network is expanded, and many areas in the peat bog flooded with water. In other seasons, water saturation shrinks due to high temperatures and evaporation. Then, only in a few canals and ditches water is observed, and in peat-cut-off pits the water level clearly drops. In extreme cases, there is a lack of water in Żarnowski Canal, and surfaces devoid of vegetation are cracked.

The state of retention is responsible for the level of water outflow from the peat bog beyond its borders. The outflow volume varies extremely seasonally and ranges from 625 m^3 of water in the dry months of the year to nearly 613,000 m^3 in the wet ones.

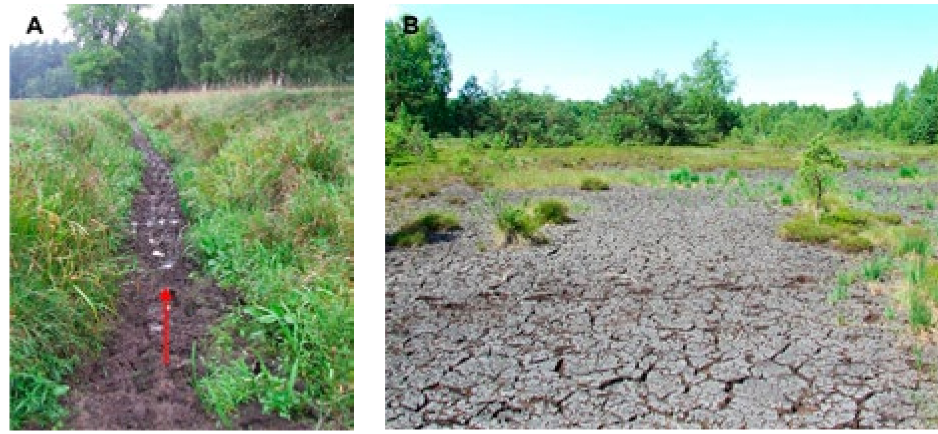

Photo 24. Drought in Wielkie Bagno in the summer of 2018: A - the drying Żarnowski Canal, B - dry and cracked surface on post-mined areas. Photo and figure by I. Chlost.

The bog's water conditions are shaped by precipitation, especially its intensity and distribution over time. It affects the range of water level fluctuations in the peat deposit, which varies depending on the location within the site. Much higher fluctuation amplitudes are noted in the dome part, as well as near drainage ditches (Fig. 8). They can reach over 100 cm in relation to the ground surface, which is very unfavourable for maintaining the proper course of peat-forming processes. A slightly smaller range of groundwater level variability occurs in the lagg part, where it reaches 85 cm. Changes in retention scale are also well illustrated by water level measurements performed on water bodies. All of them show the same variability, but with different amplitude, related to the surface of the body and location relative to drainage ditches. As a rule, however, the range of fluctuations is smaller than that recorded directly in the peat deposit.

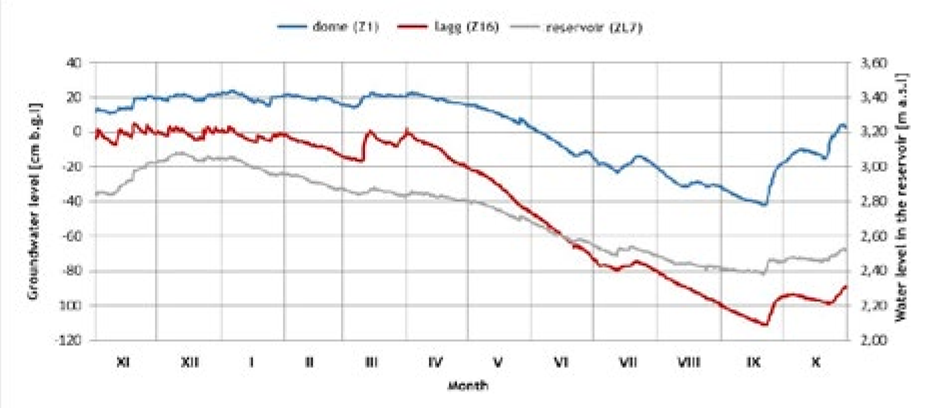

Fig. 8. Ground water level variability in the hydrological year 2018 at selected points on Wielkie Bagno.

4.3.3. Vegetation

Current vegetation of Wielkie Bagno peat bog is the result of very strong antropopression associated with drainage, afforestation and exploitation of peat on an industrial scale. Peat extraction resulted in destruction of moss bog vegetation and bog pine forests. Each time before exploitation of individual patches, as part of preparations, trees were removed, followed by the top peat layer removal along with vegetation. As a result, only a small intact fragment of former peat bog dome remained, where the peat was only 1-1.5 m thick and it was not profitable to exploit it. Today it is the most valuable, large patch of heath moss bog. As a result of peat extraction in neighbouring areas and active ditches, it is now strongly desiccated and requires active conservation measures - removing tree sprouts and improving water conditions. To the north of it there are extensive, about a century-old peat-cut-off basins, where the regeneration of moss vegetation led to the formation of young, initial stages of heath moss bog communities. The heath moss bog is still present in Wielkie Bagno in the form of several small patches. In several places, where in the last few decades this community began to transform into a young bog forest, active conservation measures were undertaken as part of the LIFE PeatRestore project - trees were removed to stop the expansion of pine. In the north-west part of the bog, behind a small dune bind, an enclave of non-forest raised bog and transitional mire vegetation with a natural, primaveral character has been preserved, with a small dystrophic lake in the central part.

The heath moss bog patch is the most valuable in terms of nature conservation element of Wielkie Bagno. In addition to the bog myrtle *Myrica gale*, it also has single tussocks of deergrass *Baeothryon cespitosum*. Younger areas after industrial exploitation in the northern part of the bog are covered by various types of regenerative moss vegetation. In the first stages of succession on such surfaces, the toothed sphagnum moss plays a key role. This moss prefers wet places, but also tolerates a fluctuations of the water table, what makes it relatively resistant on periodically dry and flooded decayed peat. Therefore, it is the main component of the moss layer of regenerative communities. With relatively stable and good water conditions, these communities have a well-developed moss layer. The herbaceous layer is dominated by both species of cotton grass, moor grass, and white beak-sedge are also numerous. Very valuable and rare species are also found here: bog-sedge, long-leaved sundew or oblong-leaved sundew. On the most desiccated parts of the post-mining surface, the vegetation no longer has a moss bog character. It consists of communities with heather or patches of moor grass. There are also the surfaces of bare, strongly decayed peat, which is not inhabited by plants.

In the central and southern parts of the bog there are extensive, shallow peat-cut-off pits filled with acidic water, brown coloured by large amounts of humic compounds. There are only algae in the water, while bryophytes and vascular plants are found only at the edges. In one of these basins, where peat was cut-off down to a mineral substrate, a regenerative communities are formed on the edges, consists of only the common rush and the toothed sphagnum moss. At the edge, on moist, decayed peat, initial communities with few mosses and a large proportion of *Juncus bulbosus* are also found. As part of the LIFE project, on flooded, the youngest post-mining reservoir near the peat mine, outside the SPN, an experimental action was planned to accelerate the regeneration of peat-forming vegetation. The work out of an effective methods of restoration of extensive excavation basins is important because in a few years there will be a need for restoration of the last, currently mined part of the peatland.

The forest vegetation of Wielkie Bagno has a form of bog pine and birch forests, similar to those described on the previous two peat bogs. Just like there, their condition is also diverse here. Well-hydrated bog pine forests are generally found only in the vicinity of open moss bog. Degraded forests dominate as a result of peat desiccation. Over a vast area, the desiccation of peat is so deep-reaching that characteristic bog-type species are absent in the undergrowth. Such forests have lost their original peat-forming properties. In the northern part of the peat bog, dying off of an old, planted stand has been observed in the last several years. Such places, depending on the current water level, have the character of regenerative raised bog communities with the predominance of cotton grass and sphagnum moss or young birch thickets with the undergrowth usually dominated by the moor grass.

- Improvement of the conservation status of Wielkie Bagno bog forests requires better hydration, which is associated with limiting their drainage through a network of old ditches. Such actions - constructing a network of wooden or peat dams on ditches - are part of the LIFE PeatRestore project. A forest route runs from Gać to Żarnowska near the northern edge of Wielkie Bagno, along which there is also a yellow-marked hiking and cycling trail. From the road you can see bog forests on the northern edge of the bog, including dying off stands and regenerating bog-type vegetation. One of the picturesque, overgrowing peat-cut-off pits is accessible for tourists via wooden footbridge and a floating bridge.
- In September and October cranes fly to the peat-cut-off pits in Wielkie Bagno for the night. You can't go to the places where they spend the night because it would frighten the birds away. From places outside the national park you can, however, in the evening or in the morning watch the strings of cranes flying to or leaving the site.

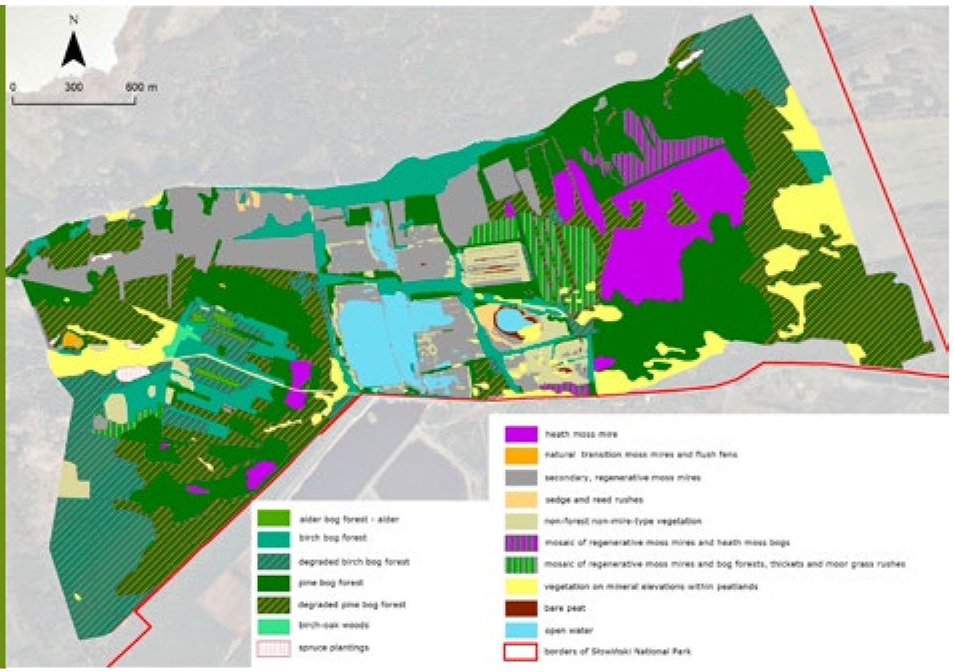

Fig. 9. Map of vegetation of Wielkie Bagno within the borders covered by the project.

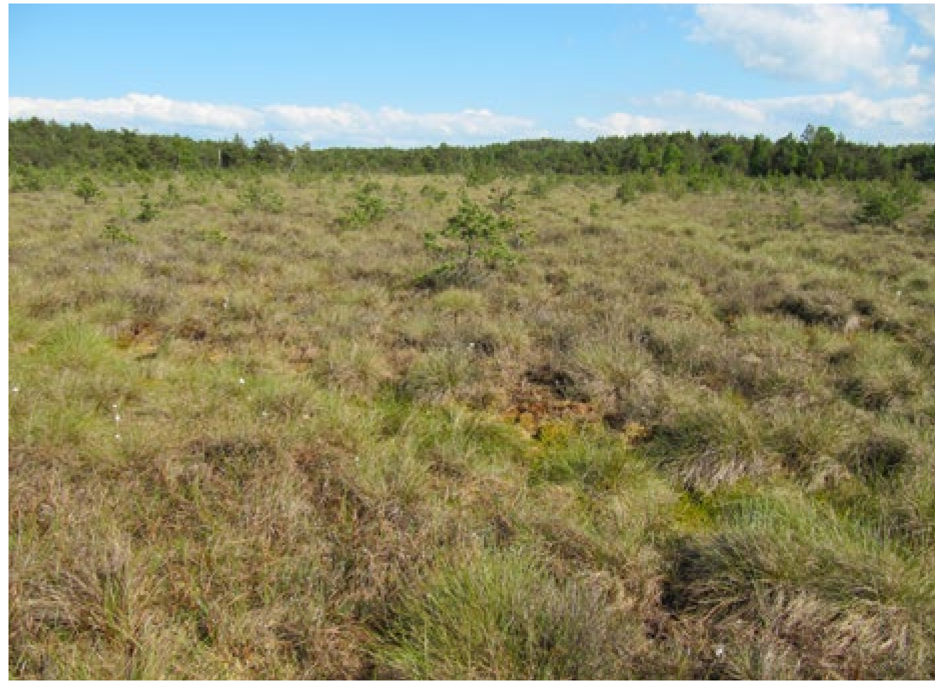

Photo 25. The largest patch of tussock-forming heath moss bog with cross-leaved heath (Erica tetralix) on Wielkie Bagno, endangered by lowered water level in the peat bog and covered with active conservation measures - periodic removal of trees and shrubs. Photo by P. Pawlaczyk.

Photo 26. The oldest areas after peat exploitation in the northern part of Wielkie Bagno with the initial form of heath moss bog communities. Photo by K. Bociąg.

Photo 27. Moss bog regenerative communities in Wielkie Bagno. Photo K. Bociąg.

Photo 28. Regenerative communities of moss bog vegetation in peat-cut-off basins in exploited in the past surfaces of the Wielkie Bagno. Shading them, growing on dikes trees are planned to be cleared. Photo by K. Bociąg.

Photo 29. A community with heather on decaying peat in the post-mining area in Wielkie Bagno, where water is scarce. Photo by K. Bociąg.

Photo 30. Bare peat during drought (Wielkie Bagno). Photo by K. Bociąg.

Photo 31. Extensive water reservoir in peat excavations.
Photo by P. Pawlaczyk.

5. ASSUMPTIONS FOR CONSERVATION MEASURES

On the peat bogs described above, the conservation objective is to stop drainage and decay of peat deposits. Conservation measures will therefore aim at restoring the favourable conditions for the development of bog-type vegetation, and counteract the development of vegetation towards degenerative communities. First of all, it is necessary to stop the drainage, i.e. water outflow through the network of former drainage ditches. These activities will consist in blocking selected drainage ditches within peatlands with peat dams, peat dams toughen with a wooden sheet piling or solid wooden sheet piling. Restoring favourable water conditions in peat (i.e. conditions for preserving peat and protecting it against decay) must take place in a few stages to allow the vegetation to adapt in time to new water conditions and not to cause rapid changes, e.g. dying off of trees on large areas. Therefore, areas where blocking ditches are planned, concentrate within the middle parts of peat bogs. Modelling of water flows shows that it is possible to obtain a certain increase in the water level in the central parts of the peat bogs in question, significant at least in wet years. Its spatial range will not go beyond the peat bog area due to stopping only the outflow of rainwater. In dry years, even blocking the ditches will not change much, as there will be no water to stop. However, unless there is a significant reduction in rainfall, water retention from wet years and periods should at least partially limit the desiccation and decay of peat.

In parallel with the improvement of water conditions in selected patches of non-forest moss bog, in which, as a result of drainage, a strong expansion of trees is observed, partial removal of trees and shrubs is performed. In addition, on several hectares in which peat was cut in the past, trees and shrubs - shading the regenerative communities of moss vegetation in former peat-cut-off pits - were removed from the dike between those basins. The overgrowth and undergrowth of trees and shrubs that appeared after active conservation measures carried out by Słowiński National Park are also to be removed from the moss bog patches. The purpose of these measures is to maintain or restore the peat-forming process in these places.

The experimental measure will test innovative methods of restoring peat-forming vegetation in areas flooded with water after peat exploitation in Wielkie Bagno. It is considered to remodel the shoreline of the post-excavation basin and shape the bottom by creating dikes and artificial islands with material dredged from the bottom of the reservoir. This will increase the length of the shoreline of the reservoir, and therefore the zone that can be occupied by peat-forming vegetation. In this way, the impact of waves on the habitat conditions in the water will be reduced, and thus the conditions for the development of vegetation on the entire post-exploitation basin surface will improve. Another potentially effective method is to create artificial, floating islands - floating wooden structures, anchored in the bottom and floating on the water surface, planted with plant species typical for peat bogs, with the hope that such islands will become sources of floating mat of bog-type vegetation on the water surface. In both cases, they are just testing new methods - they will not lead to a quick overgrowing of basins, but at most they will initiate such a long-term process. The presented LIFE PeatRestore project taking place in Słowiński National Park obviously does not have a scale significant for the greenhouse gas balance. Its purpose is to demonstrate and initiate "outside the box" thinking about peat bogs - not only as a refuge of biodiversity, but also as functional elements of the global ecosystem. The current know-how exchange of five countries should further strengthen this effect. So, if we take climate change mitigation seriously and ambitiously, then - in addition to minimizing emissions from anthropogenic sources as much as possible - we must use all methods that reduce greenhouse gas emissions, including those from degraded peatlands. We also need all possible tools to capture CO_2 from the atmosphere. This means that it is also necessary to restoring the mechanisms of carbon accumulation in peatlands on a mass scale. The project described here is a contribution to gathering the necessary experience.

Photo 32. Experiment at Wielkie Bagno - a floating island with peat bog vegetation. Photo by K. Bociąg.

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- More on LIFE PeatRestore project: https://life-peat-restore.eu/en/
- Hiking paths and touristic trails are available and marked on easily accessible tourist maps of the Słowiński National Park, usually on a scale of 1: 50,000 (different publishers). Current information can be found on the Park's official website https://slowinskipn.pl/pl/

If the world would developed as before, then at the end of the century the average temperature would rise by 4°C. This is a rolling average temperature over a 30-year period, centered in a given year, compared to the „pre-industrial era" considered as the base period 1850-1900. This would mean that potentially deadly heat waves will occur annually in 85% of land areas. In the Middle East and North Africa, areas currently inhabited by hundreds of millions of people will become hostile for human presence, residence and will lead to mass migrations. The whole Southern Europe and currently the most densely inhabited regions of Australia, Africa and South America will be in a permanent state of extreme drought. Arctic ice and coral reefs will disappear. The sea level will rise by the end of the century by 1.5-3 m and will continue to rise. This will lead to flooding of a significant proportion of all coastal cities and will force hundreds of millions of people to leave their homes. Half of animal and plant species may die out, which will cause cascading changes in ecosystems. It may not be possible for people to adapt to a 4°C warmer world.

In the so-called Paris Agreement, world governments agreed to „keep global average temperature rise well below 2 Celsius degrees above pre-industrial levels and continue efforts to limit temperature rise to 1.5 degrees". However, the actual emission limitations do not allow this goal to be achieved, but will only delay growth by 4°C by several dozen years.

The International Panel on Climate Change in a special report published in 2018 (developed by 91 authors and editors from 40 countries, who reviewed over 6,000 papers and responded to over 42,000 comments and corrections by experts and government representatives) justifies that even exceeding the threshold 1.5 degrees are likely to dramatically increase the social consequences of the climate crisis, including hunger, mass migration of people and conflicts.

The impact of climate change on extreme weather events, sea level rise, ecosystems and society is already visible. The greater the climate change will be, the more serious its consequences will be. Already at 1.5°C warming, coral reefs will be seriously threatened, the Arctic Ocean may be almost ice-free at the end of the polar day, and the acidification of ocean waters associated with our CO_2 emissions will last for thousands of years. Warming by another 0.5°C will increase the risk of floods, drought, water shortages and stronger cyclones. This will lead to a decrease in yields, extinction of species and the extension of the range of tropical diseases such as malaria. These factors will increase hunger, migration and conflicts. The rise in sea level forecast for this century at 2°C warming will be about 10 cm higher than at 1.5°C warming. It would seem that this is not much - in the long run, however, may break up the ice sheets of Greenland and West Antarctica, which will condemn future generations to sea-level rise.

Stopping global warming at 1.5°C is still possible (though with a probability of success of no more than 50-60%), but would require rapid, far-reaching and unprecedented changes in all areas of social life - including transformation, in particular energy, industry, transport and land use. Mean carbon dioxide emissions related to human activities (so-called „net emissions") would have to fall by 45% by 2030 (relative to 2010 figures) and by 2050 to zero. This also applies to emissions related to forest clearing and emissions from drained peatlands.

This means that if we want to avoid a climate catastrophe, then (among other drastic changes) we can no longer cut or buy peat. Peat must stay in peatlands. We also cannot continue the agricultural use of peat soils based on their drainage, which is currently common. Peat must be saturated with water.

Along with the rapid decarbonisation of the global economy, large-scale projects for removing CO_2 from the atmosphere would have to be implemented in parallel. There is not a single scenario leading to a 1.5°C reduction of warming that would not require such measures to a greater or lesser extent. Depending on the scenario, 380-1130 billion tons of CO_2 will have to be removed from the atmosphere. This is necessary both to compensate for all those emissions that cannot be stopped, and to remove excess carbon dioxide from the atmosphere that was previously released. Peatlands are a necessary but insufficient element of this process (their potential, assuming their mass restoration in the world, is the global absorption of approx. 1 billion tons of CO_2 annually).

Source: Nauka o klimacie https://naukaoklimacie.pl

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