Hands-on Manual on re-wetting

Sunna Áskelsdóttir

Pawel Pawlaczyk

Hands-on Manual on re-wetting

Authors:

Sunna Áskelsdóttir

Sunna Áskelsdottir has a degree in nature and environmental science from AUI (focus on soil and soil carbon). Has worked at Land and Forest Iceland (prev. Soil Conservation Service of Iceland) since 2014. Field of interest is peatland condition, GHG balance, restoration and restoration success in Iceland.

Pawel Pawlaczyk

A forester by background with experience in research and working for the nature conservation administration. He was scientifically engaged in tree biology and forest ecology. He currently works for the Naturalists' Club, a Polish conservation NGO. He is primarily concerned with the planning and implementation of nature conservation (in particular forests, waters and peatlands).

Cover photo credits: Paweł Pawlaczyk

ISBN 978-83-89830-44-9

Ogólnopolskie Towarzystwo Ochrony Ptaków | BirdLife Poland
Szeroki Dunaj 5, 00-255 Warsaw, Poland
www.otop.org.pl biuro@otop.org.pl

Fuglavernd | BirdLife Iceland
www.fuglavernd.is

Warsaw, 2024

Recommended citation:

Áskelsdóttir, S., Pawlaczyk, P. (2024). Hands-on Manual on re-wetting. OTOP BirdLife Poland, Warsaw 67pp.

The publication was prepared as part of a project 'Exchange of Icelandic and Polish experience in peatland restoration for biodiversity and climate' funded by the National Fund for Environmental Protection and Water Management (Poland) with EEA Grants and The Royal Society for the Protection of Birds.

Table of contents

1. Introduction

1.1. What „peatlands” are? How does peatland work?

Peatlands are terrestrial wetland ecosystems in which waterlogged conditions prevent plant material from fully decomposing. Consequently, the production of organic matter exceeds its decomposition, which results in a net accumulation of peat, conserved by water saturation. In the strict sense, a peatland is an ecosystem in which peat-forming vegetation occurs and in which the accumulation of peat is possible. Such living peatland is also called a mire. If the mire is drained, the peat forming process usually stops, but the peat already accumulated remains (and may start to decompose). The remnant of a drained mire, after ceasing peat formation, is a peat layer, preserved in a better or worse condition. It may be also called “peatland” in a wide sense, for example if we talk about “peatland requiring restoration”.

For practical reasons, we usually named “peatland” only the ecosystems with accumulated peat layers thicker than particular threshold, usually 30 cm.

The living peatland (the mire) is composed of the external, live layer of acrotelm, where the accumulation of biomass and peat forming process takes place, and the internal part of catotelm, composed by the deposited peat. Water saturating the peatland is a necessary factor conserving permanently the peat in catotelm and enabling peat formation in acrotelm. In case of peatland degradation, the acrotelm usually disappears and catotelm peat starts to decompose.

Basic ecological factor determining peatland function is water. Depending on sources of water supply (e.g. rain, surface flow, shallow underground layers, aquifers and springs, flood from river or other water bodies) and water parameters (in particular: trophy, content of phosphorus, calcium, iron) various mire ecosystems develop. Mires vegetation is usually very specific and strongly depends on mire ecohydrology.

In the contemporary world, most peatlands are drained, in particular to be managed as arable fields, meadows, pastures and forests. If peat is no longer permanently saturated by water, it decomposes by oxidation, which leads to degradation of the whole peatland, followed by diminishing of its ecosystem services. We need these services, thus cannot agree with their disappearance. Thus, peatlands must be permanently wet to be preserved. And peatlands which are not wet now, need to be rewetted.

1.2. What does „rewetting” mean?

Rewetting peatland in a wide sense is the process of changing a drained peat soil towards a wet peat soil[1]. But this definition still remains ambiguous, until the meaning of “wet” is precised. It should be understood at least *wet enough to prevent peat deterioration*. It means that water level of rewetted peatland should no longer be decreased artificially, even temporarily.

[1] The definition from IPCC Guidelines for National Greenhouse Gas Inventories, repeated also in Art. 3 point 23 of Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration.

Defining more precisely, rewetting is a deliberate action that aims to bring the water table of a drained peatland back to that of the peat-forming peatland. The peatland is rewetted when the mean annual water table is near or at the soil surface.

Rewetting means making the peatland wet indeed! It means to achieve full or almost full saturation of the solid profile by water, at least by capillary infiltration.

Not each improving water conditions and increasing water level can be called rewetting. The basic idea of rewetting is to switch off the process from the consecutive degradation of drained peatland to its restoration or at least conserving in non-deteriorating status. Thus, the idea is not only to raise the water level, but raise it to restore water-saturated conditions in peat.

Usually, rewetting is a necessary step in restoration of degraded peatland. Because drained peatlands formerly always have been wet, peatland restoration must always include rewetting. However, rewetting is not the same as restoration of wet, living mire. The original vegetation, as well as other ecosystem components, do not always return. Mire degradation is often irreversible and even after rewetting the original ecosystem cannot be fully restored. In particular, it is the case of nutrient legacy of long-term intensive agricultural use, or because of irreversibly changed hydraulic conditions (decrease in peat porosity, hydraulic conductivity and water storage coefficient), even rewetted conditions are far from the original ones. Development of soil microbial communities and mycorrhizae developed under drained conditions is also hardly reversible. Rewetting of partly decomposed peat usually leads to huge nutrients input and development of eutrophic vegetation. Even in such cases, rewetting creates a novel wetland ecosystem, which may lead to partial restoration of some ecosystem services provided by the wetland. In particular, rewetting conserves and maintains peat, preventing continuation of its decomposition. Therefore it is a measure of key importance for mitigation of climatic changes, even if the original mire is not restored.

Rewetted peatland may be left for natural processes. Some economic use is also possible, but usually requires specific technologies. So called "paludiculture" is a way of generating some agricultural production from rewetted (or from originally wet) peatland, for example by production of reed, cattail, alder wood, or sphagna for gardening. Some rewetted peatlands can be used as wet meadows, if mowed by specific equipment. In some cases, grazing by the wet-resistant species and breeds of animals is still possible. Nevertheless, if the drained peatland was mowed or grazed, simple continuation of mowing or grazing by continuation of the same agricultural technologies is usually not possible after rewetting.

Rewetting of drained peatland is not always feasible. In some cases, due to irreversible changes of the landscape (disappearing or subsidence of adjacent peatlands, decreasing of bottom level of draining watercourses), irreversible changes of entire peatland surface (peat subsidence, peat mining), or due to climate changes (lack of water) restoring peat-conserving water level is not achievable, despite huge efforts.

In many cases, although rewetting peatland is technically feasible, water level is decided to be only partly or only temporarily increased and re-establishment of permanent peat saturation by water is not intended. The common reason is agricultural use of land which needs to be continued – or for interests or landowners or for benefits for biodiversity related with seminatural meadows or pastures. In such situations, wetland services may be only partly, but not fully restored. Greenhouse gasses emissions from the degraded peat may be reduced, but not ceased.

Such cases – if the peat saturation by water is not achieved – are not “rewetting” sensu stricto. However, they also can provide some environmental benefits and most of the recommendations in this guidance may also apply to them.

Peatlands in Poland

About 4.7% of the Polish territory, i.e. ca 1.49 million ha, comprises peatland, in particular abundant in northern part of the country. Nevertheless, only ca 0.24 million ha is preserved as a mires, i.e. with potentially peat-forming vegetation. Elsewhere, fens predominate (92% of peatlands) and bogs comprise only about 4.5% of the peatland area. The average Polish peatland is 24 ha large and has a peat depth of 1.6m. Nevertheless, diversity of the mire system is high (Kotowski et al. 2017). Small and very small peatlands are the most common.

Of the EUNIS habitat classification system (EEA 2021), habitats of Polish peatlands classify as:

- Raised and blanket bogs (Q1),
  - Raised bogs (Q11),
- Valley mires, poor fens and transition (Q2),
  - Poor fens and soft-water spring mires (Q22),
  - Intermediate fen and soft-water spring mire (Q24),
  - Non-calcareous quaking mire (Q25),
- Base-rich fens and calcareous spring mires (Q4),
  - Alkaline, calcareous, carbonate-rich small-sedge spring fen (Q41),
  - Extremely rich moss-sedge fen (Q42),
  - Tall-sedge base-rich fen (Q43) ,
  - Calcareous quaking mire (Q44),
  - Arctic-alpine rich fen (Q45),
- Helophyte beds (Q5),
  - Tall-helophyte bed (Q51),
  - Tall-sedge bed (Q53),
- Seasonally wet and wet grasslands (R3),
  - Moist or wet mesotrophic to eutrophic hay meadow (R35),
  - Moist or wet mesotrophic to eutrophic pasture (R36),
  - Temperate and boreal moist or wet oligotrophic grassland (R37),
- Arctic, alpine and subalpine scrub (S2),
  - Subalpine and subarctic deciduous scrub (S25),
  - Subalpine Pinus mugo scrub (S26),
- Temperate heathland (S4),
  - Wet heath (S41),
- Riverine and fen scrub (S9)
  - Salix fen scrub (S92)
- Broadleaved deciduous forests (T1),
  - Broadleaved swamp forest on non-acid peat (T15),
  - Broadleaved mire forest on acid peat (T16),
- Coniferous forests (T3),

- Pinus and Larix mire forest (T3J),
- Picea mire forest (T3K).

Ombrotrophic bogs (supplied by water by rains only) are represented by several cupola-shaped true raised bogs in the northern part of the country, several mountain raised bogs in the southern part and a bit more common so called continental raised bogs dispersed among the whole country. If overgrown by trees, they evolve towards pine bog forests or mesotrophic pine-birch forests. Natural water level is usually almost on the ground level (0–15 cm below the ground). In some bogs it may fluctuate periodically during the year, nevertheless rather not decreasing below 20–30 cm. Deeper water level drop is usually a result of draining by man. If altered by draining, the ombrotrophic bogs evolve usually towards wet pine or birch forests.

Topogenous peatlands usually are developed as terrestrialization mires and may form floating mats around lakes or occupy kettleholes or other depressions with a shallow horizontal groundwater table. They encompass ecosystems of various trophic and pH status, including poor fens, and transition mires and quaking bogs (Kotowski et al. 2017). Water level dynamics may be various. In floating sphagnum carpets, the water level below the ground is very stable. In more consolidated peatlands water level can fluctuate due to groundwater level changes. If overgrown by trees, the topogenous peatlands evolve towards various kinds of bog forests, from confer bg woodlands, through swamp woodlands on acid peats, to alder swamp woodlands. If altered by draining, the topogenous mires are transformed into various kind of degraded ecosystems, including in particular mesotrophic bog forests or poor meadows.

Soligenous peatlands are fens developing in sites or more or less concentrated groundwater seepage. Detailed ecohydrology and vegetation depends on details of the water supply, in particular contents of calcium, iron, nitrogen, phosphorus as well as intensity of the water inflow. In most cases they develop as rich fens, however sometimes (in particular in mountains) also as poor fens. In case of strong seepage of groundwater, cupola-shaped spring mires or “hanging mires” may develop. If the water seeps horizontally through the peat body, so called percolating fens develop, with water level rather stable and close to the ground (Kotowski et al. 2017). Due to specific biochemical processes, in particular presence of dissolved calcium, the availability of biogens may be limited which is followed by specific low-productive but rich in species vegetation of “alkaline fens” (low sedge community with brown moss carpet), very important for biodiversity conservation. In other cases, more eutrophic vegetation, such as tall sedge rush, may also develop on soligenous mires. If overgrown by trees, the soligenous peatlands evolve towards various kinds of bog forests, from birch swam woodlands on acid peat to rich alder swamp woodlands. Draining may change water flow irreversibly, thus most of such mires are presently strongly transformed, most often towards wet meadows on a peaty soil.

Fluviogenous peatlands typically develop in extensive floodplain systems as eutrophic fens, with the vegetation of large sedges or reed beds (Kotowski et al. 2017). Water level can vary during the year, sometimes with periods of surface flood, but in the natural stage the water conditions remain very wet all year. If wooded, fluviogenous fens evolve usually towards willow bush or alder forests. Many fens of this type are drained and transformed to meadows, pastures or forests, only occasionally wet. Thus, the landscapes of wet meadows are probably the most common contemporary Polish peatland landscape. Unfortunately, drained fens used as meadows cannot be permanent: if the draining is continued, even only in some periods of the year, the process of peat decomposition in such ecosystems is unavoidable.

Kusowo raised bog.

Sphagnum floating mat in Dury mire.

Fens in Rospuda valley.

Soligenous peatlands transformed into wet meadows near Bobolice.

Alder swamp woodland. Wielkopolska region.

Fluviogenic peatland drained, degraded and transformed into wet meadow – the most common peatland landscape in Poland.

The historical area of the peat cover is more or less maintained, due to restricted historical use of peatlands as arable lands. However, active mires that still accumulate peat are rare. Particularly important remaining mires in good status include the large alkaline fen in Biebrza valley, the smaller, but almost natural, fen in Rospuda valley, several raised bogs in northern park of the country as well as in the mountains. Many well-preserved, but small mires are dispersed across the whole country, mainly in forested areas. Ca 60% of Polish peatlands and ca 85% of remaining mires are included in various kinds of nature protecting areas. Nevertheless, the protection is not always effective (Pawlaczyk 2023).

On the other hand, ca 86% of Polish peatlands has been strongly drained. Total length of draining ditches in Poland is estimated as 450.000 km. Most of the drained peatlands (in particular fens) are now under agricultural use. Polish peatlands are also extensively affected by alternation of river beds, decreasing river floods, decreasing groundwater level due to draining adjacent areas etc. Due to extensive draining and following degradation, the Polish peatlands are huge greenhouse gas emitters: the annual emission is estimated for 34 millions tonnes of CO_2 equivalent (Kotowski 2021), which places Poland among the ten worst GHG emitters from degraded peatlands in the world.

A few projects of mires restoration, mainly by rewetting attempts, were already implemented in Poland. They provide substantial experience and know-how. Nevertheless, the scale of the peatland restoration is definitely insufficient against the huge needs to rewet more than million ha. Rewetting needs are estimated as 1.2 million ha, which would be followed by GHG emission reduction by 21.7 million tonnes of CO_2 equivalent annually. Ambitious strategy of work towards peatlands rewetting and restoration (including 300.000 ha rewetted until 2030) was already proposed (Jabłońska et al. 2021), but implementation was not started. The main obstacle is the ongoing agricultural use of most of the drained peatlands and farmers' interest followed by strong resistance against more wet conditions. Even if the peatlands for potential rewetting are presently abandoned, rewetting is usually problematic due to ownership or interests of farmers in the neighborhood.

Due to high variety of Polish mire ecosystems, in particular their various and complex ecohydrology, but also various history of anthropogenic alterations, each Polish peatland needs individual ecohydrological analysis before rewetting and the rewetting solutions are hardly standardized.

Peatlands in Iceland

Peatlands of different types and conditions cover about 15–20% of the vegetated land surface of Iceland, with a higher percentage in the lowlands than in the highlands (above ~400 m.a.s.l.). Inland palustrine wetlands have the largest distribution and are mostly comprised of fens called mýrar (mires) in Icelandic. Sloping fens are found in the valleys and fjords, and topogenous fens in the flat lowlands of the western and southern parts of the island. Alluvial fens are found along some large rivers, and palsas still exist in some highland permafrost areas, although they are rapidly disappearing. Ombrotrophic peatlands are rare, most are minerothrophic or partially ombrotrophic (Arnalds et al. 2016). The Icelandic Institute of Natural History has proposed a habitat classification system based on the pan-European EUNIS classification system. Many of the peatland habitat types have a protective value with reference to the Bern Convention (Ottósson et al. 2018). The peatland habitat types according to the Icelandic classification system are as follows (Comparable EUNIS (EEA 2021) habitat type in numbers in brackets if existing):

- Philonotis-Saxifraga stellaris springs (Q24112),
- Icelandic stiff sedge fens (Q454),
- Cottonsedge marsh-fens (Q45B1),
- Juncus arcticus meadows,

- Boreal black sedge-brown moss fens, lowland and highland type (Q4222),
- Aapa mires,
- Palsa mires (Q3112),
- Icelandic black sedge-brown moss fens, two subtypes (Q4223),
- Icelandic Carex rariflora alpine fens,
- Common cotton-grass fens (Q224),
- Basicline bottle sedge quaking mires (Q2532),
- Icelandic Carex lyngbyei fens (Q531B).

A vast Aapa mire area at Mývatnsheiði North-East of Iceland.

Icelandic peatlands are strongly influenced by the volcanic nature of the island, but also by the maritime climate, mountainous landscapes, isolation and land use history. Since settlement, dryland areas have been excessively eroded. This, in addition to the volcanic activity, has resulted in large inputs of mineral matter to peatland soils, predominantly around the volcanic belt which runs through the island along a curved line from southwest to northeast. These mineral inputs make the soil comparatively fertile and result in increased pH and bulk density. With reference to the EUNIS habitat types, Icelandic wetland vegetation is dominated by vascular plants; *Carex* spp., *Equisetum* spp., *Eriphorum* spp., but also by some heathland plants, f.x. species of *Empetrum*, *Salix* and *Vaccinium*. Sphagnum moss dominated peatlands are virtually absent because of the eutrophic and basic nature of Icelandic peatlands, but other mosses are common.

Icelandic wetlands, like other Icelandic ecosystems, are relatively species poor due to the island's isolation, nevertheless they are home to some red listed and protected species.

No bird species are endemic to Iceland, but several subspecies are only found there. Icelandic wetlands are an especially important habitat to many bird populations, both breeding and migratory. In fact, almost half of all breeding birds are waders, ducks and other waterbirds, making the composition of Iceland's avifauna different from countries at lower latitudes (NÍ). Icelandic wetlands are particularly important for waders of the northern hemisphere like the golden plover (*Pluvialis apricaria*), dunlin (*Calidris alpina*), snipe (*Gallinago gallinago*), whimbrel (*Numenius phaeopus*), black-tailed godwit (*Limosa limosa*), redshank (*Tringa totanus*) and meadow pipit (*Anthus pratensis*). Swans (*Cygnus cygnus*) and geese are also common, including the graylag goose (*Anser anser*) and pink-footed goose (*Anser brachyrhynchus*). Due to Iceland's unique position on the globe, there are also a few waterbirds of North-American origin that are on the most eastern end of their distribution in Iceland, like the common loon (*Gavia immer*), Barrow's goldeneye (*Bucephala islandica*) and harlequin duck (*Histronicus histronicus*) (NÍ). It is believed that the water rail (*Rallus aquaticus*) ceased breeding in Iceland around 1970 because of extensive wetland drainage and the simultaneous outbreak of the invasive american mink (*Mustela vison*) (NÍ).

About half of Icelandic peatlands are influenced by drainage. Ditches are mostly located in lowland areas and the total ditch network extends about 30.000 km. Extensive peatland drainage began in the middle of the 20th century and peaked in 1963. It was fuelled by the modernisation of agriculture practices, f.x. introduction of large machinery, and heavy subsidization of ditch excavation by the government. The primary motive in the beginning was to create hayfields (arable land), but as time progressed it was also to improve grazing conditions and replace fencing. Due to changes in agricultural practices and increased urban settlement in recent decades, a large part of the drained areas have been abandoned or are not being used in ways that require drainage. Therefore, opportunities for rewetting are plenty, and because of the relatively short history of drainage in Iceland, often only small efforts are needed. However, peatland restoration experience is limited in Iceland, both in the context of time and size of area. The first attempts were made in 1993 with the intent of restoring bird habitats, and since then a few small projects have taken place. The general approach has rather been rewilding than restoring, lacking proper monitoring and management. Compared to mainland Europe, scientific knowledge regarding Icelandic peatlands is also poor, as only a handful of studies have been published. Since 2016, The Soil Conservation Service of Iceland (SCSI) has directed the project of peatland restoration.

Typical abandoned agricultural fields with eroding ditches.

1.3. Rationale of rewetting

Peatland drainage is always followed by deterioration of peatland biodiversity, as well as ecosystem services. Specific flora and fauna species disappear. Vegetation shifts to simplified communities. Peat shrinks and is decomposed, compacted and degraded. Loads of nutrients and dissolved organic carbon in outflow water increase, affecting rivers and lakes. Many of these changes are irreversible. But rewetting is an opportunity for ceasing and – in some cases – at least partially reversing these negative processes. Sometimes it can provide introductory conditions to peatland restoration.

Peatlands need to be wet to provide ecosystem services. If they are not, due to anthropogenic alterations, rewetting is the only possibility to at least partial restoration of the services in concern.

Specific flora and fauna of mires is adapted to wet conditions and dependent on them. Thus, restoring the role of peatlands as biodiversity hot-spots and threatened species refugees usually requires preliminary rewetting i.e. restoration of boggy water conditions. In the landscape scale, healthy, wet peatlands are crucial for general water circulation, but also for general "biodiversity richness" of the landscape and following landscape impression. In Poland: there will be neither frogs croaking in our world, cranes clangor nor flowering marigolds, without wet peatlands and other wetlands in the landscape (there will also probably be less mosquitoes, but it simply leads to less birds). In Iceland: the specific diversity of flora and fauna attracting tourists could be reduced without healthy peatlands. For example, Iceland is responsible for a large percentage of the breeding populations of many waders, whose habitats have been severely degraded across the world. Of the monitored wader populations, 48% are declining and only 16% are increasing, further heightening the relative importance of Icelandic breeding grounds. The island offers a wide range of treeless lowland habitats, in part maintained by grazing sheep, with fertile volcanic soils. These open sub-arctic habitats are rare in a global context and require protection (Tómas G. Gunnarsson, 2020). Further reclamation of degraded peatlands would therefore strengthen the status of globally declining bird populations.

In particular, rewetting of drained peatlands is necessary for mitigating climate changes. The natural bog is CO_2 absorber and – even despite some CH_4 emission – netto absorber of greenhouse gasses. The drained peatland, due to peat decomposition, became a strong CO_2 emitter. The total emission of greenhouse gasses from drained peatland is up to 20–30 tonnes of CO_2-equivalent per hectare yearly – the more the drained it is. The only way to stop peat decomposition and GHG emission is to keep peat permanently under the water level, which can be achieved only by peatland rewetting. In the world scale, keeping peatlands wet, and rewet those of them which are drained, are a significant and not omittable part of the climate change mitigation efforts (Joosten et al. 2016). If we consider climate change mitigation seriously and if we indeed are going to meet the Paris objective (keep climate warming < 2°C), we have to rewet all drained peatlands worldwide until 2050, which means we need to rewet 2 millions hectares worldwide each year.

Peatland rewetting effectively stops these CO_2 emissions, but also re-establishes the emission of methane (CH_4). Peatland management for climate must choose between CO_2 emissions from drained, or CH_4 emissions from rewetted, peatland. Generally, the CO_2 reduction effect prevails. Due to different behaviour of CO_2 and CH_4 in the atmosphere: the faster we rewet peatlands the better, i.e. from the point of view of climate protection we need to rewet all peatlands now, without postponing the action (Günther et al. 2020).

Last but not least, peatlands were drained mostly for agriculture, but drained peatland usually cannot be easily used by agriculture permanently. Peat decomposition leads to decreasing soil properties, in particular water storage capacity. Peatland subsidence leads to flooding of the land, which motivates farmers to make ditches deeper and deeper.

In most cases, the ecological benefits from wetland rewetting are in synergy, i.e. reducing GHG emission is accompanied by increasing natural values, biodiversity and other ecosystem services (such as water retention). Of course, these benefits are usually not in full synergy with economical use (usually, after rewetting business as usual cannot be longer continued, although some forms of paludiculture still can provide economical benefits). However, the ecological benefits seem prevailing under economic loss (Jabłońska et al. 2021, Stachowicz et al. 2022). Around 50 –60% of Iceland's reported GHG emissions are derived from the land use sector (~7–8.000 kt CO_2-eq.), and may to a large part be contributed to the drainage of organic soils (Umhverfisstofnun, 2022). However, data on GHG emissions from peatlands of varying conditions around the country is still being gathered so that more accurate estimates may be developed. It is also being researched to what degree eolian deposits impact the decomposition and long-term storage of carbon. Möckel et al. (2021) found that decomposition processes are slower in soils with stronger volcanic mineral characteristics, if intact. This leads to positive impacts on carbon storage of undisturbed peatlands but might cause increased emissions from drained ones. Therefore, it is important to develop special references for the GHG balance of Icelandic peatlands.

The exception may be the seminatural ecosystem on peaty soils, as wet meadows and pastures on peat. They are common in Poland and usually host specific biodiversity, in particular some threatened bird species. For optimizing the biodiversity, such ecosystems should be wet, but at least in some periods dry enough to enable mowing or grazing. Thus, is such cases, from the biodiversity and farming point of view, partial rewetting is often proposed, i.e. some increasing of water level, but only in some periods in the year and not to level typical for natural mire. Such approach remains contradictory to the need of preventing GHG emissions, for which full rewetting is necessary. Nevertheless, even in such cases, at least some increase of water level is still synergistic and acceptable for all stakeholders, including land owners-farmers.

In European Union, legal regulation on nature restoration was established in 2024[2], so rewetting of at least part of drained peatlands used for agriculture became an obligation of each Member State. According to Artt 11 (4) of the Regulation, Member States shall put in place measures which shall aim to restore organic soils in agricultural use constituting drained peatlands. Among those measures, rewetting shall be in place by 2030 on at least 7,5% of national area of drained peatlands in agricultural use, by 2040 on 13,3%, by 2050 on 16,7%. Rewetting of former peat extraction sites may be counted towards these targets, as well as rewetting drained peatlands under other than agricultural use, but up to a maximum of 40 % of the target. Restoration measures that consist in rewetting peatland, including the water levels to be achieved, shall contribute to reducing greenhouse gas net emissions and increasing biodiversity, while taking national and local circumstances into account. Where duly justified, the extent of the rewetting may be reduced by a Member State if such rewetting is likely to have significant

[2] Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration.

negative impacts on infrastructure, buildings, climate adaptation or other public interests and if such rewetting cannot take place on land other than agricultural land. The obligation for Member States to meet the rewetting targets does not imply an obligation for farmers and private landowners to rewet their land, for whom rewetting on agricultural land remains voluntary, without prejudice to obligations stemming from national law. Therefore, Member States shall incentivise rewetting to make it an attractive option for farmers and private landowners.

2. Initial peatland recognition

2.1. What natural features need to be studied before planning peatland restoration?

Polish experience

Basic rule of rewetting is rather simple: to block each artificial water outflow from drained peatland. However, in many cases, in particular of more degraded peatlands, even blocking all contemporary outflows is not enough for achieving rewetting of the entire peatland. Almost always, the results of rewetting are much better if more details of the peatland ecohydrology is considered. In particular, a good understanding of the peatland ecosystem, its original function in the landscape, history and degradation, is necessary for estimating feasibility and potential benefits in the particular case. In particular, it is necessary if the objective is not only rewetting, but also at least partial restoration of the ecosystem, ecosystem services or related biodiversity.

Due to the high diversity of Polish peatlands ecohydrology, as well as due to heavy alteration of most of them, restoration and rewetting usually requires high preliminary effort to understand mire original ecology, history, and alterations. In particular, general relation to water flows in the landscape need to be understood. Usually, following variables are significant in most of cases:

Location in the landscape: Preliminary information on how the mire was in the part and is contemporary located in relation to geomorphological structures and other mires is essential for understanding the wider context of its functioning and water supply. Is it located in a side branch of the valley? In the wing of the valley? Or in the middle? On a slope? On the watershed? By a watercourse or lake? Is it accompanied by mineral elevations which can potentially act as hydrological windows? Is/was the peatland an element of a larger peat complex, e.g., in a valley? Is/was it part of a larger sequence of peatlands of different types, e.g., within a terrain channel or on a bend? How has the area and surface of the peatland changed due to its draining and degradation? What was the original surface and area and what are today? What about drainage processes due to local watercourses: are the watercourses deepened by bottom erosion or by maintenance activities (dredging) in comparison to the original stage?

For example: spring fens are more susceptible to spontaneous or anthropologically induced erosion, thus their effective restitution after drainage is more difficult, or even impossible. Lake – or river – side mires often maintain a high level of groundwater, supported by stable surface water levels within the valley bottom, which allows for minimizing erosion processes and stable peat accumulation within the permanently irrigated peat layer.

General water availability in landscape is usually worth checking: are the original sources of landscape supply by water are still active. What is the general present hydrological balance (precipitation vs evapotranspiration), in particular considering climate changes? i.e. can we still find in the landscape enough water to rewet particular peatland? What is the present water availability during the year; is there a risk of long dry periods? Local climate should not be taken from older literature, but – due to ongoing climate changes – should be rather calculated directly from most recent data. In Poland weather data, as registered by meteorological stations, are publicly available free of charge (danepubliczne.imgw.pl), nevertheless are provided in non-user friendly formats. Using them requires a lot of human effort of using a specific software for data download.

Diversification of surface topography, ditches: The topography of the fen surface (e.g. flat or sloping, possible occurrence of dome structures, protruding mineral hills) is an important premise for further research on the origins, water supply, and functioning of the fen. The identification of ditches is the basic source of information for planning protection measures. Identification in this respect can be carried out by precise penetration of the fen, and in an advanced form by geodetic measurement of surface ordinates. Nowadays, however, a very helpful and easily accessible material is the so-called numerical model of terrain based on data from laser scanning (LIDAR). Such data in Poland are available online for download, free of charge (www.geoportal.gov.pl) and may be explored by common free GIS software (e.g. QGIS). We can then display a „hypsometric map" of the mire surface which usually reveals ditches and rills, as well as height differences of even several centimeters. Currently there are also a lot of other algorithms visualizing terrain, useful for understanding of the topography, finding ditches, assessing potential directions of potential surface water flow (for example: Hillshade, Slope, Visualization for Archaeological Topography – VAT).

Geological structure of the peatland: Thickness and stratigraphy of peat layers reveals the history of peatland formation and development. It is examined by drilling with a special peat drill, which extracts the peat core in sections. On the basis of plant residues in the peat, an expert is able to reconstruct the botanical composition of the peat from various depths, interpreting on this basis the history of changes in the fen vegetation. Assuming that the ecological requirements of individual plant communities remain unchanged, this makes it possible to interpret the sequence of changes in the conditions prevailing on the fen. Possible, although less frequently used, is the absolute dating of selected peat samples by sending them for C_{14} analysis. Most often, several boreholes are made, arranged in transects, which allows for making cross-sections showing the structure of the fen. Professionals are able to analyze many other features of the profile – old ecological conditions, in particular hydration, are shown well in e.g., remains of *Testacea*, and the history of changes in the vegetation in the area is shown by preserved plant pollens.

Peat drillings will tell you whether the peatland has a paludification origin (peat layers usually deposited on sand) or a lake origin (peat layers on gyttja), and whether it is a young formation (a thin layer of peat on gyttja) or old (thick layers of peat); whether in the past there was an accumulation of thicker tufa (cf. chapter 2, tufa lumps appear in the profile). Comparing the vegetation of the past with that of the present will enable the drawing of conclusions about the naturalness of the present form of the mire (the changes may result from natural succession, but the sharp discrepancy between the present vegetation and the sequence documented in the peat usually results from fresh anthropogenic transformations). The profile will show whether or not the mire was overgrown with trees and shrubs in the distant past and, therefore, whether the current occurrence of trees and shrubs is a natural state, an episode of repeated fluctuation or a new anthropogenic situation.

Assessing the condition of the peat (degree of decomposition) is also very important for rewetting planning purposes. The less decomposed peat, the greater its capacity for capillary infiltration of water, i.e. the more we can achieve by rewetting and the more predictable the rewetting results will be. In particular, the condition of the surface layer of the peat must be checked obligatory. If the peat is still well preserved, better results of the rewetting, more close to peatland restoration, can be accepted. If the surface peat is degraded (which is usually irreversible), after rewetting of the peatland (if at all feasible) development of eutrophic vegetation may be expected, not restoring the original mire vegetation.

Not only the exact surface, but also deeper layers of the peat need to be checked. The assessment can be done during the field works (using drilled samples) or – with more details – in the laboratory.

Peat drilling is the standard, not omittable method of recognising both peatland history and the present condition of the peat.

Recent history of the mire: The history of changes in the physiognomy of the mire (in particular, its overgrowth with trees and shrubs, forms of use, possible drainage) is a very important element of the knowledge required for its protection. Interviews with local residents and users of the mire may be a source of the findings. Old topographic maps are a good source, usually available for periods from the end of the 19th century (indexes and even map resources can be easily found on the Internet), although their good interpretation requires knowledge of the nuances of the history of cartographic art. Historical orthophoto maps and aerial photographs are very useful. The popular Google Earth program has a time slider that allows you to reach the historical orthophoto map, but the available time ranges differ. Historical orthophoto maps from the last several years are available in Geoportal (www.geoportal.gov.pl), although the extraction of material from a specific date requires quite advanced computer operations. A wider collection of archival aerial images, usually since the 1950s, has been made available for a fee by the Head Office of Geodesy and Cartography (www.gugik.gov.pl) and the purchase prices are not high. Sometimes you can even find older aerial photographs, as well as archival ground photographs, which can be very helpful.

These materials will show how and how quickly the mire vegetation has changed, or at least its physiognomy, over the last several decades – e.g., when and how quickly the mire overgrown with trees and shrubs (rapid growth in recent times will usually be a prerequisite for the need for active protection-removal of trees and shrubs, while the stability of the tree cover may mean that there is no need for it). Recent use, e.g., mowing, will often reveal itself (usually as an indication of the need to restore mowing). Sometimes it is possible to determine when the drainage ditches were dug (in the case of ditches made relatively recently and their proper blocking, perspective for the mire is better).

Ecohydrological conditions: The starting point should be the exact survey of the peatland and observation of the water – where it flows from, where it appears, where it goes and how quickly it flows out. Sometimes, even specific physicochemical aspects (deposition of calcium or iron) can be recorded visually. However, it is not enough to do it all just once. This observation should be repeated in different seasons of the year, as well as, for example, in rainy or dry periods. The perfect starting points are the "maps of surface water". They may be simple maps presenting field surveys which may be very basic in scope (what parts of terrain are flooded, boggy or wet, where the water in the ditches is and in what direction it flows), but recurrent and detailed in the survey coverage. The survey may be done by traditional walking across the peatland, but using other technologies, such as UAV (drone) photos, may be usually very helpful.

In this way, the groundwater supply can often be seen (as evidenced by visible sources, water constantly seeping from peat slopes, a strong, suddenly occurring outflow, as well as the stability of these phenomena during the year and in various weather conditions), and it can be determined which ditches pose the greatest threat to the mire.

Inventory of the ditches as well as existing dams and sluices is usually a necessary part of basic survey. For such inventory, topographic maps and terrain visualization may be useful (see above), nevertheless field survey is usually necessary for assessing the current conditions. Although in Poland an official catalog of ditches and water facilities exists, the data in it are not always reliable enough and updated, thus always must be checked in a field.

Meteorological data on temperature and rainfall, as well as hydrological data concerning water level of rivers, are useful for interpretation of the results of hydrological field surveys. In order to obtain meteo data, one can set up an own meteorological station[3] and the water level recorder, or use data from the nearest station of the national meteorological and hydrological observation network, now in Poland available at: dane.imgw.pl/data/dane_pomiarowo_obserwacyjne.

Monitoring of the water level in peat can and should be a source of supplementary information for the diagnosis. It is made in observation wells made for this purpose – usually in the form of a PVC pipe penetrated into the peat, sealed at the bottom and perforated at the appropriate depth. Once the water level in the pipe has stabilized, its depth in relation to the fen surface is measured. Manual measurement is certainly possible, but nowadays it is rather common to use sensors/recorders embedded in the pipe, so-called divers, which automatically record changes in pressure of the water column[4] during a given interval (e.g. once a day), and it is sufficient to read the collected data e.g., once a year. Usually, observations are made from a few to a dozen or so observation holes per mire, and the observations are made for at least one hydrological year (from the beginning of November to the end of October). Sometimes there are two boreholes made in one place with filtering at different depths: the water level established in them will not usually be the same, which can say a lot about possible underground supply; sometimes even artesian or sub-artesian aquifers may be discovered by such wells. Daily data is very valuable as it shows the stability of hydration – a very important feature for the assessment of the „health status" of a mire. A long-term series of measurements can provide interesting information on the reaction of hydration to changing rainfall and temperature conditions.

Measurements of the physicochemical properties of water will provide valuable information. The basic parameters that can be measured quickly in the field with a suitable

[3] A battery-powered recording station with rainfall and temperature sensors that can be installed anywhere in the area (after considering the risk of vandalism or theft), requiring data reading and battery replacement about twice a year.

[4] Usually, the sum of water column pressure and air pressure is recorded, which means that in order to interpret the results it is necessary to have data from the so-called baro-diver, i.e., a sensor and recorder of air pressure, located a few to a dozen kilometers from the mire.

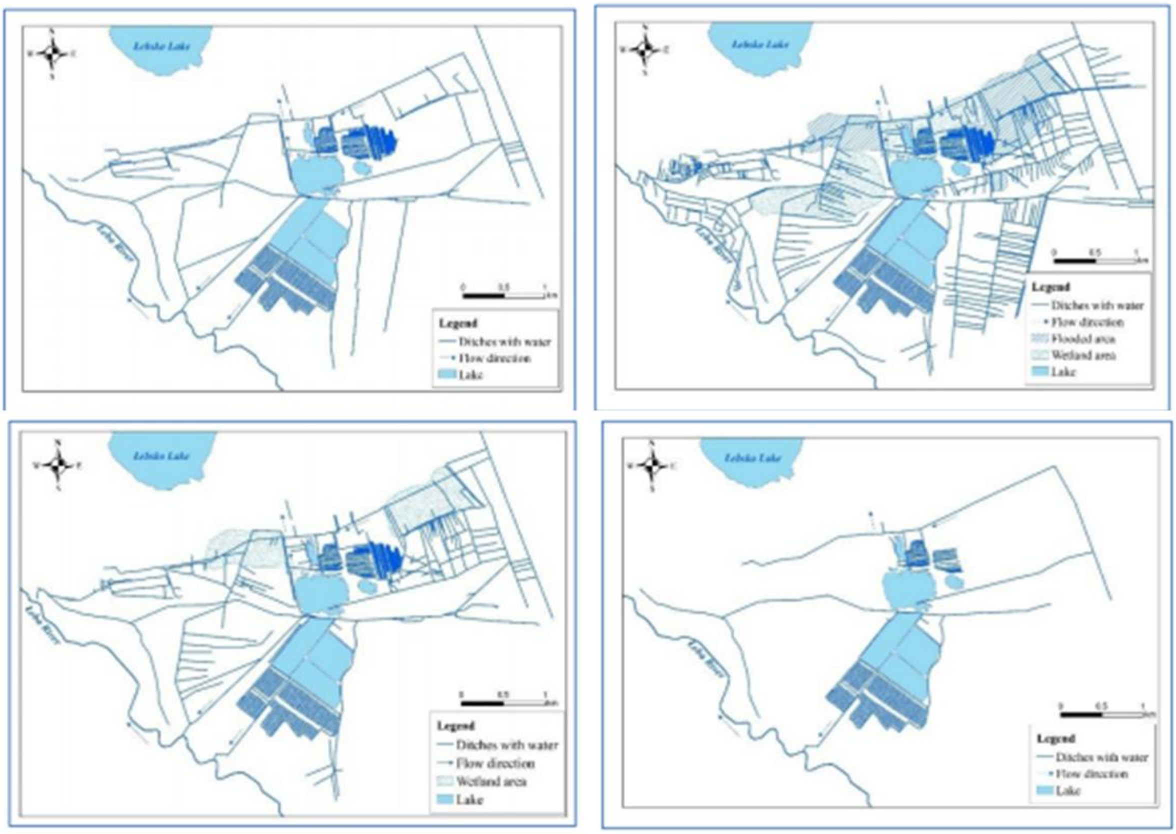
meter are temperature, reaction (pH), and electrical conductivity (indicating the number of ions). Low temperature of the water, stable throughout the year, may indicate its underground origin. An acidic reaction may indicate acidification processes, a light acidic reaction indicates rainfall water, and an alkaline reaction may suggest water richer in calcium. Conductivity of several dozen μS/cm is typical for soft rainwater, while levels above 400 – 500 μS/cm suggest strong mineralization. The relations of these parameters in different places on the fen are important: in the outflow water, water in ditches, water on the surface, in puddles and floodplains, in water in observation wells filtered at different depths; correct interpretation of such relations contributes to the understanding of the water supply to the fen. It should be remembered that stagnant water on the surface of the fen may be of precipitation origin and (e.g. rainfall) may not be reliable for the ecological characteristics of the fen; therefore, measurements in observation wells filtered in the peat are more useful.

More sophisticated water analyses may provide further information but usually require sampling and laboratory analysis. In alkaline fens, a particularly important property is the amount of calcium and magnesium ions, as well as the content of potential nutrients: nitrogen, phosphorus, and potassium, and the content of iron and aluminum. Sometimes these parameters may be necessary to select the appropriate protection method (see above).

Presence of bigger amounts of phosphorus in degraded peat or iron in the supplying water (often visible as iron precipitations) are rather bad pedictors. They indicate high risk of vegetation eutrophication after rewetting.

Ecohydrological identification can be extended in many ways, each providing valuable information to help plan the protection as accurately as possible. Ideally, the identification should go beyond the fen itself and include its landscape context, which requires groundwater measurements also in the broad surrounding area of the fen. Groundwater temperature profiles at various depths around the fen can say a lot about the intensity of the groundwater supply (Grootjans et al. 2006). Similar information can be provided by profiles of the content of calcium sulfate ions in the groundwater (Wołejko & Grootjans 2004). The potential for tufa deposition can be checked by installing microscopic slides in the flowing water for a period of about one month and then analyzing the deposits (Grootjans et al. 2015).

Very important information for the fens supplied with the groundwater would be an identification of the so-called alimentation area, i.e., the area from which the underground aquifer is supplied and from which the fen is then supplied in turn. This information is very important for protection because it identifies the area where, for example, disturbances in the flow of groundwater or its abstraction can have a significant impact on the fen. However, there are no realistic methods for identifying such an area accurately, and one can only try to guess on the basis of a precise geological diagnosis of the terrain (including the sequence of permeable and impermeable formations) and its topography.



Hydrological mapping – basic tool for recognition of water conditions. Cieśliński et al. 2022.

Flora: It is often one of the most important natural values of mires, therefore its identification is particularly advisable. It requires a sufficiently detailed penetration of the fen by an appropriate expert. It is optimal to repeat such research at least several times a year, as well as to repeat it in different years. Some vascular plant species – such as *Saxifraga hirculus* on alkaline fens or *Trichophorum caespitosum* on atlantic bogs – are surprisingly difficult to notice when they are not flowering. Many orchid species, including *Liparis loeselii*, appear in very different numbers in subsequent years. The best indicator species on mires are often moss species and not vascular plants. It is therefore important that the botanical expert carrying out the diagnosis has the appropriate skills and experience. Searching for mosses requires concentration and time, bending over and looking through herbaceous vegetation, and noticing them requires experience.

Sometimes the flora of individual sites can remain surprisingly stable, as evidenced by cases where some flora peculiarities have been found in the same places as they were reported in the 19th century. However, there are also cases of rapid changes, such as the disappearance or appearance of species. First of all, practice shows that even on sites theoretically well researched and repeatedly penetrated by botanists, one can still find previously unseen floristic peculiarities.

Vegetation: Describing a mire with its plant communities and a map of vegetation is a basic way of scientific communication and organizing information. It is important to express the diversity of the vegetation in a way that is more in line with contemporary rather than archaic classifications. Drawing a vegetation map requires detailed field mapping by the relevant expert: only in this way can plant communities be identified, described, and documented with relevées. To determine their range, it may be helpful to use the current orthophoto map, taken from national resources or made by yourself using UAV (drone) photos. It should be remembered, however, that the diversity of vegetation in phytosociological terms may be masked by the presence of, for example, reeds or sedges – mapping vegetation requires taking into account the entire flora composition, and not only the dominant ones.

The vegetation of the mire can be stable, but there are cases of significant changes even within 3–5 years, e.g., strong territorial expansion of some types of rushes, resulting in the disappearance of once existing communities.

The vegetation map may be transformed for the GEST unit map, useful for estimation of greenhouse gasses balance on bigger peatlands.

Fauna: For vertebrates, mires may be significant for some birds (e.g. *Grus grus*, *Scolopacidae*) or amphibians. However, the fauna of invertebrates may be very valuable at some sites. The peculiarities of fauna should be sought mainly in the group of beetles, in particular *Staphylinidae*. Since the invertebrate fauna of Polish mires is generally poorly recognized, it is often the mere entry of a suitable expert into a better preserved mires that results in the discovery of new localities of rare and valuable species.

Very valuable invertebrates can also be associated with groundwater outflows, often accompanying and occurring within or in the vicinity of alkaline fens. Particular attention should be paid to *Trichoptera*, *Hydracarina*, and *Coleoptera*.

It is possible that valuable, rare, and protected butterfly species may be found. Fen habitats may host: Coenonympha oedippus, Lycaena dispar, Lycaena helle, Euphydryas aurinia, Phengaris nausithous, and Phengaris teleius. The very rare Coenonympha oedippus (in Poland there are three known sites – only alkaline fens) is found on sedges. Other species tend to have a wider ecological scale, including wet meadows, and are dependent on their respective host plants rather than on the type of the fen itself. Lycaena dispar, which is found on sorrels, is still relatively common in Poland and the chances of finding it on an average alkaline fen are quite high.

The peculiarities may also be found in the fauna of the Odonata, particularly often found in ditches and by small watercourses at the fens. Quite often one can find Leucorrhinia pectoralis.

The occurrence of rare and endangered whorl snail species is relatively often associated with fens, including those listed in Annex II of the Habitats Directive (Directive 1992) – Vertigo angustior and Vertigo moulinsiana (Książkiewicz 2010).

Cultural elements: Some mires, or their vicinity, contain old technology heritage sites, e.g., old water abstraction facilities. From some sources water was taken in and pumped with the use of the so-called hydraulic ram. Some small damming facilities on the ditches may also have the status of technical heritage. Remnants of old wooden roads and piers may be preserved in the peat. Also some remnants of former peat digging (excavation holes, causeways, technical railways), although usually problematic and degrading peatland, may be considered as a part of cultural heritage (sometimes remnants of the peat industry are exposed as a tourist attraction). Some fens, flush fens, and springs may be associated with the values of non-material culture in the form of traditional field names (in northern and western Poland it is also worth looking for old German names), local history, and folklore tales.

When recognising the peatland with the idea of its rewetting, it is worth to consider preliminary, if the initial survey would be also the baseline for further monitoring. It is possible and effective, but usually needs specific methodological arrangements (such as the conserving methodology of further monitoring, permanent fixing or very detailed location of recordings).

Icelandic experience

Most degraded peatlands in Iceland have not been drained for a very long period and in many sites no tilling or further cultivation has taken place. Therefore, former characteristics and flora are often still present to some extent. However, heavily degraded peatlands can be found in Iceland, e.g. where the drainage is relatively old, no peatland plants can be found and shrubs and invasive plants, such as cow parsley (*Anthriscus sylvestris*), have taken over. Heavily drained agricultural fields on organic soils are also common but there is very limited to no experience with restoration at such sites. If a peat layer is identified somewhere in the soil profile, the assumption is made that the area was a peatland before it's degradation and may presumably be restored if socio-economic factors allow. Further information indicating previous conditions can be found by studying old aerial photos, old maps, place names and local tales. In accordance with the basic principles of ecosystem restoration, a reference ecosystem is identified in the vicinity and, as far as possible, the same measurements that are listed here should be carried out there. If that is not possible, a reference ecosystem is conceptualized. Compared to mainland Europe where land use history is longer and competition more severe, finding suitable reference ecosystems could be an advantage for the restoration of Icelandic peatlands.

Before rewetting:

Site characteristics are mapped thoroughly before rewetting procedures take place. Among the assessed factors are: Characteristics and condition of ditches and spoil banks, water flow (in flow, out flow and flow in ditches) and vegetation composition. Aerial drone image maps are created for all sites, preferably during different seasons, which aid f.x. in estimating the distribution of vegetation communities and calculating elevation models. A good time to map the topography would be after snowmelt in spring when the vegetation is relatively flat, but it is best to do vegetation mapping during noon in late summer.

Vegetation: Studying and mapping vegetation is of great importance during peatland restoration. The species composition of vascular as well as non-vascular plants, reflects site conditions such as long-term water level (WL), nutrient availability and land use history among other variables. The Icelandic habitat type index based on the EUNIS classification system is the only peatland classification system in use in Iceland. Sites are mapped according to habitat types and dominant plant species within each habitat are noted. A scale accounting for the degree of peatland degradation is in development, but the level of dryland species encroachment and moss species composition and condition is one of the main indicators of degradation. Tufted hairgrass (*Deschampsia cespitosa*), common bent (*Agrostis capillaris*) and even fall dandelion (*Leontodon autumnalis*) are tell-tale signs of degradation, and are often especially noticeable in the driest areas close to ditches. Shrubs like tea-leaved (*Salix phylicifolia*) and woolly willow (*S. lanata*) also become more prominent, particularly so if the adegradation andd for horse grazing. Further vegetation surveying may be valuable but requires skilled personnel. F.x., How and when bryophytes react to changes in the water table after drainage and restoration.

Water level: Depth and stability of the water level is the most important variable in peatland restoration and raising it is the base for further transition. WL is monitored for at least one year before any implementations take place. To account for annual differences in climate, measurements are preferably also carried out on an adjacent control site. In Iceland, sites suitable for rewetting are often in remote or excluded areas. Repeated manual measuring of WL is therefore not always feasible and divers are expensive. In some sites, the insertion of metal rods into the ground has been implemented as a low-cost method to assess the most common interval of WL height, as that part of the rod will oxidise (rust). The rods are left for at least 3 months in thawed ground. Preliminary results are promising and this method will be tested further. During the driest periods, the observed WL of open waters such as ditches and ponds can sometimes be used as an indicator of drainage intensity.

Surface conditions: Examples of surface conditions that are assessed before rewetting include the proportion of the vegetated surface, influence of grazing, and size and type of turfs/tussocks.

Soil: The state of the soil is also an indicator of peatland condition. The depth of the soil profile is measured outside of and in ditches as it is easier to penetrate the whole soil profile in ditches. Soil type is estimated, along with degradation degree of dead plant matter on the Von Post humification scale. It is also noted whether the soil has a high organic matter content, if it is mixed with minerals or if there are noticeable tephra layers in the profile. Collecting soil samples is ideal but not always possible.

Monitoring: Ideally, peatland restoration is a long-term process. Detailed baceline setting is important before restoration, preferably over more than a one-year period. In the first years after restoration, conditions of restoration structures and short term changes such as water level should be monitored. In the long-term ecosystem changes e.g. restoration successes should be monitored according to previously set goals and objectives.

2.2. Economic and social environment, stakeholders management

Polish experience

In Poland almost all territory is divided into plots being the subject of various human interests. Thus wetlands rewetting, influencing the wetland itself but sometimes also the wetland neighborhood, is usually a complex social process. In order for a rewetting project to be feasible to implement at all, it must receive at least elementary approval from relevant stakeholders (no active opposition). A more ambitious goal is for the project to bring satisfaction to at least part of society, i.e. to "claim it as their own".

Wetlands rewetting is usually "socially beneficial", i.e. from the general social point of view, the sum of the benefits (including cost of restored ecosystem services) outweighs the sum of objective losses. However, this message is not easy to convey. The basic problem is that usually other social groups benefit and others suffer losses. Benefits are rather general (as mitigating climate change), whereas losses concern particular landowners which cannot continue their business as usual.

Usually, the rewetting projects are easiest and most effective on public wetlands surrounded by other public lands. The public institution is usually easier to convince about the general social benefits of rewriting, including nature conservation needs, in particular if it has not significant economic interests. Most of the peatland rewetting projects implemented till now in Poland were located on the state owned lands managed by State Forests – which declares interest in nature conservation, try to be pro-ecological and pro-social and have no interest in managing hardly accessible wetlands. Nevertheless, necessary upscaling of wetland rewetting definitely needs including also private owned wetlands.

The main problem of many potential rewetting cases is that the territorial scope of the rewetting project must not be limited to the peatland in concern itself. It needs to affect general water circulation in the landscape, in particular affecting peatland margins and neighborhood, which is often in conflict with the present land use. Generally, it is not possible to reverse the results of landscape draining, maintaining all "economic benefits" of these draining and land use implemented owing to the draining! Ceasing or changing of some land use is usually unavoidable pricing of wetland rewetting. But achieving the stakeholder agreement for this is usually extremely difficult..

The future of peatlands rewetting must include significant incentives from public sources motivating landowners to agree with their land rewetting and supporting land use switch to paludiculture or compensating land abandoning. Nevertheless, until now, such incentives are not available.

Anyway, basic information which must be collected is the land ownership. Relevant data are collected in official cadaster but are not always easily accessible. The ownership of State Forests can be checked on the Internet map "Forest Data Bank" (www.bdl.lasy.gov.pl). Nevertheless, there are no similar online databases of land ownership of other public institutions. For rivers and channels, management of water authority Polish Waters may be supposed. Communal land may be identified by relevant communes. Sometimes, the full data of land parcels, including the owners, may be obtained from land cadaster. Nevertheless, in other cases, identification of private owners may be difficult due to restrictive personal data protection rules. Informal knowledge and knocking on doors then may be irreplaceable.

Usually, for successful implementation of a rewetting project, not only the ownership of land to be rewetted, but also all land which would be affected by rewetting – and even the land which is "perceived by the owner as potentially affected" – must be recognized. It concerns neighborhood land, but sometimes also the land, even far away, drained by the same draining system or drained to the same watercourse.

On the basis of land ownership, stakeholders' interests need to be identified. In particular: how the land is used and what for? What are the water requirements of current land use. Can the current land use be replaced by another solution? Is it possible to buy the land?

Not only real, but also imagined stakeholders' interests must be taken into consideration. It needs to be remembered that in general perception of Polish society the wetlands are still perceived negatively and people, in particular farmers, are often afraid of "too much water". The potential impact of increasing water level may be perceived as much stronger and more extensive that really is. Even rare episodes of high water level in rainy years may be used against rewetting idea.

Anyway, peatland rewetting needs to be planned in the honest process, with all necessary information available for all interested. Participatory planning would be the perfect solution. In Poland there is some experience of developing "teams of local collaboration" during preparation of management plans for Natura 2000; this approach could be easily used and adapted to the planning of peatlands rewetting. However, it should also be noticed that stakeholders' pressure can easily undermine the rewetting objectives and sense; thus the participatory character of the process should not be considered as the ultimate objective, but rather as a tool for more efficient achieving the objectives of rewetting.

How a farmer whose life consists of cow keeping will react to the idea of rewetting peatland in the neighborhood (or below) the meadows? Last but not least: how the meadow-related biodiversity follows possible ceasing of grazing after rewetting?

Icelandic experience

The majority of lowland areas in Iceland (below ~400 m.a.s.l.), where degraded peatlands are most commonly found, are privately owned. Information of land ownership in Iceland is accessible by a public database (icelandic: *lögbýlaskrá*), thus finding and contacting landowners in Iceland's small population is usually not a problem. Until recently, most peatland rewetting projects have been initiated by landowners or land managers, often in cooperation with public nature conservation organisations. A more proactive approach is needed to upscale peatland rewetting.

Although most peatland restoration projects have taken place at sites where there is little to no land use, either because of agricultural abandonment or they were only used for seasonal or light grazing, few landowners have been interested in restoring their peatlands. As in Poland, the benefits of peatland rewetting are general but not specific for landowners. Finnur R. Andrason (2022) has identified four main reasons for the unwillingness of Icelandic landowners:

- Lack of financial incentives or certified carbon units, compared to other land uses such as forestry and agriculture on organic soils, to the point that some landowners might be waiting to profit from rewetting;
- Negative, misinformed or polarized discourse and coverage by media. Peatland rewetting is a heated topic in Iceland, and has often been met with distrust and sometimes hostility by some groups;
- Disbelief in the carbon benefits of restoration, in some part due to lack of local studies;
- Lack of education to stakeholders.

Other reasons include; the fear that neighboring area will be negatively affected, that ponds or pits with steep banks created during the process will pose as a threat to livestock and people, or that the area will be difficult to cross, f.x. during sheep herding; lack of clear definitions for what counts as landuse and degraded peatland; lack of cooperation with people living in or familiar with the area; wetlands are legally protected by Icelandic nature conservation laws and therefore farmers are giving up their land indefinitely with little prospect of being able to use it in the future; emphasis on climate instead of biodiversity, as many find it easier to conceptualize benefits to biodiversity than to GHG emissions; some landowners find wetlands less aesthetically appealing than farmland and even fear being socially stigmatized for rewetting; lack of sites suitable for rewetting; unclear division of responsibilities between government agencies and municipalities; and lack of funding and skilled personnel. On a more positive note, climate change skepticism was not listed among the main obstacles of peatland rewetting in Iceland.

3. Planning approach

3.1. Paradigms, compromises, objectives

Polish experience

In Polish rewetting projects to date, general objectives usually were based on following paradigms:

- Rewetting for nature restoration. The basic idea is to restore degraded wetlands, not only for particular ecosystem services but also for their intrinsic values. The original ecosystem is the assumed target vision and rewetting to try to restore it as far as possible. Similarity to the original ecosystem is ecohydrology and linked ecological processes; repairing ecological systems destroyed by former man activity is an indicator of success. Rewetting is usually full and economic land use cannot be continued.
- Rewetting for specific biodiversity components. The basic idea is to optimize wetlands habitats of some fauna and flora species, in particular amphibians or birds. Rewetting is only as far as species ecological needs (in some cases it is not "rewetting" sensu stricto), often with the assumption to maintain traditional land use as far as possible. For example, rewetting wet meadows for waders conservation assumes maintaining high water level in spring, but decreasing it later to enable continuation of meadows mowing. Often, maintaining or restoring some wetlands ecosystem services is also taken into consideration.
- Rewetting for water retention. The basic idea is to maximize ecosystem service of water retention: keep water in the landscape, to prevent drought and to maintain water ability for forests or agricultural ecosystems. This idea is popular among foresters and some farmers and is implemented by rewetting and restoring small wetland ecosystems as the islands in a generally transformed landscape, if possible not affecting productive lands. In particular the idea of "small retention in forests" is popular among the Polish foresters.
- Rewetting for climate mitigation. The basic idea is to conserve carbon in peat to prevent greenhouse gasses emission. It requires permanent maintenance of the peat in watered conditions, i.e. full rewetting of the peatland.

Although paradigms mentioned above may be often synergistic, they differ in details, which may influence the establishment of detailed objectives of rewetting projects. Some of them need compromises between rewetting (wetland restoration) and continuation of wetland use. Such an idea is close to "wise use" of wetlands, recommended by Ramsar Convention. Nevertheless, some such solutions may not lead to "rewetting" sensu stricto i.e. do not restore conditions in which the peat will be permanently wet indeed.

Some rewetted wetlands are definitely and solely designed for nature and environment conservation, which means the economic use of them is abandoned. If located in the protected areas, they may be considered as "strictly protected" according to EU biodiversity strategy.

However, some rewetted wetlands may be still managed and profitably used. The technologies of economic use compatible with wetland rewetting are named "paludiculture". farming reed or cattail; farming sphagna for gardening, or planting and managing willows or alders may be the examples. They may be economically viable. Nevertheless, paludiculture consists of very specific activities, usually – on rewetted peatlands – requiring total "switch off" from farming business-as-usual to the new approach. The necessary investments in the relevant machinery, as well as the risk of starting something uncommon and not known, creates a high "entrance fee", even for interested farmers. As a result, until now we have no Polish examples of paludiculture implementation on rewetted wetlands.

Due to high variety of Polish wetlands, all approaches presented above have relevant examples of implementation in particular sites. The choice of relevant approach is the primary and basic decision of each peatland restoration project.

On the basis of selected approach (accepted level of compromise), rewriting objectives can be developed. They should describe expected water conditions foreseen to be achieved. Development of the rewetting objectives must taking into consideration rewetting feasibility, in particular in the context of irreversible peatland alteration, as the peat surface lowered due to peat decession, increased drainage by watercourses and ditches made deeper and deeper, general lack of water in the landscape.

On the basis of rewetting objectives, peatland restoration objectives may be developed, i.e. the vision of entire peatland restored, with its vegetation and other ecosystem components. Feasibility of restoring peatland ecosystems usually depends on severity of its degradation. In case of only slightly degraded mires, restoration of them may be possible by restoring original water conditions. Even then, some degradation processes (such as microbial changes in the soil; development of mycorrhiza supporting tree expansion) may be in some cases hardly reversible. In case of strongly degraded peatlands, with significantly compacted and depleted peat layer, or with degraded surface peat layer, rewetting may lead only to development of the novel wetland ecosystem, providing some wetland services but usually not so valuable as the original one.

Icelandic experience

Close to the end of last century, the first peatland restoration efforts in Iceland were initiated by bird enthusiasts under the incentive of habitat restoration, but also by farmers that were losing their livestock in ditches. In the following years more projects were implemented, where ponds, lakes and peatlands were restored mainly with the aim to restore bird habitats.

With the publication of the 2013 Wetland Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, emissions from drained organic soils were first accounted for in Iceland's national inventory. In a sparsely populated country with a relatively small industrial sector and large areas of drained peatlands, emissions from organic soils account for a very large part of the country's total emissions, or about 50–60% (Umhverfisstofnun). In recent decades, the issue of biodiversity loss has gained increased attention following the validation of Iceland of the Bern Convention (1993) and the UN Convention on Biological Diversity (1995), with their newly implemented Kunming-Montreal Global Biodiversity Framework targets which are supposed to replace the expired, and mostly failed, Aichi targets. Iceland also adopted the Ramsar Convention on wetlands in 1978 and has named six Ramsar wetland reserves to date (Umhverfisstofnun).

The main goals of peatland restoration are to bring back lost conditions, functions, structures, and species populations that have been degraded due to human activities. Each project may also have further, more precise, aims. The endgoal of peatland restoration is based on a native reference ecosystem, either an analogous one that has not been degraded or a conceptual ecosystem based on scientific and local knowledge. When restoring peatlands, the key function to restore is the hydrology of the site as it is prerequisite to other recovery processes for a trajectory towards a restored, healthy and functioning ecosystem (Gann et al. 2019). In Iceland that can, in some cases, be the only intervention needed. If executed properly and permanently, natural processes take over and with time the peatland ecosystem is recovered. This is of course dependent on the degradation status of the site before restoration, among other factors.

To put it simply, peatland restoration in Iceland is generally either observed as a biodiversity project with added climate benefits or a climate driven project with added biodiversity benefits. In some cases, the motivation is even mostly aesthetical, with the added benefits for biodiversity and climate.

3.2. Feasibility, general implementation concept

Polish experience

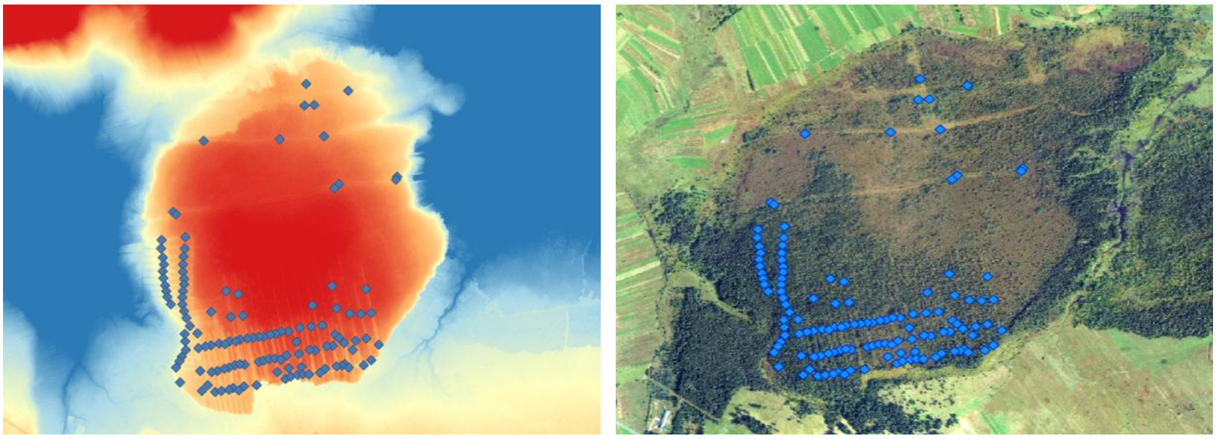
When we have an idea, what we are going to achieve, the next question is usually how to do it, i.e. how to collect and maintain sufficient amounts of water to achieve the foreseen rewetting effect. Usually rewetting is implemented by the water outflow blocking, but the question is: at what points? in how many points? The answer must be provided individually for each peatland, after recognising its individual hydrology. However, on the base of the experiences and failures of peatlands rewetting in Poland, some general principles to keep in the mind may be formulated:

- The peatland should be rewetted by "appropriate water" i.e. by the water of the same origin and chemistry as originally supplied. I.e.raised ombrotrophic bog or soligenic fen should not be rewetted by river flood. Soligenic fens with vegetation development limited by particular elements should not be supplied with water of other features;
- In case of well-preserved peat, capillary infiltration may be helpful in achieving peat saturation by water. However, if the peat is partly decomposed, it becomes hydrophobic and hardly rewettable;
- Usually, the water table should be maintained as close to the surface of rewetted peatland as possible. If the peatland surface is not flat (in particular: cupola raised bogs, hanging mires, percolating fens), water damming facilities must maintain not flat water table – it means that probably cascade of small ditches blocking would be necessary;
- The water outflow blocking should be resistant for unpredicted damages i.e. usually should be redundant;
- It is necessary to consider how the outflow blocking facilities will age. The perfect situation is to block water outflow by natural materials, which will decompose parallel to the ditches overgrowing, then will disappear finally exactly in the time they will no longer be necessary – but the worst situation is when they will disappear faster!
- The ecological effect of rewetting measures should not be overestimated. Although in some cases the effect of "water return" is fast and spectacular, in other situations the effects are hardly visible in first years; they need several years)with the wet ones among them) to manifestate. Unexpected direction of vegetation development should be expected. Only slightly degraded mires can return to their original state;

- For successful rewetting, usually each water outflow should be blocked. It can be best achieved by adaptive management: consecutive surveys of water outflow points.

Detail planning and blueprinting water outflow for peatland rewetting requires hydrological knowledge and experience. Additionally, peatland hydrology is rather specific – the appropriate expert should be, if possible, experienced "peatland hydrology engineer", not only the general hydrologist.

Sometimes, hydrological modeling is used for assessing the possible, further water conditions after rewetting. It usually needs the peatland topography, ditches survey, peat structure and basic peat parameters as entrance data. However, some rewetting projects are implemented also without very precise hydrological forecasts, based on the expert intuition only. If the experts are experienced, this approach is usually also effective.



The "cascade" approach is necessary for blocking outflow from the raised bog cupola. Baligówka bog.

The “cascade” approach of ditches blocking is used also in other countries. Bog restoration in Austrian Alps.

Waiting for the wet year. Rewetting measures in Poland are not always immediately effective; long periods of dry weather in the summer may diminish the success.

Icelandic experience

Close to the end of last century, the first peatland restoration efforts in Iceland were initiated by bird enthusiasts under the incentive of habitat restoration, but also by farmers that were losing their livestock in ditches. In the following years more projects were implemented, where ponds, lakes and peatlands were restored mainly with the aim to restore bird habitats.

With the publication of the 2013 Wetland Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, emissions from drained organic soils were first accounted for in Iceland's national inventory. In a sparsely populated country with a relatively small industrial sector and large areas of drained peatlands, emissions from organic soils account for a very large part of the country's total emissions, or about 50–60% (Umhverfisstofnun). In recent decades, the issue of biodiversity loss has gained increased attention following the validation of Iceland of the Bern Convention (1993) and the UN Convention on Biological Diversity (1995), with their newly implemented Kunming-Montreal Global Biodiversity Framework targets which are supposed to replace the expired, and mostly failed, Aichi targets. Iceland also adopted the Ramsar Convention on wetlands in 1978 and has named six Ramsar wetland reserves to date (Umhverfisstofnun).

The main goals of peatland restoration are to bring back lost conditions, functions, structures, and species populations that have been degraded due to human activities. Each project may also have further, more precise, aims. The endgoal of peatland restoration is based on a native reference ecosystem, either an analogous one that has not been degraded or a conceptual ecosystem based on scientific and local knowledge. When restoring peatlands, the key function to restore is the hydrology of the site as it is prerequisite to other recovery processes for a trajectory towards a restored, healthy and functioning ecosystem (Gann et al. 2019). In Iceland that can, in some cases, be the only intervention needed. If executed properly and permanently, natural processes take over and with time the peatland ecosystem is recovered. This is of course dependent on the degradation status of the site before restoration, among other factors.

To put it simply, peatland restoration in Iceland is generally either observed as a biodiversity project with added climate benefits or a climate driven project with added biodiversity benefits. In some cases, the motivation is even mostly aesthetical, with the added benefits for biodiversity and climate.

3.3. Formal planning requirements, legal issues and practice tips

Polish system

In Poland, before implementation of a rewetting project, usually extensive burden of collecting necessary consents is necessary. However, due to some legal exceptions, the burden in some cases may be significantly reduced.

By default, for each change of water conditions, including building of new water facility, water consent must be obtained from water authority. The water report prepared by a water expert must be attached to the application. However, building a culvert on the ditch requires only the notification of the water authority in advance, with only basic information attached. "Reconstruction of the ditch" for limiting water outflow from its own ground (not affecting other grounds) requires only simplified notification. Thus, to reduce burden, the investment needs to be named accordingly.

By default, building each facility requires obtaining a building permit from the building authority. For the application, a very detailed map must be attached, which usually requires expensive contracting the professional surveyor. However, the map and the permit is not required for reconstructing of “melioration facilities”. The building legislation does not apply at all if no “construction products” are used. Thus, to reduce burden, the measures using only natural products are often selected or the investments are named accordingly.

For building a “damming facility” on a watercourse in the natural protected area, obtaining environmental consent may be required. Nevertheless, the rule does not apply if the investment is prescribed in a management plan established for the protected area and water is dammed not more than 1 m.

Suich tips reducing burden and costs of preliminary documentation are in Poland often taken into consideration in development of detailed rewetting plans. Technical solutions offering simpler formal paths are often selected.

Icelandic system

For peatland rewetting in Iceland, a general construction permit from local authorities is usually required. Each municipality has the authority to decide if peatland rewetting needs a permit or not. It also varies between municipalities what kind of documentation is required to hand in with the application. A map or drone image of the project area accompanied by a detailed project description is most often sufficient. In some cases, municipalities have also requested signatures of consent from stakeholders (neighboring landowners). Informing adjacent landowners is a good practice and can prevent possible future discontent. They may be concerned that rewetting could negatively influence their landuse prospects. Similarly, in the cases where rivers or lakes are found in the vicinity it is recommended to consult with local fishing associations. A consultation with the The Cultural Heritage Agency of Iceland is also mandatory to prevent possible disturbance of antiques at the site. If a project is planned in an area with high conservation status, permission is needed from the Icelandic Environmental agency.

3.4. Financing

Polish experience

In Poland the most important source of funding of peatland restoration are the national and European funds dedicated to nature conservation. Big projects are usually financed partly by EU LIFE Financial Instrument or by EU Regional Development Fund managed by national institutions. Some projects are funded by UE-related funds from Norway, Switzerland or Iceland. Usually, the funding is available as grants for the best projects selected in open competition. Funding is usually available for part of the project budget; the rest must be covered from non-EU funds. Polish financial institutions: National Fund for Environment and Water Management, as well as Regional Funds, are important funding sources for many projects. However, the rules of national funding, at least in recent years, are not transparent.

From 2021, the compensation payment is available, as EU CAP measure, for some farmers whose land is flooded or strongly wet (soil fully saturated by water). However, the payment is available only as supplement to already funded agri-environmental schemes; the amount is small and it covers and requires only 12 days of water presence. Thus it cannot motivate farmers to rewetting peaty soils; it can rather only compensate for the impact of some weather or floods incidents.

Despite consideration of possible economic use of some rewetted wetlands, until now there is no example of paludiculture development on rewetted area and switching from agriculture on the drained peatland to the paludiculture on rewetted one. All existing examples of paludiculture (as farmers producing reeds for roofs cover) concerns only areas originally wet.

As in other countries, there is growing interest of some business companies to improve their "ecological image" by declaring some companion of their GHG emission. Investment some money for peatland rewetting (followed by GHG emission decreasing) is one of the possibilities. However, until now, there is no working system of such "carbon trade", allowing reliable certification of effects. There is an ongoing attempt to develop a Polish national scheme for the "carbon credits" market, similar to German one MoorFuture. The credits, calculated as estimated cost of saving symbolic 1 tonne of CO_2 equivalent by peatland rewetting, would be available for purchase for each interested, as voluntary compensation of generated greenhouse gasses emission. However, the system did not start to work yet.

Icelandic experience

As Iceland is not a part of the EU, European funds have not been available until recently. Since 2021, Iceland has been able to apply for LIFE funding although no peatland restoration projects have yet been financed by LIFE. One application is being processed now, jointly applied by six agencies and two NGOs, according to which considerable areas of peatland are to be restored in the West, South and East of Iceland. It includes detailed monitoring, stakeholder involvement, promotion and education. Hitherto, most restoration projects have been funded by the government, earliest by the Wetland committee but more recently by the SCSI. A few projects have also been funded by The Icelandic Road and Coastal Administration (IRCA) and the National Power Company as a compensation for peatlands disturbed by construction of roads and power plants.

Funding the rewetting implementation phase has been relatively straightforward since 2016, when peatland rewetting was included in Iceland's climate action plan. However, due to a lack of understanding of the importance of planning, preparation, monitoring, management and involvement of professional personnel in the process, those aspects have proven more difficult to fund. A private fund called the Wetland Fund financed a few projects between 2018–2023 (~300 ha in total), where the private sector could buy unofficial carbon credits and the income went towards peatland rewetting. Operation of the fund has now been paused as companies and landowners wait for a certified carbon credit market. As in Poland, there is no working system of carbon trade in Iceland, but interest is increasing, both in developing a national scheme and a scheme for the voluntary carbon credit market. The main obstacle is the lack of data from Icelandic peatlands, as only a few studies have been carried out and data is especially lacking for peatland greenhouse gas balances, drained or natural.

4. Implementation

4.1. Rewetting techniques

Polish experience

The most important factor of peatland rewetting is the restoring and maintenance of water level. In most cases, it requires blocking the artificial water outflow. The most frequently used technical solutions are:

Rewetting by abandoning drainage maintenance. Many peatlands, formerly drained and used for agriculture or forestry, are presently abandoned or almost abandoned. If draining systems are not recurrently maintained, they may become less effective, for example due to ditches overgrowing by plants and filling by mud. Often it is followed by at least partial rewetting of the peatland. The process requires only “doing nothing”, and only preventing further ditches maintenance or reconstruction works. However, it is not always fully effective, due to the remaining draining function of ditches. In particular, even ditches looking as inactive in a summer, may still drain the peatland and generate water outflow in a spring.

Big draining ditch abandoned, overgrown and inactivated. Słowiński National Park.

Beaver dams. In some cases, draining ditches are dammed up by beaver *Castor fiber*. It is an effective way towards wetland rewetting. It is enough not to disturb beavers. On a landscape scale beaver floods bring many environmental benefits by improving the circulation of water in the landscape, ensuring the uptake of biogenic nutrients, water retention etc. (Janiszewski et al. 2014). However, the effects are not fully predictable. In some cases beavers dams and floods may destroy valuable biodiversity elements, such as fish reproduction areas in watercourses or some parts of threatened habitats. Activity of beavers can also unpredictably hinder forestry and agricultural management. Most of such problems can be solved with simple and cheap technical solutions eliminating the negative impact of beaver dams. These are discussed in more detail in separate studies (Czech 1999, Szpaczyński 2003, Czech 2005, Campbell-Palmer et al. 2016). The most popular are pipe overflows in the beaver dams, where the pipe inlet is extended several meters into the beaver flood area and secured with a metal basket to make it difficult for the beaver to find the water escape place and clog it up. However, from the point of view of rewetting, maintaining beaver dams unaffected, even if some disadvantages must be accepted, is usually the best approach.

Draining ditch blocked by beaver dam. Perfect peatland rewetting measure. Izbickie Bagna.

Mimic of beaver dams. Structures using wood, clay etc., inspired by beaver dams. Usually not very durable, but looks very natural and – if built by an experienced constructor, designed as a network of ditches blockages, and regularly surveyed, maintainged and if necessary adjusted – can work well, The approach is used mainly in the United States (Wheaton et al. 2019), nevertheless some attempts to implement it in Poland were also recorded, in particular in Poznań region, in Bieszczady mountains and on Mała river in Mazowsze region; may be recommended for wider use.

Mimic of beaver dam, developed by local farmer in Wielkopolska region, for maintaining water in the farm area.

Beaver Dam Analog blocking drainage ditch in Bieszczady, using willow shoots - from building in autumn to the next summer. Photo credit: Andrzej Czech.

Biological structures made of herbaceous plants. Unmaintained ditches become overgrown relatively quickly. In order to increase the moisture content of the fen and inhibit excessive outflow, it is sometimes worth using this characteristic to speed up the process. A good material supporting the overgrowth of ditches are clumps of *Carex paniculata* , which are relatively easy to replant into the ditch as part of the so-called biological damming. However, it is only possible to use this solution for small ditches with low flow rates.

Ditch blocked by Carex paniculata planting.

Tree logs. In some mountain peatlands on the slopes, some rewetting effect may be achieved by blocking the surface water runoff. Very simple solution, as wood logs arranged transversely to the slope, may be effective.

Blocking the surface runoff by wooden log. Photo credit: A. Jermaczek.

Fixed wooden barriers. Low costs, easy installation, easy integration into the environment, and relatively long service life often justify the use of such a technical solution. These barriers guarantee stopping excessive water outflow or raising water level in ditches up to 4–5 m wide. The basic materials for their construction are thick (4–5 cm), although not too wide (10–15 cm), wooden boards of various lengths (1.5–2 m) with a routed tongue. The best material for the b is hardwood, e.g., oak. Alder wood can be used in immersion conditions. Thick pine boards can also perform their function for several years. In many cases (shallow ditches with low flow rate), a period of several years is sufficient for a complete overgrowing of the ditch. The natural decomposition of the partition, which no longer fulfills its function, is in this case most desirable.

There are several different techniques of building wooden barriers (cf. Pawlaczyk et al. 2002, Kujawa-Pawlaczyk & Pawlaczyk 2005, Makles et al. 2014, Center for Coordination of Environmental Projects 2016). Boards sharpened at one end so that, when driven individually into the ground, they direct themselves and press the boards previously driven into place to install a tight wall partitioning the watercourse. The depth to which the boards are driven depends on the height of the gate and the hardness of the ground. They should be driven to the greatest depth in the place where the overflow is located. In organic soil, it can be even 2–3 times deeper than the height of the damming. In hard mineral substrates, a depth slightly exceeding the damming height is sufficient for the gate to be tight and durable. A wooden barrier can also be built of horizontally placed boards. They can be joined before being placed in the ditch. Unfortunately, it can be very difficult or impossible to drive the entire structure in – so the only way is to dig it in.

It is important that the water does not flow or seep under the partition, so the gates made of vertically driven, well-fitting boards are usually more effective.

Individual wooden barriers, especially when their damming capacity exceeds a dozen or so cm, may over time be deformed and curved under the influence of water pressure. Therefore, during their construction it is appropriate to support them from the tailrace side.

An important element of the wall construction is the proper shape of the overflow. It should always be located in the middle of the watercourse and should be formed in such a way that during large water inflows, water flows over only in the middle and not on the sides of the partition. If this is not the case, the gate will be washed out and bypassed in watercourses with high flow velocity.

In order to avoid the effect of washing out and erosion of the banks and bottom of the watercourse, it is important to remember about safe levels of damming. These should be no more than 30–40 cm. In order to provide additional protection against undesirable effects of the partition, it is recommended to strengthen, for example with faggots, the edges and the bottom of a watercourse immediately behind a tight partition (so-called tailrace).

Examples of fixed wooden barriers.

Peat barriers. The simplest form is a filling of a short section (2–10 m) of ditch by peat. This type of solution may function on low flow rate watercourses, and the peat should be poorly mineralized. Ditch sections left between the partitions will spontaneously overgrow over time. Such peat barriers, although common and very useful in boreal bogs, in Poland are not very frequent, due to insufficient resistance for episodes of high water flow. In Poland, this solution is not very popular due to its low resistance to high flow episodes. Dry summers are now common in the Polish climate, but there are occasional wet or very wet periods, usually in autumn, winter or spring.

Example of peat barrier.

Peat dam strengthened by wooden elements.

Mixed wooden-peat or **wooden-clay fixed barriers.** Barriers made of two watertight wooden walls, filling the space between them with peat or clay, are very durable and effective. Peat can be loose or in jute bags. Wooden parts in this solution do not need to be sealed. The tightness of the barrier is assured by the peat/clay filling.

Example of wooden-clay barrier.

Fixed barriers made of artificial materials. In addition to wood, peat and earth, the barriers can be built using various types of plastic and sheet metal. They have the advantage of being much lighter, easier to transport and cheaper. Sometimes simple board/plywood gates are used for ditch blocking. These are small structures that help to stop the drain by, for example, backfilling the ditch with local soil. The gate is made of one piece of board which is driven or pressed into the substrate. The barriers may be built also by joining plastic sheet piling, which allows not only to build single barriers blocking the ditches but also building long plastic walls. There are advanced solutions available on the national marked, developed for hydraulic engineering structures.

The plastic barriers are usually more expensive than the wooden ones, but the difference may disappear after including the cost of field installation and may be reversed after including the costs of further maintenance. However, despite technical advantages, this solution is not, at least till now, frequently used in Poland. There are only a few examples of using such barriers in implemented restoration projects. The main reason is general resistance of the Polish nature conservationists society against implementing artificial elements in the field, in particular plastic ones.

Example of plastic barrier.

Damming with the existing hydrotechnical elements. Culverts under roads can be easily converted into a small damming facility. The construction of a stoplog seal at the inlet of the culvert (grooves in concrete walls, in which boards – stoplogs – are placed) allows for obtaining a dam with adjustable level, and building a well around the culvert inlet, for example using concrete rings, provides a damming and release structure. Damming thresholds can be built based on the existing bridges, which can serve for example as thresholds stabilizing the water level in the fen.

Damming culverts. Another solution for improving water conditions within fens in the case of a dense network of drainage ditches surrounding the fen may be the construction of so-called „throttling" culverts, i.e., culverts with cross-sections naturally limiting the outflow. The parameters of the culverts used should be adjusted to the place where they are to be installed. The width of the ditch will determine the use of one or two pipes (preferably PEHD) with the right diameter. The construction of culverts with the use of pipes with relatively small diameter, embedded in a wooden and earth dam, will allow limiting the outflow of water from the fen, due to the reduction of the ditch outflow capacity. Such a solution is also extremely important when ditches make it impossible to reach the surface of the habitat covered by the conservation measures. Building such culverts of appropriate width may enable the owner to easily reach the wetland part of the fen in order to perform manual mowing, and thus significantly affect the owner's attitude to the whole process of habitat protection. If necessary, further reduction of water drainage can be achieved by clogging the culvert further with wooden plugs or sandbags. This solution is attractive in practice also due to very simplified construction and water-legal procedures related to the construction of culverts.

Example of daming culvert. Photo credit: Dorota Horabik.

Adjustable gates. The most commonly used technical solution in Poland so far, effective and durable, but constituting a foreign element in the environment. These gates consist of concrete walls with cut-out guides, into which horizontal boards/stoplogs are inserted. Another solution is based on a lifting metal slide gate; the connections of such gates to culverts under the dyke are frequent. Similar solutions installed at pond drains are called outlet monks. To prevent malicious alteration of the damming level, solutions should be provided for enclosing the gate or monk with a steel bar cage with a padlock. Similar gates, with sliding stoplogs, can also be made of wood, which should be recommended as a more natural material.

Example of adjustable gate.

Adjustable overflows with flexible pipe. A type of flow through a dyke that is popular in Great Britain, simple, cheap and ingenious, easy to regulate; in Polish conditions probably not sufficiently resistant to malicious human actions. It involves burying a flexible pipe up to 25 cm in diameter in the dyke and setting the height of its inlet and outlet in order to determine the desired water level. This is a good method to use in beaver ponds, where there is a problem with flooding of neighboring areas, although then the pipe inlet must be extended into the pond and adequately protected so that the beavers do not clog it.

Filling entire ditches. Often the best solution would be to backfill the entire drainage ditch from the fen. The most common material used for this purpose is local material from the immediate vicinity of the ditch. When gathering the material, one should strive to protect valuable fragments of the fen surface and the valuable species sites; however, in most cases one should not be afraid of local infringement of vegetation, which in conditions of sufficient moisture regenerates quite quickly. It is also possible to form local ponds – widening of the ditches, using peat to backfill the ditch in other areas

Backfilling entire ditches is often the most beneficial solution for mires, although it is sometimes the most expensive one. In Poland, to date, filling drainage ditches is not very frequently used in practice, due to high costs and common problems with finding appropriate material. Nevertheless, in some cases (in particular slope fens; needs of restoring water percolation by the peat) this is an only effective solution.

Example of a filled ditch in Lithuania.

Filled ditch on meadow fen near Michałowo, result of bird conservation project implemented by Polish Society of Birds Conservation (PTOP).

Sometimes it is advisable to limit the drainage effect of ditches to a certain extent, but without their complete removal. This can be achieved by reducing the cross-section of the ditches by backfilling them only to a certain level. Examples would include construction of a biological structure made of faggot bundles at the bottom of a ditch, filling the ditch to the desired height, and at the same time initiating the filling with rubble and silt carried by the water flowing through it. Biological structures made of faggot bundles are made up of cut wicker shoots tied together by wire in the form of bundles (approx. 20 cm in diameter), which are placed in the bottom part of the ditch across its entire width.

Other facilities. Variety of other solutions may be necessary in specific cases. Sometimes, longer causeways are used for blocking wider water runoff. Some rewetted peatland needs to be hydrologically isolated from the neighborhood: then the hermetic wooden or plastic walls are installed. Ditches and watercourses which must cross the peatland are sometimes sealed by hermetic membranes, to prevent peatland draining. On the other hand, some watercourses in the neighborhood sometimes need to raise the bottom and water level, to raise the base of the erosion and drainage of the adjacent peatland: for this gravel prisms on the bottom of the watercourse are commonly used. More advanced hydrotechnical facilities may be used for specific purposes, but goes beyond the scope of this handbook.

When choosing technical solutions, it is worth using those that will not require special care and frequent repairs in the future. Optimal solutions are those that will not require any maintenance for the assumed period of time, i.e., about 20–25 years. Unfortunately, even a perfectly made blockage or gate requires a check from time to time. Water pressure, which is often underestimated, can be the cause of its malfunction. Relatively often, the sides of the gate are washed out and a bypassing drain forms. When planning gates in dry periods it is easy to underestimate the drainage force that can occur after heavy rain or in the spring. Beavers, which take advantage of the opportunity to raise water level even higher, may also be the cause of the gate's malfunction. During the period of „use" of those blockages by the beavers, taking care of its tightness (as opposed to taking care of the protected fen, which may be flooded) is unnecessary. Problems may arise when beavers leave the dam formed on the gate, which in such cases is usually destroyed. For managing all possible situations, a regular site survey by the site manager is necessary.

Many practical considerations, as well as tricks and tips concerning ditches blocking on forested peatlands, are summarized in a Swedish brochure by Lindh (2022), found as very useful also in Polish conditions.

More information on details of technical solutions used in Poland to neutralize the negative impact of drainage systems may be found in other publications, as: Pawlaczyk et al. 2002, Kujawa-Pawlaczyk & Pawlaczyk 2005, Pawlaczyk et al. 2005, Herbichowa et al. 2007, Makles et al. 2014, Center for the Coordination of Environmental Projects 2016).

Supplementary to water-managing measures, sometimes **vegetation or soil management measures** are implemented as part of peatlands rewetting projects. If the drained peatland is overgrown by trees, removing trees may reduce water evapotranspiration and may rescue remnants of typical bog vegetation. On the other hand, trees removing expose more peatland surface for insolation, enhancing its drying up. However, this measure is commonly implemented in Polish projects.

In many cases, vegetation of the peatland is mowed or grazed. It is done mainly for biodiversity reasons, as the measure for maintaining relevant habitats. It must be noticed that sometimes full peatland rewetting is in conflict with feasibility to mow the vegetation.

On very degraded bogs and fens, topsoil removal is sometimes applied, for removing degraded peat layer and opening the healthy moist peat as a surface for peatforming vegetation redevelopment. Such measures may be effective, but – due high costs and not enough implementation experience – are still not common in Polish rewetting projects.

On some bogs, attempts of reintroduction of peat forming vegetation (as artificial sphagna implementation) were implemented, with promising results. However, such measures are still rare in Poland and experimental only.

Trees removing to open and rescue the remnants of original peatland vegetation is a part of many peatland rewetting projects.

Icelandic experience

Iceland is a mountainous land with a short growing season, frequent freeze-thaw cycles during winter and powerful erosive forces. Therefore, backfills must be made very thoroughly and dams frequently. During the process, it is also very important to minimize the area of ground that is left uncovered because it may take a long time for vegetation to colonize.

In Iceland, rewetting has most often taken place on uncultivated land, where spoil banks are still available or at least partly available. The most common practice is to use soil on site to either backfill or dam the ditches, or a combination of both methods. It is important to regularly compress both the infill material and dams, not only in the end when filling is complete. If construction of dams and backfills is properly executed and according to site characteristics, experience has shown that need for maintenance can be negligible, which is extremely advantageous as restoration sites are often located in remote areas.

The main goal of peatland restoration is to raise the water level by stopping water from leaving the rewetted area through artificial channels (ditches), ensuring that water is evenly distributed throughout the site and fills the whole peat profile. It is important that surface water flows naturally, e.g. in old streambeds, and that water flow is impeded on or near margins of backfilled ditches to prevent water erosion and consequent destruction of dams and infills. It is crucial to study the site thoroughly before operations start and to work with respect to site conditions.

Infilling: During backfilling of ditches, there are a few important principles to keep in mind:

- Remove and conserve all vegetation from ditch and spoil bank surfaces and use them to cover the infill and other possible exposed soil surface:
    - The infill is more stable when soil is put on soil;
    - Vegetation on the surface prevents erosion;
    - Turf and vegetation can be used as a barrier to direct water in the right way, e.g. away from the former ditch, and to slow down surface water flow;
    - Some wetland plant species may have only survived in the wet conditions in the ditches since the site was drained. Therefore, it is important not to submerge them so that their further establishment and colonisation at the restored area is not hindered.

Due to the decomposition of spoil bank material and ditch erosion that occurs with time, the volume of the ditch is often greater than of the spoil bank. A solution that has presented good results to this problem is to alternately fill the ditch excessively and partly with aprox 2–5 m interval, depending on slope. The excessively filled part stops surface waterflow through the former ditch and the partly filled part acts as a shallow pond. The result is a mosaic of microhabitats with variable elevation from the ground and open waters in between.

Damming:

When no or insignificant spoil banks are available on site, damming of ditches with soil/peat is the most common method. Material is excavated close to the ditch, making small depressions or ponds. Alternatively, material from the sides of ditches in between dams may be used, making the ditch banks less steep and the shape of the resulting pond more organic. When dams are built, similar principles apply as to when ditches are infilled, with regards to f.x. preserving of vegetation and damming interval being determined by slope.

Mixed restoration methods used at Sogn site.

In Icelandic rewetting projects, experience with using other methods and other materials than in situ peat is very limited. Dams with controlled height have been tried where there is a need to manually adjust water levels, with good results.

4.2. Monitoring and adaptive management

Polish experience

Monitoring of changes, in particular of water conditions and vegetation, is a necessary part of each rewetting project. However, it is usually difficult to organize, due to most typical project financing schemes, providing funds for project implementation only. There are no financial sources ensuring long-term funding of monitoring, thus it needs to be financed by beneficiary own resources, which are usually limited. Nevertheless, monitoring needs significant investments of human and financial resources. Without it, the assessment of the rewetting results will not be possible, as well as effective learning by project experience.

The common BACI (Before-After, Control-Impact) monitoring scheme may be recommended. Often, only the BA scheme can be used, because from the point of view of rewetting objectives no parts of the site should be left as not-rewetted only for control.

Well established baseline is a precondition of good monitoring. Results of the peatland initial survey (see above) may be in some cases used as monitoring baseline – but only if the methodology of the survey was prepared for this (e.g. survey plots are well-located). Establishing a water level baseline requires not only single-time water level measurement, but recording water level dynamic. One hydrological year (November-November) seems a minimum but the data cover several years (as the water conditions change from year to year during various precipitation etc) are much better.

The very basic buy non-ommitable part monitoring is always regular site visiting. It is best if the site is regularly surveyed by the site manager: the person and the group of persons clearly linked with the site, involved in its conservation and filing responsibility for it. Such visual checks, if done by professionals with the particular site experience, can provide a lot of valuable information. Most of the significant changes can be registered.

The repeatable photography of the site may also be very helpful. It is worth to assure it is always done from the same points, in the same directions, with the same photo parameters. The aerial photos are also the perfect source of information. In Poland the public ortophotomaps (repeated by the state services every year) are used as a standard source. In recent years also the own aerial photos for UAVs are used more and more often.

However, these general surveys are usually supplemented by advanced field monitoring of the key ecological factors.

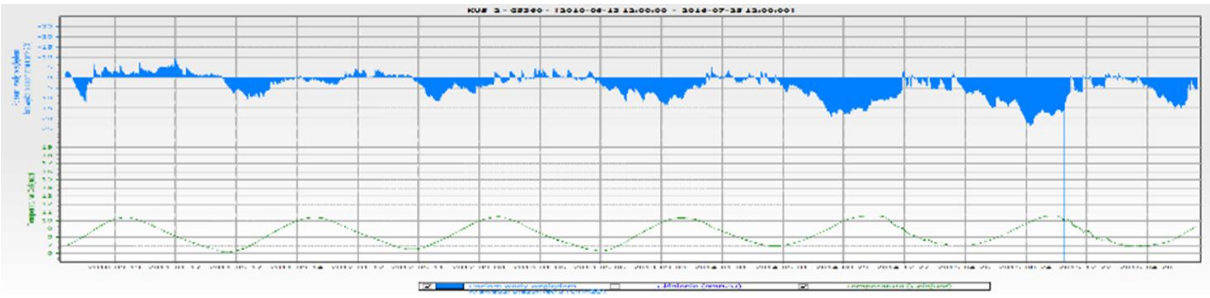
The basic ecological factor, which must be monitored in a rewetting project, is the water level. The most used monitoring techniques are:

Water conditions map is a map of the site made by visual assessment, without specific equipment. For some wetlands, in particular more complex ones, containing also some water pools and remnants of open ditches, it may be a useful monitoring tool. The water level in each pool or ditch should be recorded relative to the edge of the ditch/pond. In particular, presence/absence of the water in ditches need to be marked. For each damming facility, the difference of upstream and downstream water levels should be recorded. The areas "dry – passable in regular shoes", "wet – requiring rubber boots", and "flooded" should be mapped. Such a map, if prepared recurrently, each quarter, by several years of various precipitation, provide very useful information on water conditions,

Water level measurements in observation wells is the basic and the most used water monitoring measure. The wells must be adequately distributed on the site, because water dynamic in various parts of the peatland is usually quite different. The water level is usually recorded manually or by automatic recorder (diver). It is important to collect data on water level dynamic in an annual cycle, not only single measurements. If manual recording is applied, the relevant frequency must be assured (at least once a month). If automatic recorders are used, daily measurements are possible and useful, even more frequent ones can be used for analyzing specific aspects (as hourly data for evapotranspiration impact).

It must be noticed that assessment of project results requires at least a few years of water monitoring before implementation of rewetting measures. In Poland rainfall and water conditions in particular tears vary a lot, thus one-year monitoring is not enough for characterisation of them. Of course, using the data from shorter periods (several months or even single time point data) is not reliable. The most common mistake is organizing water monitoring only shortly before (several months, one year) implementation of rewetting measures. Such approach is fully understandable in real conditions of rewetting projects implementation in Poland, but strongly diminishes monitoring efficiency.

In some specific types of mires, for example of alkaline fens, it may be useful to monitor not only the water level itself, but also its characteristics, e.g., chemical and physicochemical. Only with this information does it become possible to interpret the hydrology and ecology of the fens supplied by groundwater, by revealing the direction of this supply. They can also warn about the changes that threaten the fen. For such characteristics it is usually sufficient to examine them at longer intervals, e.g., once a year. Depending on the needs and specific features of a particular site, local monitoring should be extended in the direction of recording of selected physicochemical parameters of water at selected points in outflows and observation wells.



Water level monitoring is not omittable element of the knowledge about the peatland in concern. Only on long-term datasets trends and regularities are visible.

Parallely to the water level monitoring, also the **vegetation monitoring** is commonly used. Vegetation usually reacts well on other ecological conditions, thus is often used as a proxy for ecohydrology characterization. Usually, permanent plots are used. In order to identify changes in vegetation effectively and quickly, it is necessary to repeat the description of the vegetation on exactly the same area. The only way to achieve such repeatability is either to permanently mark the corners of the observation plot in the field, or at least to mark the observation point. This can be done, for example, by means of posts with an underground metal marker, with distances measured to the characteristic features of the terrain. It is not possible to count on the fact that the repeatability of the observation points will be ensured by measuring their coordinates with the use of GPS. Of course the accuracy required will not be provided by a tourist-grade GPS receiver measurement (it has an average location error of 2–6 m, and this error doubles when it comes to the accuracy of repeated location of a point with previously measured coordinates. Even the use of more accurate and costly location techniques (GNSS, EGNOS, RTK corrections) is not sufficient since – although these techniques can achieve high accuracy in measuring the coordinates of a field point – it is still difficult in real time and outside the range of mobile network coverage to reach precisely the point with the set coordinates. Although the estimated scale of Braun-Blanquet coverage used for phytosociological studies is well suited for describing and comparing vegetation, it does cause some loss of information when used for the study of changes in species coverage on fixed surfaces. In grades 1 and 2 of the scale, up to five changes in species coverage (clearly visible to the observer) may not be reflected in a change. If vegetation is used as a proxy for climate impact estimation (in particular, GEST method, see below), methodology of the vegetation monitoring must clearly include variables used by estimation methodology.

Some methodological problems and tips for organizing monitoring of water and vegetation of the peatlands are presented in the publication of Pawlaczyk & Kujawa-Pawlaczyk 2017.

Implementation of vegetation monitoring.

In Poland, national standards were elaborated for monitoring of natural habitats. The methodologies are collected on the official natural habitats monitoring website. They include elements of water and vegetation monitoring. The methodologies were developed for monitoring in national scale and are not fully relevant for efficient monitoring of particular sites, nevertheless after some improvements (adding more precise and continuous water level recording, fixing the vegetation relevees plots) may be used for monitoring of rewetted peatlands covered by natural habitats. The added value is the possibility to compare results with the status assessment of the habitats in other places in Poland.

In many cases, monitoring of some indicator species or groups of species may be useful. In particular, birds are animals usually reacting fast on habitat improvements. In case of creating open water surfaces, impact on amphibians and dragonflies can also be expected. Methodology of animal monitoring on rewetted wetlands is usually the same as in other habitats and may be found in relevant monitoring guidances.

The best solution is to monitor the site as part of its regular surveys, and react to monitoring results by adjustment of conservation/rewetting measures. For example, linear water outflows from the peatland may be visible only temporarily, thus should be blocked always when found. Nevertheless, such an approach requires permanently available funds for rewetting improvements, which is rare in practice. Sometimes relevant adaptive management is achieved by consecutive projects financed externally from various sources. Most often, 2–3 projects working with the single peatland by 10–12 years in total are necessary for achieving the best rewetting level.

Icelandic experience

As in Poland, monitoring the success of restoration projects in Iceland is often difficult. Funding for monitoring is harder to secure than funding for restoration activity, but the lack of skilled professionals and site remoteness also add to the problem. Thus, Icelandic peatland restoration projects have suffered from lack of monitoring and adaptive management. The execution itself has generally been viewed as the sole part of restoration projects and very little monitoring has followed. Monitoring has mainly consisted of informal checks on restoration structures such as dam and backfill conditions, but also of the water level, both manually by professionals and land managers, and by divers when possible. In recent years, the use of drone images has increased not only during the planning phase but also to monitor general changes at restoration sites.

Currently, efforts are being made to improve monitoring procedures according to the SER standards with regards to implementation quality, duration and ecosystem impact (Gann et al. 2019). In summary, the lack of skilled manpower and appreciation of the importance of baseline setting, monitoring and adaptive management have posed hurdles for successful rewetting for climate and biodiversity benefits, as well as gaining deeper expertise in the matter.

5. Reporting and presentation

5.1. Success need indicators

Usually, for creating efficient public message or for reporting to funders, the peatland rewetter need to present synthetic and measurable results, i.e. to provide, by quantitative indicator, the information how successful rewetting is. Usually, indicators linked with the water retention aspects, the conservation status of natural habitats or species, or the climate impact are used.

5.2. Water retention

Increasing the water level in a ditch is an easily visible variable, as the difference of water level upstream and downstream of each dam. **Extension of time of ditches filling by water** is easily recordable by basic hydrological mapping.

Increasing the water level in a peat is the indicator looking simple, but difficult in real implementation. Measurements of water level in piezometers are necessary. Although some numbers can be easily generated (as difference between water level in selected place in the selected time points after and before rewetting), interpretation of them is not so easy. Firstly, the single point or even a few points not necessarily are representative for the whole peatland. The water level dynamic in the center of the moire is usually different than at the mire edge. Water level in the ditch is usually not the same as in the peat. Water level is not a stable value, its rather dynamic and changes both during the year and in wet/dry years. Thus, such single number is not very informative until a lot of methodological details explaining how it was calculated. Most reliable indicator is an "average change of water level", calculated for selected area by modeling of the water surface in a peat for situations before and after rewetting.

Volume of the water retention may be calculated from water level measurements or estimation, by modeling of the water surface in a peat and calculating over the year.

5.3. Biodiversity indicators

Area of restored habitats is the indicator most often asked by funders, but needs to be carefully clarified. In particular, it is necessary to clearly indicate, what exactly will be counted towards, i.e. what area will be considered as "restored".

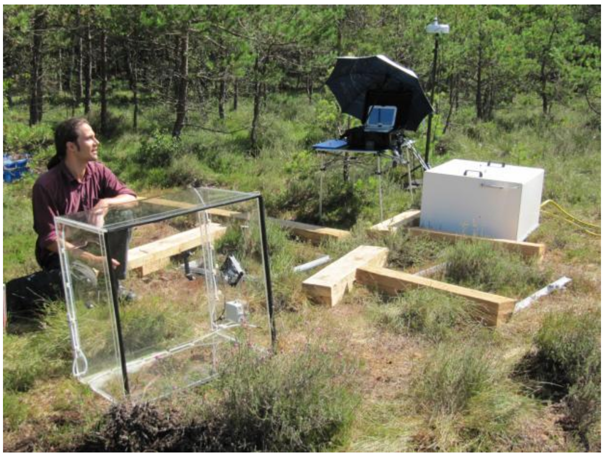
Improvement of conservation status (or area of habitat with the conservation status improvement) is usually based on the approved methodologies of conservation status assessments (see above).

Flora / fauna indicators may be site-specific indicators based on the selected species. Various variables, as the population number or density, or more advanced estimators of population conditions, may be used.

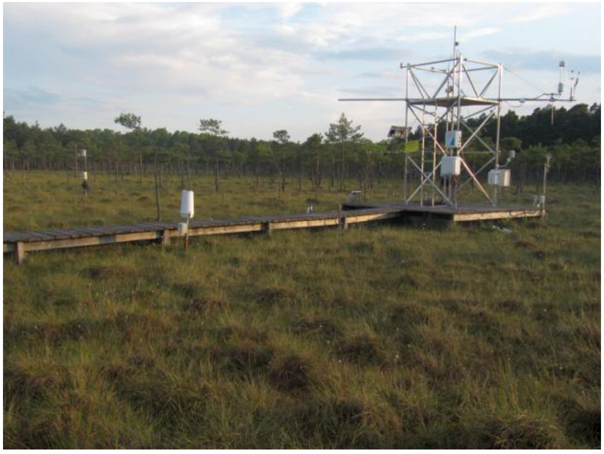
5.4. Climate benefit indicators

Saved peat volume is the basic, and in most cases the most reliable indicator, based on the calculation of the peat volume located between peat-conserving water conditions before and after rewetting. For example, modeling of the annual maxima of summer water depression in a peat before and after rewetting may be calculated, and the peat volume between them may be interpreted as "peat saving due to rewetting". Such interpretation is based on rather realistic assumption that peat which is at least temporarily above the water level will be decomposed earlier or later, thus increasing permanently saturated zone will save the peat in this zone.

GHG balance improvement is a very useful indicator, but needs very advanced and costly field measurements of GHG emission. Eddy covariance method or chamber method is used. Both methods need use of specific instruments for gas concentration measurements. Chamber method is based on recording changes of gas concentration in chambers installed on the peatland surface; thus provides only point results (gas exchange exactly at the point of measurement). Eddy covariance method is based on correlation between air movement and gas concentration, thus provides data averaged for a bigger part of the peatland surface, nevertheless requires heavy equipment to be installed on the peatland.



Chamber measurements of GHG (Słowiński National Park, Poland, PeatRestore project).



Eddy covariance measurements of GHG (Kusowo Bog, Poland).

GEST approach is based on assumption that similar mire vegetation has similar GHG emission factors. Thus, vegetation is used as the emission proxy. Vegetation (with some additional information, such as habitat moisture) need to be mapped as predefined "GEST units". On the basis of GEST units area and relevant emission factors from literature, the total emission may be calculated. The method may be used only for bigger sites with differentiated vegetation, where at least 30–40 units can be mapped. More details of method application are described in Jarašius et al. (2022).

IPPC factors approach is similar as GEST one, but extremely simplified. Land cover/use, with rough estimation of water conditions (as "very wet/wet/dry") is used as a proxy and emission factors are provided in the IPPC guidance. The method was developed for GHG emission reporting in the national scale; figures provided from single peatland are not realistic.

Annex: examples of peatlands rewetting in Poland and Iceland

Wetland birds habitat conservation by OTOP (Poland). In the end of XX century, the dams blocking water output was implemented by OTOP (Birdlife Poland) on Chełm fens. The activity was recently continued and extended to other sites as part of the aquatic warbler LIFE project. The water is raised to the level optimal for birds but enabling habitat maintenance by hay mowing.

Bagno Całowanie rewetting attempt (Poland). Całowanie Fen, one of the biggest fens in central Poland (ca 30km^2) was strongly drained by network of ditches since 1950s. From the 1990s illegal peat extraction started in the central part of the fen, significantly accelerating outflow of groundwater due to connection of the mining site to a major drainage canal. The activity was carried out under the pretext of building fishponds and lasted until 2007. In the beginning of XXI century, the ditches were partly dammed by wooden barriers, as a part of a project financed by Global Environmental Fund, implemented by Centre of Wetland Conservation (CMoK), the nature conservation NGO founded by wetlands lovers. It was probably one of the first attempts at wetland rewetting in Poland. Experiments on vegetation and soil management (mowing; topsoil removal) were then implemented, as part of LIFE project "Conservation and upgrading of habitats for rare butterflies of wet, semi-natural meadows". However, the rewetting was only partly successful due to parallel strong human pressure, in particular maintaining and renovation of ditches in the neighborhood, draining for development of the airplane landing pad and the golf area, as well as destruction of some barriers by farmers for "improving meadows water conditions". Despite Natura 2000 status, the site's deterioration continues; the projected habitat alkaline fens almost disappeared. New attempts to discuss more ambitious rewetting at least the central part of the fen (with maintaining the peripheral parts drained as the farmers want) are presently considered.

Baltic bogs conservation in Poland. Remnants of "Baltic type raised bogs" in northern Poland were surveyed and taken under active conservation by Naturalists Club Poland, the nature conservation NGO, as part of several nature conservation projects in 2003–2015, financed by LIFE and by EU funds distributed nationally. On some bogs the conservation measures are still continued by other bodies (in particular nature conservation authorities). The project concerns ca 40 sites, i.e. all known national resources of this kind of bogs. For bogs rewetting, several thousands of small dams were built on drainage ditches. The rewetting was partly successful, in particular concerning the bogs not so strongly degraded originally. However, strongly drained bogs remain dry also after blocking all ditches. The project concerned mainly state-owned bogs in management of State Forests and provided wide experience on rewetting techniques, monitoring, administrative & logistic issues, but did not need more advanced stakeholders management. Results of the first part of the project were summarized by Herbichowa et al. (2007). More at the website.

Ditches blocking in the Baltic bogs conservation project.

Alkaline fens conservation in Poland. Consecutive nature conservation projects financed by LIFE and implemented by Naturalists Club Poland, concerning alkaline fens (7230 Natura 2000 habitat) in the whole Poland. Several hundreds of various dams on drainage ditches were built to rewet drained fens; in particular „close to nature" ditches blocking techniques (as sedges planting) were used. The projects concern mires with rather complex hydrology and stakeholders relationships, thus provide extensive experience. More at Stańko et al. (2018) and at the website.

Mires conservation in NE Poland. Several peatlands rewetting projects implemented in NE Poland by Polish Society of Nature Conservation (PTOP, former North Podlasie Society of Birds Conservation), funded from various sources, from 1990. Ca 2 thousands of various dams on drainage ditches were built and several kilometers of ditches were filled, to rewet various peatlands: from drained raised bogs to meadows on a fen peat; in particular in Narew valley, Gródek-Michałowo Basin, Knyszyn Forest, Białowieża Forest; Gązwa, Sołtysek, Zielony Mechacz raised bogs. Due to various site ownership (from their own, through single collaborative owners, to the mosaic of farmers with contradictory interests), various approaches are trained. For outflow blocking mainly wooden or concrete barriers were used. In particular, an impressive project of restoration of meandering Narewka river in Białowieża was implemented: as a result of re-creating river meanders across fen in river valley, the fen itself was significantly rewetted.

Restored Narewka river in Białowieża (credit Edyta Kapowicz). Re-creating river meanders was followed by significant valley fen rewetting.

Small water retention by State Forests (Poland). Two big projects financed from EU funds, implemented in the majority of forest districts in Poland, concerned retention of water, mainly by restoration of md-forest ponds. Nevertheless, rewetting of mid-forest peatlands was also included. In particular, thousands of ditches dams were built. Although most of them were for forest ponds restoration, a significant part also included peatland restoration. In particular, in forest district Strzałowo in Mazury Lakeland, a lot of peatlands were rewetted by filling or daming drainage ditches (Ryś 2011).

"In harmony with nature – LIFE for Janowskie Forests" (Poland). Project implemented 2015–2019 by RDOS Lublin, the nature conservation authority, concerning comprehensive conservation of Janowskie Forest Natura 2000 site, including extensive rewetting of mid-forest mres and bog forests by blocking drainage ditches. 33 water damming facilities were built. More at the website.

Biebrza fens conservation by Biebrza National Park (Poland). LIFE project implemented by the Biebrza National Park in 2013–2019. Advanced nature survey, including remote sensing, was used as preparatory action. 15 water raising facilities were constructed, partly restoring the whole hydrological system. The project was implemented in the agricultural landscape, under the strong pressure of stakeholders. More at the website.

Peatlands rewetting by Kampinos National Park (Poland). Two LIFE projects implemented by the national park, focused on rewetting in a landscape scale. In 2013–2020 44 water facilities were constructed to maintain the water in the wetlands. Presently the continuation, focusing on more advanced water regulation in draining channels, is under implementation. More at the website.

PeatRestore project for bogs in Słowiński National Park. Attempt of rewetting drained and forested raised bogs, implemented in 2015–2022 by Naturalists Club, the nature conservation NGO, as a part of bigger international LIFE project, justified by climate arguments. The first bigger rewetting project in Poland focused on climate change mitigation. More than 300 water damming facilities were constructed, blocking the ditches.

Trees overgrowing peat forming vegetation were removed. Nevertheless, due to dry periods, most of the ditches remain dry. Better results are expected only after some wet years, for which we are still waiting for. More in Pawlaczyk (2022) and at the website.

Ditches blocking in the PeatRestore project in Poland.

Bagno Wizna case (Poland). Big fen in NE Poland is strongly drained, degraded, used by farmers as meadows; peat is consecutively decomposing. However, the site still provides valuable habitats for wetland birds and is designated as a protected area: Natura 2000 site. Due to abandoning of some land and lack of ditches maintenance some spontaneous rewetting processes, followed also by improving bird habitats, were started recently. Attempts of ditches renovation by farmers were recently banned by nature conservation authority, which caused farmer protests. Hydrological expertise was developed, proposing compromise between peatland conservation and farmers interest: site zonation and partial rewetting of the fen by daming some ditches (to stop the peat decomposition), but allowing maintenance of most of the ditches in general. Even such compromise is generally rejected by farmers. But continuation of farming as usual will lead to consecutive site degradation and finally also to ceasing farming possibility. The future of the site remains unclear.

Vatnsmýrin (Iceland) in Reykjavík: Vatnsmýrin is a peatland area in the centre of the capital that feeds the iconic Reykjavík Pond. The site was heavily degraded after decades of degradation. In 2009 the city of Reykjavík and The Nordic house, in Vatnsmýrin jointly started work to improve habitat for birds and wetland vegetation, decrease water pollution and improve waterflow in canals. Activities included removing construction waste and pollutants form site, eradicating invasive species and landscaping. An adjustable dam was installed to control the outflow of the area to Tjörnin.

Framengjar (Iceland) in the vicinity of Mývatn. A vast and fertile alluvial plain made by deposits from the river Kraká. A part of an internationally important bird area (Mývatn and vicinity) and one of Iceland's six designated Ramsar sites. A dynamic area with ponds, streams and diverse and lush vegetation. Historically the river Kraká was dammed for further irrigation and deposition of sediments. The area was very important because for grazing and haymaking as the harvest was reliable although working conditions were difficult. In the 1950s 20 km of ditches were excavated to drain part of Framengjar to make it machinable (workable with machines). The drainage was never fully successful, and haymaking mostly stopped in the 1970's. At that time a part of the area was restored by local farmers. In 2003 the NGO SUNN and Icelandic Road Authorities continued the restoration with the aim of restoring former habitat and hydrology. Animal welfare was also an issue as ditches had proofed to be a safety hazard for livestock (Aradóttir & Halldósrson 2011).

Bibliography

Andrason F. R. 2022. Áskoranir og tækifæri í endurheimt votlendis á Íslandi. Soil Conservation Service of Iceland. Gunnarsholt, Iceland.

Aradóttir Á. L., Halldórsson G. (eds) 2011. Vistheimt á Íslandi. Agricultural University of Iceland & Soil Conservation Service of Iceland.

Campbel-Palmer R., Gow D., Schwab G., Halley D., Gurnell J., Girling S., Lisle S., Campbel R., Dickinson H., Jones S. 2016. The Eurasian Beaver Handbook: Ecology and Management of Castor fiber. Pelagic Publishing Ltd., Exeter: 202.

Centrum Koordynacji Projektów Środowiskowych 2016. Wytyczne do realizacji zadań i obiektów małej retencji i przeciwdziałania erozji. Załącznik do Decyzji nr 552 Dyrektora Generalnego Lasów Państwowych z dnia 25.11.2016 r. (Center for Environmental Projects Coordination 2016. Guidelines on realisation of actions and facilities of small retention and erosion counteraction. Annex to the General Director of SFH no 552 of 25.11.2016).

Czech A. 1999. Bóbr. Gryzący problem. Towarzystwo na rzecz Ziemi. Access on 15.06.2018: www.tnz.most.org.pl/dokumenty/publ/inne/gryz.htm.

Czech A. 2005. Analiza dotychczasowych rodzajów i rozmiaru szkód wyrządzanych przez bobry oraz stosowanie metod rozwiązywania sytuacji konfliktowych. Instytut Ochrony przyrody PAN, Kraków. Accessed on 05.01.2018: http://www.kp.org.pl/poradniki.

European Environment Agency 2021. EUNIS terrestrial habitat classification review (tabular) – version 1, Nov. 2021.

Gann G. D., McDonald T., Walder B., Aronson J., Nelson C. R., Jonson J., Hallett J. G., Eisenberg C., Guariguata M. R., Liu J., Hua F., Echeverria C., Gonzales, E. K., Shaw N., Decleer K., Dixon K. W. 2019. International principles and standards for the practice of ecological restoration. Second edition. Restoration Ecology S1–S46.

Grootjans A. P., Adema E. B., Bleuten W., Joosten H., Madaras M., Janáková M. 2006. Hydrological landscape settings of base-rich fen mires and fen meadows: an overview. Appl. Veg. Sci. 9: 175–184.

Grootjans A. P., Bulte M., Wołejko L., Pakalne M., Dullo B., Eck N., Fritz C. 2015. Prospects of damaged calcareous spring systems in temperate Europe: Can we restore travertine-marl deposition? Folia Geobot. 50: 1–11. DOI:10.1007/s12224-015-9214-z

Gunnarsson T. G. 2020. Búsvæði og vernd íslenskra vaðfugla. Tímarit Hins íslenska náttúrufræðifélags, 90 (2–3): 145–162.

Günther A., Barthelmes A., Huth V., Joosten H., Jurasinski G., Koebsch F., Couwenberg J. 2020. Prompt rewetting of drained peatlands reduces climate warming despite methane emissions. Nature Communications 11, 1644; doi.org/10.1038/s41467-020-15499-z

Herbichowa M., Pawlaczyk P., Stańko R. 2007. Ochrona wysokich torfowisk bałtyckich na Pomorzu. Doświadczenia i rezultaty projektu LIFE04NAT/ PL/000208 PLBALTBO GS. Klub Przyrodników, Świebodzin. Accessed on 8.06.2018: http://www.kp.org.pl/pdf/ear.pdf.

Icelandic Institute of Natural History. 2018. Breeding birds. Official website of the Icelandic Institute of Natural History. Accessed on 13.12.2023: www.ni.is/en/fauna/birds/breeding-birds.

International Wader Study Group 2003. Waders are Declining Worldwide. Paper presented at the Conclusions from the 2003 International Wader Study Group Conference, Cádiz, Spain. Wader Study Group Bulletin, 101/102: 8–12.

Jabłońska E., Kotowski W., Giergiczny M. 2021. Projekt Strategii Ochrony Mokradeł w Polsce na lata 2022–2032. Generalna Dyrekcja Ochrony Środowiska.

Janiszewski P., Hanzal V., Misiukiewicz W. 2014. The european beaver (*Castor fiber*) as a keystone species – a literature review. Balt. For. 20, 2: 277–286.

Jarašius L., Etzold J., Truus L., Purre A-H., Pakalne M., Sendžikaite J., Zableckis N., Kirschey T., Bociąg K., Strazdiņa L., Ilomets M., Herrmann A., Pajula R., Pawlaczyk P., Chlost I., Cieśliński R, Gos K, Libauers K., Jurema L. 2022. Handbook for assessment of greenhouse gas emission from peatlands. Applications of direct and indirect methods by LIFE Peat Restore. Lithuanian Fund for Nature, Nature and Biodiversity Conservation Union, Vilnius.

Joosten H., Sirin A., Couwenberg J., Laine J., Smith, P. 2016. The role of peatlands in climate regulation. In: Bonn A., Allott T., Evans M., Joosten H., Stoneman R. (eds). Peatland restoration and ecosystem services: science, policy and practice. Cambridge University Press/British Ecological Society, Cambridge: 63–76.

Kotowski W. 2021. Oszacowanie emisji gazów cieplarnianych z użytkowania gleb organicznych w Polsce oraz potencjału ich redukcji. Fundacja WWF Polska.

Kotowski W., Dembek W, Pawlikowski P. 2017. Poland. In: Joosten H., Tannenberg F., Moen A. (eds). Mires and peatlands of Europe. Status, distribution and conservation. Schweizerbart Sci. Publ., Stuttgart: 549–571.

Książkiewicz Z. 2010. Higrofilne gatunki poczwarówek północno-zachodniej Polski. Poradnik ochrony siedlisk poczwarówki zwężonej *Vertigo angustior* (Jeffreys 1830) i poczwarówki jajowatej *Vertigo moulinsiana* (Dupuy 1849). Klub Przyrodników, Świebodzin.

Kujawa-Pawlaczyk J., Pawlaczyk P. 2005. Ochrona mokradeł. In: Gwiazdowicz D.J. (eds). Ochrona przyrody w lasach. T. II: Ochrona szaty roślinnej. Polskie Towarzystwo Leśne, Oddział Wielkopolski, Poznań: 81–119.

Lindh M. 2022. Metoder för dikespluggning och dikesigenläggning i skogsmark. Skogsstyrelsen; www.skogsstyrelsen.se.

Makles M., Pawlaczyk P., Stańko R. 2014. Podręcznik najlepszych praktyk w ochronie mokradeł. Centrum Koordynacji Projektów Środowiskowych, Warszawa. Accessed on 15.06.2018: www.bestpractice-life.pl/aktualnosci/ podreczniki-najlepszych-praktyk-do-pobrania.html.

Möckel S. C., Erlendsson E., Gísladóttir G. 2021. Andic Soil Properties and Tephra Layers Hamper C Turnover in Icelandic Peatlands. Journal of Geophysical Research: Biogeosciences, 126; doi.org/10.1029/2021JG006433.

Ottósson J. G., Sveinsdóttir A., Harðardóttir M. 2016. Vistgerðir á Íslandi. Fjölrit Náttúrufræðistofnunar nr. 54. Icelandic Institute of Natural History. Garðabær, Iceland.

Pakalne M., Etzold J., Ilomets M., Jarašius L., Pawlaczyk P., Bociąg K., Chlost I., Cieśliński R., Gos K., Libauers K., Pajula R., Purre A-H., Sendžikaitė J., Strazdiņa L., Truus L., Zableckis N., Jurema L., Kirschey T. 2021. Best Practice Book for Peatland Restoration and Climate Change Mitigation. Experiences from LIFE Peat Restore Project. University of Latvia, Riga, 184 p.

Pawlaczyk P. 2018. Prawne i strategiczne ramy ochrony torfowisk w Polsce. Klub Przyrodników, Świebodzin.

Pawlaczyk P. (ed.) 2022. Kompleksy torfowe Kluki, Ciemińskie Błota i Wielkie Bagno w Słowińskim Parku Narodowym – przyroda i ochrona. Doświadczenia przedsięwzięcia LIFE PeatRestore. Wydawnictwo Klubu Przyrodników, Świebodzin.

Pawlaczyk P. 2023. Poland. In: Tucker G. Nature Conservation in Europe. Approaches and Lessons. Cambridge Univ. Press: 493–513.

Pawlaczyk P. (ed.), Biedroń I., Brzóska P. Dondajewska-Pielka R., Furdyna A., Gołdyn R., Grygoruk M., Grześkowiak A., Horska-Schwarz S., Jusik Sz., Kłósek K., Krzymiński W., Ligięza J., Łapuszek M., Okrasiński K., Przesmycki M., Popek Z., Szałkiewicz E., Suska K., Żak J. 2020. Podręcznik dobrych praktyk renaturyzacji wód powierzchniowych. Oprac. w ramach przedsięwzięcia „Opracowanie krajowego programu renaturyzacji wód powierzchniowych". Państwowe Gospodarstwo Wodne Wody Polskie, Krajowy Zarząd Gospodarki Wodnej, Warszawa.

Pawlaczyk P. 2018. Prawne i strategiczne ramy ochrony torfowisk w Polsce. Klub Przyrodników, LIFE PeatRestore documents [ms.].

Pawlaczyk P., Herbichowa M., Stańko R. 2005. Ochrona torfowisk bałtyckich. Przewodnik dla praktyków, teoretyków i urzędników. Klub Przyrodników, Świebodzin.

Pawlaczyk P., Bociąg K., Cieśliński R., Chlost I., Gos K., Stańko R. 2019. Słowińskie torfowiska w ochronie klimatu. Jak ochrona przyrody w Słowińskim Parku Narodowym może przyczynić się do łagodzenia zmian klimatycznych. Wyd. Klubu Przyrodników, Świebodzin.

Pawlaczyk P., Kujawa-Pawlaczyk J. 2017. Wybrane problemy monitoringu i oceny stanu torfowisk oraz ich usług ekosystemowych. Studia i Materiały CEPL 19, 2: 103–121. Accessed on 5.06.2018: cepl.sggw.pl/sim/pdf/sim51_pdf/Pawlaczyk_Pawlaczyk.pdf.

Pawlaczyk P., Wołejko L., Jermaczek A., Stańko R. 2002. Poradnik ochrony mokradeł. Klub Przyrodników. Świebodzin.

Ryś A. 2011. Ochrona i regeneracja ekosystemów mokradłowych na terenie nadleśnictwa Strzałowo w puszczy piskiej – efekty i kontrowersje. Przegląd Przyrodniczy 22, 3: 46–67.

Skarphéðinsson, K. H., Þorleifsson E. 1998. Keldusvín – útdauður varpfugl á Íslandi. Kvískerjabók: 266–296. Sýslusafn Austur-Skaftafellssýslu, Höfn í Hornafirði, Iceland.

Stachowicz M., Manton M., Abramchuk M., Banaszuk P., Jarašius L., Kamocki A., Povilaitis A., Samerkhanova A., Schäfer A., Sendžikaitė J., Wichtmann W., Zableckis N., Grygoruk M. 2022. To store or to drain — To lose or to gain? Rewetting drained peatlands as a measure for increasing water storage in the transboundary Neman River Basin, Science of The Total Environment, 829: 154560.

Stańko R., Wołejko L., Pawlaczyk P. 2018. A Guidebook on Good Practices of alkaline fen conservation. Klub Przyrodników Publishing House, Świebodzin, 169 pp.

Szpaczyński J. A. 2003. Zabezpieczenie terenu przed działalnością bobrów. Urządzenia przelewowe, ochrona przepustów, zabezpieczenie drzew. WR&P, Ottawa. Accessed on 15.06.2018: bagna.pl/images/biblioteczka/zabezpieczenie_terenu_przed_dzialalnoscia_bobrow.pdf.

The Environment Agency of Iceland. 2022. National Inventory Report – Emissions of greenhouse gases in Iceland from 1990 to 2022.

Wheaton J.M., Bennett S. N., Bouwes N., Maestas J. D., Shahverdian S. M. (eds) 2019. Low-tech process based restoration of riverscapes. Design Manual. Utah State University Restoration Consortium.

Wołejko L., Grootjans A. P. 2004. An eco-hydrological approach to peatland management in Poland. In: Wołejko L., Jasnowska J. (eds). The future of Polish mires. Monogr. AR w Szczecinie: 49–59.

Ogólnopolskie Towarzystwo Ochrony Ptaków is NGO established in 1991, OTOP's statutory goals are: to protect wild birds and their habitats, to spread knowledge about birds, their importance and threats thereto, to collect data on national bird populations, to develop and implement conservation measures, to carry out legal actions for the protection of birds and their habitats. OTOP is an association of 1731 members (as of September 2024) employing 50 staff and supported by ca. 700 volunteers. OTOP operates on a nationwide scale running a main office in Warsaw and five regional offices, closely related to the nature reserves managed by OTOP. In Poland OTOP maintains website otop.org.pl and a database Ornitho.pl - a European citizen science internet platform for collecting data on the abundance and distribution of birds. OTOP is the only Polish partner of BirdLife International - the largest global organisation protecting birds.

Civil registration no. KRS 0000015808

www.otop.org.pl, biuro@otop.org.pl

Fuglavernd (BirdLife Island) is the main environmental organisation in Iceland, exclusively working to protect wild birds and their habitats to safekeep biodiversity and sustainability. Fuglavernd deals with the conservation of Important Bird Areas in Iceland; campaigns for wetland restoration and conservation; has a nature reserve in the east and takes care of another one in the south; engages with people through education and volunteer work as well as raising public awareness using digital and social media with a wide range of publications. Fuglavernd is a member of BirdLife International, the Coordinating hub for the Arctic and Scandinavian region of the Flyway work.

TaxpID.500770-0159

www.fuglavernd.is, fuglavernd@fuglavernd.is

ISBN 978-83-89830-44-9