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How paleoecology can support peatland restoration

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As one of the worlds' most important carbon stocks, peatlands must be protected and restored. Paleoecology can be regarded as an important tool in peatland restoration and management; as decision making is a complex and intricate task, it should consider the long-term perspective of ecosystem development.

Peatlands' role in climate change mitigation

Peatlands cover 3% of the world's land area and store one-third of global terrestrial carbon, which makes them one of the most important carbon stocks (Rydin and Jeglum 2013). Saturated conditions in peatlands protect stored carbon. Healthy peatlands are also key players at the ecosystem level because they function like sponges and accumulate water in the landscape (Rydin and Jeglum 2013). Hence, they positively affect adjacent ecosystems, such as forests or grasslands.

Most peatlands worldwide have experienced significant human pressure in the past, mainly through peat extraction (Kołaczek et al. 2018) or various forms of drainage (Talbot et al. 2010), which led to the lowering of the water table. The drying of European peatlands has intensified over the last 300 years (Swindles et al. 2019), and the proportion of degraded peatlands in Europe is high (Tanneberger et al. 2021). Conservation is, therefore, crucial to prevent peatlands from turning from carbon sinks to carbon sources and to help store more water in the currently drying and warming world. Moreover, the maintenance of resilient peatlands will reduce ongoing biodiversity loss (Rydin and Jeglum 2013).

Assessing reference conditions using peatland paleoecology

Looking into the past by reconstructing long-term environmental changes is crucial to improve reference conditions for nature protection (Valsecchi et al. 2010), environmental and forest management (Hennebelle et al. 2018; Słowiński et al. 2019), and peatland restoration (Łuców et al. 2022). Reconstructed vegetation changes, hydrological fluctuations, and disturbance records (e.g. fires, human activity) can help determine potential vegetation composition, assess the extent of human impact, and single out factors that led to main vegetation transitions.

Human impacts have long-lasting consequences that are visible in palaeoecological records. For example, the effect of the establishment of drainage ditches on the Linje poor-fen (northern Poland) had immediate consequences on the local vegetation (Marcisz et al. 2015), and drainage ditches and remains of exploitation ponds are still visible on the site more than a century after drainage ceased (Fig. 1).

Peatland histories are complex and very dynamic, and it is sometimes difficult to identify reference conditions in the past that can be set as a target for nature restoration.

A paleoecological study of the Kazanie fen (western Poland), an alkaline fen that is now under restoration, shows a diverse history of a wetland that was affected by humans over the last millennium (Czerwiński et al. 2021). Deforestation in the surrounding catchment affected its hydrology and trophic state, leading to accelerated terrestrialization of the wetland and the formation of an alkaline fen. Overexploitation of the surrounding forest, related mostly to deforestation, led to the loss of water in the catchment, which was followed by climate warming, drying and, in the end, acidification of the site. In reality, it is the anthropogenic novel ecosystem of the alkaline fen that is the target of ecological restoration (Czerwiński et al. 2021). A similar case is the Pawski Ług bog (western Poland), which is now protected as a Nature Reserve. This peatland had been functioning as an alkaline fen until ca. 700 years ago, when it switched to an acidic bog. The change was an effect of deforestation of the surrounding forests and an introduction of a feudal economy by the Knights Hospitaller (a medieval and early modern Catholic military Order of Knights of the Hospital of Saint John of Jerusalem, also known as the Joannites) who settled in the area (Lamentowicz et al. 2020). Therefore, the bog that is currently protected is, in fact, a novel anthroecosystem that is far from its pristine state.

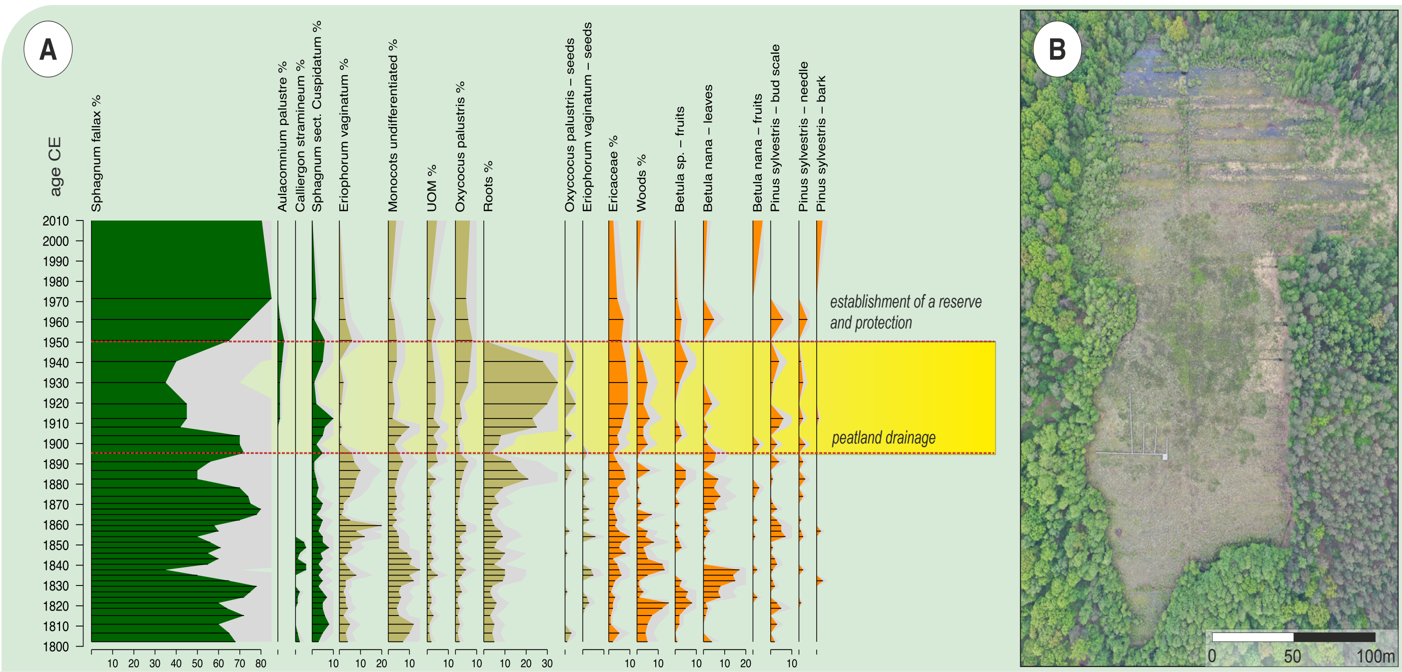

Figure 1: Linje poor-fen located in northern Poland: **(A)** paleoecological view of the effect of melioration and peat extraction at the end of the nineteenth century and **(B)** drone photo of the site taken in 2021 showing still visible areas of the drainage ditches.

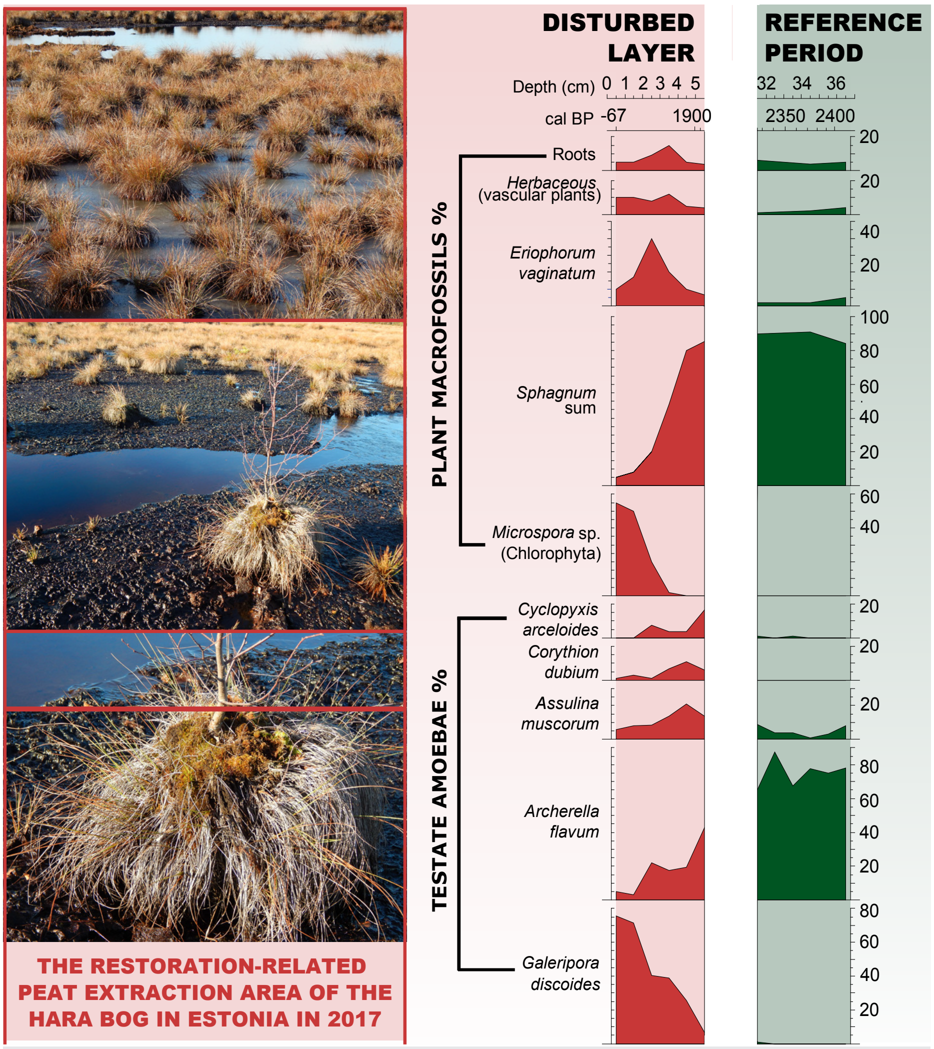

Figure 2: The restoration-related peat extraction area of the Hara bog located in northern Estonia. **(Left)** Pictures presenting the current structure of vegetation with hummocks of *Eriophorum vaginatum* and *Sphagnum* mosses, indicating fluctuations in the water table. **(Right)** Paleoecological record showing ecological contrast between restored state (current state) and pristine conditions (dated to ca. 2000 years before present) that can be regarded as a reference period for the restoration. Testate amoeba and plant macrofossil data suggest that, even though the Hara bog is far from stable and saturated conditions, it has the potential to be restored. However, the restoration of peat vegetation on bogs is a complex, difficult, and time-consuming process (figure modified from Łuców et al. 2022).

Peatland restoration efforts

In choosing proper restoration techniques, it is important to recognize the setting of the peatland, its catchment, and the factors influencing its development. Knowledge about peatland history can help implement a suitable restoration plan (Fig. 2). Yet, searching for an ecological baseline for peatland restoration may not be easy, and the efforts put into the restoration process may not result in the restoration of peatlands back to their former, pre-disturbed conditions (Łuców et al. 2022). Peatlands worldwide were influenced by various disturbance factors, and often the main one—human activity—was not present to the current extent and magnitude in the past. Therefore, it may be very hard to achieve satisfactory results in terms of biodiversity and vegetation composition.

The most common technique used for peatland restoration is rewetting drained sites using various types of dams constructed on ditches. Rewetting helps reinstate high moisture levels on the peatland and create bog-like conditions (Hancock et al. 2018), which protects carbon stored in the deeper peat and can reduce the number of peat fires (Sirin et al. 2021). However, even though novel ecosystems created through such interventions may not resemble previous peatland vegetation (Kreyling et al. 2021), e.g. be dominated by more common *Sphagnum* species or a larger proportion of vascular plants, they can still provide a carbon accumulation function that is crucial for climate change mitigation.

Furthermore, paleoecology helps us to identify the effect of restoration in the long-term context. For example, a high-resolution analysis of testate amoebae, which are very sensitive to hydrological change, can indicate even the subtle effects of the rewetting (Fig. 2; Łuców et al. 2022), enabling us to assess the effectiveness of chosen restoration techniques.

Past environmental conditions that shaped peatland vegetation and the hydrological state were very different from current ecosystem states. This, therefore, exposes a restoration paradox, the scale of which is presumably much greater than we are aware of. It opens questions of how to assess whether an ecosystem should be protected when in most cases long-term data are not considered? How to differentiate the natural succession pathways from anthropogenically induced changes in the past? And where should the restoration be directed if paleoecological data show that the protected ecosystem is the result of a past large-scale anthropogenic degradation process?

Glossary

Wetland – according to the Ramsar Convention wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters.

Peatland – a general term that characterizes an area possessing the peat (a layer usually at least 30 cm thick), while **mire** is a term for wet terrain dominated by living peat-forming plants.

Bog – ombrotrophic peatland dominated by *Sphagnum* mosses fed by rainwater, highly acidic and isolated from the minerotrophic catchment waters, might be open or wooded.

Fen – minerotrophic peatland that might be open (with e.g. sedges and brown mosses) or wooded, fed by rainwater and ground waters, alkaline and nutrient-rich.

Poor-fen – weakly minerotrophic peatland that is intermediate between fen and bog; usually dominated by *Sphagnum* mosses, but with hydrology and water chemistry like fens.

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