Paludiculture in Latvia

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Contributor: Ilze Ozola, Iluta Dauskane, Ieva Aunina, Normunds Stivrins

Global climate change impact has increased in recent decades and put urgency on implementing effective climate change mitigation (CCM) activities. Rewetting of drained peatlands is an acknowledged measure to reduce GHG emissions from organic soils in the agriculture and land use sectors. Under waterlogged conditions, decomposition of organic matter in peat decreases, and emissions of CO_2 are reduced. Thus, the soil carbon stock is saved, and wet management of the site reactivates carbon sequestration. To reach CCM targets, the first rewetting and paludiculture trials have been implemented in Latvia.

Keywords: organic soils ; peatland ; peat ; carbon credits ; agriculture ; forestry

1. Introduction

Following the Paris Agreement, climate neutrality must be achieved by 2050. There are multiple approaches to accomplish this, and a significant recommendation from CAP (Common Agricultural Policy) is to rewet organic soils and peatlands. This involves reducing the harvesting of peat and minimizing the usage of drained peatlands for agricultural and forestry purposes. Additionally, it is crucial to explore opportunities to utilize cutover peat areas and unproductive organic soils, which are not suitable for conventional agriculture and/or forestry, in order to achieve climate and biodiversity objectives [1]. Rewetting of organic soils and peatland areas to ensure climate and economically friendly usage is thought to be paludiculture.

Paludiculture is agriculture and forestry on wet and rewetted organic soils and peatlands [2]. Agroecological principles and practices, ecosystem-based management, and other approaches that work with natural processes support food security, nutrition, health and well-being, livelihoods and biodiversity, sustainability, and ecosystem services. These services include not only buffering of temperature extremes but also carbon sequestration and long-term storage, which enhances the resilience of carbon stocks and sinks [3].

Latvia is located in north-eastern Europe, within the hemiboreal zone where precipitation exceeds evaporation, thus allowing for peat formation and accumulation. Peatland comprises nearly 10–12% of the territory of Latvia [4]. Holocene peatland formation in Latvia dates to more than 11,000 years ago [5]. Peat extraction for private households increased dramatically during industrialization with melioration schemes for land reclamation in agriculture and forestry. Melioration efforts peaked in the Soviet occupation period in the 1960s–1970s when the fields for energy peat production were drained on a large scale. Later, excavation of substrate peat was implemented in sites where exploitable white peat deposits prevailed [6]. Today, the global substrate peat market has depleted exploitable white peat resources in Western Europe and keeps pressure on the Baltic peat industry for the production of high-quality peat substrates for professional horticulture and tree nurseries. To meet the demand for substrates, 0.04% of the territory of Latvia (or 4% of the peatland area) is used for peat extraction.

2. Paludiculture in Latvia

According to the results of the LIFE Restore project it has been determined that approximately 50,000 hectares of land in Latvia have been impacted by peat extraction activities. Among these, around 15,000 hectares are presently active peat extraction sites, while reclamation efforts have been undertaken or are currently in progress on approximately 17,000 hectares of land. Notably, there are approximately 18,000 hectares (equivalent to 36% of the total) that represent abandoned cutaway peatlands requiring reclamation efforts.

For a visual overview of the current and potential utilization of organic peat soils in Latvia, encompassing forestry, agriculture, and peat extraction, please refer to **Figure 1**. The management of these peat soils involves a combination of drainage and rewetting methods, which encompass both natural-origin and artificially established sites. Drained peat soils with a sphagnum peat layer have traditionally found use primarily in berry cultivation, afforestation, and peat extraction.

However, these versatile landscapes also offer opportunities for more sustainable and ecologically conscious practices, such as establishing bee pastures adorned with flora like heather and wild rosemary, which can be harmoniously combined with renewable energy sources like solar panels or windmills.

Figure 1. Management of degraded peat soils in Latvia.

Organic soils, whether drained or undrained and rich in black or white peat, hold significant potential for the implementation of wind farms and agrovoltaics—solar farming, is an innovative and sustainable land-use practice that combines agriculture with the generation of solar energy. Agrovoltaics maximizes land utilization by effectively using the same space for both agricultural production and solar energy generation. Solar panels can provide shade to crops, reducing the risk of heat stress and excessive evaporation, which can be particularly valuable in areas facing water scarcity or drought conditions, including extracted bare peat fields. Solar panels can be placed above cranberry fields. The shading effect can help manage water temperatures, reduce water usage, and improve cranberry yields. The space under solar panels can be managed to support biodiversity, creating habitats for pollinators and wildlife, e.g., bee pastures covered with heather and wild rosemary. Agrivoltaics is a novel concept in Latvia, and as a result, its potential impact on biodiversity as yet to be thoroughly investigated.

2.1. *Sphagnum* spp. Moss

In raised bogs, peat formation predominantly occurs under nutrient-poor, acidic conditions, largely due to peat mosses, specifically *Sphagnum* spp., which are well-adapted to these environments. Peat moss has a unique ability to acidify its environment using hydronium ions and creates self-regulating structures to maintain consistently high water levels. As a result of these unique conditions, layers of undecomposed and slightly decomposed peat moss accumulate, reaching depths of several meters. This type of peat, often referred to as “white peat” because of its light color, boasts properties like high porosity, low nutrient content, and a uniform fibrous structure, making it a crucial raw material for professional horticultural substrates globally. Today, nearly all vegetable and decorative plants and flowers are potted in substrates derived from white peat.

The horticultural sector, along with scientific communities, is proactively seeking alternatives to moss peat for horticultural substrates. However, potential substitutes like alternative biomass and artificial substrates often pose challenges in production costs and inconsistency in properties compared to white peat. Studies from Canada and Germany indicate that fresh peat moss biomass shares properties with white peat and can serve as an effective substitute in horticultural substrate production [7][8].

Moreover, cultivating *Sphagnum* moss, termed “*Sphagnum* farming”, has been found to be beneficial for peatland restoration in areas previously used for peat harvest and adjacent to current peat extraction sites. Such restorative efforts can significantly contribute to the ecological balance in peatland ecosystems, prioritizing both biodiversity and climate objectives. Cultivated *Sphagnum* moss can be harvested in intervals of 3 to 5 years.

In Latvia, efforts have been made to cultivate *Sphagnum* at four distinct sites. The first *Sphagnum* farming experiment began in 2012 at the Mokura Europe Ltd-owned Ķēviešu Bog, spearheaded by the Greifswald University and Greifswald Mire Centre. Later, in 2016, the Lake and Peatland Research Centre, aided by scientists and volunteers, initiated *Sphagnum* planting at Kaigu Bog, within Laflora Ltd.’s peat extraction fields.

The Rāķa Bog stands out with its extensive water management infrastructure, which includes pumps and pools and constitutes a significant portion of the project’s expenses. Rāķa Bog has a comprehensive water management system, with the most significant expense being the water pool at EUR 8491. The overall cost for water management in Rāķa Bog was EUR 12,701. Meanwhile, Ķemeru Bog only had the construction of an overflow and depressions installed, costing EUR 1530.

Located in a private, secured area, the Rāķa Bog benefits from the surrounding active peat extraction fields, ensuring equipment security and consistent water level monitoring. Contrastingly, the *Sphagnum* field in Ķemeru Bog borders a frequented tourist path. Both locations lack a permanent electrical connection, and as necessary, water pumps operate using diesel generators.

Meanwhile, in the initial phase, the irrigation system at Kaigu bog was not fully functional, and *Sphagnum* was not provided with sufficient water or even overflooded during the spring and autumn, which could have restricted *Sphagnum* growth during the initial phase or even damaged the *Sphagnum* beyond recovery. High water level fluctuations were one of the reasons (but not the only factor) for the poor establishment of *Sphagnum* moss at Kaigu bog. Moss species were severely damaged, and the area was overtaken by reed (*Phragmites australis*) and cattail (*Typha latifolia*/*angustifolia*). To ensure appropriate water quality, it is either necessary to collect only rainwater in basins or to ensure that water, before entering the basin, is filtered through peat extraction fields, natural peatlands, or peatland forests, as is the case in Rāķa Bog. This is highly important for the territory of Latvia, where sediment underlying peat layers commonly contain carbonates and groundwaters are nutrient-rich. The management of groundwater and surface water to restore *Sphagnum*-dominated habitats and irrigation of *Sphagnum* farms should focus on lowering alkalinity levels (including pH) [9]. The input of solutes from minerotrophic water may indirectly hamper *Sphagnum* growth by stimulating the growth of vascular plants, triggering unwanted vegetation shifts.

2.2. *Phragmites australis*

Common reed (*Phragmites australis*) is a tall, thin, highly productive grass that can be found in wetlands. Reed produces high and stable yields on wet sites, even with long-term flooding. Reed grows up to four meters high and remains upright after the growing season, making it suitable for harvesting in winter. Reed yield ranges from 4 to 24 t DM/ha annually. The primary production of *Phragmites* is very high, up to 10 kg dry mass per m^2 [10]. Reed is often the first peat-building species in peatlands that originated from alkaline lakes or wetland depressions.

No artificial reed fields have been established in Latvia so far, and therefore, no comparable detailed costs for *Sphagnum* farming can be provided. Latvia has 116 natural and artificial water bodies with water reservoirs (~13,400 ha in total) considered important for reed production [11].

The economical use of reed is hampered by the issues related to harvesting, transport, and drying. Dry reeds have a low density (200 kg/m^3 [11]), so transporting reeds over longer distances may not be cost-efficient. During the cold season, reed canes decrease in moisture content, but in recent years, when Latvia has had warm and wet winters, the moisture content has been higher (>20%). The rewetting of large areas may reduce the conflicts with nature conservation aims and restrictions (bird migration and nesting time in natural reed areas). Independent reed fields developed on rewetted cutover peatlands could theoretically allow the operation to run efficiently. Large-scale harvesting machinery can be used, reducing production costs. Unlike natural reed harvesting in reservoirs, reed cultivation on rewetted organic soils and wetlands would significantly reduce the cost of reed cutting and collection from EUR 500 ha^{-1} to EUR 85 ha^{-1} [12].

2.3. *Typha*

As a pioneering species of wet and muddy land, it grows well in restored peatlands and rapidly forms a dense plant cover. Cattail is suitable as a cultivation crop because it produces very high yields on rewetted sites with a high nutrient supply, even in the case of long-term overflooding. Importantly, planted cattail yields are stable over the first ten years [13]. The high productivity of the plant, and the excellent properties for insulation, construction, and fiber materials in connection with the growing demand, especially for ecological building materials, offer versatile potential for creating regional value. Growing areas can be up to 10 ha in size with high nutrient and water availability (in summer, −10–0 cm and in winter, −5–15 cm from the surface). Yield ranges from 4 to 22 t DM ha annually [14].

In Latvia, cattail grows naturally in wetlands and on the shores of lakes, but extensive areas covered with cattail are not known. In farmland, cattail is considered an undesirable plant because it indicates that the area is unkempt. However, in lakes, they are considered, like reeds, to be an indicator of heavy overgrowth. In peat extraction sites, cattail grows in ditches, and its seeds are actively restricted/prevented (i.e., cattail is eliminated) from entering the peat. Both these processes show that cattail establish and grow well on farmland and constructed marshes if allowed. The density of cattail is low (65 kg/m^3); thus, transporting cattail over long distances may not be worthwhile and costly. The productivity of cattail can range from 5 to 22 t DM ha^{-1} [14].

The first trial of a cattail field was implemented by the Lake and Peatland Research Centre in 2020 at the Tēvgaršas Bog managed by Klasmann-Deilman. The field (size 0.3 ha) was prepared on a former peat extraction site further from the current extraction fields. Total costs for the cattail farming trial field establishment were EUR 1900 (price shows surface preparation and leveling of land). Planting material was obtained from nearby ditches, and planted manually one plant per m^2. The company aimed to test such a trial to evaluate its potential as a recultivation measure and usage of the above biomass. After one year of planting, cattail was successfully spread throughout the field. Further evaluation and measurements are in progress and will be monitored by the Lake and Peatland Research Centre. As this was a scientific experiment to determine whether *Typha* establishes after installation, no additional costs were allocated in the current project. Based on this trial, a decent (like the *Sphagnum* farming project in Rāķa Bog) cost categorization will be designed for the upcoming *Typha* plantation project in the near future.

2.4. *Alnus glutinosa*

Black alder (*Alnus glutinosa*) is a scattered and widespread species that thrives in low-laying wet and riparian areas. Growth rates are up to ages 7–10, with a maximum rotation of 60–70 years for growing timber if heart rot is avoided [15]. Many strong, vertically growing sinker roots anchor the tree, and they can penetrate deeply into wet and anaerobic soils. Black alder can grow in a wide range of soils of varying nutrient status, growing equally well in acidic and basic soils, with a large range of pH values between 4.2 and 7.5. High water levels are essential when considering the utilization options in short rotation coppices or high-quality timber production. A newly established black alder plantation has a slight net (GHG in CO_2-eq.) sink of −3.4 ± 1.7 t ha^{-1} yr^{-1} [16]. The GHG balances of formerly drained fens benefit in the short term from planting black alders, mostly due to reduced CH_4 emissions. Additionally, black alder is capable of forming peat under wet and very wet conditions.

Latvia’s forests cover 3.383 million hectares and 52% of the country’s territory. According to the State Forest Register data, black alder stands occupied 92,869 ha in 2016, which increased to 104,418 ha by 2022 [17]. Notably, half of the black alder forests are under state ownership, while the other half are privately owned. During 2021, a total of 336 ha of alder trees were planted, while 1383 ha were regenerated naturally.

Although the black alder is a well-known and valuable tree in Latvia, targeted plantations are rare. One such plantation, spanning 4 hectares and consisting of planted black alder (located near Svete Lake, Dobele Municipality), was established on a 1.0–1.5 m thick fen peat layer in 2019. This plantation was established by a private landowner. The costs per hectare include seedlings (EUR 700), heap preparation (EUR 500), planting (EUR 170), and cleaning (EUR 300). The expenses for planting, as well as the initial three years of maintenance and cleaning costs, were financed through an EU project managed by the Rural Development Service as part of the application for the activity “Investments to expand forest areas and improve forest viability”.

2.5. *Phalaris arundinaceae*

Reed canary grass can grow in wet conditions, but its robust root system enables it to endure drier growing periods. This grass species can tolerate prolonged flooding, making it suitable for mowing lawns in areas where adequate drainage is not feasible. Moreover, reed canary grass serves as an effective means of soil protection against water erosion [18].

In Latvia, reed canary grass (*Phalaris arundinacea*) has shown successful cultivation. Both natural stands and established crops of this grass are primarily utilized as fodder for hay and silage. Once a stand is well-established, reed canary grass can thrive at a single site for 10–12 years, maintaining consistent biomass yields. Moreover, it holds the distinction of being the only paludiculture crop eligible for direct payments due to its classification as an agricultural crop. Recently, Latvia has experienced a decline in reed canary grass production, decreasing from 1160 ha in 2016 to 128 ha in 2022, as reported by the Rural Support Service [19]. This decline could be attributed to reed canary grass being mixed with other grasses, forming part of the perennial grasslands that encompassed 457,303 ha in 2021 and expanded to 461,357 ha in 2022.

Reed canary grass biomass is one of the alternative resources used for pellet production in the Baltics due to its sustainability in local climatic conditions and high biomass yield of 7.9–13.2 t ha^{-1}. It is an environmentally friendly source of energy that reduces energy dependence on other countries and can be grown on land that is not suitable for cereal production. In order to recultivate the former peat extraction field, the Lake and Peatland Research Centre is currently implementing a reed canary grass field on 16.4 ha at Kaigu Bog (Laflora Ltd., Kaigu Peat Bog, Latvia). Aboveground biomass will be harvested and used for pellet production. It is not only economically reasonable but also good for the climate as the reed canary grass field is a sink for atmospheric CO_2 (GWP of −11 t CO_2-eq. ha^{-1} yr^{-1}) [20]. Once the reed canary grass is planted, climate benefits can only occur in the avoidance of emissions from peat degradation by ensuring the management of close-to-surface water levels.

2.6. *Acorus calamus* and *Iris pseudoacorus*

Sweet flag (*Acorus calamus*) and yellow flag (*Iris pseudoacorus*) are often found on lakeshores and wetlands. They are often cultivated as ornamental plants in water gardens or near ponds in Latvia but can also be used as food. Furthermore, they are widely used in modern herbal medicine as aromatic stimulants and mild tonics. Yellow flag can serve as a substitute for coffee, provided it is well roasted [14]. Moreover, holding a slice of its root against a painful tooth is believed to offer instant relief. The flowers yield a lovely yellow dye. Furthermore, yellow flag has been utilized as a rehabilitation plant to reduce bacterial loads, absorb heavy metals from contaminated water, and aid in erosion control. The leaves are used in basket making or woven into mats and can

In 2019, the Lake and Peatland Research Centre, together with Laflora Ltd., agreed to test whether these plants can grow on a cutaway peatland with variable water levels. Three hundred tree seedlings were planted. The price per plant was EUR 1.5. Costs for the field preparation were not estimated as these fall within the *Sphagnum* trial field preparation costs (presented earlier). Neither cost of labor was estimated. The first results show that the plants were well established in 2020–2022, healthy and producing new offspring.

2.7. Wet Meadows

Wet meadows are transitional habitats between aquatic and terrestrial environments. Their waterlogged soils, diverse plant communities, and periodic flooding make them unique ecosystems that support a wide variety of flora and fauna. In Latvia, wet meadows have gained attention due to their potential for paludiculture: the cultivation of wet and peaty areas for biomass production.

Wet meadows are rich in biodiversity, supporting a wide variety of plants, birds, amphibians, and insects. Beyond this biodiversity, wet meadows on organic soils offer several other benefits. They function as natural sponges, absorbing excess water during wet periods and releasing it in drier times. They also assist in water purification, minimizing nutrient runoff into nearby water bodies and enhancing drought resilience.

Climate change poses both threats and opportunities for wet meadows. Changes in precipitation patterns and rising temperatures can alter the hydrology of these meadows, influencing their ecology and potential uses. However, the extended growing season has given landowners in the Ruja River valley a chance to mow the hay twice, in July and September.

The article highlights the Rūja River floodplain as a positive example of wet meadow management. The nature reserve “Rūja River floodplain” was established in 2004 and is located in the Valmiera Municipality. The 444 ha nature reserve is part of the North Vidzeme Biosphere Reserve. The nature management plan of the nature reserve Rūja River floodplain was developed within the LIFE-Nature project "Restoration of Latvian floodplain meadows for conservation of EU priority species and habitats" implemented by the Latvian Fund for Nature in 2006.

A total of 95 bird species have been recorded in the nature reserve, 26 of which are specially protected. Most of the nature reserve is agricultural land, less forest land and scrub and flowing waters. Most of the nature reserve belongs to private landowners. Most of the meadows in the nature reserve are classified by the Rural Support Service as biologically valuable meadows for which late mowing (from 1 July) or extensive grazing is preferable. This is necessary to promote the conservation of grassland and bird species.

The natural values in the nature reserve and in the wider area have been negatively affected by land reclamation and river straightening. Reclamation contributes to faster water outflow, resulting in a more rapid drop in water levels in the meadows during floods. This contributes to the overgrowth of the meadows. The maintenance of certain drainage ditches is acceptable from the point of view of nature conservation. In order to avoid landowners having to maintain ditches in their ownership, they should first be removed from the drainage register, as according to the conditions of the Good Management Practice of the Rural Support Service, drainage systems should be kept in working order, which in Natura 2000 sites is inherently contrary to the conditions necessary for the conservation of natural values in floodplain meadows. The creation of dykes on ditches or the filling in of ditches is also permitted [21].

3. Conclusions

Although the term "paludiculture" might seem new in Latvia, the cultivation of reed canary grass and black alder on wet organic soils has been practiced for decades. Some Latvian landowners have been engaged in these cultivation practices for years, even if they might not have been familiar with the term "paludiculture" or the associated environmental and climatic benefits. To determine which of the described areas qualify as paludiculture sites, further research is essential, primarily involving the monitoring of water levels to ensure they consistently remain above −30 cm, even during exceptionally dry periods.

Current examples in Latvia underline that *Sphagnum* as paludiculture is promising yet facing multiple obstacles. Small production volumes and challenging growing conditions from site to site indicate that, at present, *Sphagnum* farming cannot provide enough raw material to substitute horticultural peat at necessary levels. More knowledge, time, and investments are required.

Wet meadows hold significant ecological and economic value in Latvia. With sustainable management, these habitats can support biodiversity, offer drought-resilient fodder sources, and even pave the way for profitable paludiculture ventures.

Latvia holds considerable potential for paludiculture implementation, given its suitable conditions and available land. Nevertheless, paludiculture and rewetting are perceived as potential threats to forestry, agriculture, and peat production in Latvia. However, a comprehensive understanding of the site conditions, site-specific planning, the balance between biodiversity benefits and financial investments, and careful consideration of both short-term and long-term consequences can lead to the integration of paludiculture principles into organic soil management practices.

Prioritizing areas for rewetting that have less significant impacts on agriculture or forestry and collaborating with local stakeholders to determine mutually beneficial solutions, such as incorporating rewetted areas into eco-friendly agricultural practices, can help in tackling the challenges related to disruptions to land use.

Performing comprehensive hydrological assessments and modelling together with careful planning of infrastructure adjustments before rewetting to comprehend potential impacts on water flow and minimizing the impact on neighbouring areas are crucial to address concerns related to water management, infrastructure damage, and methane emissions.

Paludiculture implementation has the potential to play a crucial role in achieving Green Deal objectives, promoting biodiversity, creating new raw materials, and increasing the accumulation of peat and stored carbon. Nevertheless, this endeavor necessitates investment in terms of time and financial resources, changing centuries-old practices and a shift in mindset.

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