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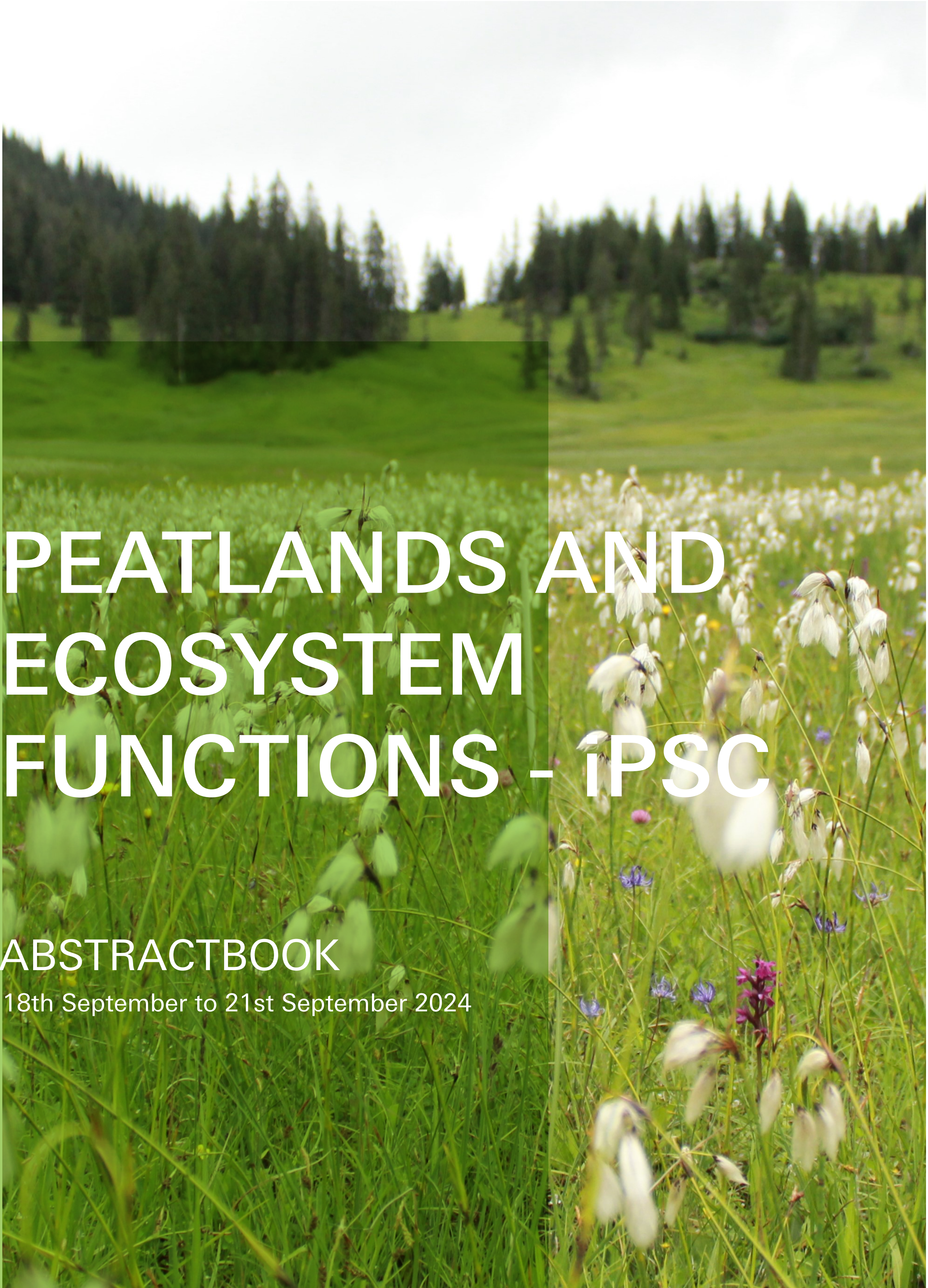

PEATLANDS AND ECOSYSTEM FUNCTIONS - iPSC

ABSTRACTBOOK

18th September to 21st September 2024

WEIHENSTEPHAN · TRIESDORF
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Arbeitsgemeinschaft Schwäbisches Donaumoos e.V.

Národní park · Chráněná krajinná oblast Šumava

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NATIONALPARK Bayerischer Wald

GREIFSWALD MOOR CENTRUM

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Donaumoos Zweckverband
Heimat verbindet.

BAYERISCHE STAATSGÜTER
Landwirtschaft gestalten

THÜNEN

LIFE FOR MIRES

DFG Deutsche Forschungsgemeinschaft

LWF Bayerische Landesanstalt für Wald und Forstwirtschaft

Bayerisches Landesamt für Umwelt

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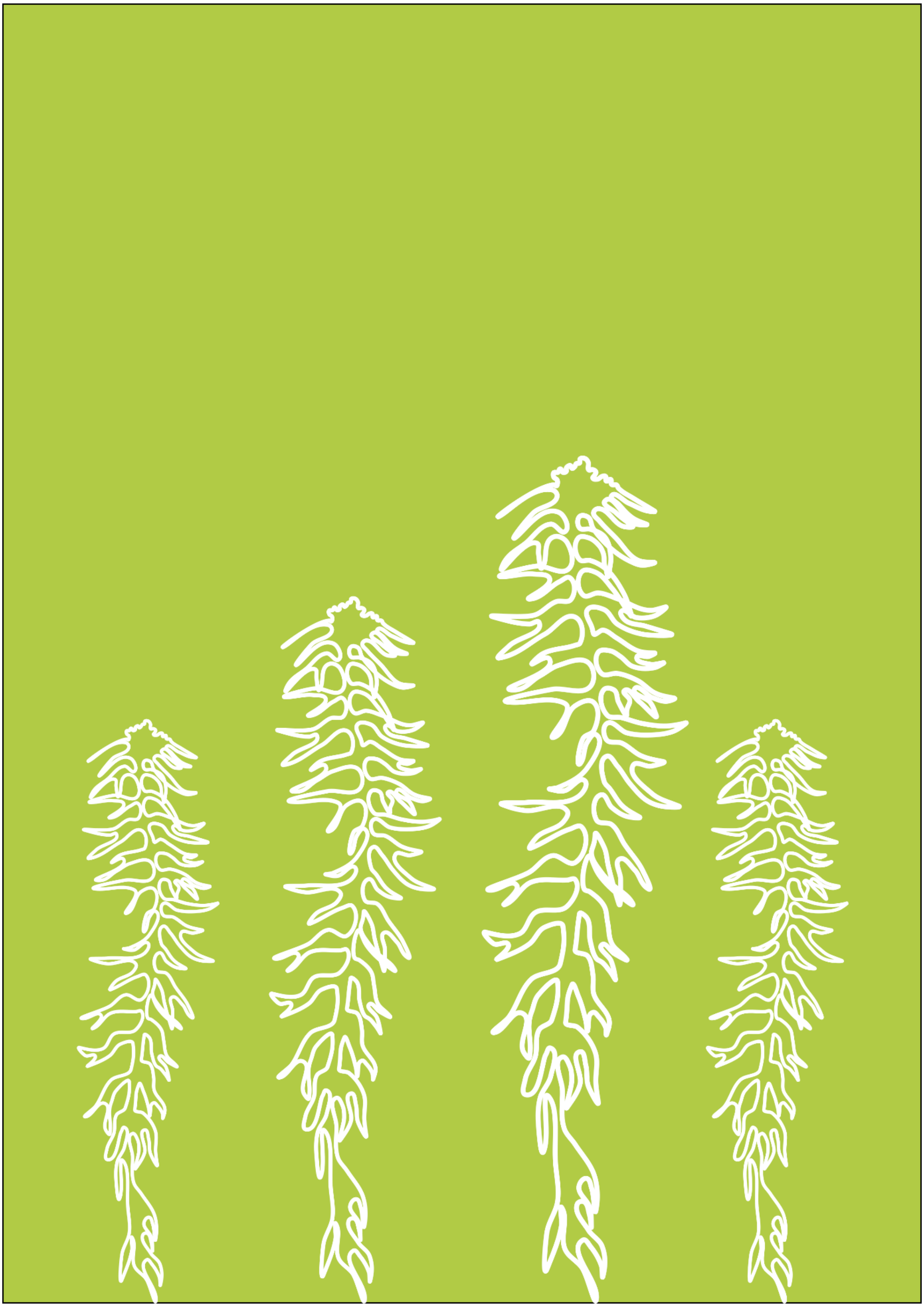

Shrinkage Behavior of Peat and Other Organic Soils

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Shrinkage i.e., the volume reduction of a soil due to desiccation and decreasing pore pressure is an important property of peat and other organic soils, i.e., soils with a soil organic carbon (SOC) content above 7.5%. It has to be considered for a precise determination of volume based physical and hydraulic soil properties in the laboratory e.g., bulk density, volumetric moisture and soil hydraulic properties. Furthermore, it leads to changing surface elevation and crack formation at the field scale. Compared to clayey soils, which also show distinctive shrinkage, peat is known to show contrasting shrinkage behavior (Fig. 1). While the general pattern has been described in literature, systematic information on the relationship between soil properties and soil shrinkage characteristics (SSC) is missing so far. Therefore, we sampled 32 horizons (n = 4 replicates each) of organic soils in Germany covering a wide range of botanical composition, development stages and degree of decompositions. We determined sample volumes with a three-dimensional (3D) structured light scanner at different moisture states from full saturation to dryness. Desiccation was achieved by suction plates up to pressure heads of -200 hPa, followed by evaporation and, finally, oven-drying at 105°C.

Volume and height of the 3D models created this way were determined by 3D graphic software and R, respectively. The volumetric moisture was determined by weighing the sample before and after scanning. Afterwards, volume and volumetric moisture were converted to moisture ratio and void ratio with the volume of solid particles. Due to small differences in particle volume between the replicates, both moisture and void ratio were normalized by dividing them by the value at saturation. This normalization led to congruent results for the replicates.

The shape of the SSCs strongly depended on the botanical composition and degree of decomposition. For example, poorly decomposed *Sphagnum* dominated peat shows distinct supernormal shrinkage under dry conditions, i.e., the pore volume loss exceeds the volume of lost water. In contrast, the SSCs of strongly decomposed amorphous peat are characterized by structural and/or normal shrinkage and thus approaching the behavior of mineral soils.

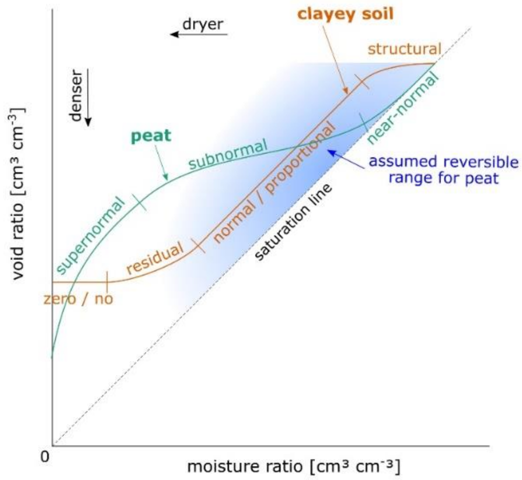

Figure: Schematic soil shrinkage characteristic of clayey soil and peat. Labelled segments denote shrinkage phases. Axes are not true to scale. From Seidel et al. (2023) after Beck-Broichsitter et al. (2020), Peng and Horn (2007), Hendriks (2004), and Pyatt and John (1989).

Furthermore, we found a linear relationship between volumetric and vertical shrinkage which can be well described with dry bulk density as the only variable and constant parameters for the majority of the investigated horizons.

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Peat Type and Climate Zone Control the Hydraulic Functions of Peat along a Bulk Density Gradient

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The Hydro-physical properties of peat play a crucial role in water and carbon cycles of peatlands. However, our knowledge of the hydraulic properties of peat soil remains limited. In this study, We compiled a global database of peat properties—including bulk density (BD), carbon density (C_d), porosity, macroporosity, and saturated hydraulic conductivity (K_s)—from tropical, boreal, and permafrost peatlands. We aimed to investigate the dynamics of these properties along a bulk density gradient across different climate zones. The results indicated a strong linear relationship between carbon density and bulk density for tropical peatlands, boreal bogs, and permafrost peatlands (C_d=0.45×BD+0.0028, R^2=0.86, p<0.0001). However, for boreal fens, the relationship between C_d and BD differed from that of other peat types and became less predictable when BD exceeded 0.2 g cm^{-3}. The total porosity decreased linearly with increasing bulk density (BD), while macroporosity exhibited a power function relationship with BD. These functions were consistent across all types of peat soils, highlighting a reliable association between bulk density and both total porosity as well as macroporosity. The results also showed that K_s generally decreased with increasing BD with the relationship between BD and K_s varying between all peat types and climate zones. This indicates that the hydraulic conductivity was strongly influenced by the peat-forming vegetation and the climate zones in which peat soils are found. All the investigated parameters can be estimated using BD with a relatively high R^2 (>0.4), therefore, the BD should be determined and used to estimate the hydro-physical properties of peat when data is not easily available.

Soil Hydro-Physical Properties and Spatial Characteristics of Northern German Peatlands: Insights for Peatland Restoration Management

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Peatlands play a crucial role in global carbon storage and hydrological regulation. However, human activities have led to their degradation, necessitating the restoration of their ecological functions. This study is a cumulative dissertation conducted within the framework of the German Research Foundation (DFG) research project BalticTRANSCOAST. It specifically focuses on the physical and hydraulic properties of peat soils and their spatial characteristics, including water movement, solute transport, and nutrient release. The investigation analyzed various peat soils collected from different inland drained fens, an inland restored fen (previously drained), an inland bog, and a recently rewetted coastal fen located in the Federal State of Mecklenburg-Western Pomerania, Germany.

Peat soils are porous media with anisotropic and heterogeneous characteristics. In this study, soil anisotropy significantly affected water movement in both drained and restored inland peatlands, with higher saturated hydraulic conductivity observed in vertical samples compared to horizontal ones. Solute transport also demonstrated anisotropic behavior, with pronounced preferential flow occurring vertically. This anisotropic structure of peat facilitated phosphate transport from drained agricultural peatlands to the surrounding environment, following the direction of preferential flow.

Geostatistical analysis indicated significant spatial heterogeneity in soil properties across varying degrees of degradation in inland peatlands. Particularly in highly degraded peat, there was notable spatial dependence observed in soil organic matter content. These geostatistical findings could provide guidance for future sampling intervals. Furthermore, extensive measurements of field-collected samples were conducted, leading to the development of new pedotransfer functions. The incorporation of “macroporosity” into these models significantly enhanced the prediction accuracy of soil hydraulic properties, especially for degraded peat soils.

Additionally, microtopography was found to influence organic carbon accumulation and nutrient leaching patterns in coastal peatlands. Compared to higher elevations, low-lying areas exhibited higher soil organic matter content and elevated carbon-to-nitrogen ratios. The relatively higher water table in low-lying areas may be one of the contributing factors. In addition, low-lying areas of this investigated coastal site are identified as “hotspots” for the release of dissolved compounds during rewetting practices, highlighting the importance of addressing potential environmental risks to groundwater and surrounding water bodies.

These findings emphasize the crucial role of incorporating spatial information on peat soil properties in both management and restoration efforts. The knowledge gained from this study contributes significantly to conserving, sustainably using, and restoring peatland ecosystems.

River connection determines soil development and physicochemical properties in hardwood floodplain forests of the lower middle Elbe

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The floodplain hydrogeomorphology creates lateral and longitudinal gradients that influence ecosystem processes. In these areas of high environmental heterogeneity, the assessment of soil properties and processes is fundamental to define the ability of a soil to function effectively as part of a healthy ecosystem. Whereas, the geomorphological heterogeneity of floodplains has been acknowledged, research on how this variability might influence soil physicochemical characteristics at the local scale are scarce. Our analyses are based on, 44 mixed topsoil samples, 135 soil drillings (2.0 m depth) and 18 reference pits (1.6 m depth) distributed in 44 hardwood floodplain forests along 150 km of the middle Elbe River. We considered four hydrogeomorphic units (HGUs) along a lateral floodplain gradient. Two HGUs located in the active floodplain and defined by their morphology Active High (AH), and Active Low (AL), and two located in the former floodplain: seepage water influenced (FS) and disconnected from the river hydrology (FD). General soil chemical characteristics (pH, EC, BS, CEC, TC, TN, C/N), plant available nutrients (Ksol, Psol), and soil texture were analyzed for a mixed topsoil sample (0-10 cm mineral soil) per site. We identified the predominant soil types per unit: AH - Fluvic Arenosols, AL - Fluvic Cambisols, FS - Gleyic Fluvisols, and FD - Fluvic Gleysols. Furthermore, we show that HGUs in the active floodplain profit from a stronger connection to the river hydrology. pH values in the AH and AL range between 5 and 5.8, compared to FS and FD which were more acidic 3.5 - 4.2. Higher pH values in the active HGUs as well as higher total P contents due to river deposition result in increased Psol availability. Lower pH and the predominance of iron mottling found in the FD could indicate increased P sorption, therefore lower Psol availability. In general, highest nutrient supply was found in the active floodplain, specifically in the AL unit, attributed to sediment deposition by flooding. The AH unit shows less influence of water retention in processes of soil formation, due to higher sand content. Sites behind the dyke, especially those in the FD unit, show little to no influence of the Elbe hydrology on its characteristics. These results improve our understanding of the soil physicochemical dynamics and their interactions in the different hydrogeomorphic units, which could support restoration and protection efforts of hardwood forest in floodplains.

Mineral nitrogen dynamics of peatland under paludiculture following organic fertilizer amendments in contrasting hydrological regimes

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Paludiculture offers the possibility of using (re)wet peat soils for sustainable agriculture. As with any agricultural crop, nutrient removal from the crop potentially must be replaced by fertilization in order to maintain nutrient balances. The fertilization of nitrogen (N) is a particularly important and at the same time problematic aspect for the productivity and functioning of peatland ecosystems. In the recent years, the inputs of N to drained peatlands in the form of fertilizers have rapidly increased due to the intensification of agricultural systems reaching up to 260 kg N ha^{-1} yr^{-1} in paddy-peatlands in China thereby impacting the functioning of peatlands ecosystems. Additionally, changing groundwater levels also modify peatland functions physically, biogeochemically and ecologically which may consequently affect N availability. The extent to which these practices impact the availability of mineral N in rewetted peatlands still need to be further understood. We investigate the effects of fertilization using liquid and solid biogas digestate and contrasting groundwater levels on the mineral N dynamics of a fen peat cultivated with reed canary grass (Phalaris arundinacea) as paludiculture. In the first week following fertilization, there was a rather short-lived increase in ammonium (NH_4^+) concentrations whereas nitrate (NO_3^-) concentrations showed an overall decreasing trend during this period. Both NH_4^+ and NO_3^- concentrations significantly ($P<0.05$) decrease with increasing pet depth. The form of fertilizer application and differences in groundwater positions did not show statistically significant differences in the concentrations of NH_4^+ and NO_3^- between the different treatments. Taken together, these results suggest that time and depth as well as type of fertilizer and groundwater level management are important factors to consider in understanding the dynamics of NH_4^+ and NO_3^- of peatlands.

Soil structure of peat and its role in ecosystem functioning

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Peatlands are well-known for their global significance as long-term carbon sinks. The soil structure of peat determines water flow, solute transport patterns and regulates the carbon and nitrogen cycles in peatlands. Compared with mineral soils, our understanding of the soil structure of peat is limited, especially its role in the ecosystem functioning. In the last several years, both laboratory and field experiments were conducted on peat soils. We also assembled a comprehensive dataset of soil properties in a broad range of peat soils, from low to highly decomposed soils in natural to heavily drained peatland settings. The main objective was to investigate the soil structure of peat and its role in water storage and biogeochemical processes. We found that the soil structure of peat is closely related to the degradation stage of peat. In natural peatlands, the soil pore structure is dominated by a large proportion of interconnected macropores. Peatland drainage substantially decreases in macroporosity and thereby in hydraulic conductivity. The soil structure of drained peat is not static but undergoes continuous changes due to biotic and abiotic drivers (e.g. freeze-thaw cycles, FTCs). Peatland drainage not only changes the soil structure of peat but also the ecosystem functions. The more a peat soil is degraded, the higher the risk of air/water pollution in peaty landscapes and the higher the DOC pore water concentration in the peat. We also estimated that the conversion of pristine peatlands into agricultural land in Germany resulted in a water storage loss of approximately 20.3 km^3, which roughly corresponds to 27 times the volume of the lake Müritz (largest lake entirely within German territory). Several decades of peatland rewetting would have a limited role in water storage recovery due to a substantial peat thickness loss prior to rewetting and low porosity of (formerly) degraded peat. In conclusion, the soil structure of peat plays an important role in peatland ecosystem services in terms of water storage capacity and conductance and more research is needed to uncover its role in carbon and nitrogen cycles.

Physical parameters of peat and other organic soils can be derived from properties described in the field

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Knowledge about the bulk density and porosity of peat and other organic soils is of major importance, as both parameters directly or indirectly effect hydrological conditions (e.g., soil moisture, water level fluctuation), soil physical processes (e.g., shrinkage, swelling, subsidence) and biological processes (e.g., peat mineralization, peat growth). The agricultural usability (e.g., trafficability, plant growth, yield) and the rewetting and oscillation capacity of peatlands also strongly depend on soil hydraulic properties and, thus, on bulk density and porosity. Additionally, knowledge of bulk density is necessary to convert concentrations (e.g., soil organic carbon content) into volume-related quantities. Bulk density and porosity depend on the botanical origin of the peat, the degree of decomposition and other pedogenetic processes. These soil characteristics can be identified directly during soil examinations in the field. In contrast, the determination of bulk density and porosity requires volume-based sampling and subsequent laboratory analyses.
Here, we present pedotransfer functions for peat and other organic soils to derive bulk density and porosity using random forest models. Based on a dataset from approximately 600 horizons from 100 peatland sites in Germany and other European countries, we built a set of different pedotransfer functions combining predictor variables determined in the field. These included the degree of decomposition, peat type (e.g., *Sphagnum* peat, *Carex* peat, amorphous peat), horizon characteristics (e.g., aggregated, oxidized, permanently saturated, ploughed), average horizon depth, rooting intensity (no roots to extremely dense, estimated from root proportion per cm^2), admixture of mineral compounds and the occurrence of carbonate (estimated using 10% hydrochloric acid). Further pedotransfer functions were built, using soil organic carbon content as an additional predictor variable.
The results show that bulk density and porosity can be predicted using only a few predictor variables (3-7) with a low bias and high coefficient of determination. Adding soil organic carbon content as an additional predictor variable further improved the pedotransfer functions. Depending on the combination of the predictor variables, root mean square errors (5-fold cross validation) varied between 0.069 to 0.099 g cm^{-3} for the bulk density and 3.8 to 4.7% for the porosity pedotransfer functions.

Establishment of a German peatland monitoring programme for climate protection - Open land (MoMoK)

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Peat and other organic soils store large amounts of soil organic matter, which is highly vulnerable to drainage. Thus, drained organic soils contribute around 7% to the total German greenhouse gas (GHG) emissions and around 44% to the emissions from agriculture and agriculturally used soils, despite covering less than 7% of agricultural area in Germany. With approximately 90% of the total emissions, carbon dioxide (CO_2) is the most important GHG with regards to drained organic soils. To evaluate possible GHG mitigation measures such as classical re-wetting, paludiculture or adjusted water management compared to the still widespread *status quo* of drainage-based peatland agriculture, an improved data set on GHG emissions, in particular CO_2, and their drivers is needed. Furthermore, spatial data and upscaling methods need to be improved.
To meet these needs, a long-term monitoring programme for organic soils is currently (2020-2025) being set up for open land at the Thünen Institute of Climate-Smart Agriculture. A consistent long-term monitoring of soil surface motions, representatively covering a broad range of organic soils and land use types will be combined with the repeated measurement of soil organic carbon (SOC) stocks to assess CO_2 emissions using standardized and peat-specific methods. Land use types comprise grassland, arable land, paludiculture as well as unutilized re-wetted and semi-natural peatlands. At each of the envisaged approximately 150 monitoring sites important parameters such as groundwater table, vegetation and soil properties are monitored. Together with the updated map of organic soils, all collected data form the basis for improving regionalisation approaches for drivers – particularly water levels and SOC stocks – and CO_2 emissions from organic soils in Germany. Here, we will present the structure of the monitoring programme, the used methods for data collection as well as first results e.g. from Bavarian monitoring sites.

Magnitude of percolation in peat profiles controls organic matter transformation in different mire types

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The transformation of organic matter in peatlands is generally assumed to decrease from top to bottom, but the knowledge about the degree of this transformation is restricted to few mires. Glatzel et al. (2023) report a rapid closure of peat oxidation processes within the first 10cm of the peat column in an Alpine raised bog and no such closure down to 40 cm peat depth in an Atlantic Blanket bog. The authors argued that the reason for this is the absence of vertical water movement in the raised bog compared to constant flushing of the peat column in the blanket bog. It is not clear whether similar differences in organic matter transformation also exist in other mire types.
This research question was tested by sampling peat profiles in 14 different peatlands in Austria, differing in altitude (200m NN to >2000m NN), precipitation, hydrogeomorphic setting and substrate. We examined peat samples for the degree of oxidation of organic carbon (Cox), thermogravimetric analysis, degree of unsaturation and Gibbs Free energy.
The results indicate almost complete preservation of recently produced organic matter in bogs and fens in mountain and lowland settings and no large influence of superficial degradation in sites lacking pronounced vertical water movement. Specifically, no pronounced difference in organic matter transformation between bogs and fens exists (Figure 1).
We conclude that the magnitude of vertical water movement and not superficial degradation of the peat or the origin of the water control the magnitude of organic matter transformation in mires of widely differing origin.

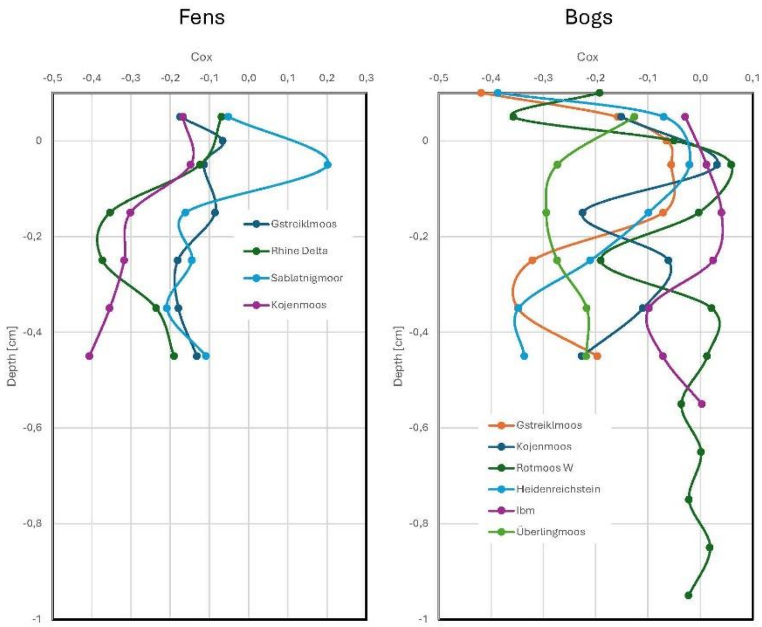

Figure: Oxidation of organic carbon (Cox) in Austrian fens and bogs.
Reference:

Glatzel, S., Worrall, F., Boothroyd, I.M. et al. Comparison of the transformation of organic matter flux through a raised bog and a blanket bog. Biogeochemistry 167, 443–459 (2024). https://doi.org/10.1007/s10533-023-01093-0

Sorption of Pharmaceutically Active Substances in Peat Soils

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Many pharmaceutically active compounds (PhACs) are contaminants of emerging concern that are increasingly being detected in the environment. Pharmaceuticals may enter wetlands as pollutants through many avenues, including contaminated human wastewater and run-off from agricultural land. As significant landscape-level water collectors, peat soils are sinks for these PhACs. Given the unique physicochemical attributes of peat soil, the retardation and removal of pharmaceutically active contaminants in peat soil is largely unclear. In this study, a batch technique was used to investigate the adsorption of six selected pharmaceutically active substances, i.e., atenolol, caffeine, amoxicillin, ampicillin, clarithromycin and erythromycin using different peat soils as sorbents. The peat soils had different physicochemical properties and were under different land use systems, including sustainable wet peatland cultivation (paludiculture). Initial adsorption rates were in the order clarithromycin (K_d 27.48 to 107.29 L kg^{-1}) > erythromycin (K_d 92.63 to 482.33 L kg^{-1}) >caffeine (K_d 22.44 to 36.93 L kg^{-1}) >atenolol (K_d 27.85 to 47.68 L kg^{-1}) > ampicillin (K_d 3.93 to 12.35 L kg^{-1}) > amoxicillin (K_d 1.80 to 14.65 L kg^{-1}). Two-parameter Freundlich and Langmuir isotherm models, as well as a two-step isotherm model derived from the Freundlich and Langmuir models, were found to be suitable in describing the sorption of most of our pharmaceutical analytes. These models combine the sorption maximum of the Langmuir model and the sorbent heterogeneity of the Freundlich model. Langmuir and Freundlich model analyses revealed that, in peat soil under spruce forest, sorption affinities were in the order clarithromycin > erythromycin > atenolol > caffeine. In peat samples where both atenolol and caffeine were detected, the sorption affinity of atenolol was higher than that of caffeine in all but one samples. In samples from both horizons of rewetted peat under *Phalaris arundinacea*, there was a greater sorption capacity but lower binding affinity for clarithromycin than erythromycin. For the beta-lactam analytes (amoxicillin, ampicillin), the Sips isotherm model and its variant, the Redlich-Peterson model, were found to be applicable, which indicated possible multilayer sorption of the PhACs. In addition, the Guggenheim-Anderson DeBoer isotherm showed a good fit to sorption with macrolide antibiotics (clarithromycin, erythromycin) and amoxicillin in two study soils, with the isotherm's C constant showing a stronger sorption interaction for erythromycin than clarithromycin. Correlation analyses between sorption K_d values and selected peat physicochemical properties revealed that atenolol sorption K_d values were significantly correlated to the highest number of properties (Organic matter, r= -0.82*; Total N, r=0.96**; pH, r= 0.96**; O/C ratio, r=0.96**; (O+N)/C ratio, r=0.96**; H/C ratio, r=0.96**, and Cation Exchange Capacity, r= -0.83*) while amoxicillin and ampicillin sorption K_d values were not significantly correlated to any of the selected peat soil properties. Sorption K_d values of erythromycin and clarithromycin were, in particular, much higher than the average values recorded in terrestrial soils, pointing to the relevance of peat soils as potential filter systems for pharmaceutically active pollutants.

Microbial community development during and after rewetting a coastal peatland

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Coastal peatlands are believed to exert a substantial influence in mitigating climate change and many of these valuable ecosystems have been drained for agriculture, becoming significant carbon sources. The impact of draining and re-wetting a peatland on the microbial community is of great importance for our comprehension of carbon cycling. The balance between methanogenic and methanotrophic microbial communities, and the interaction with other nutrient cycling microbes is especially important. Methanotrophs, especially anaerobic methanotrophs (ANME), are thought to be slow growing and may have a considerable lag time in development after an ecosystem disturbance. Multiple recent studies have found methanotroph abundance to be smaller than methanogen abundance post rewetting, potentially leading to prolonged high methane emissions. The former coastal peatland, Drammendorf, located in NE Germany, was drained in the 1970's and rewetted with brackish water in 2019. To track microbial community development, samples for 16S rRNA and metagenomic sequencing were collected in 2019 before rewetting, in 2020 6-9 months after rewetting, and again in 2022, approximately 2.5 years post rewetting. The first results reveal an increase in methanogen abundance and diversity that outpaces that of methanotrophs, as well as a strong sulfur and iron cycling community.

Discovering the composition of SOM from drained and rewetted peatlands: insights from molecular and biogeochemical parameters

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Land management practices alter biogeochemical processes which in turn influence peat properties and affect carbon and nitrogen cycling. Variation in peat properties might be another piece in the puzzle for explaining and ultimately predicting Greenhouse gas (GHG) emissions from different peatland sites. We studied how peat properties change through drainage by comparing the soil organic matter (SOM) composition of a long-term drained peatland and a rewetted peatland. SOM of peat profiles was characterized with i) thermal analysis (differential scanning calorimetry DSC coupled with evolved gas analysis of CO_2) ii) analytical pyrolysis gas chromatography with integrated mass spectroscopy (PYGCMS), iii) biogeochemical parameters indicative of SOM transformation such as C:N ratio and carbon's oxidation state (C_{ox}), and iv) ^{14}C age.
Long-term drainage resulted in increased mineralization of the peat as indicated by lower carbon content (32 vs 52% OC), C/N ratios (16 vs 32) and higher oxidation state (0.06 vs -0.37). The SOM of the drained topsoil (0-0.15 m) was significantly older (1600 vs 26 years BP) as were the deeper (0.60-0.75 m) soil horizons (5898 vs 685 years BP). PYGCMS was used to investigate the molecular composition of the peat profiles. In particular, we looked for labile and recalcitrant plant and microbial molecules and their transformation products. The molecular composition of the drained site was characterised by a lower proportion of labile compounds (fresh, high molecular weight molecules of mainly plant origin) and by a higher proportion of degraded and microbially transformed SOM. The energy density (J / g OC) tended to be lower at the drained site. In addition, the peak position of the thermograms shifted to higher temperatures, indicating higher thermal stability of peat at the drained site. Our results indicate that a combination of molecular markers and biogeochemical parameters can be used as indicators of transformed and stabilised SOM in drained and rewetted peatlands. To what extent these parameters are suitable to explain the degradation stability of peat and thus can be interpreted as an additional driving factor for the GHG emission potential of organic soils remains to be investigated.

Comparative analysis of metal and nutrient uptake in different *Sphagnum* species: Do we have a champion for water purification?

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Peatlands are critical, carbon-dense ecosystems that play a vital role in climate regulation and biodiversity conservation. However, extensive drainage for agriculture and fuel extraction has transformed these ecosystems from carbon sinks to significant greenhouse gas emitters. As a result, restoring peatlands has gained increased attention. Some *Sphagnum* mosses play a central role in peat formation by creating acidic and wet conditions that reduce organic matter decomposition, promoting peat accumulation. Consequently, *Sphagnum* is a key genus for peatland restoration. Additionally, *Sphagnum* can be cultivated in paludiculture (wet peatland use), which reduces greenhouse gas emissions and land subsidence, aids in biodiversity restoration, improves water regulation and allows productive land use. However, little is known about how rewetted peatlands could function as treatment basins, purifying water and providing clean water downstream. To address this, we investigated the absorption of various nutrients and metals by different *Sphagnum* species to identify those most effective for this purpose. Twelve species were then cultivated on bare peat for three years, after which nutrient and metal concentrations in their biomass were analysed and the accumulation calculated. Significant interspecies differences were found for most of the elements (aluminium, arsenic, barium, boron, cadmium, calcium, cobalt, chromium, copper, iron, potassium, magnesium, manganese, nickel, phosphorus, sulfur, zinc, and strontium), except lithium, mercury, molybdenum, and lead. The interspecies differences were mainly driven by some replicates of hollow species, notably *S. centrale* and *S. denticulatum*, which exhibited some of the highest accumulations. These findings highlight the variability in metal and nutrient uptake among *Sphagnum* species and underscore the importance of species selection in peatland restoration efforts aimed at water purification. However, further investigation is needed to better understand the drivers of accumulation and evaluate the effectiveness of *Sphagnum* as a pollution barrier.

Understanding Human Impacts on Peatland Degradation and Restoration: A Field Experiment Approach

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Drained peatlands in the Netherlands have undergone degradation over the course of centuries, prompting an urgent need for their restoration. Peatland degradation not only exacerbates climate change, but it also leads to land subsidence, which has negative socio-economic consequences. This research aims to examine how human activities have altered peat zones by changing water chemistry, available organic matter for degradation, and other ecological parameters in order to understand how restoration practices may affect these ecosystems. Through a field experiment conducted at the Assendelft peat site in the Netherlands, one-meter peat cores were sampled and placed in drainage pipes. Half of the samples flipped and repositioned in the field, while the other half remained in the same depth profiles as controls.
After one year, the oxic-top and anoxic-bottom sections of the cores were harvested to measure concentrations of dissolved organic carbon, soluble iron, and sulphate. Additionally, methane and carbon dioxide productions by microorganisms, along with potential activities of three hydrolytic exoenzymes and phenol oxidase, were assessed. Results indicate that, even after a year, flipped cores exhibited higher CO_2 production rates under both oxic and anoxic conditions compared to controls. Elevated microbial activity under anoxic conditions in the flipped cores is supported by lower sulphate concentrations and higher dissolved organic matter concentrations. These findings highlight the significant impact of historical and ongoing human activities on peatland biochemical status, underscoring the importance of integrating these considerations into effective restoration practices.

The Dynamics between Groundwater Tables and CO_2 Emissions at Åstrup Fen, Denmark: Primary results from a study utilizing IoT Networks, Artificial Intelligence and Aquatic Vegetation investigation

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Groundwater is a critical component in the carbon cycle within low-lying peatlands. However, its influence on carbon dioxide (CO_2) emissions is not sufficiently studied. This comprehensive research focuses on Åstrup Fen, Denmark, employing IoT networks, artificial intelligence (AI), and aquatic vegetation to investigate the correlation between groundwater tables and CO_2 dynamics.
The primary methodologies of this research include:
1) Spatial and Temporal Variability of CO_2 Dynamics: The research scrutinizes the spatial and seasonal variabilities of CO_2 dynamics at Åstrup Fen. IoT loggers, installed at three distinct points, have been recording near-surface CO_2 concentrations, temperature, humidity, and groundwater table data since March 2023. The findings up to August will be presented.
2) AI Applications for Modelling and Forecasting CO_2 Dynamics: Utilizing the parameters measured every 30 minutes at the site, along with meteorological data, AI models were employed to unravel the dynamics between groundwater tables and CO_2 concentrations. The validated AI model will subsequently be used to forecast CO_2 concentrations in response to rising groundwater tables.
3) Influence of Aquatic Vegetation: The presence of aquatic vegetation significantly impacts CO_2 dynamics. Vegetation serves as both a carbon sink and a source, with submerged plants contributing to organic matter decomposition and subsequent CO_2 release. We investigated the vegetation's coverage, above-ground biomass, and underground biomass to assess the yearly turnover of Carbon at the site. This yearly carbon turnover assists the AI models' results in yearly CO_2 reduction/production at Åstrup Fen.
In conclusion, this study offers cost-effective strategies for monitoring and analyzing the local dynamics of groundwater table changes and atmospheric CO_2 concentrations in low-lying peatlands, exemplified by Åstrup Fen, Denmark.

Picture: The installed IoT loggers at the Åstrup Fen
Picture: The vegetation species and coverage filed registration

2 Renaturierungspraxis in verschiedenen Moortypen und –landschaften

Indication of water level by vegetation structure types, peat investigation in combination with gauges

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The indication of hydrological conditions in wetlands is the first and most important challenge in understanding their functions for ecological planning or calculating climate effects by dry out peat.

The usual way is to use gauge tubes for manual measuring or automatic loggers. Unfortunately this kind of measuring is very time-consuming (for manual measuring) or rather expensive (for technical loggers). To get not only punctual knowledge about the conditions of the groundwater level in wetlands there is a need for a variety of such equipment. But even when installed, the results only can be aquired from the time after the introduction into the mires.

The indication of the ecological state by analyzing soil (peat) in combination with mapping vegetation can help to optimize using gauge tubes – for areal results as well as for results that reach back to the past.

Therefore we used more than 2000 drill holes from surface until mineral undergroud by peat augers for descriptions of different mire types and mire regions in Southern Germany and their groundwater levels. Additionally we described the actual vegetation structures – concerning dominating or indicative species and their patterns of growth to use them as indication and supplement for water measurement (vegetation structure types; after vegetation-formes by Schlüter 1984 and Succow & al. 2001; Siuda 2021; HSWT/PSC & Siuda 2023).

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Emerging challenges for realizing bog restorations in forests (Herausforderungen bei der Umsetzung von Wiedervernässungsmaßnahmen im Wald)

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About 8000 ha of boglands and transitional peat bogs are owned by the Bavarian State Forestry (BaySF). Many of these sites have been subject to forestry use and are therefore drained. In recent years several drainage systems remained unmanaged, and first renaturation measures were initiated. With the elaboration of a development concept and the creation of a team of peatland experts in the year 2023, circa 2500 ha of boglands and transitional peat bogs will be rewetted and taken out of use. The aim is ideally the establishment of pristine bog woodlands.
The main challenges can be divided in three categories: planning of dam constructions, stocking of the bog area and monitoring of the measures taken. Regarding the proper planning of dam constructions, many parameters must be considered, e.g. the depth of the ditch, the peat thickness or the composition of the underlying substrate. The predominant stocking of the bog areas with spruce plantations is a further challenge that demands circumspect actions. In practice a total clearance of the spruce plantations was not beneficial for the development of the bog habitat. However, with spruces remaining, there is the need to potentially enter the restored area in case of bark beetle infestation.
Subsequently, the verification of the renaturation actions will be done by a standardized monitoring with checking the water level of the rewetted area as main objective.
This contribution aims to discuss concrete approaches and the current strategy of the “Team Moore” of the BaySF. Especially the challenges of the upcoming renaturation of fen areas by the BaySF should become part of further discourse.

Picture: Installation of a sheet pile in Spirkenmoor close to Griesbach; © Sharon Rakowski und Kerstin Bär

Peatland Restoration in Lower Saxony: Too Big to Fail

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With over 600.000 ha of organic soils, Lower Saxony has more peatland area than any other German state. Lower Saxony is also home to three-fourths of all German bogs and, accordingly, plays an important role in protecting Germany's bogs. In 1981, Lower Saxony implemented the first peatland protection program in Germany. This program decreed that after peat extraction bogs should be restored. Over the last 40 years, more than 20,000 ha of bogs have been restored after peat extraction, hence allowing for the development and long-term testing of bog restoration techniques.

Currently, over 70% of the organic soils in Lower Saxony are drained and used for agriculture, mainly as grassland. Drained peatlands make up circa 17% of the annual GHG emissions in Lower Saxony, making drained peatlands the second largest source of emissions after of the energy sector. In order to reach federal and state climate goals, large areas of peatlands currently used for agriculture must be rewetted. Thus, the tested techniques for restoring bogs after peat extraction should be adapted to restore bog grasslands.

Twenty-six bog restoration experts collaborated on a best-practice guide, summarizing the current restoration practices in Lower Saxony. The contributing authors represent a variety of institutes, such as NGOs, private consultant companies, peat companies, universities and government ministries. In this document, bog restoration techniques and their technical implementation are described in detail. Specific guidelines are included for the restoration of bog sites with different land-use histories, such as agricultural use. For such peatlands, guidelines must be adapted to manage the strongly decomposed, nutrient-rich topsoil. Additionally, the guide includes a framework to help practitioners assess the rewetting potential of bog restoration sites.

We hope this document will be an important tool for practitioners of bog restoration in Lower Saxony. One of the most important ancillary benefits of this collaboration was the necessary discussions between authors. Through this collaboration, we now have reached a consensus on certain key issues for bog restoration in Lower Saxony.

Nature conservation and monument preservation hand in hand: Renaturation practice at Lake Federsee

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The Federsee area is the largest peatland in southwest Germany. It is part of the European Natura 2000 network designated under the Habitats and Bird Directive. It is also one of the peatlands richest in finds in Europe. Since 2011, the "Prehistoric Pile Dwellings around the Alps" have been recognized as a UNESCO World Heritage Site. Successful cooperation between archaeology and nature conservation made it possible to acquire areas, merge them via land reorganizations and to wet about 450 ha. Increased public relations work, visitor guidance and optimization of management are part of all projects.

<ins>LIFE project "Conservation and Development of Nature in the Federsee landscape"</ins> (1998 to 2002)
The new construction of the Kanzach Weir, numerous wooden weirs, pipe dams and movable dam flaps, resulted in the extensive waterlogging of around 250 hectares of peatland meadows and the Staudacher ban forest. The basis was a land reordering procedure with about 70 ha of land acquisition from project funds as well as a hydrogeological report. Additional milestones were the designation of two nature reserves (420 ha) and a management plan for about 2900 ha of peatlands.

Picture: Adjustable dam in the southern Federseeried, which has promoted the acceptance of waterlogging and allows water levels to be adjusted.

<ins>LIFE+ Project "Restoration of habitats in the Federsee peatland"</ins> (2009 to 2014)
Additional 200 ha of the Federsee peatland could be renatured. In the northern region, earthed peat was removed on 15.000 m^2 to fill 30 km of ditches, a waterbed was redesigned at 2100 m, and billet bars and wooden sheet piling walls were installed to stabilize the water balance. In the south, a glider airfield was dismantled and renatured.

Picture: Nature reserve Nördliches Federseeried: Oblique aerial photograph after implementation of the EU-LIFE+ Nature project "Restoration of habitats in the Federseemoor" in 2014 with topsoil removal, ditch closures and the relocation of two watercourses.

<ins>Revitalization of the Betzenweiler Ried</ins> (2021 - ongoing)
Aim is a close-to-nature design of the Miesach taking into account activities of beavers and the development of wet meadows over an area of 100 ha. The biotic and hydrological studies have been completed, a land reordering procedure is underway, and the action plans are to be completed and planning approval documents submitted by autumn 2024.
Decades of experience with renaturation can be drawn on in the Federsee area. The good cooperation between the real estate authority, land redevelopment, agriculture, nature conservation, forestry and water management, NABU and monument preservation has already made a lot possible in the Federsee area. It is important to maintain and expand these Corresponding authorss in order to jointly promote sustainable development.

Chose a steel sheet pile wall

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Permanent water retention requires safe technical solutions. Water-retaining structures must be particularly impermeable in regions with low rainfall. However, the type of construction also has to be selected accordingly in areas with high rainfall in order to prevent erosion caused by excess water. Another reason to choose a solid installation is to prevent damage from animals.
The installation of a steel sheet pile wall is a suitable solution for these requirements. The load-bearing capacity of the subsoil must be investigated in advance using dynamic probing. During implementation, light tracked dumpers and excavators enable the sheet piling to be transported and installed without damage.
In the Eglinger Filz in the district of Bad Tölz-Wolfratshausen, a 76 m long and a 15 m long steel sheet pile wall for water retention were installed in a 3-hectare peat cut. This was realized in 2016 with funds from the Bavaria 2050 peatland restoration climate programme. In 2020, two short sheet pile walls were installed in the Münsinger Filz to raise the water level in a small spring channel.

Picture: Peatland ecologist Cornelia Siuda and construction supervisor Axel Thiele on the installed steel sheet pile wall in the Eglinger Filz (© E. Pleyl)

So much knowledge, so much data - conceptual realisation of a moorland data and document management system for the Erzgebirgsregion

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Bogs have been rewetted in the low mountain region of Saxony for around 25 years. The measures have been planned and implemented by various stakeholders. In addition to a wealth of experience, a large number of expertise, project reports, mapping and measurement data have been collected during this time. The data is stored by the respective stakeholders, making it difficult to obtain an overview of previous measures and studies in the region. This results in a high risk of information loss or duplication of work, especially when knowledge carriers can no longer be interviewed due to retirement or a change of profession. In the MooReSax project of Sachsenforst (2021-2025), extensive data and documents from the Erzgebirgsregion were compiled and a concept was developed to systematically process and make this peatland information available. One focus was on the use and further development of existing data management structures rather than the development of new IT solutions. The aim is to provide planning-relevant moorland information for future projects. In addition to a peatland map for the low mountain region, in which potential peatland locations are shown, peatland areas, project areas, water level locations, peat thicknesses and the implementation status of revitalisations are shown spatially. Unpublished documents and data sets are spatially assigned to the areas and can be found via a document management system in the form of metadata. This basic structure will also be incorporated into the work on the Saxon Mire Programme (2024-2025) and support the development of a Saxony-wide mire information system.

This article was translated by the organisers. No guarantee for linguistic correctness.

Climate and environmental protection through peatland restoration in practical implementation with the participation of various actors

(Klima- & Umweltschutz durch Hochmoorsanierung in der praktischen Umsetzung unter Beteiligung verschiedener Akteure)

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Politics at both federal and state level will continue to rely exclusively on voluntary action for the foreseeable future and sufficient public funding can no longer realistically be expected. The only prerequisite for entering the planning level for rewetting peatlands is to identify sensible area settings under private law and to present the implementation financially in the form of business cases for those involved, making the most creative use of all conceivable financing and land securing options.
The political targets from the Paris Declaration 2015 to the national or municipal level are very ambitious in terms of both content and time. If these targets are to be even partially realized, accelerated cooperation between all relevant stakeholders is required with a clear focus on not only describing the challenges, but also solving them.

At the planning level, there are a number of administrative hurdles to overcome, particularly in Germany. Some examples are procedures relating to regional planning, water and nature conservation law, building regulations, species protection, immission control, archaeology and agriculture (e.g. ban on plowing up grassland).

The most important key points for technical implementation are summarized in the NABU guidelines for raised bog restoration. The key points are

- Removal of the agricultural topsoil (as much as necessary - as little as possible)
- Incorporation of the material in the area as far as possible
- Use of the surplus removal material
- Water management
- Procurement and propagation of suitable inoculation material
- Monitoring

The substrate industry is constantly researching potential peat substitutes and improving their quality and availability. The question is addressed as to whether and how the excess organic topsoil from rewetting projects can contribute to peat reduction in substrate production.

The NABU-IVG concept from 2014 includes, among other things, a model for peatland restauration without peat removal, but with removal of the topsoil that has been contaminated by agriculture. The participation of the peat industry in remediation measures in the course of the rewetting of peatlands therefore makes sense and can make an economic and logistical contribution to the overall plan of rewetting measures, especially in Lower Saxony, where many growing media companies are located.

3 Peatlands under stress and their ecological resilience

Reaction and resilience of Austrian mires to 35-40 years of environmental stress: A comprehensive resampling study in 200 mires

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The recent climatic changes and other human influences on the integrity of mires are suspected to result in pronounced changes in species compositions. However, this assumption has never been tested comprehensively for a large number of sites.
This study aimed at improving the knowledge basis in view of biodiversity changes by remapping the vegetation of 200 Austrian mires and comparing the current plant diversity recorded 35-40 years ago. In addition, the study intended to evaluate the CLIMOOR model (Essl *et al.* 2012) which predicts the status of Austrian mires until 2090.
Our study was based on over 1200 vegetation plots conducted during the summer of 2023, and the vegetation survey that was conducted between 1984 and 1988 (Steiner 1992). The conservation status of these mires and its change regarding moisture, nutrients, light, and pH was investigated using Landolt (1977) Indicator Values for the recorded plant species. Furthermore, we analyzed the long-term change in plant diversity using species richness and other indices (e.g. Shannon). To determine the degree of disturbance of these mires, the change in abundance of disturbance indicators (plant species) for the respective mire type was examined.
The comparison showed a significant rise of species numbers (especially in bogs, spring fens and inundation mires), reaction/pH (bogs and transition mires, not in fens) and nutrient values (all three categories), whereas light and moisture values declined in all categories. This is possibly the result of two overlapping effects: Climate change with higher temperatures affecting moisture and reaction, and nitrogen deposition from the atmosphere affecting the nutrient and light values.
Nevertheless, the resilience of mires especially from bogs and transitional mires seems to be quite high, because 40 years of stress did not yet result in dramatic changes.

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How resilient is the Puergschachen bog as a GHG sink over 7.5 years?

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Peatlands naturally act as carbon and water (H2O) sinks, but due to degradation caused by drainage and drought, peatlands can become a carbon source and lose H2O.
Puergschachen is an ombrotrophic bog situated in the inner-alpine Enns valley at an altitude of 632 m in the Eastern Alps of Austria. The raised bog covers an area of about 62 ha and is moderately degraded, as indicated by a shift in vegetation composition due to the birch encroachment and the loss of specialized bog hollow species. The bog is threatened by drainage for intensive agriculture in the surrounding area, droughts and rising air temperature due to climate change.
The eddy covariance (EC) technique was employed to provide a continuous quantification of the vertical turbulent greenhouse gas (GHG) exchange of H2O, carbon dioxide (CO2) and CH4 between the bog and the atmosphere for 7.5 years (mid-2015 to 2022). Vegetation indices were used to account for the vegetation development of the studied ecosystem.
We quantified the interannual and seasonal variability of H2O, CO2 and CH4 fluxes and evaluated the underlying factors being responsible for these variations. Furthermore, the influence of climatic stressors on the carbon and water fluxes of the bog was investigated. The annual precipitation of the last 5 years (2018-2022) was below the mean annual precipitation of 1233 mm (1985-2022), while the annual mean annual air temperature showed a strong increase, especially in the last 10 years, from 7.4°C (1985-2022) to 8.2°C (2012-2022).
In 5 out of 7 years, the Puergschachen bog was a carbon sink. However, when considering the radiative forcing of CH4, the bog only was a GHG sink in 3 out of 7 years. Nevertheless, the bog was resilient enough to become a sink again after a particularly dry year. In all the years studied, the bog had a positive climatic water balance, as the annual evapotranspiration rate was lower than the annual precipitation.

Climate and Water Stress Symptoms in S Bavarian Mires (Das „Schlenken- und Spirkensterben“ in südbayerischen Hoch- und Zwischenmooren)

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Decrease of hollow systems and die-back of *Pinus rotundata* Link are among the most striking processes currently underway in Bavarian bogs (Ringler 2021 und 2024). First, I will prove, exemplify and quantify the progressive disappearance of hollow systems in undisturbed ombrogenous and transition mires. Then I will draw your attention to the damage-map for the entire bog pine distribution area in S Bavaria. Obviously bark beetles and the foliar pathogen *Lecanosticta acicola* act as „climate change enforcement bodies“ (vgl. Blaschke 2001, Jankowski et al. 2009, Müller-Kroehling 2022 per mail). At least 2.400 out of 4.135 ha (58 percent) *Pinus rotundata* and *Pinus mugo* stands in southern bavarian peatlands are infested, severely damaged or already dead. Finally, I refer to the additional but underestimated connection of fen impairment with municipal groundwater extraction and road construction.

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Response of vegetation on the water level drop-down gradient on a calcareous fen (NW Estonia)

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It is well-known that result to drainage the field-layer species common to minerotrophic fen are outcompeted by fast-growing tall species. Are losing their advantage to habit in water-saturated anoxic conditions. In the boreal zone calcareous fens exhibit considerable fluctuations in the water level (WL) during the vegetation period with the amplitude of WL fluctuation comparable with the range for drained fens. We studied the relationship between different WL parameters (mean with SD, maximum, minimum, start of WL dropping-down), water and chemistry, topmost peat and species composition on a large (over 3000 ha) calcareous fen on drainage gradient (almost no up to important). We monitored the WL in plant communities by 56 water level divers for three years. We found that the depth of the minimum WL and the duration of the hydrological minimum period varied importantly depending on the degree of drainage. The results demonstrated that the plant species assemblages grouped the best by minimum, maximum WLD and SD values averaged for 3 years. Distribution of *Myrica*-*Carex*-brown mosses fen assemblage is characterised important WL fluctuation during summer period but by overflooding in the first half of vegetation period (up to end of June). Patches of *Sphagnum* species appear when the overflooding is of short duration in spring.

The N-factor at different layers in peatland areas of Northeastern Mongolia

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Mongolia is one of the fastest-warming countries in the world, with the annual average air temperature having increased by more than 2.4°C over the last 80 years (), significantly resulting in impacts on peatland and permafrost. Our study explores the response of different peat layers expressed in n-factors during freeze-thaw periods in the Khurkh Valley in northeastern Mongolia. The Khurkh Valley is rich in biodiversity and supports a variety of ecosystems, including peatland, wetland, grassland, and forest. In this study, we used data from permafrost boreholes BH1 (wetland), BH4 (peatland with peat layer of 40-50 cm), BH5 (peatland, with the peat layer less than 20 cm), and BH6 (wetland), within the period from 2018 to 2023

In 2018, the daily cumulative freezing n-factor pattern at BH4 was similar to that at BH1. After five years of exclusion of livestock presence, the freezing n-factor at BH4 decreased sharply from 0.63 to 0.31, while the thawing n-factor changed slightly from 0.78 to 0.69. Additionally, the freezing n-factor at the BH6 site, located next to the exclusion fence, dropped sharply from 0.73 to 0.36. Snow and vegetation accumulations may have affected the freezing n-factor in the fenced area because the fence was on the windward side.

During the thawing season, the n-factor did not change significantly, except for at the BH5 site, where it decreased from 0.98 to 0.69. The possible reason for this is that grazing in the area may have decreased due to heavy rainfall in recent years, which has made the area swampy and difficult for animals to enter.

In general, the n-factor values for 2022-2023 were similar to those of 2018-2019, but all values were lower. The values for BH4 and BH6 were even lower.

The study demonstrates that n-factors depend not only on land cover such as snow and vegetation but also on overgrazing. Additionally, the thawing n-factor is influenced by rain patterns and paludification level.

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Restoration and conservation of peatlands in areas of interest for Quito's water supply

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Ecuadorian peatlands in paramos are vital for water supply, but they have been overlooked due to the lack of public policy, funding, and guidelines for their management and administration. This is because there are knowledge gaps regarding their functioning, biodiversity, environmental services and the potential of these ecosystems in terms of climate change. Peatland degradation is driven by the construction of drains for pasture establishment, grazing, fires, and extractive activities.

FONAG, the Water Fund of the city of Quito, the high-altitude capital of Ecuador, is responsible for the protection and restoration of the sourcewater areas that supply water to the city. Within these areas in the Eastern and Western Cordilleras of the Andean Mountain range, conservation and restoration activities are implemented, such as the creation of water conservation reserves, restoration of overgrazed areas, and rewetting of peatlands.

One of these peatlands is Pugllohuma (4115 masl), located at 70 km from Quito. For more than 100 years, this peatland was part of an extensive ranch and served as a grazing area. During this time about 3680 meters of artificial drains were built to drain the peatland. Between 2010 and 2015, all exotic animals were gradually removed, and grazing regime came back to mainly the natural one in which deer are prominent. In November 2017, the drains were blocked by wooden dikes to reduce direct runoff and mitigate drying out. The effects of this restoration on water dynamics are measured every 15 days using 18 one-meter depth piezometers. With a simple linear model, the water table recession constant was calculated after periods of precipitation.

As a result of this active restoration process, data show a positive impact on the increase in the water table, especially in the blocked ditches, where water levels are 8 cm higher than in the non-blocked ditches (this represents an increase in the water table of 44% in these rewetted areas). Additionally, the time constants of the recession curve after rainfall events show an increase, i.e. drainage is now much slower. This is an early indication that active restoration of drained Andean peatlands has a positive impact on water regulation.

Finally, it is important to mention that this case is a very first one, in the rewetting of high-altitude tropical peatlands in the paramo, which on its turn is vital for water supply of cities, agriculture and hydropower in the equatorial Andes.

Pugllohuma Peatland: drain 5 years after blockage by wooden dikes. Napo Province, Ecuador © FONAG

Mountain Peatlands: Natural Laboratories for Understanding Climate Change Effects on Carbon Fluxes

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Mountain peatlands play a crucial role in the carbon (C) storage dynamics of these landscapes. Peat temperature is a key variable influencing C dynamics within peatlands. How peat temperature regulates C dynamics, particularly in relation to elevation remains relatively unknown. Through our research, we seek to understand the impact of climate change-induced fluctuations in peat temperature on C flux dynamics. We examined the thermal and carbon dynamics of two peatlands located at the upper and lower extents of their occurrence in the Canadian Rocky Mountains. We conducted an observational study in which we monitored variations in peat temperature over multiple years for both sites: capturing the extreme "Western North America heat wave" in 2021 and recurrent wintertime Chinook events. Our findings indicate significant seasonal variations in thermal dynamics across both peatlands, with extreme events causing pronounced short-term increases in soil temperature, particularly at higher elevations. Additionally, we conducted a reciprocal peat transplant experiment, exchanging peat mesocosms between sites and measuring C during the subsequent growing season. Results from this experiment highlighted the dominance of peat intrinsic properties over environmental factors in regulating the C emissions in the short-term, indicating diminished C sequestration in a future characterized by longer growing seasons, warmer air temperatures and more dynamic water tables. Our research has allowed us to contextualize the implications of intensified and more frequent weather fluctuations with climate change. It also helps us underscore the critical yet often overlooked significance of mountain peatlands in hydroecological and biochemical processes, highlighting both their susceptibility to, and resilience against, climate change.

Observing ENSO-induced Climate Variability and Seasonality of Tropical Peatlands in the Eastern Colombian Lowlands with Remote Sensing

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Tropical peatlands are vital for global carbon storage, biodiversity, and hydrological cycles, yet they are increasingly stressed by climatic fluctuations like the El Niño-Southern Oscillation (ENSO). While dry years result in lower water tables and increased fire susceptibility, wet years lead to potentially increased inflow of sediments from the nearest river, altering the biochemical properties of peatlands. Remote sensing data can provide information on surface water and vegetation structure (microwave data), and vegetation health and water content (optical and short-wave-infrared data). In this study, we combined L-band SAR (synthetic aperture radar) backscatter and vegetation indices' time-series of 10 peat and 2 non-peat sites of four different ecosystems in the eastern Colombian lowlands, to analyze changes in tropical lowland peatlands, including an assessment of ENSO-induced dry and wet years. L-band HH (horizontal sent; horizontal received) data shows strong annual variations, indicating a hydrological seasonality. The peat and non-peat sites differ in the amplitude of this seasonal signal. In L-band HV (horizontal sent; vertical received) data, which is sensible to above-ground biomass and vegetation structure, we see an increase in backscatter over the recent La Niña years, exceeding the annual variability. Non-peat sites furthermore showed a tendency to higher Normalized Difference Vegetation Index (NDVI) and lower Normalized Difference Wetness Index (NDWI) values, meaning the vegetation experiences less waterlogging. Preliminary results furthermore indicate a light correlation between ENSO phases and peatland conditions observable from space. During El Niño years (ie. drier-as-average dry season and slightly wetter wet-season), we observed a tendency to lower L-band HV backscatter in the dry season (Jan. – Feb.), indicating less above-ground biomass. In the wet season (Aug. – Sep.), the NDVI of La Niña years is significantly higher, while the L-band HV shows a multiyear increase during an ongoing La Niña phase, which could be a sign of thriving vegetation during La Niña. With an expected increase in the frequency of climate extreme events, Earth observation offers a variety of tools to monitor tropical peatland conditions, especially in remote tropical areas. Ongoing monitoring and adaptive management are essential to provide sustainable ecosystem services to local communities and the regional climate.

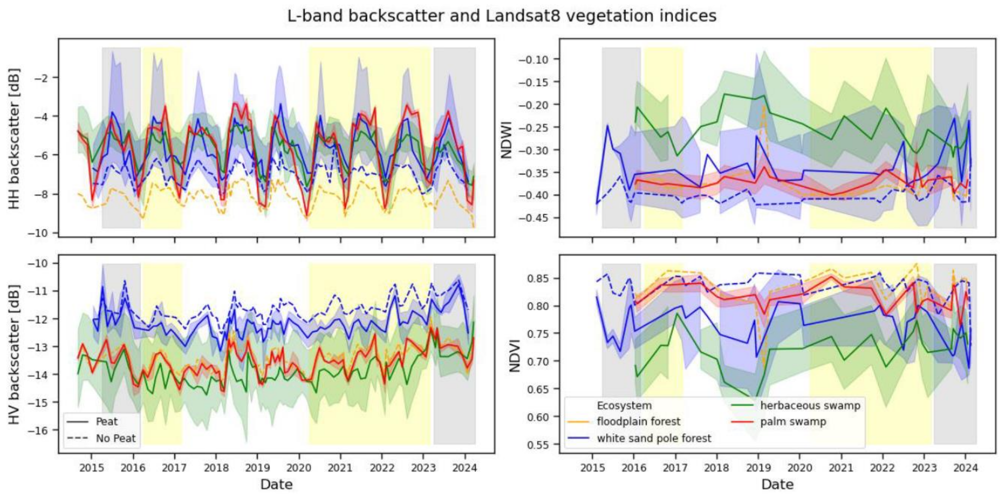

Figure: Time-series of L-band SAR HH (top-left) and HV (bottom-left) backscatter and Landsat8 NDWI (top-right) and NDVI (bottom--right) indices. The color represents different ecosystems, while the dashed lines mark no peat sites for reference. Translucent bands show the standard deviation, grey background symbolizes El Niño years and yellow background La Niña (ENSO index 3.4 with a threshold of 0.5).

4 Stoffliche und energetische Nutzung von Paludi-Biomasse

Economic efficiency of paludiculture: An economic analysis of *Typha* and *Phragmites* cultivation

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Peatlands drained for agricultural use are a significant source of greenhouse gas emissions in Germany. Large-scale re-wetting therefore has an enormous mitigation potential and can contribute to the achievement of climate policy goals. However, the required increase in water levels means a considerable restriction of current management practices. Switching to paludiculture offers the opportunity to maintain agricultural value on rewetted areas while protecting the climate. These alternative management practices are the subject of research on a number of trial sites. The economic performance of individual paludiculture crops is essential for their large-scale establishment. However, economic analyses are barely evident. The planned study will contribute to this by analysing the economic viability of the paludiculture of Typha spp. and Phragmites australis, taking into account different cultivation methods, uses and area sizes. In addition to the use of the harvest material, costs are a key factor in the added value of both paludiculture crops. For this reason, the first step is to analyse the process costs using various sources. A meta-analysis of existing literature data is complemented by detailed data collection through expert interviews. The data is then fed into a profitability analysis, which also estimates the impact of possible cost degression. Depending on the utilisation of growth, minimum selling prices for each product are determined through sensitivity analysis. Based on this, a demand analysis will determine whether the minimum selling prices can be achieved in the market. For this purpose, the willingness to pay for the individual products is estimated. As a result, potential revenues for individual products can be calculated and recommendations made for a successful market launch. The calculations require assumptions to be made. Monte Carlo simulations are used to take account of the associated risk. Various scenarios are analysed.

Potential of a mixture of potato pulp and paludiculture biomass as biogas substrate

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The Donaumoos is the largest fen area in southern Germany and a central location for paludiculture projects. Previous studies have shown that paludiculture biomass can be used in substrate mixtures for biogas plants. The Bavarian part of Donaumoos is also the main production area for starch potatoes in Bavaria. During starch production, potato pulp (Fig. 1) is produced as a by-product. However, its further utilization is limited. The organic substance of potato pulp consists of starch and easily digestible fibers. For this reason, potato pulp might be a suitable biogas substrate. However, potato pulp lacks a hardly degradable organic structure that is necessary to create suitable habitats for microorganisms within a biogas plant. Therefore, this study investigated whether the fen plant *Phalaris arundinacea* (Fig. 2) could fill this gap and supports the anaerobic digestion of potato pulp.

Figure: Potato pulp.

Figure: *Phalaris arundinacea* (reed canary grass).

The following research questions were addressed: (1) Is there an optimal mixing ratio of potato pulp and *Phalaris*, (2) how much biogas yield can be achieved and (3) which impact does the feeding of these substrates causes on the biogas process in the long term. To answer these questions, various substrate mixtures were tested in a batch-test and in a semi-continuous flow-through long-term experiment.

The specific biogas yield of potato pulp in the batch test was approximately 650 L_N kg^{-1} VS, which is comparable to that of maize silage. The co-digestion of *Phalaris* with potato pulp at a ratio of 1:3 (dry matter based) did not change the specific biogas yield. In the long-term semi-continuous flow-through fermenter experiment, the specific biogas yields of the three tested feeding regimes (potato pulp + *Phalaris* (ratio 3:1), potato pulp + *Phalaris* + clover-grass silage (ratio 2:1:0.5), potato pulp + *Phalaris* + cattle manure (ratio 2:1:0.5)) were between approximately 500 and 550 L_N kg^{-1} VS. It was found that the addition of a nitrogen-rich substrate to the potato pulp/*Phalaris* substrate mixture, both having a wide C/N ratio, is not necessary. In the long-term experiment, no biological process disturbance occurred with any feeding regime. However, the regular addition of antifoam agent was required due to considerable foam formation caused by the potato pulp.

More than a paper tiger: Paludiculture pilots in paper production and construction sector

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The restoration of lost and the extension of existing wet peatlands are important corner stones for battling the on-going climate and biodiversity crises. Many former, natural wet peatlands in
Germany have been drained in the past centuries, mainly for agriculture. Drained peatlands are a large source of greenhouse gas emissions: Some 30-40 t CO2 equivalents per hectar and year are released into the atmosphere from these farmlands. The German government recognizes the importance of wet peatlands for the future and supports their restoration in a national strategy, but implementation of rewetting is limited currently very limited in scale. The majority of former wet peatland has been turned into farmland and is privately owned.

ToMOORow, launched by the Michael Otto Environmental Foundation and the Michael Succow Foundation, partner in the Greifswald Mire Centre, is a new initative to promote the conservation of wet peatland and to highlight their valuable contributions to battling the climate and the biodiversity crises. The development of sustainable farming regimes for wet peatland ecosystems, so called paludiculture, and the set-up of follow-up production lines presents private farmers with an alternative to their regularly drained farmlands.

Together with 14 dedicated business partners and with financial support of the German
Ministry of Agriculture, ToMOORow currently builts an "Alliance of Pioneers". In this alliance, the partners exchange their knowledge, and coordinate as well as launch pilot projects to realize theoretical and pre-studied production lines in practise. As of today, the "Alliance of Pioneers" is active in the sector of paper, cardboard packaging production and the sector of construction materials. The potential for paludiculture raw materials in these two sectors alone is enormous.

In the paper and cardboard packaging sector, first estimates expect up to 15% of the required raw cellulose could be covered by in paludiculture grown reed. The local production of paludiculture cellulose would cut down transportation cost of the mainly imported raw material from international sources.

In the construction sector, the demand for insulation materials increases with market incentives for energy conserving housing. As of today, 91% of isolation material originates from non-sustainable resources. Isolation material based on reed has many native, benefical attributes, and can be a sustainable alternative to fossil polysterol products. Here we present outcomes of a feasibility study and a scientific perspective on examples of our work in the alliance, as well as more general background on paludiculture implementation.

Products made from peat fibres (ProMoFa) - new potential for peatlands and an opportunity for the Bavarian Donaumoos

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The climate targets in Bavaria are ambitious and require a great deal of effort from everyone involved. The state's peatland protection strategy aims to establish a CO2 sink in the peatlands, especially in the Donaumoos-Zweckverband Donaumoos, the largest fen in southern Germany with a natural area of 180 km². Alternative sources of income for agriculture are of great importance in order to achieve the target of 2,000 ha of moorland conservation area by 2030. At the same time, the aim in the Donaumoos is to protect and preserve the habitat of rare and endangered animal and plant species, thereby promoting biodiversity. These include meadow breeding species such as the curlew and lapwing as well as numerous insects and aquatic species.
One promising option for farms is the defibring of bog plants to produce raw materials for paper, cardboard and free-form part production. By using moisture-tolerant permanent crops on peat soils, considerable amounts of CO2 can be saved compared to wood due to the shorter production cycles. In addition, the demand for recyclable and sustainable products made from renewable raw materials is high on the market, as the wastepaper market is limited. A regional raw material source from peatland management can therefore be an interesting addition.
On January 1, 2024, a research project entitled “Products made from bog fibres” (ProMofa), funded by the Bavarian State Ministry of Food, Agriculture, Forestry and Tourism, was launched in Donaumoos.
The research work focuses on several aspects. These range from identifying suitable areas of application with the help of laboratory analyses and pilot tests, to development work on process optimization of harvesting and fibre extraction, to process and application tests in common industrial processes in the paper and packaging industry. Furthermore, innovative applications/moor products are to be tested for feasibility and marketability. The results will be used to establish a value chain and will also take economic analyses into account.

The main objectives of the project include several pillars:

- Process optimization from harvesting to the provision of quantities of raw fibers relevant to the industry
- Process and application tests in common industrial processes in the paper and packaging industry
- Development of initial marketable products through to series production in close cooperation with end customers
- Marketing concept for raw fibres and products with pricing and quality parameters.

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Paludiculture biomass: A sustainable resource for natural fibre composites in injection moulding and 3D printing?

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Natural fibre-reinforced composite materials are crucial for advancing towards a more sustainable future (Dunne et al., 2016). Established fibre crops such as hemp and flax have already been pro-cessed with bio-based polymers like polylactide (PLA) or polyhydroxyalkanoates (PHA) in various studies to produce natural fibre composite materials. Injection moulding is a key process for producing components from these composite mate-rials, enabling the production of large quantities in short processing times. 3D printing is slower but allows the manufacturing of more complex components and small series. Although the natural fibres are considerably shortened during the processes, the mechanical properties can be increased by using natural fibres as reinforcement (e.g., Müssig et al., 2020). Further, the consumption of the polymer is reduced.
A potential issue in using plant biomass for technical applications is the competition for land resources. Given the limited availability of suitable soils, conflicts may arise with other land uses, such as the production of food crops. To mitigate these conflicts, it is essential to prioritise the use of areas that are not suitable for food production, such as wetlands (paludiculture) and marginal lands, for biomass cultivation intended for technical applications. This study investigates the utilisation of biomass from these non-food production areas as a resource for developing sustainable materials.
The suitability of biomass from various plant species cultivated on such lands was investigated. These include cattail (*Typha*), reed (*Phragmites australis*), reed canarygrass (*Phalaris arundinacea*), sedges (*Carex acutiformis*) and stinging nettle (*Urtica dioica* L.). Nettle was found to grow spontaneously on phyto-managed marginal land sites contaminated by traces of metal (Jeannin et al., 2020).
Fibre-reinforced composites were fabricated through compounding and subsequently processed via injection moulding and 3D printing. Mechanical characterisations were performed, and the structure-property relationships were ana-lysed using different optical techniques. Overall, the results presented underline the potential of utilising resources from sustainable land use for the utilisation in the composite materials sector.

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The use of fen paludiculture biomass as peat replacement in horticulture – challenges and solutions

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The political and social pressure to reduce GHG emissions in all economic fields reached the horticultural sector. One aspect is the reduction of peat in growing media. Thereby, the availability of high quality substitutes such as green waste compost, wood fiber, composted bark or coir is the biggest issue. Paludiculture of rewetted fens might be a source for a new kind of biomass, which could be used as peat replacement in growing media.

In the current research we focus on *Carex acutiformis*, *Phalaris arundinacea*, *Phragmites australis* and *Typha* spp. biomass. A first screening of the material revealed that biomass needs to be harvested in late winter. If harvest is done earlier the concentration of sodium and particulary chloride ist too high. Furthermore, similar to other cellulose-rich biomass, the material is easily degradable by microorganisms and due to the wide C:N ratio nitrogen immobilization limits the possible admixture. In addition, some phytosanitary problems have been observed, in particular a high proportion of seeds and growth of saprophytic fungi. To overcome these issues we composted the material with the addition of nitrogen as it is common practice in the production of composted bark. Analogous to this we used ammonium and urea N in the first trial. Indeed, the composting process was quite intensive, but a significant formation of ammonia was observed. Thus, we also tested nitrate as a suitable N source. The intensity of the composting process was reduced, but sufficient for a complete hygienisation. Irrespective of the used N form, composting led to biomass losses of up to 50 % by volume, which is of major concern regarding the economic feasibility. Furthermore, due to this mass losses, nutrient enrichement occurred.

Subsequent plant trials showed a significant stabilization of the N balance. Usually, there even was an N release effect. But out of the plant trials arose a new question: Whereas in some trials plants suffered from manganese deficiency, in another – with material of different origin – manganese toxicity was observed. Possible reasons and our current approaches to solve the problems and further steps onto the way to produce a valuable peat substitute from fen biomass are discussed.

5 rewetted peatlands – Biodiversity hotspot or novel ecosystems

Environmental and social safeguards in conflictive context: from environmental conflict to effective local participation in tropical areas

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Natural Climate Solutions (NCS) have recently changed the valuation of high mountain ecosystems in Colombia (in social, cultural, and economic terms) for the government to the local inhabitants. Particularly in Colombia, where the land tenure rights are the axis of the permanent armed conflict, NCS can have an impact on land value related to changes in the actual and potential land use, influencing the emergence or escalation of opportunities for local actors, as well as social conflicts and socio-economic tensions and institutional actions related to their management and protection. Locally climate mitigation actions and carbon markets have driven the arrival of new actors to regions with NCS potential, changing dynamics in land tenure and the distribution of benefits from various uses by local communities, deepening uncertainty in secure land tenure and therefore escalating conflict dynamics locally. In a joint effort, the laboratory of High Mountain Ecosystems and the Observatory of Ethnic and Rural Territories from the Pontificia Universidad Javeriana in Colombia have analyzed the impact of local governance systems on ongoing implementation processes of NCS in three study areas that share the presence of high Andean páramo and peat bogs. The results of this analysis have provided guidelines to create social safeguards in the future implementation of NCS handling with social conflict and reducing the probability to environmental conflict to exist or scale in the use of violence.

Identifying risk factors for the rare, endangered fen orchid *Liparis loeselii* in NE Germany

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The cultivation of fens in Europe has led to massive anthropogenic degradation of these complex ecosystems over the past centuries, accompanied by drastic declines and even local extinctions of typical fen species. This includes the rare, endangered yellow widelip orchid (*Liparis loeselii*), which is typical for alkaline fens and strictly protected in the European Union. However, habitat preferences and threats to Central European populations have been scarcely studied, which hampers effective conservation measures.

In this study, we investigated habitat preferences of the species in Brandenburg, NE Germany, to identify main drivers for its ongoing decline. To this end, we compared the habitat conditions of 17 sites harboring extant populations with those in 11 sites where *Liparis loeselii* had recently gone extinct. We developed a special sampling design that included randomly and selectively placed plots to tackle both the rarity of the species and the heterogeneity within sites, in order to quantify various abiotic and vegetation parameters.

Sites with extant *Liparis loeselii* populations were characterized by e.g. higher soil moisture, lower peat degradation, lower nutrient availability and lower litter cover, and they differed in plant community composition from sites with extinct populations. Within sites, *Liparis loeselii* required a narrower, specific range of microhabitats with even lower nutrient availability, lower vegetation height, higher light availability, and a high cover of brown mosses.

These results suggest that a key risk for *Liparis loeselii* are declining water tables, which lead to peat degradation and eutrophication, and thus promote tall growing, competitive species. Conservation management should thus ensure sufficiently high-water tables, supported by measures that reduce nutrient availability and ensure low-growing vegetation.

Project „Insekten beleben Moore" – Promoting insect diversity on rewetted cut-over peatland

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The large-scale drainage and use of peatlands have led to a drastic qualitative and quantitative loss of habitat for insect species that specialise in raised bogs, resulting in an increasing decline in the distribution and relative abundance of these species. Peat extraction sites are often large, homogeneous areas that are largely free of vegetation. Only little structure and a few (pioneer) plant species remain even after rewetting. However, a moderate variety of different habitat structures and typical bog vegetation are important colonisation factors for the insect fauna of raised bogs.
The aim of the "Insekten beleben Moore" (InsMoor) project is to develop and implement measures to improve the living conditions for insects on rewetted peat extraction areas. The project sites in the "Totes Moor" nature reserve (Hanover region) include restoration sites in various stages of age and regeneration, as well as areas where peat extraction has just ended. The measures are first tested on scientific trial plots with different site conditions. Then the successful measures are implemented on a large scale in the Totes Moor nature reserve.

To create additional habitat structures for insects, water pools are created or different water levels and moisture gradients are initiated within an area through peat surface modelling. The results show that these measures promote recolonisation by aquatic insects (water beetles, dragonflies) and can improve the establishment of *Sphagnum*. On areas without vegetation or with incomplete recolonisation by typical bog plant species, propagated plants from local donor material (vascular plants and *Sphagnum*) are planted to accelerate the regeneration of typical bog vegetation.

The Nature Conservation Authority of the Hanover Region is responsible for implementing the restoration measures. The development of the sites is evaluated by the Institute of Environmental Planning at Leibniz University of Hanover, which examines the population development of selected insect groups as well as the development of plantings and vegetation.

The project is funded by the Federal Agency for Nature Conservation (BfN) with funds from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

Of thick shelled river mussels, weatherfishes and co. - protected species in the secondary habitat peatland

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Peatlands were systematically drained for several decades. Thereby, humans created structures that provide valuable alternative habitats for some species, so-called secondary habitats. Especially rare and endangered species, whose natural habitats hardly exist in modern cultivated landscapes, use the structures of drained peatlands, e.g. drainage ditches. These species should be considered and protected when implementing peatland protection measures. What can we do when thick shelled river mussels, weatherfishes or other protected species occur in an area relevant for protection measures? We addressed this question within the project 'Biodiversity and peatland protection' at the Species Conservation Centre within the Bavarian Environment Agency.
Using classic mapping methods and the innovative approach of environmental DNA (eDNA), we examined the occurrence of selected species in the area of the Upper Bavarian Donaumoos (South Germany). We investigated the distribution area of the thick shelled river mussel (*Unio crassus*), the common spadefoot (*Pelobates fuscus*), the European weatherfisch (*Misgurnus fossilis*), the ornate bluet (*Coenagrion ornatum*) and other dragonfly species. These species are considered as endangered and are protected either through European law by the Habitats Directive or nationwide by the Nature Conservation Law. We developed solutions for potential conflicting goals due to the occurrence of those species by collecting numerous practical examples and collaborating with experts.
We proved that species conservation concerns need to be addressed in peatland protection measures. However, these concerns generally do not prevent the rewetting of peatlands. Therefore, we provide an overview of the legal framework, suitable peatland protection measures and the specific conditions to create valuable synergies.

Paludiculture can support biodiversity conservation in rewetted fen peatlands

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Paludiculture, the productive use of wet or rewetted peatlands, offers an option for continued land use by farmers after rewetting formerly drained peatlands, while reducing the greenhouse gas emissions from peat soils. Biodiversity conservation may benefit, but research on how biodiversity responds to paludiculture is scarce. Our team of researchers conducted a multi-taxon study investigating vegetation, breeding bird and arthropod diversity at six rewetted fen sites located in Mecklenburg-Vorpommern which were dominated by *Carex* or *Typha* species. Sites were either unharvested, low- or high-intensity managed. Biodiversity was estimated across the range of Hill numbers using the iNEXT package, and species were checked for Red List status. Here we show that paludiculture sites can provide biodiversity value even while not reflecting historic fen conditions; managed sites had high plant diversity, as well as Red Listed arthropods and breeding birds. Our study demonstrates that paludiculture has the potential to provide valuable habitat for species even while productive management of the land continues. A similar approach to assessing biodiversity has been implemented in PaludiZentrale, a project accompanying nine large-scale paludiculture projects across Germany in the next 10 years. Additionally, biodiversity will be similarly assessed over the next three years in solar photovoltaic parks installed on rewetted peatlands as part of the Moor-PV project at the University of Greifswald.

Does *Sphagnum* farming create habitat for bog species?

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The cultivation of peat mosses ('*Sphagnum* farming') is a climate-friendly agricultural use of degraded bog sites under wet conditions, which creates potential habitats for peatland species. The study investigated the extent to which the cultivation sites are suitable as substitute habitats for bog-typical and threatened plant and animal species.

In 2017 and 2018, plant and animal diversity (vascular plants, bryophytes, birds, dragonflies, butterflies, and epigeic arthropods) were assessed at two experimental *Sphagnum* cultivation sites (established from 2015 to 2016) in Lower Saxony (Germany). Three rewetted cut-over restoration sites and three near-natural bogs were assessed as reference sites.

Bog-typical and threatened plant species have established at the cultivation sites. Many species were transferred from the near-natural donor sites, and a high similarity in species composition between the cultivation sites and the associated donor site was found. The potential for colonisation from the surrounding area significantly influenced the cover of associated vegetation, species composition, and vegetation structure at the cultivation sites. In comparison, the rewetted sites without the introduction of *Sphagnum* biomass were species-poor.

Furthermore, the cultivation sites showed a high potential for characteristic peatland bird species and lowland breeders, as well as for characteristic dragonfly species. In contrast, the habitat quality for butterflies was low due to the site management and the lack of windbreak structures. Only a few arthropod orders found in the used donor material were able to establish at the cultivation sites. These were mainly spiders, bugs, and beetles. In the case of beetles, the cultivation sites provided a substitute habitat for different species specialized in bogs, benefitting mainly species adapted to wet *Sphagnum* carpets. The analyses showed that vegetation structure influenced the numbers of beetle species and individuals at the cultivation sites.

Both flora and fauna assessments indicate that cultivation sites can provide substitute habitat for bog-typical and threatened plant and animal species. The extent of the suitability likely depends on both the installation (e.g., irrigation system, the origin of the donor material) and the management (e.g., harvesting of *Sphagnum* biomass, mowing of vascular plants).

Sphagnum paludiculture sites as surrogate habitats for bog species of many species groups – results of long-term investigations in NW Germany

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In the peatland Hankhauser Moor (Lower Saxony, NW Germany), the first 4 ha of bog grassland were converted into a *Sphagnum* paludiculture in 2011 and expanded to 17 ha in the meanwhile. To do this, the degraded topsoil was first removed, and an irrigation system was built, after which fragments of *Sphagnum* were spread as ‘founder material’ on the unvegetated peat soil and the area was rewetted. In addition to vegetation development, spiders, dragonflies, avifauna and other species groups were recorded over many years. Factors influencing colonisation and the preservation of biodiversity were also considered. It is concluded that *Sphagnum* paludiculture sites are important surrogate habitats for bog species, their occurrence of which can be controlled by the management of the sites.

6 Exchange of greenhouse gases from organic soils

Influence of water management on ghg-balances along a land use intensity gradient in fen peatlands

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In Europe, about half of all peatlands are under influence of landuse. They are often drained to facilitate classical landuse options, causing the accumulated organic matter to be degraded and thereby triggering a significant increase in greenhouse gas (GHG) emissions. Many studies suggest raising the overall water level in drained peatlands will lead to significant savings in GHG emissions. Hence, to combine agricultural landuse, peat conservation and climate protection on a large scale, we suggest the concept of water management systems in currently drained, agriculturally used peatlands. Our ongoing research encompasses two interconnected research projects, called MOORbewi and MOORclimbII. Both projects focus on GHG fluxes from peat-soils influenced by water management systems, the potential of climate protection and synergies with conservation of biodiversity. Measurements and data collection take place on a large array of different land-use intensities, reaching from highly intensive arable maize fields, over moderately used meadows, sowed with a grassland seed mixture adapted to wet conditions, to extensively managed species-rich litter meadows. We installed suitable water management systems in every research site to lower water levels and allow for better accessibility for farming machinery when needed, but ensure near surface water levels for the vast majority of the year. To validate the impact of water management systems on GHG-balances we measure the exchange of CO_2, CH_4 and N_2O between the ecosystem and the atmosphere with a portable manual chamber system in combination with infrared gas analysers and gas chromatography. Our aim is to identify applicable water management systems and optimized water level-dynamics to combine carbon conservation and adapted agricultural usage. Lastly, we want to look at water management as a mitigation option for water dependent litter meadows and species rich wet meadows threatened by the influence of climate change.

Don’t blame the birches – impact of birch encroachment as a consequence of insufficient rewetting on carbon balances and evapotranspiration in a rewetted bog

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Natural bogs are often characterized by a *Sphagnum*-dominated vegetation. In the last decades, encroachment with vascular species such as *Betula* spec. was observed in many natural and rewetted bog ecosystems. This is presumably caused by climatic changes, insufficient rewetting and increased nutrient input. It can lead to dense tree populations, which affect vegetation composition, evapotranspiration and the constitutions of the peat as well as processes in the peat body.

Our project was investigating the impact of birch encroachment as a consequence of insufficient rewetting on water and carbon balances in a rewetted, former peat extraction area in north-west Germany. Therefore, two sites were installed in close proximity to each other (400 m), one open site (OS) with a more mire-specific vegetation and higher water tables and the second one with an increasingly dense birch population (~10 years), a lower *Sphagnum* density and more fluctuating water tables (tree site, TS). At both sites, eddy covariance measurement systems for water (H_20) and carbon dioxide (CO_2) fluxes were installed. One year of chamber measurements of CO_2, H_2O and methane (CH_4) was conducted at microform scale. Using this data, we could compile complete carbon (C) and greenhouse gas (GHG) balances and trace the fluxes to the different microforms and the birches.

Over the main investigation period (11/2020 – 10/2021), the mean annual water tables were comparably high (OS: -0,07 m; TS: -0,20 m). This was leading to rather high CH_4 emissions, especially at OS (OS: 36.1 ± 3.4 g CH_4-C m^{-2} a^{-1}; TS: 7.1 ± 1.5 g CH_4-C m^{-2} a^{-1}). Contrasting to that, the uptake of CO_2 was high at OS (-267.8 ± 7.8 g CO_2-C m^{-2} a^{-1}) and rather low at TS (-19.9 ± 3.9 g CO_2-C m^{-2} a^{-1}). This results in differences in the GHG and C balances (Fig.1). In contrast to common assumptions, evapotranspiration was clearly higher at the OS than at the TS. We assume this to be caused by lower water tables and increased shading and wind protection at TS. The results do highlight the impact of trees in combination with highly variable water levels on the ecosystem and suggest that the tree encroachment at this site is rather a consequence of insufficiently high water levels than the cause of those.

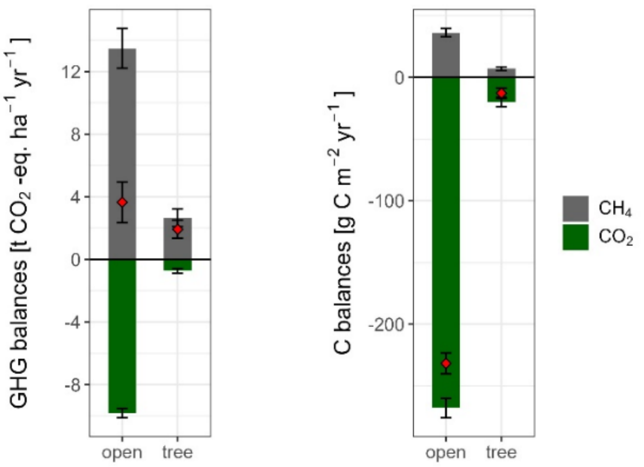

Figure: Greenhouse gas balance and carbon balance of the open site and the site under tree encroachment (tree site) over the investigation period (2020/21).

Paludiculture as a nature-based solution for organic soils - Results of GHG mitigation potentials in fen peatlands

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The concept of paludicultures is growing in importance as a promising climate mitigation measure and a sustainable alternative to current agricultural use of organic soils. Besides agricultural and economic viability, quantifying the climatic effects of paludicultures is essential to give reliable policy advice and facilitate sustainable management decisions with regard to climate change. Emission factors (EFs) of the relevant greenhouse gases (GHG) carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) for a variety of potential paludiculture plants are still rare, especially from comparable treatment and site conditions.

Five different temperate fen plant species (*Carex acutiformis*, *Phragmites australis*, *Phalaris arundinacea*, *Typha latifolia and T. angustifolia*) were established as paludicultures under different management and rewetting conditions at three former grassland or arable sites on fen peatland in southern Germany. One to five years after plant establishment, we measured fluxes of CO_2, CH_4 and N_2O to obtain annual budgets (n=81 / 38 drained: −11 to −22 cm, 43 rewetted: +4 to −10 cm) using manual and automatic closed chambers. Besides gas flux measurements, we observed vegetation growth parameters (LAI, NDVI) and biomass yield. Ground water levels (GWL) were manipulated to generate a water table gradient spanning annual mean GWL between −22 to 4 cm to derive an optimum GWL for GHG mitigation. The mean resulting total GHG balances are −13.0 ± 13.9 t CO_2-eq ha^{-1} yr^{-1} under rewetted conditions (annual mean GWL ≥ −10 cm) and −1.0 ± 9.8 t CO_2-eq ha^{-1} yr^{-1} under drained conditions (annual mean GWL < −10 cm). Our dataset revealed that a maximum mitigation potential could be achieved at a GWL of −7 cm. These values represent first paludiculture EFs for potential integration into the German national GHG inventory.

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Adaptation of fen peatlands to climate change: rewetting and management shift can reduce greenhouse gas emissions and offset climate warming effects

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Over the past decades, draining and intensive agricultural use of organic soils have transformed peatlands from providing vital ecosystem services to being greenhouse gas (GHG) emission hot spots. Agricultural use of drained peatlands contributed approximately 53.7 Mio. t of GHGs to the total national GHG emissions of Germany in 2021. Regional climate projections forecast a 0.7 to 1.8 °C increase in air temperature for southern Germany until 2050. As microbial mineralization is temperature dependent, climatic warming will most likely lead to an increase of GHG emissions from drained organic soils.
In an experimental field study, emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were measured in an agriculturally used grassland system on organic soil in 2017 using the closed chamber method. For testing the effects of predicted climate warming and rewetting as a potential climate mitigation strategy, the study compared intensive grassland and extensive sedge-dominated paludiculture under ambient conditions versus experimentally increased water table (annual mean of −13.0 cm below soil surface) and temperature (annual mean air temperature increase of 0.9 °C; use of open top chambers).
We found that warmer conditions increased GHG emissions in the intensive grassland system from 48.4 to 66.9 t CO_2-eq ha^{-1} yr^{-1}. Rewetting of the intensive grassland reduced the emissions to 20.6 t CO_2-eq ha^{-1} yr^{-1}. The combined effect of extensification (sedge-dominated paludiculture systems) and rewetting under warming conditions even resulted in net cooling with an uptake of 13.1 t CO_2-eq ha^{-1} yr^{-1}.
Our results suggest that in a warmer world adaptation measures for organic soils should include rewetting to reduce the net climate effect of a system. An additional shift in grassland species community (extensification) may even result in restoring the carbon sink function thus presenting the highest emission reduction potential.

The relationship between vegetation type and greenhouse gas budget of moist and wet German peatlands

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Drained organic soils contribute an important share of greenhouse gas (GHG) emissions in many European countries and are therefore included in the national GHG inventories. This makes upscaling of peatland GHG balances to a national scale necessary. Suitable input data for this needs to be available on a national scale. One possible predictor is vegetation in the form of biotope type data, since plants influence GHG fluxes directly through various processes, indicate abiotic site conditions and the data is routinely gathered in the context of biodiversity monitoring.

Focusing on German peatlands which are either unused, used for nature conservation or under low-intensity agricultural use, we develop a vegetation classification by clustering biotope types of the German federal biotope type classification. We combine this with a collection of published annual carbon dioxide (CO_2) and methane (CH_4) budgets to investigate the dependencies between GHG fluxes, vegetation type and water level.

Some vegetation types such as semi-natural bogs show minor spread along water levels and comparatively little scatter regarding GHG balances. In contrast, the GHG budgets of other, especially drier, vegetation types like low-intensity bog grassland and areas dominated by dwarf shrubs vary strongly along water levels. Thus, vegetation type as the only predictor of GHG fluxes is insufficient in these cases. *Sphagnum* paludiculture and recently rewetted bog sites with little vegetation show small CH_4 emissions even with water levels close to the surface. Especially for treed and alpine peatlands, data availability is a strong limitation to further analysis.

In conclusion, knowledge of water levels can substantially improve upscaled GHG estimates especially for drier vegetation types. Our results can be used in conjunction with biotope type data to scale up emissions from peatlands under no or low-intensity use.

Valuation of **Peat**land Ecosystem **S**ervices – **VALPEATS**

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The drainage of peatlands represents a global ecological challenge, disrupting the water and carbon cycle and contributing significantly to CO_2 emissions, particularly in Germany where peatlands are major emission hotspots. The VALPEATS project addresses the need for scalable and efficient monitoring methods to support the rewetting of peatlands – a crucial step in reducing CO_2 emissions and restoring ecosystem services.
Our approach integrates real-time data collection through sensors, hydrological modeling, and AI-driven drone image recognition technology for vegetation classification, which will be combined with external data sources such as climate and satellite observations. This innovative monitoring tool will not only quantify greenhouse gas emissions efficiently but will also be able to track biodiversity restoration and evaluate paludiculture growth heterogeneity.
A key aspect of our strategy involves the automation and extension of the GEST model (Couwenberg et al., 2008, 2011) to enable an annual ex-post assessment of emissions based on vegetation and hydrological data. Further it is supporting high-resolution biodiversity identification. This data collection serves as basis for the verification of environmental certificates. Furthermore, it contributes to the economic development of paludiculture value chains through data transfer for smart farming applications.
The outcomes of VALPEATS will be accessible through a web portal, providing landowners and stakeholders (environmental planning offices, project developers, nature capital developers, scientific institutes, and public authorities) with relevant information on peatland conditions, vegetation development, and saved GHG-emissions. This project not only contributes to achieving environmental policy goals, but also fosters the development of sustainable land management practices and industrial value chains.

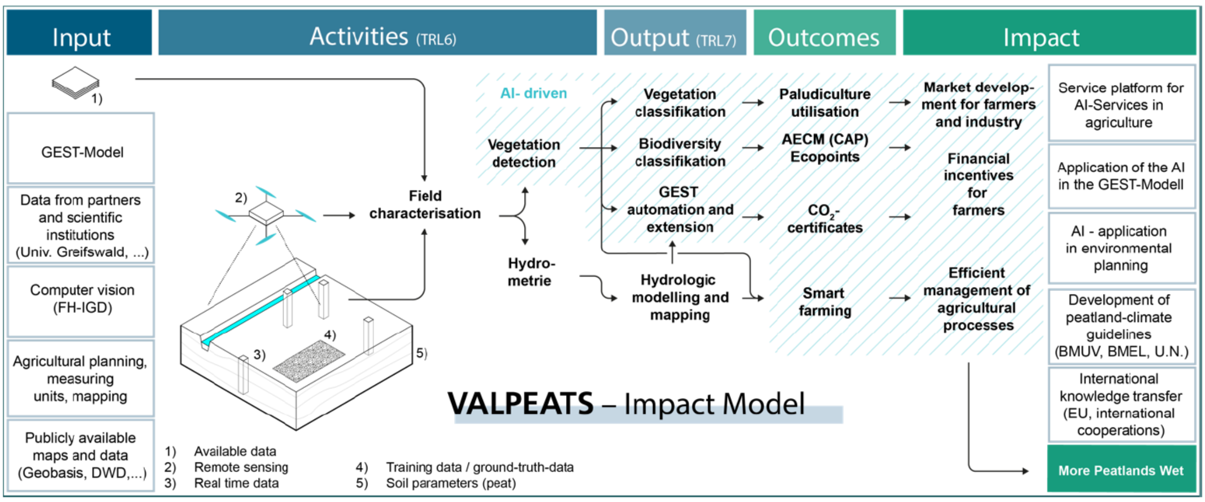

Figure: VALPEATS Impact Model

Ref:
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Greenhouse gas emissions and mitigation potential of Bavarian peatlands

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Bavaria is one of five federal states in Germany, which are rich in peatlands/organic soils. With approximately 221,000 hectares, peatlands cover just over 3% of the Bavarian state area. However, only around 5% of this area is currently in a near-natural state, while almost 90% has been drained for agriculture and forestry.
Based on nearly 150 annual datasets from seven Bavarian peatland regions and 81 treatments, peatland emissions for Bavaria were recalculated. Greenhouse gas budgets for CO2 and CH4 were empirically modeled based on land use. By combining land use data (ALKIS®) and a high-resolution water level map (Friedrich et al., in preparation), emissions can be reported from the level of individual land plots to the entire area. The current calculation of greenhouse gas emissions from Bavarian peatlands results in 6.7 million tons of CO2-equivalents per year (5.7-7.3 mio. t CO2-eq yr-1). This corresponds to about 8% of Bavaria's total greenhouse gas emissions. As a result/subsequently, Bavaria's target of climate neutrality by 2040 can only be achieved by reducing peatland emissions.
With the help of land-use-specific empirical modeling, it becomes possible to illustrate the mitigation potentials achievable through land use change and adjustments in management practices. In theory, comprehensive rewetting and the end of peatland management could reduce peatland emissions by 86% to 0.9 mio.t CO2-eq yr-1. However, due to pressures on land and socio-economic aspects, restoration/rewilding of all disturbed peatland areas is not possible. Results from our project show that adapting agriculture to wet grassland and forest management and turning arable land into paludiculture, make it possible to achieve a net reduction in greenhouse gas emissions while maintaining economic viability. Thus, adjustments in peatland management can make a significant contribution to Bavarian greenhouse gas emission reduction.
This study was funded by the Bavarian State Ministry for the Environment and Consumer Protection as part of the KliMoBay project.

Reporting updated CO_2 emission values for Dutch organic soils using a process-based model framework

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Following the Paris Agreement (2015) that aims to limit climate warming, the Dutch government presented a National Climate Agreement in 2019. In the land use sector, the peatland meadows are currently estimated to contribute ~4.6 to 7 Mton per year of CO_2 to the national Dutch greenhouse gas emission. In the National Climate Agreement, the aim is to reduce the net CO_2 emission from the peatland meadows with 1 Mton per year by 2030.

To comply with the greenhouse gas emission reduction targets for peatlands, a set of measures that raise groundwater levels are proposed and currently being tested in pilots. the Netherlands Research Programme on Greenhouse gas dynamics in Peatlands and organic soils (NOBV) investigates the effects of the proposed measures on the greenhouse gas emission balance under different environmental conditions.

In the National Climate Agreement, it was decided that annual progress made in reducing greenhouse gas emissions needs to be monitored. Hereto, the NOBV consortium developed SOMERS (Subsurface Organic Matter Emission Registration System), which is based on a multi-model ensemble approach. Within SOMERS, existing models are supplemented by two newly developed models for assessing groundwater dynamics and peat decomposition that require limited data input and have a short runtime. Using numerical models that simulate groundwater and carbon dynamics, the CO_2 emission derived from peat decomposition is calculated on parcel level.

The process-based models in SOMERS are used to i) annually monitor the achieved reduction by the implemented measures, ii) to determine the yearly emissions as part of the LULUCF emission reporting, and iii) to establish the effects of measures under standardized conditions, to be used in policy development.

The outcomes of the models are tested with annual carbon flux estimates from 10+ measurement sites. In the long run, we envisage to fully couple the modelling approach with the automated field measurements that are being collected in the new national measurement network and to include CH_4 and N_2O.

The results from SOMERS show that the national emission from the Netherlands is lower than previously reported. There are several reasons for these lower values, most importantly lower measured emissions find their way into SOMERS. In this contribution, SOMERS will be introduced, and the calibration and validation approach will be discussed. The new national peatland CO_2 emission budget based on SOMERS is presented, which will form the base of the LULUCF-sector reporting in the Netherlands from 2025 onwards.

Not seeing the bog for the trees - peatland forests, their differing perceptions and a plea for a new understanding

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The presentation aims to provide an overview of the many current issues surrounding peatland forest conservation.

Forests and other habitats characterized by woody plants are important components of peatland ecosystems worldwide, from the rainforest to the taiga. However, peatland forests often play a subordinate, and in many cases even a rather negative, role in the considerations and target systems of classic peatland conservation. The widespread perception of "peatlands“ and „forests" as two distinct units overlooks the fact that a significant proportion of the natural and near-natural habitats in peatlands also contain woody plants in their vegetation cover. The range extends from extremely stunted, very sparse shrubby stands in raised bog centers, at high altitudes or in the regions near the two poles, where the woody plants have often only reached a height of a few meters after more than 100 years due to wetness, cold and lack of nutrients, to densely stocked, shady bog edge forests or fen forests on low moor sites. Several tree species, some of them subendemic, which have adapted to grow in peatlands through special adaptations, also occur in Bavaria as climatic relic species, such as the Erect bog pine (*Pinus rotundata*), bog Scots pine (*Pinus sylvestris turfosa*) and Carpathian birch (*Betula pubescens carpathica).*

Wherever the water level is not permanently higher than 10-15 cm below ground level, tree-like woody plants can get established. This applies in particular to subcontinental, summer-dry regions, but also peatlands with a natural, albeit barely noticeable, surface slope. Many of the Bavarian raised and transitional bogs and fens were therefore originally covered with a vegetation mosaic containing also woody plants. The current proportion of around one third of the peatlands being wooded corresponds to the overall proportion of forested areas in Bavaria.

The biodiversity benefits of wooded peatlands are not inferior to the semi-natural, largely completely open peatland habitats, at least not peatland inhabitants as a whole are considered and not just a few species groups with a strong connection to open land structures. Many of the peatland species, including sub-endemics such as the raised bog ground beetle (*Carabus menetriesi pacholei*), which is a priority species of Annex II of the EU habitats (FFH) Directive, prefer bog forests or transitional sites between forest and open land.

On average, across all areas, the peatlands under forest are in a better state of conservation than agricultural including grassland peatlands in terms of their greenhouse gas balance and the preservation of the peat body. According to monitoring, many forested peatlands have already spontaneously re-wetted and self-regenerated at least partially in recent decades, as the former ditch systems that are very often no longer maintained are increasingly decaying and covered by wet moss and sedge vegetation. Nevertheless, the forested parts of the peatlands do still often require further, albeit well-planned improvement or even restoration of their hydrological conditions, in particular by closing still fully functioning ditches (in raised bogs) and by raising the groundwater level again (in fens). Rewetting can also be achieved in the presence of cover of woody plants, and can often times even be particularly successful, with the woody plants as border forests providing wind calm as the „oasis effect“ and providing added humidity as the „nursing effect“ for peatland plants.

The forestry use of (partially) wetted peatlands can be an option for peatland protection in the future where abandonment or full-scale rewetting are not an option. It requires stands and harvesting methods adapted to wet management. In many cases, considerable investments and forest conversion measures are necessary here.

Development of the bog forests in Southern Germany between 1996 and 2015

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The main trees of the Southern German raised Bogs are *Pinus mugo* and *Pinus rotundata* (the tree form and the procumbent form of the mountain pine), *Picea abies* (spruce) and *Pinus sylvestris (*European red Pine). These trees dominate the border forests on carbonate rich and poor transition bogs and on ombrotrophic raised bogs. The bogs are part of the man-made landscape influenced by stray harvesting, draining, peat cutting, afforestation and development of pastures and meadows. The major human influence on the bogs started in the15th century and culminated in the middle of the 19th century. Since the 1970s the focus is on renaturation, which starts to show results.

My first inventory of about 700 southern German transition- and raised bogs (1969-1973) included a systematically coding. A remapping of the same areas (2012-2014) allowed a computerized interpretation of the developments in the last 50 years. The development was depending on the precipitation in the bog region (varying from900mm/a to 1700 mm/a), the starting conditions, and the intensity of the land use in the near surrounding.

More than 50% of all artificial spruce forests improved to Vaccinium spruce forests (*Vaccinium myrtillus* and *V. uliginosum*), in zones with more than 1200 mm precipitation raised bog *Sphagnum* species increased.

Spruce raised bog border forests are natural parts of the raised bog zonation in Southern Germany. The area in the documented natural bogs was stable, some highlights are their new development in old peat cutting areas stabilizing the *Sphagnum*-growing complexes.

The area of forests with bog pine *(Pinus mugo* 422 ha and *Pinus rotundata*1047 ha) stayed stable, the increase of raised bog *Sphagnum* species (*S. magellanicum* and *S. rubellum*) in the *Pinus rotundata* forests was higher since their stands are less dense than *Pinus mugo* forests.

European red Pine is mixed in all border forests. Forests with dominant European red Pine have their main occurrence in eastern part of south Bavaria. They developed on drained bogs with secondary heather heath (*Calluna* heath), with an increase of raised bog *Sphagna*.

Carbonate rich transition bog forests have their main occurrence in the Bavarian Allgäu. They developed mainly by extensive pasturing. In the past 50 years the Succession led to an increase of raised bog *Sphagna* and nearly 100% decrease of the moss species depending on carbonat rich water (*Scorpidium scorpioides, Drepanocladus revolvens, Sphagnum contortum*, *S. subsecundum).*

The results of re-mapping are a frame for renaturation projects. We should work with the nature and not against her, especially in a time with rapid climatic changes. They are also a request to start a long-term monitoring project.

WaMoBiKi - Forested peatlands: contribution to biodiversity and climate protection and sustainable use for their preservation

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Forested peatlands - as naturally forested or silviculturally managed sites on peatland and other organic soils - provide an important contribution to the conservation of native and specific peatland biodiversity. They are relevant links in climate change mitigation through both accumulated carbon stocks in soil and stocks stored in wood. In their natural state, they form important water reservoirs and stabilizers in the landscape water balance.
Due to their frequently underestimated functions and their often degraded state due to drainage, with the release of considerable amounts of greenhouse gases, the task of reconciling the sustainable use of forests on peatlands and their functions for climate protection and biodiversity is more important today than ever before. Among others, this is referred to in the Peatland Protection Strategy of Germany.
The WaMoBiKi project addresses the challenge of systematizing the complex components of these ecosystems for Germany's forest sites according to the current state of knowledge in order to derive concrete strategies and instructions for future action embedded in the current political framework and to communicate them to the relevant decision-makers and actors.
The project is funded by the Federal Agency for Nature Conservation with funds from the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV).
The forest ecosystems on peatlands are listed, described and assigned in ecograms by means of literature research. These depict the occurrence according to trophy, acid-base ratios and water levels. The researched ecosystem types are supplemented by expert interviews and adjusted if necessary. Based on available data, mire-specific and endangered species of the different natural areas of Germany are listed. Drainage stages are assigned to the peatland sites as well as greenhouse gas emissions, leaching of dissolved organic carbon and flood protection parameters are determined by research. Furthermore, existing silvicultural methods for forest management on wet sites will be elaborated.
In the second phase of the project, best practice examples for the conservation of biodiversity while managing forested peatlands under wet conditions will be researched. Exemplary mapping will be carried out on the respective areas and effects of the change of use will be determined. The areas will be evaluated with regard to their greenhouse gas savings and their effects on the water balance of the peatlands and the landscape water balance. The resulting results will be processed and made available to practitioners.

A toolkit for field identification and ecohydrological interpretation of peatland deposits in Germany

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Successful peatland restoration requires a knowledge of peatland stratigraphy in order to understand the hydrological and ecological conditions under which peat formation occurred and to identify realistic objectives and measures for the specific site. So far, the ability to accurately identify peat deposits and lake sediments has been largely restricted to experts. To facilitate identification by others, we provide an identification key for common peatland deposits in Germany and introduce standardised portraits of 17 peat and six gyttja types with extensive descriptions and supporting photographs. We also provide information on the indicative value of the peatland deposits in terms of site conditions at the time of deposition.

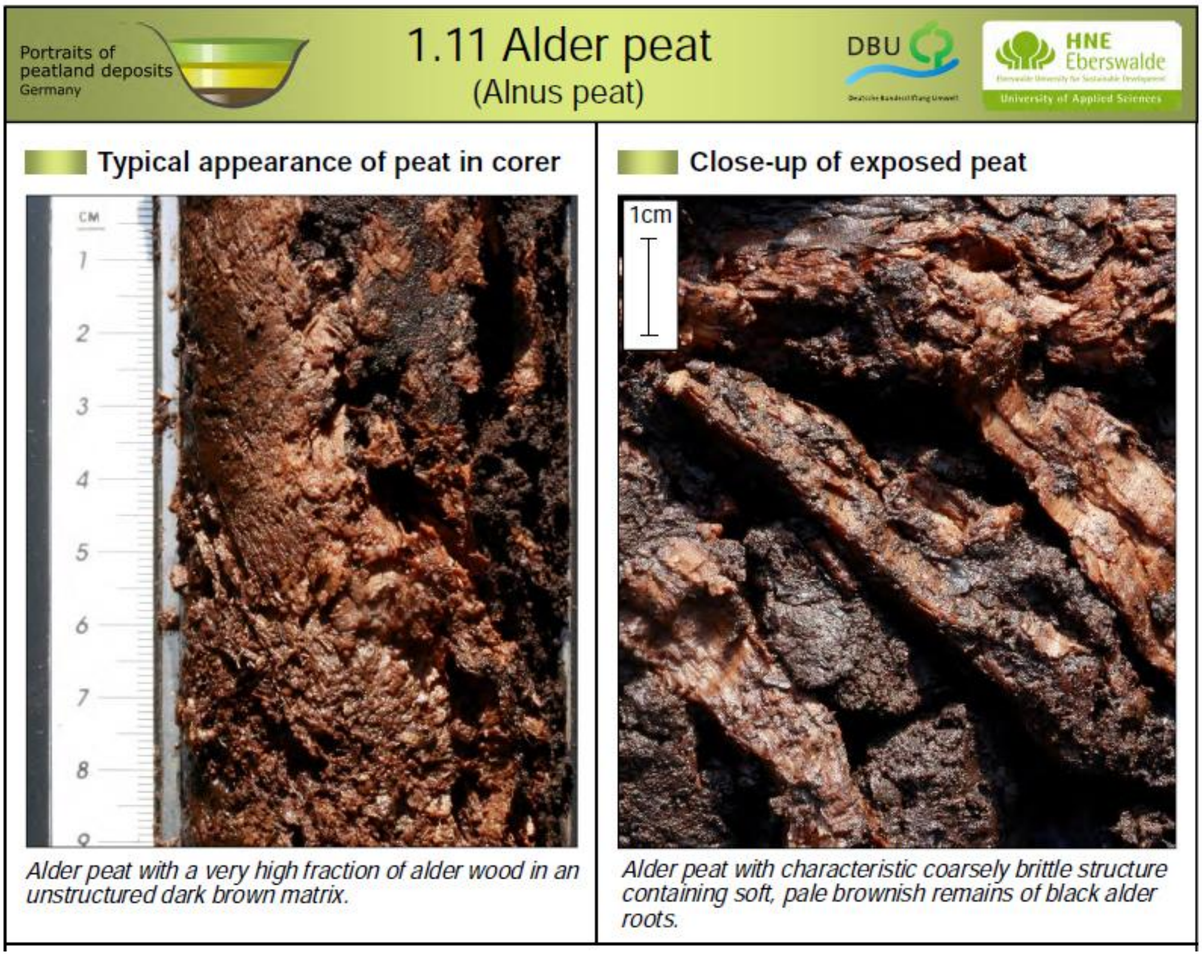

Figure: Excerpt from the portrait of alder peat

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Schulz, C., Meier-Uhlherr, R., Luthardt, V. & Joosten, H. (2019) A toolkit for field identification and ecohydrological interpretation of peatland deposits in Germany. Mires and Peat, 24(32), 1–20. (Online: http://www.mires-and-peat.net/pages/volumes/map24/map2432.php); doi: 10.19189/MaP.2019.OMB.StA.181

Some peatland genetic, hydrological, hydroclimatic, hydromorphological and pyrological aspects of a peatland-forest interaction in (predominantly) acidic nutrient-poor peatlands

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(using common material with H. Stegmann, P. Zinke, K. Kessler, I. Dittrich (†), A. Münch, I. Kornevič, G. Kuksin und D. Wendel)

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Based on the definition of the Russian bog forest classic P'JAVČENKO (1963), an own bog-genetic definition of bog forests with different types is established. Using our own bog stratigraphic investigations from the Erzgebirge and photographic material from Russia and Central and Eastern Europe, we show under which bog genetic and terrain situations such - mostly natural - bog forests can occur.

The soil development under raised bog forests shows that, at least in the case of secondary degradation, degrading bog soil horizons can also occur under wet peat moss blankets, which is a significant consequence of the intensive penetration of tree roots between the trees. The macroporosity generated by the tree roots is an essential formation mechanism and transport pathway for the humic substances formed in peatland forests and, in the case of rewetting, also a drainage pathway if the relief is appropriate, as well as an accelerator of fire spread in the case of underground peat fires.

Some hydrological and hydroclimatic relationships between bog trees and bog soil or bog soil vegetation show that atmospheric water balance balances depend on the spatial scale under consideration and need not always be as unfavorable as is often postulated by "anti-forest" bog conservationists. For example, there can be a stock-climatic (evaporation-reducing) protective function for embedded peat moss-dominated ground vegetation, while at the same time there is an increased lowering of the water level in the area close to the trees due to tree transpiration. This microclimatically induced flow equilibrium is certainly to be assessed differently in different macroclimatic situations.

Peat extraction, bog subsidence and drainage-induced bog shrinkage have irreversibly changed the relief of many bogs. Rewetting measures that accept this relief as a given are usually unable to regenerate the original mire ecotope zonation. Examples of the hydromorphological analysis and ecotope prognosis developed by the author and colleagues show that other/new ecotope zonations are often realistically desirable and that wet and dry peatland forests will play a greater role in the future.

Certain negative effects of peatland forests, such as increased DOC discharge into reservoirs or increased potential fire spread, can be mitigated by mitigating management in the peatland and its immediate surroundings.

Biomass and Structure of Peatland Forests

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In recent decades, peatlands have become increasingly important due to their role as a biodiversity hotspot and natural carbon sink in the context of climate change. The driving effect of peatland drainage on greenhouse gas emissions and the deterioration of the water balance of neighboring ecosystems is regularly subject to scientific research and is now also widely recognized by society. The restoration of peatlands has since become an integral part of the political agenda to mitigate climate change.

Besides greenhouse gas emissions, the project "Moorbodenmonitoring für den Klimaschutz - Wald" also investigates the effects of peatland restoration on peatland forests, which represent up to 15 % of all peatland areas in Germany. It analyzes the influence of peatland restoration and thus the rise in groundwater levels on biomass stock and structural development of peatland forests.

Therefore, 33 peatland forest sites in Germany were examined regarding their tree population, the occurrence of deadwood and their regeneration. The individual sites were categorized by the predominant tree species, the peatland type and the current hydrological status. The growth of the peatland forest stands is analyzed by its stand biomass. The Forest Structure Index additionally compares the structural diversity of the respective peatland forests.

The evaluation of the study shows a clear dependence of forest growth and structural diversity on the dominant tree species in the stand and its specific response to the increase in water levels in peat soils. Alder stands on wetter sites are characterized by higher stand biomass and a broader distribution of different tree dimensions. In addition, the amount of deadwood and species diversity on the peatland also increases. Pines and spruces are better adapted to the conditions of drained peatlands. Under the influence of peatland restoration, they follow an inverse development in contrast to alder peatland forests. Contrary to the original assumption, the yield and structure of Downy birch stands cannot benefit from the rewetting of peatland soils and their development is more similar to that of the conifers.

Suitability of tree species on organic soils - Results from the MoorWald project

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There are around 1.8 million hectares of peatland in Germany, 92% of which are currently drained. With 53 million tonnes of CO_2 equivalents annually, these cause around 7.5% of total German greenhouse gas emissions (including CH_4 and N_2O). The National Peatland Conservation Strategy of the Federal Republic of Germany inter alia aims at the reduction of greenhouse gas emissions from peatlands used for forestry purposes. This can only be achieved by permanently rewetting the affected areas and requires the forest stands to adapt to the subsequently changing hydrological conditions. Actually 15 % of peatlands in Germany are used as forest areas.

A data set from the German national forest inventory (NFI) was combined with data from organic soils (Roßkopf et al. 2015) in order to obtain an overview of how much forest area actually exists and which forest stands occur on organic soils. In total, 2267 NFI Plots are located on organic soils, of which 1387 NFI Plots occur on fens, 281 NFI Plots on bogs and 599 NFI Plots on inorganic sites. The tree species spruce, pine, downy birch and black alder grow on these soils and show different growth reactions on the three organic soil types fen, bog as well as anmoor due to their different site requirements. This is also confirmed by results of a literature research.

Evaluations of the NFI data show that the tree genius spruce and alder take up the largest part of the forest area on organic soils with 25 and 22 %. On the other hand, pine and birch are represented with 15 and 13 %. Black alder showed the greatest increase in stocks in the evaluation period from 2002 to 2012 on fen sites. This is also in line with the results of the literature research. Further findings are that downy birch is more likely to find its habitat in the edge areas of the renatured areas. According to NFI evaluations, the highest occurrence of the birch is in bogs with 29 %. No clear recommendations for action could be found in the literature for spruce and pine. Both tree species are unsuitable for sites heavily influenced by water. This is also shown by the evaluations of the NFI data.

Black alder is the only tree species that can be used on completely waterlogged sites. The risk of tree populations dying after groundwater level increases can only be reduced by gradually raising the water level over several years, because only than the root systems of the trees have adapted to the changed soil moisture conditions. This leads to small reductions in emissions but maintains the growth of the different tree species.

Peatland restauration vs. removal of trees?

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The question of the removal of trees or even parts of entire forests for the sake of optimal rewetting is often critical, in several regards.

A complete functional understanding of the original mire development in all its parts should be foundation of any planning of measures. Anthropogenic changes and attempts of utilization of the bog until today have to be considered as well. Therefore, analysis of actual and former vegetation, water level, water supply, thickness of peat and current peat conditions as well as the system and condition of drainage systems and especially ditches and trenches have to be examined. And finally, climate data of past and present, but also under the influence of climate change are essential and have to be considered.

An example of the removal of naturally occurring Erect bog pines (Pinus rotundata) 30 years ago in a part of a relatively well-preserved peat bog in upper Bavaria (Ochsenfilz)reveals that higher evapotranspiration after removal of trees under climate change conditions with hot summer periods led to a superficial dryness the in moss and herb layers in this part of the peat bog. The proximity of a lightly stocked Erect bog pine stand, on the other hand, helped preserve wet carpets of typical bog sphagna, even though old overgrown trenches still exist in this part of the bog.

To fully understand this, field examination was supplemented by GIS-evaluations (ESRI-Spatial Analyst, module “surface” and module “hydrology”). Concentration lines of discharge can show us where surface runoff takes place. This was to be seen only in the edges of the peat bog, not in the crucial area where the pines have been removed. Terrain relief has also to be observed; possible by GIS-terrain sections (ESRI 3D-Analyst).

	
Light bog pine stock with dominance of Eriophorum vaginatum and Sphagnum medium (magellanicum).	Drilling in this area shows an acrotelm of resent and subrezent Sphagnum medium of 0,3m, wet up to the surface. Actual vegetation with Eriophorum vaginatum and Sphagnum medium,
	
Open bog area after removal of bog pines, but with young growth of pines.	Detail of open bog: high water level, but dominance of heather (Calluna vulgaris) shows the superficial drying-up during warm summers in the last 2 decades.

What role can and should virgin and secondary peatland forests play in the future of peatlands?

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As part of S Bavarian peatland longterm monitoring (Ringler 2021) I try to roughly quantify current woody dynamics of southern Bavarian peatlands according to bog and fen types. I can only very briefly raise the following follow-up-questions: Which types of peatland forest (e.g. Kaule et al. 2018) are being created and in what proportions? Which are similarly regressive and threatened like all primarily open mire vegetation types? Which types of peatland forest with outstanding vegetation ecology are to be regarded as no-go zones for any timber use and nature conservation-oriented clearing work (see Wagner et al.1997)? How much unplanted replanting of peatland sites is "natural", and how much is anthropogenic, i.e. stimulated by change of use/end of use? Can rewetting projects stop the tendency for woody plants to spread over peatlands that have been out of use for around 50 years? What proportion of the secondary peatland stocking can be regarded as a return to the pre-utilization state (e.g. in formerly cleared *Pinus mugo* peatlands)? Can "open raised bog expanses" and woody wet intermediate bog complexes even make it into the 22nd century in a changed climate (see Frankl 1996 and Kaule & Peringer 2015)? Which botanical species conservation functions previously attributed solely to open mire complexes can be at least partially taken over by which bog and fen forests?

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8 Socio-economic impacts challenges and impacts of peatland transformations

Sustainable Management of Peatland Ecosystem in Malaysia: Enhancing Governance and Strengthening Institutional Capacity

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Malaysia has been with a large area of peatland ecosystems with approximately 2.6 million ha. This accounts for 0.7% of the global peatland area and 12 % of the tropical peatland area. Approximately 0.32 Malaysia has been blessed with a large area of peatland ecosystems with approximately 2.6 million ha. This accounts for 0.7% of the global peatland area and 12 % of the tropical peatland area. Approximately 0.32 million ha of peat swamp forest while the balance of the peatland is under different land use such as crop plantation and agrifood production activities. The reduction in peatland areas has caused concern among the policymakers and is developing strategies to prevent the destruction of the peatland ecosystem. The objective of the paper is to discuss these strategies and their impacts on the efforts to manage the peatland ecosystems sustainably. This paper will look into various strategies taken by the government to address this issue such as enhancing governance of peatland management at different levels of government and developing policies and activities to strengthen the institutional capacity. It will also discuss and evaluate previous activities and propose strategies to enhance the sustainable management of the peatland ecosystem in Malaysia.

What is considered to be meaningful in the communication on peatland rewetting, and how has this changed over time? Findings from a discourse analysis of German newspaper articles since 1975

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Drained organic soils, mostly former peatlands, emit considerable amounts of greenhouse gases, especially CO2. CO2 emissions can be stopped by rewetting the drained organic soils, therefore rewetting would contribute to achieving international climate protection targets. However, those who strive to achieve such goals run into conflicts with the owners and users of these soils, primarily farmers who – standing in a long tradition of peatland colonisation – fear for their livelihoods.
In order to understand the land use conflicts that are developing around the climate-motivated rewetting of organic soils in Germany, we analysed how the German public communicated about "peatland rewetting" historically. For this purpose, we used a data corpus consisting of 758 newspaper articles published by three national newspapers and three newspapers located in the peatland-rich regions of north-west and south-east Germany. From the 1970s onwards, the loss of a typical landscape component (including for "the homeland"), which is also protected by international nature conservation conventions, was initially publicly lamented. In the mid-2000s the dynamics of the discourse changed as peatlands were publicly addressed as carbon reservoirs and their drainage as a cause of CO2 emissions. Farmers in particular, who previously hold ambivalent positions about the problematization of the destruction of peatland soil through peat extraction, now find themselves under pressure of societal expectations. The results are interpreted with reference to various conceptual frameworks of memory studies to determine how constructive communication about the re-wetting of organic soils remains possible in this field of tension.

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Socio-economic impact of peatland rewetting on farm structures in Bavaria: An analysis in the context of climate protection

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This contribution outlines the socio-economic impact of peatland on farm structures in Ba-varia. Seven farm structures were identified using cluster analysis based on farm data from the integrated management and control system (InVeKoS) and the livestock register for EU agriculture expenditures. In the further analysis, fictitious farms were created for the five structures with an average peatland share of more than twelve percent. These were used to illustrate and compare the effects of rewetting the currently drained agricultural land and converting it to wet grassland or paludiculture. The Bavarian peatland management program was considered as a compensation option. It was found that intensive arable farms with high contribution margins per hectare would be particularly affected, whereas farms with low average contribution margins could even achieve windfall profits through compensation. In the case of livestock farms, the annual feed production before and after rewetting measures was considered. The reason for this was that, despite the use of peat-friendly farming prac-tices, the land still needs to produce enough feed to maintain the current livestock popula-tion. In the case of 'grassland only farms' it could be seen that there may be larger feed gaps depending on the proportion of peatland on the farm. On the other hand, farms with both grassland and arable land can use arable land for fodder production in the future to compen-sate for the resulting feed gaps. The impact analysis specified the effects of peatland re-wetting on different farm structures and illustrated the need for measures to provide politi-cal support for farms.

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Reviving Peatlands: The Role of Knowledge and Communication

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After rewetting drained peatlands, traditional agricultural practices on these lands are no longer feasible (Tanneberger et al., 2020). Although converting to paludiculture or installing photovoltaic systems may allow continued use, this shift represents a significant paradigm change and requires multidimensional rethinking in agriculture (Humpenöder et al., 2020; Tanneberger et al., 2020; Sommer and Frank, 2024). Well-designed and harmonized policy measures are essential to ensure rewetting aligns with climate goals (Grethe et al., 2021; Sommer and Frank, 2024; Wichmann and Nordt, 2024). Just as peatland drainage was a collective societal responsibility, peatland rewetting should not be the sole concern of individual landowners but must be supported and undertaken by society as a whole (Tanneberger et al., 2020). Public acceptance is crucial for implementing climate policies (Upham et al., 2015; Drews and van den Bergh, 2016).
Perception and valuation of peatlands and their ecosystem services have been studied globally (Reed et al., 2017; Byg et al., 2017, 2020; Glenk et al., 2021; Grammatikopoulou et al., 2021; Ward et al., 2021; Lees et al., 2023). However, studies addressing the knowledge and communication of information of peatlands across the general population are still rare. This is surprising because both of them are of high relevance for decision makers (most notably policymakers) and campaigners. To overcome this research gap, we conduct an Internet-based study with more than 500 participants from Germany, comprising a nationally quota-representative sample (age, gender, education). To elicit the current state of knowledge, we design a quiz, which is, to our knowledge, the first empirical study to systematically assess public knowledge of peatlands. The quiz covers four areas: general knowledge of peatlands, current usage, emissions/emission reduction, and paludiculture/wetland utilization. Through a randomized controlled experiment, participants are presented with systematically varied information (i.e. information provision experiment; Haaland et al. 2023) to reveal whether their preference attitudes towards the implementation of predefined rewetting paths are altered by differently communicated information. All in all, the study provides valuable insights into the role of knowledge and communication in fostering public acceptance of rewetting measures.

An analysis of land use on peatlands and their economic implications

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A precise description of land use on peatlands and their economic implications can help to establish tailor-made policies that aim for rewetting peatlands for climate protection. There are a number of estimates in the literature how much rewetting of drained peatlands would cost. The focus is often on opportunity costs of rewetting based on the contribution margin which range between 300 and 2000 EUR/ha (e.g. Willenbockel 2024). The calculation is usually based on data from agricultural statistics (agricultural census) which are recorded at district or municipal level. As the data only describes the proportion of land use in districts/municipalities, it does not provide information how peatlands are exactly used. Other approaches using remote sensing and crop type maps can be location specific but cannot link plots to farms. Data from the Integrated Administration and Control System (IACS) is geo-referenced and provides highly accurate as well as detailed information how farms manage their land.
Due to the high level of uncertainty about land use on organic soils, the objective here is to describe the land use on organic soils and what their current economic value is in terms of the standardized contribution margin. The article aims to answer the following questions: What is the current status quo of drained peatland management? How dependent are farms on peatlands and which options do farms have? What is the implication for their business orientation?
To answer these questions, IACS data was retrieved from the federal states Lower Saxony and North Rhine-Westphalia of the year 2020 and linked to the updated map of organic soil of Germany (Wittnebel et al. 2023). To get information on livestock densities on peatlands, data from the livestock information system (HIT) were used. Moreover, the contribution margins are based on planning data from KTBL and yield data at district level.
Preliminary results show that the main land use on bog and fen peatlands hardly differs and consists as expected mainly of permanent grassland followed by maize. However, there are differences in treposols which are mainly characterised by arable farming. Overall, the farms in Lower Saxony are highly affected. For example, 30% of farms in Lower Saxony have at least 20% of their land on organic soils. In regions with high livestock densities and little room to shift production to mineral soils, the opportunity costs are much higher than the above stated values.

Literature:

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9 Hydrological models for peatlands: processes, scales and applications

Modelling ditch blocking impact on field peat water level for emission reporting using MODFLOW – assessing effects of model structure and parameterization

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Ditch blocking is widely acknowledged as a method for peatland rewetting. Unfortunately, its impact on field water level is not easy to estimate, e.g. due to the variability of soil layers and their soil physical properties. In order to account for the effect on greenhouse gas emissions of peatlands in national inventories and in the evaluation of subsidy schemes, a method to quantify its effect on peat water level based on nationally available data sets is needed but not yet existing.
As a first step, we used the process-based transient groundwater model flow MODFLOW6 implemented in Python using the FloPy package to simulate ditch blocking on field scale. We investigated the influence of model setting and parameterization on the model output in comparison to observed peat water level time series. We calibrated the physical parameters of the model using the general-purpose global optimization program Shuffled Complex Evolution (SCE-UA). The model was tested in a grassland fen peat site, located in Gnarrenburger Moor, Northwest Germany, exhibiting a shallow, strongly degraded peat layer comprises of reed peat over leafy moss peat (80 cm) situated above a highly conductive sand layer. Ditch, peat and sand water heads were monitored daily from October 2020 to September 2023. Ditch blocking was conducted in September 2021. Daily precipitation and evapotranspiration data are obtained from the German Weather Services (DWD).
The model was able to simulate water level both in the peat and underlying sand layer well. The performance was best when optimized with water level from both peat and sand layer. When optimized with only water level from the peat layer, the optimizer fails to approximate the conductivity of the sand layer. We showed that important parameters to be calibrated for each layer are hydraulic conductivity, specific yield, and anisotropic ratio. Additionally ditch bed conductivity is necessary to be calibrated. Subsequently, the calibrated model was used to simulate different scenarios of ditch blocking height and the effect on hydraulic head in the peat layer.

Hydrological impacts of engineered restoration measures in degraded raised cutaway bogs

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Peats have the unique ability to effectively store water and carbon, a capability that has been compromised by global peatland degradation. The mechanisms by which surface water contributes to the water balance in degraded raised bogs remain poorly understood. This study aims to examine the long-term performance of engineered designs for peatland restoration, focusing on bog hydrology, with particular emphasis on water quantity, water levels, and water flows.
The primary goal was to assess the effectiveness of drain blocking and bunds in supporting restoration measures. These structures are intended to re-establish hydrological conditions conducive to peat formation and carbon sequestration. Peat hydraulic conductivity, measured at 10^-8 cm/s (which is 20% less than normal peat hydraulic conductivity), and water levels within the cells, as well as upstream and downstream of the drain blocks, were monitored using loggers.
The degraded bare catchment was divided into 92 small sub-catchments (bunded cells) interconnected by weirs and conduit pipes. Drone imagery and QGIS software were used to determine the area of these sub-catchments. A flume was installed at the outlet to monitor discharge. A Storm Water Management Model (SWMM) was employed to calculate the water balance for the site and flow at the outlet point, and the model was calibrated with the flume data to optimize accuracy.
Results shows that engineered structures are effective in maintaining the high-water levels necessary for peat formation and will inform future restoration projects and support the sustainable management of peatland ecosystems. This study underscores the need for integrated hydrological approaches to ensure the resilience and effectiveness of peatland restoration initiatives.

Using process-based modelling on parcel level to calculate nation-wide rewetting effects on peatland hydrology

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The Dutch government presented a National Climate Agreement in 2019, stating the overall ambition of reducing the national greenhouse gas emission by 49% in 2030 (compared to 1990). Within the land use sector, the peatland meadows are currently estimated to emit ~4.6 to 7 Mton per year of CO_2 due to peat decomposition processes. To comply with the emission reduction targets for peatlands, rewetting measures are currently being tested in Netherlands Research Programme on Greenhouse Gas Dynamics in Peatlands and Organic Soils (NOBV).

To register and comprehend the effects of these rewetting measures on CO_2 emissions, the registration system SOMERS (Subsurface Organic Matter Emission Registration System) was developed, which is currently used for assessment of provincial emission reduction goals and calculations of national emissions. To calculate these CO_2 emissions, it is important to understand the effects of the measures on the groundwater level regime. PeatParcel2D, a hydrological model in the SOMERS framework, is focused on efficiently making process-based computations of peatland groundwater dynamics on a parcel scale, for large areas under different environmental conditions.

To calculate these groundwater dynamics, PeatParcel2D simulates the most important physical conditions for peat oxidation processes: groundwater level, soil moisture and soil temperature. Concerning the groundwater level, a procedure was developed to automatically create a groundwater model for every peat parcel in the Netherlands based on nationwide data to simulate daily groundwater fluctuations. The hydrogeological parametrization required an extensive calibration procedure to estimate saturated hydraulic conductivity and specific yield. These parameters were obtained with a stochastics analysis using systematically collected groundwater level measurements from organic soil parcels across the Netherlands. This approach results in parcel groundwater dynamics that can be used to assess parcel hydrological processes, but also regional or national large-scale effects of rewetting measures.

In this contribution, PeatParcel2D will be introduced, and the calibration and validation approach of the groundwater model will be discussed. We present predictions, under idealized average weather conditions, to establish hydrological effects of different mitigation measures, and how hydrological conditions can (negatively) influence the effects of these measures. Furthermore, we demonstrate how the results were used for estimates of national application of different measures, and if the National Climate Agreement targets can be met. Lastly, we will elaborate on new measures and the challenges of applying local models on a nationwide scale.

Mapping Bavarian Peatlands: High-Resolution Water Level Insights Using AI

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Introduction: Climate emission mapping and identification of potential action areas for mitigation are increasingly important in peatland management, as highlighted by the KliMoBay Project (Klatt et al., 2023) [DOI: 10.5281/zenodo.10202686]. Given that peatland water levels are crucial for emission calculations, there is a pressing need for robust, Bavarian-wide water level modeling. Recent maps based on 25-meter resolution showed promising results; however, we found that higher resolutions might enhance the machine learning regressions used for more accurate water level predictions.
Method: By refining the resolution to 2 meters, we address the limitations of 25-meter resolution, particularly for small-scale drainage structures such as peat cuttings and ditches. By automating the process from downloading Digital Elevation Models (DEM) and Deutscher Wetterdienst (DWD) data to processing it for machine learning, we can integrate new predictors and climate data quickly and efficiently.
Results: Our findings demonstrate that higher resolution improves the accuracy of water level predictions, especially at the edges of drainage structures. Additionally, the ability to rapidly incorporate new data and potential predictors enhances the reusability of the method.
Outlook: There remain opportunities to further refine the prediction capabilities of our algorithm. Identifying areas with inaccuracies can be addressed by incorporating new measurements or discovering additional predictors. The new script structure facilitates the easy implementation of these enhancements, paving the way for continuous improvements in water level modeling for Bavarian peatlands.

10 Wet management and strategies in agriculture

The Netherlands Research Programme on Greenhouse gas dynamics in Peatlands and organic soils (NOBV)

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In the Netherlands, almost all peatlands are drained and 85% are in agricultural use. In 2019, the Dutch government has set the aim to reduce the emissions by 1Mton of $CO_{2\text{-eq}}$ per year from these areas by 2030. Since the establishing of the reduction aim, a series of instruments have been developed to support policy development and monitor results of the designed policy. The instruments include a research programme, The Netherlands Research Programme on Greenhouse gas dynamics in Peatlands and organic soils (NOBV) and an innovation programme (VIP-NL) which are closely linked. The research programme aims at establishing effects of measures and identify steering conditions, and to build a monitoring system. The innovation programme studies newly proposed measures on their effects on agricultural production, farmers' incomes, biodiversity, but also measure design and maintenance requirements.
Several working groups have been started to discuss and disseminate the results of the programmes. The monitoring system is used both to monitor the combined effects of all measures taken since 2016 and to reevaluate the reduction aim when deemed necessary.
In this contribution, an overview will be given of the organisation and set-up of the instruments and groups in the Dutch peatland policy world is provided. The role of research in policy development and evaluation is discussed. In addition, the measured effects of more dairy farm focused measures and more nature-centred measures are discussed. Also trade-offs between different measures and impacts of large scale implementation of measures on for instance water management is part of the presentation. Lastly attention is given to feasible management options for the Dutch peatlands in 2050.

Paludiculture – future wetland generation from degraded peatlands

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Paludiculture is a land use strategy in wetscapes (wet peatland landscapes), which combines the productive use of wet peatlands and the provision of ecosystem services. Wetland ecosystem services provide, among others, water retention, biomass production, and intact soil carbon stores. Regulating services may also facilitate water purification, flood control, wildfire prevention and regional cooling.
Important drivers of ecosystem service provision are water level and vegetation dynamics. Typical wetland species can be farmed as paludiculture plants and crops, such as *Sphagnum*, *Carex*, *Phragmites*, *Typha* and *Alnus*. Some species of these genera have been recognized as important peat forming plants that can conserve soil carbon. While knowledge regarding biomass yields is quite well established, little is known about species-specific potential to promote ecosystem services in wet and rewetted peatlands.
Here, we summarize findings from a range of paludiculture field studies and mesocosm experiments. The data are discussed and compared to existing paludiculture literature and a farm scale model of ecosystem service provisioning.

The relevance of drainage ditches as breeding habitat for mosquitoes (Diptera: *Culicidae*) in Northern Germany

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As a result of the intensive wetland management practices, drainage ditches have become a characteristic feature of many landscapes, especially in Northern Germany. When natural wetlands have been drained out, ditches can provide key habitats for a variety of aquatic and merolimnic invertebrates, including rare and endangered species. At the same time, these water bodies serve as breeding habitats of mosquitoes, which are considered both, nuisance species and vectors of pathogens. In this study, we analyzed the number of emerging mosquitoes in dependence of the ecological characteristics of different drainage ditches in Northern Germany.
In 2020, eleven ditches were equipped with 14 emergence traps each. The emergence traps were sampled biweekly from April to September. At each sampling event, several environmental parameters were measured including temperature, conductivity, pH, water level and water level width as well as the coverage of *Lemnoidae*, *Callitriche*, *Poaceae* and filamentous algae inside the emergence trap. All emerging insects were identified to order level. In addition, the mosquitoes were identified to species level using morphological and molecular methods. Species-environment relationships were analyzed separately for the three dominant mosquito taxa by means of multivariate statistics (GLMMs).
More than 60,000 insects were collected from the emergence traps, including 2,244 mosquito specimens. Among them we found at least 7 mosquito taxa. This involved 1,571 *Culex pipiens s.s.*, 364 *Culiseta annulata*, 244 *Anopheles maculipennis s.l.*, 7 *Cx. modestus*, 6 *An. claviger* s.l., and 1 *Cx. territans/hortensis*. While *Cx. pipiens s.s.* and *Culiseta annulata* mainly emerged from small ditches with low water level (< 0.2 m) and width (< 1 m) also characterized by rather low pH values (4-6), An. maculipennis s.l. was also found in larger ditches with high conductivity. In addition, we observed strong indications that a dense Lemna coverage prevented the emergence of *An. maculipennis s.l*. This study underlines that ditches provide relevant breeding sites for mosquitoes, whereby the mosquito diversity strongly differs in dependence of the ecological characteristics of the ditches.

Rewetting of grassland on bog peatlands in Lower Saxony

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Natural peatlands developed under wet climate and landscape conditions. In the last centuries peatlands were drained for agricultural and forestry use. This caused peat degradation and greenhouse gas emissions. Nowadays, raising the water level seems to be the best solution for peatlands and climate protection. Nevertheless, peatland properties and landscape have changed and the development cannot simply be reversed. Moreover, farmers have established economically viable grassland systems on peatlands. Even if it is clear that things cannot continue like this a transformation path starting with partial rewetting could help farmers to adapt and to establish bit by bit new ways of wet peatland use.

In Lower Saxony there are about 201.000 ha bogs of which 54 % are under agricultural use. Since 2016 field trials on grassland were conducted to raise the water table. Ditch blocking, ditch impoundment and subsurface irrigation were tested under the climate conditions of Northwest Germany. It came out, that by ditch blocking, i. e. retention of excess water in summer, the mean water table was not raised. Ditch impoundment, i.e. ditch blocking and pumping water into the ditch, lead to higher mean peatland water tables, but with higher water tables near the ditch than further away from the ditch. The most efficient rise of the water table was achieved with subsurface irrigation, i.e. ditch impoundment with drain pipes to direct the water into the peat.

Ditch impoundment and subsurface irrigation strongly reduced peat subsidence during the field trial. In dry years grassland yields of the rewetted meadows were higher than those of the control treatments due to better water availability and less calamities. Nevertheless, in wet years, especially with wet autumns, the trafficability by conventional machinery was restricted leading to less grassland cuttings. Despite the high mean water tables, greenhouse gas emissions were not or only slightly reduced by ditch impoundment or subsurface irrigation.

The results show that rewetting of rain-fed bogs to be used for agriculture depends on the supply of water in summer. This applies as long as the cultivated plants do not tolerate flooding in winter. Moreover, the topsoil enriched with nutrients may generally be a problem or rewetting, resulting furthermore in CO2-emissions plus methane emissions.

Thus, for grassland farmers there is currently no way of reducing greenhouse gas emissions while maintaining the grassland production system. Therefore, farmers should not be obligated to rewet their peatlands without having an economic alternative.

Grassland management on rewetted fens: results of field experiments in Bavaria

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Peat conserving grassland management requires water tables above 30 cm below surface. Such wet grasslands often produce low feed quality and face rapid encroachment by non-feed or toxic species such as *Juncus effusus* or *Senecio aquaticus*. Against this background we have performed field experiments to establish and manage grasslands on rewetted fens with medium intensity (three to four cuts per year) to produce forage for dairy farms. Dairy farms constitute the main users of fen grassland in Germany. The following research questions were addressed:

1. How to establish wetness tolerant grasses on cropland and in dry grassland?
2. Which high quality feed grasses cope well with continuously shallow water table?
3. What is the quality of the produced forage and what are potential uses in dairy farms?
4. Which grass species guarantee a good trafficability in wet conditions (shear strength)?

The experiments converting cropland to grassland were carried out at the research station Karolinenfeld near Rosenheim. Six different grass species mixes were sown, including a new one tailored for long-term grass swards in South Germany („LfL mix“). Experiments converting existing grassland to wetness tolerance were carried out on real farms in fens along the Danube with adapted versions of the LfL mix.
Grass establishment: When converting cropland to grassland sowing is best made in the autumn before raising the water table. Sward renewal in dry conditions was not successful. Sowing after rewetting may be more promising.
Grass species choice: After up to five experimental years, we conclude: Reed canary grass (*Phalaris arundinacea*) and tall fescue (*Festuca arundinacea*) perform best regarding competition against weeds, trafficability, biomass and feed quality. Reed canary grass will become the dominant species in continuously wet conditions. Ryegrass (*Lolium perenne*), black bent (*Agrostis gigantea*) and clover died, leaving open space with bad trafficability, which was quickly colonized by soft rush (*Juncus effusus*).
Forage amount, quality and use: Annual biomass yield ranged between 8 and 10 tonnes of dry matter and was conserved as hay, haylage or silage. Protein contents (80 to 120 g per kg dry matter) and potassium contents (15 to 18 g K per kg dry matter) were relatively low. Grassland with high share of tall fescue produced forage with the highest energy density in all cuts (5.3 to 5.9 MJ NEL per kg dry matter). The forage was used in a dairy farms as structure component, is well suited for late lactating cows due to the low K content and for heifers.

Water management for *Sphagnum* and *Typha* paludiculture

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Paludiculture is the productive use of rewetted peatlands with peat conservation. This requires constant high-water tables close to the peat surface and mostly water management. There are different paludiculture ‘crop plants’ with different demands on the water supply and also peatlands, which differ in terms of their site conditions - nutrient-poor bog or nutrient-rich(er) fen.
Promising paludiculture crop on rewetted, degraded bogs is peat moss (*Sphagnum*) for harvesting and utilizing the biomass, e.g. as peat substitute in horticulture. On rewetted, degraded fens cattail (*Typha*) can be cultivated for a variety of potential applications, including construction material.
In order to evaluate and optimise the water management, investigations were carried out at a field study site for *Sphagnum* paludiculture at the peatland Hankhauser Moor (17 ha size, NW Germany, Lower Saxony) with long term research since 2011 and for *Typha* paludiculture at the polder Teichweide (10 ha size, NE Germany, Mecklenburg-Western Pomerania) with research since 2019. Here we studied irrigation and outflow volumes, water tables in combination with weather conditions (precipitation, temperature, humidity) and plant growth.
Water management for paludiculture is successfully possible, but is a challenging task given the different demands on the water supply by species throughout the year and large differences between the years. The majority of irrigation water is required during the summer months. In addition to high evapotranspiration, significant seepage losses occur due to the artificially maintained hydraulic gradients. We identify differences in water management for *Sphagnum* and *Typha* paludiculture. *Sphagnum* is highly susceptible to desiccation and flooding, requiring a precise water management that ensures a water table is maintained at a depth of a few centimeters below the surface. *Typha* paludiculture allows for fluctuations in the water table that are more pronounced than those observed for *Sphagnum*. These fluctuations range from shallow inundation to shorter dry periods with deeper water tables.

The establishment phase of paludiculture with sedges – planting a sea of grass

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Paludiculture is the presumably most efficient land use to combine climate mitigation and productivity in mires. Important for the large-scale application of paludiculture are optimised methods to establish the specific paludiculture plants.
In the previous project "MOORuse" (2016-2022), also conducted at the HSWT, many potential paludiculture plants have been compared and the Lesser Pond-Sedge (*Carex acutiformis*) proved to have the best GHG-Balance, be highly productive and very robust. But it seems to be more difficult to establish than other species found in mires since it has a low germination rate and a slow youth development.
In this group of two-year field experiments during the project "MoorBewi" we tried to answer the question: Can we facilitate or accelerate the establishment of Swamp-Sedges by means of agricultural weed control?
Within the first weeks after Planting and Sowing, we did a process-comparison of cutting, harrowing and hoeing (up to the limit of practicability due to the elevated water level). The experiment took place at two sites with different groundwater levels. In addition, weed-suppression methods were evaluated. We have used organic and biodegradable plastic ground cover as well as nurse crops and also planted directly in the old grass sward.
We found that an increase in the yield of the first year is only feasible by using full weed suppression - a biodegradable foil. But within the second year, all differences in yield between the management strategies have levelled out. The water level is a far more important predictor for the yield of the second year and presumably following years. The only difference remaining in the second year, is that the mechanical weed management in the first weeks of the first year, still has a lasting impact when it comes to the amount of other (companion) plant species in the plot.

In conclusion it is not necessary to do weed management for a basic establishment of Lesser Pond-Sedges. Even if planted directly into an existing grassland, the sedges will form a closed canopy within two years, given a suitable, high water level. Weed management can only be recommended, if the desired end-product demands a very clean plant composition or if the harvest of the first year is worth more than the investment in weed management.

Putting Paludiculture into Practice – Six Years of large-scale *Typha* cultivation in North East Germany

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The cultivation of wetland plants provides promising options for sustainable peatland farming. However, practical experiences with cropping paludiculture are limited so far and the implementation remains challenging. We present experiences and lessons learned from largescale *Typha* cultivation in Northeast Germany. *Typha* is adapted to water-saturated soils, enables peat conservation and has a high value creation potential based on the material use of the biomass. In 2019, a *Typha* field of ~10 ha was established on a drained fen grassland by the project Paludi-PRIMA (2019-2022). The work is continued by the project Paludi-PROGRESS (2022-2025). We gained valuable experiences on site selection, planning and approval processes (water and nature conservation law) and construction work (site preparation, water management). Commercially grown seedlings of two species (*T. latifolia, T. angustifolia*) were planted with two densities (0.5 and 1 plant/ m2) using planting machines from forestry. Further, we tested seeding by drone as well as by hand. Site establishment, biomass productivity and quality has been monitored. A first harvest trial with a tracked machine was conducted in December 2021, followed by a complete harvest of the pilot site in January 2023 and a summer harvest trial in June 2024. The biomass was tested for different processing options. Cost data of all implementation steps from site selection to harvest are collected to assess the economic viability in dependence of biomass quality and utilisation options. The pilot site is also monitored regarding GHG emissions, nutrient and water balances, as well as biodiversity and peat building potential.

Picture: *Typha* pilot site in spring 2023, surrounded by drained grassland. (© T. Dahms, 2023)

Barriers to implementation are mainly related to the EU Common Agriculture Policy, the protection of permanent grassland, the possible consideration of *Typha* stands as protected habitat and the high investment costs. Lessons learned and research results are used to elaborate recommendations for farmers, authorities and policy makers in order to facilitate a large-scale implementation of paludiculture.

More information is available on the projects' websites:
Paludi-PRIMA: https://moorwissen.de/prima-en.html
Paludi-PROGRESS: https://moorwissen.de/paludi-progress-2.html

Peat formation potential of *Typha* spp. on a paludiculture pilot site

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As part of the Paludi-PROGRESS project (Putting paludiculture into practice – Optimization of cattail and reed cultures, project period 2022-2025) 10 ha of a drained peatland in northeast Germany were rewetted and set up as a paludiculture pilot site for cattail cultivation (first project generation, Paludi-PRIMA, project period 2019-2022). In summer of 2019, the construction work was carried out to establish the site. In September, *Typha latifolia* and *Typha angustifolia* seedlings (25,000 per species) were planted on the field with a row spacing of 2 m and a planting density of 0.5 and 1 plant per m2.
To assess the peat formation potential of cattail, we examined the above- and belowground biomass accumulation and decomposition as well as the effects of water level and temperatures on it. We set up 20 plots of 4 m x 1 m (to cover more than one planting row) distributed over the pilot site to reflect the micro relief of the site and thus mirror different water levels. In February 2023 after a machine harvest of the site, ingrowth cores and litter bags were installed to assess the above- and belowground biomass decomposition and accumulation. The litter bags were filled with *Typha* plant material (roots, rhizomes and leaves), *Lipton* rooibos tea bags were used as standard material. The installations remained in the plots for one year, until January 2024. Aboveground biomass accumulation was examined by harvest in January 2024. The data are currently analysed, and the results will be presented at this conference.
The overall results of the project provide valuable information on the peat formation potential of cattail, which is not known so far.

Productivity and biomass quality of cattail (*Typha* spp.) on a 10 ha paludiculture pilot site in northeast Germany

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The Paludi-PROGRESS project (Paludiculture in practice: Optimisation of cattail and reed cultures, project period 2022-2025) aims to test and further develop the cultivation of cattail (*Typha* spp.) as a new permanent crop on wet peatlands. One of the main tasks is to evaluate the productivity and biomass quality of cattail on a 10 ha rewetted peatland, established in September 2019.

In the time period of 2021 until 2023 biomass samples were collected twice a year, in summer (July) and winter (November/December). Prior to the first sampling in 2021, four different density categories were identified based on the visual impression of the cattail vegetation (dense to rare cattail plant occurrence). Sampling plots were randomly distributed within these sub-areas of the pilot site (10 per density category). Since a mechanical harvest trial took place on a small area in winter 2021, the influence of cutting on the biomass could also be observed in the following year. Furthermore, the site was fully harvested at the beginning of 2023. To monitor the cattail vegetation, several parameters were recorded for each plot: e.g. number of cattail plants and spadices, plant height and diameter, dry weight, water content and chemical composition (carbon, nitrogen, phosphorous, potassium, lignin, cellulose and hemicellulose).

From winter 2021 to winter 2022, cattail biomass productivity has more than doubled from 1.8 to 5.0 t dm/ha when considering the total pilot site. In the dense areas, the biomass even increased from 4.1 to 7.4 t dm/ha. Different stand densities showed an influence on morphological parameters but had a minor effect on the chemical composition of the biomass. The harvest trial in 2021 did not have a significant impact on the parameters considered. In winter 2023, the biomass density decreased again to 3.6 (total site) and 4.9 t dm/ha (dense areas). Next to other environmental factors, harvesting the total site could have shown a negative effect on the regrowth of cattail in 2023.

The collected data show unique results about the development of cattails on a large-scale pilot site and therefore provide important information for future use of cattail from commercial-scale cultivation. Additionally, it is important to evaluate whether the given growing conditions lead to appropriate biomass quality for various utilization options.

Economic Prospects of Photovoltaic Systems on Rewetted Peatlands

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The Renewable Energy Sources Act (EEG 2023) introduced subsidies for photovoltaic (PV) systems on rewetted peatlands (peatland PV) for the first time, in addition to conventional ground mounted PV systems. Accordingly, ground-mounted PV systems on previously drained and agriculturally used peat soils are eligible for increased feed-in tariffs if these sites are permanently rewetted.
This combination could have a dual climate benefit: rewetting reduces greenhouse gas emissions from the soil, and the generated electricity replaces fossil energy sources. PV systems on rewetted peatlands thus support climate change mitigation in both the energy and LULUCF sectors. Additionally, this could provide farmers with an alternative use for these sites, offering new opportunities for income and value creation. An opportunity that other options like paludiculture have not yet provided.
However, the use of rewetted peatlands for PV systems has been tested in only a few projects, resulting in limited practical experience and data. This raises the question of the possible economic output and subsidy requirements for the expansion of these systems. To answer these questions expert interviews with project developer and experts of nature and climate protection as well as geology and hydrogeology are conducted. This study focuses on technical requirements for potential foundation systems and associated cost structures.
For the analysis, we compare three different PV systems: Conventional ground mounted PV with steel pilings on dry mineral soil, PV with steel pilings on rewetted peatland, and PV with plastic pilings on rewetted peatland. We examine the cost differences between systems on dry mineral soil and those on rewetted peatland, considering factors such as rewetting costs, investment costs (material and technical requirements), installation costs, and recurring costs. To determine the necessary feed-in tariff for profitable operation under the assumed conditions, we calculate the required funding in comparison to PV on dry land, based on the Levelized Cost of Electricity (LCOE). We further provide insights into the key factors affecting the profitability of peatland PV systems. Given the novelty of peatland PV, there is still uncertainty in some of the assumptions. Our findings indicate that, although peatland PV systems have higher costs compared to conventional PV systems, they *can* still be profitable and serve as a viable alternative for peatland use, particularly if projects are larger and peat depths are shallow.


Photovoltaic on peatlands © Thünen-Institut/Heinrich

Photovoltaics and rewetted peatlands- legal framework and foundation systems

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The combination of photovoltaic systems and the rewetting of drained peatlands is currently discussed as a possible concept to transform regions towards a rewetted utilization of peatlands. Photovoltaic systems on rewetted peatlands (peatland PV) are a possibility to simultaneously use areas for climate protection by increasing water levels and for electricity production from renewable energy sources. In Germany, a basic legal framework is provided by the national peatland protection strategy and the photovoltaic strategy as well as the Renewable Energy Sources Act (EEG). With the EEG 2023, for the first time, drained and agriculturally used peatland is included as a category for photovoltaic plants. Requirements regarding the practical implementation of peatland PV within the EEG are published by the Bundesnetzagentur.

Practical experience in the field of peatland PV is available to a very limited extent. Therefore, after looking at the legal framework, interviews were conducted with experts from the fields of photovoltaics and project planning, nature and climate protection as well as geology and hydrogeology in order to gain initial insights into the practical implementation and construction. The aim was to aggregate existing expert knowledge from areas associated with the implementation of peatland PV and to create an initial starting point for further research. Because of the limited practical experience, the interviews focused on the discussion of the construction, especially regarding potential foundation systems and their suitability for peatland areas. In addition to the discussion of these systems, general challenges related to the construction process and the compatibility of rewetted peatlands and photovoltaic systems were taken into account.

Predominantly, the preferred solution for the foundation on narrow peat bodies are pile-driven systems. Adaptations for these systems are discussed to address the special characteristics of peatlands. For example, metal plates are mentioned as a possible solution to deal with a lower ability of weight- bearing. Floating systems are mentioned as a potential option for sites with thicker peat bodies. Different special solutions are discussed additionally. The result is an initial overview of different solutions to use as a foundation for photovoltaic plants, which could be supplemented and adjusted with in-creasing practical experience. A need for further research is identified, particularly in the area of practical implementation and regarding the investigation of the long-term suitability of different foundation approaches.

11 Classification and mapping of organic soils including remote sensing

Cross-scaling exploration of peatland areas - from satellite to microscope

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The transformation of peatland areas for sustainable use requires detailed information on condition and development of the soil. BGR is therefore developing and applying geophysical and remote sensing methods to provide rapidly available proxies for the state and characteristics of peatlands (see Picture 1). This includes the spatial distribution, thickness, structure and deformation of peat soil deposits and can provide the basis, for instance, for planning and assessing ecological measures and forecasts.
The interferometric analysis of spaceborne synthetic aperture radar imagery provides information on deformation of the peatland surface. A corresponding long-term monitoring program determines the deformation rate covering several years, but also e.g., the seasonal deformation patterns, which allows the estimation of a changing water storage capacity in the soil. To supplement such remote sensing information, helicopter-borne geophysics acquires and combines radiometric and electromagnetic data to identify the extent of peatlands from the air. With these results, we can update available but partly outdated peatland maps. Furthermore, our research has shown that the average peat thickness can be estimated approximately.
Ground and drone geophysical investigation are applied on much smaller scales but provide the opportunity to gather geophysical data with higher spatial resolution and a wider range of geophysical parameters such as electric resistivity and dielectric permittivity, natural gamma-ray intensity, and proton nuclear magnetic resonance relaxation. These are sensitive to the distribution of the soil water content and material contrasts between peat and mineral soil layers as well as different kinds of peat. In the Gnarrenburger Moor, for instance, we estimated the peat thickness using ground penetrating radar measurements with an accuracy of +/- 10-20 cm up to a depth of 5 m. In addition to the in-situ exploration in the field, laboratory investigation using representative sample material are performed to quantify the relationship of the measured geophysical variables and the peat soil parameters of interest such as hydraulic conductivity and degree of decomposition.
Geophysical research is currently underrepresented in peat science. However, the manifold geophysical methodology has a great potential to support activities such as rewetting and renaturation by observing the soil changes in space and time, e.g., the distribution and alteration of soil hydraulic properties. Our future work is therefore aimed on corresponding long-term monitoring strategies.

Picture: BGR (Federal Institute for Geosciences and Natural Resources, Germany) combines as set of different geophysical and remote sensing methods for investigating peatland areas at a broad range of spatial dimensions from regional to plot scales.

Mapping and characterising peatland using ground-penetrating radar (GPR) and nuclear magnetic resonance (NMR)

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The thickness, inner layering and state of degradation of peat deposits is important knowledge that is needed when describing the peatland status and to plan renaturation or sustainable land use. Besides a one-time assessment of the recent status, also monitoring changes with time are of interest in this context. Geophysical methods can provide such information on different scales and with different spatial resolution and accuracy. In addition, they are ideally suited for monitoring purposes due to their minimal-invasive characteristics. Therefore, our research focuses on testing and assessing the performance of diverse geophysical investigation methods on peatland areas.
We conducted a ground-penetrating radar (GPR) and nuclear magnetic resonance (NMR) survey at a peatland site in northern Germany (Gnarrenburger Moor). The site has been in agricultural use for decades and is well investigated. It is characterised by a layer of peat with varying thicknesses between 0-4 meters (see Figure 1a), which covers mineral sediments. The internal layering within the peat layer, a sequence of white and black peat as typical for most peatlands in the Northwest of Germany, is reflecting changes in climate and vegetation during sedimentation as well as different levels of peat alteration (see Figure 1b). We demonstrate that GPR mapping provides a fast 3D insight into the total thickness and internal structure, while NMR and minimal-invasive GPR soundings enable a characterisation of the peat material at particular locations. The deduced physical properties can be transformed into estimates of water content and provide qualitative information on the degree of peat alteration in the different layers.
The geophysical results are compared to visually inspected vertical soil sampling data. GPR is capable to identify the boundary between the peat and the mineral sediments below due to the strong contrast in the water content. The transition from white to black peat causes a weak reflection in parts of the investigated area, where in other parts, it interferes with a number of peat internal reflections that are probably caused by changes of the peat-forming material. The NMR relaxation behaviour showed to be associated with different degrees of peat alteration and can thus be used to assign the GPR structural information to the material of the layers. Our study demonstrates that ground-based geophysics, and especially the combination of GPR and NMR can provide detailed information on the peatland status and can easily be upscaled to effectively cover areas on the kilometre scale.

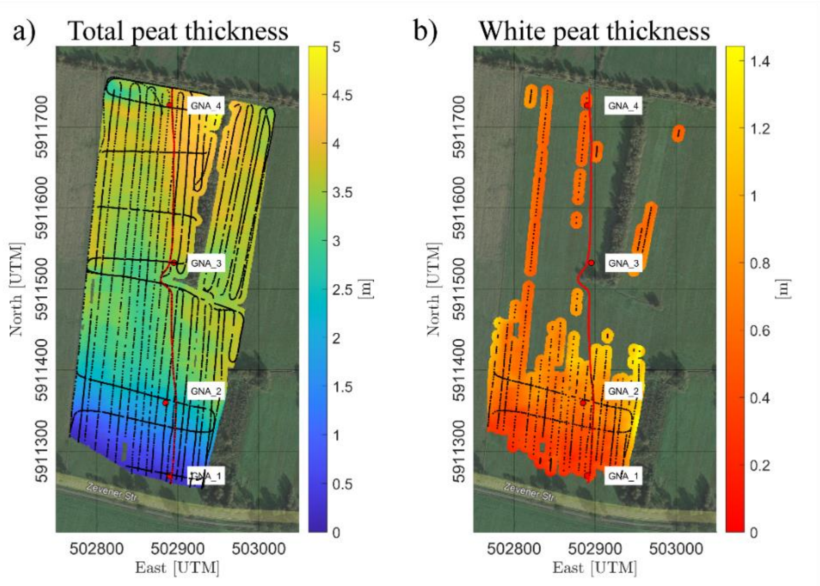

Figure: Peat thickness at the Gnarrenburg test site based on a ground-penetrating radar survey:
a) Total peat thickness. b) White peat thickness.

Potential of radar remote sensing for monitoring the status of peatlands

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Remote sensing data has claimed its place in environmental monitoring at least since the launch of ESA's Copernicus programme. In addition to in situ measurements, our research project is investigating the extent to which we can use remote sensing data to estimate methane emissions from peat soils on a large scale. Radar signals can penetrate the typical peatland vegetation of grasses and mosses, and their reflection can provide information about the water content of the soil. The phase information of the radar signal is also used to derive soil motion. In a near-natural peatland, a seasonal oscillation of the peat body is to be expected, which swells in the water-rich winter months and shrinks in the hot and dry summer months. If the peatland is heavily drained, no movement or only shrinkage is to be expected, but a stronger emission. The hyperspectral measurements offer the potential to distinguish vegetation classes from each other through spectral signatures. They serve as an indicator of the condition of the peatland, which correlates with the emission behaviour. Together with weather information, these data should in future serve as new input parameters for a peatland model based on remote sensing data. The methane emissions estimated from this model are to be compared with the methane emissions measured in situ via chambers, thereby improving and evaluating the model.

Indication of water level by vegetation structure types, peat investigation in combination with gauges

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The indication of hydrological conditions in wetlands is the first and most important challenge in understanding their functions for ecological planning or calculating climate effects by dry out peat.
The usual way is to use gauge tubes for manual measuring or automatic loggers. Unfortunately, these measuring is very time-consuming (for manual measuring) or rather expensive (for technical loggers). To get not only punctual knowledge about the conditions of the groundwater level in wetlands there is need for a variety of such equipment. However, even when installed, the results only can be acquired from the time after the introduction into the mires.
The indication of the ecological state by analyze of soil (peat) in combination with mapping vegetation can help to optimize using gauge tubes – for areal results as well as for results that reach back to the past.
Therefore, we used more than 2000 drill holes from surface until mineral underground by peat augers for descriptions of different mire types and mire regions in Southern Germany and their groundwater levels. Additionally, we described the actual vegetation structures – concerning dominating or indicative species and their patterns of growth to use them as indication and supplement for water measurement (vegetation structure types; after vegetation-forms by Schlüter 1984 and Succow et al. 2001; Siuda 2021; HSWT/PSC & Siuda 2023).

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HSWT/PSC & Siuda (2023): Tabellen der Vegetationsstrukturtypen und ihre Grundwasserstände. Non published manuscript.

PEATMAP: A prototype model for the study of peatland and swob distribution, ecology and carbon dynamics in the Iberian Peninsula landscape mosaic

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Peatlands are of major importance in the current era of global change due to their unproportioned carbon storage. Because of this, many countries are assessing the condition of peatlands, but this effort assumes the availability of accurate distribution maps, which is not always the case. For example, important distribution gaps remain in the West Mediterranean realm, where peatlands/swobs are often overlooked or misclassified as other ecosystems. To address this issue, the PEATMAP project aims to provide a predictive distribution model for regional peatlands/swobs combining: (i) peatland and peatland species occurrence records; (ii) environmental soil, precipitation and temperature predictor data and (and (iii) the stratification the results and site selection for ground-truthing.

We identified 25 vascular indicator species and 2 moss species of both mountainous and non-mountainous peatlands/swamps in the Iberian Peninsula. Iberian peatlands. A database of occurrence records was built based on filtered data from GBIF, published literature, and own records from field surveys since 2011. We assembled thirteen predictor variables that describe topographic, soil and hydroclimatic factors, to reflect the putative relationships with the indicator species presence.

A potential distribution model was performed for each species using MaxEnt software. Resulting maps of potential distributions were cross-validated and those with AUC >= 0.75 were classified into suitable/unsuitable areas. We then combined these maps to create a richness map of indicator species, for both mountain and non-mountainous environments.

We also compiled an up-to-date database with known peatland distribution records, from different sources. We overlaid it with the predictive map to identify the areas needing field surveys to identify peaty systems not yet described in the literature.

The species richness map was consistent with the occurrence likelihood of these wetlands and suggested many additional sites worth surveying. The results indicate a wider potential for peatland occurrence, especially along the west and SW sandy seaboard and in meridional mountains. They also suggest the potential presence of many small and medium-sized peatlands, suggesting a more common occurrence potential than is currently assumed in the West Mediterranean. Finally, many potential peatlands and swobs were predicted to occur outside protected areas, suggesting a high vulnerability to detrimental human activities.

The Global Peatlands Assessment: The State of the World's Peatlands

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The work presented is in collaboration with the Greifswald Mire Centre and other partners of the Global Peatlands Initiative.

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The Global Peatlands Assessment (GPA), being the Global Peatlands Initiative (GPI) flagship product, sets the baseline for global peatland mapping, research, and policy. It enhances our understanding of peatlands, including their distribution, conditions, and necessary actions for their protection, restoration, and sustainable management.

The GPA presents the global extent and status of peatlands, alongside policy and governance options for their protection. Designed to engage decision-makers, it offers a detailed overview of the current state of peatland policy frameworks by region and provides specific recommendations. The GPA includes regional assessments that highlight hotspots of value (nature's contributions to people and ecosystem services), hotspots of change (status and drivers), and hotspots of response (policy and action). The assessment features an updated Global Peatland Map and several thematic maps, developed in collaboration with key partners at the Greifswald Mire Centre. It also addresses various mapping methodologies to advance peatland mapping and monitoring, while identifying knowledge and data gaps to improve the Global Peatland Database.

Key global data from the GPA research analysis indicate approximately 488 million hectares of peatlands globally, comprising 3.8% of the world's surface area. Around 12% of the world's peatlands are degraded, mainly due to intensive agricultural activities, forestry and peat extraction. Drained peatlands contribute significantly to global greenhouse gas emissions, with nearly 2,000 megatons of CO_2 emissions annually, representing around 4% of all anthropogenic emissions. About 19% of peatlands are within protected areas, but this does not guarantee that they are in good condition, nor does it imply that they are actively managed or undergoing restoration. The GPA also provides valuable statistics on global peatland carbon stocks, estimated at 600,000 Mt C, and covers peatland biodiversity, including species diversity, richness, and threatened flora and fauna species.

Peatlands are found in 177 of the 193 UN member states. As the collaboration of the GPI grows, more peatland areas are being discovered globally, thanks to our expanding partnerships with researchers and governments, which are continually enhancing the Global Peatland Database.

As an extension of the work of the GPA, a Global Peatland Hotspot Atlas is being developed to identify current peatland threats and drive targeted actions. The Atlas will feature a series of new maps that analyze the global distribution of peatlands in relation to geographic data on land use (such as degradation due to urbanization, agriculture, and industrialization), protection status, and climate change-related events such as fire and floods.

Clarification: The "Global Peatlands Assessment: The State of the World's Peatlands" report was produced and coordinated by UNEP and the Global Peatlands Initiative, in collaboration with GPI partners and the support of 226 contributors from all regions of the world. The production of the global peatland maps and the collection of the global peatland database were carried out by the Greifswald Mire Centre, with the support of Alexandra Barthelmes and Cosima Tegetmeyer.

Outline of legal solutions for securing land for the rewetting of peat soils

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The instruments available for securing peatland soils for large-scale rewetting measures are only partially suitable for better advancing peatland soil protection.
The systematic use of land protection instruments requires an area map in which the rewetting potential and the current and future land requirements of agriculture have been determined. Otherwise, there is a risk of random and incoherent results. The purchase or exchange of land presupposes that sufficient replacement land or funds are available. In addition, the landowners must be prepared to give up their utilised peatland. In the rather rare cases of private sale, the current state right of first refusal is limited to nature conservation reasons.
Larger rewetting measures interfere with the regional land use structure. Land consolidation procedures are a suitable instrument for this. With the exception of corporate land consolidation, these must serve predominantly private-benefit purposes. They may also serve environmental and nature conservation purposes. Climate protection has not yet been included as a purpose.
Land consolidation procedures take a long time and are laborious. Simple procedures based on mutual agreement, such as voluntary land swaps, are preferable. Land consolidation reaches its limits in moorland-rich areas where there are a large number of farms with a high proportion of land on moorland. Here, support programmes for the relocation of farmland and sites are an option. Expropriation in the context of water law planning approval/determination can be considered as a last resort if a "restricted site" blocks the voluntary rewetting measures of several landowners. So far, this has been more of a theoretical case.
As giving up land use is not a viable option for many agricultural and forestry businesses, the question arises of how to secure further yields through wet utilisation options, in particular paludiculture. These and their value chains must be promoted and established. Further management of rewetted peatlands is possible without a change of ownership. The state purchase of rewetting rights can have a supportive effect here. This instrument has proven its worth for agricultural use in floodplains. For permanent rewetting, an easement or a right of use in rem from the public sector is entered in the land register. The landowner receives an equivalent value in return, e.g. 20 % of the land value. Compensation rules protect the farmer in years in which the land cannot be used because it is too wet. Countries should use standard contracts with the same conditions. Long-term leases can prevent land from being changed and trigger civil liability and compensation claims. These points also need to be clarified.

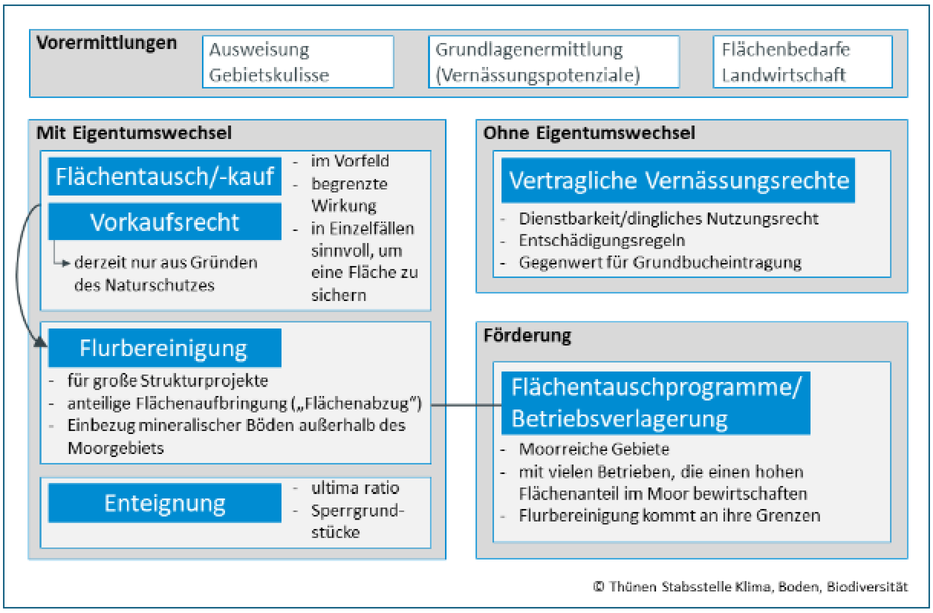

Figure: Illustration of the instruments for securing land

Still peatland or already peat forest - challenges in preserving intact peatlands through statutory biotope protection

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The various political strategies and programs for peatland protection not only intend to restore or rewet degraded peatlands, but also to (more) consistently protect intact peatlands in the future.
The presentation will therefore focus on the legal framework for the protection of intact peatlands. The purpose will be to illustrate whether and how the existing regulations impede the effective conservation of peatlands. The focus will be on the provisions of the Federal Nature Conservation Act (BNatSchG) and Directive 92/43/EEC (Habitats Directive).
The lecture will first deal with the status of intact peatlands as legally protected biotopes according to § 30 (2) BNatSchG. § 30 (2) BNatSchG prohibits actions that adversely affect certain biotope types, including “bogs” (No. 2). However, certain peatland degradation stages are also protected by the regulation. Measures to preserve a peatland that impair a degradation stage may therefore, in principle, be prohibited. Against this background, the lecture will discuss whether and to what extent peatland degradation stages are also considered “peatland” within the meaning of the provision and are protected, and whether such “conflicts” between peatlands and their degradation stages can be meaningfully resolved within the framework of § 30 BNatSchG.
Following on from this, the presentation will examine the provisions of §§ 31 ff. BNatSchG and the Habitats Directive. Annex I of the Habitats Directive also provides for the protection of both peatland biotopes and peatland degradation stages. Accordingly, similar demarcation problems may arise in the application of the Directive, in particular in the selection of the areas to be protected, as in the context of § 30 (2) BNatSchG. The lecture will therefore also present the definition problems described in the light of the Habitats Directive and explain how the Habitats Directive solves these problems.
Finally, the handling of definition problems under both legal regimes will be compared. On the basis of this, the presentation will formulate a concrete proposal as to how the regulations on the conservation of peatlands could be adapted in favor of peatland protection.

Peatland farming for climate protection Allgäu (MoorLandwirtschaft für Klimaschutz Allgäu (MoLaKlim))

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The BMUV Moorpiloten project MoorWERT in the Bavarian Allgäu essentially pursues the strategy of generating knowledge for the implementation of peatland protection strategies on agricultural land from practical measures with landowners and farmers willing to cooperate. Three important observations and conclusions can be drawn:

Firstly, a change in awareness can already be observed: in 2018, the topic of rewetting was still new to many - the very idea met with fundamental rejection almost everywhere (experience from previous projects). In the winter of '23 / '24 alone, around 50 on-farm dialogues were held on the acquisition for further project areas. The results show that about half of the farmers interviewed are clearly aware of the need for changes in peatland management. From an agricultural point of view, however, there are also many restrictions. Here, the conversion of existing farm structures, e.g. dairy farming, is often a key challenge.

Secondly, since 2023, the MoorWERT project has been able to financially compensate both landowners and land managers for disadvantages for the first time. This involves both changes in value due to temporary project-related rewetting and additional management costs and reduced yields. The process of clarifying the legal framework for subsidies and grants as well as other framework conditions can already provide information for future funding guidelines. However, even this important component is not yet generating a broad “wave of implementation”. In addition to unclear legal framework conditions (e.g. repatriability) and technical challenges (e.g. drainage pipe measures, suitable agricultural machinery), there is great skepticism among almost all farmers regarding subsidies and the long-term economic viability of wet peatland farming. Therefore, the establishment of viable value chains with paludiculture biomass that contribute significantly to farm income can be decisive.

Thirdly, the strong fragmentation of ownership structures in certain regions is an additional challenge: there are often individual owners in a hydrological complex who are fundamentally opposed to rewetting measures and thus block others from participating. However, if there is the possibility that substantial exchange areas (non-organic soils) are available, it is immediately apparent that farmers are willing to participate in voluntary land exchange procedures.

Recommendations for large-scale rewetting concepts can be drawn from this. According to the findings of MoorWERT so far, this requires technically sound planning and support that can address a large number of stakeholders, flexible funding instruments, the rapid establishment of value chains and, last but not least, the purchase of exchange areas with subsequent voluntary land exchange procedures.

12.2 Peatland conservation, restoration and management policies and programs

Bright spots in peatland conservation and restoration

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The conservation and rewetting of the world' s carbon densest ecosystem, peatland, plays a key role reaching global climate and biodiversity goals, supporting human health and wellbeing. The challenge to conserve 460 million ha of (near)natural peatland and rewet 50 million ha of drained and/or degraded peatland is vast. Currently, peatland scientists and restoration practitioners predominantly focus on overcoming social and physical problems of conservation and rewetting. While recognizing the need to address the existing challenges in peatland conservation and rewetting, this work aims to balance the problem-oriented focus of many peatland scientists and practitioners with a positive perspective, that emphasizes the successes achieved despite the difficulties. By reviewing past peatland conservation and restoration projects across various metrics, we identify ‘bright spots’, i.e. positive ‘outliers’ in peatland conservation and restoration, which can be (on-ground) projects, regulations or ideas, with outcomes that exceed the ordinary. Bright spots have beyond-local impacts, provide new insights, and/or drive substantial change in perceptions, policy or practice.

We collected bright spots in several categories: scale, cost efficiency, innovation, social impact, ecosystem service restoration success, and multi-layered collaboration. Bright spots were gathered with a semi-structured search in peer-reviewed papers, grey literature, and other publicly available sources. Bright spots were identified on a global scale, to show a variety of contexts. From these, we highlight success factors that may aid future peatland conservation and restoration endeavours.

Our work shows that peatland conservation and restoration efforts can be successful over large spatial scales, persist for decades, yield benefits for climate, water supply, biodiversity, and land subsidence, and can be cost effective. These bright spots highlight that peatland restoration can be used as a nature-based solution to mitigate climate warming, conserve and restore unique biodiversity, and support human livelihoods. Because peatland restoration is still in its infancy, conservation and restoration will likely advance rapidly and generate both ecosystem services and novel wet peatland uses that benefit nature while tackling grand societal challenges. We propose to learn from lighthouse projects, to foster a solution-oriented debate and to inspire policy makers, land managers, and communities to take action. We invite our audience to contribute bright spots to our existing list and seed the start of a comprehensive bright spot database.

Restoration of peatlands in Ukrainian Polissya within the framework of the project "Promoting sustainable livestock management and ecosystem conservation in Northern Ukraine"

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The project is being implemented during 2022-26 covering the Ukrainian Polissya regions (Volyn, Rivne, Zhytomyr, Chernihiv, Kyiv oblasts), where peatlands are situated, and Forest Steppe (Vinnytsia, Khmelnytsky oblasts), which are among the most agriculturally productive areas in Ukraine.

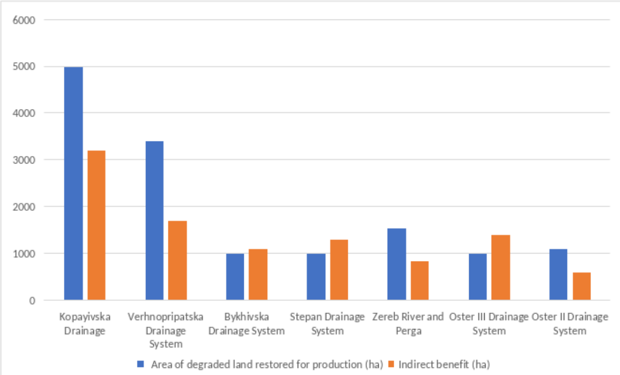


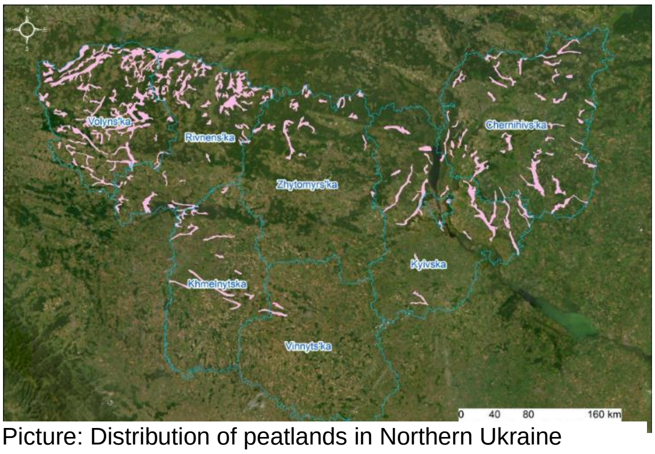
Figure: Areas of restoration sites

The project aims to develop a model of a sustainable food system in Northern Ukraine that will help improve soil fertility, protect endangered and peatlands-related species, and reduce GHGs emissions. The project addresses the following components: implementation of Integrated land use management plans, peatland restoration and promotion of sustainable livestock production and value chains; conservation of valuable natural habitats; development of a measurement, verification, and reporting system for assessing GHGs fluxes from peatlands; communication, trainings, and knowledge dissemination.

The expected results of the project will be improved agricultural practices on 2.98 million hectares, enhanced state of biodiversity, conservation of 18 significant peatland species, restoration of more than 36100 hectares of peatlands, conservation of 68000 hectares of valuable ecosystems, increased knowledge of sustainable livestock production on wet peat soils, and introduction of paludiculture.

The restoration activities will be carried out at 7 peatlands/project sites. Most of them are destroyed and drained by drainage systems that are inefficient or not used, namely: Kopaivska, Verkhneprypiatska, Bykhivska in Volyn Oblast, Stepanska in Rivne Oblast, River Zherev and Perga in Zhytomyr Oblast, and Osterska-II and Osterska-III in Chernihiv Oblast. Peat soils are widespread within all restoration sites. The project sites are overlapping or situated close to the Nature Reserve fund objects (National Nature Parks, Nature Reserves, Nature Landscape Parks), Emerald Network sites, and wetlands protected by the Ramsar Convention, which are home of many rare and endangered species.

As of today, under the project umbrella, it was collected materials and data on the main characteristics of the restoration sites (Fig. 1), the assessment report and feasibility study of the preliminary scientific and technical analysis of the restoration sites have been prepared, the structure of land use within the restoration sites has been assessed, stakeholders of potential restoration sites have been identified, communications with them have been conducted, melioration systems and hydrological features of the restoration sites, pyrogenic degradation of the landscapes have been studied. The next stage is the development of restoration projects to be implemented in 2024.



Picture: Distribution of peatlands in Northern Ukraine

Restoration of degraded peatlands is important for biodiversity conservation, as peatlands are unique ecosystems that provide habitats for many species of plants and animals as well as ecosystem services for communities. Peatland restoration also ensures their stability and protects them from further degradation and is crucial for preserving valuable ecosystems and maintaining the water balance in the landscape.

The Leyte Sab-a Peatland Forest Restoration Initiative Project (2018-2021)

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The Leyte Sab-a Basin Peatland (LSBP) is the largest peatland in the tropical Leyte Island, Philippines, with current estimates of 2,107.64 hectares and one of the two confirmed peatlands in the Philippines. Despite various ecosystem services and ecological significance, LSBP is heavily threatened by land use conversion through peat drainage and agriculture. The Leyte Sab-a Peatland Forest Restoration Initiative (LSPFRI) project followed the Forest Landscape Restoration process, which was used to regain the ecological functions of a degraded forest landscape while improving the well-being of the population across the landscape. The initiative espoused a holistic and integrated approach to developing and implementing peat swamp restoration mechanisms and sustainable peat swamp forest management. The approach was science-based and ecological, had a legal backbone, and was participatory and gender-responsive.

The essential strategies that the project employed include increasing public awareness, changing perceptions and plans through information exchange, and increasing the number of champions. The 4-year project has achieved the following outcomes:

1) Developed a baseline for the Leyte Sab-a Basin Peatland as a basis for policy formulation. This project has updated the physical, biodiversity, and socio-economic profile of the peatland and the landownership with the legal research on the CARP areas. With the latter, reinstatement strategies have been identified and proposed.

2) Increased awareness of the peatland's role and functions across multi-scalar stakeholders. At the community level, organizing and engaging CARP beneficiaries and landowners has resulted in restoration efforts, including the revegetation of 48 hectares. Peatland-friendly livelihoods were also tested as part of the rehabilitation/restoration strategies. Both contribute to the development of proof-of-concept for restoration strategies. Meanwhile, local government plans and programs have been initiated for peatland restoration and conservation.

3) Other sectors or groups are increasingly interested in participating in the Leyte Sab-a restoration efforts. Other stakeholders, such as other academies within the province, organizations, and government agencies, have expressed support for and future collaboration in peatland restoration efforts.

4) A significant number of knowledge products have been developed to contribute to awareness-raising and the science of understanding peatland. The project developed videos, manuals, coffee table books, posters, and case stories to contribute to knowledge on peatland.

Partners:

IIRR · Forest Foundation Philippines · Visayas State University · Weavers · Environmental Legal Assistance Center

Paludiculture Innovation Project – A case study from the UK

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Peat soils, often referred to as "black gold" because of their productive potential, are non-contiguously present across the West Midlands of England. Protecting these soils, which were drained for agriculture, offers one solution towards achieving Net Zero, as their continued use comes at a significant cost in terms of greenhouse gas emissions. There is increasing interest in paludiculture as an alternative practice to current management. Most lowland peat in England (~75%) is under private ownership and being farmed so economically feasible alternatives are most desirable. Water management is another challenge for paludiculture as it is critical for successful crop establishment, so reliable monitoring is needed. Moreover, monitoring nutrient loads is essential for crop growth and development, and can also have environmental implications due to leaching. The combined effect of these factors impacts soil biological communities, consequently influencing nutrient cycling as well as the breakdown, preservation or accumulation of carbon in peat soils. This study at Harper Adams University aims to contextualise the conversion to a paludiculture system by creating a resource of national significance, and by developing a long-term research and educational facility.

POSTER

Poster

Fraunhofer Institutes IGD, IGP and IVV and Universität Greifswald

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The rewetting of peatlands needs to be accelerated. This goes hand in hand with adapted wetland management to maintain productivity, the establishment of value chains to make paludiculture biomass commercially viable, and the valuation of peatland ecosystem services to attract private sector capital for rewetting purposes.
As part of the BWSF initiative (Biogenic Value Creation and Smart Farming), the Fraunhofer-Gesellschaft is conducting peatland research and development projects to find solutions for climate-friendly and economically prosperous peatland transformation.
In this context, research and development on a wide range of peatland-related topics is being carried out at several institutes in line with their respective expertise. For the scientific collaboration, a cooperation agreement was concluded with the University of Greifswald, where the peatland project office of the Institute for Graphic Data Processing (IGD) is also located.

Project Areas:
- Valuation of peatland ecosystem services (Development of an AI-based monitoring approach)
- Development of lightweight machinery for paludiculture
- Development of a customized quantum-cascading-laser-spectroscopy setup and data processing algorithms for open path gas measurements of marker compounds such as CO2 or N2O
- Use of paludiculture biomass in packaging production (Fibre, fibre preparation and packaging production process for Moulded fibre, thermoformed or folding carton packaging)

Soil analysis and accompanying hydrological investigations to assess the peat condition and restoration potential of fen areas in the Schuttertal

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There are more and more efforts and projects to restore or rewet peatlands. Sometimes all that is left is an attempt to raise the water level. Not far from the Donaumoos, the large contiguous fen area in southern Germany, lies the much lesser known Schuttermoor, about 15 kilometres north of the Danube. In the former valley of the Schutter-Danube, a peat body was able to develop as a result of a shift in the course of the river.
Here, too, efforts are being made to maintain or improve selected peatlands in a healthy, intact condition. The next step will therefore be to further assess the potential areas that have already been identified. Within the framework of bachelor's and master's theses, especially in the study programme "Environmental Processes and Natural Hazards" at the Catholic University of Eichstätt-Ingolstadt under the direction of the "Soil Geography and Soil Erosion" teaching and research unit, the first part of a comprehensive analysis has been carried out. Dealing with soil science and hydrological issues for a number of areas in the district of Eichstätt.
In addition to traditional land surveying, hydrological investigations (water level measurements on ditches and watercourses) and mapping of peat soils, detailed investigations are also being carried out. These may include UAV flights to produce high-resolution aerial photographs or 3D models, or various measurement techniques focusing on soil hydrological conditions. These include properties such as infiltration capacity and water conductivity. Laboratory analyses are based on the field methods and are checked for suitability or tested themselves. For example, the size distribution of aggregates or their wettability is determined using the water droplet method.
The aim of the work is to determine and evaluate the current condition of the peatlands. This can and should serve as a basis for recommending potential measures or adapted management of the area, thus actively contributing to soil protection on peatlands in line with the National Peatland Protection Strategy.

Does water vapor affect flux determination? - Comparison of two NDIR with and without correction

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In this study, we compared two datasets generated by two different types of nondispersive infrared sensor analysers from LI-COR Biosciences GmbH; the Analyzer LI-840 has an integrated water vapor correction, the model LI-820 has not. Water vapor can lead to interferences in measuring CO_2 (dilution, band broadening, cross-sensitivity), resulting after LI-COR Biosciences GmbH in an overestimation of CO_2 uptake. We took samples in an environment with high water vapor levels, a rewetted peatland. Here, we connected the two analysers with the same tubes and let them measure the same plots at the same time.

We used the collected data for flux calculations and then determined the differences in these fluxes between the Analysers. The comparison revealed differences, but we could not link them directly to water vapor. Highest differences between the CO_2 fluxes of the different analysers were up to 1.8 g CO_2 -C per square meter per day which levelled after calculating daily-flux-balances. We found out that changes in water vapor and flux differences of the two analysers differentiated partly from correlation observed in other studies. Here, differences in Ecosystem respiration (R_{eco}) fluxes, which are higher with correction, behaved as described in the literature .Net ecosystem exchange (NEE) and GPP (gross carbon production), which were partly higher and lower did not. Additionally, we found discrepancies in the dataset, like datasets had different time stamps or water vapor was not measured correctly, that were due to issues in the sampling and calibration of the devices. Therefore, this study should be repeated with adjustments.

Cultivation of *Typha* as a new permanent agricultural crop - initial results regarding the carbon and climate balance

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The productive use of wet or rewetted peatlands (=paludiculture) represents an alternative land use option for farmers that is compatible with a groundwater table that is permanently at the peat surface and, thus, minimizes peat mineralization. This allows for maintainance of the production function and reduction of greenhouse gases (GHG) at the same time. Data on GHG emissions from paludiculture on fens is still sparse, especially for *Typha* paludiculture and the results so far are strongly divergent. Many fen plants e.g., common reed, sedges and cattail, that are suitable for paludiculture have large aerenchymatic tissue. CH_4 emissions therefore play a major role in the carbon footprint of such systems. In a fen peatland in North-East Germany, a ~10-ha large paludiculture pilot site was established in 2019 including the installation of irrigation ditches and causeways. In the site the two cattail species *Typha angustifolia* and *T. latifolia* were planted and sown. Before this conversion, the site was drained and used as grassland.
GHG measurements have been carried out every two to four weeks since November 2023 on all elements of the *Typha* site (drier and wetter *Typha*, ditches, causeways) with closed manual chamber measurements and the whole site with an eddy covariance tower. We assume, as known from other studies, that the causeway contributes by far the most to global warming of the site due to the high CO_2 emissions. The ditches could act as a hotspot for CH_4 and CO_2, whereas the *Typha* area may represent a GHG sink. Here we show results from the first 9 months after the start of the GHG measurements and set these in perspective to a short review of the results of other available studies.

WEIHENSTEPHAN · TRIESDORF
University of Applied Sciences

Peatland Science Centre

How subsurface irrigation influences greenhouse gas fluxes from intensively managed grassland on bog peat soil

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Artificially drained peatlands are commonly used as grasslands in Western Europe, thereby causing high carbon dioxide (CO_2) emissions. Especially in Germany and the Netherlands, a major use of drained peatlands is for fodder production for dairy farming. Increasing water levels is essential to reduce CO_2 emissions. However, water management by subsurface irrigation (SI) is controversially discussed as a potential measure to reduce greenhouse gases (GHG) and maintain intensive grassland use. Two intensively managed grasslands in North-Western Germany with identical management histories on bog peat soil and different water management were selected to evaluate the effects of permanently elevated water levels on GHG exchange, i.e., an experimental intervention site (INT) (SI, targeted water levels of -0.3m) and a deeply drained reference site (REF). We present results from five years of observation on the effects of SI with grassland renewal on GHG emissions. The average mean annual water level in the first four years of the INT site was close to the targeted value and thus more than 40cm higher than at the REF site. Net ecosystem exchange (NEE) at the INT site was showing net uptake in 2020 and 2021 compared to other years, but the net ecosystem carbon balance (NECB) was also showing lower – losses at the INT. Critical side effects caused by grassland renewal in INT led to extremely high N_2O emissions in 2019. They decreased in the following years but remained higher than at the REF site. By contrast, methane (CH_4) was negligible at both sites. Although SI management could reduce the total GHG emissions in this study after grassland renewal period, the reduction effect was decreasing over the years.

Monitoring of GHGs flux dynamics at "le Viote" mountain peatland (Eastern Alps, Italy) under climate change pressure.

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This presentation focuses on the alpine peatland "le Viote" (46.01 N, 11.04 E, 1560 m asl), located at the centre of a plateau in the Mt. Bondone area, in the eastern Italian Alps (Figure), where the fluxes of methane (CH_4) and carbon dioxide (CO_2) between the peatland ecosystem and the atmosphere have been measured by chamber technique since summer 2024. The objectives of the current research activities are to analyse the spatial and temporal variability of both GHGs with special attention to CH_4 fluxes, considering the response to climatic drivers, the influence of peatland vegetation community types, hydrology and natural and anthropogenic disturbances history. These activities build on 10+ years of CO_2 fluxes monitoring by eddy covariance and a more limited dataset of CH_4 fluxes, providing a temporal background for detecting flux magnitude changes.

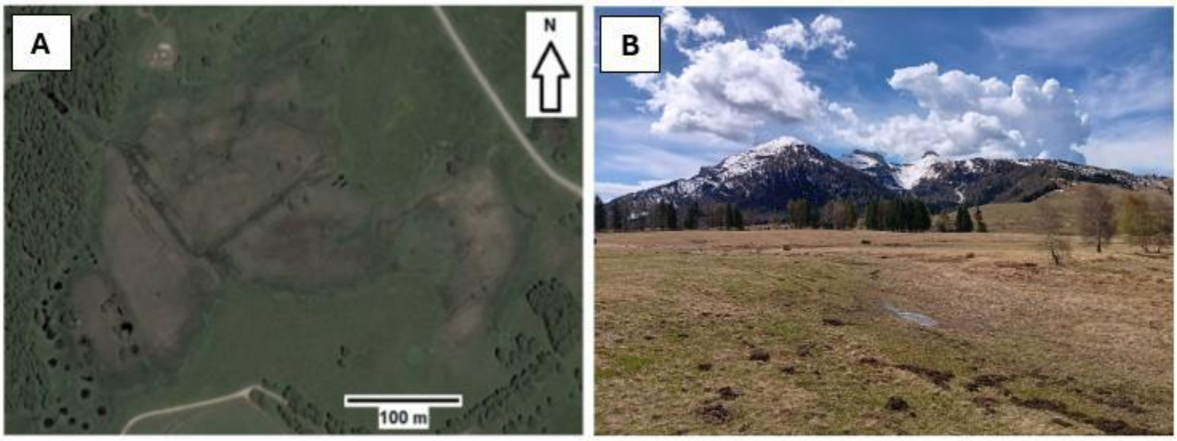

Figure: “Le Viote” peatland seen by satellite image from Google Earth (**A**) and in the field (**B**).

Hydrological studies on wet meadow paludicultures in the LivingLab Teufelsmoor – peatland water level, water balances, nutrient balances

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The use and simultaneous rewetting of peatland sites is becoming an increasingly important issue in today's society. The hydrology and soil characteristics of an area are important factors that determine whether a site is suitable for certain paludicultures or other types of use and their effects on greenhouse gas exchange and nutrient dynamics.

Osterholz-Scharmbeck (North-Western Germany) is one of the districts in Germany with the highest share of peatlands and other organic soils. Here, in the Teufelsmoor, retention areas have been managed for over 10 years, inundating them from January to April/May. This is intended to preserve species-rich wet meadows and to protect meadow birds. These species require low intensity management, but there are currently no options for utilizing the harvested biomass. The project "LivingLab Teufelsmoor - climate and nature protection-oriented wet management of wet peat soils with innovative biomass utilization in the district of Osterholz" aims to establish an innovative value chain, achieve nature conservation goals and reduce greenhouse gas (GHG) emissions. In addition, paludicultures are to be established on further, currently deep-drained areas in the district. Therefore, GIS analyses will be conducted to find well-suited sites with a high potential for rewetting.

Water levels need to be known to understand GHG emissions and properties of the biomass. Further, the water levels in a retention area will be monitored in detail in order to calculate GHG emissions over the whole project area and to enable, if necessary, optimization of the hydrological situation. In addition, at another wet meadow and a reference area, not only water levels but also the water balance will be measured. To do so, discharge measurements will be carried out and data from eddy covariance measurement systems will be used to determine evapotranspiration. The water quality will also be examined at these sites and water samples will be taken regularly depending on the flow rate in order to determine the pH value and the concentrations of different solutes. The results will enable upscaling of the measurement results of GHG emissions and provide information on the water requirements and nutrient retention of and by wet meadow paludicultures.

Effects of Drainage of Percolation Mires on the Hydraulic Functionality of their Peat

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This research describes the properties of peat from percolation mires in a different state of degradation in relation to the hydraulic functionality of these mires.
Pristine percolation mires are characterised by a continuously high supply of groundwater which leads to the formation of slightly humified, loosely structured peat. The high hydraulic conductivity of this peat allows water to easily percolate through it and especially through the uppermost layers of the peatland. This way, also deeper groundwater is redistributed over the whole surface, where it promotes the growth of typical brown moss-small sedge vegetation.
Drainage, however, changes the characteristics of the peat. Lower and more fluctuating water tables result in an increase of the humification degree and the bulk density. Depending on the drainage intensity and land use, water will no longer percolate through the dense superficial layer but flow beneath or on top of it. Especially in percolation mires that have undergone intense drainage and land use, groundwater will no longer reach the soil surface. Overall, drainage and land use change water flow and the hydrological regime of percolation mires.
In most drained percolation mires restoration measures are inevitable to restore permanent groundwater discharge and, consequently, high water tables into the soil surface. Especially in formerly heavily drained peatlands removal of the dense superficial peat layers might be necessary to promote groundwater to discharge at the soil surface, which is a prerequisite for the initiation of a percolating regime.

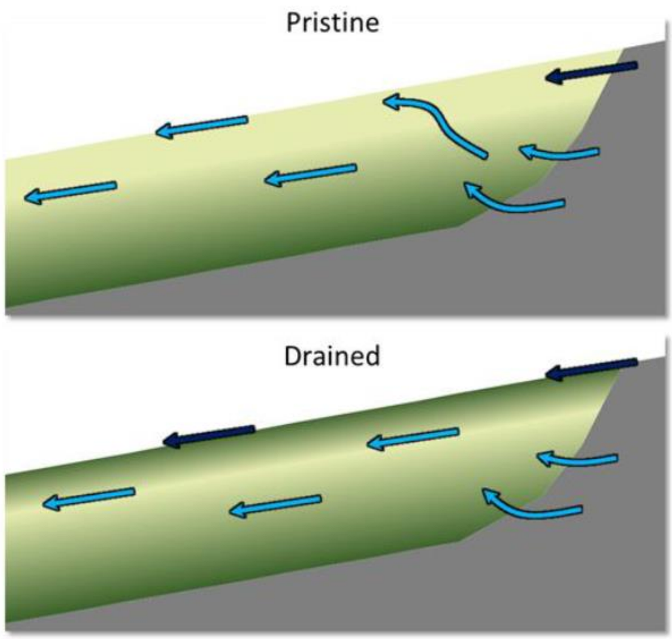
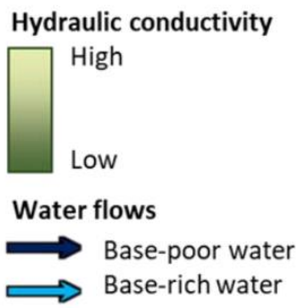


Fig. 1: Hydraulic properties of peat in pristine and drained percolation mires.



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Are commercial soil moisture probes up to the challenge of organic soils?

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The soil moisture content is a crucial factor for the release of greenhouse gases, particularly in peatlands, influencing various and biogeochemical processes, as well as the exchange of methane, carbon dioxide, and nitrous oxide between soil and atmosphere. Additionally, soil moisture significantly influences trafficability and management practices. Monitoring water table depth also provides useful information in this regard, however, with this information soil moisture can only be roughly estimated and does not necessarily reflect the volumetric water content (VWC) or water filled pore space (WFPS) of the soil.

Electromagnetic-based sensors are widely used for non-destructive, *in situ* soil moisture measurements due to their ability to provide automated continuous data at high temporal resolution. These sensors use a variety of techniques like capacitance, impedance, time- or frequency-domain reflectometry (TDR, FDR), and transmissometry (TDT). Generally, the sensors estimate VWC by correlating it with the dielectric permittivity (ε) of the soil, utilizing the contrast between the permittivity of dry soil and water.

While generic calibrations from manufacturers are available for certain soil types, they often lack accuracy for organic soils. Thus, soil specific calibration is strongly recommended for reliable measurements not only for organic soils, but standardized calibration protocols are missing. However, it is essential to note that calibration only adjusts the correlation between ε and VWC, not the measurement of ε itself. Unfortunately, little attention has been given to the performance of soil moisture probes in measuring high ε values (> 40), common in organic soils. In contrast, considerable work has been devoted to accurately measuring ε over the typical mineral soil range (< 40). However, to compare the impact of VWC or WFPS on greenhouse gas exchange and trafficability across different peatlands, reliable moisture probes are crucial.

We aim to evaluate the ability of soil moisture probes to accurately measure the whole range of the dielectric permittivity from approximately 40 to 80. Therefore, different commercial probes will be tested under laboratory conditions using different reference solutions. Preliminary results will be presented.

MooRe - Multi-scale monitoring of peatland restoration

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Peatlands have great potential to reduce CO2 emissions and improve species conservation at the same time. In Germany, Bavaria has a large proportion (9.5%, approx. 220,000 ha) of peatlands and the aim of Bavarian policy is to rewet and restore a substantial part of these peatlands (55,000 ha) till 2045. Monitoring the measures and the associated CO2 savings as accurately as possible is essential in order to measure the reduced CO2 emissions. Up to now, this is done based on the PEP-Model, with input data from water table measurements and vegetation indicators. However, the assessment of a spatially explicit water table and the exact delineation of hydrolocal impact areas has still some uncertainties. Therefor the aim of the MooRe project is to develop a method using innovative remote technologies (such as an ultralight aircraft and drones) to quantify the success of rewetting and the associated emission savings. Essentially, this involves the delineation of hydrological impact areas and the validation of model-based water level maps. A combination of satellite and airborne remote sensing and in-situ measurements will be used for this purpose. The project is currently in the second data collection phase in seven project areas. In particular, in-situ data on water levels and vegetation in permanent squares and structure types are being collected. This will help an AI model to read and validate the data from the remote sensing data and to reduce uncertainty in the assessment of restoration effects.

Assessing prepolarized surface NMR for peatland investigations with the help of laboratory NMR

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A sensor for non-invasive soil moisture detection, based on the principle of prepolarized surface-nuclear magnetic resonance (PP-SNMR) was developed. First measurements were conducted on a profile covering the transition from mineral to peat soil in the Gnarrenburger Moor in northwest Germany.
The prototype, consisting of distinct coil systems for prepolarization, stimulation and detection of the proton magnetization of the soil water molecules, has a size of 2.0 by 2.0 m. A sequence of free induction decay (T2*) measurements is conducted with varying depth sensitivities, from which, by inverse modeling, the partial water content as a function of depth and relaxation time T2* (Figure 1a) is reconstructed.
To provide ground truth for the in-situ measurements with the PP-SNMR sensor, laboratory experiments were carried out using undisturbed soil samples from five positions on the test area at depths between 0.0 m to 0.66 m. Within this depth range, we identify three types of soils: decomposed peat near the surface, undecomposed white peat, and mineral soil at the bottom. The laboratory measurements were performed with a single-sided NMR system PM25, which provides water content and T2 relaxation distributions.
Figure 1 shows the results of in-situ and laboratory measurements for an example position. The T2 distributions measured in the laboratory (Figure 1b) are in accordance to the distributions of T2* in the field for relaxation times >0.005 s, which corresponds to the effective dead time of the PP-SNMR prototype. Water associated with shorter relaxation times is undetectable with PP-SNMR. Therefore, the PP-SNMR sensor underestimates the total water content, especially for the decomposed peat (Figure 1c). Additionally, the deviations might stem from the different sensitive area of the two methods and material heterogeneity.

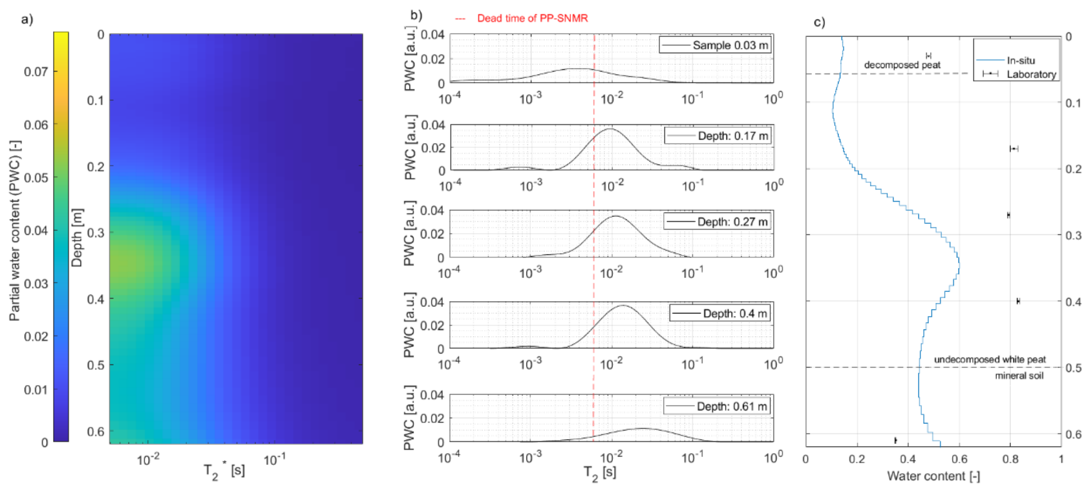

Figure: Partial water content distribution from PP-SNMR as a function of depth and relaxation time T2* (a), T2 distributions measured at the laboratory (b), Water content calculated from both methods (c).

Acknowledgements
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Seasonal and depth-specific DOC changes along a degradation transect of Puergschachen bog

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Drainage of peatlands for land reclamation has influenced bogs in many Austrian regions, including the ombrotrophic Puergschachen bog (Styria). Changing climatic conditions, additionally alter hydrological settings, resulting in the encroachment of higher plants and the leakage of bog water, particularly in boundary areas. These interactions can lead to additional liquid C losses by outflow and change dissolved organic C (DOC) qualities. Therefore, we aimed to evaluate how DOC and physicochemical water parameters differ between sites along a degradation transect (slight, intermediate, strong) and depths, and to determine how these parameters change seasonally. Depth-related water samples were collected seasonally (spring, summer, and autumn) from Puergschachen bog and analysed in the field for pH, electric conductivity (EC), oxidation-reduction potential (ORP) and dissolved oxygen (DO). Following filtration (0.45 µm), samples were analysed for DOC and total dissolved nitrogen (TDN). Specific ultraviolet absorbance (SUVA) of filtered samples was measured using a microplate spectrophotometer. Peat samples were collected, and separated into depth-sections of 10–20, 34–45, 60–70 and 85–90 cm. Sections were analysed for C-, N-, P- and S-degrading enzymatic activities and microbial biomass C. Chemical parameters exhibited minimal variations across all seasons and depths, with the exception of significant differences in ORP between intermediate and slight sites ($p < 0.03$), DO between intermediate and slight sites ($p < 0.001$) and between slight and strong sites ($p < 0.001$). DOC and TN showed significant differences between intermediate and strong, as well as low and strong sites ($p < 0.01$). DOC data revealed only minor seasonal variations, whereas differences between sites were found to be more relevant. Furthermore, $SUVA_{254}$ indicated that the aromaticity of DOC varies (insignificantly) between sites, with the highest values observed in the strongly degraded sites, and the lowest values observed in the less degraded sites. The microbial biomass C was found to be highest in the upper horizons and to be constantly lower in the deeper horizons over time. Additionally, the seasonal changes were found to be highest in the upper horizons, with a peak in summer. N-acetylglucosaminidase (NAG) activities were found to be significantly higher in the upper horizons than in the deepest depths, with a seasonal pattern that exhibited peaks in summer. Our results indicate that stronger degraded sites at the edges of the bog tend to have higher DOC concentrations with higher aromaticity, which may indicate the risk of C losses due to leakage.

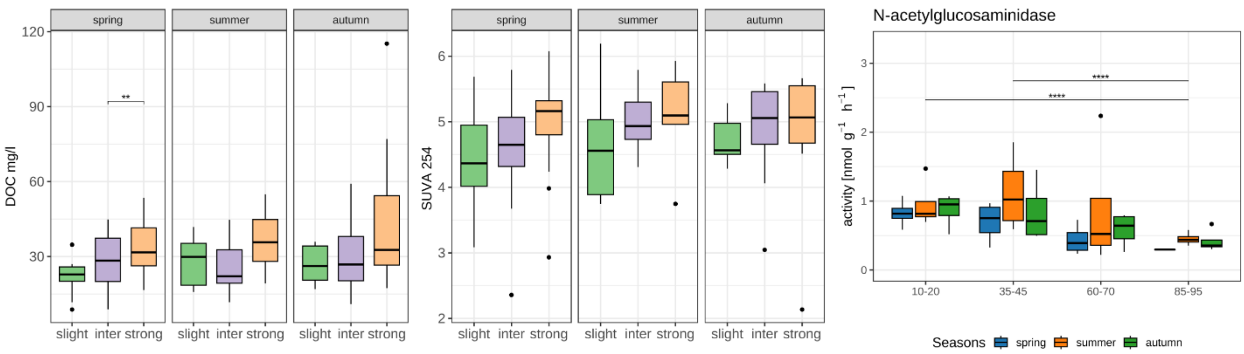

Figure: Seasonal DOC concentrations along a degradation transect (left) and aromaticity ($SUVA_{254}$) of DOC (centre). Depth-specific, seasonal variation of N-degrading enzymatic activities.

Landscape ecological systemanalysis (LESA) of the „Külsenmoor“

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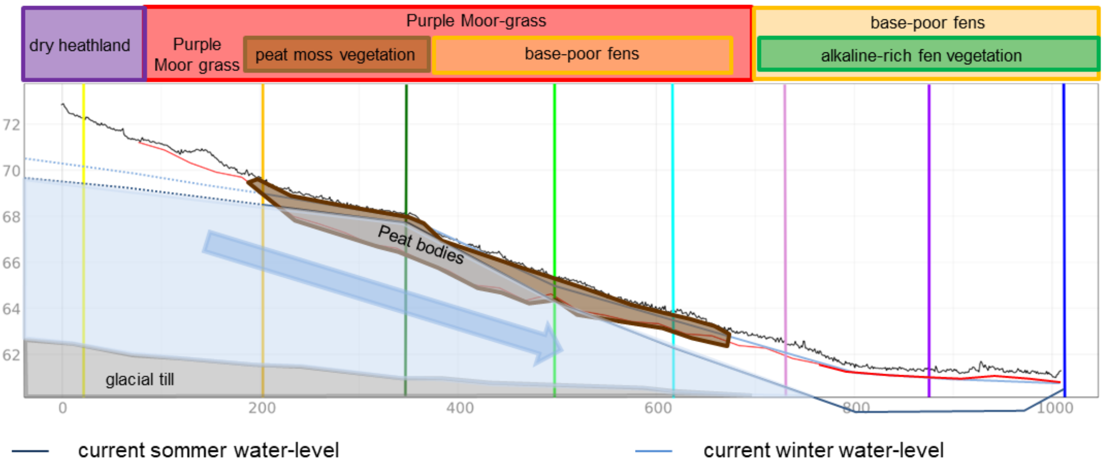
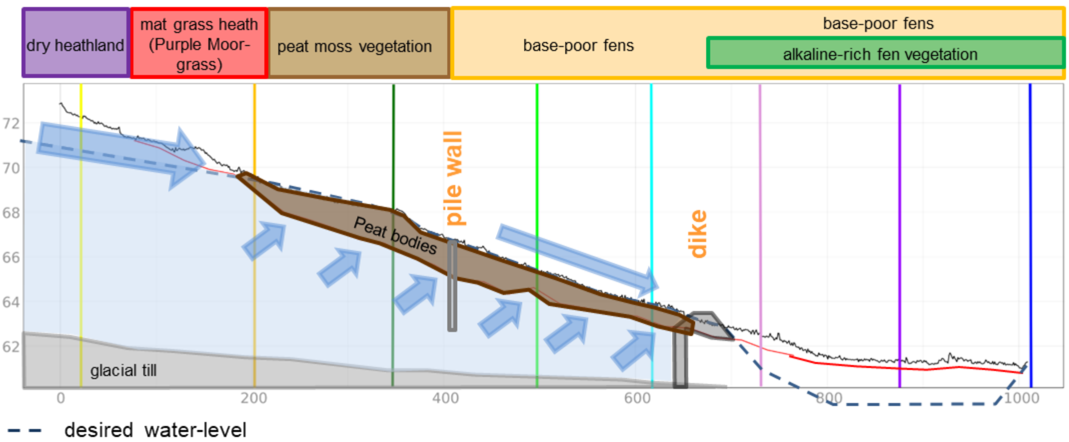
The Külsenmoor has degraded the last 20 years. The area open mire, habitat of Narthecium ossifragum, Gentiana pneumonanthe and Boloria aquilonaris, is still declining.

initial state



By a landscape ecological system analysis (LESA) the hydrogenetic mire type was determined as a sloping fen, which is recharged by phreatic, base-poor groundwater. Below this phreatic aquifer a layer of glacial till occurs, that functions as the boundary to the deeper aquifer. The shallow groundwater in the phreatic aquifer runs off too early and fast. Consequently, water tables have dropped too deep. This is the reason for the degeneration of the fen and its characteristic species.

target state



Appropriate measures, as a low embankment and a pile wall are planned to recover the original hydrology aiming at longer residence times and higher groundwater tables in the phreatic aquifer. We expect that the characteristic vegetation, flora and will return.

State peatland management in Upper Bavaria

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The Bavarian Climate Programme entered into force as from April 24th, 2007 as a result of a decision of the Bavarian Council of Ministers, and has been rolled forward since then. The aim is to lower the GHG emissions per capita in the German State of Bavaria, starting from 6 tons per year down to 2 tons by 2050. The program encompasses almost 150 measures in the areas of climate protection, climate adaptation and climate research, including the Peatland Master Plan. Its modules of Peatland Wilderness Programme, Peatland Forest Programme and Peatland Farmers Programme comprehensively provide for the climate protection potential of peatlands.
The financial budget for the peatland projects increased from initially about one million € in the year 2008 up to currently 20 million € per year. In this period of time, the according staff grew from one to currently 13 project employees, which work full or part-time (25 % - 100 %). They are based at the Bavarian government as well as in 12 Bavarian districts. Since April 2020, the peatland projects are funded by LNPR, a Bavarian regulatory guideline for landscape management and nature parks.
In the poster you can see the tasks, project areas and achievements of the peatland managers of Bavaria.

PaludiZentrale – Coordination of large projects to jointly develop overarching results on paludiculture

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Peatlands and other carbon-rich soils in Germany are predominantly drained and are responsible for 7% of national greenhouse gas (GHG) emissions. Some 43 million tons of CO_2 equivalents per year, or 80% of these GHG emissions, come from peatlands used for agriculture. Rewetting such areas would be an effective climate protection measure. This does not have to lead to the abandonment of productive land use, as plants that grow on rewetted peatlands can be used as raw material for many purposes, like horticulture substrates, building material or bioplastics.
However, the switch from drainage-based to wet peatland utilisation is not yet taking place on a large scale, as such a transformation poses many challenges for farmers, in particular complex approval procedures, high installation and maintenance costs, limited expertise in paludiculture management and a lack of established value chains for the biomass produced.
To prepare the conversion to paludiculture, the German government is funding nine large-scale, long-term projects in different peatland regions in Germany. Their common goal is to implement on practice-relevant scale all steps, from the planning and implementation of rewetting, establishment and management of wet agriculture to the processing and marketing of the products. As part of the projects, scientific studies are carried out on the effects of paludiculture on greenhouse gas emissions, nutrient fluxes, biodiversity and other ecological parameters, as well as on economic and socio-economic issues. In order to be able to derive nationwide representative results, the project accompanying studies need to be carried out using comparable methods and the data must be comprehensively collected and analysed. The PaludiZentrale-project is responsible for the overarching coordination and consultation of the nine large-scale projects. The central objectives are networking of the projects, harmonization of the accompanying scientific studies, coordinated data management, data synthesis and the development of recommendations for action for economically viable paludicultures. Of high importance for this are the thematic working groups which are organized by the PaludiZentrale within the project network and consist of members that are responsible for the respective topic in their project. In the working groups methods are tested and defined, results are discussed, and syntheses are planned and conducted. The project network is the “PaludiNetz”.
In our contribution we will present the project approach and aim, illustrate the joined work in the project network and give an outlook on the next steps.

Evaluation of water control techniques to raise water tables on peatlands used for agricultural purposes

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Due to various anthropogenic influences, including drainage and agricultural utilisation, most of the fen areas in Bavaria, Germany, are severely degraded. To stop the decomposition of the peat and the associated greenhouse gas emissions it is necessary to raise the water table. In order to be able to lower the water table before management measures, if necessary, water control techniques should be used.

Within the project "Development of peat conserving management measures for agricultural peatland and climate protection" different water control techniques on several study sites in Bavaria were evaluated, taking into account site factors, in order to specifically raise and variably adjust the water tables in the peatlands through water retention. Traditional as well as innovative approaches such as weirs, shafts in the drainage system and subsurface irrigation were considered. Particular attention was also paid to the structural requirements of the water control techniques.

The results show that the targeted raising of water tables on agricultural peatlands using water control techniques is challenging but possible. Under favourable conditions such as even terrain and sufficient inflow from the catchment area a substantial raise of the water table can be achieved. Under non-favourable conditions additional water supply from nearby water bodies might be necessary to obtain high water tables, especially in the summer season. The results present important insights for the planning and implementation of rewetting measures as part of the Bavarian peatland farming programme.

Climate certificates and peatland protection – a report about risks and chances from the praxis in Bavaria

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Climate certificates contain risks and chances for peatland protection initiatives. There is a great confidence loss within businesses in climate certificates, yet a relevant market exists. Acceptation and interest for landowners and farmers is rising while too many players entering the discussions might cause more harm than use. Legislative efforts are trying to make way for a responsible use of climate certificates under a constant threat of overregulation on the one hand and opening the market for „greenwashing“ on the other. Climate certificates may offer further stabilisation for realizing and financing climate projects in a politically and economically volatile world but not without risks, which should be carefully considered. CO2-regio offers a glimpse into the praxis of climate certificates in Bavaria on an exemplary cooperation project with the counties Ebersberg and Munich.

Strategic Planning for Sustainable Management of the South-East Pahang Peat Swamp Forest under the Sustainable Management of Peatland Ecosystems in Malaysia (SMPEM) Framework

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The Southeast Pahang Peat Swamp Forest is a critical ecosystem in Malaysia, known for its unique biodiversity and carbon sequestration potential. However, the forest is under threat due to deforestation, land conversion, and climate change. To address these challenges, this project employs a multi-stakeholder approach to develop a comprehensive plan for the sustainable management of the forest. This poster aims to present current work on the development of the strategic planning framework. This project is based on a comprehensive assessment of the ecological, social, and economic conditions of the forest, the needs and priorities of local communities and stakeholders, as well as peatland forest fire management. At the end of this project, it is hoped that it can highlight the importance of preserving the peat swamp forest and the need for effective conservation and management strategies to protect its biodiversity and carbon sequestration potential of the peatland. The strategic plan developed in this study will provide a framework for the sustainable management of the Southeast Pahang Peat Swamp Forest, ensuring the long-term conservation of this critical ecosystem and its contributions to the country's environmental and economic well-being.

The Global Peatland Hotspot Atlas

Fabrice Inkonkoy
United Nations Environment Programme / Global Peatlands Initiative. *The work presented is in collaboration with the Greifswald Mire Centre and other partners of the Global Peatlands Initiative.*
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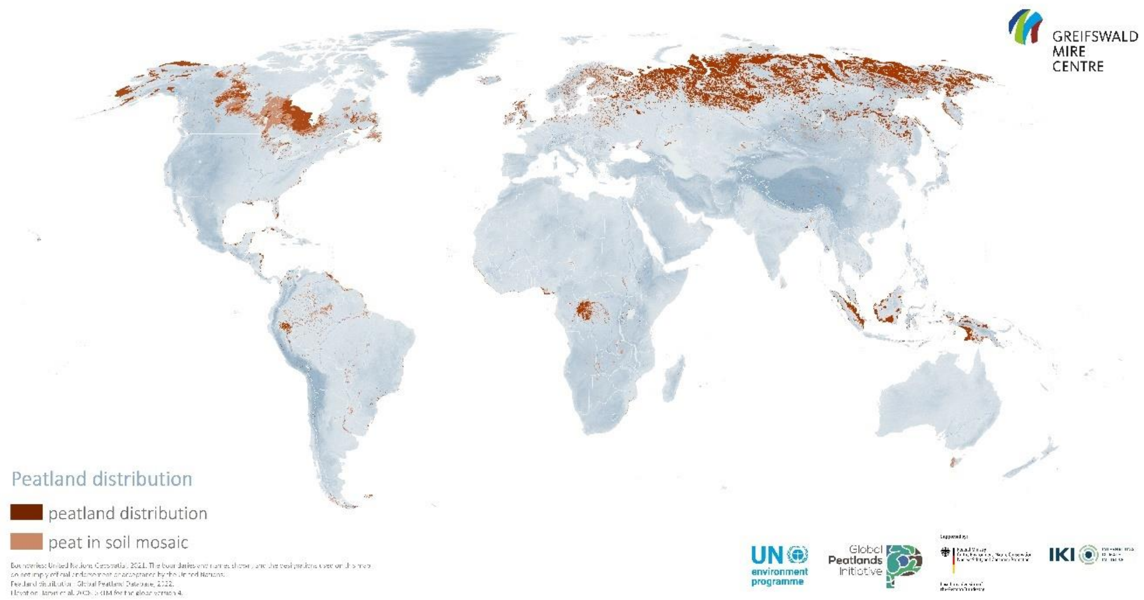
Despite their critical role in mitigating climate change and providing essential ecosystem services, peatlands face significant threats and remain among the most poorly understood and under-monitored ecosystems globally.

The Global Peatlands Assessment (GPA), being the Global Peatlands Initiative (GPI) flagship product, sets the baseline for global peatland mapping, research, and policy. It enhances our understanding of peatlands, including their distribution, conditions, and necessary actions for their protection, restoration, and sustainable management.

The GPA presents the global extent and status of peatlands, alongside policy and governance options for their protection. Designed to engage decision-makers, it offers a detailed overview of the current state of peatland policy frameworks by region and provides specific recommendations. The GPA includes regional assessments that highlight hotspots of value (nature's contributions to people and ecosystem services), hotspots of change (status and drivers), and hotspots of response (policy and action). The assessment features an updated Global Peatland Map and several thematic maps, developed in collaboration with key partners at the Greifswald Mire Centre.

As an extension of the work of the GPA, a Global Peatland Hotspot Atlas is being developed to identify current peatland threats due to urbanization, industrialization, land use, and climate change. The Atlas will present an updated version of the global and regional distribution of peatlands, encompassing a wide range of thematic layers, including biodiversity and species richness, protected areas, mountain peatlands, permafrost peatlands, peatlands in arid and sub-arid climates, drainage and degradation, GHG emissions, traffic routes and urbanization, agriculture, industrialization (mining, oil, and gas deposits), floods and subsidence, fires, among others. The objective of the Atlas is to identify where future impacts on these ecosystems may jeopardize ecosystem functionality, ecosystem services, resilience towards climate change, and biodiversity protection. Furthermore, it aims to highlight the global potential for peatland conservation, restoration, and sustainable management, while spotlighting regions of particular vulnerability for future planning and development.

Clarification: The "Global Peatlands Assessment: The State of the World's Peatlands" report was produced and coordinated by UNEP and the Global Peatlands Initiative, in collaboration with GPI partners and the support of 226 contributors from all regions of the world. The Global Peatland Hotspot Atlas, currently under development and expected to be published by UNEP and the GPI during UNFCCC COP29, is an extension of the work done for the GPA. The Atlas will feature new maps and research, with the global peatland maps and the collection of the global peatland database compiled by the Greifswald Mire Centre, supported by Alexandra Barthelmes and Cosima Tegetmeyer.



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Methane and nitrous oxide measurements on a water buffalo meadow with a dynamic chamber system

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Landscape conservation associations favor grazing on rewetted peatlands as an alternative land use, because of the potential for an increase in biodiversity compared to other land uses. However, greenhouse gas emissions from these sites are still unknown.
Therefore, we installed an Eddy covariance flux tower on a rewetted fen peatland, near Leipheim in southern Germany. The area was first in agricultural use, now it is a water buffalo meadow. A preliminary data analysis of 2023 showed high methane (CH4) fluxes; nitrous oxide (N2O) fluxes were not measured.
Therefore, we added dynamic chamber measurements in 2024. We selected four types of vegetation covers: *open peat, short grass, rushes,* and *sedges*.
As expected, the data suggest higher fluxes in summertime, and lower in wintertime; due to differences in soil temperatures. In addition, we assume, that treatments with lower vegetation covers will show high N_2O fluxes and higher covers high CH_4 fluxes.

Impact of macrophyte colonization on GHG emissions (CH_4 and CO_2) and net ecosystem carbon balance of a rewetted, riverine mire

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Peatlands play a crucial role in the global carbon (C) dynamics. Drainage and agricultural use transformed most natural European peatlands from a net carbon (C) sink to a net C source. Rewetting of peatlands, despite of potentially resulting in enhanced methane (CH_4) emissions, holds the potential to mitigate climate change by greatly reducing CO_2 emissions. Thus, rewetting of previously drained peatland is often seen as a viable instrument to restore their C-sink function. However, whether and how fast this might be achieved, strongly depends on the particular transition process and its different stages, including recolonization of typical wetland plant communities. Especially, open water areas often initially created after rewetting due to peat subsidence following drainage and a highly variable water level might further complicate the transition. Here, we present five consecutive years (2014 to 2018) of automatic CO_2 and CH_4 flux chamber measurements following rewetting of a formerly long-term drained peatland in the Peene river valley, in Mecklenburg-Western Pomerania, NE Germany (N53°52.5′, E12°53.3′). Four automatic chambers were positioned along a spatial gradient from the shore of a shallow polytrophic lake, establishing after rewetting in 2004, toward its center. During the study period, succession of macrophytes (mainly *Typha latifolia*) was taking place from the shoreline into the open water areas, reaching the different chambers along the transect during different years of the study period. While the macrophytes have gradually spread from the shoreline into the open water area, especially in drier years, this process was periodically delayed by years with exceptional inundation. The latter resulted in a transport of additional organic material into the measurement site potentially fueling carbon emissions. Using the automatic chamber measurements, we were able to investigate the impact of wetland plant community and especially macrophyte colonization on CH_4 and CO_2 emissions as well as the thereon based net ecosystem carbon balance (NECB). In doing so, we not only found a significant increase in CO_2 exchange with succession of macrophytes, but also a reduction in CH_4 emissions and thus a transition towards a net carbon sink. Overall, this study highlights the importance of an integrative approach to understand the C cycling and GHG emission potential of rewetted peatlands, encompassing the entire area with its mosaic of different vegetation forms. This should be ideally done through a study design including proper measurement site allocation as well as longer-term measurements.

Designing the nature-friendly expansion of photovoltaics on rewetted peatland

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The amendment of the Renewable Energy Act (EEG) on July 28, 2022, introduced new economic incentives for constructing solar installations on drained and agriculturally used peatlands that are designated for rewetting (§ 37 Abs. 1 Nr. 3e EEG). However, there is currently a lack of practical experience in establishing and operating these so-called "Peatland-PV" systems. This research project aims to investigate how the use of Peatland-PV systems offers opportunities for both nature restoration and the energy transition.

The project spans from September 1, 2023, to November 30, 2025, and is organized into several work packages:

AP 1: Identification of nature conservation criteria for (1) potential areas, (2) areas for further investigation and (3) exclusion areas for Peatland-PV and development of spatial maps.
AP 2: Development of specific design requirements for Peatland-PV systems in accordance with ecological objectives. This includes an impact assessment to derive the necessary standards for site selection, construction, dismantling, operation and maintenance that balance renewable energy production with ecological preservation.
AP 3: Creation of a research approach to evaluate the effects of Peatland-PV installations on the ecological quality of the sites.
AP 4: Exploration of legal and planning frameworks to support the environmentally sustainable implementation of Peatland-PV. This includes proposing solutions for the implementation of the nature-friendly design of Peatland-PV installations at the legal and planning level.
AP 5: Identification of legal options for a regional socio-economic reconciliation of interests.
AP 6: Development of recommendations for action and identification of further research needs for evaluating and optimizing Peatland-PV systems. These guidelines will be crucial for informing policymakers and practitioners on best practices for combining renewable energy expansion with peatland conservation.

This research is essential for understanding how Peatland-PV systems can contribute to nature conservation objectives. The findings will provide a basis for integrating Peatland-PV into broader conservation and energy strategies, ensuring that renewable energy development supports peatland restoration and biodiversity preservation.

Keywords: Peatland-PV, Peatlands, Renewable Energy, Nature Conservation, Ecological Impact, Energy Transition.