

Peatland Restoration for Greenhouse Gas Emission Reduction and Carbon Sequestration in the Baltic Sea Region

3rd Monitoring Report, Finland



LIFE PeatCarbon

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2025

Helsinki

Summary

The objective of the LIFE PeatCarbon project is to rewet drained and managed peatlands to allow them to develop towards their original pre-drainage stage. Specific objectives are to return the water balance of the wetland as close as possible to the pre-drainage situation, which further supports re-establishment of the open northern aapa mire habitats and the peatland functionality in terms of carbon sequestration. The estimated greenhouse gas (GHG) reduction achieved by the rewetting is 3500 tons CO₂ eq. y⁻¹ in the Finnish sites. The monitoring, conducted before and after the rewetting, aims to a landscape scale assessment of the peatland restoration success in terms of vegetation, hydrology, GHG fluxes, and climate change mitigation potential. In Finland, LIFE PeatCarbon is coordinated by Finnish Meteorological Institute, and the other partners are Natural Resources Institute Finland and University of Oulu.

Two forestry drained peatlands were restored in 2024; in all, 81 and 15 ditches were blocked, respectively. The monitoring set-up includes a systematic grid of vegetation inventory points, annual drone imaging with different sensors, sets of GHG monitoring plots (with multiple points), and water table level monitoring wells in the non-drained and drained sections of the peatland. In addition, there is a drained reference plot in a non-rewetted drained peatland forest downslope from Välisuo. Vegetation data and drone images have been used to assess habitat type distribution. The GHG monitoring started in fall 2022 continuing over the year 2023, representing the pre-restoration conditions. The first vegetation inventory was conducted in July 2023. Restoration work started in early 2024 (winter) by harvesting the tree biomass and it continued until July 2024 when the harvests and ditch damming and blocking were finished.

Initial impacts of rewetting were expected in 2025 and reported in this report. Pre-rewetting hydrological monitoring revealed spatially and temporally variable water table levels in the peatlands and substantially lowered water levels in the well-drained parts of the peatlands. The short period after the restoration indicated positive response to rewetting. Hydrological model verified spatial differences, but also a sustained and clear increase in water level independent of seasonal hydroclimatic conditions. Pre-restoration GHG data showed that CH₄ fluxes were the highest in the wettest habitat types and very small in the drained habitats and in the dry string-tops, due to variation in water table level. Preliminary estimates of the pre-rewetting annual CO₂ balance showed that the drained peatland forest was a small sink and the sink function decreased after the rewetting. Microbial data showed that before rewetting, there was methanogenic activity present in all habitats, but it was smallest in the drained habitats. After rewetting, microbial population responded soon.

1. Restoration sites in Finland

Välisuo and Matorovansuo peatlands are meso-eutrophic fens where the pine fen margins have been drained for forestry in the late 1960s – early 1970s. The drainage of Välisuo also resulted in drainage of a peatland forest downslope. The sites are in Pallas Research Area, in the Municipality of Kittilä (Fig. 1) and are among the northernmost drained peatlands in Finland. As typical for the northern boreal Finland the peatlands are aapa mires, which are minerotrophic peatlands with substantial groundwater and surface water inputs. The peatlands have pattern of strings (elongated hummocks),

perpendicular to downslope, and flarks (wet depressions) between the strings. The strength of the patterning varies across the sites. There are several peatland types within each peatland (Fig. 1b), the pre-drainage peatland types include e.g. flark fen, herb-rich fen, and pine fen (note that land-cover classification uses different terminology in Fig.1).

Drainage lowered WT and allowed growth of peatland forests (from now on, *drained*), while the central and wettest parts of the peatlands largely remained open (from now on, *undrained*). However, the drainage ditches surrounding the entire peatlands have likely affected the hydrology causing vegetation changes, such as increased shrub abundance in Välisuo.

The sites have been actively monitored since fall 2022, and the period until July 2024 represents the pre-restoration situation. The monitoring has been conducted following the *LIFE PeatCarbon Monitoring Protocol* (Task 3.1, June 2023), that was formulated based on the grant agreement document and monitoring harmonization meeting held in Helsinki, March 2023.

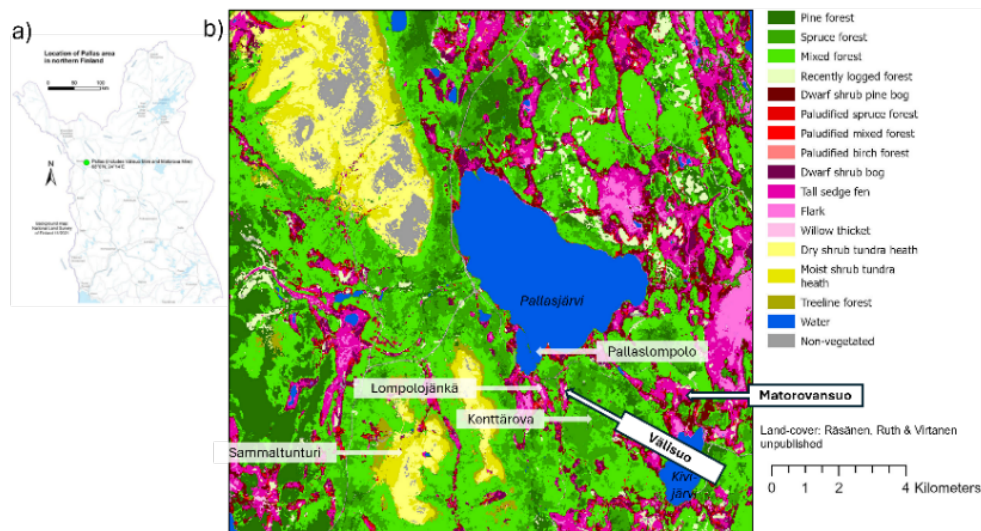


Fig. 1. a) LIFE PeatCarbon rewetting sites in northern Finland (68°N, 24°14'E). b) Locations of Välisuo and Matorovansuo peatlands in Pallas Research Area. The background map shows land-cover classification by Räsänen et al. (unpubl.). FMI has micrometeorological stations for long-term CO₂ and CH₄ flux measurements in alpine tundra (Sammaltunturi, ICOS, GAW station), peatland (Lompolojänkä, ICOS), lake (Pallaslompolo, ICOS), and spruce forest (Kenttäröva, ICOS) ecosystems.

2. Rewetting for Ecological Restoration

Forestry drained peatlands, Välisuo and Matorovansuo, were rewetted in summer 2024 (Fig. 2). The rewetting process included harvesting tree biomass to mimic the original tree density and damming ditches, using wooden dams and combination of the harvested trunks, peat, and rocks, to enable

water table to rise (see the *Restoration Plan D1.1*). The rewetting activities were executed by Metsähallitus, authority that has conducted peatland rewetting in many protected areas in Finland.

Logging was conducted using heavy machinery in winter when the peat was frozen and covered with snowpack and continued by a logger during summer. On average, logging halved the pine needle LAI and change in landscape is clear, even though tree density remained a bit higher than targeted for the pine flark fens. Trees that were present before the drainage were supposed to remain at the sites, excluding a small fraction of commercially viable timber (eastern margin of Matorovansuo).

The ditch damming started after the retreat of spring floods in July. Both peat dams and dams with harvested trunks, peat, and rocks were built in both sites, 81 in Matorovansuo and 15 in Välisuo (Fig. 3). The dams worked and signs of water table rise were observed during autumn 2024 (please see section on *Hydrology Monitoring*). The ditch damming was completed by the end of July, so the most active summer months fell somewhere between drainage and rewetted. However, GHG monitoring was continued over this period to ensure as much data as possible. The original peatland vegetation, including numerous *Sphagnum* species, and variation of microtopography were largely present even before rewetting, which will benefit the vegetation succession after the restoration. However, the ditch excavation had left substantial peat banks (dry elevated microforms) where ditch placing was intensive.

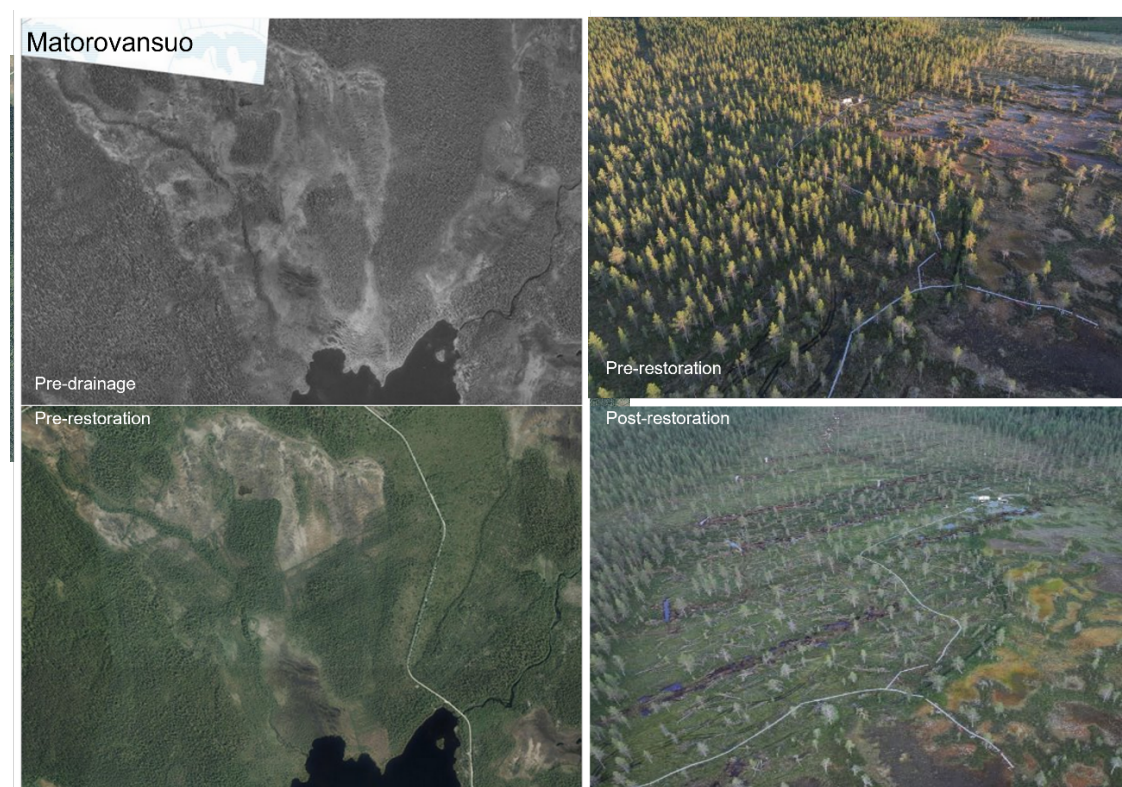




Fig. 2. Left) Aerial images of Matorovansuo before (1950s) and a recent image after drainage (National Land Survey of Finland) and after restoration (2025). Right) Drone images before and after the rewetting in 2024 (photos Jack Chapman). Boardwalks, along which the GHG monitoring plots locate, and the eddy covariance station (white backsides of the solar panels) are visible in the drone images.



Fig. 3. Rewetting included logging, to return the open peatland habitats and decrease evapotranspiration, and damming the drainage ditches. Much of the harvested biomass was left on the site and partly

placed in the ditches (photos Sari Juutinen).

3. Vegetation monitoring to follow the effect of peatland rewetting

In July 2023, we established 205 permanent vegetation monitoring points and conducted the pre-rewetting vegetation inventory (Fig. 4). Inventory also included the permanent GHG measurement points. In each point, we measured %-cover of plant species and water level relative to the moss surface. Concurrently with the vegetation inventory, we conducted drone flights with multispectral, thermal and lidar sensors over both study areas. In addition, we ordered a VNIR-SWIR WorldView-3

satellite imagery from the study area (*Remote sensing WP 3 task 3.7*). The plots will be revisited again in July 2026.

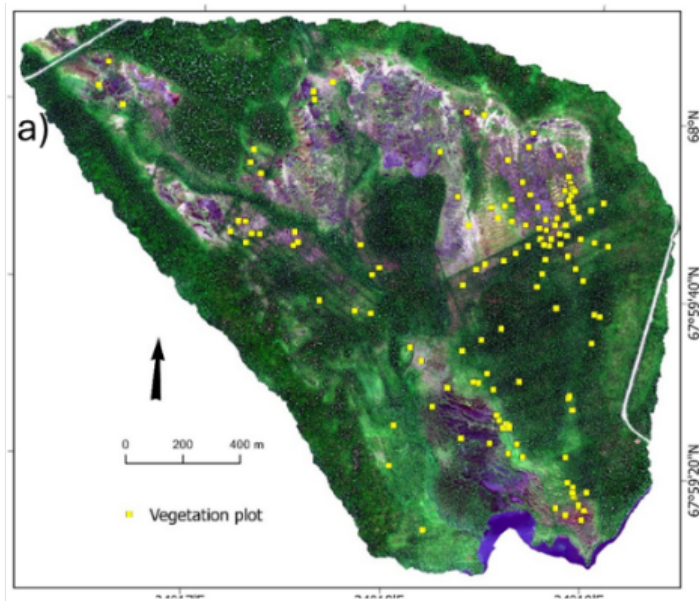
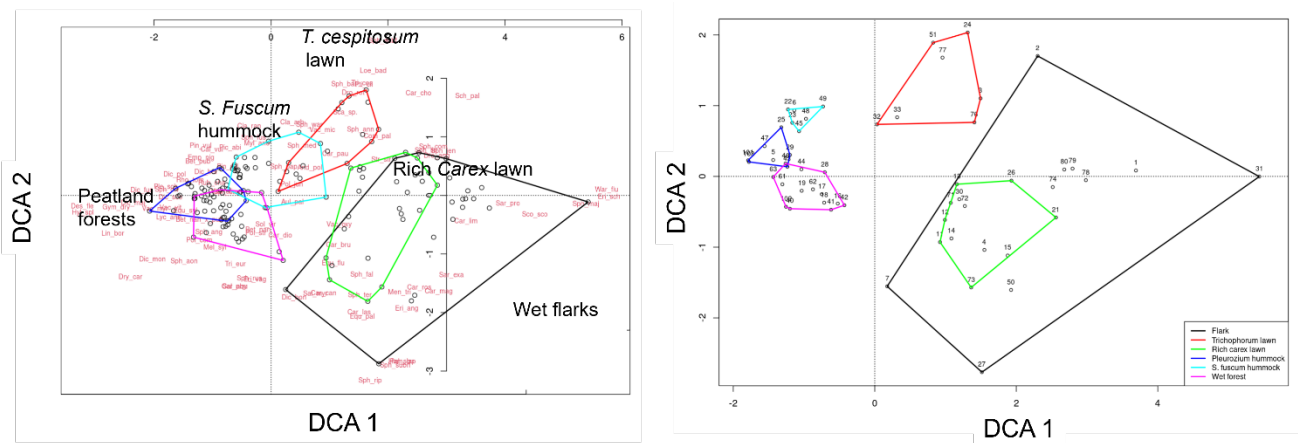


Fig. 4. The locations of vegetation inventory plots in the Matorovansuo peatland, laid over the multispectral drone image collected concurrently with the vegetation inventory in 2023. Plots in N-E sector are in the tree-survey plots around the EC mast. The plots and plots in Välisuo will be revisited in July 2026.

The vegetation data (ground vegetation) were analysed to define ecologically relevant habitat types in the Välisuo and Matorovansuo peatlands (Fig. 5). The resultant types defined by cluster analysis arranged along the moisture gradient so that the drained peatland forest habitats, *Pleurozium* hummocks and wet forests and dry *Sphagnum fuscum* hummocks were in the other end and wet undrained habitats, mud bottom flarks, *Sphagnum lidbergii* lawns, *Carex magellanica* lawns, *Trichophorum* lawns, in the other end. Vegetation in the GHG measurements points represented the overall variation in the vegetation (Fig. 5). The same points were also classified based on the GEST typification procedure (greenhouse gas flux estimation types, Jarašius et al. 2022) to be tested in remote sensing-based upscaling and comparison between approaches and comparison between Latvian and Finnish sites. GEST validation was conceived in June 2025 together with Latvian and Finnish partners.



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Fig 5. left) DCA ordination of all vegetation points and species according to their ground-layer vegetation communities. Right) DCA ordination of GHG measurement points based on vegetation. The species and plots arranged along moisture gradient.

To estimate tree biomass and its fractions and leaf area index (LAI), a tree plot survey was conducted in the source area of the EC measurement at the beginning of June 2023 and after the logging in 2024 (Fig. 6). The survey plots with a radius of 9.7–16 meters, the size depending on tree number, were arranged along eight compass points at regular distances. In each survey plots, trees were numbered and measured for breast height diameter (bhd), height (h), and canopy height. Field data of needle mass and LAI were collected to build empirical models to estimate LAI based on tree numbers and bhd (Fig. 6).

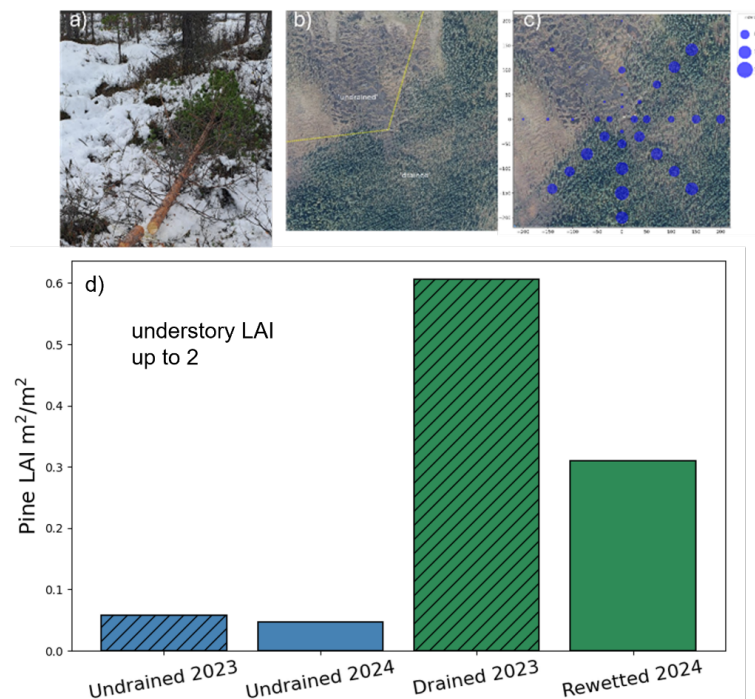


Fig 6. a) Data of needle mass and LAI were collected from a sample of trees to build empirical relationships between bhd and needle LAI. b) Sectors of EC footprint representing undrained and drained habitats. c) Estimates of average pine needle LAI in each tree plot before rewetting. d) average pine needle LAI in the undrained and drained sectors before and after the rewetting.

4. Hydrology Monitoring

Measurements conducted during the third reporting period followed the same monitoring setup established in previous years. Hydrological monitoring initially began in November 2022 with the installation of the first piezometers in Välisuo and Matorovasuo. Additional installations were carried out during summer 2023 and again in early May 2024. The measurement programme has continued uninterrupted since then and extended throughout 2025.

In total, 94 monitoring locations for frequent measurements have been established across the study areas (Table 1). Of these, 56 sites include short open-bottom piezometers used to monitor the peatland water table within greenhouse-gas monitoring plots. These measurements are conducted manually by FMI as part of their carbon-flux monitoring. The water quality in all short piezometers is regularly measured during the manual GHG monitoring (pH, O₂, temperature, electric conductivity), and samples are collected to identify changes in dissolved organic matter content. Additionally, peat water levels are measured across peatlands at approximately 206 sites as part of the UAV-based monitoring (one-time sampling in 2023 and 2026).

In addition, 16 locations are equipped with long piezometers installed to measure hydraulic heads in deeper peat layers and the underlying mineral soil, enabling the assessment of deeper groundwater flow directions (Fig. 7, Table 1). All long piezometers are equipped with IoT pressure sensors transmitting data at 15-minute intervals via LoRaWAN technology. Furthermore, seven of the short piezometers also host IoT pressure sensors. The sensors used are primarily Decentlab PR-26 units, with several Caproc Aqua-26 sensors installed to replace malfunctioning earlier devices.

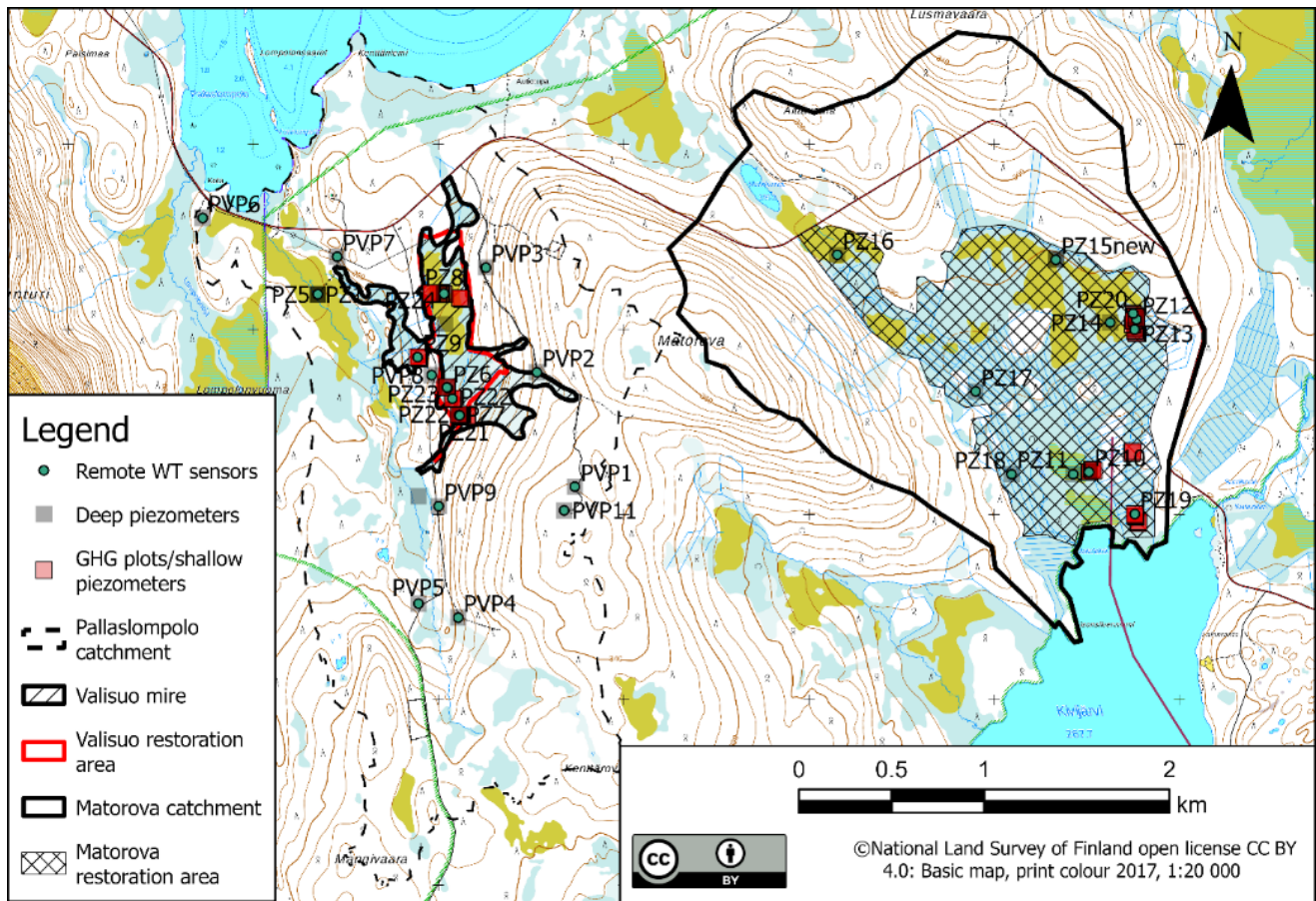


Fig 7. Map of WT continues monitoring points conducted with IOT sensors. Additional monitoring points done within Pallaslompola catchment is also marked.

Table 1. Details on hydrological monitoring points with installed remote sensors. Shallow open-pipe piezometers are indicated by scree length equal to zero.

Areal_location	Location/Name	Land altitude (m a.s.l. N2000)	Extension pipe length (m)	Scree length (m)	Pipe length above ground (m)	Pipe length below ground (m)	Level of pipe top (m a.s.l. N2000)	Level of screen bottom (m a.s.l. N2000)	Total pipe length (m)
Lompolojankka	PZ1	270.77	0.5	1	0.43	1.07	271.20	269.70	1.50
Valisuo	PZ2	279.88	1.00	1.00	1.00	1.00	280.88	278.88	2.00
Lompolojankka	PZ5	270.77	3.39	1	1.14	3.25	271.92	267.52	4.39

Valisuo	PZ6	288.4 3	1.14	1	1.08	1.07	289.5 1	287.3 6	2.15
Valisuo	PZ7	289.4 9	1.82	1	1.05	1.78	290.5 4	287.7 2	2.83
Valisuo	PZ8	284.8 8	3.74	1	1.38	3.37	286.2 6	281.5 2	4.75
Valisuo	PZ9	282.0 5	NA	0	0.1	0.65	282.1 5	281.4 0	0.75
Matorovasu o	PZ10	269.7 1	1.01	1	1	1.02	270.7 1	268.7 0	2.02
Matorovasu o	PZ11	269.5 0	2	1	0.97	2.04	270.4 7	267.4 7	3.01
Matorovasu o	PZ12	274.9 5	1.04	1	1.05	1	276.0 0	273.9 6	2.05
Matorovasu o	PZ13	274.8 6	1.48	1	1.01	1.48	275.8 7	273.3 9	2.49
Matorovasu o	PZ14	275.4 5	2.65	1	1.05	2.61	276.5 0	272.8 5	3.66
Matorovasu o	PZ15new ***	280.0 5	1.18	1	0.93	1.265	280.9 8		2.19
Matorovasu o	PZ16						282.0 4		
Matorovasu o	PZ17	275.2 1	1.07	1	1.425	0.655	276.6 3	274.5 6	2.08
Matorovasu o	PZ18	272.5 4	2.00	1	1.15	1.86	273.7 9	270.6 9	3.01
Matorovasu o	PZ19	268.8 82	NA	0	0.045	0.455	268.9 27	268.4 27	0.5
Matorovasu o	PZ20	275.3 3	NA	0	0.055	0.445	275.3 8	274.8 8	0.5
Valisuo	PZ21**	289.4 0	NA	0	0.11	0.64	289.5 1	288.7 6	0.75
Valisuo	PZ22	288.8 6	NA	0	0.1	0.65	288.9 6	288.2 1	0.75
Valisuo	PZ23**	288.3 3	NA	0	0.09	0.45	288.4 2	287.8 8	0.54
Valisuo	PZ24	284.9 9	2	1	1.1	1.91	286.0 9	283.0 8	3.01
*In additions 3 sensors installed but not mapped									
**Sensor failed and needs replacement									

***Monitoring point discontinued due to animal disturbance

We conducted a maintenance campaign in July 2025 when we did manual groundwater-level measurements at all continuous monitoring locations, battery replacements, and the replacement of malfunctioning equipment.

Continuous data collected from the start of monitoring until October 2025 were converted to groundwater levels (m a.s.l.) and filtered to remove sampling-related disturbances and short-term anomalies. IoT-based monitoring represents a new operational application in far north, and several sensors experienced malfunction due to harsh environmental conditions, suboptimal installation, and wildlife disturbances, e.g., animals pulling up instruments or tipping monitoring pipes. These issues resulted in temporary data gaps at some locations and, in a few cases, the loss of monitoring sites. All affected installations were assessed during the maintenance campaign, and faulty equipment was replaced where possible. The data corrections still require further processing for some locations.

Preliminary analysis indicates substantial spatial variation in response to rewetting: a stronger positive response (WT rise) was observed in Välisuo, while the responses have been weaker in Matorovasuo (Fig. 8). However, the location of the monitoring point relative to undrained and drained areas had an impact.

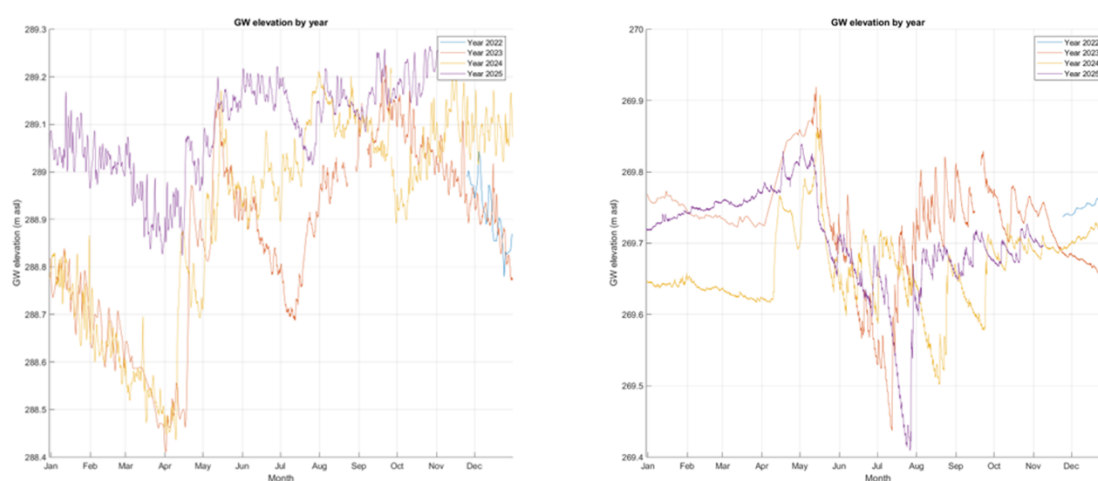


Fig 8. Time-series of GW elevation measurements at monitoring well (left) PZ7 (in Välisuo) showing highest GW after rewetting (2025) and at monitoring well (right) PZ10 (Matorovasuo, undrained) showing less-explicit impact of restoration on the water table.

It should be pointed out that peatlands' hydrological state and its dynamics is dependent on the preceding hydrological state that reflects the meteorological conditions of previous days, weeks and months and thus, the data from the various years cannot be directly compared but instead requires more robust analyses, e.g. numerical models to test what-if scenarios such as what would be the water table in a particular location if no rewetting or if no logging. Several fully distributed, integrated

hydrological model setups have been developed for the Matorovansuo catchment using HydroGeoSphere (HGS), as described in more detail in the following section, see Sec. 5.

5. Hydrological modeling

Integrated Surface–Subsurface Model Setup

An integrated surface–subsurface hydrological model was developed for the Matorovansuo peatland using HydroGeoSphere (HGS). Two model configurations were implemented on an identical 3D mesh: a drained (pre-rewetting) setup and a rewetted (post-rewetting) setup. This ensured that differences in simulated hydrological response arise solely from rewetting measures rather than numerical or structural inconsistencies.

Model calibration was conducted for the drained configuration using a multi-stage approach combining steady-state and transient calibration. First, a steady-state calibration was performed to reproduce long-term mean groundwater levels observed in monitoring wells. Hydraulic conductivities and retention parameters were adjusted to achieve realistic groundwater storage and spatial water table patterns. Second, transient calibration was carried out using PESTPP-GLM, targeting both stationary and non-stationary groundwater observations, as well as eddy-covariance based evapotranspiration (AET) and observed snow depth. Calibration parameters included peat hydraulic conductivities, anisotropy ratios, porosity, and retention curve parameters within a parsimonious zone-based parameterization. Regularization and singular value decomposition were applied to stabilize the inverse problem and reduce parameter non-uniqueness.

Following calibration, both the drained and restored model setups were simulated over a full hydrological year, using identical climatic forcings. Initial conditions were derived from multi-year spin-up simulations to minimize the influence of arbitrary starting states. Model outputs were analyzed at daily resolution, focusing on water table depth (WTD) and its temporal and spatial response to hydroclimatic inputs. This paired-simulation design enables a direct attribution of differences in groundwater dynamics to restoration measures.

Temporal Water Table Response

Water table depth (WTD) exhibits pronounced seasonal variability in both management scenarios over the simulated hydrological year (Fig. 9). Median WTDs are shallowest during spring snowmelt (May) and autumn rainfall (September), and deepest during late winter (March) and mid-summer (July).

Across all months, the rewetted configuration maintains systematically shallower median WTDs than the drained configuration with an average WT upward shifts of approximately 25 cm (Fig. 9). The monthly median separation between scenarios persists throughout the year, demonstrating a sustained restoration effect independent of seasonal hydroclimatic conditions. In addition to raising groundwater levels, restoration reduces temporal variability: interquartile ranges (IQRs) are

consistently narrower under restored conditions, indicating dampened water table fluctuations relative to the drained case.

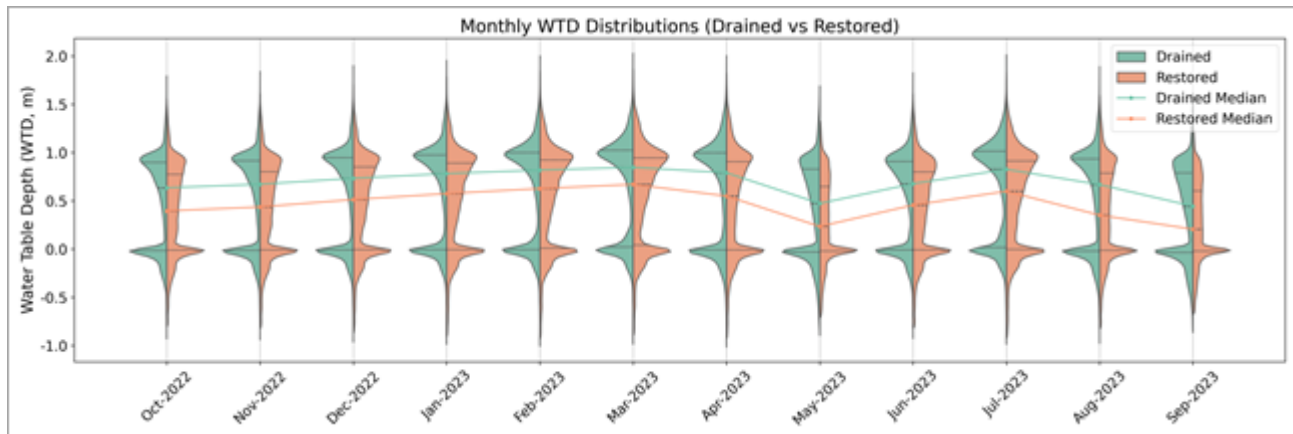


Fig. 9 Monthly distributions of daily water table depth (WTD) across the Matorovasuo peatland for drained and restored scenarios over a full hydrological year (October 2023–September 2024). Violin plots represent all peatland grid-cell, with quartiles and medians shown; connected median lines illustrate seasonal groundwater dynamics.

Spatial Variation in Water Table Responses

The spatially varying effect of restoration was quantified as the difference in annual mean WTD between rewetted and drained simulations. Results indicated a dominantly negative WTD difference (i.e., water table rise) across most of the peatland, confirming the spatial effectiveness of restoration measures (Fig. 10). The strongest water table rises occurred along infilled ditches and upstream of the dam structures. Notably, substantial water table rises were also observed in undrained sections of Matorovansuo (see southern-central and northeastern areas), demonstrating indirect hydrological benefits extending beyond intensive drainage. In the northeastern Matorovansuo, localized zones of strong water table rise were observed adjacent to marginal ditch infills, indicating reduced lateral groundwater losses. In the southern undrained section, water table increases were associated with damming along the collector drain, which historically drained the eastern mire sector.

At the domain scale, annual mean WTD distributions show a clear shift toward wetter conditions following restoration. For the entire peatland, the median annual mean WTD decreases from 70 cm (drained) to 47 cm (restored). Disturbed peatlands exhibit a comparable magnitude of change, while undisturbed peatlands show a median WTD decrease from 46 cm to 24 cm, with the dominant mode shifting toward near-surface conditions. This indicates that restoration substantially alters groundwater conditions not only locally but at the peatland scale.

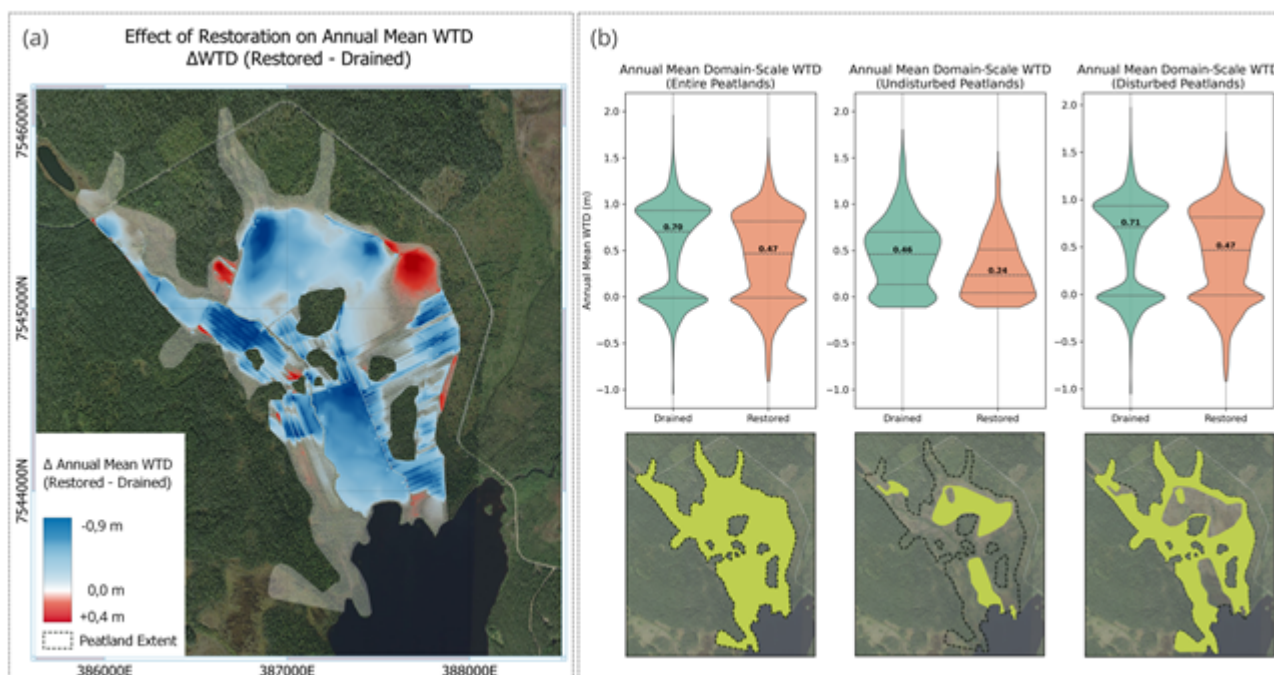


Fig. 10 Spatial and domain-scale groundwater response to restoration in the Matorovasuo peatland. (a) Difference in annual mean water table depth (WTD) between restored and drained scenarios (blue: rise; red: decline). (b) Violin plots of annual mean WTD for the entire, disturbed, and undisturbed peatland areas.

6. Monitoring Greenhouse Gas Fluxes Before and After Rewetting

The monitoring sites for the chamber measurements of CO_2 , CH_4 , and N_2O fluxes were established in late summer 2022 in Välisuo and Matorovansuo peatlands (Fig. 11). The set-up includes 17 plots, each having 3 measurement points with intact vegetation ($n=51$) and equipped with preinstalled collars (area 58 cm $\times$ 58 cm). The collars ensure a gas-tight chamber seal. In the northern transect in Matorovansuo, vegetated points where CO_2 flux represent autotrophic and heterotrophic respiration, are paired with trenched points ($n=6$), where CO_2 flux represents heterotrophic respiration only (Alm et al. 2007). In the trenched points, vegetation has been removed and root ingrowth prevented which allows measuring contribution of peat decomposition to the CO_2 respiration. In addition, fluxes are measured in five ditch locations (three replicates/location, $n=15$) distributed across the study sites. In the ditch points, GHG fluxes were measured using mainly floating chambers. Each measurement point is equipped with a soil and near-soil air temperature and moisture data-logger (Tomst, hourly logging interval) and a water table monitoring well. Continuous WT monitoring is conducted in several locations as part of hydrological monitoring (Task 3.3, see Sec. 4).

The eddy covariance (EC) system for measuring net ecosystem exchange of CO_2 and energy fluxes was set up at Matorovansuo at the beginning of June 2023 (Fig. 12). It consists of instrumentation (Li-7200 and Metek uSonic-3 anemometer) at height of 14 meters (above tree canopy) and data

loggers for fluxes and auxiliary data (wind, photosynthetic photon flux density, global radiation, soil and air temperature, air humidity, soil moisture, and water table depth). The system is powered by solar panels and a windmill and has a generator for reserve. It provides high frequency data of net ecosystem CO₂ exchange above the tree canopy, that is, including CO₂ exchange of soil, ground vegetation and tree components. The pre-processed data has 30-min resolution. Our set-up allows distinguishing data from source areas that are *undrained* (ditches only surround this large area) and *drained* peatland forest. These are the northern and southern wind sectors, respectively (Fig. 12).

In all monitoring plots, GHG flux measurements started in fall 2022 and are continuing. The year 2025 represents the first full calendar year after the rewetting. Chamber measurements of CO₂, CH₄ and N₂O have been conducted fortnightly during the snow-free season (end of May–November) and monthly, using the snow-gradient and chamber methods, during the snow period (Lohila et al. 2016). During each chamber measurement, gas concentrations inside the chambers were determined using portable Licor analysers LI-7810 and 7820, which were paired and carried in a backpack. In addition, in 24 points, net ecosystem exchange of CO₂ (NEE) and ecosystem dark respiration (ER) were measured using paired transparent and opaque chambers. This approach allows estimation of ecosystem gross photosynthesis (GP) as difference between NEE and ER (Alm et al. 2007). Each transparent chamber measurement was replicated applying screens to get data to define the response of photosynthesis to photosynthetic photon flux density (PPFD). Water table location, soil and chamber temperature, and soil moisture were measured during each GHG measurement.

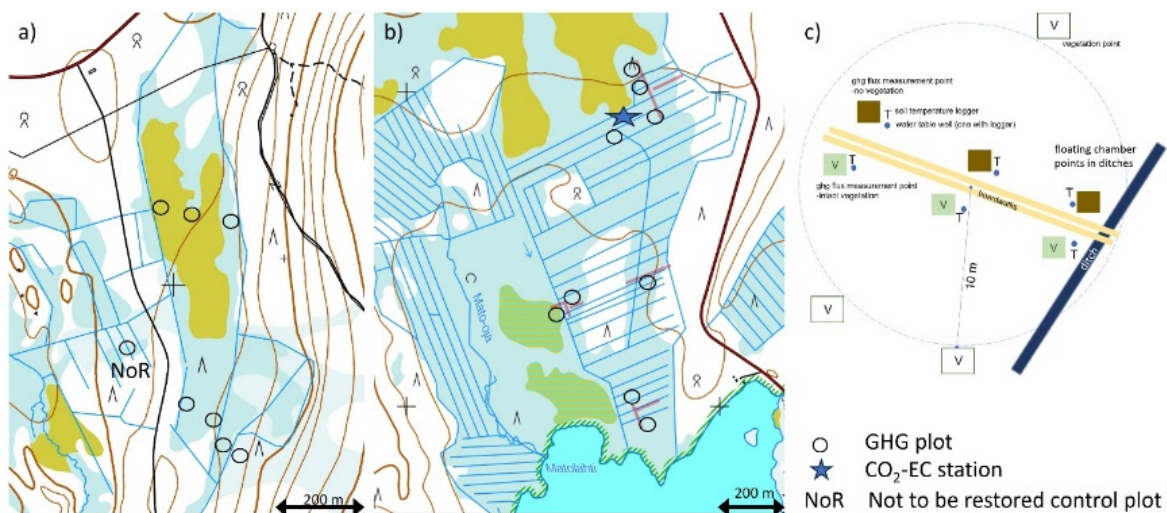


Fig. 11. Välisuo and Matorovansuo consists of drained and nondrained parts. No-rewetting control plot locates in a peatland forest. Monitoring plot set-up for the chamber measurements of CO₂, CH₄, and N₂O fluxes a) in Välisuo, b) Matorovansuo peatlands, and c) a schematic representation of a monitoring plot. Ditch plots (n=5) not marked. The location of the EC for measuring the net ecosystem exchange of CO₂ is shown on the map of Matorovansuo. Map National Land Survey of Finland 2023.



Fig. 12. Left) The eddy covariance measurement set-up for measuring CO_2 flux at Matorovansuo peatland. Middle) Drained and undrained source areas of the EC measurement. Data are attributed according to wind direction. Right) Chamber measurements were conducted in trenched and intact, vegetated points. The peatland type is a pine flark fen. Photos Jack Chapman, satellite image from National Land Survey of Finland 2023.

True leaf-area index per species was determined (ICOS methodology) every two weeks over the snow-free season in the same GHG monitoring plots that were used to measure NEE and ER. Annual moss growth was measured using so called moss-brushes as a scale and by taking samples of moss biomass. These data are needed to analyse and model GHG exchange (gap-filling models) and additionally provided for the modeling task (task 3.8–3.9) for the plant functional type distribution parametrization. In addition, we have sampled peat, litter, and tree and understory biomass data (inc. roots) for modeling and carbon flux estimation.

Our GHG monitoring data covered the pre-rewetting period (fall 2022–summer 2024) and a post-rewetting period (July 2024–Dec 2025). Monitoring will be continued during year 2026. Before the rewetting, ecosystem total respiration of CO_2 was highest in the driest and forested habitats (*Pleurozium* hummocks and wet forests) as well as in the *Sphagnum fuscum* habitats that are in the high strings of the undrained peatland (Fig. 13). In turn, habitat specific median CH_4 fluxes were greatest in the wettest habitats, flark and rich *Carex* lawns. Fluxes of N_2O were negligible during the pre-restoration period. After the rewetting, there was no major changes in median CO_2 , CH_4 , and N_2O fluxes, which was expected as the water level rise is spatially heterogeneous and gradual. However, CH_4 fluxes increased slightly in the most drained forested habitats, wet forest, *Trichophorum* lawn, and *Sphagnum fuscum* hummock. It is typical that CH_4 fluxes recover with a lag and, in addition, year-to-year comparisons are prone to differences caused by weather variation. After data collection period, data will be analysed and using statistical models the real rewetting effects can be explored.

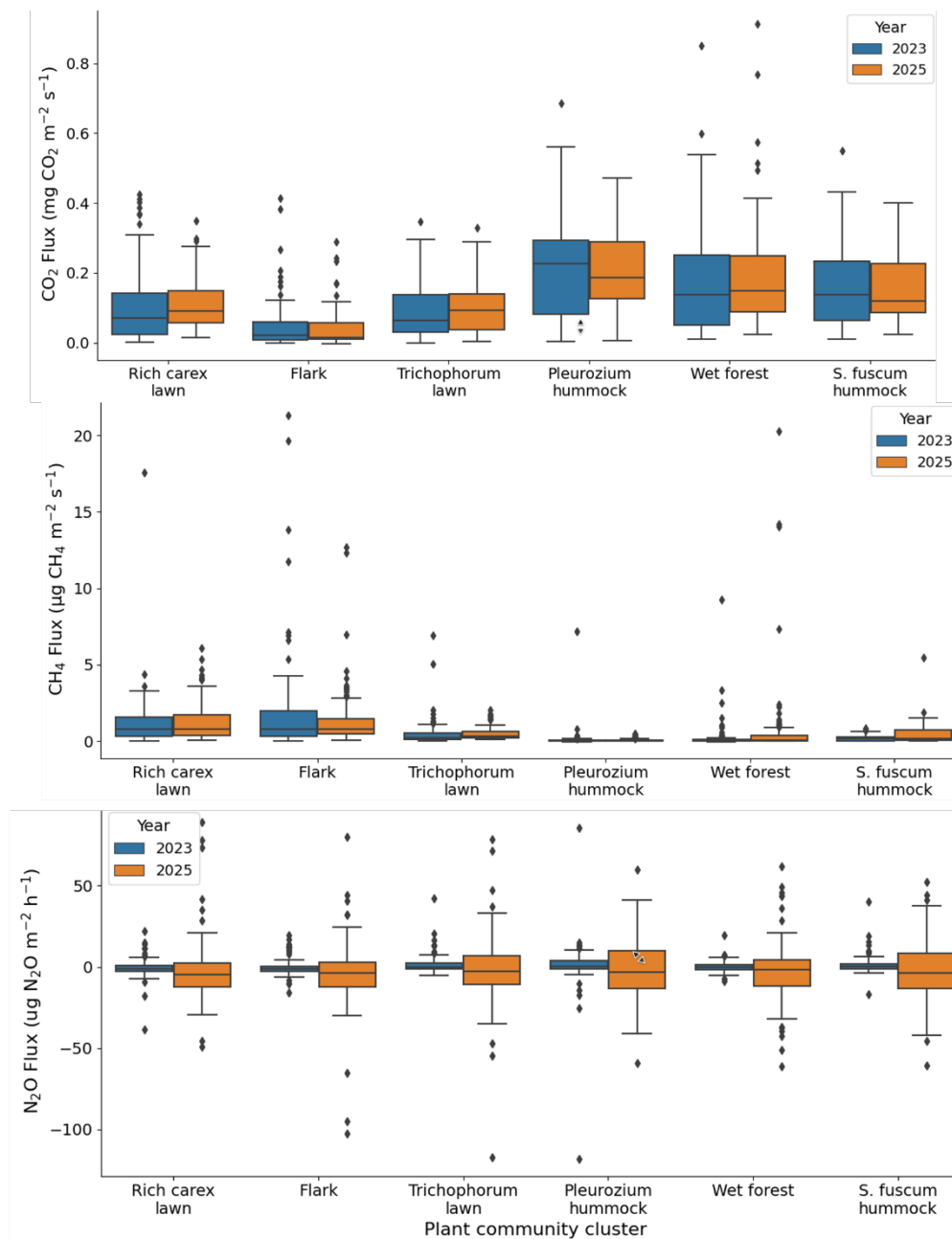


Fig. 13 Ecosystem total respiration of CO₂ (top), CH₄ fluxes, and N₂O fluxes in before (2023) and after (2025) rewetting among the plant community clusters.

Preliminary estimates of the daily and annual CO₂ balances from EC measurements indicated that the peatland forest was a small sink of CO₂ in annual scale, while the undrained footprint area (with large areas of wet flarks) had near zero balance (Fig. 14 and 15). Both the carbon uptake (GP) and losses as ecosystem respiration (R) were larger in the drained peatland forest than in the undrained peatland. After the rewetting, ecosystem gross photosynthesis decreased in the drained sector leading to smaller net uptake (more positive or less negative NEE) (Fig. 15). This could be due to logging when the needle LAI decreased but also the ground layer vegetation was partly covered by the logging residues. Interestingly, after the rewetting, gross photosynthesis increased in the

undrained sector. It resulted in increased CO_2 uptake relative to the previous year. We will continue to measure the ecosystem-level CO_2 exchange during year 2026. Data will be comprehensively analysed after the measurement period, including footprint attribution and gap-filling using up-to date methodologies. In that phase, the vegetation phenology and weather variability will be accounted for.

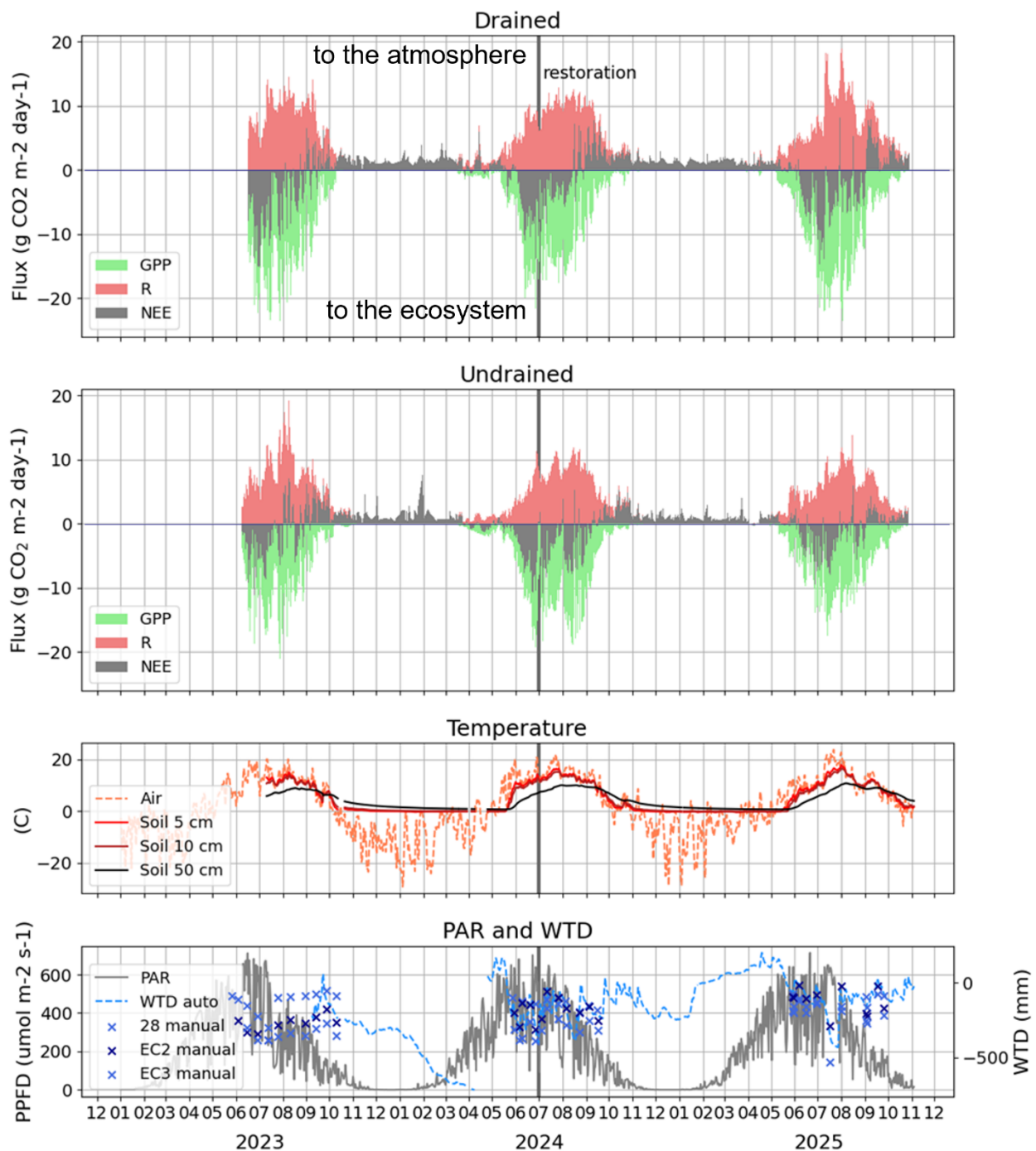


Fig. 14. Time series of daily ecosystem CO_2 exchange (GPP = gross photosynthesis, R =total respiration, NEE =net ecosystem exchange) in Matorovansuo from June 2023 to December 2025. Vertical line indicates the end of operations aiming to rewetting (restoration). Top) Forestry drained sector (see Fig. 12, 2024 July onwards rewetted), middle) undrained sector, below) temperature and water level

time series (x = manual measurement in three locations, dashed line=continuous measurement in a drained strip).

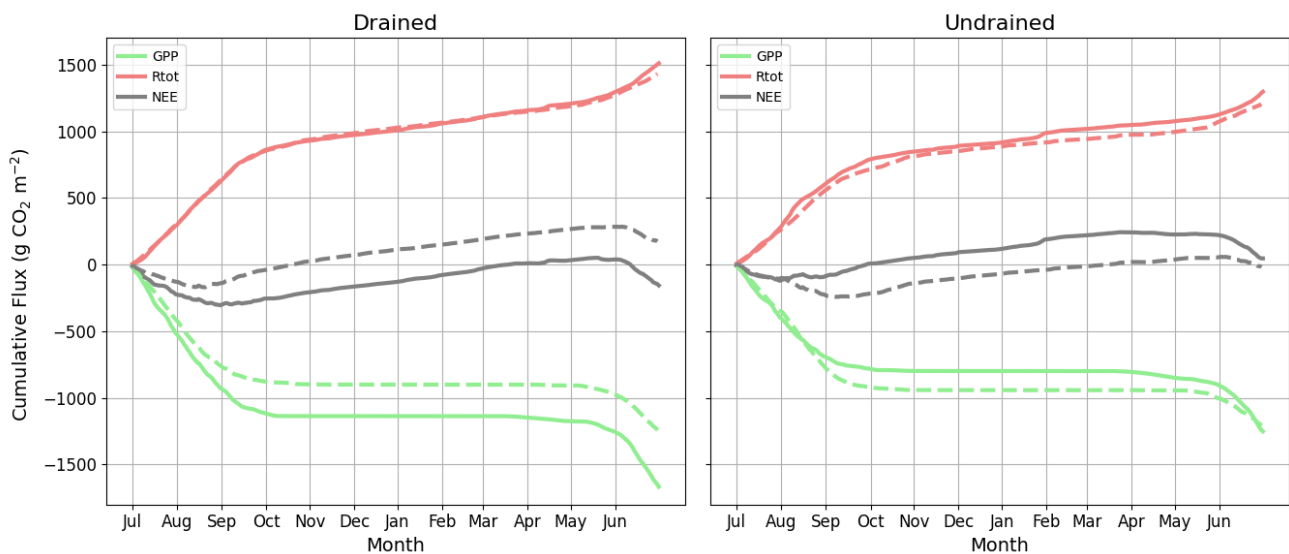


Fig. 15 Preliminary estimates of cumulative CO₂ fluxes (gross photosynthesis GPP, total respiration R, and net ecosystem exchange NEE), from July to July in before (solid lines 2023-2024) and after the rewetting (dashed line 2024-2025) in drained and undrained sectors. Note, negative values denote ecosystem sink function, while positive values denote release to the atmosphere.

7. Microbial community composition and activity monitoring

We have collected samples for microbial community composition via metagenomics, and community activity via metatranscriptomics, from 53 GHG points four times during 2023 (June, early July, early August, September) and in September 2024, two months after restoration actions. Samples were collected from approximately 10 cm depth with sterile instruments and stored in dry ice immediately. DNA and RNA extractions took place at Luke laboratories. DNA was sequenced from July samples as then the highest growth rate of vegetation usually takes place and RNA for monitoring microbial activity from all samples. The 53 samples selected present both drained and more pristine central areas of the peat samples. Results indicate methanogenic activity in all sites but activity more in undrained, water saturated sites (Fig. 16). However, the activity of methane oxidation genes was present and active in most of the sites.

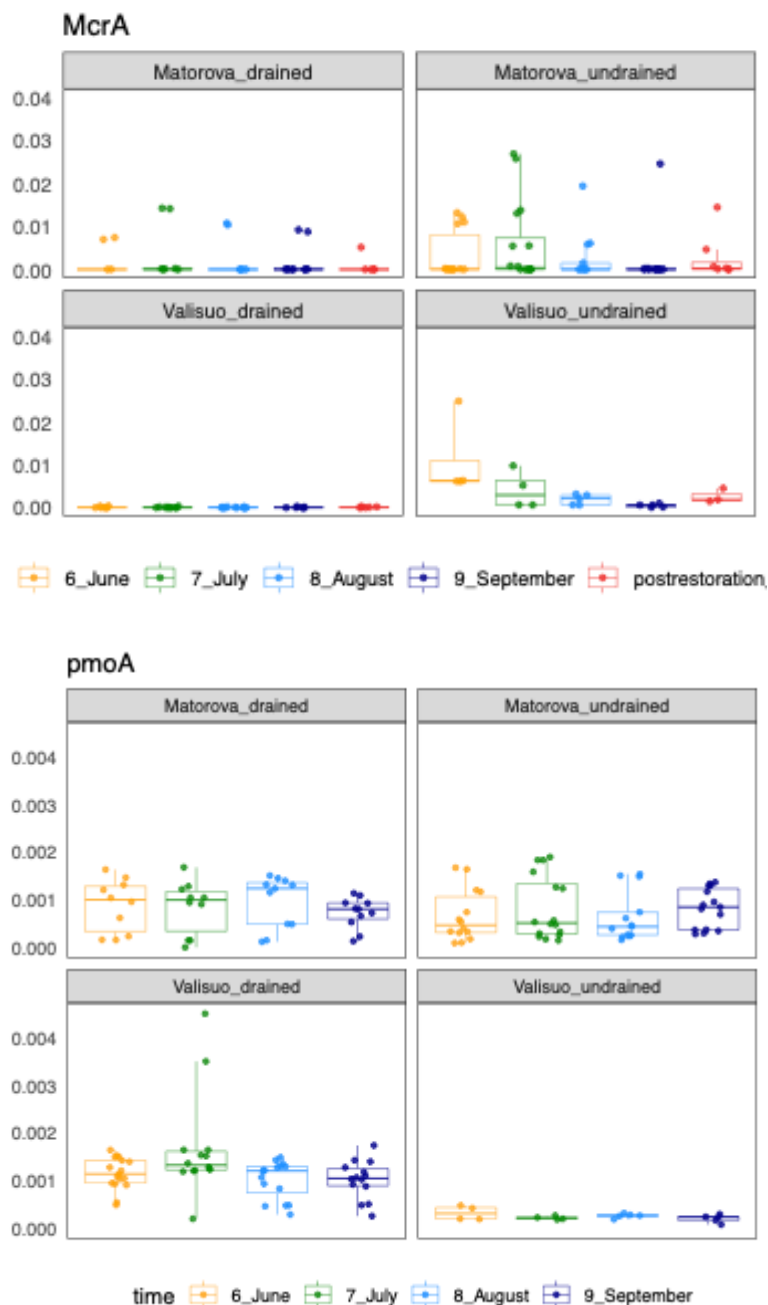


Fig. 16 Activity of genes involved in methane cycling. *McrA* for methane production and *PmoA* for methane oxidation.

A clear shift was observed in microbial community functional potential 2 months after restoration actions (Fig. 17). In samples collected before restoration actions clustering was observed based on the drained and undrained areas of both studied peatlands. However, with restoration activity of functional genes active in these samples shifted to same direction, indicating similar processes in these rewetted sites.

Decomposition experiment was established to monitor decomposition rate and peat production potential to complement the existing intensive GHG measurements. A litterbag method (1 mm mesh)

and litter types common to hummocks and hollows were used (i.e. *Betula nana*, *Eriophorum vaginatum*, *Carex rostrata*, *Sphagnum angustifolium*, *Pleurozium schreberi*). Three parallel sets of each leaf litter type were placed on the soil surface, and two sets of each root litter type were buried on the topmost 15 cm. The decomposition rate approached through mass loss will be determined after 1, 2 and 3 years of exposure of the litters to decomposition *in situ*. Additionally, cellulose was used a standard control to pinpoint the differences in decomposition rate in space and time. In addition to molecular biology analyses, degradation of peat in both drained and undrained areas are studied with litter bag decomposition experiments. These studies benefit also GHG flux and C flux task and WP4.

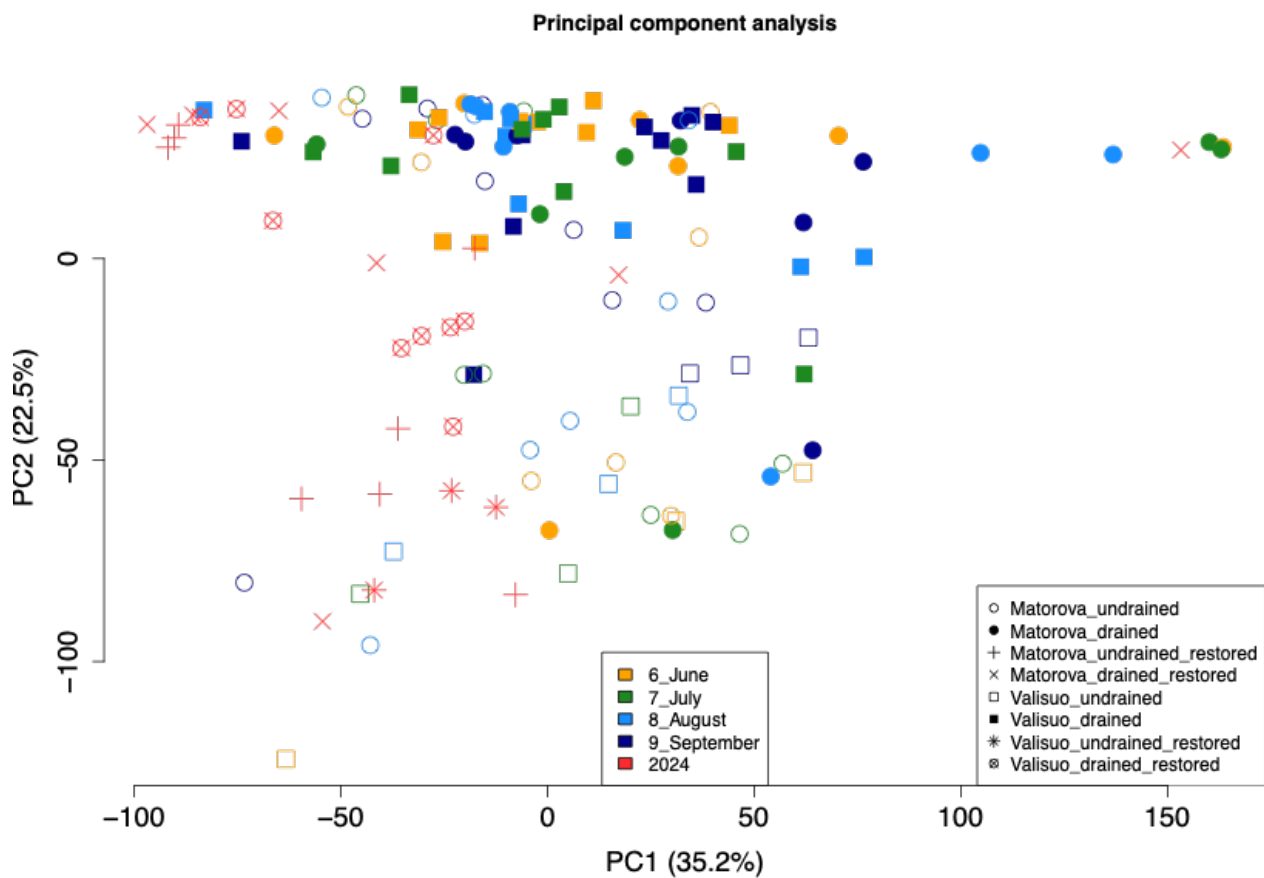


Figure 17. PcoA analysis of the active functional diversity of the studied 53 sites with microbial community analysis. Post-restoration samples (2024) are marked with red, and they show shift in microbial processes occurring with rewetting.

8. Remote Sensing

During 2025, we finalized our remote sensing-based habitat and GEST mapping using vegetation and drone data from 2023. As reported in previous chapter, the vegetation data were clustered into ecologically meaningful habitats which were relevant from GHG upscaling point of view. As for the

GEST-types, there were several classes which were observed only a few times, which is not sufficient for classification task. Therefore, we merged some of the less abundant classes with more commonly observed classes. This resulted in five different GEST-types across the sites.

To produce spatial maps, we defined the final delineation of the study sites (Fig. 18) which is mostly based on peatland mask of National Land Survey of Finland. Using vegetation plots and drone data, we produced categorical map of the vegetation clusters using object-based-image-analysis which included mean-shift-segmentation and random forest classification. The classification performance varied between 55% (vegetation clusters) and 61–78% (GEST-types), but the upscaled maps look mostly meaningful (Fig. 16). During 2026, we re-visit the vegetation inventory plots and start similar classification procedure to post-restoration maps.

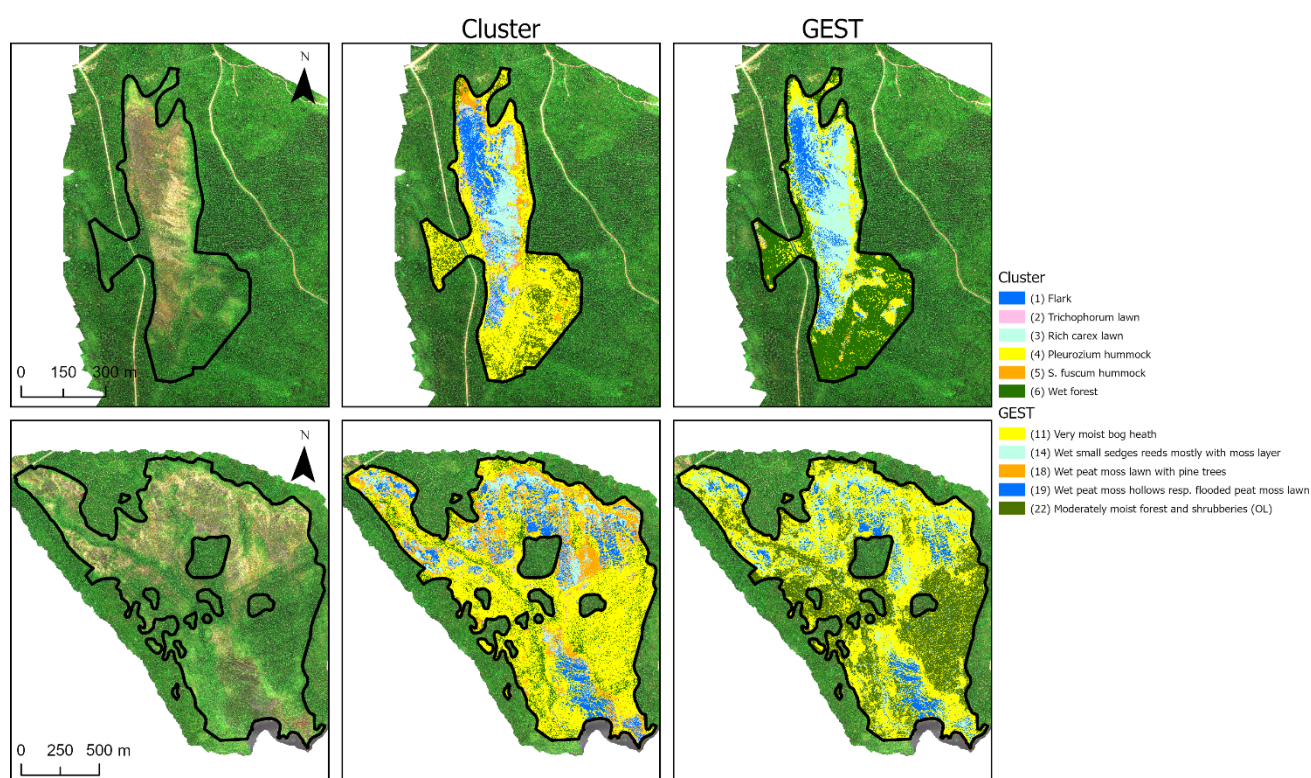


Fig. 18 Delineation of the sites and the final habitat (Cluster) and GEST-type maps for Välisuo (top row) and Matorovansuo (bottom row).

We also conducted spatial water table modelling using field measurements from vegetation plots in 2023 and drone data. Random forest regression performed relatively well ($R^2 = 0.52$), and using drone LiDAR-derived metrics from topography, vegetation height, and surrounding canopy, the model performance increased compared to multispectral data only model ($R^2 = 0.37$). We will conduct similar upscaling using field data from 2024–2026. We also aim to compare the outputs from hydrological process model to our remote sensing-based outputs.

For nationwide GHG assessments, we produced peatland type area distributions across Finland using peatland classification map produced by Geological Survey of Finland (Fig. 19). It contains undrained and forestry drained peatland areas in Finland with high thematic accuracy (number of classes 39).

Because the GHG model requires estimates of vegetation cover and water table fluctuations, we merged the 39 classes into four distinct types: spruce mire forests, pine mire forests, open mires and flark fens, which we further divided into drained and undrained types (based on the dataset information). In 2026, we will produce area distributions for peat extraction sites and their different after-use options.

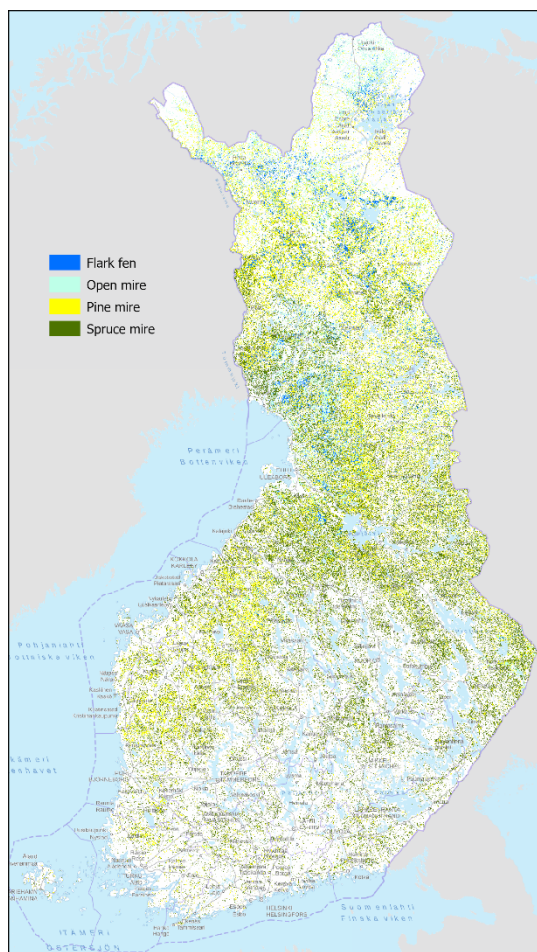


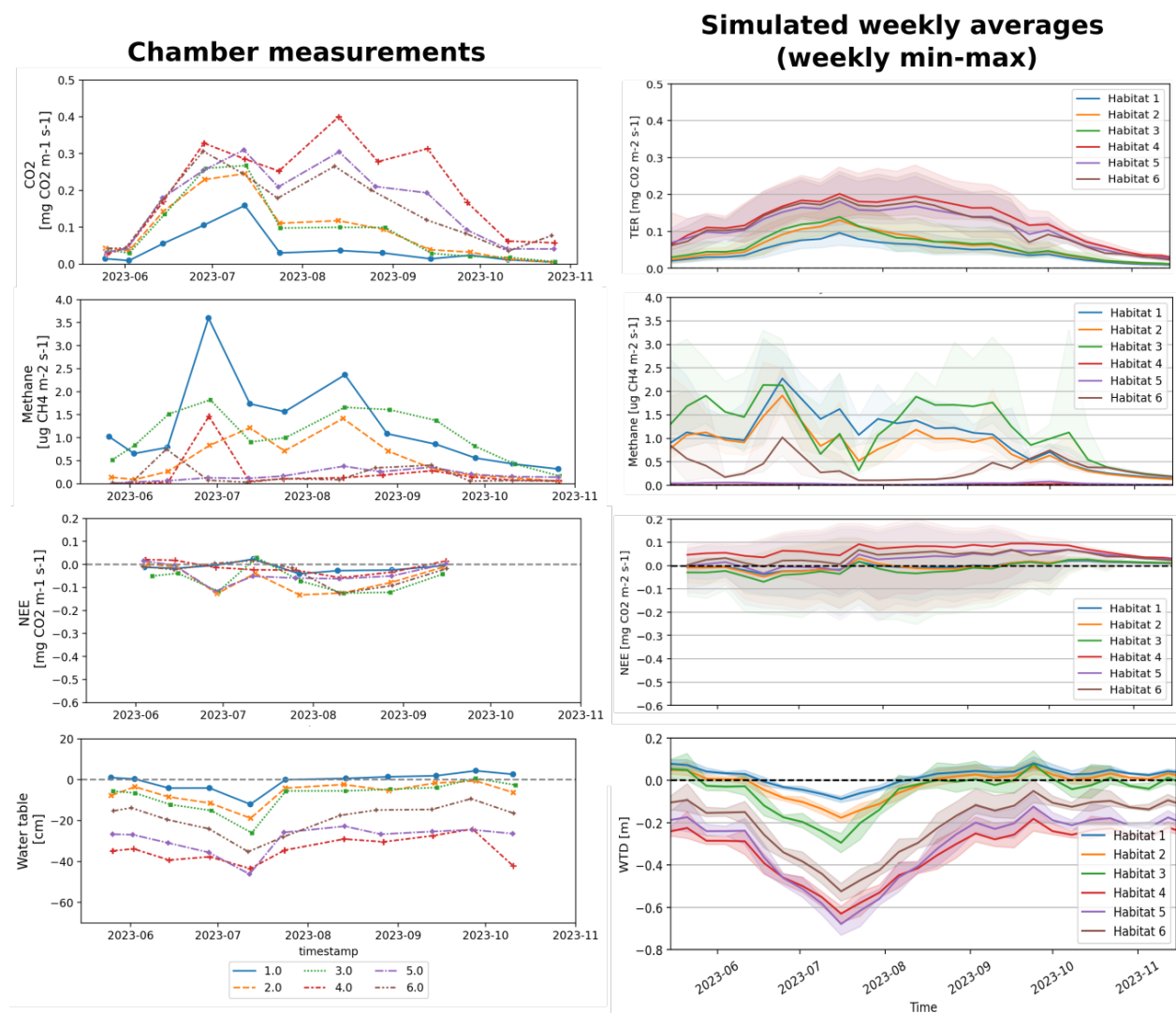
Fig.19 Spatial distributions of drained and undrained spruce mire forests, pine mire forests, open mires and flark fens.

9. Calibration of ecosystem model for peatland GHG emission estimations

In 2025, work continued developing the description of the peatland landscape in the JSBACH-HIMMELI ecosystem model. The model now includes a description of six new peatland specific plant functional types (PFTs): aerenchymatous plants (methane transport), sphagnum mosses, other mosses, bare peat, evergreen shrubs and deciduous shrubs. The calibration of the new PFTs is based on vegetation analyses from the project sites, Matorovansuo and Välisuo, before the restoration. As described earlier, the vegetation plots have been clustered into six distinct peatland habitats based on the differences in vegetation distributions (see Sec. 3). The habitats display divergence in

measured water table levels (in relation to the moss surface), and species coverages. These differences were mirrored in the ecosystem model set-ups to predict the spatial variability of greenhouse gas fluxes in the mire ecosystem. Understanding the greenhouse gas dynamics of each habitat is important for improving the predictive capabilities of the model when considering the restoration of the mires and the expected changes in the habitat distributions.

The model output has now been calibrated against CO₂ and CH₄ chamber measurements from 51 chambers together with water table depths from the same locations (Fig. 20). The model can reproduce the differences in CO₂ (heterotrophic respiration + autotrophic respiration from ground vegetation) and CH₄ fluxes across the habitats based on species coverage and water table data. Although, some parameters still need to be adjusted.



Fig

Fig. 20 Measured chamber and simulated methane fluxes, respiration from ground (TER/CO₂), net ecosystem exchange (NEE), and water table depth across the peatland habitats 1-6.

Further in 2025, we have upscaled the habitat level fluxes to peatland landscape carbon budgets. To accomplish this, we calibrated the model output against ecosystem-level CO₂ fluxes from the eddy covariance tower at Matorovansuo. This was done by integrating the maps representing the habitat distribution over the mire (Fig. 18) with JSBACH-HIMMELI outputs. We compared model output with

eddy covariance fluxes based on wind direction and the associated share of habitats in each direction. Wind directions were grouped into four categories with a similar distribution of habitats to ensure a reasonable number of measurements in each group. (Fig. 21). This calibration is also performed with the flux data prior to the restoration (year 2023), so the ecosystem level fluxes (simulated and measured) include the carbon uptake by tree biomass, that is excluded from the calibration against the chamber measurements.

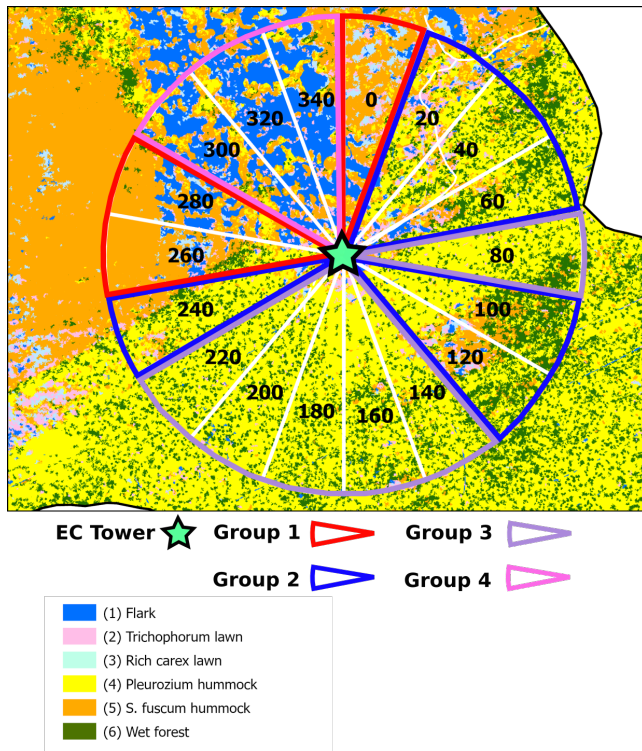


Fig 21 The map of peatland habitats in the vicinity of the eddy covariance tower. Groups 1-4 present different wind directions with similar habitat coverages.

The model slightly overestimates the carbon uptake from the trees (Fig. 22-23) and the simulated early summer sink capacity seems to be larger than measurements suggest. Otherwise, the dynamics of net ecosystem exchange (NEE) over the growing season are reasonable, and the magnitudes align across the wind direction groups with the observed ecosystem CO₂ fluxes.

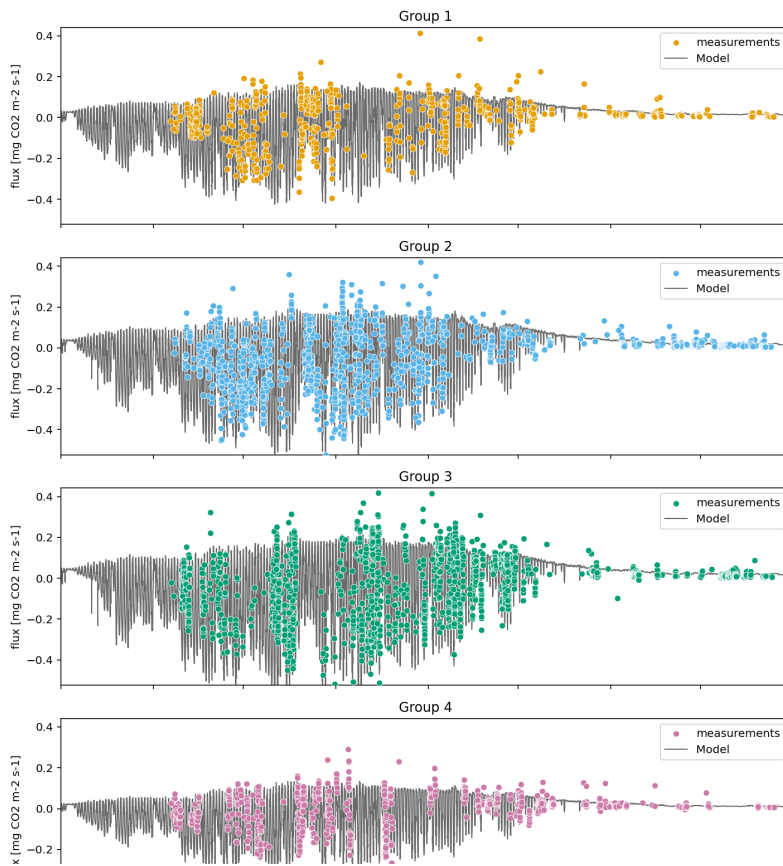


Fig 22. Modelled and measured (eddy covariance) net ecosystem exchange time series across the wind direction groups 1-4.

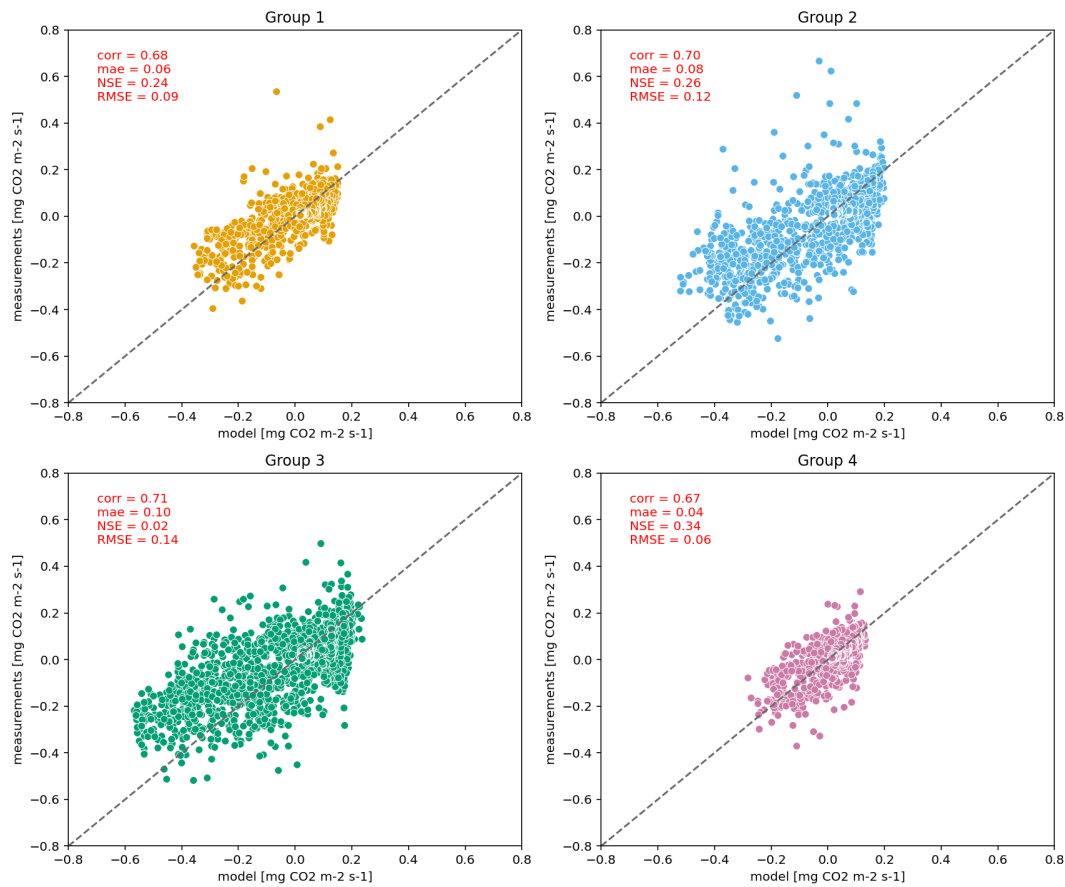


Fig 23. Performance metrics of simulated net ecosystem exchange against the eddy covariance measurements across the wind direction groups 1-4.

10. Communication and Dissemination Activities

Meetings and photo exhibition

LIFE PeatCarbon PMT V project meeting was held in Helsinki in 10–12 June 2025. The meeting was organized at the Finnish Meteorological Institute, with 35 participants, including Invited Guest Lecture by Igors Semjonovs 'Peatland restoration and carbon crediting: experiences in Latvia' for FMI personnel (~50 researchers at site and remotely). After the meeting a one-day field trip was made to restoration sites near Helsinki (Rottasniitunsuo and Tervalamminsuo), and a small team of Latvian and Finnish researchers continued to Pallas for vegetation analyses and GHG measurements.

LIFE PeatCarbon Photo exhibition was opened in Helsinki on June 10, 2025. The project researchers collected 156 photos of peatlands in Latvia, Finland and Denmark (see Fig. 24). These include previously restored peatlands and peatland habitats that are currently being restored and are the subject of ongoing research. The photos captured the unique beauty and diversity of the flora and fauna of peatland ecosystems. The photo exhibition was under display in FMI building in Helsinki in 10–30 June 2025 and was later moved to University of Oulu. At the same time, it is travelling in Latvia.

Finnish LIFE PeatCarbon team members attended multiple relevant conferences, e.g. Scientific meeting of Finnish environmental infrastructures (ACTRIS, AnaEE, eLTER & ICOS), April 2025, and Intecol Wetlands conference, Tartu, July 2025, and visited MPI Hamburg for JSBACH ecosystem model development, July 2025, and had several remote meetings with Vrije Universiteit Amsterdam (Tanya Lippmann) regarding peatland model development.





Fig. 24 Left: LIFE Peat Carbon photo exhibition at FMI, right: Igors Semjonovs presenting carbon crediting concept at FMI, Field trip in Tervalamminsuo

Collaboration with inventory makers

Throughout 2025, Finnish research institutions and national inventory authorities strengthened cooperation to support the country's greenhouse gas (GHG) reporting, with a particular focus on the LULUCF sector. The first expert seminar was held on 14 April 2025 at the Finnish Meteorological Institute in Helsinki. Researchers from the Finnish Meteorological Institute and Natural Resources Institute Finland (LUKE) met with national greenhouse gas inventory compilers from Statistics Finland and LUKE. Participants reviewed the methodology of Finland's national GHG inventory, including LULUCF emission estimations, and discussed modelling and top-down approaches in search for synergies and collaboration. The dialogue continued 4 December 2025 at the University of Helsinki/HIKET meeting, where experts placed special emphasis on peatland emissions — a key component of Finland's land-use sector. Researchers and inventory compilers examined current estimation methods and explored ways to reduce uncertainties through improved modelling and data integration. Collaboration will be extended into 2026 with a remote expert meeting on 20 January, bringing together researchers from FMI and LUKE with national inventory specialists. Discussions focused on refining LULUCF methodologies and defining concrete next steps for continued cooperation.



Fig. 24 Jukka-Pekka Myllykangas from LUKE National Inventory compilers' team talking about organic soils in the inventory on Dec 4th, 2025.

UNESCO Ecohydrology Demosite Designation

The Matorovansuo peatland restoration site has been designated as a UNESCO Ecohydrology Demosite, recognizing it as an example of solution-oriented research applying ecohydrological principles to address environmental and societal challenges. As part of the UNESCO Ecohydrology Network, the site serves as an international reference for nature-based climate solutions, integrating hydrological restoration with greenhouse gas mitigation and ecosystem recovery. The designation will be supported by UNESCO-led promotional activities, including regional and global events, to disseminate the project's research outcomes and restoration practices to broader scientific, policy, and stakeholder communities.

11. Conclusions

The monitoring data collected during the pre-restoration has been combined with the data collected during and immediately after the restoration. The preliminary analyses and habitat type classification, model calibrations and simulations set us in a good position to continue monitoring and to perform the regional assessment. Long enough monitoring periods are needed for proper assessment of the initial restoration effects. We will continue monitoring during the year 2026

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Appendix information

Plot and species data are appended as an excel file *SpeciesData_Välisuo&Matorovansuo2023*