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

## 2nd Monitoring Report, Finland

LIFE PeatCarbon

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## Summary

The objective of the LIFE PeatCarbon project is to restore 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, return the open aapa mire habitats, and the peatland functionality in terms carbon sequestration. The estimated greenhouse gas (GHG) reduction achieved by the restoration is 3500 tons $CO_2$ eq. $Y^{-1}$ in the Finnish sites. The monitoring, conducted before and after the restoration measures, 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. In Finland two forestry drained peatland 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, sets of GHG monitoring plots, water table level monitoring wells in the nondrained and drained sections of the peatlands together with drone images before and after restoration to assess habitat type distribution. In addition, there is a drained reference plot in a non-restored drained peatland forest downslope from Välisuo. The monitoring was started in fall 2022. Thus, the conditions at the site were representative for pre-restoration in summer 2023, impacted by on-going restoration work in summer 2024, and first wide-scale post-restoration impacts are expected to be observable only in summer 2025. 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 signs of rising water levels. Pre-restoration data showed that $CH_4$ 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. Microbial data showed that there was methanogenic activity was present in all the habitats, but it was smallest in the drained habitats. Preliminary estimates of the annual $CO_2$ balance (Jul 1st, 2023–Jun 30th, 2024) showed that the drained peatland forest was a $CO_2$ sink (about 64 g C $m^{-2}y^{-1}$) while the undrained sector had near zero $CO_2$ balance. Vegetation analyses and remote sensing imagery from multiple sources were used to map the habitat distributions in the pre-restored sites. Preliminary ecosystem model results demonstrated the model's ability to accurately simulate GHG fluxes at site levels when calibrated with diverse datasets. Remote sensing analyses will be further used in upscaling and model simulations.

## Restoration sites in Finland

The Finnish sites, Välisuo and Matorovansuo peatlands, are meso-eutrophic fens where the pine fen margins have been drained for forestry in 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 probably the northernmost peatland restoration sites. As typical for the northern boreal Finland, the peatlands are aapa mires, i.e. minerotrophic fens. The peatlands are, as typical, sloping and 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).

The central and wettest parts of the peatlands were not drained per se, but the ditches surrounding the entire peatlands have affected the hydrology causing vegetation changes, such as increased shrub absence in Välisuo. Thus, parts of the peatlands were well drained and turned into peatland forests (from now on, *drained*), while other parts of the peatlands were affected, but remained open resembling still natural peatlands (from now on, *undrained*).

The sites have been actively monitored since fall 2022, and the period until July 2024 represents the pre-restoration situation. The study set-up includes a systematic grid of vegetation inventory points, sets of GHG monitoring plots, water table level monitoring wells in the nondrained and drained sections of the peatlands together with drone images before and after restoration to assess habitat type distribution. In addition, there is a drained reference plot in a non-restored drained peatland forest downslope from Välisuo. 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.

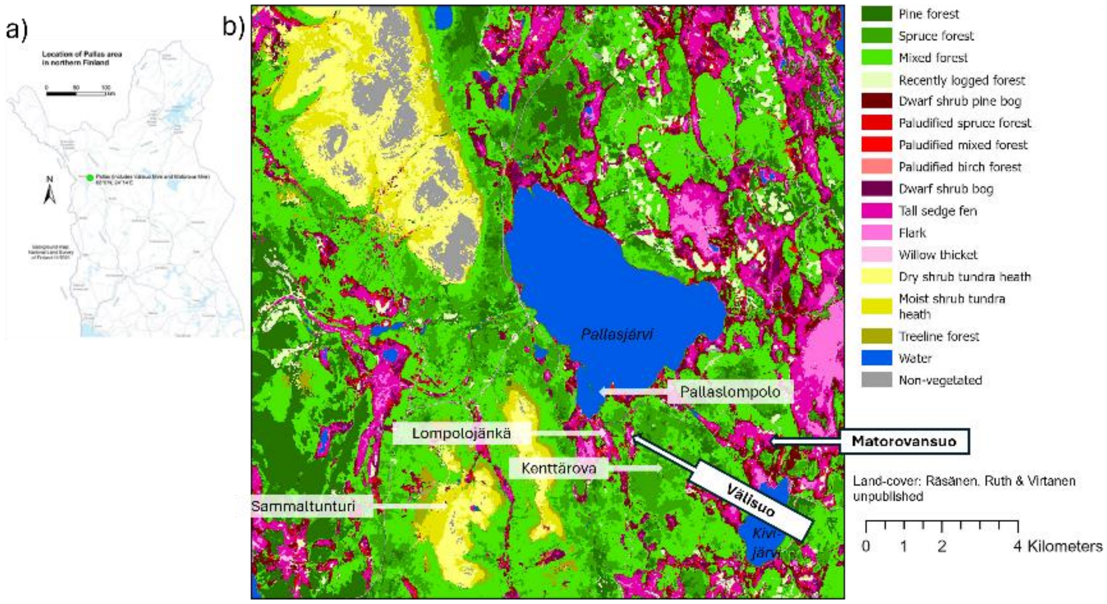

***Fig. 1.*** *a) LIFE PeatCarbon restoration sites in northern Finland (68°N, 24'14°E). b) Locations of Välisuo and Matorovansuo peatlands in Pallas Research Area. The backround map shows land-cover classification by Räsänen et al. (unpubl.). FMI has micrometeorolocal stations for long-term $CO_2$ and $CH_4$ flux measurements in alpine tundra (Sammaltunturi, ICOS, GAW station), peatland (Lompolojänkä, ICOS), lake (Pallaslompolo, ICOS), and spruce forest (Kenttärova, ICOS) ecosystems.*

## Ecological Restoration (WP 2, task 2.4)

As planned, the Välisuo and Matorovansuo were restored in spring–summer 2024 (fig. 2). Thus, the conditions at the site were representative for pre-restoration in summer 2023, impacted by on-going restoration work in summer 2024, and first wide-scale post-restoration impacts are expected to be observable only in summer 2025. The restoration included harvesting tree biomass to mimic the original tree density and damming ditches, using wooden dams and combination of the harvested trunks and peat, to enable water table to rise (see the *Restoration Plan D1.1*). The restoration activities were executed by Metsähallitus, authority that has conducted peatland restoration in many protected areas in Finland. The restoration started with tree harvest in the winter when the peat was frozen and covered with snowpack and manual work continued during summer. Harvesting resulted in tree biomass mimicking the original tree density of 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). After snow melt and retreat of spring floods in early July, the ditch damming started. Both peat dams and a combination of the harvested trunks and peat were built in both sites, 81 in Matorovansuo and 15 in Välisuo (Fig. 3). Early signs of water table rise were observed during autumn (please see section on *Hydrology Monitoring*). The ditch damming was finished by the end of July, leaving the most active summer months under disturbance by restoration work. However, measurements were continued also during and right after this period. The original peatland vegetation is largely present in both sites which will benefit the vegetation succession after the restoration.

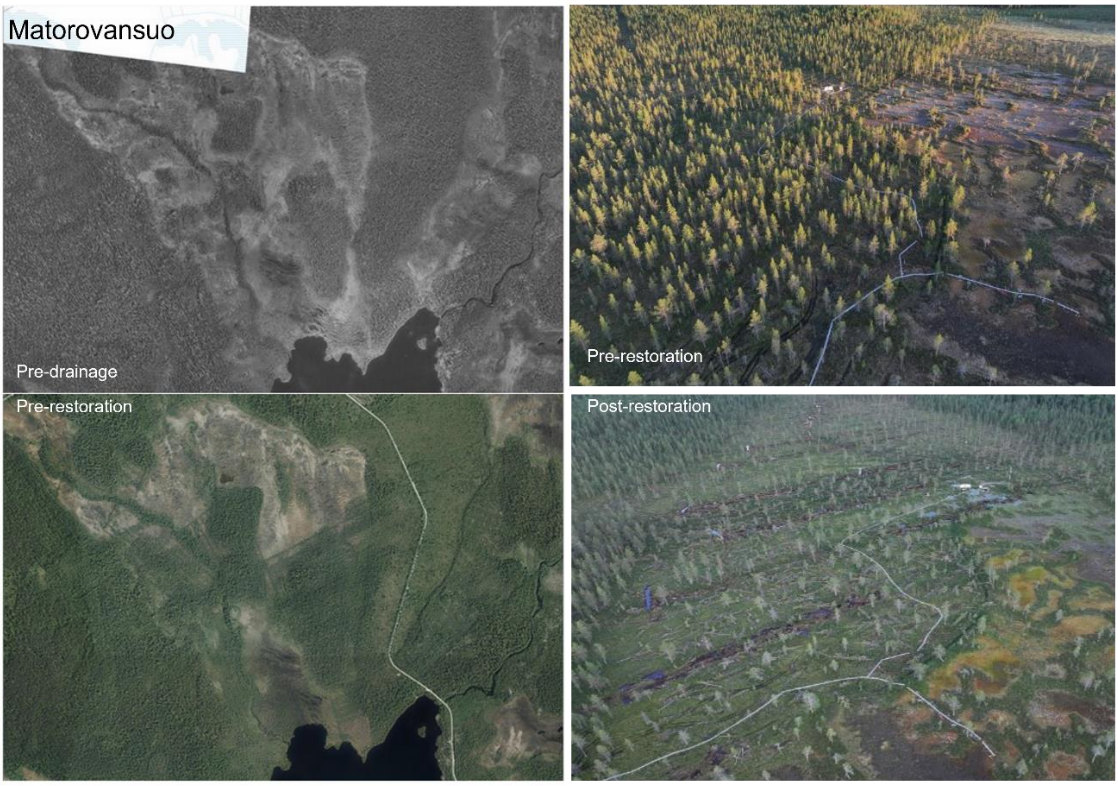

**Fig. 2.** *Left) Aerial images of Matorovansuo before (1950s) and after drainage (national Land Survey of Finland). Right) Drone images before and after the restoration in 2024. Boardwalks, along which the GHG monitoring plots locate, and the eddy covariance station (white backsides of the solar panels)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

**Fig. 3.** *Ecological restoration included harvests of tree biomass, to return the open peatland and decrease evapotranspiration, and rewetting by blocking the ditches. Much of the harvested biomass was left on the site. Left) This Scots pine started its growth in a pristine peatland. Middle and right) pine trunks were laid into ditches and, in part, covered by peat (Sari Juutinen).*

## Vegetation monitoring to follow the effect of peatland rewetting (WP 3 task 3.2)

In July 2023, we established 205 permanent vegetation monitoring points and conducted the pre-restoration vegetation inventory (Fig. 4a). Inventory also included the permanent GHG measurement points. In each point %-cover of plant species and water level were measured. 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 2026.

The vegetation data (ground vegetation) were analyzed to define ecologically relevant habitat types in the Välisuo and Matorovansuo peatlands (Fig. 4b). 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, mudbottom flarks, *Sphagnum lidbergii* lawns, *Carex magellanica* lawns, *Trichophorum* lawns, in the other end.

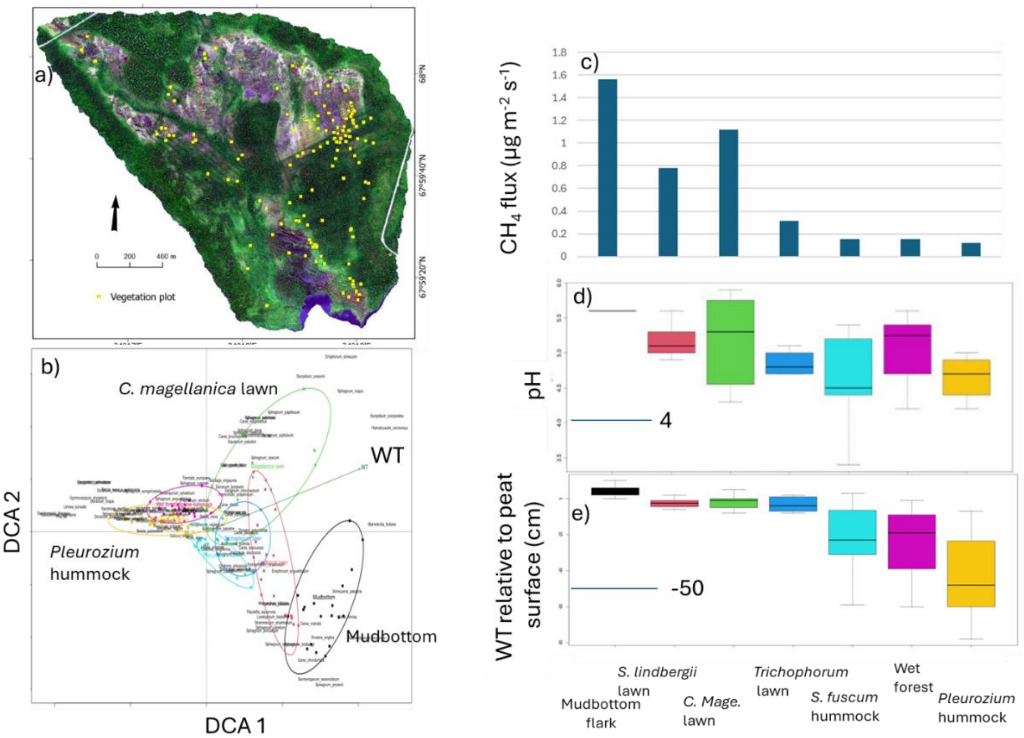

***Fig. 4.*** *a) The location of vegetation inventory plots in the Matorovansuo peatland, laid over the multispectral drone image collected concurrently with the vegetation inventory in 2023. b) Detrended correspondence ordination (DCA) plot of species and sample points. Habitat types from the cluster analysis are indicated. Water level (WT) increases (wetter) in the direction of the arrow. Mean snow-free season c)* $CH_4$ *fluxes, d) pH, and e) water level relative to ground surface in the habitats. Wet forest and Pleurozium hummock were drained habitats with Scots pine overstory.*

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 (Fig. 5). 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.

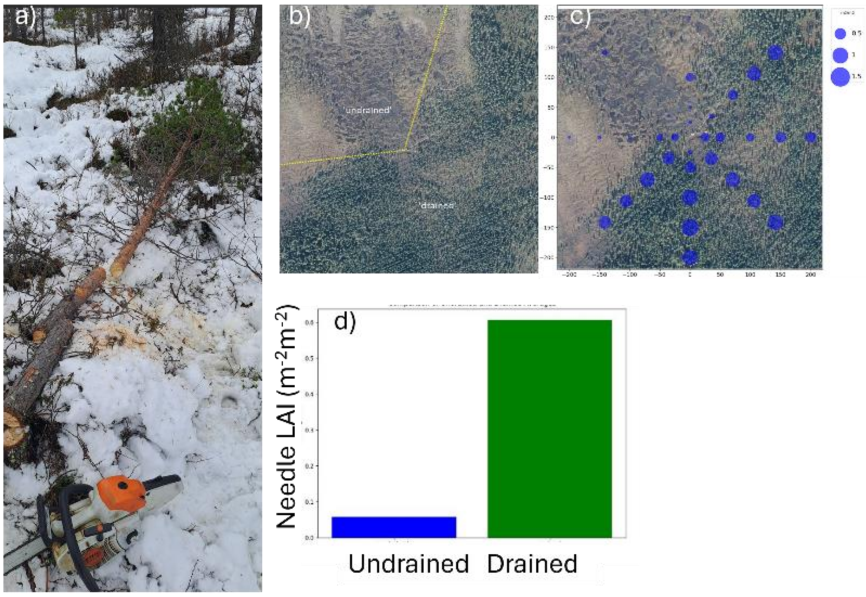

***Fig 5.*** *Pine needle leaf area index (LAI) was estimated for the drained and undrained sectors in the EC source area. a) Data of needle mass and LAI were collected from a sample of trees to build empirical relationships between bhd and needle LAI. Estimates of average pine needle LAI in c) each tree plot and d) average LAI in the undrained and drained sectors before the restoration.*

## Hydrology Monitoring (WP 3, task 3.3)

The hydrological monitoring started in November 2022 when the first piezometers were installed in Välisuo and Matorovasuo. Additional piezometers were installed in summer 2023 and at the beginning of May 2024. Now, there are monitored in a total of 94 monitoring locations that include (1) short open-bottom piezometers to track peatland water table within GHG monitoring and in vegetation inventory plots in 80 locations and (2) long piezometers to monitor hydraulic heads in deeper peat and underlying mineral soil to reveal groundwater flow directions (in 14 locations) (Fig. 6, Table 1).

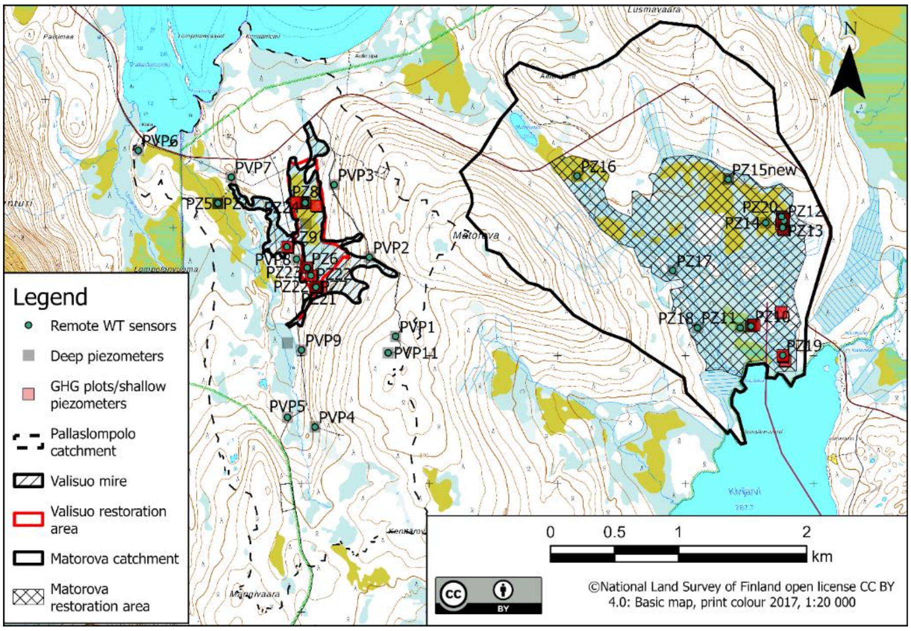

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***Fig 6.*** *Map of WT monitoring points.*

All longer piezometers accommodate Decentlab PR-26 sensors that transmit data at 15-minute intervals using LoraWan technology. Water tables are measured manually in all short piezometers, and 6 of those also accommodate Decentlab PR-26 sensors. The water quality of all short piezometers is regularly sampled during the GHGs manual monitoring (pH, $O_2$, T, EC) and samples analysed to identify changes in dissolved organic matter content.

In September 2024, the monitoring points accommodating continuous WT sensors were located with high-precision GPS (Trimble Inc.) and the water table was measured manually to transform the sensor data into reference levels of meters above sea water level. Hydrological water table monitoring will continue in 2025, and it will include a manual GW monitoring campaign for all the sensors to ensure quality of the remote sensors.

***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) | Screen 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 |
| Lompolojankka | PZ5 | 270.77 | 3.39 | 1 | 1.14 | 3.25 | 271.9 | 267.52 | 4.39 |
| Valisuo | PZ6 | 288.43 | 1.14 | 1 | 1.08 | 1.07 | 289.51 | 287.36 | 2.15 |
| Valisuo | PZ7 | 289.49 | 1.82 | 1 | 1.05 | 1.78 | 290.54 | 287.72 | 2.83 |
| Valisuo | PZ8 | 284.88 | 3.74 | 1 | 1.38 | 3.37 | 286.26 | 281.52 | 4.75 |
| Valisuo | PZ9 | 282.05 | NA | 0 | 0.1 | 0.65 | 282.15 | 281.40 | 0.75 |
| Matorovasuo | PZ10 | 269.71 | 1.01 | 1 | 1 | 1.02 | 270.71 | 268.70 | 2.02 |
| Matorovasuo | PZ11 | 269.50 | 2 | 1 | 0.97 | 2.04 | 270.47 | 267.47 | 3.01 |
| Matorovasuo | PZ12 | 274.95 | 1.04 | 1 | 1.05 | 1 | 276.00 | 273.96 | 2.05 |
| Matorovasuo | PZ13 | 274.86 | 1.48 | 1 | 1.01 | 1.48 | 275.87 | 273.39 | 2.49 |
| Matorovasuo | PZ14 | 275.45 | 2.65 | 1 | 1.05 | 2.61 | 276.50 | 272.85 | 3.66 |
| Matorovasuo | PZ15new | 280.05 | 1.18 | 1 | 0.93 | 1.265 | 280.98 |  | 2.19 |
| Matorovasuo | PZ16 |  |  |  |  |  | 282.04 |  |  |
| Matorovasuo | PZ17 | 275.21 | 1.07 | 1 | 1.425 | 0.655 | 276.63 | 274.56 | 2.08 |
| Matorovasuo | PZ18 | 272.54 | 2.00 | 1 | 1.15 | 1.86 | 273.7 | 270.69 | 3.01 |
| Matorovasuo | PZ19 | 268.882 | NA | 0 | 0.045 | 0.455 | 268.927 | 268.427 | 0.5 |
| Matorovasuo | PZ20 | 275.33 | NA | 0 | 0.055 | 0.445 | 275.38 | 274.88 | 0.5 |
| Valisuo | PZ21** | 289.40 | NA | 0 | 0.11 | 0.64 | 289.51 | 288.76 | 0.75 |
| Valisuo | PZ22 | 288.86 | NA | 0 | 0.1 | 0.65 | 288.96 | 288.21 | 0.75 |
| Valisuo | PZ23 | 288.33 | NA | 0 | 0.09 | 0.45 | 288.42 | 287.88 | 0.54 |
| Valisuo | PZ24 | 284.99 | 2 | 1 | 1.1 | 1.91 | 286.09 | 283.08 | 3.01 |

*In additions 3 sensors installed but not mapped
**Sensor failed and needs replacement

Ground Penetrating Radar (GPR) surveys were conducted in May and June 2024 to complement data for hydrological studies (Fig. 7 and Fig. 8). Both surveys, in total, covered ~26.5 km of terrain and were analysed during the autumn of 2024. In addition, complementary measurements were collected to validate GPR data in June and collect additional geological information. These included two seismic refraction lines done (~200m) in the Pallaslompolo catchment (including Välisuo) and manual peat depth measurements in Matorovasuo. Manual peat depth probing was done in 73 locations across Matorovasuo to validate GPR. The GPR interpretations, including bedrock depths (Fig. 8), peat depths, and the identified presence of various soil types, clay/coarse soil, will be incorporated in both the Välisuo and Matorovasuo models.

**Fig. 7.** *Ground penetrating radar (GPR) survey was done in April 2024. The radar was pulled with a snow mobile to access non-traversable peatland sections.*

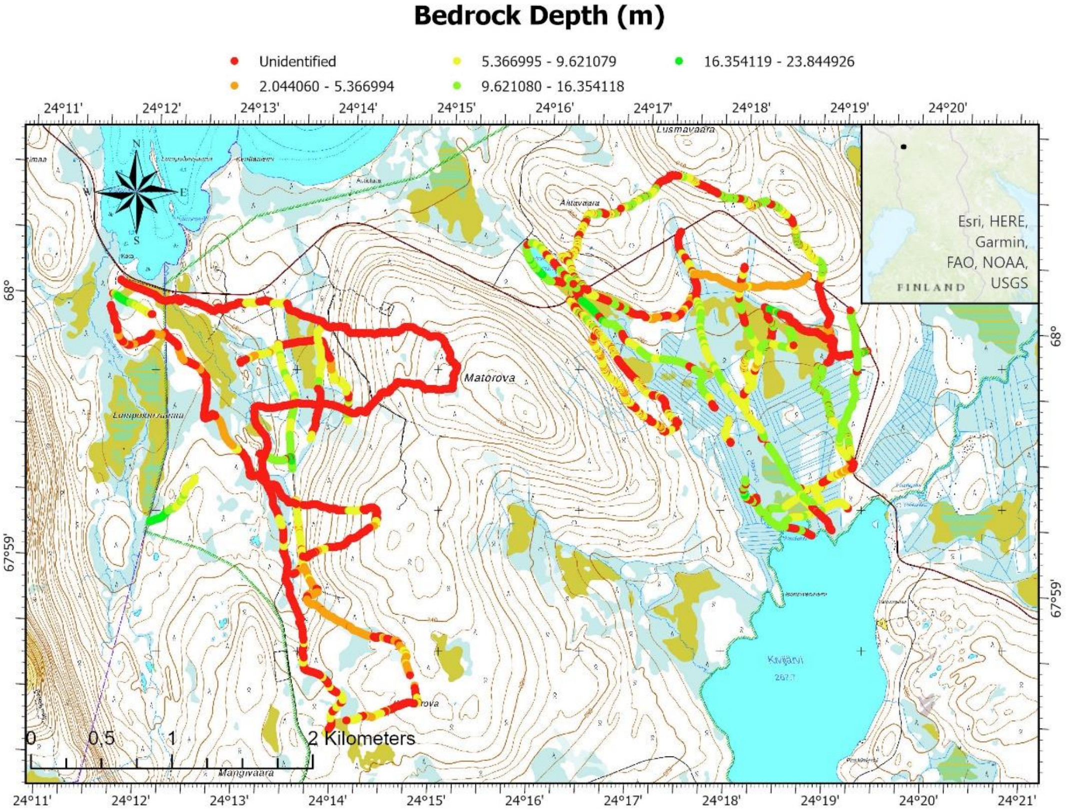


**Fig. 8.** *Preliminary map of bedrock depths identified with GPR.*

The water level monitoring between November 2022 and November 2024 allows us to establish a first “glance” at the impact of the restoration on hydrology. The preliminary analysis indicates that WT levels in well drained peatland areas experienced less drop during summertime in comparison to wetter undrained (less affected areas) in both peatlands.  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: what would be the water table in a particular location if restoration wouldn’t be done or if logging wouldn’t be done. We will test these questions more rigorously in 2025 after the incorporation of geological data and successful calibration of models for both restoration areas.

Several fully distributed, integrated hydrological model setups have been developed for Matorovansuo catchment using HydroGeoSphere (HGS). These models will be enhanced with geological data derived from recent GPR surveys and peat depth measurements (during 2024 campaigns) to create a detailed 3D subsurface grid. They are also driven by environmental forcings and climate data from 2021–2024, encompassing both pre- and post-restoration conditions. The models are designated to simulate the hydrological response of the catchment under various management scenarios, including pristine, drained, and restored conditions. They are currently being enhanced with a Hydraulic Mixing Cell solver to enable a fine-scale analysis of changes in surface saturation and in-stream runoff generation mechanisms at the cell scale. Furthermore, this modeling exercise explores the primary sources of in-stream water across the catchment, addressing critical questions about how and where water enters the stream, and how drainage and restoration practices influence the catchment's internal hydrological processes. The previously built and calibrated Välisuo model was enhanced with improved mesh and tested for computing efficiency.

## Monitoring climatic impacts on peatlands before and after rewetting (WP 3, task 3.4)

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. 9). The set-up includes 17 plots, each having 3 measurement points with intact vegetation (n=51) and equipped with preinstalled collars (area 58 cm × 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).*

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. 9–10). 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 $CO_2$ exchange above the tree canopy, that is, including $CO_2$ 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. 9–10).

In all plots, GHG flux measurements started in fall 2022 and are continuing. Chamber measurements of $CO_2$, $CH_4$ and $N_2O$ 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 analyzers LI-7810 and 7820, which were paired and carried in a backpack. In addition, in 24 points, net ecosystem exchange of $CO_2$ (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 (PFFD). Water table location, soil and chamber temperature, and soil moisture were measured during each GHG measurement.

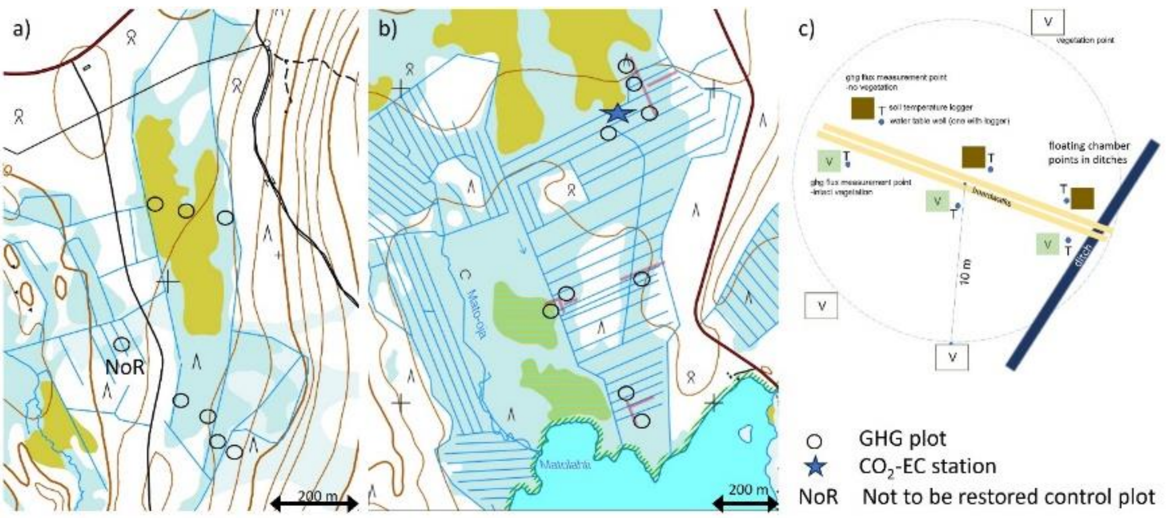


***Fig. 9.*** *Välisuo and Matorovansuo consists of drained and nondrained parts. Non-restored control plot locates in a peatland forest. Monitoring plot set-up for the chamber measurements of $CO_2$, $CH_4$, and $N_2O$ fluxes a) in Välisuo, b) Matorovansuo peatlands, and c) a schematic representation of a monitoring plot. Ditch plots(n=5) not marked. The location of the EC for measuring the net ecosystem exchange of $CO_2$ is shown on the map of Matorovansuo. Map National Land Survey of Finland 2023.*

***Fig. 10.*** *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.*

Our GHG monitoring data cover the pre-restoration period (fall 2022–summer 2024) and a short post-restoration period (Jul –Dec 2024). Monitoring will be continued during the year 2025, when the initial restoration responses can be evaluated. Data analyses on the climate impacts of drainage and restoration will be conducted after the monitoring period. The eddy covariance system measured ecosystem $CO_2$ exchange above the peatland forest canopy and captured the net $CO_2$ fluxes of soil, ground and tree vegetation (Fig. 11a–b).

In the 24 GHG measurement points measured for NEE and R using chamber method, true leaf-area index per species was determined (ICOS methodology) every two weeks over the snow-free season. 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 analyze and model GHG exchange (gap-filling models) and these data are provided for the modeling task (*task 3.8–3.9*) for the plant functional type distribution parametrization. In addition, we have collected peat and biomass data and estimated above-and below-ground biomass. These data will be processed after the monitoring period, because we need the estimates of biomass after the restoration.

Across both peatlands, pre-restoration methane fluxes were highest in the wettest undrained habitats (mudbottom flark, *Sphagnum lindbergii* lawn) and in undrained open peatlands (*Carex magellanica* lawns). Methane fluxes were smallest in the well drained forested habitats (*Pleurozium* hummocks, wet forests) and in the *Sphagnum fuscum* habitats in high strings of the undrained peatland (Fig. 4c–e). Due to the water table rise, $CH_4$ emissions are likely to increase the driest communities after the restoration. Fluxes of $N_2O$ were negligible during the pre-restoration period. GHG flux monitoring will be continued in the year 2025 and full assessment of the restoration effects will be conducted after the monitoring period.

Summer 2024 was warm and long and less cloudy than the previous summer 2023 (Fig. 11c). Water level data from the drained forest indicated that the water level was somewhat closer to the ground surface after the restoration in July 2024 (about 10–20 cm below the ground) than in pre-restoration July 2023 (about 20–30 cm below the ground, Fig. 11d). There was a trend of higher WT also in late autumn in 2024 compared to the year 2023 (see section *Hydrological Monitoring* for peatland-level hydrological status).

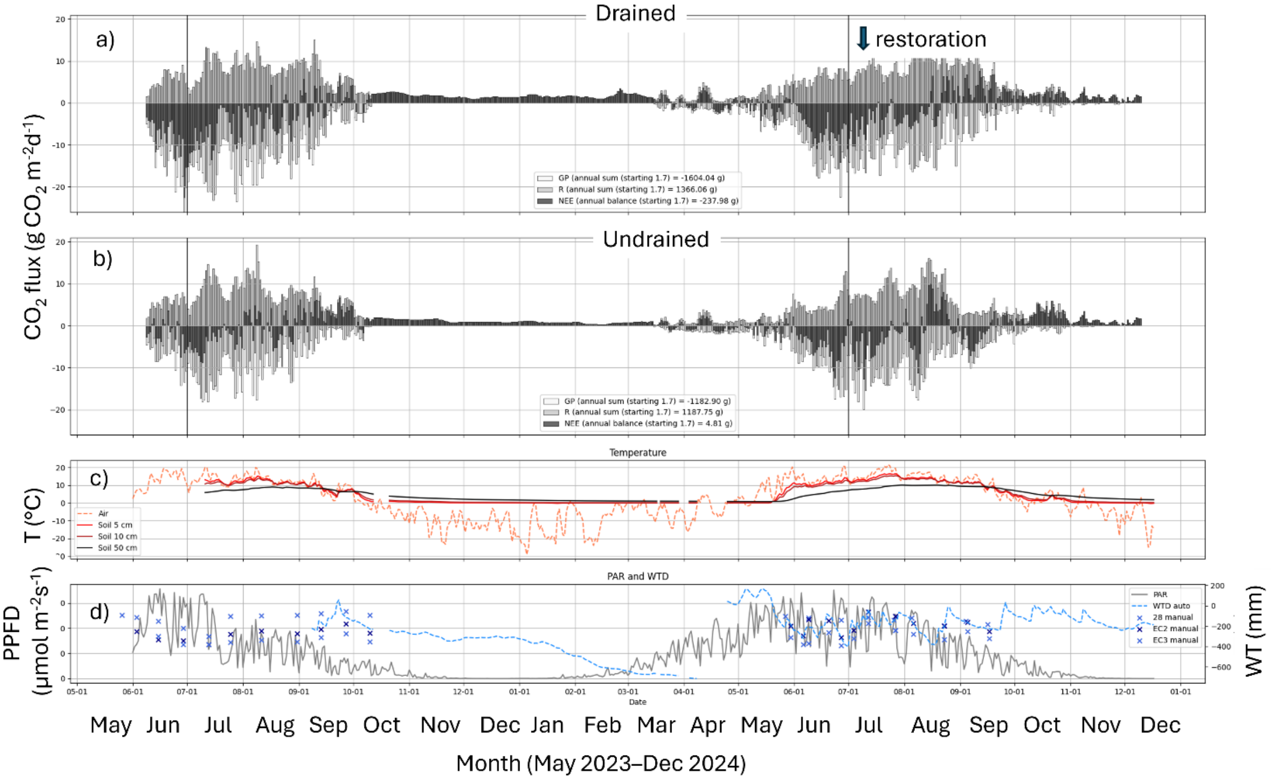


***Fig. 11.*** *Eddy covariance results of daily $CO_2$ exchange in Matorovansuo from June 2023 to December 2024 a) in drained (peatland forest) and b) nondrained (open, less affected) peatlands. Shades of grey distinguish the flux components: gross photosynthesis (GP, negative sign), ecosystem respiration (R, positive sign), and net ecosystem exchange (NEE, negative sign indicates ecosystem uptake of $CO_2$ and positive sign indicates release of $CO_2$ to the atmosphere). c-d) Air and soil temperature and water table depth logged near the EC mast (dried peatland).*

Preliminary estimates of the annual $CO_2$ balance (Jul 1st, 2023–Jun 30th, 2024) showed that the drained peatland forest was a $CO_2$ sink (about 64 g C $m^{-2}y^{-1}$) while the undrained sector had near zero $CO_2$ balance. Both the carbon uptake (GP) and losses as ecosystem respiration (R) were larger in the drained peatland forest than in the undrained peatland. In order to examine the effect of the restoration on ecosystem $CO_2$ exchange, we compared the drained and undrained sectors during the period of July-September in years 2023 and 2024 (Fig. 12). The comparison showed that before the restoration in 2023, the drained peatland forest was notably larger C sink (81 g C $m^{-2}$ $period^{-1}$) than the nondrained peatland (3 g C $m^{-2}period^{-1}$). After the restoration, in turn, the undrained peatland was larger C sink (31 g C $m^{-2}$ $period^{-1}$) than the drained peatland (19 g C $m^{-2}$ $period^{-1}$).

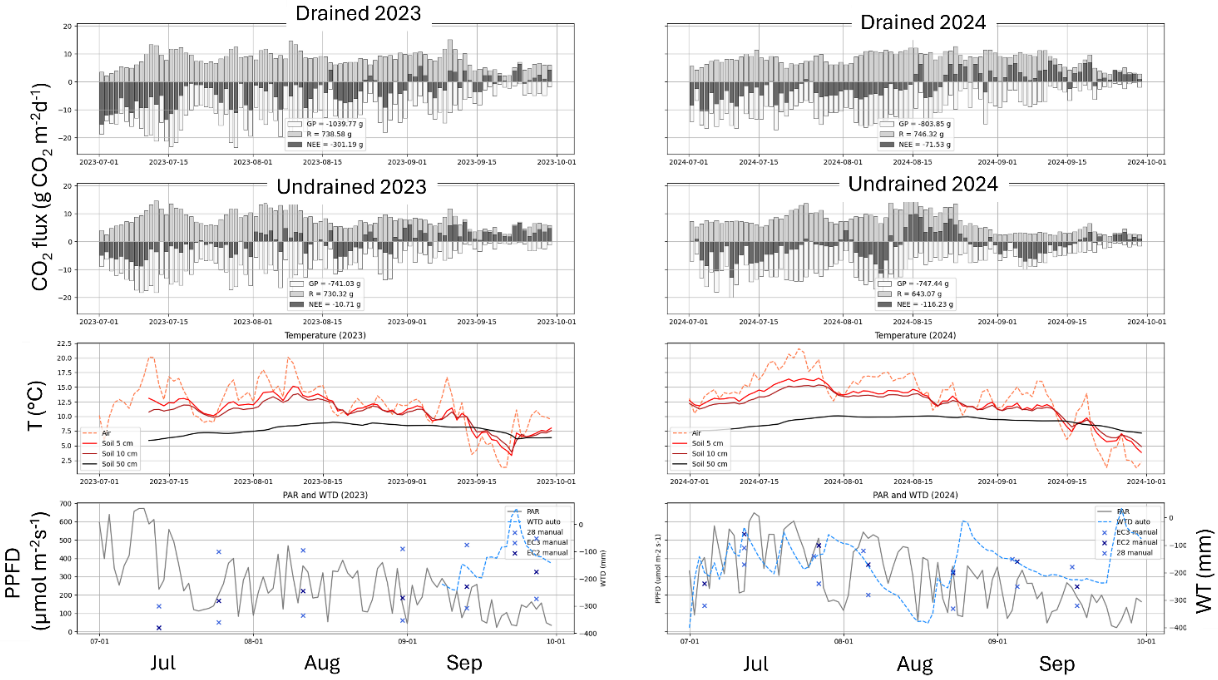


***Fig. 12.*** *Comparison of daily $CO_2$ exchange in drained and undrained sectors in July–September period before (left) and after (right) the restoration. Shades of grey distinguish the flux components: gross photosynthesis (GP, negative sign), ecosystem respiration (R, positive sign), and net ecosystem exchange (NEE, negative sign indicates ecosystem uptake of $CO_2$ and positive sign indicates release of $CO_2$ to the atmosphere). Air and soil temperature and water table depth in the lowest panels.*

The change in NEE of the drained sector was mainly due to decrease in ecosystem gross photosynthesis (GP), because ecosystem respiration (R) rates were about the same in both years. Logically, GP decreased due to the tree harvest as part of the restoration because pine needle LAI contributing to the ecosystem photosynthesis decreased (Fig. 12). Presumably, a small increase in water level and thinner oxic peat layer compensated for increases in decomposition (R) resulted by increased litter mass availability (dead roots, harvest residue).  In the undrained sector, in contrast, ecosystem GP was about the same in both years (vegetation was not manipulated), but R was larger before the restoration than after the restoration (Fig. 12). The latter can be due to a small rise in water level. It is noteworthy that the harvested tree biomass was left on the site in the EC source area, i.e. short-term carbon pool remained the same. These monitoring analyses are preliminary. Besides restoration measures, $CO_2$ exchange is very responsive to variation in vegetation, temperature, irradiation, water availability, and vapor pressure deficiency and thus a more thorough data analysis and gap-filling modeling will be performed after the last monitoring year.

## Microbial community composition and activity monitoring (WP 3, Task 3.6)

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). Samples were collected from approximately 10 cm depth with sterile instruments and stored in dry ice immediately (Fig. 13). DNA and RNA extractions took place at Luke laboratories. DNA was sequenced from June 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. Initial results indicate methanogenic potential in all sites but activity more in undrained, water saturated sites (Fig. 4). However, the activity of methane oxidation genes was present and active in most of the sites.

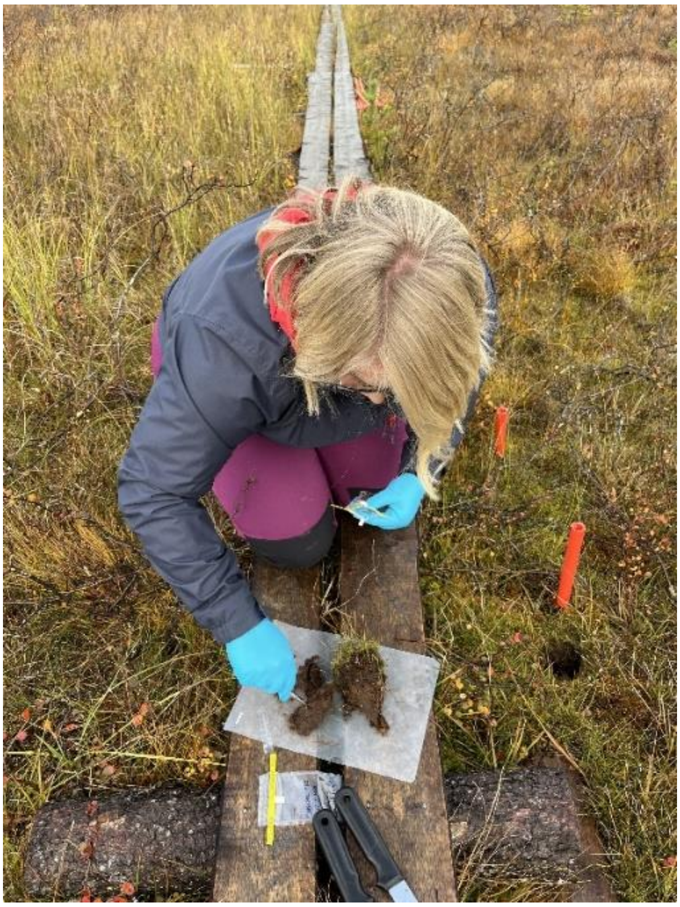


***Fig 13**. Sampling for microbiology monitoring. Samples were collected from peat cores aseptically and deep frozen immediately. The further processing took place in Helsinki, Finland.*

## Remote Sensing (WP 3, task 3.7)

Using the vegetation data collected in 2023 (Fig. 4a–b, appendix), we conducted preliminary analyses on vegetation communities (habitats) and used it for mapping the habitat distributions in

Välisuo and Matorovansuo. These will be needed for process modeling (WP2) and to upscale the observational GHG data for the entire peatlands, which will take place at the end of the monitoring period. First, the plots were clustered based on the species abundance (%-cover). Ward’s method, based on Bray Curtis dissimilarity was used. The resulting habitat types were both ecologically meaningful and relevant for GHG upscaling (Fig. 4c–d). The GHG monitoring points were distributed to these habitat classes, meaning that our GHG point sample is representative.

Second, these classes were upscaled to a categorical map using captured drone imagery and aerial imagery of National Land Survey of Finland. The upscaling was conducted with object-based-image-analysis which included mean-shift segmentation and random forest classification. The overall accuracy was around 70%, even though there were few classes with smaller classification accuracy. The spatial distribution of the upscaled habitat classes was reasonable (Fig. 14). Moreover, first post-restoration drone flights were conducted in early August 2024, a few weeks after the completion of restoration activities. In 2025 we will update our habitat mapping, conduct GEST-type classifications (Jarašius et al. 2022) for pre-restoration habitats, and process the 2024 drone data. We will also start nationwide peatland type classification for the model simulations of peatland GHG fluxes.

We conducted preliminary remote sensing analyses on peatland surface wetness. We used water table depth data from July 2023 together with drone and satellite imagery. First, we tested how drone bands, and different spectral, thermal, and topographical indices correlate with the water table depth in open peatland area (Fig. 15). Second, we tested and developed downscaling methodology of coarse resolution OPTRAM-that could be used as high-resolution proxy for surface wetness (Fig. 16). In 2025, we will continue our analyses further and include machine and deep learning methods to spatial water table depth monitoring also including treed areas.

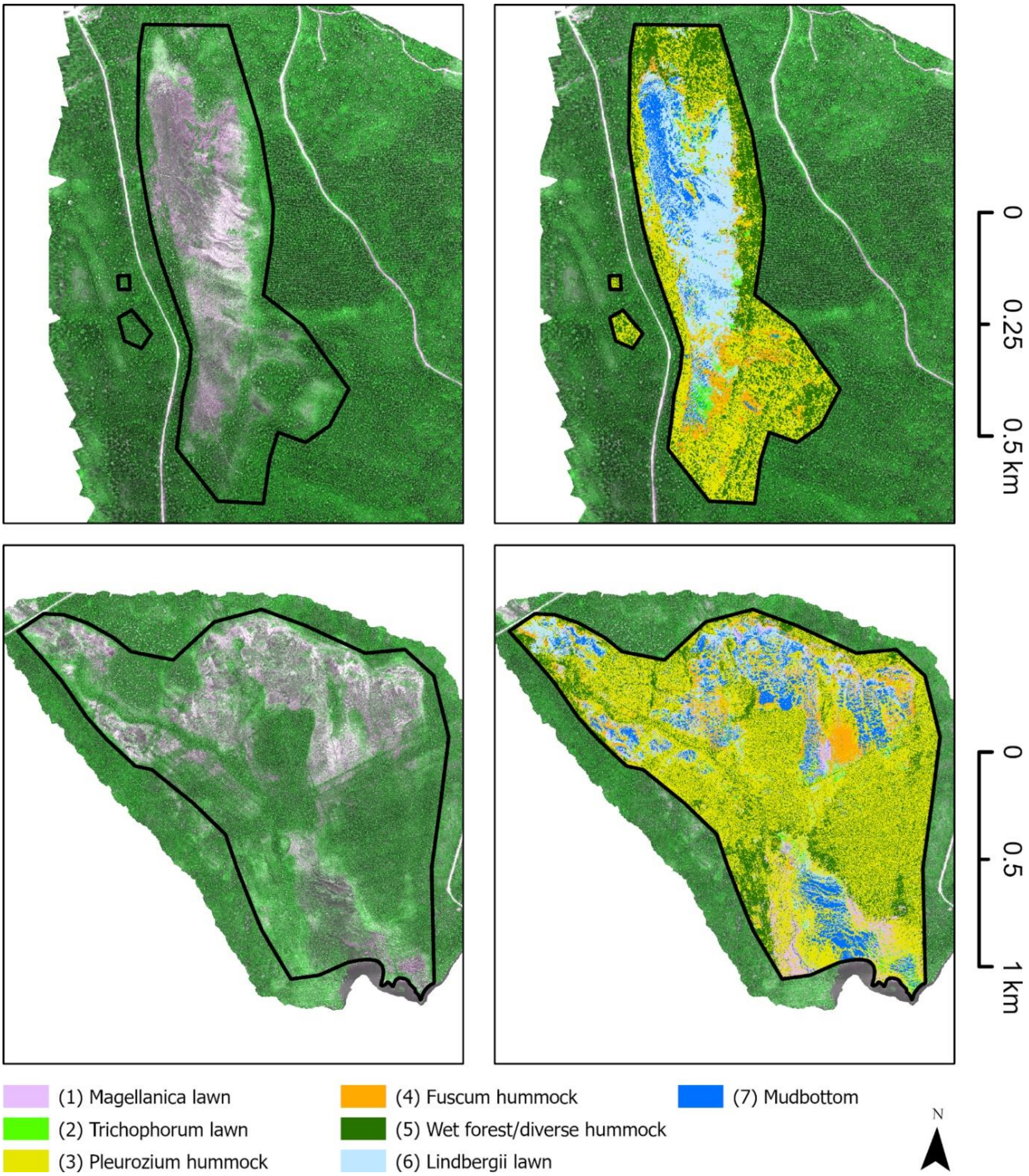


***Fig. 14.*** *Left) Delineation of Välisuo (top) including the reference area and Matorovansuo (bottom) peatland upscaling areas, laid over drone images. Right) Preliminary habitat type maps of Välisuo (top) and Matorovansuo (below). The habitat types "Pleurozium hummock" and "Wet forest/diverse hummocks") were forested habitats before the restoration. Habitat type "Trichophorum lawn" occurs in affected peatland at the edges of drained peatland forests.*

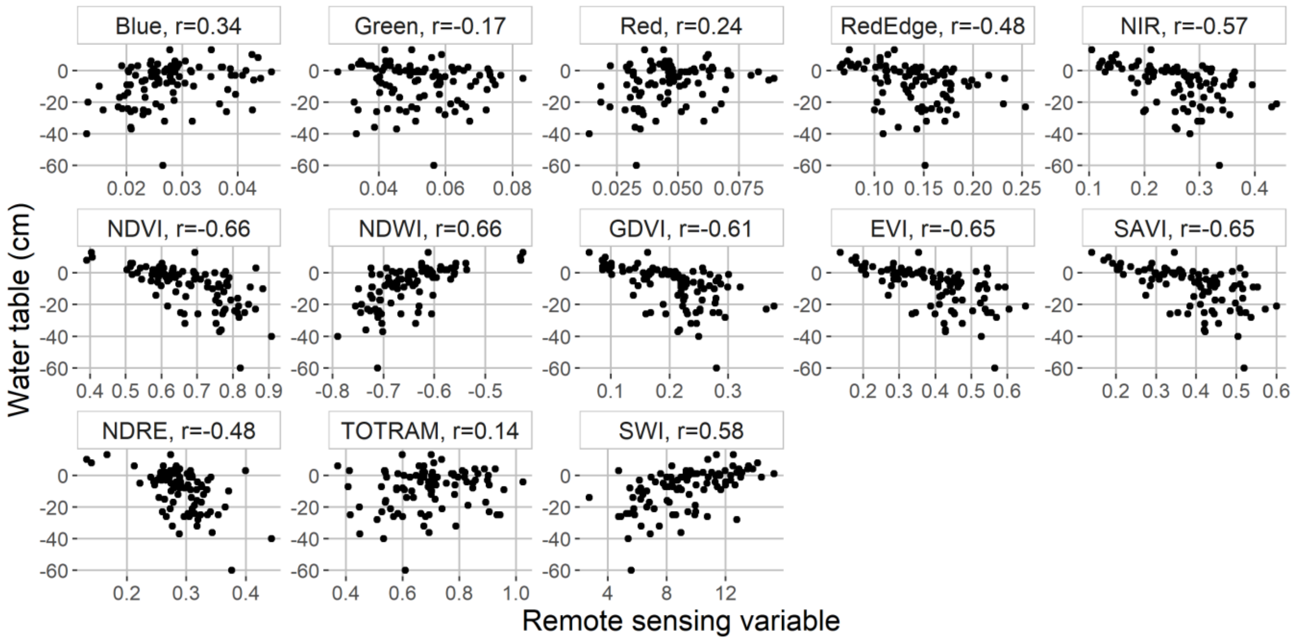


***Fig. 15.*** *Scatterplots and spearman correlations between drone derived spectral bands and indices and field measured water table depth.*

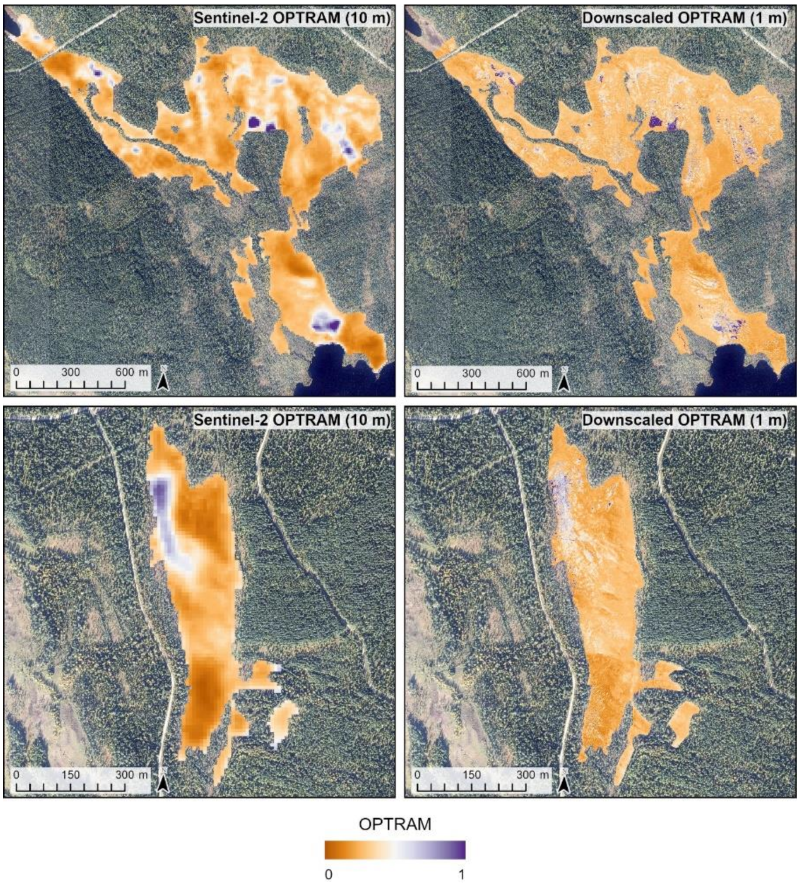


***Fig. 16.*** *Sentinel-2 OPTRAMs and their drone based downscales in Matorovansuo (top) and Välisuo (bottom). The scale indicates wetness scale, blue being wet and orange dry.*

## Calibration of ecosystem model for peatland GHG emission estimations (WP3, task 3.8)

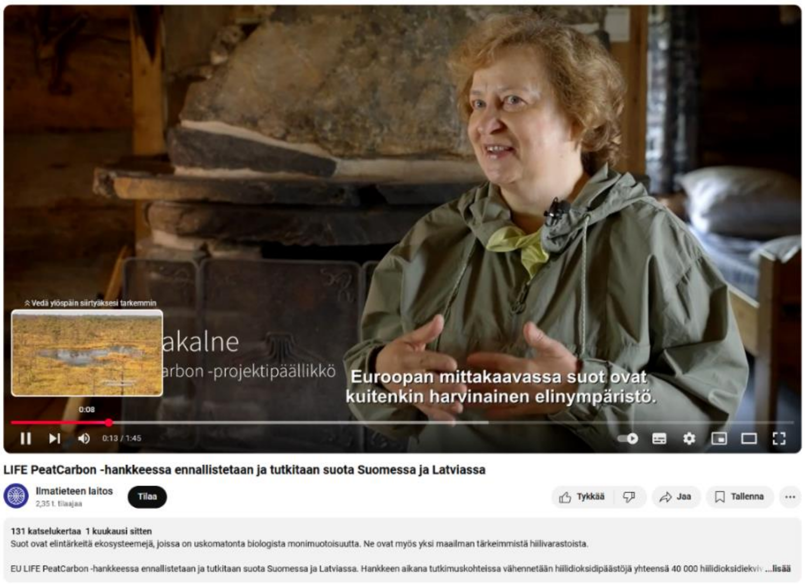
Data and analyses at peatland sites were used in *ecosystem model calibration*. New plant functional types (most importantly mosses and aerenchymatous plants) with specific carbon and hydrological impacts were added to the wetland vegetation description in the model, using information from vegetation analyses. Site-level inputs, including vegetation leaf area, species distributions, habitats and related soil water levels were used in setting up the model simulations. Measured methane and carbon dioxide fluxes, soil carbon content and daily water table dynamics were critical in refining the model's predictive capabilities. Preliminary results demonstrated the model's ability to accurately simulate GHG fluxes at site levels when calibrated with diverse datasets. Remote sensing analyses will be further used in upscaling.

## Communication and Dissemination Activities (WP 5 and WP 6)

Finnish LIFE PeatCarbon team members attended multiple relevant conferences (e.g. National peatland seminar in Helsinki in February, ALFAWetlands annual meeting in Illmitz in May, SERE in Tarto in August). Updates from the monitoring sites have been posted via LIFE PeatCarbon webpage and social media. On November 2024 we organized National Hydrological and Climate Modeling Seminar at FMI, where several talks related to GHG and hydrological measurements and modeling in LIFE Peat Carbon project were presented for stakeholder audience consisting of over 90 participants from Finnish universities and research institutes (Fig. 17).

***Fig. 17.*** *We organized Hydrological and Climate Modeling Seminar at FMI, where several talks related to GHG and hydrological measurements and modeling in LIFE Peat Carbon project were presented for audience consisting of over 90 participants from Finnish universities and research institutes.*

We organized Peatland Restoration Excursion in Pallas in early July 2024. Project lead and a delegation from Latvia, representatives from Metsähallitus, and Finnish partners met, explored the LIFE PeatCarbon sites and FMI's measurement stations in the area. Excursion included also presentations about the Finnish monitoring data and arts and science video performance "Soiden Soidinmenot" accompanied by avant-garde jazz by Heikki Rinnekangas and Juho Karjalainen. During 2024, project videos were finalized including three videos which had material from Finland: one for social media, one introducing the project and one highlighting the restoration work in Pallas. NABU produced the videos which Kuume Productions and Juho Karjalainen filmed and post-processed (Fig. 18). NABU reported that the restoration video with social media focus has gathered over 30 000 views in the first week of publishing and the video highlighting restoration work in Finland was showcased in the Peatland Pavillion at COP29.



Euroopan mittakaavassa suot ovat kuitenkin harvinainen elinympäristö.

LIFE PeatCarbon -hankkeessa ennallistetaan ja tutkitaan suota Suomessa ja Latviassa

131 katselukertaa 1 kuukausi sitten

Suot ovat elintärkeitä ekosysteemejä, joissa on uskomatonta biologista monimuotoisuutta. Ne ovat myös yksi maailman tärkeimmistä hiilivarastoista.

EU LIFE PeatCarbon -hankkeessa ennallistetaan ja tutkitaan suota Suomessa ja Latviassa. Hankkeen aikana tutkimuskohteissa vähennetään hiilidioksidipäästöjä yhteensä 40 000 hiilidioksidiekv ...lisää

*Fig. 18.* *Screenshot of LIFE PeatCarbon project video from FMI's YouTube channel.*

## Conclusions

The monitoring data collected during the pre-restoration data will be used together with the data collected after the restoration. The preliminary analyses and habitat type classification, model calibrations and initial simulations set us in a good position to continue monitoring. Long enough monitoring periods are needed for proper assessment of the initial restoration effects. We will continue monitoring during the years 2025 and 2026.

## References

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## Appendix information

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