Peatland restoration for greenhouse gas emission reduction and carbon sequestration in the Baltic Sea region

Initial Impact Assessment Report, Finland

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Summary

LIFE PeatCarbon aims to a landscape scale assessment of the peatland restoration success in terms of hydrology, vegetation, greenhouse gas (GHG) fluxes, and climate change mitigation potential. The sites in Finland, Matorovansuo mire and Välisuo Mire, drained for rorestry in 1960–1970, will be restored in 2024 according to the restoration plan, which was finalized in late 2023. In this *Initial Impact Assessment Report*, we describe the restoration activities and their effects on hydrology, flora and fauna, and GHG exchange.

The restoration activities include both rewetting and tree harvesting since the restoration aims to return the ecology of a pristine peatland in the area. Rewetting will be conducted through ditch blocking, by building dams from wood and peat as well as filling ditches with tree trunks and peat, and via directing water to the peatland. There is a targeted plan for tree biomass harvesting to return the original tree biomass density of the pine fen. The trees that have survived from the pre-drainage are identifiable and are kept. The plan was conducted by Timo Penttilä, who is an expert in peatland ecology and restoration. The planning was supported by a substantial amount of fieldwork to achieve the best possible knowledge, for example about the drainage paths and present conditions of the ditches.

Ditching and subsequent drainage were more intense in the peatland margins where drainage allowed forest (Scots pine mainly) growth. The entire peatland basins were, however, surrounded by ditches that affect the hydrology, but still the central wet parts have remained treeless. Although, signs of slight drainage and vegetation changes are visible. Restoration will have a major impact on hydrology of these sites. The main aim is to return the high-water table level, typical water flow, and the chemical composition to the original state. We expect that this will lead to a shift in vegetation towards pristine vegetation in the affected areas. Moreover, due to rise in water level and vegetation succession, we expect an increase in the carbon sink function due to decreasing ecosystem respiration. The estimated GHG emission reduction following the restoration is 3500 t CO_2 eq. y^{-1}. Initial changes in hydrology, vegetation, and ecosystem GHG exchange will be assessed based on monitoring before and after the restoration.

1. Site description

1.1. Location, Climate, and Geography

The Finnish LIFE PeatCarbon restoration targets, Välisuo (67.996°N; 24.227°E) and Matorovansuo (67.997°N; 24.311°E) peatlands are in the municipality of Kittilä, in the Pallas Research Area on State owned land. The sites are part of the Pallas Ecosystem-Atmopshere Supersite (Lohila ym. 2015; Marttila ym. 2021). The Pallas Supersite consists of versatile research infrastructure for monitoring and studying the atmosphere, ecosystems and their interactions. Pallas is located 170 km north of the Arctic Circle, partly in Pallas-Yllästunturi National Park. The Finnish Meteorological Institute (FMI) has a long history of atmospheric monitoring at Pallas: the first weather station was established near Lake Pallasjärvi in 1935. The measurements of atmospheric composition were started in 1991, and the Sammaltunturi station was established as a node of the Pallas–Sodankylä Global Atmosphere Watch (GAW) station in 1994. Currently, Pallas comprises one of the most important research infrastructures in Finland and in the wider circumpolar region, contributing to numerous European and global research programmes, such as GAW, ICOS, ACTRIS and EMEP. Pallas also serves as a platform for scientific collaboration with international as well as national research institutes (LUKE, SYKE and GTK).

The sites belong to the north-boreal vegetation zone and are at the southern edge of northern aapa mires (Fig. 1). Peatlands are sedge fens with a typical pattern of strings and flarks, the patterning formed against slope. Mean annual temperature is 0.4 °C (2003–2019), and mean July and mean January temperatures are +13.9 °C ja -11.3 °C, respectively. Mean annual precipitation is 647 mm (2008–2019), of which 42% as snow. The maximum snow depth is usually reached in April, up to 105 cm. In winter, the soil is frozen up to 50 cm depth. First snow arrives typically in mid-October and melts by the end of May (Marttila et al. 2021).

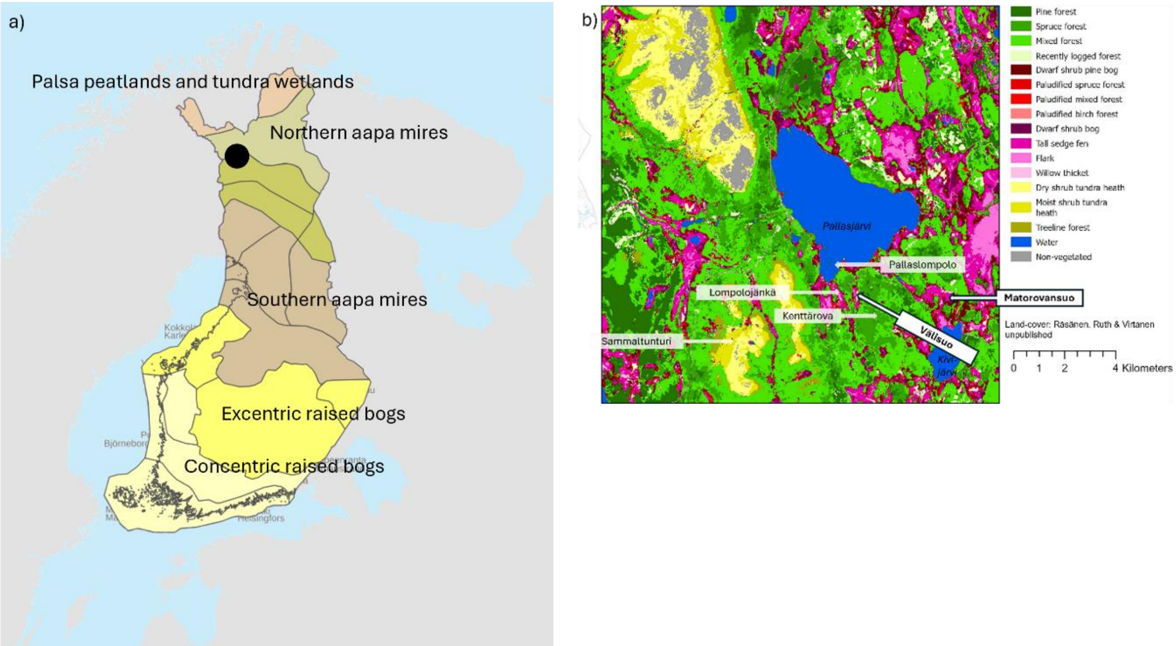

Fig. 1. a) Distribution of peatland complex types in Finland. Black dot pointing the Pallas Research Area. b) Locations of Välisuo and Matorovansuo peatlands in Pallas Research Area. The backround map shows land-cover classification by Räsänen et al. (unpubl.). FMI has micrometeorolocal stations for 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.

Välisuo and Matorovasuo peatlands are underlined granodiorite, but the bedrock in nearby areas to the mires is classified as granite or tholeiitic basalts (Fig. 2, Johansson and Kujansuu 2005). The site belongs to the Lapland rapakivi granite bedrock area, where bedrock is porous and weathered up to tens of meters. The quality of bedrock under Välisuo and Matorovasuo peatlands is not known, but previously done ground penetrating radar (GPR) measurements indicate that some minor fractures are present. In addition, an unspecified major fault crosses the Kivijärvi lake from north-west to south-east orientation. In general, the rapakivi granite layer is expected to be thinner in higher altitude areas as glacier activity likely wears out most of the weathered bedrock, whereas the weathered layer in the valley might be much deeper.

The surficial geology was shaped during the last glaciation and deglaciation period (Johansson and Kujansuu 2005). The area was deglaciated about 10 000 years ago. Quaternary soil deposits are generally thin, and topsoil consists mainly of glacial till soils and is classified as gravely sandy till or sandy till. The bedrock was found at depth of 1.2 m in the wet forest upslope of Välisuo peatland. The mineral soil thickness increases towards the central parts of the Välisuo peatland basin, and the bedrock was not reached when a 5.4 m. deep borehole was drilled. Maximum peat depth reaches 3 m in the eastern central Välisuo, while large areas have peat depth 1–1.5 m.

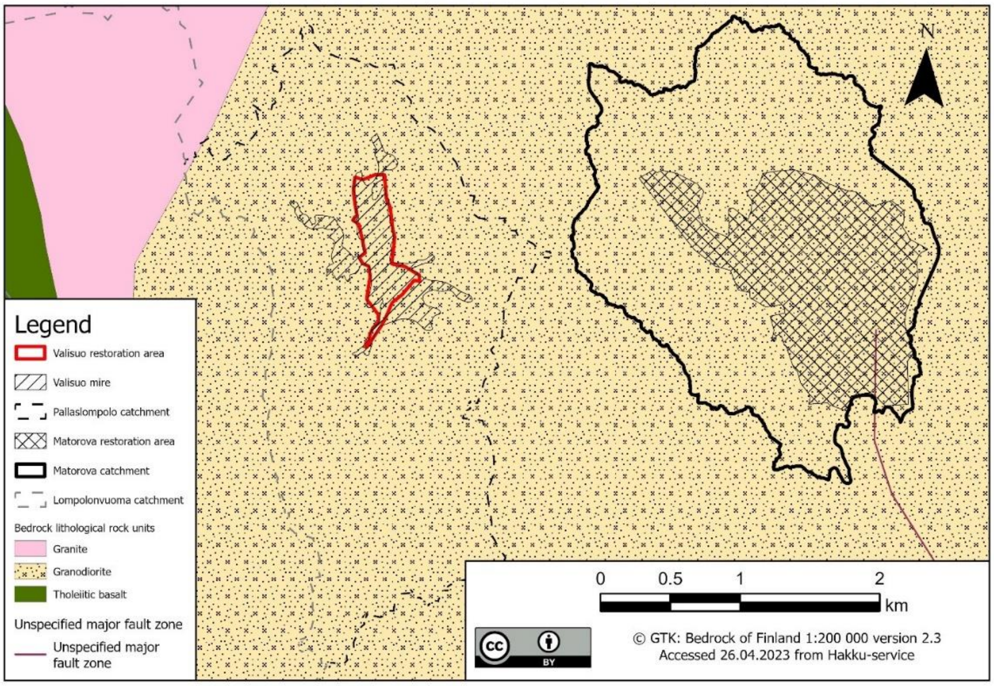

Fig. 2. Bedrock map of the Välisuo and Matorovansuo peatland areas.

1.2. Välisuo and Matorovansuo peatlands

The catchment of Matorovansuo reaches the slopes of Matorova hill and has an area of 556 ha (Fig. 3). The peatland's area, including a few mineral soil islands, is about 200 ha. The densely diched area (strips) covers about 85 ha (Fig. 4) and the area inside the diches circling the basin, the total area to be restored is about 183 ha. Besides the drainage, the logging road on the northern and eastern side of Matorovansuo has affected the water flows to some degree. Due to the drainage, tree density has increased in the originally treed parts of the peatland. Basal area is, however, small, mostly less than 10 m^2 ha^{-1} and tree height is approximately 12 m. There are only a few stands of commercially viable forests in the western margin. The site is minerotrophic fen affected by surface and ground water inputs. There are numerous springs at the peatland edges. Peatland drains to Kivijärvi lake which is 7 m lower than the northern part of the peatland and waters are collected into the Mato-oja stream entering the lake. The peatland margins are dominated by oligotrophic vegetation, i.e. pine fens and sedge fens, while there are large mesotrophic flark fens in the northern and southern parts.

Fig. 3. The catchment boundaries of Välisuo (red) and Matorovansuo peatlands (grey).

The areas of catchment and peatland basis of Välisuo are 156 ha and 27 ha, respectively (Fig. 3). Peatland receives surface and ground waters from the western slope of Matorova hill and it drains to north towards Pallasjärvi lake, west towards Lompolojänganoja stream, and to south (Fig. 3 and 4). Peatland is circled by drainage ditches and there are some additional ditches in the wet forested margins. The area of increased tree growth is about 5.5 ha while the rest of the peatland has remained treeless. Thus, the total restoration area is about 24 ha which includes treeless but affected central parts. Vegetation is oligotrophic with ombrotrophic features in the drainage divide (center) where *Sphagnum* moss vegetation has been increased due to drainage. The northern part consists of wet mesotrophic flark fens and rich fens, and southern part consist of oligotrophic sedge fens and flark fens.

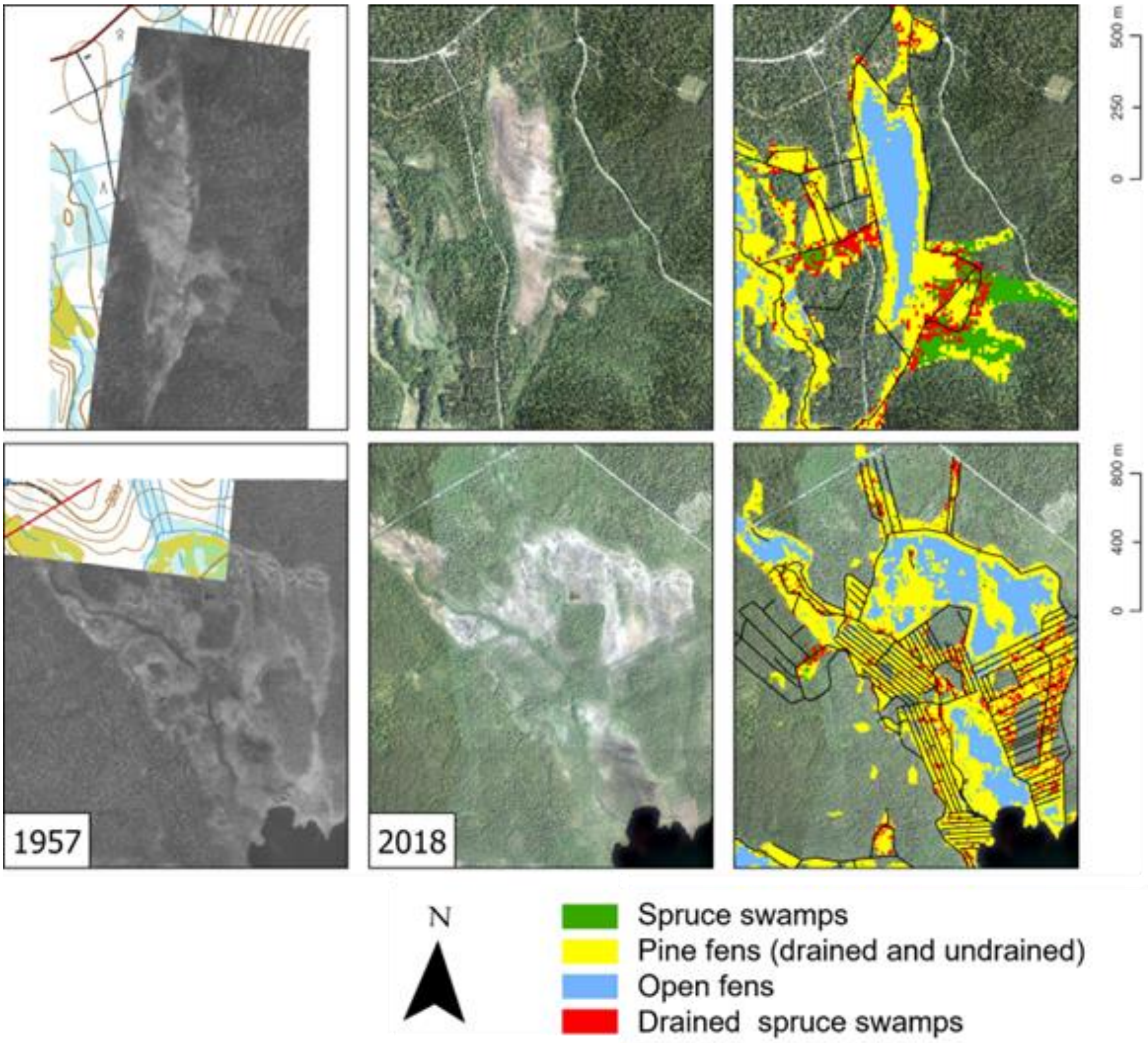

Fig. 4. Aerial images of pre- and post-drainage Välisuo (top) and Matorovansuo (below) peatlands achieved in the years 1957 and 2018, respectively. On the left, coarse land-cover classification, simplified from classification by Finnish Geological Survey. Ditch lines are indicated by the black lines.

2. The Objectives and Means of the Restoration

The restoration aims to return the natural water balance that prevailed before the drainage. Therefore, the water flows will be directed to the natural paths and flows out from the peatland will be slowed (not stopped). In addition, harvests will focus on biomass formed after the drainage aiming to original tree density and halting evapotranspiration. Besides *Scots pines*, *Betula nana* thickets will be harvested. The old pines survived the drainage will remain.

Because the timber is not economically viable, most of the harvested biomass will be used to fill ditches. The old water paths were located from the old aerial images (Fig. 4) and field work was done to plan how to redirect the waters to these original paths. The volume of water entering the mire will be increased by damming the ditches at the peatland margins. Trees will be removed from the ditch margins so allow access to excavators. Landowner, Metsähallitus (Finnish Forest authority) has informed and heard the local reindeer herder’s association which supports the restoration. The public has been also informed about the plan via a newspaper article.

2.1. Matorovansuo restoration

Damming the two large north-south ditches in the eastern side will be important to prevent drainage of the northern east part of Matorovansuo and to restore the flark fen in the south (fig. 5). Particularly the deepest ditches need dense damming. In part, ditches are overgrown, and modest actions will be enough. However, ditches will be filled with peat to return the original flow paths. The harvest supports damming as when decrease evapotranspiration.

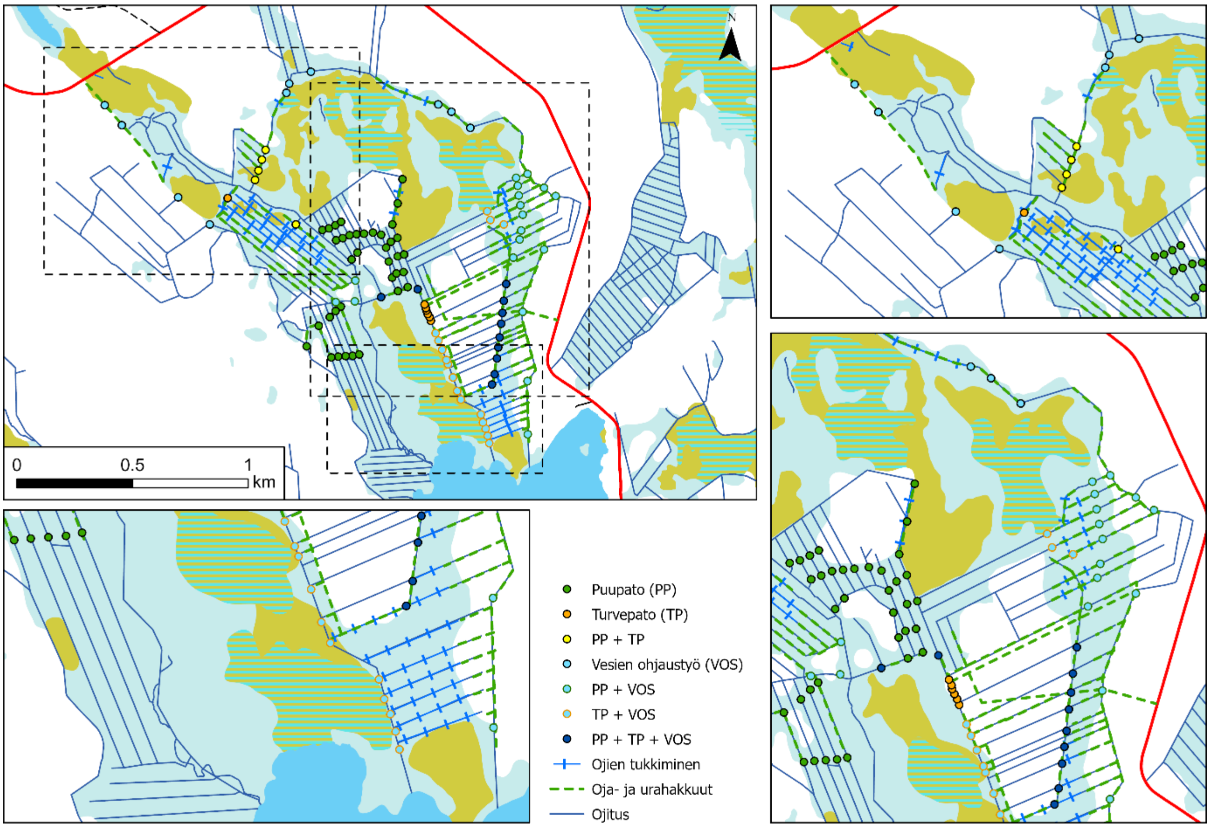

Fig. 5. Locations of the tree dams (PP), peat dams (TP), blocked ditches (ojien tukkiminen), re-direction pathways (VOS), and harvests (oja- ja urahakkuut) in Matorovansuo peatland.

2.2. Välisuo restoration

The natural outflows (north, south and west) have been cleared during the past ditching. These will be filled with harvest residues, tree trunks, and dams (Fig. 6). This design, with outflow through harvest residues, will mimic natural slow outflow dynamics of the sites.

In both peatlands, using harvest residues and small trees to fill in ditches is an economic way to slow down the water flow. The material collects detritus and supports *Sphagnum* overgrowth, and moreover, increase the long-term carbon storage. In deep slopes, proper tree dams are needed. When tree and peat dams are combined, a geotextile is placed between tree and peat dams. In addition, water will be redirected to the peatland centers above the dams.

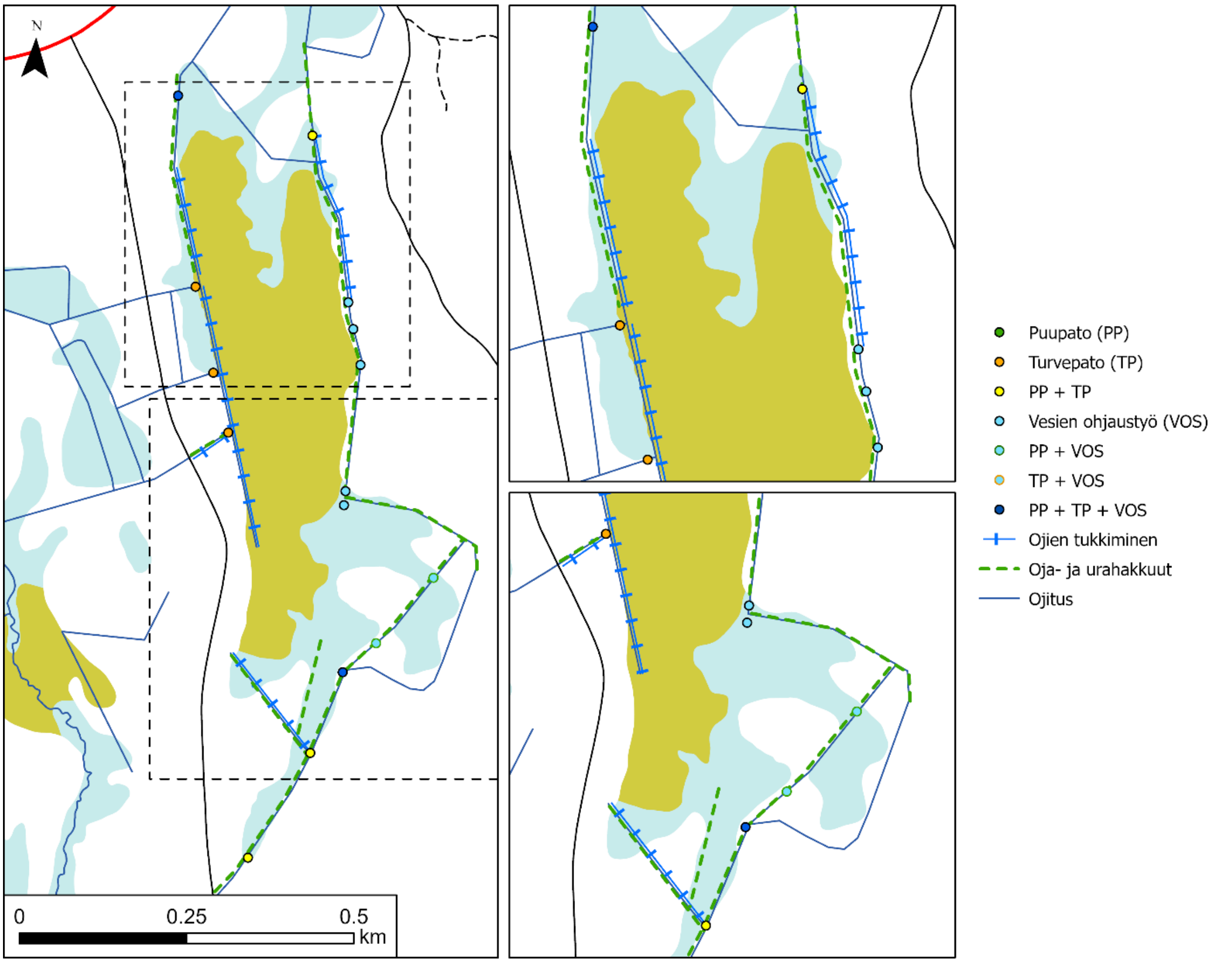

Fig. 6. Locations of the tree dams (PP), peat dams (TP), blocked ditches (ojien tukkiminen), re-direction pathways (VOS), and harvests (oja- ja urahakkuut) in Välisuo peatland.

2.3 Instructions for tree dams (PP) and combined tree and peat dams (PP+TP)

Detailed instructions on how to build tree dams, peat dams, combined tree and peat dams and water directing pathways will be given, with precise GPS information, to the operating units.

- Harvester will collect a trunk pile in PP locations: 10 to 15 trunks with 4 m length. The more trunks the deeper the ditch. Note, in the PP and TP locations no harvest residues (not waterproof)
- Next to the pile, the excavator will dig perpendicular groove (whole ditch depth) to fit the trunks. Trunks will be laid into the groove to form a dam. If VOS, excavator will dig a small ditch above the dam to direct water to the peatland. Excess peat will be laid on top of the dam.

- In the case of combined tree and peat dam (PP+TP), the peat dam will be built above the tree dam. A geotextile will be set between tree and peat dams. The length of the peat dam can be adjusted by an experienced driver.

3. The Impacts of Restoration

3.1. Hydrology

The largest hydrological impacts are expected in the next spring after snow melt (that is 2025 spring) when water level is expected to rise permanently. Thereafter, slower processes will take place. Those are related to hydrological changes in the filled ditches and development of the surface water routes. The fastest impacts will take place in the least drained areas, while the changes will be the most important in the most drained areas.

water level increase will affect the dynamics between surface and ground water flows. It is expected that more mineral rich ground water will spring up to the central parts of peatlands which will benefit the rich aapa peatland vegetation. The slowing-down of the flows in Mato-oja stream, Lompolojänganoja stream, and other flow paths will decrease nutrient and solid loading to Kivijärvi and Pallasjärvi lakes (See Fig. 3). Large variation in seasonal flow rates is typical feature of aapa mires always. Restoration may smoothen the seasonal extremes.

3.2. Vegetation

The greatest changes in species composition will take place in the vicinity of filled/dammed ditches. Harvests, harvester and excavator tracks will benefit the vegetation succession towards natural vegetation. We expect that the original species densities will return well because the species have survived in the area (Appendix 2). The largest changes will, most likely, occur in the western and eastern part of Matorovansuo, which used to be pine flark fens and drainage turned those into peatland forest (Fig. 7). *Betula nana* will suffer from the rewetting and its abundance will return to a lower level, typical in pristine peatlands. *Sphagnum* mosses will benefit at the cost of forest mosses.

The vegetation changes will be smaller in Välisuo, in terms of tree species. We expect, however, that restoration will lead to increased abundance of brown mosses (*Bryales*) due to increased minerogenic ground water inputs. In the southern end, species changes are likely because the drainage has led to increases in S*phagnum* moss and tussock forming *Trichophorum cespitosum* abundance (Fig. 8).

Fig. 7. Strings and flarks in undrained (left) and Scots pine dominated forest in drained (right) Matorovansuo, respectively. Abundant Sphagnum lindbergii in flarks suggest some drainage effect due to the ditching in the peatland margins. Scattered pines are typical for pine fens (left). Betula nana benefits from the drainage and increases its growth in the understory of drained peatland forest (right)

Fig. 8. Oligotrophic sedge fen (left) and spruce (Picea abies) swamp with a lush dwarf birch (Betula nana) understory (right) in Välisuo peatland. There are notable effects of drainage on peatland vegetation, that is increase of Betula pubescense and Trichophorum cespitosum abundances (left) and increased Picea abies and B. nana growth (right).

3.3. Greenhouse gas fluxes

The estimated GHG emission reduction following the restoration is 3500 t CO_2 eq. y^{-1}. Following the rising water level, increases in CH_4 fluxes are expected. That is part of the natural functionality of peatlands. It is possible the drained peatland forest are currently carbon sinks in an ecosystem scale. That is because the water table is rather high regardless of the drainage and thus the relative contribution of soil respiration due to peat decomposition can be lower. It is estimated that the peatland forests in northern Finland are more likely carbon sinks than peatland forest in southern Finland based on the national greenhouse gas inventory. It is noteworthy that the tree sink is temporary, and restoration aims to the protection of old peat carbon storage. We expect, thus, that after the initial phase, soil respiration will decrease, and the peatlands will be small carbon sinks.

3.4. Other species

The restoration will increase areas of open wet habitats which will benefit the bird species nesting and living in open peatlands. These species, already present in the area, include *Tringa erythropus*, *Calidris pugnax*, *Circus cyaneus*, *Lymnocryptes minimus*, *Motacilla flava* (Appendix Table 1). In the ecotone between forests and open peatlands, in turn, live species such as *Luscinia svecica* and *Calcarius lapponicus*.

The Pallas-Yllästunturi National Park is in the ecotone of north boreal and sub-arctic biomes and near the northern tree line. Consequently, there meet southern (Vipera berus, Lyrurus tetrix, Circaea alpina, Matteuccia struthiopteris) and northern species (Gulo gulo, *Stercorarius longicaudus*, Calcarius lapponicus). Nationally, the open aapa mire habitats are threatened and teir restoration will be beficial for the biodiversity.

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Appendix Table 1. Protected bird species in Pallas-Yllästunturi National Park (https://www.ymparisto.fi/fi/luonto-vesistot-ja-meri/luonnon-monimuotoisuus/suojelu-ennallistaminen-ja-luonnonhoito/natura-2000-alueet/pallas-ounastunturi)

Code	Species in Finnish	Species
A161	mustaviklo	*Tringa erythropus*
A640	selkälokki (alalaji fuscus)	*Larus fuscus fuscus*
A861	suokukko	*Calidris pugnax*
A217	varpuspöllö	*Glaucidium passerinum*
A480	sinirinta	*Cyanecula svecica*
A127	kurki	*Grus grus*
A082	sinisuohaukka	*Circus cyaneus*
A152	jänkäkurppa	*Lymnocryptes minimus*
A066	pilkkasiipi	*Melanitta fusca*
A098	ampuhaukka	*Falco columbarius*
A860	jänkäsirriäinen	*Calidris falcinellus*
A767	uivelo	*Mergellus albellus*
A065	mustalintu	*Melanitta nigra*
A002	kuikka	*Gavia arctica*
A862	pikkulokki	*Hydrocoloeus minutus*
A096	tuulihaukka	*Falco tinnunculus*
A001	kaakkuri	*Gavia stellata*
A605	lapinuunilintu	*Phylloscopus borealis*
A108	metso	*Tetrao urogallus*
A241	pohjantikka	*Picoides tridactylus*
A534	sinipyrstö	*Tarsiger cyanurus*
A170	vesipääsky	*Phalaropus lobatus*
A194	lapintiira	*Sterna paradisaea*
A260	keltavästäräkki	*Motacilla flava*
A876	teeri	*Lyrurus tetrix tetrix*
A162	punajalkaviklo	*Tringa totanus*
A140	kapustarinta	*Pluvialis apricaria*
A277	kivitasku	*Oenanthe oenanthe*
A456	hiiripöllö	*Surnia ulula*
A166	liro	*Tringa glareola*
1934	pohjanharmoyökkönen	*Xestia borealis*
1972	lapinleinikki	*Ranunculus lapponicus*
1528	lettorikko	*Saxifraga hirculus*
1389	isonuijasammal	*Meesia longiseta*
1355	saukko	*Lutra lutra*
1912	ahma	*Gulo gulo*
A054	jouhisorsa	*Anas acuta*
A223	helmipöllö	*Aegolius funereus*
A727	keräkurmitsa	*Eudromias morinellus*
A104	pyy	*Bonasa bonasia*
A222	suopöllö	*Asio flammeus*

A039	metsähanhi	Anser fabalis
A062	lapasotka	Aythya marila
A146	lapinsirri	Calidris temminckii
A264	koskikara	Cinclus cinclus
A236	palokärki	Dryocopus martius
A038	laulujoutsen	Cygnus cygnus

Appedix 2. Plant species in Välisuo and Matorovansuo before the restoration

Vascular plants	Lichens and mosses
Andromeda polifolia	*Aulacomnium palustre*
Betula nana	*Cladonia arbuscula*
Betula nana x pubescens	*Cladonia rangiferina*
Betula pubescens	*Dicranum bergerii*
Calluna vulgaris	*Dicranum bonjeanii*
Carex aquatilis	*Dicranum fuscescens*
Carex brunnescens	*Dicranum majus*
Carex canescens	*Dicranum montanum*
Carex chordorhiza	*Dicranum polysetum*
Carex dioica	*Dicranum scoparium*
Carex lasiocarpa	*Hamatocaulis lapponicus*
Carex limosa	*Hylocomnium splendens*
Carex magellanica	*Loeskypnum badium*
Carex pauciflora	*Mylia anomala*
Carex rostrata	*Paludella squarrosa*
Comarum palustre	*Pleurozium schreberi*
Deschampsia flexuosa	*Polytrichum commune*
Drosera anglica	*Polytrichum juniperinum*
Drosera rotundifolia	*Polytrichum strictum*
Dryopteris carthusiana	*Ptilidium ciliare*
Empetrum nigrum	*Sarmentypnum exannulatum*
Equisetum fluviatile	*Sarmentypnum procerum*
Equisetum palustre	*Scapania sp.*
Equisetum sylvaticum	*Scorpidium scorpioides*
Eriophorum angustifolium	*Sphagnum angustifolium*
Eriophorum scheuzeri	*Sphagnum annulatum*
Eriophorum vaginatum	*Sphagnum aongstroemii*
Gymnocarpium dryopteris	*Sphagnum balticum*
Linnea borealis	*Sphagnum capillifolium*
Lycopodium annotinum	*Sphagnum compactum*
Melampyrum sylvaticum	*Sphagnum divinum*
Menyanthes trifoliata	*Sphagnum fallax*
Picea abies	*Sphagnum fuscum*
Pinguicula vulgaris	*Sphagnum jensenii*
Pinus sylvestris	*Sphagnum lindbergii*
Rhododendron tomentosum	*Sphagnum majus*
Rubus chamaemorus	*Sphagnum medium*
Salix myrtilloides	*Sphagnum papillosum*
Salix phylicipholia	*Sphagnum riparum*
Scheuzeria palustris	*Sphagnum russowii*
Solidago virgaurea	*Sphagnum subfulvum*
Trichophorum cespitosum	*Sphagnum subnitens*
Trientalis europaea	*Sphagnum teres*
Vaccinium microcarpum	*Sphagnum warnstorfii*
Vaccinium myrtillus	*Straminergon stramineum*

Vaccinium oxycoccos	*Warnstrofia fluitans*
Vaccinium uliginosum	
Vaccinium vitis idaea	