Handbook for Assessment of Greenhouse Gas Emissions from Peatlands

Applications of direct and indirect methods by *LIFE Peat Restore*

Handbook for Assessment of Greenhouse Gas Emissions from Peatlands

Applications of direct and indirect methods by
LIFE Peat Restore

2022

Authors:

Leonas Jarašius[1,6], Jonathan Etzold[2], Laimdota Truus[3], Anna-Helena Purre[3,7], Jūratė Sendžikaitė[1,8], Līga Strazdiņa[4], Nerijus Zableckis[1,6], Māra Pakalne[4], Katarzyna Bociąg[5], Mati Ilomets[3], Andreas Herrmann[2], Tom Kirschey[2], Raimo Pajula[3], Paweł Pawlaczyk[5], Izabela Chlost[5], Roman Cieśliński[5], Krzysztof Gos[5], Krišjānis Libauers[4], Žydrūnas Sinkevičius[1], Leticia Jurema[2]

[1] – Lithuanian Fund for Nature (LT), [2] – Nature and Biodiversity Conservation Union (DE), [3] – Tallinn University (EE), [4] – University of Latvia (LV), [5] – Naturalists' Club (PL), [6] – Foundation for Peatland Restoration and Conservation (LT), [7] – Elige OÜ (EE), [8] – Nature Research Centre (LT)

The book was prepared and printed with the financial support of the European Commission's LIFE programme and co-financiers within the project "Reduction of CO_2 emissions by restoring degraded peatlands in Northern European Lowland" (LIFE15 CCM/DE/000138, *LIFE Peat Restore*).

Language editor: Michael Manton.
Design and layout: JSC Studio Dilemma, Lithuania.
Printed by Printing House Petro Ofsetas, Lithuania.
Cover images: Pūsčia peatland (Lithuania) – photos by Žydrūnas Sinkevičius.

Citation:

Jarašius L. *et al.* 2022. Handbook for assessment of greenhouse gas emissions from peatlands. Applications of direct and indirect methods by LIFE Peat Restore. Lithuanian Fund for Nature, Vilnius, 201 p.

Publisher: Lithuanian Fund for Nature (Lithuania)
Printed: 500 copies

ISBN 978-9986-570-22-6 (print)
ISBN 978-9986-570-23-3 (online)

Co-financiers:

CONTENTS

INTRODUCTION

Peatlands are most crucial for preventing and mitigating the effects of the rampant climate crisis. The natural interaction of peatlands with the atmosphere are exacerbated and negatively influenced by human activity. Sources and sinks of carbon associated with land use can be significant determinants of the rate and magnitude of atmospheric CO_2 change. While pristine peatlands sequester carbon, peatland degradation by drainage and land-use leads to significant CO_2 emissions – net sinks have been turned into sources of greenhouse gases. Globally peatlands store a total of around 550 Gt of carbon, i.e., they are the biggest soil carbon sinks on this planet. Thus, conserving the remaining undrained peatlands is a global priority. Another necessity is to restore all the hitherto drained peatlands and stop their degradation. Southeast Asia and Europe are current emission hotspots from degraded peatlands.

The UNFCCC Paris Agreement from December 2015 (adopted by 196 parties) is a legally binding global framework that was set out to limit global warming to well below 2 °C. One demand of the Paris Agreement is the integration of honest balances in Nationally Determined Contributions (NDC) including the binding reduction paths for emissions resulting from Land Use, Land-Use Change and Forestry (LULUCF). In the 2 °C scenario report, the global scientific advisory IPCC ruled that by 2050 all degraded peatlands must be restored in order to re-establish their long-term role as net carbon sinks after 2050. The ambition level needs to be increased tremendously to not fail with this exercise. In 2019, following the commitments by the European Union and its member states to comply with the Paris Agreement, the objective to achieve a climate-neutral EU by 2050 was endorsed.

All these political goals require a solid scientific foundation and informed decisions in peatland management. Apart from the restoration measures one of the main objectives of *LIFE Peat Restore* was to monitor the GHG balances, compare direct GHG measurements with indirect approaches and document lessons learnt from the restoration of the project sites in Estonia, Latvia, Lithuania, Poland and Germany. Direct measurements of carbon dioxide, methane and nitrous oxide fluxes were recorded, however the assessment methods applied are labour- and time-intensive as well as costly. A promising indirect approach is the use of vegetation and the water table as proxies for estimation of GHG emission. The project *LIFE Peat Restore* has implemented the *Greenhouse Gas Emission Site Type (GEST)* approach for the first time in the Baltic states and assessed the validity of indirect approaches with direct flux measurements in a collaborative joint effort of all project partners.

This handbook presents the summary of the results of GHG assessment of the project *LIFE Peat Restore* and provides an overview of how to best evaluate GHG emissions from peatlands in the Northern European Lowland. The handbook includes an *Updated GEST catalogue* (*Annex 3*) and an illustrated description of GESTs identified in the *LIFE Peat Restore* project (*Annex 4*).

Glossary

The glossary sets out the meanings of concepts described, and terms used in this publication. Most definitions are based on Joosten et al. (2017) and marked with an asterisk (*).

Aerenchyma:
A modification of the parenchyma to form a spongy tissue that creates spaces or air channels in the leaves, stems and roots of some plants, which allows exchange of gases between the shoot and the root.

Aerechymous shunt species:
Vascular plant species with aerenchyma that pump air into the rhizosphere and transport methane from the anaerobic soil layer directly into the atmosphere. As a consequence, an area with many shunt species may have a two times higher methane emission than other areas with a similar water table depth.

Bog*:
Mire only fed by precipitation.

Calcareous*:
Rich in calcium carbonates.

Calcareous fen*:
(1) A fen with a very high mineral richness in peat and water pH>7. Characterised by basiophile (calciphile) species. Synonymous to extremely rich fen;
(2) A fen with communities depositing tufa (travertine, terrestrial chalk).

Carbon dioxide (CO_2):
A colourless, odourless and non-poisonous gas (made up from one atom of carbon and two atoms of oxygen) formed by combustion of carbon and in the respiration of living organisms and is considered a greenhouse gas.

Carbon dioxide equivalent (CO_2-eq.):
A metric measure used to compare the emissions from various greenhouse gases on the basis of their Global Warming Potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

Carbon sequestration:
(1) The process of removing carbon from the atmosphere and storing it in a reservoir (peat), as a natural process in growing peatlands;
(2) A long-term storage of carbon in plants, soils, geologic formations, and the ocean.

Carbon sinks:
Reservoirs that retain carbon and keep it from entering Earth's atmosphere. Carbon is transferred naturally from the atmosphere to terrestrial carbon sinks through photosynthesis; it may be stored in aboveground biomass as well as in soils.

Climate change mitigation:
Strategies and policies that reduce the concentration of greenhouse gases in the atmosphere either by reducing their emissions or by increasing their capture.

Cut-away peatland:
Peatland after all the peat which can be economically removed has been extracted.

Degradation:
Changes which negatively affect the structure or function of the site and thereby lower the capacity to supply products and/or services.

Dissolved Inorganic Carbon (DIC):
sum of the aqueous forms of inorganic carbon (CO_2, H_2CO_3, HCO^-_3, CO^{2-}_3) in a solution.

Dissolved Organic Carbon (DOC):
sum of the aqueous forms of organic carbon (e.g., organic matter from simple organic acids to more complex humic and fulvic acid) in a solution.

Ebullition:
one of the pathways of greenhouse gas flows when GHGs are released as bubble fluxes from the water saturated soil or water bodies to the atmosphere.

Ecosystem*:
A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.

Electrical conductivity:
A measurement of water's capability to pass electrical flow. This ability is directly related to the concentration of ions in the water. These conductive ions come from dissolved salts and inorganic materials.

EU importance habitat type:
A habitat type listed in the Annex I of the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

Eutrophic*:
(1) Nutrient-rich; (2) Base-rich.

Fen:
Peatland which in addition to precipitation water also receives water that has been in contact with mineral soil or bedrock.

GEST approach:
An instrument developed as a rough assessment of GHG emissions before and after rewetting of drained peatlands to avoid costly direct GHG measurements. It uses vegetation components as a proxy for a certain emission level of peatlands. Combination of plant species indicating long-term water table depths and other characteristics relevant to GHG fluxes (e.g., peat type, pH, nutrient status), associated with annual mean GHG fluxes of carbon dioxide and methane (expressed as CO_2-eq) based on literature or country-specific measurements.

GHG: *see Greenhouse Gas.*

GHG emissions:
A release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.

Global warming potential (GWP):
An index describing the radiative characteristics of well-mixed greenhouse gases that represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation is known as global warming potential. This index approximates the time-integrated warming effect of a unit mass of a given greenhouse gas in today's atmosphere, relative to that of carbon dioxide.

Greenhouse effect*:
Warming resulting from when solar radiation is trapped by the atmosphere; caused by atmospheric gases that allow short wave radiation to pass through but absorb long wave heat that is radiated back from the warmest surface of the Earth.

Greenhouse Gas Emission Site Type (GEST):
Mire vegetation form classified to indicate quality and quantity of greenhouse gas emissions. A combination of plant species indicating long-term water table depths and other characteristics relevant to GHG fluxes (e.g., peat type, pH, nutrient status), associated with annual mean GHG fluxes of carbon dioxide and methane (expressed as CO_2-equivalents) based on literature or country specific measurements. In absence of vegetation, water table depth is used as the main proxy.

Greenhouse gas (GHG):
Any gas in the atmosphere that contributes to the greenhouse effect. These include primary carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and water vapour. Most occur naturally as well as being created by human activity. In this publication the term refers to those GHG relevant for peatland management: carbon dioxide, methane and nitrous oxide.

Groundwater*:
(1) All water beneath the land surface; (2) All underground water beneath the water table.

Groundwater level:
Level of water under the land surface in which pore spaces are saturated.

Habitat*:
The ecological environment of an organism or community.

Hydrology*:

(1) The occurrence, circulation, distribution, and properties of the waters of the Earth and its atmosphere; (2) The study of the occurrence, circulation, distribution, and properties of the water of the Earth and its atmosphere.

Kettlehole peatland:

A flat peatland in a kettle-shaped basin formed by the melting of an ice block that was buried by glacial outwash of a retreating glacier.

Lagg*:

A fen strip between a bog and the surrounding mineral surface.

Lawn*:

A mire feature, situated generally 5–20 cm above the water table, with a dominance of graminoids whose roots and rhizomes make the lawn so firm that a footprint rapidly disappears.

Mesotrophic* (used for water bodies and soils):

(1) With median nutrient and base status; (2) With median base status.

Methane (CH_4)*:

A greenhouse gas consisting of one atom of carbon and four atoms of hydrogen. Methane is produced naturally from rotting organic matter.

Methanogenic bacteria:

Unique among prokaryotes because they produce a hydrocarbon, methane (CH_4), as a major product of anaerobic metabolism. The main taxonomic characteristic of a morphologically diverse group of bacteria *Methanobacteriaceae.*

Minerotrophic*:

Supplied with nutrients by the lithosphere and the pedosphere.

Mire*:

A peatland where peat is currently being formed and accumulating.

Net Ecosystem Exchange (NEE):

CO_2 exchange between a particular ecosystem and the atmosphere – characterised by the difference between gross photosynthesis (P_g, negative values) or gross primary production (GPP, negative values) and ecosystem respiration (R_{ECO}, positive values). If the NEE is negative, the ecosystem is a CO_2 sink from the atmosphere, and in reverse, positive values of NEE indicate larger respiration than photosynthesis, so the ecosystem is a CO_2 source to the atmosphere.

Nitrous oxide (N_2O)*:

A greenhouse gas consisting of two atoms of nitrogen and one atom of oxygen. Nitrous oxide is created when fuels are burned and may also be released from drained peatlands during nitrification and denitrification.

Nutrient*:

Substance that nourishes an organism.

Oligotrophic:

Poor to extremely poor in nutrients.

Ombrogenous:

Only receiving precipitation water.

Ombrotrophic:

Only supplied with nutrients by the atmosphere.

Peat:

Sedentarily accumulated material consisting of at least 30% (dry weight) of dead organic material. Peat formation from dead plant particles in mires, where they do not decompose completely in water due to lack of oxygen.

Peatland*:

An area with or without vegetation with a naturally accumulated peat layer at the surface.

Piezometer:

A device which measures the pressure of groundwater at a specific point. They can be read by data loggers or portable readout units, allowing faster or more frequent reading.

pH:

A logarithmic scale that indicates the concentration of hydrogen ions in the solution. It is used to specify the acidity or basicity of an aqueous solution. Acidic solutions (solutions with higher concentrations of H^+ ions) are measured to have lower pH values than basic or alkaline solutions.

Plant community*:
A collection of associated plant species that forms a relatively uniform patch that is distinguishable from neighbouring patches of different communities.

Proxy*:
A variable that can be used to represent another variable; an indicator.

Pristine peatland:
Peatland not disturbed by human activity.

Raised bog:
Usually dome-shaped peatland that has its water level above that of the surrounding mineral soil due to its moisture being fed only by the atmosphere.

Restoration*:
Management to assist the recovery of a degraded ecosystem.

Rewetting:
(1) Process of restoring natural water flow and saturating peatland,
(2) Raising the water table and making a peatland wet or moist again.

Succession:
Gradual and continuous change in species composition and community structure over time in the same area.

Transitional mire*:
(1) Mire with properties between a rich fen and a bog, i.e., a mire characterised by a dominance of *Sphagnum* species together with some mineral soil water indicators covering poor fen and intermediate fen;
(2) Mire with medium nutrient availability;
(3) Mire that in a drained state is covered by at least 20 cm of birch peat, pine peat or *Scheuchzeria*-brown moss peat; (4) Mire in a stage of succession from geogenous to ombrogenous peat growth.

Transpiration*:
The process by which plants (and animals) release water vapour to the atmosphere.

Trophic conditions:
Nutrient availability.

Vegetation*:
The plant cover at a given place taken as a whole.

Vegetation form:
Vegetation type based on the joint classification of vegetation and environmental conditions. In this publication it used to identify GEST (see *Chapter 2.1.1.*).

Vegetation unit:
Neutral term describing any classified unit of vegetation distinguished, according to one or another feature, e.g., floristic composition, physiognomy, ecological conditions (examples of plant communities, associations and vegetation forms).

Water level:
Depth of sub-soil or above-soil water surface, relative to the soil surface.

Abbreviations

BEF – biomass expansion factor

CH_4 – methane

CO_2 – carbon dioxide

CO_2-eq. – carbon dioxide equivalent

DIC – Dissolved Inorganic Carbon

DBH – diameter (of tree stem) in the breast-height

DOC – Dissolved Organic Carbon

EC – electrical conductivity

ECD – Electron Capture Detector

EU – European Union

GWL – groundwater level

GEST – Greenhouse gas Emission Site Type

GHG – greenhouse gas

Gt – gigatons = 1 000 000 000 tons

GPP – gross primary production

GWP – Global Warming Potential

HA – Humic Acid

IPCC – Intergovernmental Panel on Climate Change

LAI – leaf area index is one-sided green leaf area per unit ground surface area that has been developed to characterise plant canopies

LIDAR – Light Detection and Ranging

LULUCF – Land Use, Land-Use Change and Forestry

ME/EUT – mesotrophic/eutrophic

n/a – not available

nd – no data

NEE – Net Ecosystem Exchange

NP – National Park

NR – Nature Reserve

N_2O – nitrous oxide

NDC – Nationally Determined Contributions defined by the Paris Agreement

OL – oligotrophic

PAR – Photosynthetically Active Radiation

P_g – gross photosynthesis

R_{eco} – ecosystem respiration

T_{air} – air temperature

UNFCCC – United Nations Framework Convention on Climate Change

VCS – Verified Carbon Standard

LIFE Peat Restore **project sites** (Figure 1):

EE-SU – Suursoo-Leidissoo peatland (Estonia)

LV-AU – Augstroze Nature Reserve (Latvia)

LV-BA – Baltezers Mire Nature Reserve (Latvia)

LV-EN – Lake Engure Nature Reserve (Latvia)

LT-AM – Amalva peatland (Žuvintas Biosphere Reserve, Lithuania)

LT-PL – Plinkšiai peatland (Lithuania)

LT-SA – Sachara peatland (Lithuania)

LT-PU – Pūsčia peatland (Gražutė Regional Park, Lithuania)

LT-AU – Aukštumala peatland (Nemunas Delta Regional Park, Lithuania)

PL-KL – Kluki (Słowiński National Park, Poland)

PL-CB – Ciemińskie Błota (Słowiński National Park, Poland)

PL-WB – Wielkie Bagno (Słowiński National Park, Poland)

DE-BB-1 – fen at the mouth of River Pfauenfließ (Biesenthaler Becken Nature Reserve, Germany)

DE-BB-2 – fen at Lake Hellsee (Biesenthaler Becken Nature Reserve, Germany)

DE-BB-3 – fen near lake Plötzensee (Biesenthaler Becken Nature Reserve, Germany)

Project sites

1 – Suursoo-Leidissoo peatland (EE-SU),
2 – Augstroze Nature Reserve (LV-AU),
3 – Lake Engure Nature Reserve (LV-EN),
4 – Baltezers Mire Nature Reserve (LV-BA),
5 – Plinkšiai peatland (LT-PL),
6 – Sachara peatland (LT-SA),
7 – Pūsčia peatland (LT-PU),
8 – Aukštumala peatland (LT-AU),
9 – Amalva peatland (LT-AM),
10 – Słowiński National Park (3 peatlands: Kluki (PL-KL), Ciemińskie Błota (PL-CB), Wielkie Bagno (PL-WB),
11 – Biesenthaler Becken Nature Reserve (3 peatlands: fen at the mouth of River Pfauenfließ (DE-BB-1), fen at Lake Hellsee (DE-BB-2), small fen near Lake Plötzensee (DE-BB-3).

Figure 1. Location of the *LIFE Peat Restore* project sites in Estonia, Latvia, Lithuania, Poland and Germany.

1. PEATLAND-RELATED GREENHOUSE GASES AND POSSIBILITIES FOR THEIR ESTIMATION

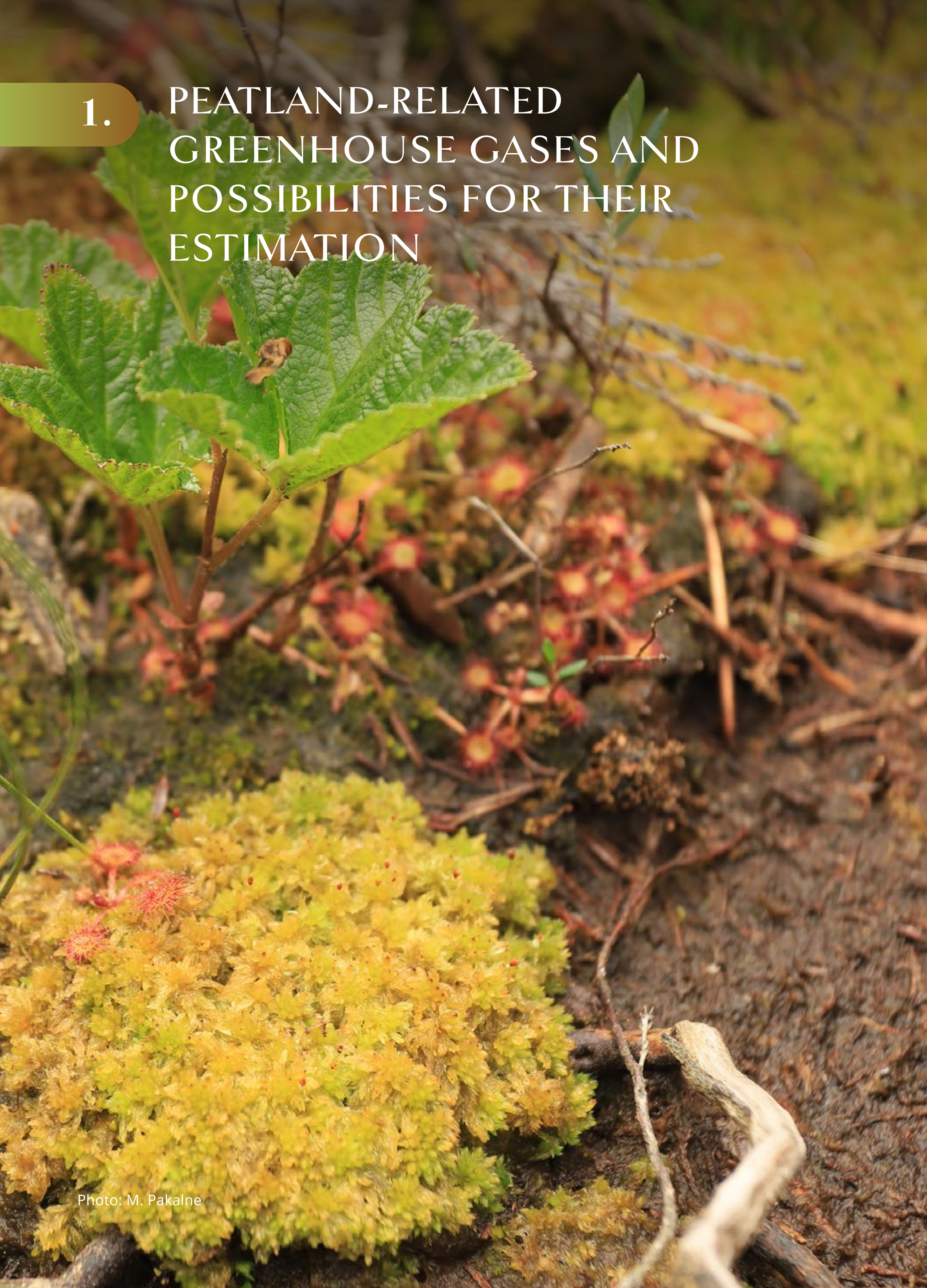


Photo: M. Pakalne

Peatland-related GHGs 1.1.

Peatlands, disturbed and natural ones, interact with the atmosphere as an important source or sink of greenhouse gases, like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In addition to gas fluxes, aquatic carbon loss in the form of dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) play an important part in peatland carbon cycling (Swenson *et al.* 2019). Carbon accumulation in undisturbed peatlands (mires) is a long-term process. Although there is interannual variation in weather conditions and hydrology of peatland sites, natural peatlands always form carbon sinks over a longer timescale. Despite only covering 3% of the earth's land surface, peatlands contain at least 550 gigatonnes of carbon. This is more than twice the carbon stored in all forest biomass, and equivalent to 75% of all carbon in the atmosphere (Joosten & Couwenberg 2008, de la Haye *et al.* 2021). Anthropogenic disturbances and land use release this accumulated carbon back to the atmosphere.

Without peatland rewetting the world's drained peatlands will continue to emit CO_2, with direct negative effects on the magnitude and timing of global warming. These effects include a higher risk of reaching tipping points in the global climate system and possible cascading effects (Steffen *et al.* 2018). In contrast, peatland rewetting can be one important measure to reduce climate change and attenuate peak global warming. The sooner drained peatlands are rewetted, the better it is for the Earth's climate (Günther *et al.* 2020) (Figure 2).

The CO_2 exchange between an ecosystem and atmosphere (Net Ecosystem Exchange, NEE) is the difference between carbon uptake by plants through photosynthesis, and carbon release through ecosystem respiration (R_{eco}; respiration of all auto- and heterotrophic organisms) (Figure 3). Higher water levels and water-logged conditions are unfavourable for aerobic microorganisms and results in substantial carbon accumulation in peat sediment. Therefore, vegetation has an important role in carbon cycling and accumulation. CO_2 exchange correlates rather well with vascular plant cover and leaf area, a higher leaf area leads to higher CO_2 accumulation from the atmosphere to the ecosystem. This process depends on several factors: local weather conditions, the impact of management activities such as the restoration of water levels, and the occurrence of different plant communities (Purre 2021). It is a very sensitive balance that depends on environmental parameters, like the length of the growing season, temperature, amount of photosynthetically active radiation (PAR) and optimality of water levels for plant production, and plant suitability to growing in particular sites. Respiration increases with rising air and soil temperatures and fluctuating water levels (Wilson *et al*. 2007), as well as with a higher abundance of plants (Purre *et al*. 2019).

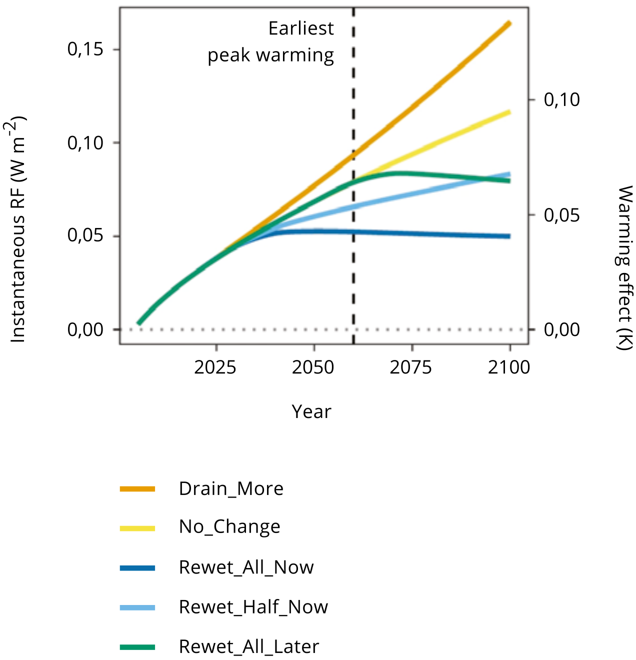


Figure 2.

The impact of Peatland restoration on climate change mitigation based on five peatland rewetting scenarios according to Günther *et al.* 2020: *Drain_More* – 2020–2100 the area of drained peatlands continues to increase at the same rate as between the years 1990–2017; *No_Change* – the area of drained peatlands remains the same as in 2018; *Rewet_All_Now* – rewetting of all drained peatlands in the period 2020–2040; *Rewet_Half_Now* – rewetting half of drained peatlands in the period 2020–2040; *Rewet_All_Later* – rewet all drained peatlands later in period 2050–2070.

In comparison to CO_2 fluxes, CH_4 and especially N_2O fluxes are strongly related with microbial activity. With rising water levels and higher abundance in herbaceous vegetation, especially aerenchymatous shunt species, methane (CH_4) emissions increase (Lazcano *et al.* 2020). In water-saturated conditions methanogenic microorganisms (archaea and methanogenic bacteria) dwell in peat releasing methane as a residue of their metabolism. Methane gas is emitted from peat to the atmosphere via diffusion, ebullition and transported through shunt plant species. Rewetting creates an appropriate habitat for methanogenic microorganisms and methane emission increases, especially in the first years after the rewetting. Differently from CH_4, environmental variables impacting the N_2O fluxes are less known, but general trends reported in the scientific literature show that fertilisation of peatlands increases N_2O emissions (Gong *et al.* 2019; Minkkinen *et al.* 2020). Drainage leads to deeper water levels and also increases N_2O fluxes (Minkkinen *et al.* 2020).

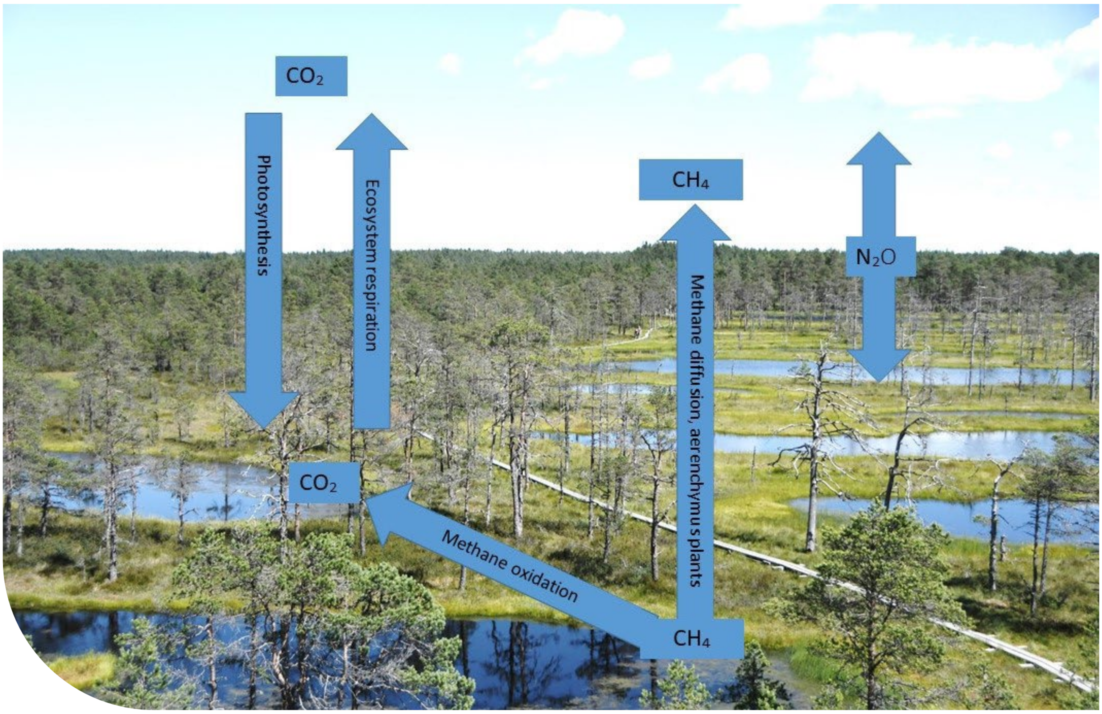


Figure 3. Principal scheme of the main GHG process in peatlands.

With successful restoration and establishment of peatland vegetation communities, the amount of carbon involved in their photosynthetic process is significantly higher than the global warming potential of released CH_4 and N_2O. Indeed, the peatland changes from a carbon emitting ecosystem to carbon sequestering ecosystem.

Rewetting of drained peatlands is a relatively low-cost action that can reduce GHG emissions in the Land Use, Land-Use Change and Forestry (LULUCF) sector. To assess the net climate effect of rewetting measures and the total restoration process at the project level, suitable emission factors need to be considered and clarified. For example, many direct measurements are needed to identify the underlying processes and relationships that affect GHG fluxes on peatlands, because of high uncertainties in GHG measurements.

1.2. Assessment of peatlands' impact on the climate

Assessing the carbon balance in natural, drained or rewetted peatlands can be achieved either by the application of direct GHG measurements in the field, or indirect estimates, using scientifically acknowledged methods. Direct measurements are very precise, however they are laborious, sophisticated and expensive whereas indirect methods (e.g. GEST, IPCC Guidelines for National Greenhouse Gas Inventories) are less expensive and present an opportunity to evaluate GHG fluxes by collecting and interlinking certain peatland characteristics. In the *LIFE Peat Restore* project both the GEST (Greenhouse Gas Emission Site Type) and direct measurement methodologies were used (Figure 4). In addition, the advantages and disadvantages of each of the above mentioned methodologies are presented.


A

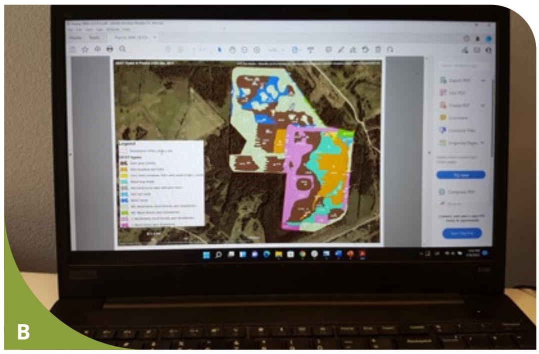

B

Figure 4. Indirect measurements: Fieldworks on GEST mapping in the Pūsčia (Lithuania) project site (A) and GEST mapping by using GIS technologies (B). Photos: J. Sendžikaitė (A) and L. Jarašius (B).

The GEST approach has been developed for assessing GHGs (CO_2 and CH_4) emissions from degraded and rewetted peatlands using vegetation as a proxy (Couwenberg 2009; Couwenberg *et al*. 2008, 2011; Joosten *et al*. 2015). The approach was justified by the evaluation of a comprehensive amount of literature on GHG flux measurements and grouping them into GESTs depending on site parameters and vegetation features. For more information see *Chapter 2.1.*

Direct measurements of ecosystem GHG fluxes are generally divided into micro-meteorological methods, like **Eddy Covariance** and **chamber techniques** (Figure 5). The Eddy Covariance method is a tower based micro-meteorological method that averages GHG fluxes across the ecosystem scale (Aubinet *et al.* 2012). Whereas chamber measurements record concentration of specific GHGs from a limited small-scale area over a certain time-interval and frequency. The gas flux is calculated based on an increase (efflux) or decrease (influx) of gas concentrations in the chamber (Collier *et al*. 2014).

Figure 5. Direct measurements: manual chamber measurement in Suursoo-Leidissoo, Estonia (A), Eddy Covariance tower in Tervalamminsuo, Finland (B), 3D sonic anemometer and part of the flux tower in Siikaneva, Finland, (C) and automated chamber measurement system in Zarnekow, Germany (D). Photos: R. Pajula (A), A-H. Purre (B–C), A. Herrmann (D).

Compared to direct GHG measurements, the GEST approach is less expensive and time consuming (Couwenberg 2011; Couwenberg *et al.* 2011). Therefore, it can be used to assess the effects of climate change mitigation on individual peatlands. However, the GEST approach is not as precise as direct GHG measurements, as it still lacks comprehensive data from different geographic regions, representing all peatland types, and does not cover all variations of weather conditions. Moreover, it does not consider N_2O emissions as these are very erratic in time and space, and there is a lack of widely applicable indicators (Joosten *et al.* 2015). In addition, the movement of aquatic carbon (DIC and DOC) is not considered in GEST. On the other hand, the mapped vegetation offers advantages to upscale results to larger areas.

Other approaches to assess indirect GHG emission can also be used. For example, in forestry, biometry and common allometric relations using biomass production of ecosystems (increase of biomass of growing stock and litter production) can be used. The carbon content of wood, if not measured, is calculated as 50% of the dry weight (Laiho & Laine 1997). The Intergovernmental Panel on Climate Change (IPCC) published a supplement to the 2006 Guidelines for National GHG Inventories (Edenhofer *et al*. 2014), which includes emission factors for organic soils lists based on the land use categories. The main advantage of this methodology is that using land use categories helps to assess the GHG balance at a national scale.

GEST APPROACH FOR GHG EMISSION ASSESSMENT

2.

Photo: R. Pajula

As direct measurements of GHG emissions are laborious, complex, and expensive, the Greenhouse Gas Emission Site Types (GESTs) approach has been developed by the mire research group at Greifswald University, Germany, to assess GHG (CO_2 and CH_4) emissions from degraded and rewetted peatlands using vegetation as a proxy (Couwenberg *et al.* 2008, 2011; Couwenberg 2009, 2011). This approach is based on interlinking vegetation types, water table depth, peat properties and thickness. GHG flux values are assigned to the vegetation types following a standardised protocol and using published emission values from plots with similar vegetation and water level in regions with similar climate and flora (Couwenberg *et al.* 2008, 2011). Currently, the approach identifies 34 GESTs, covering different types of peatlands, pristine and impacted by human activities. In this way, the GEST approach helps to estimate the amount of sequestered tons of GHG emissions in CO_2-equivalents due to rewetting of drained peatlands (Joosten *et al*. 2015).

In 2017, the GEST approach was approved by the Verified Carbon Standard (VCS) as a method to estimate GWP of temperate peatlands (Emmer & Couwenberg 2017). This approach has been further developed, however more detailed investigations and additional data collection from geographical regions other than the temperate zone are necessary to improve it, e.g., by integrating climatic gradients and calibration GESTs described for other climatic regions, adjusting to new vegetation types etc.

Couwenberg *et al.* (2008, 2011) summed up the reasons given in the literature, why vegetation is a good indicator for assessment of GHG emissions:

- Vegetation composition is significantly related to soil moisture content (Ellenberg *et al.* 1992; Schaffers & Sýkora 2000; Koska *et al.* 2001).
- Vegetation is also controlled by other various site factors that determine GHG emissions from peatlands, such as nutrient availability, soil reaction (pH) and land use (history).
- Vegetation is directly and indirectly responsible for the predominant part of GHG emissions through regulating of CO_2 exchange, by supplying organic matter (incl. root exudates) for CO_2 and CH_4 formation, by reducing peat moisture and by providing possible bypasses for methane fluxes via aerenchyma of 'shunt species' (Joabsson *et al*. 1999; Whalen 2005).
- Vegetation reflects the long-time water level conditions and thus provides indication of average GHG fluxes on an annual time scale.
- Vegetation allows fine-scaled mapping (e.g., on scales 1:2,500–1:10,000) that allows the estimation of area size and the GHG emission rate.

The GEST approach includes mapping of vegetation types characterised by the presence of species groups that are indicative not only for specific water level classes but also other site conditions (peat properties, etc.).

Methodology of GEST approach 2.1.

The application of GESTs consists of several steps that includes both desktop studies and field work. The first step is to analyse literature, maps and any other site data about historical land use, reclamation, forestry and peat mining, which can provide an overview of the site and a better understanding about its conditions. This is followed by fieldwork, to obtain precise data about vegetation types and abundance as well as site hydrology, which is used to assign the vegetation into the GESTs.

The crucial point of the application and identification of GESTs is the acquisition of detailed data about the vegetation. In case of peatland restoration projects, this should be completed before the implementation of restoration measures (baseline state) and after a certain time following the restoration actions, when vegetation has adapted to the improved hydrological conditions (post-restoration state). For the determination of GESTs, an assignment of identified vegetation units to the so-called vegetation forms according to Koska *et al.* (2001) is required. The vegetation forms are characterised by the presence or absence of certain ecological-sociological species groups and their common physiognomy, which indicate certain site conditions like moisture, trophic state and acidity (Ellenberg *et al.* 1992).

The principal scheme of GEST approach consists of the four steps (Figure 6):

I. Determination of the vegetation form.
II. Identification of GESTs.
III. Spatial information assessment.
IV. GHG emissions estimation.

I. Determination of Vegetation Form

1.

Differentiation of all homogeneous vegetation units in the field

2.

Identification of the correct vegetation form (*Open peatland sites, Meadows, Forest and shrubberies,* etc.)

3.

Localization and positioning of the vegetation units

4.

Association of occurring species groups to hydrological and chemical site factors

II. Identification of GESTs

1.

Selection of the corresponding GEST from the GEST-Catalogue

2.

Decision to include and describe a new GEST in the GEST-Catalogue

III. Spatial Information Assessment (mapping of GEST units)

IV. GHG Emissions Estimations

1.

Non-forested GESTs:
Multiply emission factor by the spatial information (in ha) to obtain the annual GHG-emissions

2.

Forested GESTs:
a. Multiply emission factor by the spatial information (in ha) to obtain the annual GHG-emissions;
b. Additional information to the growth rates of biomass of the wooden vegetation

Figure 6. The principal scheme of GEST approach applied in the *LIFE Peat Restore* project.

2.1.1. Determination of the vegetation form

First, a differentiation of homogeneous vegetation units, which are related to physiognomic-structural aspects, ecological conditions and floristic composition, is performed (Figure 7). These vegetation units are later assigned to groups, like *Forested peatlands* (forest and shrubberies, etc.) or *Open peatland areas* (grassland, meadows, bare peat, peat moss lawn, etc.). In addition, in every distinguished vegetation unit a representative assessment of plant species composition and coverage have to be performed based on the principles of the Braun-Blanquet (1964) approach. The next step includes localization and positioning of the vegetation units using GPS and transferring these units in an appropriate aerial map or electronic device with quantitative area (in ha) information of every unit in every site. Finally, the presence or absence of *ecological-sociological species groups* (Koska *et al*. 2001) has to be determined. These groups are related to characteristic hydrological and chemical parameters,

Figure 7. Field work for vegetation assessments in the *LIFE Peat Restore* project sites: A – Plant cover estimation in Suursoo-Leidissoo site (Estonia). 10×10 m monitoring plot with smaller subplots, their borders marked with a tape; B – tree height measurement with electronic height metre on the vegetation monitoring plot in the Suursoo-Leidissoo site; C–D – mapping of GEST units in Pūsčia (C) and Sachara (D) peatlands (Lithuania). Photos: R. Pajula (A), L. Truus (B), J. Sendžikaitė (C) and Ž. Sinkevičius (D).

i.e., water level, trophic level (expressed as the peat C:N ratio), base richness (pH) (*Tables 1–2*). Of all the available parameters, the mean annual ground water level is considered to be the best single explanatory variable for CO_2 and CH_4 emissions (Couwenberg *et al.* 2011; Joosten *et al*. 2015). The GEST approach describes the mean annual water level in soil moisture classes (Koska *et al*. 2001; *Table 1*). Direct water level measurements are not obligatory, but more precise information about site hydrology would improve the GEST identification.

Table 1. Soil moisture classes and associated water tables (modified after Koska *et al*. 2001). Soil moisture classes are characterised by: WLw: long-term median water level in the wet season; WLd: long-term median water level in the dry season; and WD: water supply deficit. Seasonally alternating wetness is indicated by a combination of different classes, e.g., 5+/4+ refers to a WLw within 5+ range and a WLd within 4+ range. Strongly alternating wetness is indicated by a tilde-sign, e.g., 3 refers to a WLw within 4+ range and a WLd within 2+ range (according to Joosten *et al*. 2015).

Soil moisture class	Water level relative to surface (+ above, - below)
7+ Upper sublittoral	WLw/WLd: +250 to +140 cm
6+ Lower eulittoral	WLw: +150 to +10 cm; WLd: +140 to +0 cm
5+ Wet (upper eulittoral)	WLw: +10 to -5 cm; WLd: +0 to -10 cm
4+ Very moist	WLw: -5 to -15 cm; WLd: -10 to -20 cm
3+ Moist	WLw: -15 to-35 cm; WLd: -20 to -45 cm
2+ Moderately moist	WLw: -35 to-70 cm; WLd: -45 to -85 cm
2- Moderately dry	WD: <60 l/m^2
3- Dry	WD: 60–100 l/m^2
4- Very dry	WD: 100–140 l/m^2
5- Extremely dry	WD: >140 l/m^2

Table 2. Trophic level and pH scale for peatlands (according to Succow & Stegman 2001)

Peat properties	Abbreviation	Characteristics
Trophic level		
Oligotrophic – very poor	o-vp	C/N >40
Oligotrophic – poor	o-p	C/N 33–40
Mesotrophic – rather poor	m-lm	C/N 26–33
Mesotrophic – medium	m-hm	C/N 20–26
Eutrophic – moderately rich	e-mr	C/N 13–20
Eutrophic – rich	e-r	C/N 10–13
Polytrophic – very rich	p-vr	C/N <10
pH scale		
Acid	Ac	pH_{KCl} <4.8
Sub-neutral	Sub	pH_{KCl} 4.8–6.4
Alkaline	Alk	pH_{KCl} >6.4

2.1.2. Identification of GESTs

The aforementioned vegetation forms were assigned to a GEST, as indicated in the project's *Updated GEST Catalogue* (*Annex 3*). First the GEST catalogue by Reichelt (2015) was updated during the implementation of the *LIFE Peat Restore* project using both assessed field data and the following literature (Audet et *al.* 2013; Drösler *et al.* 2013; Juszczak, Augustin 2013; Ojanen *et al.* 2013; Günter *et al*. 2015; Hommeltenberg *et al.* 2014; Koch *et al.* 2014; Minke 2015; Vanselow-Algan *et al.* 2015; Wilson *et al.* 2016; Fortuniak *et al.* 2017). The project's *Updated GEST Catalogue* (see *Annex 3*) provides information on the GESTs and their grouping, corresponding vegetation forms, characteristic plant species, emission factors, comments on project amendments and the data references. In particular, references used in Reichelt (2015) were reviewed and complemented with new scientific literature up to 2018 (when the GESTs were assessed). As a result, emission factors ($CO_{2,}$ CH_4 and the combined GWP estimates) used in this project are highlighted in bold font. If the used emission factors differ from the original values of Reichelt (2015), the original values are provided in brackets.

As large areas of the project's peatlands are covered by woody vegetation, and emission factors of forested GESTs are less known, because common direct GHG chamber measurements are not possible to collect, due to vegetation height, literature on GHG from forest biomass were analysed. In accordance with Spangenberg (2011), emission factors from GESTs of open unused peatlands with a similar soil moisture class and trophic levels were used (extrapolation). Emission estimates from relevant literature reflecting woody vegetation are given in brackets. Part of these sources rely on Eddy-Covariance tower measurements.

In several cases, vegetation units identified represented the equivalent site conditions and vegetation forms assigned to certain GESTs of Reichelt (2015). However, several vegetation units identified during the project did not correspond to any of the existing GESTs of the catalogue (Reichelt 2015). After review, six **new GESTs** were incorporated into the project's *Updated GEST Catalogue* (see *Annex 3*; in red) based on the following reasons:

a) differences in soil moisture classes. Significant parts of the project sites, especially in Lithuania, are severely damaged due to deep drainage. This is confirmed by water level measurements, and the assessed vegetation units which indicate these dry site conditions of soil moisture classes 2- or even 3-. Similarly, "dry" vegetation forms assigned to GESTs are not listed in Reichelt (2015). Therefore, four new "dry" GESTs needed to be defined: 2. *Moderately moist/dry bog heath,* 5. *Bare peat dry (OL),* 21. *Dry forest and shrubberies (OL)* and 25. *Dry forests and shrubberies (ME/EUT)*.

b) differences in species composition and tree layer. In Latvian and Estonian, site vegetation forms (sensu Koska *et al.* 2001) with alkaline and very moist or wet conditions were identified. These vegetation forms could not be assigned to any of the previous GESTs listed in Reichelt (2015). Therefore, a new GEST 10. *Very moist/wet calcareous meadows, forbs and small sedges reeds* was identified.

In the Estonian site and the three Lithuanian sites another new GEST was defined due to differences in species composition and physiognomy: 18. *Wet peat moss lawn with pine trees.* This new site type is similar to the GEST 16. *Wet peat moss lawn* in Reichelt (2015) but features a high abundance of sparsely growing *Pinus sylvestris.*

More details on the six new GESTs are provided in *Chapter 4.1.2.* and *Annex 4*.

Assessment of spatial information 2.1.3.

Each identified GEST needed to be precisely mapped to obtain the following spatial information; size (in ha) and location as well as the estimated number of trees per unit area for forested peatlands. As the identified vegetation units were previously mapped and assigned to corresponding vegetation forms, it was not complicated to combine all vegetation forms that belong to the same GEST. The distinguished mapped GESTs were matched with the attribute tables to provide comprehensive data on all obtained information: vegetation description, water level, data on chemical analysis, tree density, etc.

In many areas, especially in relatively small peatlands, the mapping may be simple if the vegetation is rather homogeneous. Then it may be enough to conduct a field survey using GPS and orthophoto maps or combine other spatial data (e.g., topographic maps or LIDAR data). In cases with more heterogeneous vegetation or large areas, the mapping of vegetation units is challenging. In such cases, an integrated method was used to map the vegetation: data of the field studies were combined with map data and remote sensing data (aerial photographs, satellite data, LIDAR data and drone images). The primary and preliminary information about a site's state can be obtained from aerial photographs or remote sensing images. The next step after this was to visit the site and find relations between the units distinguished on maps and actual habitat types (vegetation units). More detailed information about the results of the application of remote sensing methods are provided in *Chapter 5.2*.

2.1.4. Estimation of GHG emissions

After mapping and obtaining the area of each GEST, the GHG emissions were estimated. To obtain the annual GHG emissions per GEST, its area (in ha) was multiplied by the respective emission factor (in Carbon dioxide equivalents, CO_2-eq's). This allows for the total GHG emissions (in CO_2-eq's) all of the GESTs to be estimated. It should be noted that GHG emissions estimations for non-forested and forested GEST differ. As tree biomass is an important factor of the GHG balance in peatlands, it was therefore included into calculations used to estimate the GHG emissions for the forested GESTs. Information about the growth rates of wooden vegetation biomass was considered. However, current studies have shown that carbon sequestration of tree biomass in drained peatland forests does not outweigh the amount of carbon that is released during the decomposition of peat (Hommeltenberg *et al.* 2014b). The formulas and tables used to calculate the fixed carbon in living (wooden) biomass are provided in *Annex 1*.

The changes of potential GHG emissions were calculated for 3 scenarios: (1) *Baseline* – before restoration measures, (2) *Post-restoration* – 50 years after implementation of restoration activities and (3) *Spontaneous succession* – without any restoration measures (50 years later). In the *LIFE Peat Restore* project, GHG emissions were assessed for all three GHG emission scenarios on the existing and predicted GESTs and corresponding emission factor data (Updated GEST-catalogue (see *Annex 3*), 2018; Reichelt 2015; Couwenberg 2011; Couwenberg *et al*. 2011; Joosten *et al.* 2015). The differences between the two scenarios (1) and (2) provides an estimate of the potential to reduce GHG (or GWP).

The predicted estimates of changes in GESTs, in the *Post-restoration scenario*, is quite complicated due to many factors, and can potentially affect the desired outcomes (Figures 8–10). To predict the realistic scenario results, a wide range of factors that impact a site needs to be assessed, e.g., hydrological modelling data, actions foreseen in planning documents (e.g., nature management plans), climatic conditions, activities outside the project site (planned reclamation, agricultural or any other human activities expansion), as well as the judgements and predictions by experts. Following analysis of these variables, the potential vegetation changes can be processed, and future GESTs' coverage can be predicted.

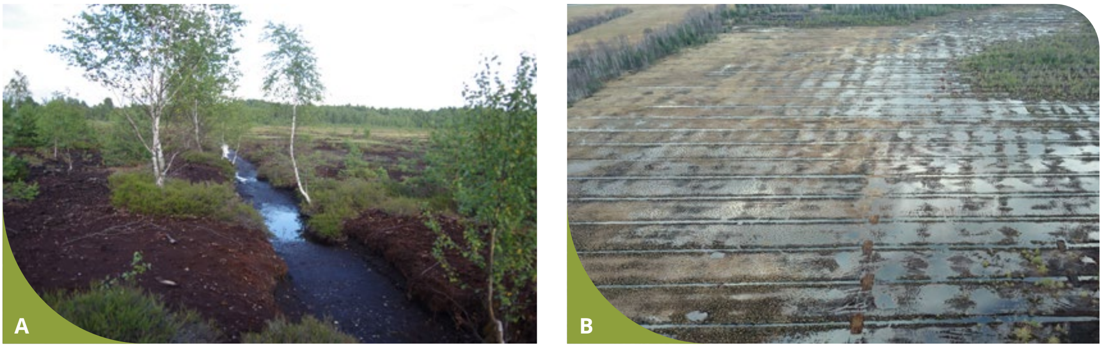


Figure 8. Bare peat and open drainage ditches (A) gradually will overgrow by typical bog vegetation after rewetting (B) in Pūsčia peatland (Lithuania). Photos: Jarašius L. (A) and Ž. Sinkevičius (B).

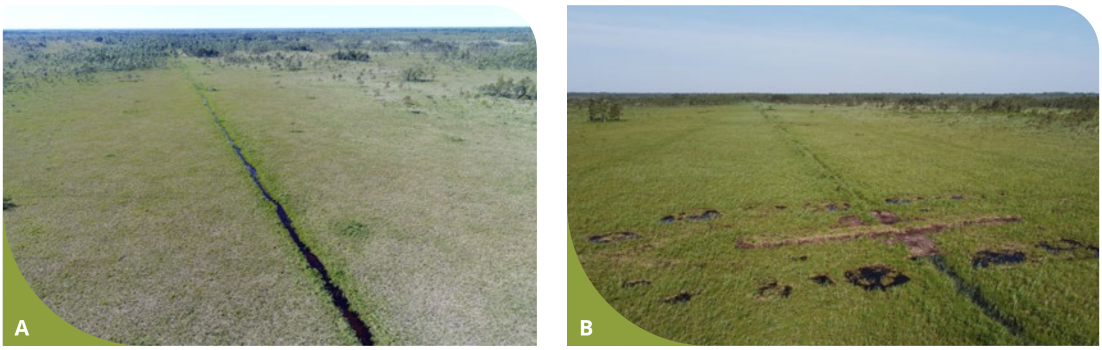


Figure 9. Pennu ditch in GEST 10. *Very moist/Wet calcareous meadows, forbs and small sedges reeds* before dam building (in May 2018; A) and after (in June 2021; B) in Suursoo-Leidissoo peatland (Estonia). Photos: R. Pajula.

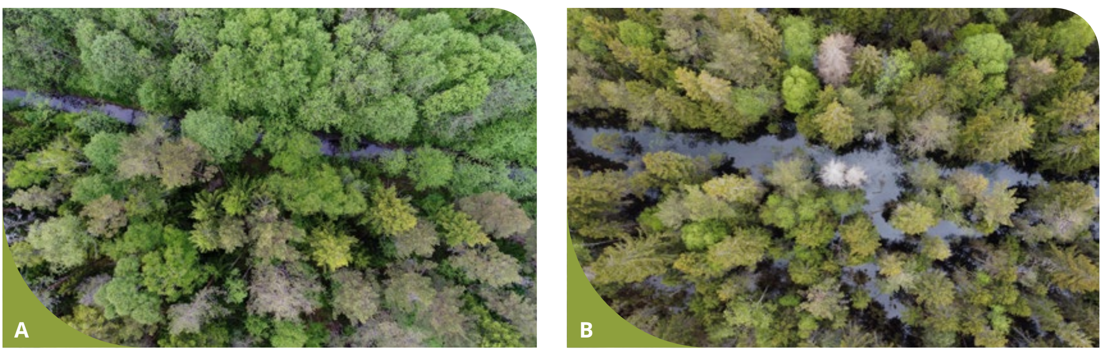


Figure 10. Forest developed due to drainage ditch around Kaldamäe stream before restoration measures (A; in June 2018) and prolonged flooding around stream after building dams (B; in June 2021) in Suursoo-Leidissoo peatland (Estonia). Photos: R. Pajula.

2.2. Practical example of calculating GHG emissions using the GEST approach

Using the Suursoo-Leidissoo project site (3340 ha) in Estonia as an example, we show the potential distribution of the GESTs for the three scenarios (Figure 11; see Subchapter 2.1.4). First, we mapped the distribution of current GESTs to form the *Baseline scenario.* Second, based on the predicted increase in water level, because of damming ditches, we modelled and mapped the *Post-restoration* distribution pattern of GESTs on the site. Third, we modelled and mapped the distribution of plant cover (as GESTs) using the *Spontaneous scenario* (without restoration measures).

Figure 11. GEST distribution of three scenarios for the Suursoo-Leidissoo project site in Estonia.

The results demonstrate that whatever the scenario is, up to five GESTs were identified. GWP for the three scenarios were calculated by multiplying the area of each GEST with the specific emission factors as outlined in the *Updated GEST catalogue* (see *Annex 3*). Our *Post-restoration scenario* calculations predicted that GHG emission from the site may decrease by more than 30% (from 18 575 to 12 936 t CO_2-eq./yr) within 50 years. In contrast, the S*pontaneous scenario* (without restoration measures) indicates that GHG emission would increase by about 60% (from 18 575 to 29 128 t CO_2-eq./yr; *Table 3*).

Table 3. GEST scenarios and predicted changes of GWP in Suursoo-Leidissoo project site, Estonia.

GESTs		GWP estimate, t CO_2 eq./ ha/ yr*	GEST scenarios					
			BASELINE		PROJECT (RESTORATION)		SPONTANEOUS SUCCESSION	
			Area, ha	Total GWP, t CO_2 eq./yr	Area, ha	Total GWP, t CO_2 eq./yr	Area, ha	Total GWP, t CO_2 eq./yr
10.	*Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT)*	2.9	602	**1745.8**	1175	**3407.5**	51	**147.9**
18.	*Wet peat moss lawn with pine trees (ME)*	4.1	823	**3374.3**	1207	**4948.7**	435	**1783.5**
24.	*Very moist forests and shrubberies (OL)*	4.7	859	**4037.3**	504	**2368.8**	974	**4577.8**
27.	*Moist forests and shrubberies (ME)*	12.2	733	**8942.6**	144	**1756.8**	1854	**22618.8**
28.	*Very moist forests and shrubberies (EUT)*	1.6	297	**475.2**	284	**454.4**	0	**0.0**
TOTAL:			3314	**18575.2**	3314	**12936.2**	3314	**29128.0**

*Data according to the Updated GEST catalogue (see *Annex 3*).

3. DIRECT GHG MEASUREMENT METHODS IN THE *LIFE PEAT RESTORE* PROJECT

Photo: R. Pajula

GHG measurement setup 3.1.

Greenhouse gas studies must be set up keeping in mind the purpose of the study, therefore different set-ups can be applied depending on the aim of the study, site characteristics, and accessibility of the site, availability of resources, and other considerations. Although all project partners of the *LIFE Peat Restore* project were using the transparent chamber method, three different chamber set-ups were used for GHG measurements due to availability of technology. Using similar methods, although with slightly different technological approaches, may lead to slight difference in conclusion, and thus must be taken into consideration. However, the general directions of fluxes and orders of magnitude were similar in the *LIFE Peat Restore* project.

In Estonia's Suursoo-Leidissoo peatland, the largest restoration site on the *LIFE Peat Restore* project, GHG measurement points were positioned along three transects (Figure 12A). Transects started near the ditch in the area with the strongest drainage impact and extended 200–400 m, where the effect of drainage was weaker (and vegetation more "natural"). Transects and measurement points were located to distinguish the GESTs in the study site, so that GHG measurements could be performed. In other project areas, one representative measurement station with 3 (Poland, Germany) or 5 (Latvia, Lithuania) measurement collars were set per GEST in the project area (Figure 13). GHG measurement points are located close to other measurement points like water level, peat chemistry, solar radiation, and vegetation.

It can be expected that restoration activities, firstly influence vegetation communities and therefore GHG fluxes near ditches that are more affected by drainage. Also, the spatial distribution of GESTs are closely related to the effectiveness of drainage. Changes in vegetation communities and GHG balances are slower further away from the ditches. This can be tested with the transect method used in Suursoo-Leidissoo restoration site, whereas using the set-up used in other project sites still gives information about the GHG fluxes related to the studied GEST.

In other restoration sites (in Latvia, Lithuania, Poland, and Germany) one GEST was chosen per restoration site for GHG measurements in the most representative and accessible location on the site (*Table 4*). Such setup gives similarly good information about the GHG balance of a certain GEST. However, this does not allow analyses and generalisations of the broader effect of restoration for the whole study site.

One of the original project tasks was to fill gaps in the *GEST catalogue* by performing direct measurements in new and the most prevailing GESTs in each country. From the six new GESTs identified during the project area mapping (see *Chapters 2.1.2.* and *4.1.2.*), GHG emissions were directly measured in three of them: 5. *Bare peat dry (OL)*, 10. *Very moist/Wet calcareous meadows, forbs and small sedges reeds,* and 18. *Wet peat moss lawn with pine trees*.

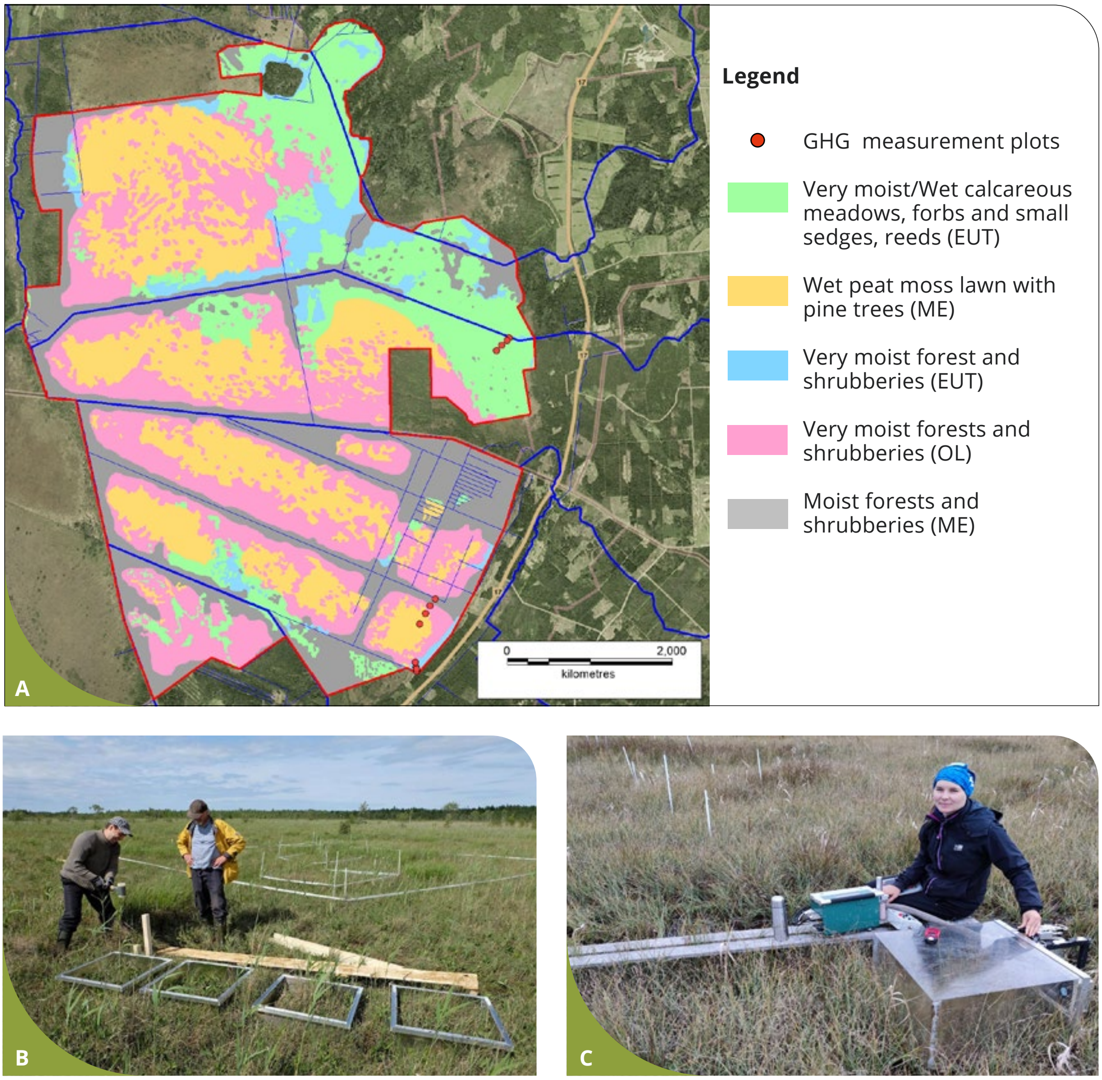


Figure 12. Locations of GHG measurement plots and distribution of GEST types in Suursoo-Leidissoo restoration site (Estonia, A, base map from Estonian Land Board). Each measurement plot consists of four measurement points/collars (B–C). Photos: R. Pajula.

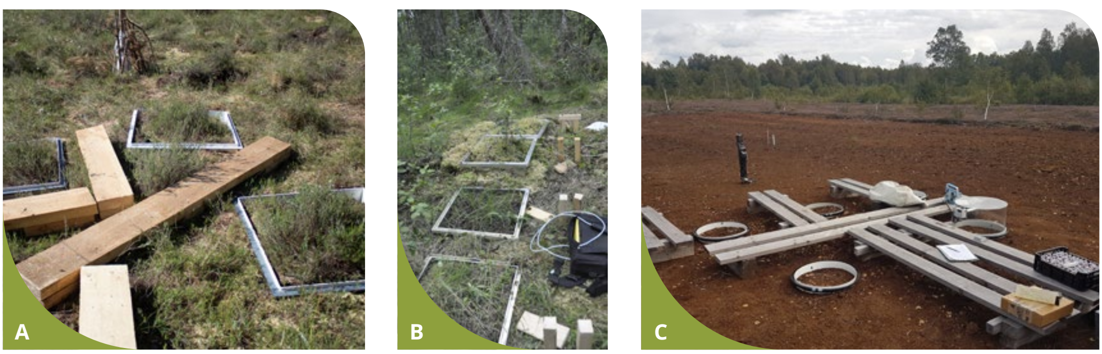


Figure 13. Examples of different measurement plots in the *LIFE Peat Restore* project sites: A – Wielkie Bagno, B – Suursoo-Leidissoo peatland, C – Aukštumala peatland. Photos: A. Herrmann (A), A.-H. Purre (B) and G. Spalva (C).

Data of the direct GHG measurements were recorded over three years (2018–2020) in Estonia, Poland and Germany and over two years (2019 and 2020) in Latvia and Lithuania. In total, GHG measurements were collected in 11 GESTs. The number of measurement plots varied between each GEST based on size, vegetation and accessibility. In parallel, indirect GHG estimations for each *LIFE Peat Restore* project site were estimated according to the GESTs methodology (see *Chapter 2.2.*).

Table 4. The list of GESTs and number of measurement collars where direct GHG measurements were carried out. Project sites: EE-SU – Suursoo-Leidissoo peatland, LV-AU – Augstroze Nature Reserve, LV-BA – Baltezers Mire Nature Reserve, LV-EN – Lake Engure Nature Reserve, LT-AM – Amalva peatland, LT-AU – Aukštumala peatland, LT-PU – Pūsčia peatland, LT-SA – Sachara peatland, PL-WB – Wielkie Bagno, DE-BB-2 – Biesenthal Becken Nature Reserve.

GESTs		Estonia	Latvia	Lithuania	Poland	Germany
5.	*Bare peat dry (OL)* NEW			LT-AU – 5		
6.	*Bare peat moist (OL)*			LT-PU – 5		
9.	*Wet meadows and forbs*		LV-BA – 5			
10.	*Very moist/Wet calcareous meadows, forbs and small sedges, reeds* NEW	EE-SL – 16	LV-EN – 5			
11.	*Very moist bog heath*				PL-WB – 3	
16.	*Wet peat moss lawn*		LV-AU – 5			
18.	*Wet peat moss lawn with pine trees* NEW	EE-SL – 8				
22.	*Moderately moist forest and shrubberies (OL)*			LT-AM – 5		
24.	*Very moist forests and shrubberies (OL)*	EE-SL – 8				
27.	*Moist forests and shrubberies (ME/EUT)*	EE-SL – 4		LT-SA – 5		DE-BB – 3
28.	*Very moist forests and shrubberies (ME/EUT)*	EE-SL – 12				

NEW – a new GEST.

3.1.1. Measuring equipment

Different measurement equipment, including two types of chambers, were used to estimate GHG fluxes of different GESTs in the *LIFE Peat Restore* project sites. Selection of the equipment depends on the site conditions, and also on resources, such as funding, time and manpower. For interpretation of measurement results, it is necessary to consider the equipment used, the site location and characteristics and vegetation type. Therefore, detailed descriptions of the equipment used are provided below.

Measurement collars

In Germany and Poland square PVC-collars with size 75×75 cm reaching up to 15 cm depth were used (Figure 13A). In the Estonian site square aluminium collars with size 60×60 cm reached about 20–30 cm depth into the peat (Figure 13B). Round plastic collars with a diameter of 50 cm were installed at a shallower depth (5–10 cm) in Latvia and Lithuania, and impacting the roots less than the deeper collars (Figure 13C). Thus, the different collar sizes used cover different areas and amounts of vegetation.

Measurement chambers

In the *LIFE Peat Restore* project three chamber types were used:

- transparent *Plexiglas* chambers (size 60×60×30 cm, volume – 110 l) were used for all measurements in Estonia. It was covered with an opaque hood for respiration, CH_4 and N_2O measurements.
- transparent square *Plexiglas* chambers (size 78×78×50 cm, volume – 304 l) were used for NEE measurements, and the same size white square plastic chambers for measuring R_{ECO} and other GHGs in Polish and German sites.
- transparent *Plexiglas* chambers (diameter 50 cm, height – 35 cm, volume – 70 l) were used for NEE and together with an opaque hood also for R_{ECO} measurements. White opaque plastic conical chambers (basis diameter – 50 cm, height – 40 cm, volume 65 l) were used for CH_4 and N_2O flux measurement in Latvian and Lithuanian peatlands.

In Latvia and in Lithuania, the transparent chamber was climate-controlled via internal and external metal thermoelectric cooling ribs powered by a rechargeable 12-V battery. In addition, ice packs were fixed inside the chamber. Chambers are also equipped with PAR (transparent chambers only) and temperature sensors for logging variables inside the chamber during the greenhouse gas flux measurements and temperature control of the transparent chambers. In Latvia and Lithuania TRP-2 probe (PP Systems, Hitchin, UK) was used to measure PAR and temperature inside the chamber, and an additional temperature sensor was used to measure the ambient air temperature.

In the Estonian site, chamber and ambient temperature sensors were built into the chamber control to control the cooling system, keeping the chamber temperature ±2 °C from the ambient temperature. Additionally, for measuring PAR inside the chamber PAR sensor LI-190R (Li-Cor, Nebraska, USA) was installed into the chamber.

For manipulating the PAR levels inside the chamber during the NEE measurements, shading nets were used. In Estonia gardening shades were used reducing 65% and 88% of ambient PAR, whereas in Latvia and Lithuania covers made from synthetic textile reduced 50% and 25% of ambient PAR. In Poland and Germany, several NEE measurements were done during different times of day creating natural PAR variations and shading nets were not used. This is possible if the number of measurement collars is low and distributed close to each other, however it is hard to manage, if the measurement collars are distributed on the large areas.

Gas analysers

Different gas analysers can be used for measuring different GHGs in the sites. Li-Cor (Nebraska, USA) analysers were used for CO_2 flux measurements in Estonian (LI-6400), Polish and German (Li-810) project sites. An EGM-4 (PP Systems, Hitchin, UK) was used in Latvia and Lithuania. The used infra-red gas analysers (IRGA) have similar working principles, but they vary in accuracy, weight and price level. In addition, they have different possibilities to combine auxiliary chambers and sensors for measuring air and peat temperatures, PAR, and H_2O, as well as controlling these variables for conducting more sophisticated experiments.

In the Estonian site, CH_4 and N_2O were measured on the site with a separate IRGA Gasmet DX-4030 (Gasmet Technologies Inc, Vantaa, Finland). This IRGA's detection limits for CO_2 is <10 ppm, CH_4 is 0.06 ppm, and N_2O is 0.02 ppm. Although this IRGA is also suitable for CO_2 flux measurements, the Li-6400 was used due to higher accuracy of the latter, and availability. In other countries of *LIFE Peat Restore*, samples were collected from the chamber headspace by gas-tight syringes and bottles and transported to the laboratory for analysis. In Latvia and Lithuania, the concentrations of CO_2, CH_4 and N_2O in the collected air samples were determined using the Shimadzu GC-2014 (Shimadzu Inc., Kyoto, Japan) gas chromatographic system (equipped with an electron capture detector (ECD), a flame ionisation detector and a Loftfield autosampler (Loftfield *et al.* 1997) in the Climate Change Laboratory of the Department of Geography, University of Tartu, Estonia. In Poland and Germany, the samples were analysed in the laboratory with a gas chromatograph (GC-2010 Plus AF; Shimadzu Inc., Kyoto, Japan) equipped with a Flame Ionization Detector (FID) for analysing the methane concentration (detection limit 1 ng), Thermal Conductivity Detector (TCD) for analysing the CO_2 concentration (detection limit 1 µg) and an Electron Capture Detector (ECD) for analysing the N_2O concentration (detection limit 1 pg).

3.1.2. GHG measurements with chambers

Due to site accessibility during winter and funding limitations, GHG measurements were collected only during the growing season. The measurements started in April/May, and were done at least once a month until the end of October/November. In the first measurement year (2018) measurements started somewhat later (July) in Estonia due to building of measurement infrastructure (i.e., setting up the measurement plots and building boardwalks).

Measurements were collected during the daytime between 9 to 17, local time. In Estonia, CO_2 measurements were done during a two-minute period and CO_2 content in the chamber was recorded every 15 seconds. In Latvia and Lithuania, the CO_2 concentrations were recorded during a 2 min and 30 second period, with recordings taken every second, three replicas of CO_2 flux measurements were collected in each measurement collar during each session. In Germany and Poland, three- and six-minutes measurement period for NEE and R_{ECO} were used, respectively and the CO_2 flux was recorded every second. In total, 7 (Estonia), 12 (Latvia and Lithuania) and 15 (Germany and Poland) CO_2 concentration measurements were collected in each CO_2 flux measurement series in each measurement collar.

In addition to full-light measurements, two additional measurements with artificial shading were done in the Baltic countries (Estonia, Latvia, and Lithuania) to measure NEE under different light conditions (Figure 14). In both Poland and Germany, the measurements started early in the morning before sunrise and covered the natural light conditions over the whole day to capture the full spectrum of radiation. Ambient light levels were observed to be stable during the light and shaded measurements. The chambers were ventilated between each flux measurement. Finally, the chamber was covered with an opaque hood in Estonia, whereas the other project partners used a separate opaque chamber.

To measure the CH_4 and N_2O fluxes, the chambers were also covered with an opaque hood or opaque chamber was used. In Estonia, methane and nitrous oxide flux measurements were done during a 10-minute period with the CH_4 and N_2O content in the chamber recorded every 20 seconds, in total, 30 recordings were collected from each collar during each measurement session. The chamber was ventilated between each measurement to ensure ambient gas concentrations inside the chamber and avoid contamination in Estonia. Whereas the other project partners used different chambers for each collar. In countries where samples were analysed in the laboratory, CH_4 and N_2O samples were collected for one hour. In Latvia and Lithuania, samples were taken every 20 minutes (totalling four samples) and in Poland and Germany samples were taken every 10 minutes (totalling seven gas samples) per chamber. In addition, ambient air samples were collected to compare the concentration measured in the samples from the chamber.

CH_4 and N_2O greenhouse gases measurement samples were collected using syringes and drawn into 50 ml glass bottles (Figure 14D), which were vacuumed to ensure that air from the chamber can be sucked in the bottle. If there was evidence of air leakage between bottle and ambient air (e.g., there is no noise of air movement after the opening of bottle), it was replaced with an additional sampled bottle (8 extra bottles were collected in the field). Usually, around 5–10% of the bottles were replaced due to the clear evidence or suspicion of air leakage. The samples were kept in a dark and cool box and transported to the laboratory within 30 days of measurement. In the laboratory, the concentrations of CH_4 and N_2O were determined with gas chromatographs and suitable detectors described in Subchapter 3.1.1.

Figure 14. GHG measurements with transparent (A), shaded (B) and opaque (C–D) manual chambers in Pūsčia peatland. Photos: J. Sendžikaitė.

Additional parameters measured for reconstructing GHG fluxes

Parameters, such as vegetation distribution and development variables (leaf-area-index of vascular plants (LAI_{vasc}) in Estonia, and average height of vegetation in other countries), groundwater levels (GWL), PAR, air and peat temperatures at 5 cm (Latvia, Lithuania, Poland and Germany) and at 10 cm (Estonia) depth were recorded to reconstruct the spatial and temporal variability of GHG fluxes. These variables were measured during the GHG flux measurement campaigns as explanatory variables for the GHG models. In addition, those variables were either logged (GWL, PAR, air and peat temperatures), or reconstructed via modelling in case of vegetation variables for growing season as an input for GHG models.

LAI inside the collar was derived from direct measurements of plant leaf area parameters (leaf height and width) according to the species-specific shape area equations (see Wilson *et al.* 2007). To model seasonal change in LAI_{vasc} during the growing season, Gaussian normal distribution was used to plot measurements of each data set, depending on species composition, fitting on log-normal models could be preferred in some other sites (Wilson *et al*. 2007). This method provides highly comparable results with directly measured LAI (Wilson *et al*. 2007), while not requiring destructive methods. Expanding the field data sets were performed according to equation 1:

$$LAI_{vasc} = LAI_{max}\, exp\left(-0.5\left(\frac{DOY - x_{max}}{b}\right)^2\right), \qquad \text{(Eq. 1)}$$

Where:

LAI_{max} is the maximum LAI of the vascular plants in the measurement plot during the growing season;

DOY is the day of the year (Julian date);

x_{max} is DOY when the maximum LAI_{vasc} occurs;

b is a shape parameter.

An example of *Sphagnum* and vascular plant dominated measurement plots for the Suursoo-Leidisoo site is provided in Figure 15.

GWL was measured both manually and with automatic loggers using perforated piezometric tubes in all sites during the project. The logging of measurements was recorded at hourly intervals. The amount of measurement wells depended on the amount of GHG measurement points and the microtopographic variability. In the Estonian site, for GHG reconstructions the water level was logged using a 2-hour step in each vegetation measurement plot near the GHG measurement points (data from 12 loggers in total were used for GHG reconstructions).

Automated weather station logging located in the middle of a treeless area of the Suursoo-Leidissoo project site recorded the T_{Air}, PAR, precipitation, air pressure every half hour. In addition, separate PAR sensors and peat temperature sensors were installed in measurement plots with different tree cover and microrelief, and recorded data reading every 30 minutes. In each of the project's GHG measurement sites, soil moisture and temperature sensors were also installed as well as PAR sensors. Furthermore, we also measured the groundwater level close to the measurement plot.

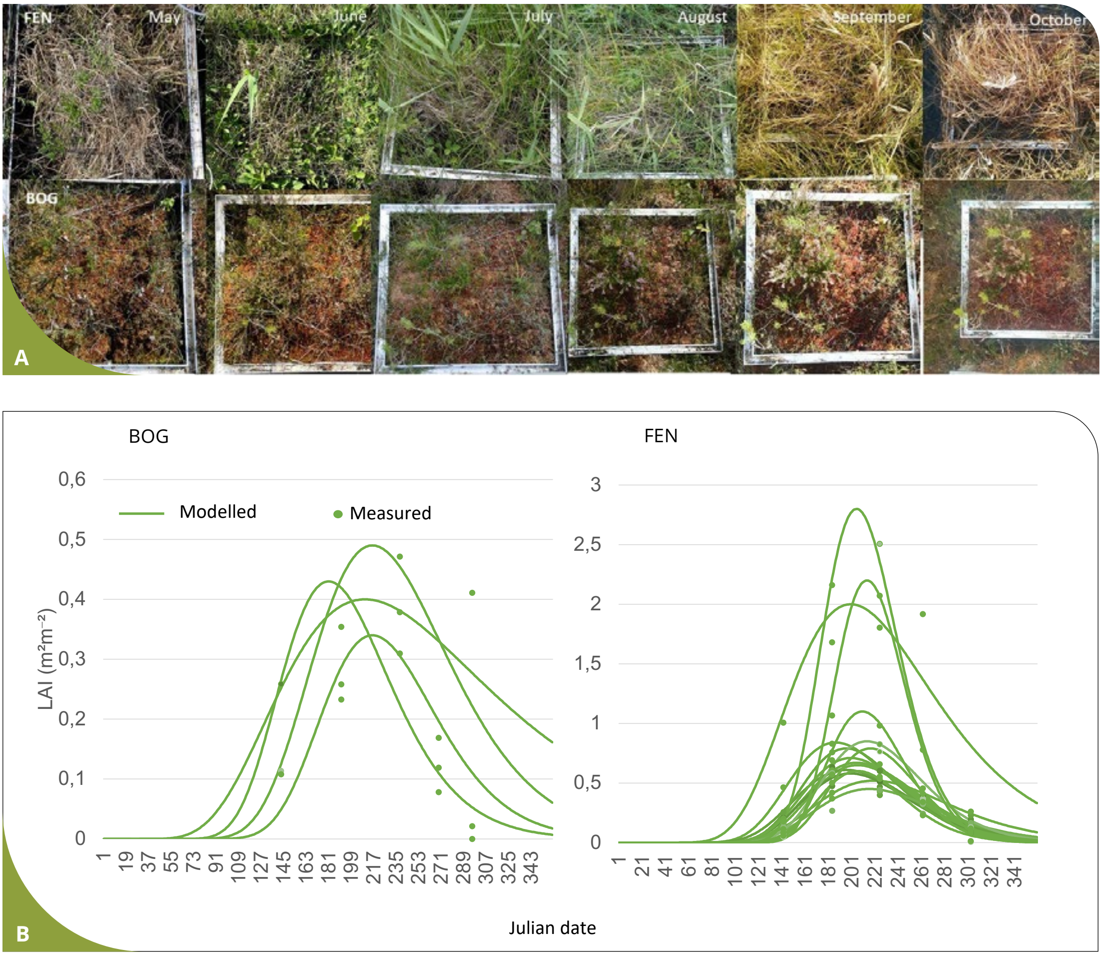


Figure 15. Temporal variations in vegetation development in two measurement points in Suursoo-Leidissoo in 2019 (A), and expanding the field data sets (points) to growing season development (lines) of LAI_{vasc} (B).

3.1.3. The GHG flux calculations and quality control

GHG flux calculations were similar for all the sites, however the formulas were slightly modified. The GHG flux rates were calculated based on linear change in greenhouse gas concentrations in time, volume of the chamber and temperature in the chamber (Eq. 2 in Estonia, Eq. 3 in other countries). The linear method was chosen, as this method was considered suitable by Kandel *et al.* (2016) for flux calculations in the case of short (few minutes) chamber closure periods.

$$F_{CO_2, CH_4, N_2O} = \frac{M \text{ x } P \text{ x } V}{R \text{ x } T \text{ x } coef \text{ x } A} \quad \text{(Eq. 2)}$$

$$F_{CO_2, CH_4, N_2O} = \frac{M \text{ x } P \text{ x } V \text{ x } \Delta c \text{ x } f1 \text{ x } f2 \text{ x } f3}{R \text{ x } T \text{ x } A \text{ x } t} \quad \text{(Eq. 3)}$$

where:

F = GHG - Flux [mg CO_2, CH_4 m^{-2} day^{-1} or µg N_2O m^{-2} day^{-1} for Eq.1; and µg CO_2-C, CH_4-C, N_2O-N m^{-2} h^{-1} for Eq. 2];
M = molar mass of the gas [g × mol^{-1}];
P = atmospheric pressure [Pa];
V = volume of the chamber headspace and the collar [m^3];
Δc = GHG concentration change during the closure time/measurement [ppm, ppb];
f1 to f3 = conversion factors for molecule to element value, for chamber area A to 1 square meter and for chamber closure time to 1 hour;
R = universal gas constant [8.314472 m^3 × Pa / K × mol];
T = air temperature in the chamber [K];
t = chamber closure time [s];
A = chamber area [m^2].

Negative fluxes show an uptake of CO_2 by photosynthesis processes, whereas positive fluxes (efflux) show an increase of CO_2 by respiration (Figure 16). Positive and negative fluxes can also occur for both methane and nitrous oxide. In case of CO_2 fluxes, gross primary production (GPP; negative) was calculated by subtracting Ecosystem Respiration (R_{eco}; positive) from the NEE (can be positive or negative; NEE= P_g + R_{eco}; P_g=NEE-R_{eco}; Figure 17).

Data sets not fulfilling the requirements of data quality were excluded from the further analysis during the flux calculation phase. The data quality requirements were as follows:

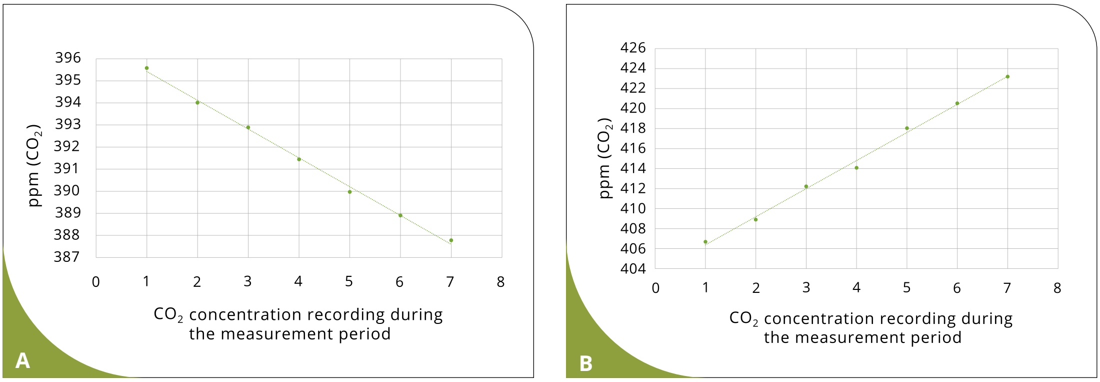


Figure 16. Examples of negative (A, net ecosystem exchange under full light) and positive flux (B, ecosystem respiration) in case of CO_2 measurements.

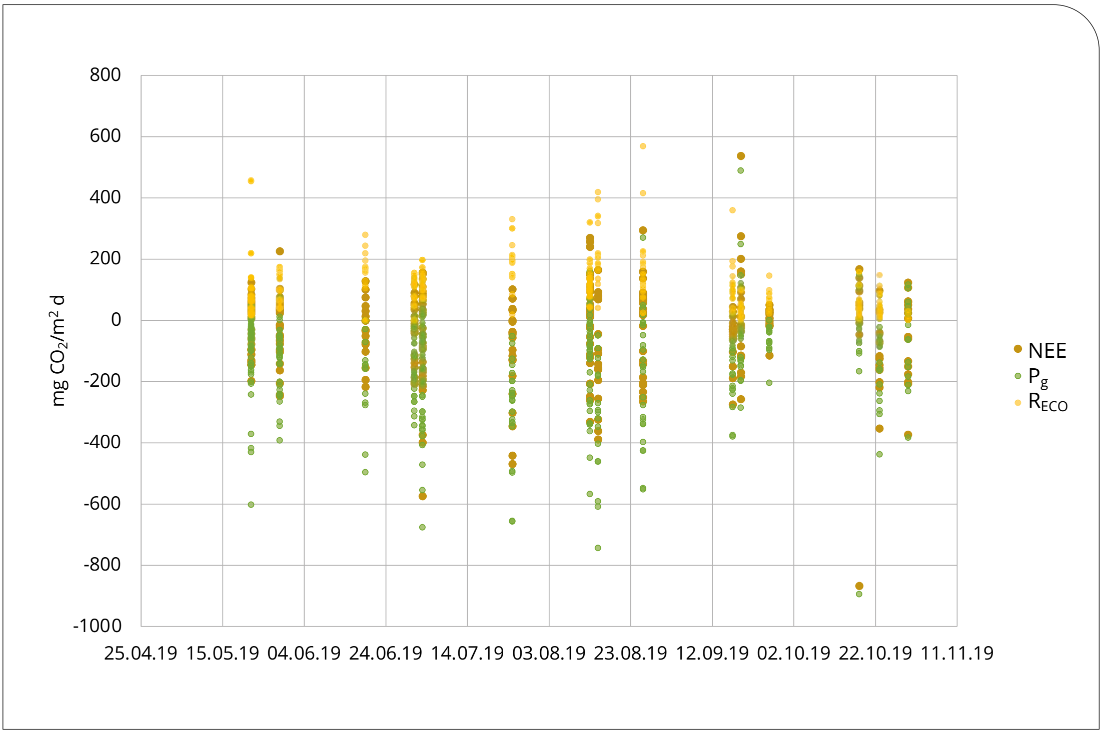


Figure 17. Calculated CO_2 fluxes in Suursoo-Leidissoo in 2019 fulfilling the flux quality criteria.

variation of PAR during the flux measurement should not be more than ±15%, inside temperature of the chamber should not vary more than ±5°C and the determination coefficient (R^2) of the measured flux at least 0.9. Very low fluxes (±0.2 ppm s^{-1}) were accepted regardless of their R^2 value.

3.1.4. The GHG flux reconstructions and quantification of uncertainties

GHG flux reconstructions were derived from "occasionally" measured data and extrapolated to full GHG balances for studied periods. Data sets for GHG were parameterised for each measurement plot to model hourly GHG fluxes during the growing season and to estimate annual GHG balances; the different measurement years (2018, 2019 and 2020) were modelled separately. Different input variables were used to model the different greenhouse gases. CO_2 exchange is mainly explained by differences in PAR and air or peat temperatures, and to a lesser extent spatial and temporal variations in LAI and sometimes GWLs, CH_4 had the strongest relationship with GWL, and N_2O was mainly related with air and peat temperatures.

Ecosystem Respiration

For modelling Ecosystem Respiration (R_{ECO}, mg CO_2 m^{-2} h^{-1}), we used similar equations according to an arrhenius approach like Lloyd & Taylor (1994). For example, characterising the non-linear relationship between temperature (soil or air) and the measured respiration. Equation 4 was used in Latvia, Lithuania, Germany and Poland, whereas Equation 5 was used in Estonia. Both equations use the same modelling parameters, E_0 and b, to describe the sensitivity of the respiration to temperature, and R_{ref} and r_0, to describe the respiration rate at a certain temperature (normally 0°C or a minimum temperature, where biological processes take place). The differences between the equations are the only fitting parameter T_{Soil}/T_{Air}, because of different availability of data or because of a better model fitting result.

$$R_{eco} = R_{ref} \times exp\ (E_0 \times \left(\left(\frac{1}{T_{ref} - T_0}\right)\right) - \left(\frac{1}{T_{Soil/Air} - T_0}\right)) \quad \text{(Eq. 4)}$$

where:
R_{eco} = Ecosystem Respiration [g CO_2-C × m^{-2} × h^{-1}];
R_{ref} = respiration rate at reference temperature;
E_0 = activation energy [K];
T_{ref} = reference temperature; 283.15 [K];
T_0 = temperature, where biological processes are possible; 227.13 [K];
$T_{Soil/Air}$ = soil or air temperature [K].

$$R_{eco} = r_0 \times exp\ (b \times T_{air}) \quad \text{(Eq. 5)}$$

where:
r_0 is the respiration rate (mg CO_2 m^{-2} h^{-1}) at the temperature 0°C;
b is the sensitivity of respiration to air temperature T_{air} (1/°C).

The calculated parameters R_{ref} and E_0 were used subsequently for modelling R_{eco} fluxes for each growing season.

Gross Primary Production

By subtraction of the measured NEE from the modelled R_{ECO} gross photosynthesis (P_g) was derived. For modelling P_g (mg CO_2 m^{-2} h^{-1}) the non-linear model was parameterized based on the saturating response to PAR and in Estonia also taking into account the changes in LAI_{vasc} during the growing season. This was done by the basic function of Michaelis & Menten (1913) adapted to available data based on Equation 6 in Germany, Poland, Lithuania, Latvia and on Equation 7 in Estonia.

$$P_g = 2 \times P_{gmax} \times (0{,}5 - \frac{1}{\left(1 + EXP\left(\frac{-2 \times alpha \times PPFD}{P_{gmax}}\right)\right)}) \qquad \text{(Eq. 6)}$$

where:
P_g = Gross Primary Production [μmol CO_2 * m^{-2} * s^{-1}];
P_{gmax} = maximum gross primary production at full light;
alpha = initial quantum yield;
PPFD = Photosynthetic photon flux density.

$$P_g = \frac{P_{max} \times PAR}{(k + PAR} \times \frac{LAI_{vasc}}{(LAI_{vasc} + s)} \qquad \text{(Eq. 7)}$$

Where:
P_{max} is the maximum hourly P_g at light saturation (mg CO_2 m^{-2} h^{-1});
k is the PAR value, when P_g reaches half its maximum (μmol m^{-2} s^{-1});
s is the value of LAI_{vasc} (m^2 m^{-2}) where P_g reaches half its maximum.

If the vascular plants were not present on the plot, their abundance was very low or it did not change over the growing season, the LAI_{vasc} was not a significant predictor of P_g and therefore LAI_{vasc} was omitted from the model. Afterwards NEE was calculated by adding hourly modelled R_{eco} to hourly modelled P_g.

The calculated model parameters were used to fill the gaps between different measurement campaigns. As independent variables we used the continuously measured temperature and photosynthetic radiation. Finally, measured and modelled fluxes were compared, and all modelled flux rates were summed by measurement to calculate the total yearly GHG fluxes. CH_4 and N_2O fluxes were reconstructed by creating regression models with groundwater levels and air temperature respectively for each GEST. For methane emission reconstructions, linear regression models were used (CH_4 flux = GWL*a+c), where *a* and *c* were model parameters. For N_2O emission reconstructions, we used second order polynomial regression models (N_2O flux = T_{air}2d+T_{air}+f), models were modified and parameterized according to measured data. In case of low or missing correlation between WTL and CH_4 and T_{air} and N_2O respectively, we interpolate the fluxes between each measurement campaign.

To evaluate each model fit, we plotted observed *vs* reconstructed values for each plot in addition to plotting measured *vs* reconstructed Pg and NEE values against PAR and respective R_{eco} values against T_{Air} or T_{Soil}, CH_4 values against GWL, and N_2O values against air temperatures. In addition, measured and modelled flux values were plotted to evaluate model fit. For annual GHG flux estimation data from Alm *et al.* (2007) was used, according to which non-growing season fluxes make up about 30% of growing season fluxes. This is also supported by the results of Järveoja *et al*. (2016) in Estonia. Examples of flux reconstruction quality control are shown in Figure 18.

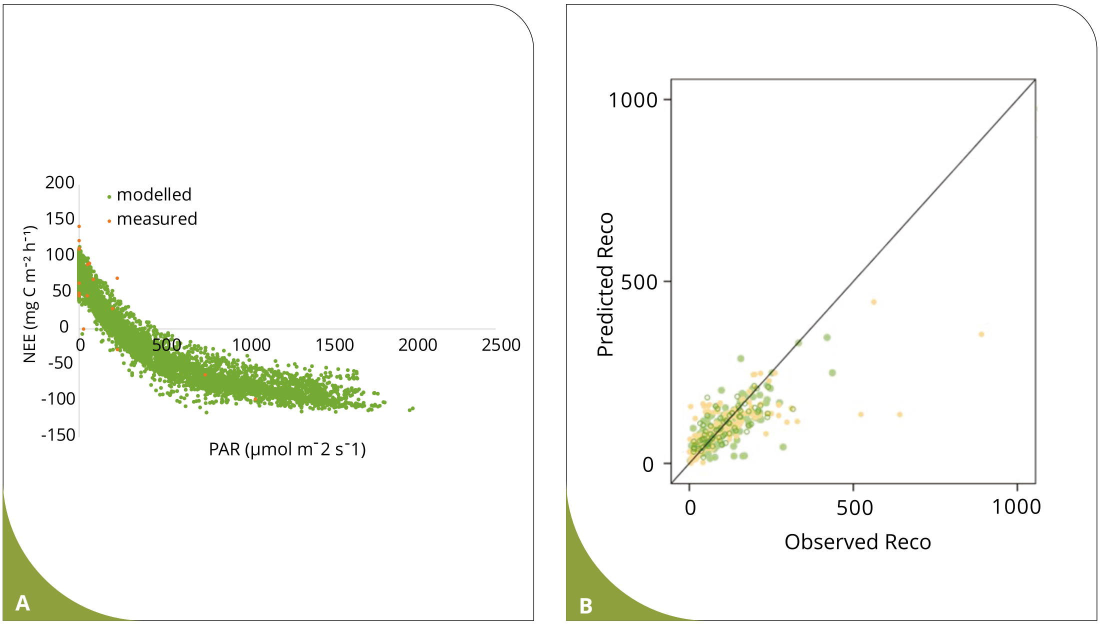


Figure 18. Modelled and measured fluxes plotted against PAR (A) and modelled versus measured fluxes plotted against each-other (B).

Model uncertainties for each of the GHG flux models were calculated in Estonia according to Equation 8, proposed by Aurela *et al.* (2002):

$$E_r = \sqrt{\sum_{i=1}^{n} \frac{(F_{obs} - F_{mod})^2}{(n-1) \times n}} \quad \text{(Eq. 8)}$$

where random error (E_r) is calculated as the difference of observed (F_{obs}) and predicted (F_{mod}) hourly fluxes and averaged across accepted measured hourly flux values. For calculating random error of reconstructed NEE, which include random errors from both, respiration and photosynthesis models, error accumulation principle was used according to Equation 9:

$$E_r = \sqrt{E_{r(P_g)}^2 + E_{r(R_{ECO})}^2} \quad \text{(Eq. 9)}$$

where:

E_r is random error of NEE;

$E_r(P_g)$ is random error of Pg model (according to Equation 4);

$E_r(R_{ECO})$ is a random error of R_{ECO} models (according to Equation 4).

This allowed us to assess and quantify any errors related to flux measurement, calculations and modelling procedures and analyse the uncertainties related with the reported fluxes. In Estonia, random errors related with fluxes remained below 10% of respective fluxes in each measured GEST. Flux errors were not calculated in the other countries. In conclusion, in all the project sites, CO_2 and CH_4 were measured directly with suitable frequency (at least once a month during the vegetation season), using dark and light chambers for CO_2 measurements, and annual GHG emissions were estimated based on modelling, the flux estimations from direct measurements in this project fulfil the criteria set by Couwenberg *et al*. (2011). Currently, the Updated GEST catalogue (*Annex 3*) has not yet been supplemented by measurement results of the *LIFE Peat Restore* project.

4. MEASUREMENT RESULTS

Photo: Z.Sinkevičius

Indirect measurements 4.1.

The GEST assessment 4.1.1.

During the implementation of the Project, 29 GESTs in the 11 project sites were identified. Among them, six new GESTs that are not described in Reichelt (2015) were identified. The description of all identified GESTs can be found in *Annex 4*, which provides detailed information about vegetation cover, hydrology, chemistry, and other characteristics. *Table 5* demonstrates that the project partners have chosen different peatland types for restoration, ranging from fens over transitional mires to raised bogs in different stages of degradation. In total the mapped area of GESTs covers 7259 ha, out of which open peatlands cover 4269 ha and forested peatlands 2990 ha. It should be noted that in Latvia, during the development of the Management Plans for Augstroze NR and Baltezers Mire NR, huge parts of their territories (3090 and 136 ha, respectively) were mapped for GESTs. However, the restoration areas of these Latvian sites were only 148 and 40.5 ha, respectively.

The highest diversity of GESTs was observed in Poland (23) and Lithuania (19), where drainage and peat extraction caused the most severely damaged habitats. The lowest diversity of the GESTs was observed in Estonian (-5) and Latvian (-14), these sites were also less degraded. Despite the fact that the project site in Germany was rather small, with 6 GESTs it was represented by a comparably high diversity (*Table 5*).

The largest spatial area of the open GESTs were *16. Wet peat moss lawn* (2009 ha) and *18. Wet peat moss lawn with pine trees* (863 ha), these GESTs were mainly identified in the Latvian and Estonian project sites. The GEST *10. Very moist/Wet calcareous meadows forbs and small sedges reeds* also occupied a significant part of Estonian and Latvian project sites (649 ha). The smallest spatial area of the open GESTs consists of oligotrophic *7. Bare peat wet, 5. Bare peat dry, 3. Moist reeds and (forb) meadows,* as well as *4. Moist bog heath* (1.7 ha, 2.8 ha, 4.3 ha, 10.7 ha, respectively).

The largest areas of the forested GESTs are constituted of oligotrophic *24. Very moist forests and shrubberies* (862 ha) and *22. Moderately moist forests and shrubberies* (622 ha), as well as meso- and eutrophic *27. Moist forests and shrubberies* (742 ha). The Dry and Moderately moist forested GESTs were particularly common in Lithuanian and Polish sites.

Table 5. GESTs identified in 2018 in the project sites (*Baseline scenario*) in the five *LIFE Peat Restore* countries (area in hectares); newly defined GESTs are marked in red [NEW].

GEST No. and name		EE*	LV*	LT**	PL**	DE**	Total, ha
OPEN PEATLANDS							
1.	*Moderately moist (forb) meadows*	–	15.9	0.9	26.7	–	43.5
2.	*Moderately moist/dry bog heath* [NEW]	–	–	3.6	8.8	–	12.4
3.	*Moist reeds and (forb) meadows*	–	–	4.2	–	0.1	4.3
4.	*Moist bog heath*	–	–	6.4	4.3	–	10.7
5.	*Bare peat dry (OL)* [NEW]	–	–	2.8	–	–	2.8
6.	*Bare peat moist (OL)*	–	–	31.0	0.6	–	31.6
7.	*Bare peat wet (OL)*	–	–	–	1.7	–	1.7
8.	*Very moist meadows, forbs and small sedges reeds*	–	9.4	4.3	–	0.2	13.9
9.	*Wet meadows and forbs*	–	34.5	9.9	–	–	44.4
10.	*Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT)* [NEW]	602.0	46.6	–	–	–	648.6
11.	*Very moist bog heath*	–	–	2.2	10.4	–	12.6
12.	*Very moist peat moss lawn*	–	–	–	29.0	–	29.0
13.	*Wet tall sedges reeds*	–	11.1	–	4.0	–	15.1
14.	*Wet small sedges reeds mostly with moss layer*	–	–	8.6	3.6	–	12.2
15.	*Wet tall reeds*	–	85.6	5.4	0.1	–	91.1
16.	*Wet peat moss lawn*	–	1992.2	3.8	13.1	–	2009.1

17.	*Peat moss lawn on former peat-cut off areas*	–	–	0.7	106.3	–	107.0
18.	*Wet peat moss lawn with pine trees* NEW	823.0	–	40.1	–	–	863.1
19.	*Wet peat moss hollows resp. flooded peat moss lawn*	–	282.5	–	0.3	–	282.8
20.	*Open water/ditches*	–	2.6	8.3	22.5	–	33.4
FORESTED PEATLANDS							
Oligotrophic (OL) peatlands							
21.	*Dry forests & shrubberies* NEW	–	30.5	11.5	9.4	–	51.4
22.	*Moderately moist forest and shrubberies*	–	21.1	91.0	510.1	–	622.2
23.	*Moist forests and shrubberies*	–	303.8	28.7	151.3	–	483.8
24.	*Very moist forests and shrubberies*	859.0	–	–	2.6	–	861.6
Mesotrophic (ME) and eutrophic (EUT) peatlands							
25.	*Dry forests and shrubberies* NEW	–	–	84.4	3.7	–	88.1
26.	*Moderately moist forests and shrubberies*	–	207.2	43.2	263.6	0.7	487.7
27.	*Moist forests and shrubberies*	733.0	1.1	1.0	0.2	6.4	741.7
28.	*Very moist forests and shrubberies*	297.0	46.9	–	7.3	5.4	356.6
29.	*Wet forests and shrubberies*	–	–	–	36.4	2.0	38.4

State of peatlands in 2018:
 * – damaged by draining,
 ** – severely damaged by draining and/or destroyed by peat extraction

4.1.2. New GESTs

Six new GESTs were identified in the *LIFE Peat Restore* project. The reasons why the new GESTs were described are explained in *Chapter 2.1.2*. These new GESTs should be regarded as a supplement to previously described GESTs. Climatic, meteorological conditions, land use or other causes made the description of new GESTs necessary. In this chapter, six new GESTs are briefly introduced. More details are presented in *Annex 4*.

2. *Moderately moist/dry bog heath*

The GEST *2. Moderately moist/dry bog heath* is characterised by a lower water level, higher trophic level in the peat (C:N ratio – 42) and denser coverage of *Calluna vulgaris* compared to GEST *4. Moist bog heath.* This GEST was identified in intensively drained oligotrophic peatlands in Lithuania (LT-AM, LT-PU) and Poland (PL-WB). Due to dry conditions, species that are commonly found in GEST *4. Moist bog heath* (*Drosera rotundifolia, Rhynchospora alba*) are absent. *Calluna vulgaris* dominates in vegetation cover, solitary tussocks of *Eriophorum vaginatum* can be found as well. The tree layer is scarce, the bryophyte layer is formed by brown and feather mosses.

5. *Bare peat dry (oligotrophic)*

The GEST *5. Bare peat dry (oligotrophic)* occurs on heavily drained peatlands damaged by peat extraction, usually shortly after cessation of economic activity. The GEST was identified only in one project site – Aukštumala peatland (LT-AU), which was recently abandoned after peat mining activities. Compared to the GEST 6. *Bare peat moist (oligotrophic)* it is characterised by very scattered vegetation patches (up to 5%) and very low water levels.

10. *Very moist/Wet calcareous meadows, forbs and small sedges reeds (eutrophic)*

The GEST *10. Very moist/wet calcareous meadows, forbs and small sedges reeds (mesotrophic)* is a drainage-impacted alkaline fen, which has spread at the Suursoo-Leidissoo site in Estonia (EE-SL) and the Engure site in Latvia (LV-EN). Both sites developed as a result of terrestrealisation of uplifting coastal areas of the Baltic Sea. Both sites are dominated by low-growing sedges and brown mosses but are also overgrowing by tussock-forming *Molinia caerulea* in dryer sites and by *Cladium mariscus* in the wettest parts in the Engure site (LV-EN). This GEST is found on alkaline and very moist or wet sites.

18. *Wet peat moss lawn with pine trees*

The GEST *18. Wet peat moss lawn with pine trees* is similar to the GEST *16. Wet peat moss lawn,* but in contrast is covered sparsely with trees – mainly *Pinus sylvestris* but may also contain *Betula pubescens*. Coverage of dwarf shrubs is high and *Sphagnum* mosses have almost continuous coverage. The GEST was identified in four project sites (EE-SL, LT-AM, LT-PU, LT-SA). The vegetation composition is almost similar in these sites (see *Annex 4*) although vegetation development history differs. Lithuanian sites developed on oligotrophic (*Sphagnum*) peat while in the Estonia site, *Sphagnum* peat starts to develop on former sedge-brown moss peat (succession initiated by drainage). Dwarf form of *Pinus sylvestris* covers up to 30% in the Lithuanian sites and young (up to 3–4 m height) pine trees grow in the Estonian site. The very dense dwarf shrub layer is typical for the project sites of both countries. The continuous moss cover is mostly formed of *Sphagnum* species, but brown and feather mosses cover the surface below tree crowns.

21. *Dry forest and shrubberies (oligotrophic)*

The GEST *21. Dry forest and shrubberies (oligotrophic)* occurs in peatlands severely damaged by drainage or peat mining activities. The GEST was identified in Lithuania (LT-PU, LT-AM) and Poland (PL-WB, PL-KL). Due to unfavourable hydrologic conditions, *Sphagnum* mosses are almost absent and replaced by other bryophyte species like *Dicranum polysetum, Pleurozium schreberi* and *Polytrichum commune*, whereas the tree layer coverage is very high (up to 80%) and mainly consists of *Betula* spp. The vegetation composition is slightly different between countries. *Picea abies* dominate the tree layer of Polish sites, whereas the Lithuanian sites were mostly dominated by *Betula pendula, B. pubescens*.

25. *Dry forests and shrubberies (mesotrophic/eutrophic)*

GEST *25. Dry forests and shrubberies (mesotrophic/eutrophic)* occurs in similarly damaged peatlands. The GEST was identified in Amalva (LT-AM) and Kluki (PL-KL) project sites. Tree and shrub layers are very dense (up to 90 and 70% coverage, respectively) and dominated by *Betula pendula* and *Populus tremula, Salix* spp., *Frangula alnus* in Lithuania, as well as *Alnus glutinosa* and *Picea abies* in Poland.

4.1.3. Assessment of predicted GWP reduction based on the GEST approach

The *LIFE Peat Restore* project actions helped to restore at least 5300 ha of damaged peatlands in Estonia, Latvia, Lithuania, Poland and Germany. Our GEST-GHG calculations prove significant reduction of the GHG emissions (*Table 6*, Figure 19). Rewetting and other restoration measures aimed at improving the peatland functions will potentially reduce the GHG emissions from 46 888.1 t CO_2-eq./yr (*Baseline scenario*) to 32 434.3 t CO_2-eq./yr (*Project scenario*), which is a reduction of 14 452.7 t CO_2-eq./yr, i.e., about 31%. The *Post-restoration scenarios* of almost all project sites demonstrated a positive effect for climate change mitigation, but the emission reduction potential in different project sites was quite diverse. This is mainly determined by the degree of peatland damage which varied from slightly damaged (e.g., in Estonia and Latvia) to severely damaged (e.g., in Lithuania and Poland). The average value of GWP reduction potential was 4.4 t CO_2-eq./yr/ha and varied from 0.0 t CO_2-eq./yr/ha (Engure Lake NP, Latvia) to 20.0 t CO_2-eq./yr/ha (Amalva peatland, Lithuania).

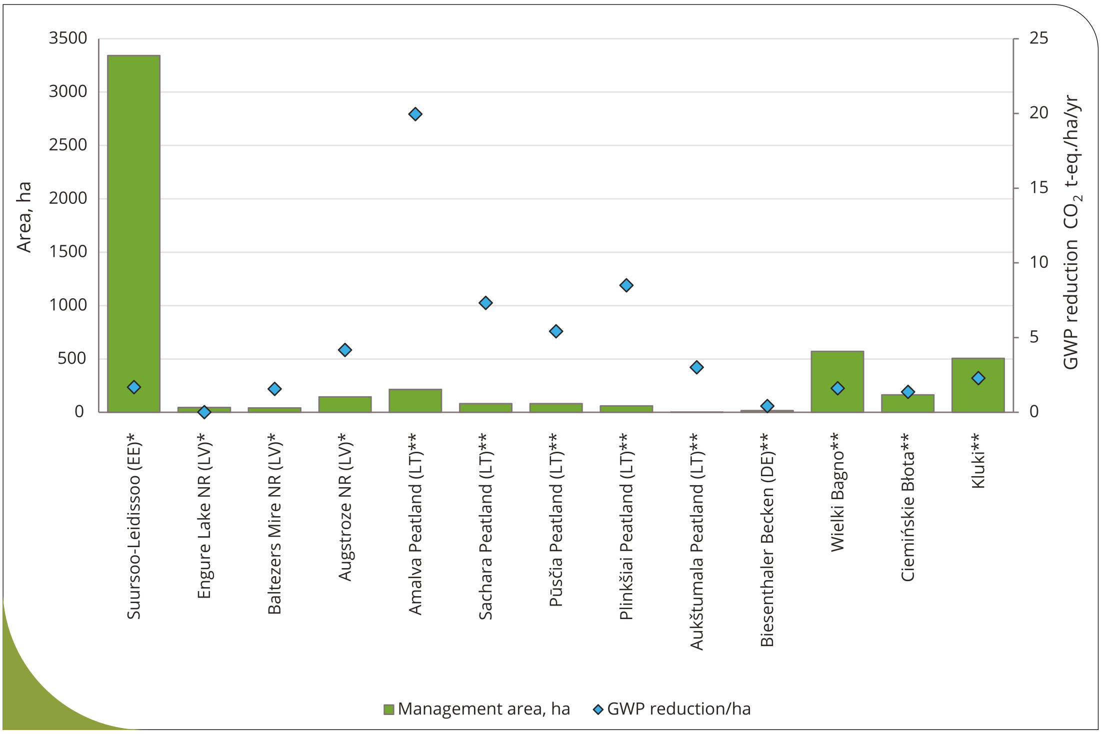


Figure 19. Management area and GWP reduction in t CO_2-eq/ha/yr on *LIFE Peat Restore* project areas. State of peatlands in 2018:
* – damaged by draining,
** – severely damaged by draining and/or destroyed by peat extraction.

Table 6. Summarised GWP for *Baseline* and *Project (restoration) scenarios* given in t CO_2-eq/ha/yr and all project sites, calculation for management area

Project site	Project area, ha	Mana-gement area, ha	GEST GWP balance scenarios, t CO_2-eq./ha/yr		GWP reduction in project area, t CO_2-eq./ha/yr	GWP reduction per 1 ha in manage-ment area, t CO_2-eq./ha/yr
			Baseline	Project (Resto-ration)		
Suursoo-Leidissoo EE-SU*	3 343	3 343	18 575.2	12 936.2	5 636.0	1.6
LV-Engure Lake NP LV-EN *	106	46	32.2	32.2	0.0	0.0
Baltezers Mire NR LV-BA*	228	42	307.3	241.8	65.5	1.5
Augstroze NR LV-AU*	1 880	145	749.2	145.1	604.1	4.2
Amalva Peatland LT-AM**	215	215	5 820.0	1 530.0	4 290.0	20.0
Sachara Peatland LT-SA**	82	82	850.0	250.0	600.0	7.3
Pūsčia Peatland LT-PU**	81	81	968.5	530.0	438.5	5.4
Plinkšiai Peatland LT-PL**	60	60	787.6	277.5	510.0	8.5
Aukštumala Peatland LT-AU**	10	2	12.0	6.0	6.0	3.0
Biesenthaler Becken DE-BB**	16	16	-7.4	-14.0	6.6	0.4
Wielkie Bagno PL-WB**	570	570	7 097.1	6 183.1	914.0	1.6
Ciemińskie Błota PL-CB **	163	163	2 138.0	1 917.6	220.4	1.4
Kluki PL-KL**	506	506	9 558.4	8 400.1	1 158.3	2.3
		Total	***46 888.1***	***32 434.3***	***14 452.7 30.8%***	***4.4***

State of peatlands in 2018:
* – damaged by draining,
** – severely damaged by draining and/or destroyed by peat extraction.

In the **Estonian** restoration site, Suursoo-Leidissoo peatland (3343 ha), the present vegetation pattern is a result of amelioration of the previously open alkaline fen (GEST *10. Very moist/Wet calcareous meadows, forbs and small sedges reeds*). Vegetation changed because of hydrological restoration, caused shifts in areas of presently existing GESTs – increase of opened alkaline fen site GEST *10. Very moist/Wet calcareous meadows*, *forbs and small sedges reeds* but also GEST *18. Wet peat moss lawn with pine trees*. In both GESTs carbon sequestration increases due to improved growth conditions of peatland plants, especially mosses. The project results demonstrate the linear growth of *Sphagnum* carpet biomass, these increments already increased in the first summer after rewetting. Notably, the GHG emission reduction is a result of a decrease in area of the heavily drained forest *23.* and *27. Moist forests and shrubberies* (both oligotrophic and mesotrophic/eutrophic).

In **Latvia**, the reduction of GHG emissions is mainly related to the restoration of a degraded raised bog (Figure 20). In terms of climate change mitigation, the main goal of Latvian sites was to restore the raised bog in Augstroze NR (LV-AU), where the largest GHG emissions are caused by 22. *Moderately moist forest and shrubberies* (OL) or degraded raised bog, which currently occupies one quarter of the entire restoration area in Augstroze NR. Re-wetting the degraded parts of the raised bog by blocking the drainage ditches significantly improves the site conditions and increases the area of the open raised bog or *16. Wet peat moss lawn*. According to *Post-restoration scenario*, in other habitats, such as the transition mire and the alkaline fen, no significant changes in GESTs or total GEST-type coverage and GHG emissions are observed by the end of the project. In all cases, the *Spontaneous succession scenario* with *no restoration* leads to the replacement of peat-forming vegetation with drier plant communities, which may result in interruption of the peat formation process, and establishment of a forest community in a few decades, especially in combination with climate variables that favour overgrowth of drained fens and transition mires. Based on the *Project (restoration) scenario*, the total amount of GWP emissions in Latvian sites will be reduced by 61%. The biggest GWP reduction (604.1 t CO_2-eq./yr) is expected from the Augstroze (LV-AU) site.

Figure 20. A ditch in the Augstroze peatland, Latvia, before (A) and after rewetting (B). Photos: A. Priede (A) and M. Pakalne (B).

The biggest GHG reduction potential was determined to be in the **Lithuanian** peatlands, characterised by heavily drained and damaged habitats, before the implementation of restoration actions. In the *Baseline scenario* the largest part of GHG emissions comes from various forested GESTs (oligotrophic 22. *Moderately moist forest and shrubberies,* as well as mesotrophic and eutrophic 25. *Dry forest and shrubberies*) and oligotrophic *Bare peat (dry* and *moist)*, which occupies a significant part of Lithuanian project sites (Figure 21). Project actions will have a positive impact on GHG emission reduction. Based on the Project *Post-restoration scenario*, the total amount of GWP emissions in Lithuanian sites will be reduced by 69%. The biggest GWP reduction (4290 t CO_2-eq./yr) is expected from the Amalva (LT–AM) site, which is the largest and most damaged project area in Lithuania (*Table 6*).

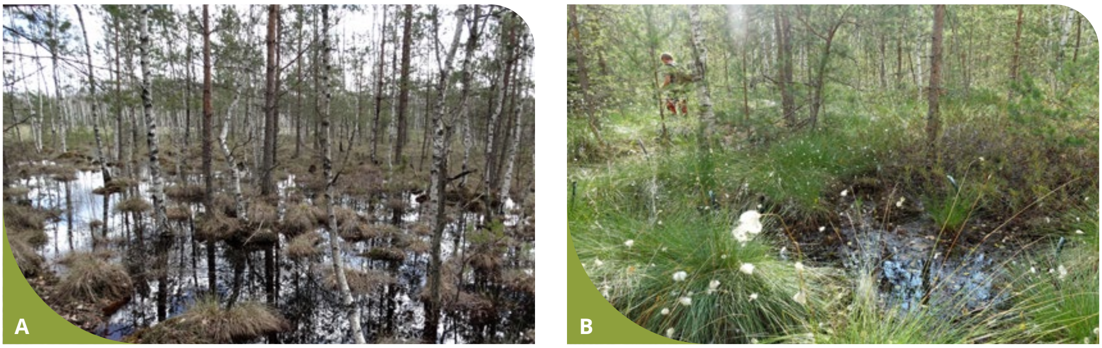


Figure 21. The rise of water level was noticed soon after the implementation of restoration measures (March 2020, A), even during the active vegetation period (July 2021, B) in Sachara peatland, Lithuania. GEST *22. Moderately moist forest and shrubberies (OL)* will be gradually replaced by *23. Moist forests and shrubberies (OL)*. Photos: J. Sendžikaitė.

In **Poland** under the *Baseline scenario*, forests – *Moderately moist forests and shrubberies* (both oligotrophic and mesotrophic/eutrophic), which occupy more than 60% of the area, have the largest emission share on each of the project sites. Under the *Post-restoration scenario* forecasts, the current emissions of the project sites will decline in the next 50 year as a result of restoration, but the peatlands will still be dominated by forested GESTs. Because of this, the GHG reduction potential is not significant. According to *Post-restoration scenario* predictions, in each of these bogs the share of the worst preserved *22. Moderately moist forests and shrubberies (oligotrophic)* will be replaced by *Moist* and *Very moist forests and shrubberies* (GESTs 23 and 24) (Figure 22), and in the Wielkie Bagno (PL-WB) also by *Wet* and *Very moist peat moss lawn* (GESTs 12 and 16). In the Kluki peatland (PL-KL), this change will be the greatest (by approx. 20%, over 100 ha). In Kluki and Wielki Bagno peatlands, the area is occupied by *17. Peat moss lawn on former peat-cut off areas* will also be extended by several hectares. The area of water reservoirs will also slightly increase in the Wielkie Bagno. Based on the *Post-restoration scenario*, the highest CO_2 reduction is expected in Kluki site (1158.3 t CO_2-eq./yr), a little lower – from Wielkie Bagno (914.0 t CO_2-eq./yr) and significantly lower from Ciemińskie Błota (220.4 t CO_2-eq./yr), which is also the smallest and best preserved project site in Poland (*Table 6*).

Figure 22. A drained bog on Wielkie Bagno before (November 2017) and soon after removal of trees (March 2018). Photos: K. Bociąg.

The mostly forested drained peatlands in Biesenthaler Becken site, Germany, under the *Baseline scenario* showed a negative GWP. This is mainly due to the forest biomass, as these degraded peatlands were assessed as a carbon sink before restoration. For the *Post-restoration scenario* GHG emission sequestration would almost double as the main emissions caused by drainage would have been significantly decreased (*Table 6*).

4.2. Results of direct measurements and comparison with the Updated GEST catalogue

Net Ecosystem Exchange (NEE) is the sum of GHG exchange between ecosystem and atmosphere. If the NEE is negative, the ecosystem is a CO_2 sink from the atmosphere, whereas a positive NEE indicates larger respiration than photosynthesis, so the ecosystem is a CO_2 source to the atmosphere. Here we present results from three investigation years (2018–2020) from three sites – Suursoo-Leidissoo, Estonia for five GESTs, Biesenthaler Becken, Germany and Wielkie Bagno, Poland for one GEST each. From sites in Lithuania (Aukštumala, Amalva and Pūsčia) and Latvia (Baltezers, Engure and Augstroze), reconstructed results from 2019 of one studied GEST per site are presented. Detailed descriptions of GHG measurement and reconstruction methodologies for each project site is provided in *Chapter 3*, number of measurement plots in each site and GEST are given in *Table 4*.

The GHG fluxes varied between the different GESTs, but also within the same GEST between the different measurement years and/or in different countries (*Table 7*). This was demonstrated in Estonia and Germany, where data from the same GEST *27. Moist forests and shrubberies (ME/EU)* were reconstructed for all three years. Similarly, GHG emissions were smaller in the *10. Very moist/wet calcareous meadows, forbs and small sedges reeds* in Estonia during all measurement years compared to the same GEST in Latvia in 2019.

Weather conditions varied significantly between the measurement years in 2018–2020. Meteorological data from all project sites are provided in *Annex 2*. In 2018, the vegetation season was dry and warmest of all three years in Estonia, in the German site the highest air temperatures and lowest amount of precipitation in the vegetation season were recorded, whereas in Poland it was relatively wet. Although the mean air temperature in 2020 was relatively warm, the precipitation was above long-term average in Estonia but below long-term average in Germany and Poland. In 2019 meteorological conditions were closest to the long-term mean values. The geographic locations of the different sites resulted in rather large heterogeneity in the weather conditions and their deviations from the long-term averages of the project sites.

In addition, the direct GHG measurement results of the two Lithuanian sites were impacted by restoration activities – Pūsčia site (LT-PU) was already rewetted in 2018 (i.e. before the first direct measurements in 2019), as well as a moss-layer-transfer technique (including rewetting) was implemented in the Aukštumala site (LT-AU) only in the end of the measurement season of 2019.

The detailed descriptions of the restoration activities in all *LIFE Peat Restore* project sites are provided in Pakalne *et al*. (2021). Specific description of restoration impact on the GHG balances of drained peatland ecosystems can be found in Escobar *et al.* (2022).

Table 7. Modelled annual GHG fluxes of GESTs in 8 project sites. Negative values indicate GHG uptake by the GEST from the atmosphere and positive values indicate GHG emissions from the GEST to the atmosphere. New GESTs are marked in red NEW

Site		GEST	Year	CO_2 (t CO_2 -eq./ ha/yr)	CH_4 (t CO_2 -eq./ ha/yr)	N_2O (t CO_2 -eq./ ha/yr)	Total emission (t/CO_2 -eq./ ha/yr)
EE-SU	10.	*Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT)* NEW	2018	-3.3	0.3	0.0	-3.0
			2019	1.8	0.9	0.0	2.7
			2020	1.5	0.1	0.0	1.6
	18.	*Wet peat moss lawn with pine trees* NEW	2018	1.1	0.0	0.0	1.1
			2019	4.9	10.8	0.0	15.6
			2020	-5.5	1.3	0.0	-4.2
	24.	*Very moist forests and shrubberies (OL)*	2018	-2.1	0.1	0.0	-2.0
			2019	-0.9	2.3	-0.0	1.4
			2020	-11.2	0.3	-0.0	-10.9
	27.	*Moist forests and shrubberies (ME/EUT)*	2018	27.1	0.1	0.0	27.2
			2019	23.2	1.8	0.0	25.0
			2020	22.9	0.2	0.0	23.1
	28.	*Very moist forests and shrubberies (ME/EUT)*	2018	1.9	0.0	0.0	1.9
			2019	1.6	-0.4	0.0	1.2
			2020	-6.5	0.0	0.0	-6.5
LV-BA	9.	*Wet meadows and forbs*	2019	10.2	12.7	0.7	23.6
LV-EN	10.	*Very moist/wet calcareous meadows, forbs and small sedges reeds* NEW	2019	3.4	2.7	0.4	6.5
LV-AU	16.	*Wet peat moss lawn*	2019	7.1	5.1	0.2	12.4
LT-AU	5.	*Bare peat dry (OL)* NEW	2019*	16.7	11.5	3.1	31.3

Table 7 (continued)

LT-AM	22.	*Moderately moist forest and shrubberies (OL)*	2019	49.3	-0.2	0.1	49.2
LT-PU	6.	*Bare peat moist (OL)*	2019**	14.4	1.4	0.1	15.9
DE-BB	27.	*Moist forests and shrubberies (ME/EUT)*	2018	38.4	0.63	2.6	41.6
			2019	36.4	0.38	5.0	41.8
			2020	32.3	0.2	3.4	35.9
PL-WB	11.	*Very moist bog heath*	2018	-1.7	0.07	1.1	-0.5
			2019	-2.0	-0.03	0.7	-1.3
			2020	-1.8	0.04	0.3	-1.5

* – indicates direct measurement results after the restoration activities, ** – indicates the direct measurement periods coinciding with the restoration period.

Largest emissions in the project sites are generally related to **CO_2**. The strongest CO_2 emitters in the project sites were the two forested GESTs: *22. Moderately moist forest and shrubberies (OL)* and *27. Moist forests and shrubberies (ME/EUT)*. In these forested peatland ecosystems (and in the other wooded peatland GESTs) only understory GHG flux measurement results are presented. In Suursoo-Leidissoo and Wielkie Bagno sites some less-disturbed GESTs were also CO_2 sinks during favourable years; in these communities carbon accumulation is expected to increase as a result of restoration activities. Most of the project sites were strongly degraded before the restoration works, therefore having low water table, altered (or even absent) vegetation communities and having high respiration rates.

The interannual variation of CO_2 emissions is closely related with differences in weather conditions and their interannual variations (photosynthetically active radiation, temperatures, precipitation, length of the vegetation period) and therefore also other environmental variables (e.g., water table fluctuations) and vegetation development (Purre 2021). The impact of weather deviations during the measurement years from the long-term averages had different effects in various GESTs. Therefore, higher CO_2 emissions in the *27. Moist forests and shrubberies (ME/EUT)* in temperate Germany were recorded compared to the results in boreal Estonia. This was expected due to differences in climate and site conditions. CO_2 emissions tend to increase in dry years, especially in disturbed peatland communities with sparse cover of vegetation or bare peat areas (Purre *et al.* 2019). In this project, unfavourable conditions are characteristic in former extracted peatland sites in Lithuania, but also in the understory of deeply drained forest communities on peatlands in Estonia and Germany.

CH_4 emissions varied considerably between years and sites the GEST *9. Wet meadows and forbs* and *5. Bare peat dry (OL)* recording the highest values in 2019 also in *18. Wet peat* *moss lawn with pine trees.* Higher CH_4 emissions are related to higher water tables, as well as a higher presence of herbaceous plants (especially aerenchymus) (Vanselow-Algan *et al.* 2015; Swenson *et al*. 2019; Creevy *et al.* 2020; Lazcano *et al.* 2020). In the case of the GEST *5. Bare peat dry (OL)*, high methane emissions are probably the result of fluctuating water levels (Dinsmore *et al.* 2009). The water table level is high during the spring and autumn but low during the summer period. Another factor may be the rewetting activities done in September 2019 as they probably increased the CH_4 emissions from this GEST. In the GESTs, *28. Very moist forests and shrubberies (ME/EUT)* and *22. Moderately moist forest and shrubberies (OL)* a small methane uptake was observed. Small methane uptakes have been reported before in drained fens (Nykänen *et al.* 1998).

Large temporal differences in CH_4 fluxes are possible, e. g., after changes in environmental conditions which are also supported in the GHG flux measurement results of the project. In relatively pristine communities, methanogenic bacteria manage to survive dry periods (Estop-Aragonés & Blodau 2012; Urbanová & Bárta 2020), and methane can be released as "pulses" if suitable environmental conditions occur (Dowrick *et al.* 2006; Estop-Aragonés & Blodau 2012; Keane *et al.* 2021). This could result in high spatial and temporal variations in methane emissions. Still the knowledge about the methanogenic and methanotrophic communities and their intricate balances is scarce, especially in site-scale peatland ecosystems, as most of the detailed experiments have been conducted under laboratory conditions.

N_2O emissions were very small in most of the studied GESTs. N_2O fluxes were closely related to nitrogen deposition (Leip *et al.* 2011) – being lowest in Estonia and increased towards Western Europe. N_2O emissions were highest in the Biesenthaler Becken project site in Germany. Addition of nitrogen to peatlands, through atmospheric deposition or fertilisation, increases N_2O emissions (Gong *et al.* 2019). The N_2O fluxes are higher in drained (Järveoja *et al.* 2016; Minkkinen *et al.* 2020) nutrient-rich (Gong *et al.* 2019; Minkkinen *et al*. 2020) peatlands. Moreover, warmer air temperatures e. g., during heat waves tend to increase N_2O fluxes in peatlands (Yi *et al.* 2022). In the relatively nutrient poor peatland community with a high-water level in the Estonian Suursoo-Leidissoo site, the GEST *24. Very moist forests and shrubberies (OL)*, very small N_2O uptake was observed; and thus supports the findings of Rigney *et al.* (2018)

DIRECT MEASUREMENT RESULTS AND COMPARISON WITH THE GEST CATALOGUE

Directly measured reconstructed CO_2 and CH_4 emissions were not incorporated into *Updated GEST catalogue* (*Annex 3)*, but were compared with GEST estimations based on the *Updated GEST Catalogue* for the same GESTs (*Table 8*) and presented in *Annex 4* (Description of Greenhouse Gas Emissions Site Types (GESTs) identified in the *LIFE Peat Restore* project). Although few GEST emission values were similar to direct measurement results in the Project's sites (*18. Wet peat moss lawn with pine trees*) or were in between the direct measurement results in different project sites (*10. Very moist/Wet calcareous meadows, forbs and small sedges reeds* in Lake Engure, Latvia and Suursoo-Leidissoo, Estonia). Some GESTs (*4. Moist bog heath*; *24. Very moist forests and shrubberies (OL)* and *28. Very moist forests and shrubberies (ME/EUT*) showed carbon uptake according to the direct measurement results, although their GHG emissions values in the GEST catalogue indicated small carbon emissions. In comparison, the GHG *16. Wet peat moss lawn* was marked as a carbon accumulating community in the *Updated GEST catalogue* whereas significant carbon emissions were measured from area in this Project. Many GEST emission values, in the catalogue (*5. Bare peat dry (OL)*; *22. Moderately moist forests and shrubberies (OL); 27. Moist forests and shrubberies (ME/EUT)* (on both measured sites)) significantly underestimated the carbon emissions in comparison with the results of direct measurements in the project sites. These differences can be quite large, exceeding three times the size of the emission reported in the *Updated GEST Catalogue* (see *Annexes 3* and *4*).

Table 8. Comparison of the GWP values in the *Updated GEST Catalogue* (*Annex 4*; data with and without trees) and measured with transparent chambers and modelled at ten GESTs (understory vegetation and soil) in nine sites (for Estonian, Polish and German sites mean of 2018, 2019 and 2020, and for Latvian and Lithuanian sites data from 2019). New GESTs are presented in red [NEW].

GESTs		Site	GWP (t CO_2-eq./ha/yr)		
			Catalogue, data with trees	Catalogue, data without trees	*LIFE Peat Restore* direct measurements reconstructed
5.	*Bare peat dry (OL)* [NEW]	LT-AU	–	7.5	28.2
6.	*Bare peat moist (OL)*	LT-PU	–	6.2	15.8
9.	*Wet meadows and forbs*	LV-BA	–	5.8	22.9
10.	*Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT)* [NEW]	EE-SL	–	2.9	0.4
		LV-EN			6.1
11.	*Very moist bog heath*	PL-WB	–	4.6	-1.8
16.	*Wet peat moss lawn*	LV-AU	–	-0.3	12.2
18.	*Wet peat moss lawn with pine trees* [NEW]	EE-SL	–	4.1	4.2
22.	*Moderately moist forests and shrubberies (OL)*	LT-AM	-3.2	20.0	49.1
24.	*Very moist forests and shrubberies (OL)*	EE-SL	-0.55	4.7	-3.8
27.	*Moist forests and shrubberies (ME/EUT)*	EE-SL	21.6–30.3	12.2	24.1
		LT-SA			n/a
		DE-BB			36.1 (25.7*)
28.	*Very moist forests and shrubberies (ME/EUT)*	EE-SL	-9.9 – -1.7	1.6	1.1

* Considers carbon fixed in wooden biomass

Our results indicate that the emission values presented in the *Updated GEST catalogue* (*Annex 3)* may not consider the full variation of the environmental conditions and carbon emissions. This can result in significant mismatch when used e.g., carbon reporting of the peatland related emissions in the LULUCF sector. Similarly, Tiemeyer *et al.* (2020), noted that the vegetation-based proxies such as GEST are lacking emission data as they are currently not available in adequate detail, temporal resolution or wall-to-wall at national level. Thus, vegetation-based methods do not comply with the national requirements of "*accuracy* and *completeness*". This issue could be approached in future by presenting the uncertainty limits of the values in the GEST catalogue, as has been done in IPCC emission factors, but also updating the GEST emission values in time with increasing amount of emission data. Still, the GESTs could provide a significant value for upscaling the direct measurement from the measurement points to the whole site. With increasing GHG emissions, GEST could be used for initial and broad carbon reduction reporting after rewetting where direct measurements are not possible. Direct measurement results presented by the *LIFE Peat Restore* project partners, provides the data to fill these gap and this data can be used for updating and improving the GEST catalogue in the future.

As indicated previously in *Chapter 4.2.*, meteorological conditions strongly impact the GHG emissions. The strong effect of drought years (such as 2018) on peatland related carbon emissions have been reported before (e.g. Dowrick *et al.* 2006; Fenner & Freeman, 2011; Lund *et al*. 2012; Purre *et al.* 2019, Koebsch *et al.* 2020). Drought periods increase CO_2 emissions (Fenner & Freeman, 2011; Lund *et al*. 2012; Purre *et al.* 2019, Koebsch *et al.* 2020) and decrease CH_4 emissions (Dowrick *et al.* 2006, Koebsch *et al.* 2020). This was generally so also in the direct measurement sites of the *LIFE Peat Restore* project. The drought impacts on carbon emissions depend on the drought periods timing, severity and duration (Lund *et al.* 2012), but also on affected vegetation communities (Wang *et al.* 2015) and substrate properties (Stirling *et al.* 2020). In some cases CO_2 emissions can decrease during the drought *via* higher gross photosynthesis if sufficient water supply remains available for plants (Koebsch *et al.* 2020) as in the Estonian site in *10. Very moist/Wet calcareous meadows, forbs and small sedges reeds*. Drought impacts can stretch further into following years, affecting the carbon emissions long-term as presented by Koebsch *et al*. (2020) in fen ecosystems, whereas in raised bog, CO_2 sink function recovered in the following year post-drought (Lund *et al.* 2012). A review by Stirling *et al*. (2020) supports that the nutrient-poor peatland communities are less affected by drought than nutrient-rich sites. This, and different plant functional types present in the GESTs could explain the different drought impact and following recovery in different GESTs as demonstrated in *Table 7*. The inclusion of drought years into GEST carbon emission estimations is important as the drought frequency and severity is estimated to increase in Europe due to climate change (Spinoni *et al.* 2018; Grillakis 2019).

As an example of directly measured GHG flux upscaling using the GESTs within the Suursoo-Leidissoo peatland site, Estonia is provided in *Table 9*. Carbon emissions from all five GESTs present from the Estonian site were directly measured during the three-year period and GESTs were mapped for the whole project site. In addition, emission values were calculated for the project site and based on the emission values without trees as provided in the *Updated GEST catalogue* (see Annex 3). Most of the recorded GHG emission values differed from directly measured emissions on the sites; the difference between the values varied between 2.4% and 87% and the average difference of the emission values was approximately 40%.

Table 9. Example of upscaling of carbon emissions based on GESTs represented in the Estonian site based on *Updated GEST Catalogue* values and direct measurements. New GESTs are presented in red [NEW].

GESTs		Area (ha)	GHG emission data			
			In the Updated GEST catalogue (t CO_2-eq./ha/yr)	Modelled from measurements, means of three year (2018–2020) data (t CO_2-eq./ha/yr)	In the Updated GEST Catalogue (t CO_2-eq./per site area/yr)	Measurements (transparent chamber), reconstructed
10.	*Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT)* [NEW]	602	2.9	0.4	1 745.8	240.8
18.	*Wet peat moss lawn with pine trees(ME)* [NEW]	823	4.1	4.2	3 374.3	3 456.6
24.	*Very moist forests and shrubberies (OL)*	859	4.7	-3.8	4 037.3	-3 264.2
27.	*Moist forests and shrubberies (ME)*	733	12.2	24.1	8 942.6	17 665.3
28.	*Very moist forests and shrubberies(EUT)*	297	1.6	-1.1	475.2	-326.7
TOTAL:		3 314			**18 575.2**	**17 771.8**

The difference between the GEST estimates and direct measurements most likely result from the climate variability as measurements from the temperate climate zone were used in the calculations, whereas the Suursoo-Leidissoo project site is located in the boreal zone. Therefore, the GEST emission factors do not consider the climatic and plant community variations in the northern Baltics. Also, during our three measurement years, one extreme drought period occurred in 2018, which affected the GHG emissions of that year. Therefore, the results of direct measurements and GEST emissions are not expected to be too similar. Still, the lower directly measured values for *10. Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT) 24. Very moist forests and shrubberies (OL)*, and *28. Very moist forests* *and shrubberies (ME/EUT)* were compensated by the higher measured emissions in *27. Moist forests and shrubberies* than emission values presented in the *Updated GEST catalogue*. Therefore, the total area carbon emissions estimated based on two different methods within the project based on direct measurements and GEST values, were relatively similar. The difference between the GHG emissions calculated according to two different methods remained within 5% for the Estonian example.

Based on the above, the actual recovery efficiency for GHGs sequestration after rewetting could be a little higher because 1) the reduction at the expense of the most emitting type is greater and less drained sites where carbon sequesters; 2) the conditions of less drained GESTs that maintain the structure falling in the same type after the restoration improves and so the sequestration ability also improves. Based on the GHG balance measured in current GESTs with drainage effects, no conclusions can be drawn for the types in the recovered state, as their GHG sequestration capacity is improved compared to the pre-restoration situation. In order to draw such conclusions, there is a need for direct measurements of natural reference areas of the same types to have an informed basis for comparison.

4.3. Benefits and drawbacks of direct measurements and GEST approach

Photo: J. Sendžikaitė

In order to test the applicability of the GEST approach (Couwenberg *et al.* 2011) in boreal and temperate peatlands the *LIFE Peat Restore* project team applied this approach in parallel with direct GHG measurements by chamber method. New data from five project countries are a valuable supplement for the development of the GEST approach considering geographical variations of the European continent. In *Table 10*, we briefly describe the benefits and drawbacks of direct measurements and the GEST approach we found out during our work.

Table 10. Benefits and drawbacks for choosing methodology for GHG estimation.

Parameter	Direct measurements	GEST approach
Vegetation	Vegetation analysis is needed to choose the measurement points and describe the temporal variations in vegetation development inside the measurement point.	Precise vegetation cover data based on field works.
Water level	Measured during GHG measurement sessions in every measurement point, obligatory.	Soil moisture class (Koska et al. 2001) is obligatory. Direct WL measurement is recommended: 1. automatic water level loggers or 2. manually.
Other ecological parameters	Air and peat temperatures, PAR, LAI or vegetation height.	Peat depth, peat properties (pH, C:N ratio), timber volume assessment (in forested GEST units).
Measured GHGs	CO_2, CH_4, N_2O and other gases if deemed necessary.	CO_2, CH_4
Time	Takes time – measurements at least once per month per vegetation season; repeated measurements at least for three years recommended, additional time for modelling of measurement results.	Possible to have estimations of one vegetation season as vegetation reflects environmental parameters more generally.
Accuracy or precision	Accurate for the measurement point.	More general
Scale	Site scale	Can be upscaled to regional or country levels.
Measurement frequency	Annual GHG balance (measured throughout the year) on the basis of at least 3-year measurements. The sufficient spatial frequency of measurement plots must be achieved to provide results close to “true” values and reduce the impact of possible outliers.	Before restoration and after 3–5 years when vegetation has adapted to wetter conditions.
Skills	Specific equipment for measurements, scientific knowledge and general geobotanical education needed.	Vegetation and habitat investigations experience as well as spatial assessment (mapping) skills required.
Costs	Expensive	Relatively cheap

The most appropriate method must be chosen for each individual case of the GHG assessment, that considers the availability of measurement equipment and experienced staff, as well as financial possibilities.

5. CHALLENGES AND SOLUTIONS

Photo: J. Sendžikaitė

5.1. Differences in species composition among countries

To correctly identify the GEST, i.e., the vegetation forms, a rich number of plant species are described in Koska *et al*. (2001). In total, about 500 different vascular plant and bryophyte species found in Germany are provided in the methodology. However, due to climatic differences, the species list could not be directly applied to countries within the Boreal region. Some examples of common species which are missing from the list are *Alnus incana, Juniperus communis, Comarum palustre, Rubus chamaemorus, Vaccinium vitis-idaea*, and bryophytes *Dicranum polysetum, Hylocomium splendens, Sphagnum girgensohnii*, *S. tenellum*, which are all characteristic of the peatlands and bog woodland in Baltic States and Poland. Also, the lichens which are good indicators to various processes in peatlands (Marcisz *et al*. 2017), are lacking from descriptions of GESTs. For this reason, the species list has to be broadened to adapt it to regions with vegetation communities different from Germany.

Bearing in mind that GESTs are based on functions of plant species communities and their response to abiotic factors, the new species from the project sites were categorised accordingly. Depending on the taxa, the appropriate plant functional trait and life-form was selected for each species, or the expert knowledge about the species' ecology was used, as well as its associations to regional vegetation community based on literature (for example in Latvia, Salmiņa 2009; Laiviņš 2014). Subsequently all species were grouped into the most related GEST vegetation forms that already exist or, on rare occasions, new vegetation forms or even new GESTs were identified and described. For example, the plant communities of Lake Engure NP are unique even at a Latvian scale. As predicted, the vegetation forms that partially correspond to existing GEST *8. Very moist meadows, forbs and small sedges reeds* (Reichelt 2015) were inadequate. Hence three vegetation forms reflecting the calcareous conditions (*Primula farinosa-Schoenus ferrugineus*-community, *Scorpidium scorpioides-Cladium mariscus*-community, and *Phragmites australis*-community on calcareous fen) were proposed and assigned as a newly created GEST *10. Very moist/Wet calcareous meadows, forbs and small sedges reeds* (*Chapter 4.1.2*).

A similar problem was encountered with some non-existent vegetation units in Poland, Słowiński NP, where a vegetation map was prepared together with a GEST map. Previous maps and community classifications, adopted in Poland, were used and tested for this purpose. However, plant communities from the Polish phytosociological systematics (Matuszkiewicz 2008), based on the school of J. Braun-Blanquet (1964), could not always be directly attributed to vegetation forms related to the GESTs from the previous catalogue (Reichelt 2015).

Despite poor phytosociological documentation, about 30 vegetation units were eventually "translated" into vegetation forms and GESTs, based on the work of Succow & Joosten (2001). Some of them had to be divided into several vegetation units from the GEST catalogue. For example, phytocoenoses included in the *Vaccinio uliginosi-Pinetum* Kleist 1929 complex had to be divided between 4 vegetation units used in the *Updated GEST catalogue* (2018) and assigned to three different GESTs: *Eriophorum vaginatum-Pinus sylvestris*-community to the GEST *24. Very moist forests and shrubberies (OL)*, *Vaccinium uliginosum-Pinus sylvestris*-community to the GEST *23. Moist forests and shrubberies (OL*), and *Molinia caerulea-Pinus sylvestris*- and *Pleurozium schreberi-Pinus sylvestris*-communities to the GEST *22. Moderately moist Forest and shrubberies (OL)*. Some vegetation units have been added to the *Updated GEST Catalogue* (*Annex 3*), e.g., *Molinia caerulea-Betula pubescens*-community.

In summary, the project found several ways to cope with vegetation that did not correspond to previously described GESTs (e.g., in Reichelt 2015), by creating the *Updated GEST Catalogue* (*Annex 3*) and identifying new vegetation types to the described GESTs or identifying completely new GESTs (see *Chapters 2.1.2* and *4.1.2*).

Furthermore, in the Polish project sites, the heterogeneous surfaces of former peat extraction fields, which form a mosaic of different plant communities and GESTs (such as forests and 17. *Peat moss lawn on former peat-cut off areas*), also proved to be a challenge for mapping the GESTs. It was agreed that the most valuable and smallest areas were mapped in detail, while the rest were considered to be broader units, estimating the proportion of individual GEST units visually and / or based on data from the digital terrain model and other LIDAR data.

It should be also noted that some of the identified GESTs may be related to several habitats of European importance and *vice versa* i.e., one habitat may correspond to many GESTs, as the concept of both systems are based on vegetation communities and their response to abiotic factors. Thus, the identification of GESTs might become easier if plant and tree species could be classified to plant functional types, which correspond to certain types of GESTs. 21 of the 29 GESTs identified in *LIFE Peat Restore project* sites are associated with habitats of European importance, mainly mires (e.g., 7120 Degraded raised bogs) and forests (e.g., 91D0 *Bog woodland). Relations between GESTs and habitats of European importance are provided in *Annex 4*.

5.2. Mapping the GESTs and applying the remote sensing approach

Although current satellite images are of great quality, more detailed maps are still required, thus, remote sensing might be more useful. Therefore, remote sensing was applied to map the GESTs in two project sites in Latvia, Madiešēnu Mire in Augstroze NR (1881 ha) and the management area of Lake Engure NP (48 ha), and on the Estonian site Suursoo-Leidissoo (3343 ha). An overview of the use of remote sensing for vegetation classification on Latvian restoration areas is provided in Figure 23.

The University of Latvia in cooperation with the Institute for Environmental Solutions (Latvia) collected remote sensing data by flying laboratory ARSENAL (Airborne Surveillance and Environmental monitoring system). The sensor system of the hyperspectral sensor CASI-1500 (spatial resolution 1 m) and high-resolution RGB camera, Trimble Aerial Camera 60M (spatial resolution 0.1 m) was used. The reference data to perform remote sensing data algorithm training were collected in field by the project experts. Change of the spectral colour indicates differences in vegetation composition. High quality orthophoto were also used to compare the results. In cases where the vegetation mosaic was too diverse, the data were merged to maintain the homogeneity of peatland vegetation.

In Estonia, an integrated method was used to map vegetation, which included analysis of field data and remote sensing data. The main basis of mapping was the latest available orthophoto map compiled by the Estonian Land Board. The most useful tool for separating forests and open communities was the LIDAR-based map of land cover height. Additionally, satellite data was used to distinguish some vegetation types that were similar on orthophoto maps. *Sentinel* multispectral satellite data via *Sentinel Playground* (Sentinel Playground) and *Copernicus Open Access Hub* (Copernicus) were used. In addition, data collected by drone (both the visual spectrum and multispectral data) were used. When mapping the GEST units (larger than 0.2 ha), relatively broad vegetation classes were used that indicated the trophic level of the mire communities and the presence of woody cover. The reason for choosing relatively broad vegetation classes was that they can be mapped more accurately and reliably throughout the area. For more details, read the corresponding sections in the separate book of the *LIFE Peat Restore* project (Pakalne *et al*. 2021).

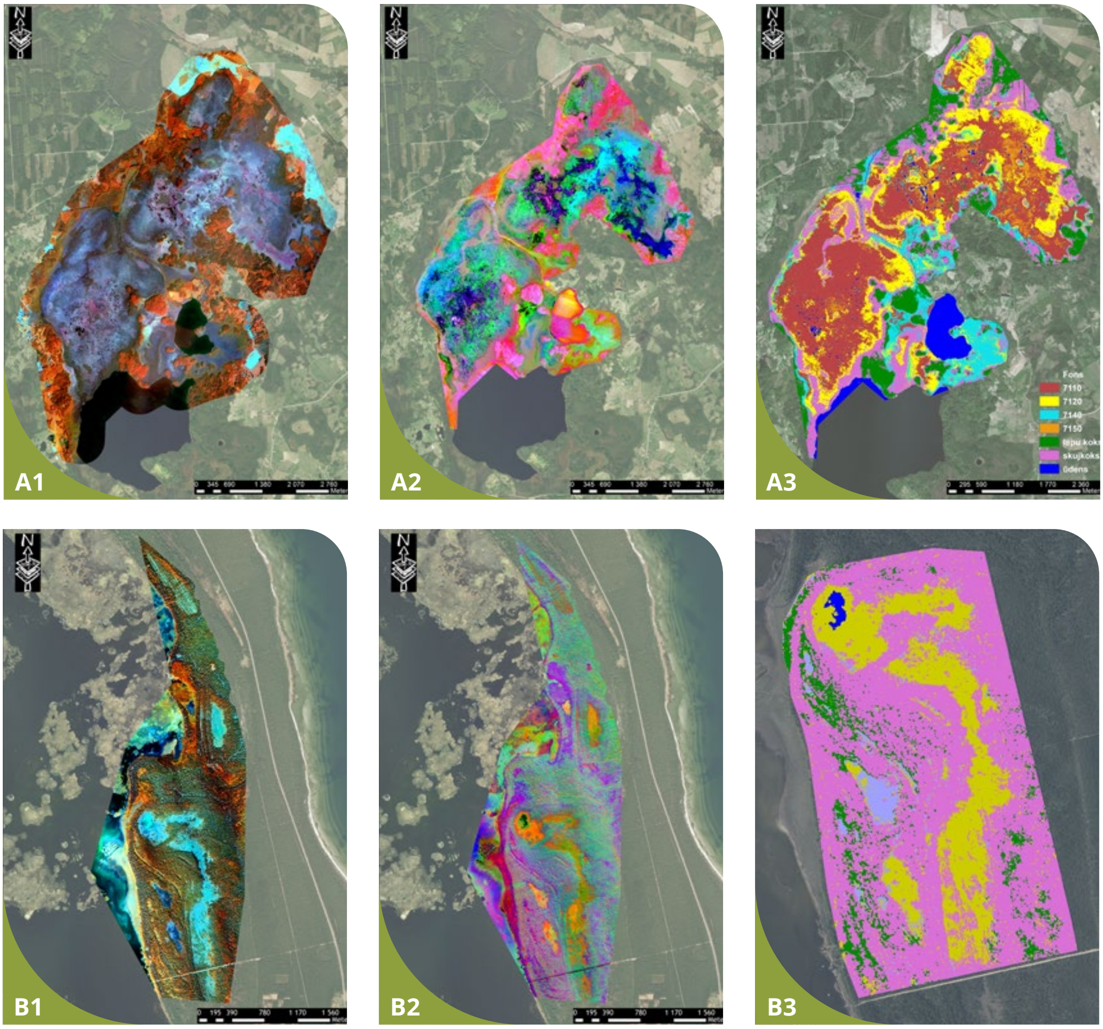


Figure 23. A – Madiešēnu Mire in Augstroze NR, Latvia; B – management area of Lake Engure NP, Latvia. The first step of remote sensing was to collect the hyperspectral data over the study areas (A1, B1). Next, using the principal component analysis, the data were classified using three of the most informative principal components (A2, B2). After calibrating the reference data in the field, remote sensing data algorithm training was performed to gain a final vegetation classification map (A3, B3). The most important GESTs according to Table 5 in A3: carmine red = 16, light blue = 19, yellow = 22, magenta = 23, green = 26; in B3: yellow = 10, blue = 13. Author: Institute for Environmental Solutions, 2019.

5.3. Challenges in direct measurements

Direct measurements are highly specific, and the project partners had to combat several challenges related with finding competent personnel to perform the GHG measurement related tasks, acquiring equipment, difficulties with site accessibility and machinery faults and logging gaps. Firstly, direct measurements need special, relatively expensive technology and competent people with experience and knowledge of various issues from planning the study to performing the measurements, data analysing and flux modelling to reconstruct the seasonal and annual GHG fluxes. These issues were challenging, especially in Latvia, Lithuania and Poland, where the use of direct measurements, such as transparent chambers, is relatively low or even absent. Although in Germany and Estonia, such experience and knowledge base were present, it was the case in Latvia, Lithuania and Poland, where competent persons, especially for the more technical modelling part had to be sourced from other countries. With the increasing importance of LULUCF related to GHG flux measurements and reporting, and related mitigation projects, this project helped to grow the competence and technological base towards understanding GHG measurements in countries with low expertise. This was completed through international cooperation of the projects and its workshops.

Another challenge during the direct measurements was site accessibility, as the project sites were not initially chosen for direct measurements. The direct measurements, especially in the case of chamber measurements conducted in the project, need regular transportation of relatively heavy equipment to and from the site. Transporting such equipment in difficult landscape conditions (soft and wet peat substrate, dense vegetation and forest, inundated areas and crossing the ditches) for relatively long distances and in different weather conditions is physically demanding and also time consuming. This limits the amount of work that could be completed, makes the measurements expensive and also affects the locations of the measurements point. Therefore, optimisation between the most representative and suitable points including its accessibility is needed. This, combined with the limited amounts of funds, resulted in restricting measurement months, as during the winter, additional batteries are needed for heating the equipment, and the accessibility with snowy conditions and frost during the winter decreases even more, especially in the northernmost site in Estonia.

Finally, machinery and logger malfunctions also caused problems. These loggers and machinery, although considered suitable for the fieldwork, must endure harsh conditions that can eventually cause fatal failures and smaller malfunctions that disturb the work. With direct measurement equipment, such issues mainly can already be found out during the measurements and sometimes also be quickly fixed. Larger malfunctions can endanger the measurements if replacement machinery is not available and acquisition of new machines requires additional funding, or time-consuming repairing at producer is needed. On the other hand, malfunctions of automatic loggers can result in large data gaps affecting the interpretation and reconstruction of results or making it more time consuming. To some extent this can be mitigated by the replications and regular controls of loggers, loggers with automatic data transmission, or using data from alternative sources (e.g., national monitoring) in case of malfunctions. Although many of these dangers could be mitigated or prevented by planning or additional costs, these things were not foreseen in the *LIFE Peat Restore* project budget and plans, thus providing challenges to overcome for the project team.

All these challenges limited the number of direct measurements and their spatial variability, especially in countries where allocated funds did not cover the possibilities for more detailed direct measurements. The number of measurement plots in each site and GEST is provided in *Table 4* (see *Chapter 3*). This could have some impact on the deviations between the direct measurement results in the project sites and emission data provided in the *Updated GEST catalogue* (*Annex 3*). Still the differences in the measured and *Updated GEST catalogue* GHG emissions were significant. These differences were probably caused by latitudinal differences in project site vegetation communities, environmental and climatic conditions (including the differences in length of the vegetation season), and interannual variations of the measurement years' meteorological conditions (e.g., drought impacts) which are not considered in the GEST catalogue. Despite the challenges presented here, we consider the direct measurement results in this project to provide valuable input to the peatland related GHG flux knowledge base.

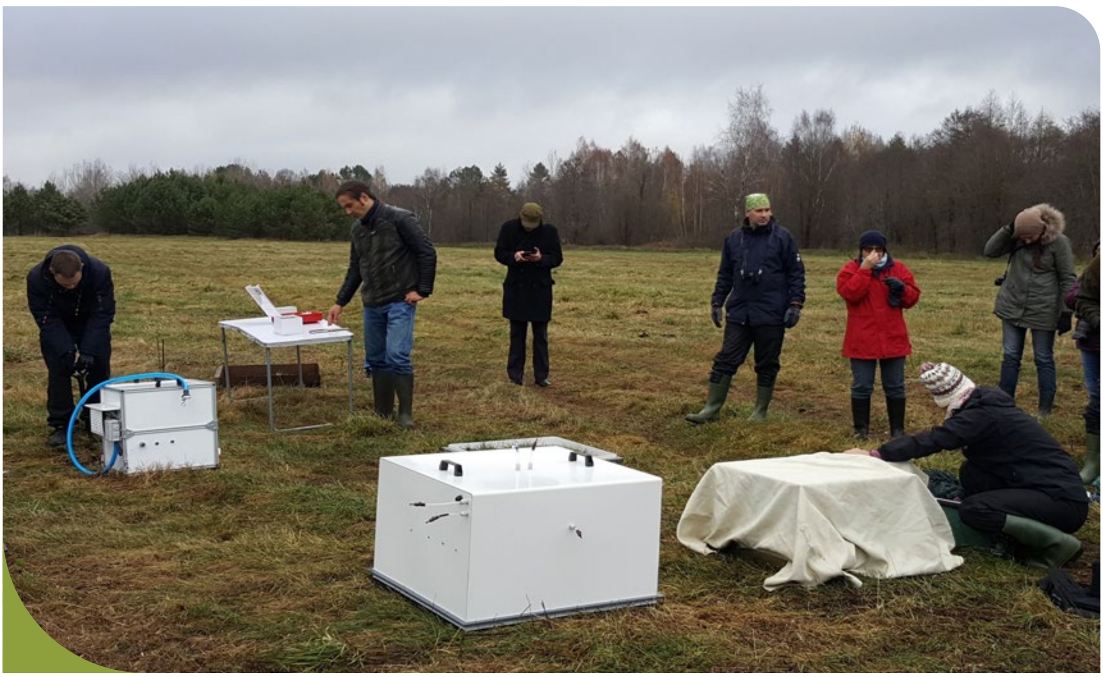


Figure 24. Workshop to test on the field the different GHG measurement systems used in the *LIFE Peat Restore* project, 22–26 October 2018, Vilnius, Lithuania. Photo: J. Sendžikaitė.

5.4. Challenges in tree biomass assessment

Carbon stored in woody biomass is an important factor of the GHG balance in peatlands and was therefore included into calculation of GHG emissions. Almost all project sites showed a positive climate effect for the *Post-restoration scenario*, although forested peatlands make up significant spatial amounts of the identified GESTs. The effect of the forest biomass to the carbon balance and also the carbon sequestration rate by trees is not consistent for all sites. In Latvia, Lithuania and Poland the effect of wood biomass is very low and resulted only in a small decrease of the total emissions. Studies in the boreal zone (Ojanen *et al*. 2013, 2014; Uri *et al*. 2017) show that on average, the carbon balance in drained peatland forests should be close to zero. The carbon source/sink function depends on soil fertility, tree age or weather conditions. As demonstrated by Ojanen *et al.* (2014), there are high relative uncertainties in soil net CO_2 exchange and that most of the tree biomass data are from mineral soil forests. Hommeltenberg *et al*. (2014b) also emphasises that carbon sequestration in tree biomass of drained peatland forests does not outweigh the amount of carbon that is released during the decomposition of peat.

The calculation of the aboveground biomass as well as the estimation of the carbon sequestration by trees depends on the available plant-physiological data and the used model approach. The integration of carbon sequestration by trees in the whole GHG balances was obstructed by missing GHG values from comparable forested sites and also with missing plant physiological data like the increments of different tree species. We suggest using national forest inventory data, because the given values of the different species depend on age, yield class and also the vegetation growing period. It is also important to consider the temporal dimension and the usage of the grown-up wood biomass, because on a short-term view (10 years) forests may absorb more carbon than natural peatlands, but they naturally continue draining the peatlands they grow on in a long-term perspective, which leads to higher CO_2 emissions. Also, if the wood biomass grown-up on peatlands is used for forestry, the fixed carbon will be released in the atmosphere somewhere else.

Tree biomass relation to GHG fluxes and carbon sequestration in restored peatlands needs further analyses and will be considered in other projects (*LIFE Multi Peat*, 2021–2026).

6. CONCLUSIONS AND RECOMMENDATIONS

Photo: M.Pakalne

1. GHG emissions from drained and/or rewetted peatlands following restoration should be measured. There are two typical methods: i) direct GHG emission measurements collected in the field, or ii) indirect evaluations using proxy parameters, such as vegetation composition and mean water level. The GEST approach is an example of an indirect method, which is based on GHG emissions obtained from direct measurements in sites of similar vegetation and conditions (see *Chapter 1.2.*).

2. The GEST is a recommended approach to broadly estimate the fluxes of GHG in rewetted peatlands. As presented in *Chapter 4.1.*, the indirect estimates of GHG emission reduction in the *LIFE Peat Restore* project's sites were derived by mapping 29 GESTs in 11 sites, covering an area of more than 5000 ha. Six new GESTs were identified and described in the *Updated GEST catalogue* (*Annex 3*). Data collected on water level, chemical properties, species composition, prevailing vegetation cover and direct GHG emission measurements for model validation has improved knowledge on the GEST approach (*Annex 4*), and allowed for more accurate predicting and modelling of peatland restoration.

3. GHG emission calculations conducted by the *LIFE Peat Restore* project based on the GEST approach showed that project peatlands after restoration measures will improve their functions and potentially reduce the GWP by 31% and provide an average reduction of ~4 t CO_2-eq./ha × yr. The largest reductions in GHG emission following peatland restoration are predicted in strongly degraded forested peatlands, which will largely be replaced by open peatland habitats (represented by the GESTs *Wet peat moss lawn, Wet peat moss lawn with pine trees*, etc.).

4. The majority of the 11 GESTs directly measured in the *LIFE Peat Restore* project had significant GHG sources. Results show some of the GESTs were also carbon sinks during certain periods within the project, however only one GEST was a carbon sink throughout the entire project period. The carbon sink functioning of the GESTs on different study years were affected by the meteorological data variations from the long-term average conditions. The release of GHG emissions from the vegetation understory was highest on deeply drained peatlands with forest (see *Chapter 4.2.*).

5. Incorporating direct measurement results from geographically and environmentally heterogeneous project sites with one-to-three-year measurement periods show the need for direct measurements that cover large spatial and temporal variability. One-year measurements can be severely affected by extreme weather events, such as droughts. Multi-annual direct measurements covering different vegetation communities are needed to give the most realistic estimations of carbon balances (see *Chapter 4.2.*). In addition, aquatic carbon loss (DOC and DIC) and tree related GHG fluxes should be incorporated into future GHG balance estimations.

6. The directly measured carbon emissions in the project sites and the GEST emission values diverged by 40% on average. This mismatch was more pronounced in the afforested and bare peat GESTs. However, only one GEST (*Wet peat moss lawn with pine trees*) had insignificant differences in the results derived from the two different methods. This suggests that the GEST emission factors, and our direct measurements do not cover the whole spatial and temporal variability of the carbon balance in one GEST and that direct measured site-specific GHG emission data should be used.

7. The GEST approach could be used to upscale direct measurements of GHG emission fluxes. In our upscaling example (Suursoo-Leidissoo site, Estonia, see *Table 9*), microsite level under- and over-estimations in the *Updated GEST Catalogue* (*Annex 3*) emission values evened out at the GEST site scale. Although the upscaled directly measured and GEST estimated carbon balance of the Suursoo-Leidissoo project area was similar, this may not apply to many other sites. Updating the GEST emission factors based on a greater number of direct measurements is essential to improve the accuracy of the GEST approach. Currently, the GEST approach has strong potential to be upscaled with directly measured GHG fluxes for larger project sites, as presented in *Chapter 4.2*.

8. Due to natural spatial and temporal variability of carbon emissions within one GEST, providing error limits for the GEST emission factors would greatly benefit the applicability of the method and interpretation of the results.

9. Both GHG assessment methods have their advantages and disadvantages. Compared to direct GHG measurements, the GEST approach is less expensive and time consuming; therefore, it is more attractive to be used on a wider scale. However, the GEST approach is not as precise and accurate as direct GHG measurements at a microsite scale. Given the GEST emission factors are based on the parameters from peer-reviewed articles, comprehensive data from various geographic regions are still missing for all representative peatland types, for instance the variations of climatic conditions, geology and other specific features of peatland sites (see *Chapter 4.3.*). The GEST approach is most suitable for initial and long-term carbon reduction reporting after rewetting, where direct measurements are not possible.

10. Although the GEST approach is less resource demanding in comparison to direct GHG measurements, it can require enormous human resources and time for mapping the GESTs in large peatlands, where even small patches of different GESTs might appear. Using remote sensing techniques to identify differences in vegetation cover, GESTs, or even the associations with *habitats of European importance* can offer solutions to minimise resources and maximise efficiency. The *LIFE Peat Restore* project identified that 21 of the 29 GESTs were associated with "habitats of EU importance" (see *Chapters 2.1.3.*, *5.1.* and *5.2.*).

REFERENCES

Adhikari A., Shah R., Baral S., Khanal R. 2011. Terminologies used in climate change. Kathmandu, Nepal, IUCN. *https://portals.iucn.org/library/sites/library/files/documents/2011-118.pdf.*

Alm J., Shurpali N.J., Minkkinen K., Aro L., Hytönen J., Laurila T., Lohila A., Maljanen M., Martikainen P.J., Mäkiranta P., Penttilä T. 2007. Emission factors and their uncertainty for the exchange of CO_2, CH_4 and N_2O in Finnish managed peatlands. *Boreal Environment Research*, 12: 191–209.

Aubinet M., Vesala T., Papale D. (eds). 2012. Eddy Covariance: A practical guide to measurement and data analysis. 438 p. Springer Science & Business Media.

Audet J., Johansen J.R., Andersen P.M., Baattrup-Pedersen A., Brask-Jensena K.M., Elsgaard L., Kjaergaard C., Larsen S.E., Hoffmann C.C. 2013. Methane emissions in Danish riparian wetlands: Ecosystem comparison and pursuit of vegetation indexes as predictive tools. *Ecological Indicators*, 34: 548–559. *https://doi.org/10.1016/j.ecolind.2013.06.016*.

Aurela M., Laurila T., Tuovinen J.P. 2002. Annual CO_2 balance of a subarctic fen in northern Europe: Importance of the wintertime efflux. *Journal of Geophysical Research*, 107: ACH 17-1–ACH 17–12.

Braun-Blanquet J. 1964. Pflanzensoziologie. Grundzüge der Vegetationskunde. 866 p. DritteAuflage. Wien–New York.

Collier S.M., Ruark M.D., Oates L.G., Jokela W.E., Dell C. J. 2014. Measurement of greenhouse gas flux from agricultural soils using static chambers. *Journal of Visualized Experiments*, 90: e52110. *DOI:10.3791/52110. https://www.jove.com/pdf/52110/jove-protocol-52110-measurement-greenhouse-gas-flux-from-agricultural-soils-using-static.*

Couwenberg J. 2009. Emission factors for managed peat soils (organic soils, histosols). An analysis of IPCC default values. 14 p. *Wetlands International*, Ede. *http://www.imcg.net/media/download_gallery/climate/couwenberg_2009a.pdf.*

Couwenberg J. 2011. Vegetation as proxy for greenhouse gas fluxes – the GEST approach. In: Tanneberger F., Wichtmann W. (eds). *Carbon credits from peatland rewetting. Climate – biodiversity – land use. Science, policy, implementation and recommendations of a pilot project in Belarus*: 37–52. Stuttgart.

Couwenberg J., Augustin J., Michaelis D., Joosten H. 2008. Emission reductions from rewetting of peatlands. Towards a field guide for the assessment of greenhouse gas emissions from Central European peatlands. 28 p. DUENE Greifswald/RSPB Sandy.

Couwenberg J., Thiele A., Tanneberger F., Augustin J., Bärisch S., Dubovik D., Liashchynskaya N., Michaelis D., Minke M., Skuratovich A., Joosten H. 2011. Assessing greenhouse gas emissions from peatlands using vegetation as a proxy. *Hydrobiologia*, 674: 67–89. *https://doi.org/10.1007/s10750-011-0729-x*.

Creevy A.L., Payne R.J., Andersen R., Rowson J.G., 2020. Annual gaseous carbon budgets of forest-to-bog restoration sites are strongly determined by vegetation composition. *Science of the Total Environment*, 705: 135863. *https://doi.org/10.1016/j.scitotenv.2019.135863.*

de la Haye A., Devereux C., van Herk S. 2021. Peatlands across Europe: Innovation & Inspiration. 42 p. Barcelona, Bax & Company. *https://northsearegion.eu/media/17421/web-version-peatlands-across-europe.pdf*.

Dinsmore K. J., Skiba U.M., Billett M.F., Rees R.M. 2009. Effect of water table on greenhouse gas emissions from peatland mesocosms. *Plant and Soil*, 318 (1): 229–242. *https://doi.org/10.1007/s11104-008-9832-9.*

Dowrick D.J., Freeman C., Lock M.A., Reynolds B. 2006. Sulphate reduction and the suppression of peatland methane emissions following summer drought. *Geoderma*, 132 (3–4): 384–390. *https://doi.org/10.1016/j.geoderma.2005.06.003*.

Drösler M., Adelmann W., Augustin J., Bergman L., Beyer C., Chojnicki B., Förster C., Freibauer A., Giebels M., Görlitz S., Höper H., Kantelhardt J., Liebersbach H., Hahn-Schöfl M., Minke M., Petschow U., Pfadenhauer J., Schaller L., Schägner J.P., Sommer M., Thuille A., Wehrhan M. 2013. Klimaschutz durch Moorschutz: Schlussbericht des Vorhabens "Klimaschutz - Moorschutzstrategien" 2006–2010. Technische Universität München. P. 201 S. *https://edocs.tib.eu/files/e01fb13/735500762.pdf*.

Ellenberg H., Weber H.E., Düll R., Wirth V., Werner W., Paulissen D. 1992. Zeigerwerte von Pflanzen in Mitteleuropa. 2. und verbesserte Auflage. *Scripta Geobotanica*, 18: 1–258.

Emmer I., Couwenberg J. 2017. VM0036. Methodology for rewetting drained temperate peatlands. Version 1.0. 81 p. Silvestrum climate associates, University of Greifswald. *https://verra.org/wp-content/uploads/2018/03/VM0036-Rewetting-Drained-Temperate-Peatlands-v1.0.pdf*.

Escobar D., Belyazid S., Manzoni S. 2022. Back to the Future: Restoring Northern Drained Forested Peatlands for Climate Change Mitigation. *Frontiers in Environmental Science*, 10: 834371. *https://doi.org/10.3389/fenvs.2022.834371.*

Estop-Aragonés C., Blodau C. 2012. Effects of experimental drying intensity and duration on respiration and methane production recovery in fen peat incubations. *Soil Biology & Biochemistry*, 47: 1–9. DOI: *10.1016/j.soilbio.2011.12.008.*

Fenner N., Freeman C. 2011. Drought-induced carbon loss in peatlands. *Nature Geoscience*, 4: 895–900. *https://doi.org/10.1038/ngeo1323.*

Gong Y., Wu J., Vogt J., Le T.B. 2019. Warming reduces the increase in N_2O emission under nitrogen fertilization in a boreal peatland. *Science of the Total Environment*, 664: 72–78. *https://doi.org/10.1016/j.scitotenv.2019.02.012*.

Grillakis M.G. 2019. Increase in severe and extreme soil moisture droughts for Europe under climate change. *Science of the Total Environment*, 660: 1245–1255. *https://doi.org/10.1016/j.scitotenv.2019.01.001.*

Günther A., Barthelmes A., Huth V., Joosten H., Jurasinski G., Koebsch F., Couwenberg J. 2020. Prompt rewetting of drained peatlands reduces climate warming despite methane emissions. *Nature Communications*, 11, Article No 1644. *https://www.nature.com/articles/s41467-020-15499-z.*

Günther A., Huth V., Jurasinski G., Glatzel S. 2015. The effect of biomass harvesting on greenhouse gas emissions from a rewetted temperate fen. *Global Change Biology Bioenergy*, 7: 1092–1106. DOI: *10.1111/gcbb.12214*.

Hiraishi T., Krug T., Tanabe K., Srivastava N., Baasansuren J., Fukuda M., Troxler T.G. (eds). 2014. 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Methodological guidance on lands with wet and drained soils, and constructed wetlands for wastewater treatment. 354 p. IPCC. *https://www.ipcc.ch/site/assets/uploads/2018/03/Wetlands_Supplement_Entire_Report.pdf.*

Hommeltenberg J., Mauder M., Drösler M., Heidbach K., Werle P., Schmid H.P. 2014a. Ecosystem scale methane fluxes in a natural temperate bog-pine forest in southern Germany. A*gricultural and Forest Meteorology*, 198–199: 273–284. DOI: *10.1016/j.agrformet.2014.08.017*.

Hommeltenberg J., Schmid H.P., Drösler M., Werle P. 2014b. Can a bog drained for forestry be a stronger carbon sink than a natural bog forest? *Biogeosciences*, 11(13): 3477–3493. *https://doi.org/10.5194/bg-11-3477-2014*.

Eggleston H.S., Buendia L., Miwa K., Ngara T., Tanabe K. (eds). 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan. *https://www.ipcc-nggip.iges.or.jp/public/2006gl/*.

Edenhofer O., Pichs-Madruga R., Sokona Y., Farahani E., Kadner S., Seyboth K., Adler A., Baum I., Brunner S., Eickemeier P., Kriemann B., Savolainen J., Schlömer S., von Stechow C., Zwickel T., Minx J.C. (eds). 2014. Climate Change 2014: Mitigation of Climate Change. Summary for Policymakers and Technical Summary. Part of the Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, New York, USA. *https://www.ipcc.ch/site/assets/uploads/2018/03/WGIIIAR5_SPM_TS_Volume-3.pdf.*

Järveoja J., Peichl M., Maddison M., Soosaar K., Vellak K., Karofeld E., Teemusk A., Mander Ü. 2016. Impact of water table level on annual carbon and greenhouse gas balances of a restored peat extraction area. *Biogeosciences*, 13 (9): 2637–2651. *https://doi.org/10.5194/bg-13-2637-2016*.

Joabsson A., Christensen T.R., Wallén B. 1999. Vascular plant controls on methane emissions from northern peatforming wetlands. *Trends in Ecology and Evolution*, 14(10): 385–388. DOI: 10.1016/s0169-5347(99)01649-3.

Joosten H., Couwenberg J. 2008. Peatlands and carbon. In: Parish F., Sirin A., Charman D., Joosten H., Minaeva T., Silvius M. *Assessment on peatlands, biodiversity and climate change*: 99–117. Global Environment Centre, Kuala Lumpur and Wetlands International Wageningen.

Joosten H., Tanneberger F., Moen A. (eds). 2017. Mires and peatlands of Europe. Status, distribution and conservation. 780 p. Schweizerbart Science Publishers, Stuttgart.

Joosten H., Brust K., Couwenberg J., Gerner A., Holsten B., Permien T., Schäfer A., Tanneberger F., Trepel M., Wahren A. 2015. *MoorFutures®. Integration of additional ecosystem services (including biodiversity) into carbon credits – standard, methodology and transferability to other regions*. 120 p. BfN-Skripten 407, Bonn. MoorFutures: Integration of additional ecosystem services (bfn.de)

Juszczak R., Augustin J. 2013. Exchange of the greenhouse gases methane and nitrous oxide at a temperate pristine fen mire in Central Europe. *Wetlands*, 33(5): 895–907. DOI: *10.1007/s13157-013-0448-3*.

Juszczak R., Humphreys E., Acosta M., Michalak-Galczewska M., Kayzer D., Olejnik J. 2013. Ecosystem respiration in a heterogeneous temperate peatland and its sensitivity to peat temperature and water table depth. *Plant and Soil*, 366 (1/2): 505–520. *https://www.jstor.org/stable/42952399*.

Kandel T.P., Lærke P.E., Elsgaard L. 2016. Effect of chamber enclosure time on soil respiration flux: A comparison of linear and non-linear flux calculation methods. *Atmospheric Environment*, 141: 245–254.

Keane J.B., Toet S., Ineson P., Weslien P., Stockdale J.E., Klemedtsson L. 2021. Carbon dioxide and methane flux response and recovery from drought in a Hemiboreal ombrotrophic fen. *Frontiers in Earth Science*, 8, 562401. *https://www.frontiersin.org/articles/10.3389/feart.2020.562401/full*.

Koch S., Jurasinski G., Koebsch F., Koch M., Glatzel S. 2014. Spatial variability of annual estimates of methane emissions in a *Phragmites australis* (Cav.) Trin. Ex Steud. dominated restored coastal brackish fen. *Wetlands*, 34 (3): 593–602. DOI: *10.1007/s13157-014-0528-z.*

Koebsch F., Gottschalk P., Beyer F., Wille C., Jurasinski G., Sachs T. 2020. The impact of occasional drought periods on vegetation spread and greenhouse gas exchange in rewetted fens. *Philosophical Transactions Royal Society B*, 375: 20190685. *https://doi.org/10.1098/rstb.2019.0685.*

Koska I., Succow M., Clausnitzer U., Timmermann T., Roth S. 2001. Vegetationskundliche Kennzeichnung von Mooren (topische Betrachtung). In: Succow M., Joosten H. (eds), *Landschaftsökologische Moorkunde*: 112–184. Schweizerbart, Stuttgart.

Laiho R., Laine J. 1997. Tree stand biomass and carbon content in an age sequence of drained pine mires in southern Finland. *Forest Ecology and Management*, 93 (1–2): 161–169.

Laiviņš M. 2014. Latvijas meža un krūmāju augu sabiedrības un biotopi. *Mežzinātne,* 28 (61): 6–38.

Lazcano C., Deol A.S., Brummell M.E., Strack M. 2020. Interactive effects of vegetation and water table depth on belowground C and N mobilization and greenhouse gas emissions in a restored peatland. *Plant and Soil*, 448: 299–313. *https://doi.org/10.1007/s11104-020-04434-2*.

Leip A., Achermsnn B., Billen G., Bleeker A., Bouwman A.F., de Vries W., Dragosits U., Döring U., Fernall D., Geupel M., Herolstab J., Johnes P., Le Gall A.C., Monni S., Nevečeřal R., Orlandini L., Prud'homme M., Reuter H.I., Simpson D., Seufert G. 2011. Integrating nitrogen fluxes at the European scale. In: Sutton M., Howard C.M, Erisman J.W, Billen G., Bleeker A., Grennfelt P., van Grinsven H., Grizzetti B. (eds), *The European Nitrogen Assessment: Sources, Effects and Policy Perspectives*: 345–376. Cambridge: Cambridge University Press. *doi:10.1017/CBO9780511976988.019*.

Lloyd J., Taylor J.A. 1994. On the temperature dependence of soil respiration. *Functional Ecology*, 8(3): 315–323. *https://doi.org/10.2307/2389824*.

Loftfield N., Flessa H., Augustin J., Beese F. 1997. Automated gas chromatographic system for rapid analysis of the atmospheric trace gases methane, carbon dioxide, and nitrous oxide. *Journal of Environmental Quality*, 26(2): 560–564. *https://doi.org/10.2134/jeq1997.00472425002600020030x.*

Lund M., Christensen T.R., Lindroth A., Schubert P. 2012. Effects of drought conditions on the carbon dioxide dynamics in a temperate peatland. *Environmental Research Letters*, 7(4): 045704. *https://doi.org/10.1088/1748-9326/7/4/045704*

Marcisz K., Gałka M., Pietrala P., Miotk-Szpiganowicz, G., Obremska M., Tobolski K., Lamentowicz M. 2017. Fire activity and hydrological dynamics in the past 5700 years reconstructed from *Sphagnum* peatlands along the oceanic-continental climatic gradient in northern Poland. *Quaternary Science Reviews,* 177: 145–157. *DOI: 10.1016/j.quascirev.2017.10.018.*

Matuszkiewicz W. 2008. Przewodnik do oznaczania zbiorowisk roślinnych Polski. 536 p. Warszawa: Wydawnictwo Naukowe PWN.

Michaelis L., Menten M.L. 1913. Die Kinetik der Invertinwirkung. *Biochemische Zeitschrift*, 49: 333–369.

Minke M., Augustin J., Burlo A., Yarmashuk T., Chuvashova H., Thiele A., Freibauer A., Tikhonov V., Hoffmann M. 2016. Water level, vegetation composition, and plant productivity explain greenhouse gas fluxes in temperate cutover fens after inundation. *Biogeosciences* 13: 3945–3970. *https://doi.org/10.5194/bg-13-3945-2016*.

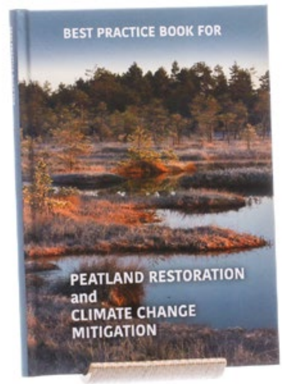
Minkkinen K., Ojanen P., Koskinen M., Penttilä T. 2020. Nitrous oxide emissions of undrained, forestry-drained, and rewetted boreal peatlands. *Forest Ecology and Management*, 478: 118494. *https://doi.org/10.1016/j.foreco.2020.118494*.

Nykänen H., Alm J., Silvola J., Tolonen K., Martikainen P.J. 1998. Methane fluxes on boreal peatlands of different fertility and the effect of long-term experimental lowering of the water table on flux rates. *Global Biogeochemical Cycles*, 12(1): 53–69. *https://doi.org/10.1029/97GB02732.*

Ojanen P., Lehtonen A., Heikkinen J., Penttilä T., Minkkinen K. 2014. Soil CO_2 balance and its uncertainty in forestry-drained peatlands in Finland. *Forest Ecology and Management*, 325: 60–73. *https://doi.org/10.1016/j.foreco.2014.03.049.*

Ojanen P., Minkkinen K., Penttilä T. 2013. The current greenhouse gas impact of forestry-drained boreal peatlands. *Forest Ecology and Management*, 289: 201–208. *https://doi.org/10.1016/j.foreco.2012.10.008*

Pakalne M., Etzold J., Ilomets M., Jarašius L., Pawlaczyk P., Bociag K., Chost I., Cieśliński R., Gos K., Libauers K., Pajula R., Purre A.-H., Sendžikaitė J., Strazdina L., Truus L., Zableckis N., Jurema L., Kirschey T. 2021. Best Practice Book for Peatland Restoration and Climate Change Mitigation. Experiences from LIFE Peat Restore Project. University of Latvia, 184 pp. *https://www.botanika.lu.lv/fileadmin/user_upload/lu_portal/botaniskais/2019/SADARBIBA/LIFE/Peatland_restoration_gramata.pdf.*



Penman J., Gytarsky M., Hiraishi T., Krug T., Kruger D., Pipatti R., Buendia L., Miwa K., Ngara T., Tanabe K., Wagner F. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Annex 3A.1 Biomass Default Tables for Section 3.2 Forest Land. *https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/Anx_3A_1_Data_Tables.pdf*

Purre A.H., Pajula R., Ilomets M. 2019. Carbon dioxide sink function in restored milled peatlands – The significance of weather and vegetation. *Geoderma*, 346: 30–42. *https://doi.org/10.1016/j.geoderma.2019.03.032*.

Purre A.H. 2021. Carbon dioxide dynamics and recovery of vegetation on restored peatlands. Tallinn University, Dissertations of Natural Sciences no 66: 207 p. *(PDF) Carbon dioxide dynamics and recovery of vegetation on restored peatlands*.

Reichelt K.F. 2015. Evaluierung des GEST-Modells zur Abschätzung der Treibhausgasemissionen aus Mooren. Master of Science (MSc.) Thesis: 55 p. Greifswald: University of Greifswald.

Rigney C., Wilson D., Renou-Wilson F., Müeller C., Moser G., Byrne K.A. 2018. Greenhouse gas emissions from two rewetted peatlands previously managed for forestry. *Mires and Peat*, 21, Article 24: 1–23. *http://mires-and-peat.net/media/map21/map_21_24.pdf*.

Salmiņa L. 2009. Limnogēno purvu veģetācija Latvijā. *Latvijas Veģetācija,* 19. 193 p. *http://botany.lv/wp-content/uploads/2014/10/Vegetacija_19.pdf.*

Schaffers A.P., Sýkora K.V. 2000. Reliability of Ellenberg indicator values for moisture, nitrogen and soil reaction: a comparison with field measurements. *Journal of Vegetation Science*, 11: 225–244. *https://doi.org/10.2307/3236802*.

Sendžikaitė J., Truus L., Strazdiņa L., Jarašius L., Herrmann A., Pajula R., Kirschey T., Zableckis N., Pakalne M., Sinkevičius Ž., Pakalnis R. 2018. First data on application of GEST approach in the Baltic Region: vegetation mapping of pilot peatlands. *Vegetation of Mires. Current Research on classification, mapping, use and conservation*: 115–119. Minsk, Grodno, *http://botany.by/wp-content/uploads/2018/10/Sbornik-Rastitelnost-bolot-2018.pdf.*

Spangenberg A. 2011. Einschätzung der Treibhausgasrelevanz bewaldeter Moorstandorte in Mecklenburg-Vorpommern hinsichtlich des Minderungspotentials nach Wiedervernässung [1]: 29 p. Institut für Dauerhaft Umweltgerechte Entwicklung der Naturräume der Erde (DUENE) e.V., Greifswald. *https://www.moorwissen.de/doc/publikationen/Spangenberg_(2011)_Einsch%C3%A4tzung_der_Treibhausgasrelevanz_bewaldeter_Moorstandorte_in_MV.pdf.*

Spinoni J., Vogt J.V., Naumann G., Barbosa P., Dosio A. 2018. Will drought events become more frequent and severe in Europe? *International Journal of Climatology*, 38(4): 1718–1736. *https://doi.org/10.1002/joc.5291.*

Steffen W., Rockström J., Richardson K., Lenton T.M., Folke C., Liverman D., Summerhayes C.P., Barnosky A.D., Cornel S.E., Crucifix M., Donges J.F., Fetzer I., Lade S.J., Scheffer M., Winkelmann R., Schellnhuber H.J. 2018. Trajectories of the Earth system in the anthropocene. *Proceedings of the National Academy of Sciences of the United States of America*, 115(33): 8252–8259. *DOI: 10.1073/pnas.1810141115*.

Stirling E., Fitzpatrick R.W., Mosley L.M. 2020. Drought effects on wet soils in inland wetlands and peatlands. *Earth-Science Reviews*, 210: 103387. *https://doi.org/10.1016/j.earscirev.2020.103387*.

Succow M., Joosten H. (eds). 2001. Landschaftsökologische Moorkunde. 622 p. Schweizerbart, Stuttgart.

Succow M., Stegmann H. 2001. Abiotische Kennzeichnung von Mooren (topische Betrachtung) - Nährstoffökologisch-chemische Kennzeichnung [Abiotic characterisation of peatlands (topical consideration) - nutrient ecological-chemical characterisation. In: Succow M., Joosten H. (eds) Landschaftsökologische Moorkunde, 2nd Edition, Chapter 3.3: 75–85. Schweizerbart, Greifswald.

Swenson M.M., Regan S., Bremmers D.T.H., Lawless J., Saunders M., Gill L.W. 2019. Carbon balance of a restored and cutover raised bog: implications for restoration and comparison to global trends. *Biogeosciences*, 16(3): 713–731. *https://doi.org/10.5194/bg-16-713-2019.*

Tiemeyer B., Freibauer A., Borraz E.A., Augustin J., Bechtold M., Beetz S., Beyer C., Ebli M., Eickenscheidt T., Fiedler S., Förster C., Gensior A., Giebels M., Glatzel S., Heinichen J., Hoffmann M., Höper H., Jurasinski G., Laggner A., Leiber-Sauheitl K., Peichl-Brak M., Drösler M. 2020. A new methodology for organic soils in national greenhouse gas inventories: data synthesis, derivation and application. *Ecological Indicators*, 109: 1–14. *https://doi.org/10.1016/j.ecolind.2019.105838.*

Urbanová Z., Bárta J. 2020. Recovery of methanogenic community and its activity in long-term drained peatlands after rewetting. *Ecological Engineering*, 150: 105852. *DOI: 10.1016/j.ecoleng.2020.105852*.

Uri V., Kukumägi M., Aosaar J., Varik M., Becker H., Soosaar K., Morozov G., Ligi K., Padar A., Ostonen I., Karoles K. 2017. Carbon budgets in fertile grey alder (*Alnus incana* (L.) Moench.) stands of different ages. *Forest Ecology and Management*, 396: 55–67. *DOI: 10.1016/j.foreco.2017.04.004.*

Vanselow-Algan M., Schmidt S.R., Greven M., Fiencke C., Kutzbach L., Pfeiffer E.-M. 2015. High methane emissions dominated annual greenhouse gas balances 30 years after bog rewetting. *Biogeosciences*, 12(14): 4361–4371. *https://doi.org/10.5194/bg-12-4361-2015*.

Wang H., Richardson C.J., Ho M. 2015. Dual controls on carbon loss during drought in peatlands. *Nature Climate Change*, 5: 584–588. *https://doi.org/10.1038/nclimate2643*.

Whalen S.C. 2005. Biogeochemistry of methane exchange between natural wetlands and the atmosphere. *Environmental Engineering Science*, 22: 73–94. *https://doi.org/10.1089/ees.2005.22.73*.

Wilson D., Alm J., Riutta T., Laine J., Byrne K.A, Farrell E.P., Tuittila E.-S. 2007. A high resolution green area index for modelling the seasonal dynamics of CO_2 exchange in peatland vascular plant communities. *Plant Ecology,* 190: 37–51. *https://doi.org/10.1007/s11258-006-9189-1*.

Wilson D., Farrell C.A., Fallon D., Moser G., Müller C., Renou-Wilson F. 2016. Multiyear greenhouse gas balances at a rewetted temperate peatland. *Global Change Biology*, 22(12): 4080–4095. *DOI: 10.1111/gcb.13325*.

Yi B.L., Lu F., Bu Z.-J. 2022. Nitrogen addition turns a temperate peatland from a near-zero source into a strong sink of nitrous oxide. *Plant Soil Environment*, 68: 49–58. *https://doi.org/10.17221/411/2021-PSE*.

ANNEXES

Photo: L. Strazdina

ANNEX 1

Calculation of fixed carbon in living (wooden) biomass (BEF-method, Penman *et al*. 2003)

Equation 1: C = [V x D x BEF] x (1+R) x CF
C = fixed carbon in wooden Biomass
V = Stem volume of tree species [m^3 * ha^{-1}]
D = Basic wood density of species
BEF = Biomass expansion factor for conversion of stem biomass to above-ground tree biomass per species
R = Root:Shoot ratio
CF = carbon fraction [IPCC 2003 Standard-value 0.5]

Table 1. Biomass expansion factors (BEF), means and ranges are shown; lower values originate from younger forests or forests with a small stock; higher values originate from mature forests or forests with a higher stock

Forest type	Minimum DBH (cm) stem diameter in breast height (ca. 130 cm above ground)	BEF (with bark) application for stock data	BEF (with bark) application for growth rate data
Spruce/Fir	0–12.5	1.3 (1.15–4.2)	1.15 (1–1.3)
Pine		1.3 (1.15–3.4)	1.05 (1–1.2)
Broadleaf forest		1.4 (1.15–3.2)	1.2 (1.1–1.3)

Table 2. Wood densities of stem and branch (Penman *et al*. 2003)

Genus	Species	Stem	Branch
Alnus	spp.	0.45	0.49
Betula	spp.	0.51	0.56
Fraxinus	*excelsior*	0.57	0.60
Populus	spp.	0.35	0.38
Pinus	*sylvestris*	0.42	0.56
Quercus	*robur*	0.58	0.62
Salix	spp.	0.45	0.49

Branch wood of trees show higher densities than stem wood, hence the differentiation in branch and stem density increases the calculation precision of carbon-sequestration.

Equation 2: $C = [V \times D_s + V \times (BEF-1) \times D_b] \times (1+R) \times CF$

Where:
C, V, BEF, R, CF = see above
Ds = Stem wood Density
Db = Branch wood density

Table 3. Root : Shoot ratio (R) for calculation of below ground biomass (Penman *et al.* 2003).

Vegetation Type	Aboveground Biomass (t * ha-1)	R (Average)	Standard deviation
Conifer forest/ Plantation	<50	0.46	±0.21
	50-150	0.32	±0.08
	>150	0.23	±0.09
Oak forest	>75	0.35	±0.25
Other broadleaf forest	<75	0.43	±0.24
	75-100	0.26	±0.1
	>150	0.24	±0.05

ANNEX 2

Table 1. Meteorological information for the study sites and years.
Sources: Estonian Weather Service (long-term data for period 1961–1990), Latvian Nature, Geological and Meteorological Centre (long-term data for 1991–2020); Lithuanian Hydrometeorological Service (1981–2020), German Weather Service – station Angermünde (long term data from 1961–2010), Polish Weather Service (long-term data for 1991–2020)

Site	Variable	Long-term	2018	2019	2020
EE-SU	Annual average temperature (°C)	5.2	7.2	7.5	±0.21
	Growing season (May–October) average temperature (°C)	12.2	14.8	13.4	±0.08
	Annual precipitation (mm)	666	540	743	±0.09
	Growing season (May–October) precipitation (mm)	409	353	410	±0.25
LV-BA	Annual average temperature (°C)	7.3	nd	8.4	nd
	Growing season (May–October) average temperature (°C)	13.7		14.5	
	Annual precipitation (mm)	658		610	
	Growing season (May–October) precipitation (mm)	373		347	

Table 1 (continued)

Site	Variable	Long-term	2018	2019	2020
LV-EN	Annual average temperature (°C)	5.7	nd	8.3	nd
	Growing season (May–October) average temperature (°C)	13.7		13.8	
	Annual precipitation (mm)	13.7		552	
	Growing season (May–October) precipitation (mm)	600		349	
LV-AU	Annual average temperature (°C)	6.5	nd	8.0	nd
	Growing season (May–October) average temperature (°C)	13.6		13.8	
	Annual precipitation (mm)	743		814	
	Growing season (May–October) precipitation (mm)	470		525	
LT-AU	Annual average temperature (°C)	8.2	nd	10.2	nd
	Growing season (May–October) average temperature (°C)	13.9		16.1	
	Annual precipitation (mm)	733		683	
	Growing season (May–October) precipitation (mm)	508		448	
LT-AM	Annual average temperature (°C)	9.4	nd	9.1	nd
	Growing season (May–October) average temperature (°C)	16.2		15.3	
	Annual precipitation (mm)	650		398	
	Growing season (May–October) precipitation (mm)	433		221	
LT-PU	Annual average temperature (°C)	9.4	nd	7.9	nd
	Growing season (May–October) average temperature (°C)	16.2		14.1	
	Annual precipitation (mm)	650		625.5	
	Growing season (May–October) precipitation (mm)	433		390	
PL-WB	Annual average temperature (°C)	8	9.1	9.2	9.3
	Growing season (May–October) average temperature (°C)	13.5	15.8	14.7	14.3
	Annual precipitation (mm)	571	925	490	489
	Growing season (May–October) precipitation (mm)	380	522	276	316
DE-BB	Annual average temperature (°C)	8.6	10.4	10.9	10.7
	Growing season (May–October) average temperature (°C)	14.6	17.1	16.5	15.8
	Annual precipitation (mm)	520	436	470	439
	Growing season (May–October) precipitation (mm)	303	224	276	276

ANNEX 3

Updated GEST catalogue
(compiled by *LIFE Peat Restore*)

GEST / *Corresponding vegetation form*	**Occuring plant species**
OPEN PEATLANDS	
1. Moderately moist (forb) meadows *Cirsium oleraceum-Arrhenatherum elatius-community* *Molinia caerulea-Daucus carota-Deschampsia cespitosa-community* *Cirsium oleraceum-Urtica dioica-community* *Phragmites australis-Aegopodium podagraria-Urtica diocia-community* *Juncus effusus-Deschampsia cespitosa- community* *Pteridium aquilinum-Molinia caerulea-community* *Molinia caerulea-community*	***Calamagrostis epigejos, Rubus caesius,*** *Aegopodium podagraria, Agrimonia eupatoria, Agrostis tenuis, Alchemilla* spp., *Anthoxanthum odoratum, Anthriscus sylvestris, Briza media, Carex hartmanii, C. nigra, Cirsium oleraceum, Cynosurus cristatus, Dactylis glomerata, Deschampsia cespitosa, Festuca rubra, Filipendula ulmaria, Galium album, G. boreale, G. uliginosum, Geranium palustre, Geum rivale, Knautia arvensis, Leontodon hispidus, Listera ovata, Luzula campestris, Pimpinella saxifraga, Phleum pratense, Plantago lanceolata, Platanthera bifolia, Poa pratensis, Polygala vulgaris, Prunella vulgaris, Ranunculus auricomus, Taraxacum officinale, Trifolium repens*
2. Moderately moist/dry bog heath NEW	***Calluna vulgaris, Pleurozium schreberii,*** *Agrostis capillaris, Betula pendula, Salix cinerea*
3. Moist reeds and (forb) meadows *Lythrum salicaria-Urtica dioica-Phragmites australis-community* *Dianthus superbus-Molinea caerulea meadow* *Polygonum bistorta-Cirsium oleraceum meadow* *Filipendula ulmaria-Galeopsis tetrahit-Molinia caerulea-community* *Filipendula ulmaria-Urtica dioica-Polygonum bistorta-community* *Filipendula ulmaria-Urtica dioica-Cirsium oleraceum-community* *Cicuta virosa-Carex acutiformis-Phragmites australis-community* *Molinia caerulea-Dicranella cerviculata-community*	***Phragmites australis, Pohlia nutans, Urtica dioica,*** *Carex acutiformis, Solidago canadensis, Epilobium spec., Juncus effusus, Deschampsia caespitosa, Peucedanum* sp., *Calamagrostis* sp., *Molinea caerulea, Dicranella* sp., *Brachythecium rutabulum, Carex flava, Dicranella cerviculata, Dicranum polysetum, Calamagrostis epigejos, Rubus idaeus*
4. Moist bog heath *Calluna vulgaris-community* *Calluna vulgaris-Molinia caerulea-community*	***Calluna vulgaris, Eriophorum vaginatum,*** *Cladonia* spp., *Polytrichum strictum*
5. Bare peat dry (oligotrophic) NEW	

Legend to colour and font code

– New GEST

Font size in "Occuring plant species" – Frequency (qualitatively)

*Green font** – New vegetation type (not included in the vegetation form-concept

Red font – Extrapolated from other GEST

nd – No data

Bold in columns "CO_2/CH_4 emissions/GWP" – Values used in *LIFE Peat Restore*

Purple font – Data without considering wood biomass, partly extrapolated from other GEST

[Value] in columns "CO_2/CH_4 emissions/GWP" – Data considering wood biomass

(Value) in columns "CO_2/CH_4 emissions/GWP" – Accord. to Reichelt 2015

Water level	CO_2 emissions (t CO_2-eq./ ha/year)	CH_4 emissions (t CO_2-eq./ ha/year)	GWP estimate (t CO_2 eq./ ha/year)	Aim/Remarks	References
2+	**20.0**	**0.0**	**20.0**	**Gapfilling** **Extrapolated from GEST Moderately moist grassland**	Couwenberg *et al.* 2011
2+/2-	**nd**	**nd**	**nd**	**Gapfilling** **New GEST** (suggested to use a bit higher values as for the GEST *Moist bog heath*)	No references
3+	**4.6** (-2.8)	**7.5** (0.0)	**12.2** (3.0)	**Calibration**	Koch *et al.* 2014 Fortuniak *et al.* 2017 Wilson *et al.* 2016
3+	**9.4** (12.3)	**0** (0.2)	**9.4** (12.5)	**Calibration**	Drösler *et al.* 2013
2-/3-	**7.0**	**0.4**	**7.5**		Maljanen *et al.* 2010 Couwenberg *et al.* 2011

GEST / *Corresponding vegetation form*	**Occuring plant species**
6. Bare peat moist (oligotrophic)	Patchily occurring: *Betula pendula, Calluna vulgaris, Camphylopus introflexus, Equisetum arvensis, Eriophorum vaginatum, Polytrichum strictum, Rhynchospora alba*
7. Bare peat wet (oligotrophic)	
8. Very moist meadows, forbs and small sedges reeds *Scirpetum sylvatici meadow* *Juncus-Carex nigra-reed* *Tall sedges-Cirsium oleraceum meadow* *Peucedanum palustre-Molinia caerula-community* *Caltha palustris-Filipendula ulmaria-community* *Polygonum bistorta-Caltha palustris-Carex paniculata-community* *Carex nigra-Caltha palustris-Filipendula ulmaria-community* *Galium palustre-Carex paniculata-community* *Sedges-Eriophorum-reed*	***Carex rostrata, Carex lasiocarpa, Phragmites australis, Eriophorum angustifolium, Molinea caerulea, Calliergonella cuspidata, Comarum palustre, Menyanthes trifoliata, Oxycoccus palustris, Salix aurita,*** *Carex acutiformis, Poa pratensis, Rubus idaeus, Urtica dioica, Lysimachia vulgaris, Lythrum salicaria, Peucedanum palustre, Thelypteris palustris, Utricularia* spp.*, Salix lapponum, Salix rosmarinifolia, Sphagnum* spp.*, Bryum pseudotriquetrum, Scorpidium scorpioides, Campylium stellatum, Calla palustris, Carex limosa, Chamaedaphne calyculata, Dactylorhiza incarnata, Drosera rostrata, Equisetum fluviatile, Eriophorum vaginatum, Lysimachia thyrsiflora, Pedicularis palustris, Rhynchospora alba, Sphagnum teres, Juncus effusus, Scirpus sylvaticus, Calamagrostis canescens, Calliergon cordifolium, Climacium dendroides*
9. Wet meadows and forbs *Valeriana-Polygonum bistorta meadow (wet)* *Caltha palustris-Filipendula ulmaria-community (wet)* *Rhynchosphora alba-community* *Rhynchosphora alba-Eriophorum vaginatum-community* *Rhynchosphora alba-Trichophorum alpinum-community* *Trichophorum alpinum-community*	***Rhynchospora alba, Trichophorum alpinum, Carex dioica, C. echinata, C. lasiocarpa, C. limosa, C. nigra, C. rostrata, Dactylorhiza cruenta, D. baltica, D. fuchsii, D. maculata, Drosera anglica, D. rotundifolia, Epipactis palustris, Eriophorum latifolium, E. vaginatum, Juniperus communis, Menyanthes trifoliata, Vaccinium oxycoccos, Phragmites australis, Platanthera bifolia, Pinguicula vulgaris, Trichophorum cespitosum, Sphagnum warnstorfii, Calliergon giganteum, Campylium stellatum, Cinclidium stygium, Fissidens adianthoides, Scorpidium scorpioides, Tomenthypnum nitens,*** *Sphagnum capillifolium, Sphagnum fallax*
10. Very moist/Wet calcareous meadows, forbs and small sedges reeds (eutrophic) NEW *Primula farinosa-Schoenus ferrugineus-community* *Scorpidium scorpioides-Eleocharis quinqueflora-community* *Scorpidium scorpioides-Cladium mariscus-community* *Phragmites australis-community on calcareous fen*	***Myrica gale, Molinia caerulea, Schoenus ferrugineus, Carex hostiana, C. flacca, C. panicea, C. lepidocarpa, C. dioica, Primula farinosa, Pinguicula vulgaris, Parnassia palustris, Epipactis palustris, Equisetum variegatum, Phragmites australis, Sesleria caerulea, Linum catharticum, Potentilla erecta, Eupatorium cannabinum, Gymnadenia conopsea, Triglochin palustre, Drepanocladus revolvens, Scorpidium scorpioides, Campylium stellatum, Fissidens adianthoides, Calliergonella cuspidata, Cladium marisus, Phragmites australis,*** *Menyanthes trifoliata*

Water level	CO_2 emissions (t CO_2-eq./ ha/year)	CH_4 emissions (t CO_2-eq./ ha/year)	GWP estimate (t CO_2 eq./ ha/year)	Aim/Remarks	References
3+	**6.2** (9.0)	**0.0** (0.0)	**6.2** (9.0)	**Calibration**	Vanselow-Algan *et al.* 2015 Wilson *et al.* 2009 Wilson *et al.* 2016
4+ (5+)	**1.5** (1.3)	**0.1** (0.2)	**1.6** (1.5)	**No target GEST**	Bortoluzzi *et al.* 2006 Wilson *et al.* 2016
4+ (5+)	**-0.5** (12.6)	**2.3** (0.3)	**1.9** (13.0)	**Calibration**	Tauchnitz *et al.* 2008 Audet *et al.* 2013 Drösler *et al.* 2013 Rinne *et al.* 2007
5+	**±0.0** (-3.9)	**5.8** (7.4)	**5.8** (3.5)	**Gapfilling/Calibration** **Extrapolated from rewetted grassland**	Audet *et al.* 2013
4+/5+	**2.4**	**0.5**	**2.9**	**Gapfilling** **New GEST**	Drösler *et al.* 2013

GEST / *Corresponding vegetation form*	**Occuring plant species**
11. Very moist bog heath *Eriophorum vaginatum-Erica tetralix-Sphagnum spp.-community* *Erica tetralix-Calluna vulgaris-Myrica gale-Sphagnum spp.-community*	***Calluna vulgaris,*** *Rhododendron tomentosum* (syn. *Ledum palustre*), *Sphagnum* spp., *Molinea caerulea, Polytrichum strictum, Sphagnum magellanicum*
12. Very moist peat moss lawn *Peat moss lawn with large Eriophorum hummocks or Molinia caerulea* *Molinia caerulea-Eriophorum vaginatum-Sphagnum fallax-community* *Eriophorum vaginatum-Erica tetralix-Sphagnum spp.-community*	***Sphagnum medii,*** *Calluna vulgaris, Eriophorum vaginatum, Sphagnum* spp.
13. Wet tall sedges reeds *Ranunculus lingua-Carex elata-Phragmites australis-community (wet)* *Valeriana dioica-Berula erecta-Carex paniculata-community (wet)* *Carex gracilis reed* *Carex rostrata-Salix aurita-Eriophorum angustifolium-community* *Carex acutiformis-comunity* *Phragmites australis-Carex spp.-community*	***Carex elata, C. pseudocyperus, Phragmites australis, Myrica gale***
14. Wet small sedges reeds mostly with moss layer *Sphagnum recurvum-Eriophorum angustifolium-community* *Calliergonella cuspidata-Viola palustris-Carex appropinquata-community* *Sphagnum teres-Viola palustris-Carex appropinquata-community* *Parnassia palustris-Carex nigra-community* *Sphagnum recurvum-Juncus effusus-community* *Juncus effusus-Phragmites australis-Calamagrostis canescens-community* *Juncus effusus-community* *Carex nigra-Calliergonella cuspidata-community*	***Carex rostrata, Sphagnum fallax, Eriophorum vaginatum, Carex canescens, Agrostis canina, Sphagnum cuspidatum****, Eriophorum angustifolium, Juncus effusus*
15. Wet tall reeds *Solanum dulcamara-Galium palustre-Phragmites australis-community* *Rorippa amphibia-Typha latifolia-Phragmites australis-community* *Bidens tripartita-Veronica anagallis-aquatica-Gyceria maxima-community* *Phragmites australis-Carex rostrata-community*	***Phragmites australis, Acorus calamus, Carex rostrata, Comarum palustre, Eleocharis palustris, Equisetum fluviatile, Isoetes lacustris, Littorella uniflora, Lobelia dortmanna, Myriophyllum alterniflorum, M. verticillatum, Nitella flexilis, Nuphar lutea, N. pumila, Polygonum amphibium, Potamogeton lucens, P. natans, Ranunculus reptans, Sparganium angustifolium, Utricularia vulgaris,*** *Salix cinerea, Carex nigra, Epilobium palustre, Lemna minor, Lycopus europaeus, Poa palustris, Calamagrostis canescens*

Water level	CO_2 emissions (t CO_2-eq./ ha/year)	CH_4 emissions (t CO_2-eq./ ha/year)	GWP estimate (t CO_2 eq./ ha/year)	Aim/Remarks	References
4+	**1.7** (4.7)	**3.0** (0.9)	**4.6** (5.5)	**Calibration**	Drösler 2005 Lund *et al.* 2007
4+ (5+)	**-1.1** (-4.3)	**3.4** (1.5)	**2.3** (-3.0)	**Calibration**	Bartoluzzi *et al.* 2006 Drösler 2005, 3 sites Drösler 2013, 2 sites
5+ (4+)	**-0.1** (1.0)	**8.5** (9.5)	**8.4** (10.5)	**Calibration**	Günther *et al*. 2014 Wilson *et al.* 2009
5+ (4+)	**-3.5** (-2.0)	**6.8** (4.7)	**3.3** (2.5)	**Calibration**	Drösler *et al.* 2013 Audet *et al.* 2013, 3 sites Juszczak & Augustin 2013 Minke *et al.* 2015, 4 sites Beetz *et al.* 2013 Helfter *et al.* 2015 Wilson *et al.* 2016 Wilson *et al.* 2009
5+	**-2.3** (0.2)	**6.3** (6.5)	**4.0** (6.5)	**Calibration**	Günther *et al.* 2014, 2 sites Audet *et al.* 2013, 3 sites Wilson *et al.* 2009

GEST / *Corresponding vegetation form*	**Occuring plant species**
16. Wet peat moss lawn *Sphagnum magellanicum-community* *Eriophorum vaginatum-Sphagnum recurvum-community*	***Eriophorum vaginatum, Sphagnum cuspidatum,*** *Andromeda polifolia, Calluna vulgaris, Chamaedaphne calyculata, Drosera anglica, D. rotundifolia, Empetrum nigrum, Rhododendron tomentosum* (syn. *Ledum palustre*), *Vaccinium microcarpum, V. oxycoccos, Rhynchospora alba, Rubus chamaemorus, Trichophorum cespitosum, Vaccinium uliginosum, V. vitis-idaea, Cladopodiella fluitans, Dicranum polysetum, Polytrichum commune, Sphagnum fuscum, S. capillifolium, S. fallax, S. flexuosum, S. magellanicum, S. rubellum, S. tenellum, Cladonia stellaris, C. stygia, Mylia anomala*
17. Peat moss lawn on former peat-cut off areas *Eriophorum vaginatum-Molinia caerulea-Sphagnum spp.-community* *Eriophorum vaginatum-Eriophorum angustifolium-Molinia caerulea-Sphagnum spp.-community* *Eriophorum angustifolium-Calla palustris-Sphagnum spp.-community* *Eriophorum angustifolium-Molinia caerulea-Sphagnum spp.-community* *Eriophorum angustifolium-Rynchospora alba-Molinia caerulea-Sphagnum cuspidatum-community*	***Sphagnum* spp., *Sphagnum cuspidatum,*** *S. fallax, Eriophorum vaginatum, E. angustifolium, Molinea caerulea, Dicranella cerviculata, Phragmites australis, Carex rostrata*
18. Wet peat moss lawn with pine trees NEW *Pinus sylvestris-Sphagnum magellanicum-community*	***Pinus sylvestris*, *Sphagnum magellanicum,* *Sphagnum* spp., *S. rubellum, S. medii,*** *Eriophorum vaginatum, Rhododendron tomentosum* (syn. *Ledum palustre*), *Calluna vulgaris, Menyanthes trifoliata, Vaccinium uliginosum, Sphagnum fallax*
19. Wet peat moss hollows resp. flooded peat moss lawn *Sphagnum cuspidatum-Carex limosa-community* *Sphagnum recurvum-Carex limosa-community*	***Sphagnum cuspidatum,*** *Calla palustris, Carex limosa, C. elata, C. lasiocarpa, C. rostrata, Chamaedaphne calyculata, Comarum palustre, Drosera rotundifolia, D. anglica, Equisetum fluviatile, Eriophorum vaginatum, E. latifolium, Menyanthes trifoliata, Molinia caerulea, Lysicmachia thyrsiflora, Vaccinium oxycoccos, Rhynchospora alba, Scheuchzeria palustris, Succisa pratensis, Thelypteris palustris, Calliergonella cuspidata, Sphagnum recurvum, S. magellanicum, S. teres, Utricularia* sp., *Eriophorum angustifolium*
20. Open water/ditches	

Water level	CO_2 emissions (t CO_2-eq./ ha/year)	CH_4 emissions (t CO_2-eq./ ha/year)	GWP estimate (t CO_2 eq./ ha/year)	Aim/Remarks	References
5+ (4+)	**-0.5** (-3.0)	**0.3** (5.3)	**-0.3** (2.0)	**Calibration**	Drösler 2013, 3 sites
5+ (4+)	**1.5** (2.8)	**0.4** (37.3)	**1.9** (40)	**Calibration**	Drösler 2005 Drösler *et al.* 2013 Bortoluzzi *et al.* 2006
4+	**3.9**	**0.2**	**4.1**	**Gapfilling/Calibration** **New GEST** **Data without woods**	Drösler *et al.* 2013
5+	**-3.1** (-4.6)	**12.0** (11.8)	**8.9** (7)	**Calibration**	Drösler 2005 Drösler 2013, 2 sites Vanselow-Algan *et al.* 2015
6+	**nd** (+-0)	**2.8** (3.2)	**nd** (3.0)	**Gapfilling**	Van den Pol-van Dasselaar *et al.* 1999, 3 sites

GEST / *Corresponding vegetation form*	**Occuring plant species**
FORESTED PEATLANDS ***Oligotrophic peatlands***	
21. Dry forest and shrubberies NEW *Picea abies (planted)-community*	***Picea abies,*** *Betula pendula, Pinus sylvestris, Corylus avellana, Sorbus aucuparia, Crepis paludosa, Paris quadrifolia, Galium odoratum, Geum urbanum, Oxalis acetosella, Rubus saxatilis, Viola* spp., *Brachythecium rutabulum, Eurhynchium angustirete, Plagiomnium affine, P. undulatum, Rhodobryum roseum*
22. Moderately moist forest and shrubberies *Pleurozium schreberi-Pinus sylvestris-community* *Pleurozium schreberi-Betula pubescens-community* *Molinia caerulea-Pinus sylvestris-community* *Molinea caerulea-Betula pubescens-community*	***Betula pendula, B. pubescens, Picea abies, Vaccinium myrtillus, V. vitis-idaea, Calluna vulgaris, Pleurozium schreberii, Pinus sylvestris, Eriophorum vaginatum, Vaccinium uliginosum, Molinia caerulea, Andromeda polifolia, Empetrum nigrum, Rhododendron tomentosum*** **(syn.** ***Ledum palustre*****),** ***Oxalis acetosella, Rhynchospora alba, Rubus chamaemorus, Dicranum polysetum, Vaccinium oxycoccos, Polytrichum commune, P. juniperinum, Sphagnum fuscum, S. magellanicum, S. capillifolium, Cladonia stellaris, Frangula alnus, Lycopodium annotinum, Rubus idaeus, Polytrichum strictum,*** *Agrostis capillaris, Calamagrostis epigejos, Fragaria vesca, Rubus nessensis, Dicranum scoparium, Brachythecium rutabulum, Plagiomnium undulatum*
23. Moist forests and shrubberies *Vaccinium uliginosum-Betula pubescens-community* *Vaccinium uliginosum-Pinus sylvestris-community* *Myrica gale-community*	***Vaccinium uliginosum, Eriophorum vaginatum, Betula pendula, Andromeda polifolia, Carex echinata, C. nigra, C. rostrata, Ledum palustre, Molinia caerulea, Vaccinium oxycoccos, Rubus chamaemorus, Hylocomium splendens, Betula pubescens,*** *Pinus sylvestris, Calluna vulgaris, Dicranum polysetum, Pleurosium schreberi, Sphagnum fallax, S. magellanicum, S. rubellum*
24. Very moist forests and shrubberies *Eriophorum vaginatum-Betula pubescens-community* *Eriophorum vaginatum-Pinus sylvestris-community*	***Eriophorum vaginatum, Betula pubescens,*** *Pinus sylvestris, Empetrum nigrum, Rhododendron tomentosum* (syn. *Ledum palustre*), *Myrica gale, Sphagnum* spp.
Mesotrophic and eutrophic peatlands	
25. Dry forests and shrubberies NEW *Picea abies (planted)-community* *Alnus glutinosa (planted)-community*	***Populus tremula, Rubus idaeus, Acer platanoides, Fraxinus excelsior, Picea abies, Quercus robur, Corylus avellana, Padus avium, Sorbus aucuparia, Tilia cordata, Ulmus glabra, Aegopodium podagraria, Anemone*** **spp.,** ***Asarum europaeum, Campanula latifolia, Convallaria majalis, Galium odoratum, Hepatica nobilis, Galeobdolon luteum, Lathyrus vernus, Oxalis acetosella, Paris quadrifolia, Stellaria holostea, Atrichum undulatum, Eurhynchium angustirete, Plagiomnium undulatum, Rhytidiadelphus triquetrus, Betula pendula,*** *Urtica dioica, Molinia caerulea, Frangula alnus*

Water level	CO_2 emissions (t CO_2-eq./ ha/year)	CH_4 emissions (t CO_2-eq./ ha/year)	GWP estimate (t CO_2 eq./ ha/year)	Aim/Remarks	References
2-/3-	**26.02**	**0.0**	**26.0**	**Gapfilling** **New GEST** **Data without woods** extrapolated from *Picea abies* stands in temperate Germany, no peat	Matteucci *et al.* 2000
2+	**20.0** [-3.1]	**0.0** [-0.11]	**20.0** [-3.22]	**Gapfilling** **Data without woods** extrapolated from GEST *Moderately Moist (forb) meadows* [Data with woods]	Ojanen *et al.* 2014, 2 sites Meyer *et al.* 2013 calculated for *Picea abies* stands
3+	**9.4** [-2.2]	**0.0** [-1.8]	**9.4** [-4.0]	**Gapfilling** **Data without woods** extrapolated from GEST *Moist bog heath* [Data with woods]	Ojanen *et al.* 2014, 2 sites Hommeltenberg *et al.* 2014 (similar vegetation but different water level)
4+	**1.7** [-2.3]	**3.0** [1.75]	**4.7** [-0.55]	**Calibration** **Data without woods** extrapolated from GEST *Very moist bog heath* [Data with woods]	Hommeltenberg *et al.* 2014
2-/3-	**43.4**	**0.0**	**43.4**	**Gapfilling** **New GEST** **Data without woods** extrapolated from deciduous forests in Wisconsin	Bolstad *et al.* 2004

GEST / *Corresponding vegetation form*	**Occuring plant species**
26. Moderately moist forests and shrubberies *Rubus fruticosus-Frangula alnus-community* *Rubus fruticosus-Betula pubescens-community* *Molinia caerulea-Quercus robur-community* *Rhamnus cathartica-Quercus robur-community* *Cirsium oleraceum-Salix cinerea-community* *Circaea alpina-Fagus sylvatica-community* *Milium effusum-Alnus glutinosa-Fraximus excelsior-community* *Urtica dioica-Sambucus nigra-Alnus glutinosa-Fraxinus excelsior-community* *Betula sp.-Quercus robur-community*	***Betula pendula, Rubus idaeus, Frangula alnus, Calamagrostis epigejos, Betula pubescens, Molinea caerulea, Salix cinerea, Populus tremula, Brachythecium rutabulum, Lycopodium annotinum, Pinus sylvestris, Lysimachia vulgaris,*** *Padus serotina, Dryopteris carthusiana, Polytrichum formosum, Scleropodium purum, Vaccinium myrtillus, Quercus robur, Rubus caesius, Pyrola rotundifolia, Carex hartmanii, Carex vaginata, Fragaria vesca, Dicranum scoparium, Rubus nessensis, Brachythecium oedipodium, Salix aurita, Artemisia vulgaris, Calamagrostis canescens, Carex hirta, Urtica dioica, Polytrichum juniperinum, Pteridium aquilinum*
27. Moist forests and shrubberies *Molinia caerulea-Frangula alnus-community* *Sphagnum-Betula pubescens-community* *Lysimachia vulgaris-Quercus robur-community* *Potentilla erecta-Salix cinerea-community* *Rhamnus cathartica-Betula pubescens community* *Carex acutiformis-Salix cinerea-community* *Athyrium filix-femina-Alnus glutinosa-community* *Padus avium-Alnus glutinosa-Fraxinus excelsior-community* *Carex remota-Alnus glutinosa-Fraxinus excelsior-community* *Urtica dioica-Salix cinerea-community* *Urtica dioica-Carex acutiformis-Alnus glutinosa-Fraxinus excelsior-community* *Carex acutiformis-Betula pubescens-community*	***Alnus glutinosa, Betula pendula, Athyrium filix-femina, Fraxinus excelsior, Picea abies, Salix cinerea, Cardamine amara, Carex sylvatica, Chrysosplenium alternifolium, Cirsium oleraceum, Crepis paludosa, Filipendula ulmaria, Geranium robertianum, Geum rivale, Stellaria nemorum, Urtica dioica,*** *Carex acutiformis,* ***Sorbus aucuparia, Ulmus glabra, Carex*** **spp.,** ***Phragmites australis,*** *Vaccinium myrtillus, V. vitis-idaea, Eriophorum vaginatum, Hylocomium splendens, Humulus lupulus, Impatiens parviflora, Populus tremula, Rubus fruticosus, Betula pubescens, Corylus avellana, Dryopteris carthusiana, Eupatorium cannabinum, Galeobdolon luteum* agg., *Plagiomnium undulatum*
28. Very moist forests and shrubberies *Eriophorum angustifolium-Salix aurita-community* *Carex rostrata-Betula pubescens-community* *Thelypteris palustris-Salix aurita-community* *Sphagnum-Betula pubescens-Alnus glutinosa-community* *Betula humilis-Salix repens-community* *Carex-Salix pentandra-community* *Salix pentandra-Betula pubescens-community* *Valeriana dioica-Salix pentandra-community* *Valeriana dioica-Betula pubescens-community* *Thelypteris palustris-Salix cinerea-community* *Carex elongata-Alnus glutinosa-community* *Alnus glutinosa-Salix cinerea-community* *Cardamine amara-Alnus glutinosa-community* *Iris pseudocorus-Alnus glutinosa-community* *Galium palustre-Alnus glutinosa-Fraxinus excelsior-community*	***Alnus glutinosa, Carex acutiformis, Betula pubescens, Sphagnum squarrosum, Myrica gale,*** *Menyanthes trifoliata, Molinia caerulea, Carex* spp., *Sphagnum* spp., *Pinus sylvestris, Betula pendula, Frangula alnus, Athyrium filix-femina, Galium palustre, Geum rivale, Iris pseudacorus, Lycopus europaeus, Lysimachia vulgaris, Peucedanum palustre, Solanum dulcamara, Thelypteris palustris, Climacium dendroides, Calliergonella cuspidata*

Water level	CO_2 emissions (t CO_2-eq./ ha/year)	CH_4 emissions (t CO_2-eq./ ha/year)	GWP estimate (t CO_2 eq./ ha/year)	Aim/Remarks	References
2+	**20.0** [1.0]	**0.0** [nd]	**20.0** [1.0]	**Gapfilling** **Data without woods** extrapolated from GEST *Moderately moist (forb) meadows* [Data with woods]	Ojanen *et al.* 2014
3+	**4.6** [21.59-24.98]	**7.5** [0.004-5.35]	**12.2** [21.59-30.33]	**Gapfilling** **Data without woods** extrapolated from GEST *Moist reeds and (forb) meadows* [Data with woods]	Schäfer & Joosten 2005
4+	**-0.5** [-10.72--5.97]	**2.1** [0.81-4.27]	**1.6** [-9.91--1.7]	**Gapfilling** **Data without woods** extrapolated from GEST *Very moist meadows, forbs and small sedges reeds* [Data with woods]	Schäfer & Joosten 2005

GEST / ***Corresponding vegetation form***	**Occuring plant species**
29. Wet forests and shrubberies *Eriophorum angustifolium-Salix aurita-community* *Carex rostrata-Betula pubescens-community* *Thelypteris palustris-Salix aurita-community* *Sphagnum-Betula pubescens-Alnus glutinosa-community* *Betula humilis-Salix repens-community* *Carex-Salix pentandra-community* *Salix pentandra-Betula pubescens-community* *Valeriana dioica-Salix pentandra-community* *Valeriana dioica-Betula pubescens-community* *Thelypteris palustris-Salix cinerea-community* *Carex elongata-Alnus glutinosa-community* *Alnus glutinosa-Salix cinerea-community* *Cardamine amara-Alnus glutinosa-community* *Iris pseudocorus-Alnus glutinosa-community* *Galium palustre-Alnus glutinosa-Fraxinus excelsior-community* *Eriophorum vaginatum-Betula pubescens-community* *Eriophorum vaginatum-Pinus sylvestris-community* *Myrica gale-Salix aurita-community*	*Betula pubescens, Carex acutiformis, Alnus glutinosa, Betula pendula, Salix* spp., *Frangula alnus, Pinus sylvestris, Juniperus communis, Carex lasiocarpa, C. limosa, C. rostrata, Comarum palustre, Equisetum fluviatile, Eriophorum vaginatum, Menyanthes trifoliata, Vaccinium oxycoccos, Phragmites australis, Rhynchospora alba, Sphagnum teres, S. magellanicum, Calliergonella cuspidata*
GESTs from Open peatland not identified in *LIFE Peat Restore* project	
Wet bog heath	***Calluna vulgaris, Erica*** **sp.**
Very moist tall sedges reeds	
Flooded tall sedges reeds & Typha-reeds *Rorippa amphibia-Typha latifolia-Phragmites australis-community (flooded)* *Ranunculus lingua-Carex elata-Phragmites australis-community (inundated)* *Drepanocladus revolvens-Carex diandra-community (flooded)* *Sphagnum denticulatum-Carex rostrata-community*	
Flooded Phragmites & Phalaris reeds *Utricularia vulgaris-Cladium mariscus-community* *Typha angustifolia-Lemna minor-Phragmites australis-community* *Schoenoplectus lacustris-Phragmites australis-community*	
Flooded reeds with lateral matter transport from surrounded areas *Ranunculus lingua-Carex elata-Phragmites australis-community (flooded)* *Circuta virosa-Carex acutiformis-Phragmites australis-community* *Typha angustifolia-Lemna minor-Phragmites australis-community (flooded)*	
Extremely flooded reeds (>20 cm above surface) *Solanum dulcamara-Galium palustre-Phragmites australis-community (inundated)* *Rorippa amphibia-Typha latifolia-Phragmites australis-community (inundated)*	

Water level	CO_2 emissions (t CO_2-eq./ ha/year)	CH_4 emissions (t CO_2-eq./ ha/year)	GWP estimate (t CO_2 eq./ ha/year)	Aim/Remarks	References
5+	**-3.5** [-4.89]	**6.8** [0.04-11.46]	**3.3** [-4.85-6.57]	**No Target GEST** **Data without woods** extrapolated from GEST *Wet small sedges reeds mostly with moss layer* [Data with woods]	Schäfer & Joosten 2005
5+ (4+)	**3.1** (0.0)	**21.6** (17.8)	**24.7** (18.0)	**Calibration**	Vanselow-Algan *et al.* 2015
4+	**0.5** (10.7)	**6.9** (1.6)	**7.4** (12.5)	**No target GEST**	Sommer *et al.* 2004, 2 sites Günther *et al.* 2014, 2 sites Drösler *et al.* 2013
6+/5+	**1.2** (-1.1)	**14.6** (6.8)	**15.8** (5.5)	**No target GEST**	Günther *et al.* 2014 Minke *et al.* 2015, 3 sites
5+/6+	**-15.7** (-12.4)	**13.0** (12.4)	**-2.7** (0.0)	**No target GEST**	Minke *et al.* 2015
6+	**-2.9** (2.4)	**37.0** (40.9)	**34.0** (43.5)	**No target GEST**	Gelbrecht *et al.* 2008 Drösler *et al.* 2013, 2 sites
6+	**-32.8** (-32.7)	**33.6** (26.2)	**0.8** (-6.5)	**No target GEST**	Minke *et al.* 2015

REFERENCES

Audet, J., Johansen, J. R., Andersen, P. M., Baattrup-Pedersen, A., Brask-Jensen, K. M., Elsgaard, L., Kjaergaard, C., Larsen, S.E., Hoffmann, C.C. (2013): Methane emissions in Danish riparian wetlands: ecosystem comparison and pursuit of vegetation indexes as predictive tools. In: Ecological Indicators 34, p. 548–559. DOI: 10.1016/j.ecolind.2013.06.016.

Aurela, M., Riutta, T., Laurila, T., Tuovinen, J.-P., Vesala, T., Tuittila, E.-S., Rinne, J., Haapanala, S., Laine, J. (2007): CO_2 exchange of a sedge fen in southern Finland - the impact of a drought period, Tellus 59B, p. 826-837.

Beetz, S., Liebersbach, H., Glatzel, S., Jurasinski, G., Buczko, U., Höper H. (2013): Effects of land use intensity on the full greenhouse gas balance in an Atlantic peat bog. In: Biogeosciences 10, p. 1067-1082. DOI:10.5194/bg-10-1067-2013.

Bolstad, P. V., Davis, K. J., Martin, J., Cook, B. D., Wang, W. (2004): Component and whole-system respiration fluxes in northern deciduous forests. Tree Physiology Vol. 24, p. 493-504.

Bortoluzzi, E., Epron, D., Siegenthaler, A., Gilbert, D., Buttler, A. (2006): Carbon balance of a European mountain bog at contrasting stages of regeneration. In: The New phytologist 172 (4), p: 708-718. DOI: 10.1111/j.1469-8137.2006.01859.x.

Couwenberg, J., Thiele, A., Tanneberger, F., Augustin, J., Bärisch, S., Dubovik, D., Liashchynskaya, N., Michaelis, D., Minke, M., Skuratovich, A., Joosten, H. (2011): Assessing greenhousegas emissions from peatlands using vegetation as a proxy. In: Hydrobiologia 674, p. 67–89. https://doi.org/10.1007/s10750-011-0729-x.

Drösler, M. (2005): Trace gas exchange and climatic relevance of bog ecosystems, Southern Germany. PhD Thesis. TU München, Freising.

Drösler, M., Adelmann, W., Augustin, J., Bergmann, L., Beyer, C., Chojnicki, B. *et al.* (2013): Klimaschutz durch Moorschutz. Schlussbericht des BMBF-Vorhabens "Klimaschutz - Moornutzungsstrategien" 2006-2010.

Eschenbach, C., Middelhoff, W., Steinborn, W., Wötzel, J., Kutsch, W., Kappen, L. (1997): Von Einzelprozessen zur Kohlenstoffbilanz eines Erlenbruchs im Bereich der Bornhöveder Seenkette. In: EcoSys Supplement 20, p. 121-132.

Fortuniak, K.; Pawlak, W., Bednorz, L., Grygoruk, M., Siedlecki, M., Zielinski, M. (2017): Methane and carbon dioxide fluxes of a temperate mire in Central Europe: In Agricultural and Forest Meteorology 232, p. 306-318 DOI: 10.1016/j.agrformet.2016.08.023.

Gelbrecht, J, Zak, D., Augustin, J. (2008): Phosphor- und Kohlenstoff-Dynamik und Vegetationsentwicklung in wiedervernässten Mooren des Peenetals in Mecklenburg-Vorpommern - Status, Steuergrößen und Handlungsmöglichkeiten. Leibniz-Institut für Gewässerökologie und Binnenfischerei (IGB-Bericht 26).

Günther, A., Huth, V., Jurasinski, G., Glatzel, S. (2014): The effect of biomass harvesting on greenhouse gas emissions from a rewetted temperate fen: In: Global Change Biology Bioenergy 7, p. 1092-1106. DOI: 10.1111/gcbb.12214.

Helfter, C., Campbell, C., Dinsmore, K. J., Drewer, J., Coyle, M., Anderson, M., Skiba, U., Nemitz, E., Billett, M. F., Sutton, M. A. (2015): Drivers of long-term variability in CO_2 net ecosystem exchange in a temperate peatland. In: Biogeosciences,12, p. 1799–1811. DOI: 10.5194/bg-12-1799-2015.

Hommeltenberg, J., Mauder, M., Drösler, M., Heidbach, K., Werle, P., Schmid, H. P. (2014): Ecosystem scale methane fluxes in a natural temperate bog-pine forest in southern Germany. Agricultural and Forest Meteorology 198-199. p. 273-284.

Juszczak, R., Augustin, J. (2013): Exchange of the Greenhouse Gases Methane and Nitrous Oxide between the Atmosphere and a Temperate Peatland in Central Europe. In Wetlands 33, p. 895-907. DOI: 10.1007/s13157-013-0448-3.

Koch, S; Jurasinski, G.; Koebsch, F.; Koch, M.; Glatzel, S. (2014): Spatial Variability of Annual Estimates of Methane Emissions in a Phragmites australis (Cav.) Trin. Ex Steud. Dominated Restored Coastal Brackish Fen. In: Wetlands 34 (3), p. 593-602. DOI: 10.1007/s13157-014-0528-z.

Lund, M., Lindroth, A., Christensen, T. R., Ström, L. (2007): Annual CO_2 balance of a temperate bog, In: Tellus 59B, p. 804-811.

Maljanen, M., Oskarsson, H.; Sigurdsson, B. D.; Gudmundsson J.; Huttunen, J. T.; Martikainen, P. J. (2010): Greenhousegas balances of managed peatlands in the Nordic countries– present knowledge and gaps. Biogeosciences 7, p. 2711–2738.

Matteucci, G., Dore, S., Stivanello, S., Rebmann, C., Buchmann, N. (2000): Soil respiration in Beech and Spruce Forests in Europe: Trends, Controlling Factors, Annual Budgets and Implications for the Ecosystem Carbon Balance. In: Schulze, E.-D. (eds) Carbon and Nitrogen Cycling in European Forest Ecosystems. Springer. p. 217-236.

Minke, M.; Augustin, J., Burlo, A.; Yarmashuk, T., Chuvashova, H., Thiele, A. *et al.* (2015): Water level, vegetation composition and plant productivity explain greenhouse gas fluxes in temperate cutover fens after inundation. In: Biogeosciences Discussions 12, p. 17393-17452.

Ojanen, P., Minkkinen, K., Penttilä, T. (2013): The current greenhouse gas impact of forestry-drained boreal peatlands. In: Forest Ecology and Management 289. p. 201-208.

Reichelt, K. F. (2015): Evaluierung des GEST-Modells zur Abschätzung der Treibhausgasemissionen aus Mooren. Master Thesis. Institut für Botanik und Landschaftsökologie, Greifswald

Rinne, J., Riutta, T., Pihlatie, M., Aurela, M., Haapanala, S. Tuovinen, J-P., Tuittila, E.-S., (2007): Annual cycle of methane emission from a boreal fen measured by the eddy covariance technique, In: Tellus 59B, p. 449-457.

Schäfer, A. & Joosten, H. (2005): Erlenaufforstung auf wiedervernässten Niedermooren: ALNUS-Leitfaden. Institut für Dauerhaft Umweltgerechte Entwicklung der Naturräume der Erde (DUENE) e.V., Greifswald. 68 p.

Sommer, M., Fiedler, S., Glatzel, S., Kleber, M. (2004): First estimates of regional (Allgäu, Germany) and global CH_4 fluxes from wet colluvial margins of closed depressions in glacial drift areas. In: Agriculture, Ecosystems & Environment 103, p. 251-257. DOI: 10.1016/j.agee.2003.09.019.

Spangenberg, A. (2011): Einschätzung der Treibhausgasrelevanz bewaldeter Moorstandorte in Mecklenburg-Vorpommern hinsichtlich des Minderungspotentials nach Wiedervernässung. Institut für Dauerhaft Umweltgerechte Entwicklung der Naturräume der Erde (DUENE) e.V., Greifswald. 29 p.

Tauchnitz, N., Brumme, R., Bernsdorf, S., Meissner, R. (2008): Nitrous oxide and methane fluxes of a pristine slope mire in the German National Park Harz Mountains. In: Plant Soil 303, p. 131-138. DOI: 10.1007/s11104-007-9493-0.

Van Den Pol-Van Dasselaar, A., Van Beusichem, M., Oenema, O. (1999): Methane emissions from wet grasslands on peat soil in a nature preserve. In: Biogeochemistry 44, p. 205-220.

Vanselow-Algan, M., Schmidt, S.r., Greven, M., Fiencke, C., Kutzbach, L., Pfeiffer, E. M. (2015): High methane emissions dominated annual greenhouse gas balances 30 years after bog rewetting. In: Biogeosciences 12 (14), p. 4361-4371. DOI: 10.5194/bg-12-4361-2015.

Wilson, D., Alm, J., Laine, J., Bryne, K.a., Farrell, E.p., Tuittila, E.-S. (2009): Rewetting of cutaway peatlands: Are we re-creating hotspots of methane emissions? In: Restoration Ecology 17 (6), p.796-806.

Wilson, D., Blain, D., Couwenberg, J., Evans, C. D., Murdiyarso, D., Page, S. E., Renou-Wilson, F., Rieley, J. O., Sirin, A., Strack, M., Tuittila, E.-S. (2016): Greenhouse gas emission factors associated with rewetting of organic soils. In Special issue: Greenhouse gas fluxes in degraded and restored peatlands: global perspectives: Mires and Peat 17, p. 4-28, DOI: 10.19189/MaP.2016.OMB.222.

ANNEX 4

Photo: M. Pakalne

Description of Greenhouse Gas Emissions Site Types (GESTs) identified in the *LIFE Peat Restore* project

This Annex briefly introduces all Greenhouse Gas Emissions Site Types (GESTs) identified in the *LIFE Peat Restore* project sites in Estonia, Latvia, Lithuania, Poland and Germany (see Introduction, Figure 1). The Project sites represent different peatland types of the Baltic Sea Region and includes peatlands, from raised bogs, transition mires and fens to forested peatland and lakes. All these project sites have been affected by drainage and some by peat extraction. According to the GEST approach there are two main peatland groups: i) *Open peatlands*, and ii) *Forested peatlands*, which are divided to *Oligotrophic*, and *Mesotrophic and eutrophic peatlands*. Each GESTs description is based on field surveys and data obtained by the project team's peatland experts. In addition, we used data from scientific publications (Couwenberg 2011; Couwenberg *et al.* 2011; Audet *et al.* 2013; Drösler *et al.* 2013; Juszczak & Augustin 2013; Ojanen *et al.* 2013; Günter *et al.* 2014; Hommeltenberg *et al.* 2014; Koch *et al.* 2014; Minke 2015; Vanselow-Algan *et al.* 2015; Wilson *et al.* 2016; Fortuniak *et al.* 2017; etc.) and other sources (Joosten *et al.* 2015; Reichelt 2015) to support our GESTs descriptions. An "Updated GEST catalogue" was compiled by the *LIFE Peat Restore* team in 2018 (see *Chapter 2.1.2.*). Six new GESTs have been added to the *Updated GEST Catalogue* (Annex 3) and marked by the sign NEW.

At the end of the Annex summarised data on water level and peat properties characteristic of GESTs identified in *LIFE Peat Restore* project sites (*Table 41*) and *Index of plant species with photographs* are provided.

List of GESTs identified in *LIFE Peat Restore* project sites

OPEN PEATLANDS

1. Moderately moist (forb) meadows
2. Moderately moist/dry bog heath NEW
3. Moist reeds and (forb) meadows
4. Moist bog heath
5. Bare peat dry (oligotrophic) NEW
6. Bare peat moist (oligotrophic)
7. Bare peat wet (oligotrophic)
8. Very moist meadows, forbs and small sedges reeds
9. Wet meadows and forbs
10. Very moist/Wet calcareous meadows, forbs and small sedges reeds (eutrophic) NEW
11. Very moist bog heath
12. Very moist peat moss lawn
13. Wet tall sedges reeds
14. Wet small sedges reeds mostly with moss layer
15. Wet tall reeds
16. Wet peat moss lawn
17. Peat moss lawn on former peat-cut off areas
18. Wet peat moss lawn with pine trees NEW
19. Wet peat moss hollows resp. flooded peat moss lawn
20. Open water/ditches

FORESTED PEATLANDS

OLIGOTROPHIC PEATLANDS (OL)

21. Dry forest and shrubberies NEW
22. Moderately moist forest and shrubberies
23. Moist forests and shrubberies
24. Very moist forests and shrubberies

MESOTROPHIC AND EUTROPHIC PEATLANDS (ME/EUT)

25. Dry forests and shrubberies NEW
26. Moderately moist forests and shrubberies
27. Moist Forests and shrubberies
28. Very moist forests and shrubberies
29. Wet forests and shrubberies

OPEN PEATLANDS

1. Moderately moist (forb) meadows

Figure 1. *Moderately moist (forb) meadows* on Wielkie Bagno in Słowiński National Park, Poland (A–B) and Aukštumala peatland, Lithuania (C–D). Photos: K. Bociąg (A–B) and J. Sendžikaitė (C–D).

GENERAL DESCRIPTION

Moderately moist (forb) meadows can be represented by plant communities of various genesis, e.g., Słowiński National Park (Poland) (Figure 1, A–B). Some of them occur on highly decomposed, acidic, oligotrophic or mesotrophic-rather poor peat soils (Table 1) which include both drained raised bogs, and on drained poor fen areas that have been previously used for agricultural purposes.

Molinia caerulea dominates the vegetation cover on drained raised bogs habitats, while in post-agricultural areas grasslands are characterised by higher species diversity: grass cover is formed by *Molinia caerulea*, *Deschampsia caespitosa* and *Juncus effusus* with randomly located patches of *Pteridium aquilinum*. *Betula pubescens* and *B. pendula* are common in the shrub layer. The moss layer is poorly developed, composed of brown or feather mosses and/or *Sphagnum* species.

Moderately moist (forb) meadows occur on spontaneously revegetated areas of abandoned peat-mining areas (e.g., Aukštumala peatland (LT-AU), Lithuania) in acidic mesotrophic-medium poor peat soils (Table 1). *Calamagrostis epigejos* and *Rubus caesius* are dominant and form a dense vegetation cover. *Aegopodium podagraria*, *Agrostis capillaris*, *Achillea cartilaginea*, *Epilobium palustre*, *Bidens tripartita*, *Juncus effusus*, *Lysimachia vulgaris*, *Stachys palustris*, *Tanacetum vulgare* and other vascular plant species also occur (Figure 1, C–D). *Salix aurita* and *Frangula alnus*, as well as young trees of *Betula pubescens* and *B. pendula* begin to form a shrub layer.

Table 1. Water level and peat properties characteristic of GEST *Moderately moist (forb) meadows*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
PL-KL	2+	-54; -138; +1	Ac	nd	o-vp, o-p, m-lm	nd
LT-AU		nd		4.4	m-hm	25

PL-KL– Kluki (Poland); LT-AU – Aukštumala peatland (Lithuania).

VEGETATION

Occurring plant species (Figure 2)**:**

PL: ***Molinia caerulea, Deschampsia caespitosa, Juncus effusus,*** *Pteridium aquilinum, Calliergonella cuspidata, Sphagnum fallax, S. fimbriatum, S. palustre, S. cuspidatum.*

LT: ***Calamagrostis epigejos*, *Rubus caesius*,** *Aegopodium podagraria*, *Agrostis capillaris*, *Achillea cartilaginea*, *Epilobium palustre*, *Bidens tripartita*, *Juncus effusus*, *Lysimachia vulgaris*, *Stachys palustris*, *Tanacetum vulgare*.

Molinia caerulea

Deschampsia cespitosa

Calamagrostis epigejos

Aegopodium podagraria

Juncus effusus

Rubus caesius

Figure 2. Plant species occurring in the GEST *Moderately moist (forb) meadows*. Photos: J. Sendžikaitė (A–B, D–E), K. Obelevičius (C) and E. Ostašenkovas (F).

Vegetation communities:

PL: *Juncus effusus-Deschampsia cespitosa* community, *Molinia caerulea* community, *Pteridium aquilinum-Molinia caerulea* community.

LT: *Calamagrostis epigejos-Rubus caesius* community.

Relation to habitats of EU importance:

PL: Some patches occur on 7120 Degraded raised bogs still capable of natural regeneration.

LT: none.

GHG emissions*:

CO_2 emissions – 20.0 t CO_2-eq./ha/year

CH_4 emissions – 0.0 t CO_2-eq./ha/year

GWP estimate – 20.0 t CO_2-eq./ha/year

*According to Updated GEST catalogue (see *Annex 3*), extrapolated from *Moderately moist grasslands*.

LIFE Peat Restore sites: PL-CB, PL-KL, LT-AU.

Moderately moist/dry bog heath NEW 2.

Figure 3. *Moderately moist/dry bog heath* and *Calluna vulgaris*. Photo: K. Bociąg.

GENERAL DESCRIPTION

GEST *Moderately moist/dry bog heath* occurs on drained raised bogs and abandoned peat quarries with oligotrophic-very poor acidic peat soils (Figure 2, Table 2). *Calluna vulgaris* dominates in the vegetation cover, solitary groups of *Ledum palustre* and tussocks of *Eriophorum vaginatum* can be found as well. Tree layer is scarce (up to 15%; *Pinus sylvestris*, *Betula pendula*, *B. pubescens*), shrubs can cover up to 5–30%, dwarf shrubs cover 60–95%, the grass layer is very scarce (up to 10%). The bryophyte layer (coverage is 20–80%) is formed by brown and feather mosses (*Pleurozium schreberi*, *Dicranum polysetum*, *Aulacomnium palustre*), only solitary patches of *Sphagnum* can be found in moist surface.

Table. 2 Water level and peat properties characteristic of GEST *Moderately moist/dry bog heath*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LT-AM	2+/2-	nd	Ac	2.4	o-vp	42

LT-AM – Amalva peatland (Lithuania).

VEGETATION

Occurring plant species (Figure 4)**:**

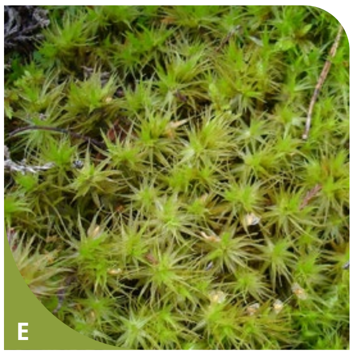
LT: *Calluna vulgaris, Pleurozium schreberi, Dicranum polysetum*, *Eriophorum vaginatum*, *Vaccinium vitis-idaea*, *Betula pendula*, *Salix cinerea.*

Calluna vulgaris.
Usually, flowers are pale pink-to-mauve in colour.

Calluna vulgaris.
Sometimes flowers can be white.

Eriophorum vaginatum
(flowering)

Vaccinium vitis-idaea



Dicranum polysetum

Cladonia sp.

Figure 4. Plant species occurring in the GEST *Moderately moist/dry bog heath*. Photos: J. Sendžikaitė.

Vegetation communities:
LT: *Calluna vulgaris* community.

Related habitats of EU importance:
PL: 7120 Degraded raised bogs still capable of natural regeneration.
LT: none.

GHG emissions:
No data. We used factors from *4. Moist bog heath* GEST unit (see: Updated GEST catalogue; *Annex 3*.

LIFE Peat Restore sites: LT-AM, LT-AU, PL-WB.

Moist reeds and (forb) meadows 3.

Figure 5. *Moist reeds and (forb) meadows* in Biesenthaler Becken (Germany). Photo: C. Schulz.

GENERAL DESCRIPTION

The GEST *Moist reeds and (forb) meadows* belongs to open moist grasslands under slightly eutrophic sub-neutral calcareous conditions (Table 3). Usually, it is represented by abandoned and slightly drained fen grasslands (Biesenthaler Becken (DE-BB-1), Germany). Only a few vascular plant species like *Urtica dioica*, *Phragmites australis, Carex acutiformis*, *Scirpus sylvaticus* dominate (Figure 5). Species diversity is relatively low. The alien species *Solidago canadensis* has been observed to invade grassland communities in the Biesenthaler Becken site.

Small patches of *Moist reeds and (forb) meadows* occur on oligotrophic-very poor acidic or sub-neutral peat soils of the abandoned peat quarry in Pūsčia peatland (LT-PU), Lithuania. Species diversity is higher compared to the Biesenthaler Becken site in Germany. Grass coverage is 60–70%. *Phragmites australis, Carex acutiformis* or *Scirpus sylvaticus* dominate the grass layer. Quite frequently but not abundantly other vascular plant species can be found: *Calamagrostis* sp., *Carex flava, C. lasiocarpa, Urtica dioica, Epilobium palustre, Epipactis palustris, Lycopus europaeus, Rubus idaeus*, etc. Moss coverage is scarce (up to 10–20%) with *Dicranella* spp., *Dicranum polysetum* and *D. scoparium*. *Frangula alnus* and young trees of *Betula pendula* and *B. pubescens* are also observed.

Table 3. Water level and peat properties characteristic of GEST *Moist reeds and (forb) meadows*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
DE-BB-1	3+	nd	Sub-Alk	nd	e-r	nd
LT-PU			Ac-Sub	3.2–6.4	o-vp	57–98

DE-BB-1 – Biesenthaler Becken (Germany), LT-PU – Pūsčia peatland (Lithuania).

VEGETATION

Occurring plant species (Figure 6)**:**

DE: ***Urtica dioica, Carex acutiformis, Phragmites australis, Solidago canadensis,*** *Scirpus sylvaticus, Rubus idaeus*, *Carex paniculata, Humulus lupulus.*

LT: ***Phragmites australis, Carex acutiformis, Scirpus sylvaticus,*** *Rubus idaeus, C. flava, C. lasiocarpa, Trichophorum alpinum, Lysimachia thyrsiflora, Filipendula ulmaria, Salix cinerea, Urtica dioica, Calamagrostis* sp., *Epilobium palustre, Epipactis palustris, Lycopus europaeus, Frangula alnus, Betula pendula, B. pubescens, Dicranella* spp., *Dicranum polysetum, D. scoparium, Brachythecium rutabulum*.

Vegetation communities:
DE: *Filipendula ulmaria-Urtica dioica-Cirsium oleraceum* community.
LT: *Phragmites australis* community.

Relation to habitats of EU importance: none.

GHG emissions*:
CO_2 emissions – 4.6 (-2.8) t CO_2-eq./ha/year
CH_4 emissions – 7.5 (0.0) t CO_2-eq./ha/year
GWP estimate – 12.2 (3.0) t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: DE-BB-1, LT-PU.

Phragmites australis

Urtica dioica

Scirpus sylvaticus

Carex acutiformis

Epipactis palustris

Rubus idaeus

Filipendula ulmaria

Trichophorum alpinum

Epilobium palustre

Figure 6. Plant species occurring in GEST Moist reeds and (forb) meadows. Photos: J. Sendžikaitė (A–H) and D. Matulevičiūtė (I).

4. Moist bog heath

Figure 7. GEST *Moist bog heath* in Pūsčia peatland (Lithuania). Photo: Ž. Sinkevičius.

GENERAL DESCRIPTION

Occurs on heavily drained raised bogs and abandoned peat mining areas with oligotrophic-poor acidic peat soils (Table 4). *Calluna vulgaris* dominates the vegetation cover, *Eriophorum vaginatum*, *Drosera rotundifolia* and *Rhynchospora alba* are common, and solitary groups of *Rhododendron tomentosum* (*syn. Ledum palustre*) occur (Figure 7). In the Polish sites, *Molinia caerulea* is often a co-dominant species. Tree layer (*Betula pendula*, *B. pubescens*, *Pinus sylvestris*) is scarce (up to 20%), shrub coverage is up to 5%, dwarf shrub cover is dense (60–80%) and grass layer – very scarce (up to 15%). Coverage of the bryophytes (*Polytrichum strictum*, *Dicranum polysetum*, *Pleurozium schreberi* and even alien *Campylopus introflexus*) can vary from 5% to 70%.

Table 4. Water level and peat properties characteristic of GEST *Moist bog heath*

Project sites	Water level		Peat properties			
			pH		C:N	
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LT-PU	3+	nd	Ac	3.0	o-vp	33

LT-PU – Pūsčia peatland (Lithuania).

VEGETATION

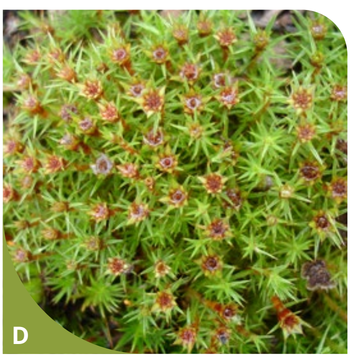
Occurring plant species (Figure 8)**:**

LT and **PL:** ***Calluna vulgaris, Eriophorum vaginatum, Cladonia* spp., *Polytrichum strictum, Molinia caerulea,*** *Betula pendula, Pinus sylvestris, Rhododendron tomentosum* (*syn. Ledum palustre*), *Drosera rotundifolia, Rhynchospora alba, Campylopus introflexus, Dicranum polysetum.*

Calluna vulgaris

Eriophorum vaginatum

Cladonia sp.



Polytrichum strictum

Pinus sylvestris

Betula sp.

Rhododendron tomentosum (syn. *Ledum palustre)* | *Drosera rotundifolia* | *Campylopus introflexus* – alien species

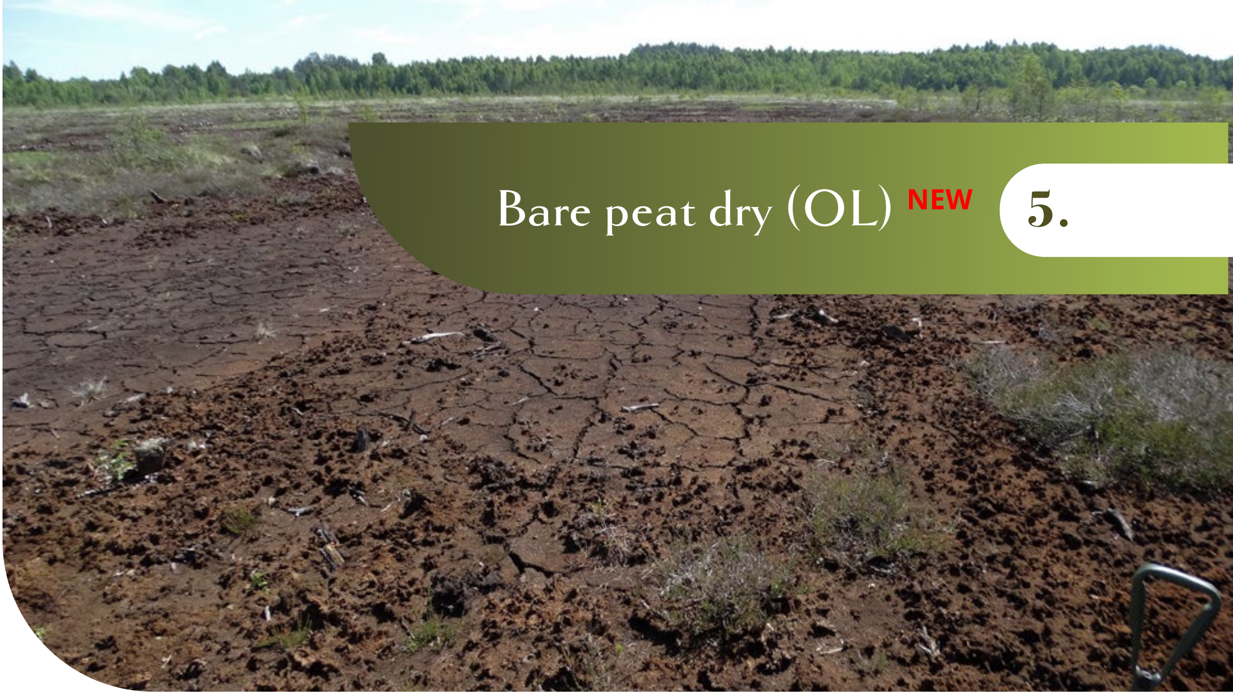
Figure 8. Plant species occurring in GEST *Moist bog heath.* Photos: J. Sendžikaitė.

Vegetation communities:
LT: *Calluna vulgaris-Eriophorum vaginatum* community.
PL: *Calluna vulgaris*, *Calluna vulgaris-Molinia caerulea* communities.

Relation to habitats of EU importance:
PL: 7120 Degraded raised bogs still capable of natural regeneration.
LT: none.

GHG emissions*:
CO_2 emissions – 9.4 (12.3) t CO_2-eq./ha/year
CH_4 emissions – 0.0 (0.2) t CO_2-eq./ha/year
GWP estimate – 9.4 (12.5) t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: LT-PU, PL-WB, PL-KL, LV-AU.



Bare peat dry (OL) NEW 5.

Figure 9. *Bare peat dry (OL)* in Aukštumala peatland (Lithuania). Photo: L. Šveistytė.

GENERAL DESCRIPTION

Occurs on heavily drained peatlands damaged by peat extraction, usually shortly after cessation of economic activity (corresponds to active extraction sites). Bare peat dominates with very scarce vegetation cover (up to 5%), only solitary plants of *Molinia caerulea*, *Eriophorum vaginatum*, *Juncus* spp. occur (Figure 9). Large water level fluctuations (from -92 cm to +6 cm) and low water level values in dry growing periods are unfavourable for recovery of typical or natural peatland vegetation (Table 5).

Table 5. Water level and peat properties characteristic of GEST *Bare peat dry (OL)*

Project sites	Water level		Peat properties			
			pH		C:N	
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LT-AU	2-/3-	-52; -92; +6	Ac	4.4	m-Im	30

LT-AU – Aukštumala peatland (Lithuania).

VEGETATION

Occurring plant species (Figure 10)**:**

LT: *Molinia caerulea*, *Juncus alpinoarticulatus*, *Bidens tripartita*, *Eriophorum vaginatum*, *Drosera rotundifolia*, *Calluna vulgaris, Carex* spp., *Rhynchospora alba, Polytrichum strictum*.

Molinia caerulea

Juncus alpinoarticulatus

Bidens tripartita

Figure 10. Plant species occurring in GEST *Bare peat dry (oligotrophic).* Photos: J. Sendžikaitė (A, C) and L. Šveistytė (B).

Vegetation communities: none.

Relation to habitats of EU importance: none.

GHG emissions

Table 6. GHG emissions from GEST *Bare peat dry (OL)*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
7.0	16.7	0.4	11.5	7.5	28.2

* Updated GEST catalogue (see *Annex 3*).

** LT-AU. Measurement period 2019, modelled data.

LIFE Peat Restore site: LT-AU.

Bare peat moist (OL) 6.

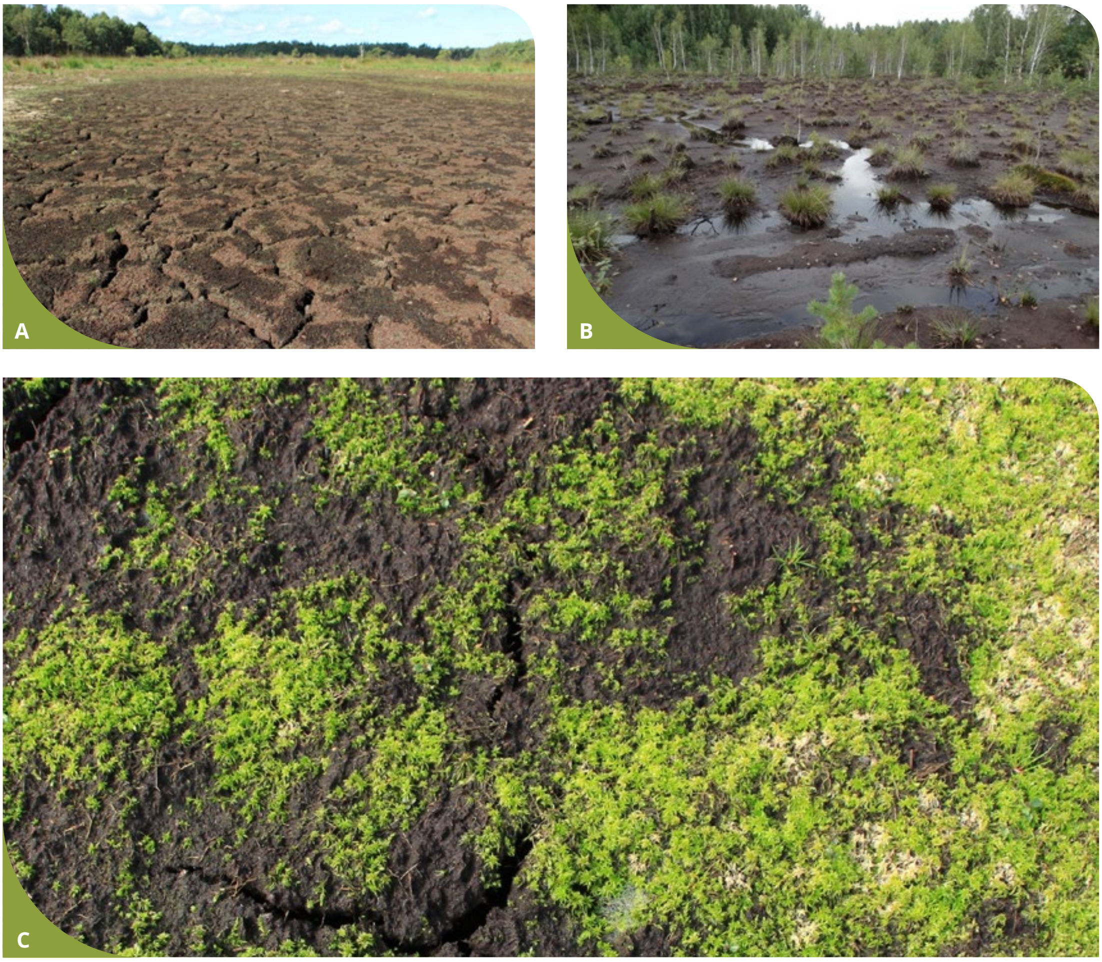


Figure 11. *Bare peat moist (OL)* on Wielkie Bagno (Poland, A, C) and Pūsčia peatland (Lithuania, B). Photos: K. Bociąg (A,C) and J. Sendžikaitė (B).

GENERAL DESCRIPTION

Bare peat moist (oligotrophic) occurs on vast post-extraction areas on drained peatlands (Figure 11). *Calluna vulgaris, Rhynchospora alba, Eriophorum vaginatum, Betula pendula, Polytrichum strictum* and even alien moss *Campylopus introflexus* are common. The peat is acidic, very poor and highly decomposed (Table 7). During wet periods water accumulates and hampers natural vegetation succession. Vegetation cover is poor (<5%). *Molinia caerulea, Eriophorum angustifolium, Drosera intermedia* (PL-WB)*, Sphagnum cuspidatum, Dicranella cerviculata* grow solitarily or in small groups.

Table 7. Water level and peat properties characteristic of GEST *Bare peat moist (OL)*

<table>
<tr><th rowspan="3">Project sites</th><th colspan="2">Water level</th><th colspan="4">Peat properties</th></tr>
<tr><th rowspan="2">Soil moisture class (Koska et al. 2001)</th><th rowspan="2">Mean, min and max WL, cm (LIFE Peat Restore)</th><th colspan="2">pH</th><th colspan="2">C:N</th></tr>
<tr><th>Based on plant indicators</th><th>LIFE Peat Restore</th><th>Based on plant indicators</th><th>LIFE Peat Restore</th></tr>
<tr><td>PL-WB</td><td rowspan="4">3+</td><td>nd</td><td rowspan="4">Ac</td><td>nd</td><td rowspan="4">o-vp</td><td>nd</td></tr>
<tr><td>LT-SA</td><td>-35, -64, -6</td><td>2.7</td><td>66–85</td></tr>
<tr><td>LT-PL</td><td rowspan="2">nd</td><td>2.6</td><td>91</td></tr>
<tr><td>LT-PU</td><td>2.6–4.2</td><td>59–72</td></tr>
</table>

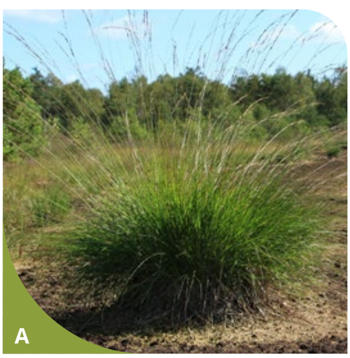
PL-WB – Wielkie Bagno (Poland); LT-SA – Sachara peatland, LT-PL – Plinkšiai peatland, LT-PU – Pūsčia peatland (Lithuania).

VEGETATION

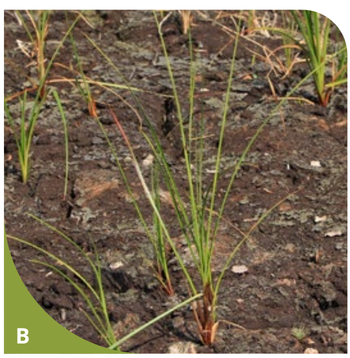
Occurring plant species (Figure 12)**:**

PL: ***Eriophorum angustifolium***, ***Juncus bulbosus***, ***Sphagnum cuspidatum***, *Molinia caerulea, Drosera intermedia, Dicranella cerviculata.*

LT: ***Calluna vulgaris, Eriophorum vaginatum, Pinus sylvestris,*** *Betula* spp., *Drosera rotundifolia, Eriophorum angustifolium, Equisetum arvense, Empetrum nigrum, Vaccinium uliginosum, Polytrichum strictum, Dicranella* sp., *Campylopus introflexus, Cladonia* spp.



Molinia caerulea



Eriophorum angustifolium

Drosera intermedia

Juncus bulbosus *Dicranella cerviculata* *Eriophorum vaginatum*

Figure 12. Plant species occurring in *Bare peat moist (oligotrophic)*. Photos: K. Bociąg (A–D), L. Strazdiņa (E) and J. Sendžikaitė (F).

Vegetation communities: none.

Relation to habitats of EU importance:

PL: none (in large new areas of peat fields after excavation), 7120 Degraded raised bogs still capable of natural regeneration (in small areas in complexes of regenerating raised bogs).

LT: none.

GHG emissions

Table 8. GHG emissions from GEST *Bare peat moist (OL)*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
6.2 (9.0)	14.4	0.0 (0.0)	1.4	6.2 (9.0)	15.8

* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

** LT-PU. Measurement period 2019, modelled data.

LIFE Peat Restore sites: PL-WB, LT-PL, LT-SA, LT-PU.

7. Bare peat wet (OL)

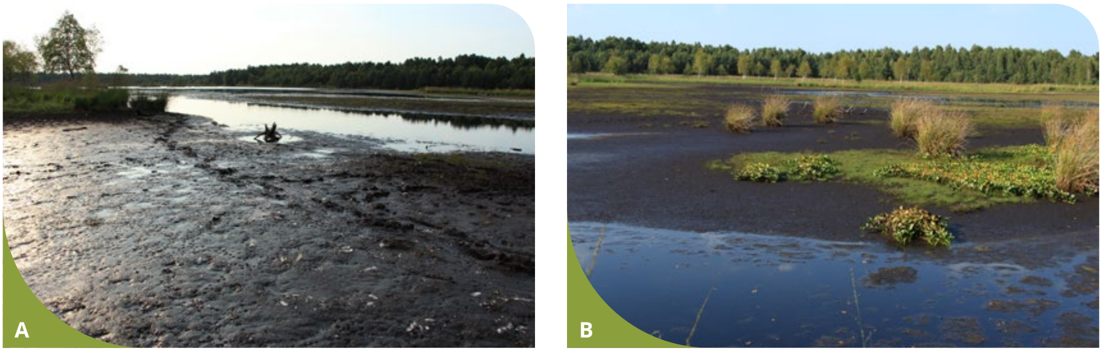


Figure 13. *Bare peat wet (OL) site* on post-excavation areas on Wielkie Bagno, Słowiński National Park, Poland. Photos: K. Bociąg.

GENERAL DESCRIPTION

Bare peat wet (OL) is characteristic of vast post-excavation areas within drained peatlands (Figure 13). The Wielkie Bagno peatland, Poland, has exposed post-excavation water bodies as a result of long-term peat subsidence. Peat soil is acidic and very poor (Table 9). High water levels in the wet season hinder spontaneous development of vegetation. Vegetation cover is very sparse (<5%) with only scattered patches of *Sphagnum cuspidatum, Juncus bulbosus, Warnstorfia exannulata*.

Table 9. Water level and peat properties characteristic of GEST *Bare peat wet (OL)*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
PL-WB	4+(5+)	nd	Ac	nd	o-vp	nd

PL-WB – Wielkie Bagno (Poland).

VEGETATION

Occurring plant species (Figure 14)**:**

PL: *Sphagnum cuspidatum, Juncus bulbosus,* *Eriophorum vaginatum, Warnstorfia exannulata.*

Sphagnum cuspidatum

Juncus bulbosus

Figure 14. Plant species occurring in GEST *Bare peat wet (oligotrophic).* Photos: M. Pakalne (A) and K. Bociąg (B).

Vegetation communities: none.

Relation to habitats of EU importance:
PL: 7120 Degraded raised bogs still capable of natural regeneration.

GHG emissions*:
CO_2 emissions – 1.5 (1.3) t CO_2-eq./ha/year
CH_4 emissions – 0.1 (0.2) t CO_2-eq./ha/year
GWP estimate – 1.6 (1.5) t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore site: PL-WB.

8. Very moist meadows, forbs and small sedges reeds

Figure 15. *Very moist meadows, forbs and small sedges reeds* in Biesenthaler Becken (Germany), Pūsčia peatland (Lithuania) and Augstroze Nature Reserve (Latvia). Photos: C. Schulz (A), J. Sendžikaitė (B) and K. Libauers (C).

GENERAL DESCRIPTION

GEST *Very moist meadows, forbs and small sedges reeds* was identified in self-regenerated parts of peat quarry abandoned after peat extraction (Pūsčia peatland, Lithuania) and in slightly drained fen grasslands (Biesenthaler Becken, Germany) (Figure 15). The peat properties vary widely, from oligotrophic-poor to eutrophic-rich (Table 10). Vegetation cover is represented by a rather high diversity of species. Because of high-water levels, tree coverage is rather scarce, but shrub layer coverage can reach up to 40%, and herb layer might cover up to 90%. In vegetation cover *Carex* spp., *Eriophorum angustifolium, Phragmites australis, Scirpus sylvaticus* dominate.

Table 10.

Table 10. Water level and peat properties characteristic of GEST *Very moist meadows, forbs and small sedges reeds*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LT-PU	4+(5+)	nd	Ac	4.0–4.7	o-p	33–34
DE-BB-1	4+		Sub-Alk	nd	e-r	nd

LT-PU – Pūsčia peatland (Lithuania); DE-BB-1 – Biesenthaler Becken (Germany).

VEGETATION

Occurring plant species (Figure 16)**:**

LT: ***Carex lasiocarpa, C. rostrata, C. acutiformis, C. nigra, C. pseudocyperus, Phragmites australis, Eriophorum angustifolium, Scirpus sylvaticus, Calliergon cordifolium, Calliergonella cuspidata,*** *Galium palustre, Lysimachia vulgaris, Potentilla palustris, Calamagrostis canescens, Stellaria palustris, Salix rosmarinifolia, S. aurita, S. cinerea*, *Betula pendula*, *Alnus glutinosa, Agrostis capillaris, Deschampsia caespitosa, Epilobium palustre, Equisetum fluviatile, Eriophorum vaginatum, Filipendula ulmaria, Juncus effusus, Juncus alpinoarticulatus, Lycopus europaeus, Lythrum salicaria, Climacium dendroides*, etc.

LV: ***Vaccinium oxycoccos, Eriophorum vaginatum, Carex limosa,*** *C. lasiocarpa, C. rostrata, Drosera rotundifolia, Molinia caerulea, Frangula alnus, Sphagnum warnstorfii.*

DE: ***Phragmites australis, Carex acutiformis, Urtica dioica, Rubus idaeus,*** *Poa pratensis, Calamagrostis epigejos, Glyceria maxima, Carex paniculata, Athyrium filix-femina, Thelypteris palustris, Epilobium palustre, Humulus lupulus, Lysimachia vulgaris, Lythrum salicaria, Rumex aquaticus, Scutellaria galericulata, Solanum dulcamara*.

Carex lasiocarpa | *Carex acutiformis* | *Carex nigra*

Carex pseudocyperus | *Equisetum fluviatile* | *Lythrum salicaria*

Figure 16. Plant species occurring in GEST *Very moist meadows, forbs and small sedges reeds*. Photos: Ž. Sinkevičius (A), J. Sendžikaitė (B–D, F) and K. Libauers (E).

Vegetation communities:
LT: *Carex* spp.-*Eriophorum angustifolium-Phragmites australis, Scirpus sylvaticus* communities.
DE: *Carex nigra-Caltha palustris-Filipendula ulmaria* community.

Relation to habitats of EU importance:
LT and **LV:** 7140 Transition mires and quaking bogs.
DE: none.

GHG emissions*:
CO_2 emissions – -0.5 (12.6) t CO_2-eq./ha/year
CH_4 emissions – 2.3 (0.3) t CO_2-eq./ha/year
GWP estimate – 1.9 (13.0) t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: LT-PU, DE-BB-1, LV-AU.

Wet meadows and forbs 9.

Figure 17. *Wet meadows and forbs:* A – during spring in Baltezers transition mire habitat in Latvia; B – an example of spontaneous revegetation of abandoned peat quarry (20 years after cessation of peat mining and first damming efforts on the edges of the peatland in 2003, Pūsčia peatland, Lithuania). Photos: A. Priede (A) and J. Sendžikaitė (B).

GENERAL DESCRIPTION

Dominating plant species are *Rhynchospora alba*, *Trichophorum alpinum, Carex flava* and other species of *Cyperaceae*, as well as *Vaccinium oxycoccos*, *Andromeda polifolia* and *Calluna vulgaris*. The moss layer is very rich in species in the natural habitats (Baltezers mire, Latvia; Figure 17, A) and poor in spontaneously revegetated peat quarries on former raised bog areas (Pūsčia peatland, Lithuania; Figure 17, B). For this reason, peat properties vary widely (Table 11): from acid oligotrophic-very poor (in heavily damaged peatlands) to sub-neutral (pH – 5.8) or alkaline (pH – 6.5) eutrophic-rich (in typical transition mires), where alkalinity has favoured the presence of several calciphilous plant and moss species, such as *Ophrys insectifera* and *Ctenidium molluscum*. The water level is high, albeit fluctuating due to drainage ditches. Drainage has caused development of dense *Pinus sylvestris* and *Frangula alnus* cover in the mire, especially in the marginal area around ditches.

Table 11. Water level and peat properties characteristic of GEST *Wet meadows and forbs*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LV-BA	5+	nd	Sub-Alk	5.8–6.5	nd	nd
LT-PU*		-8, -32, +30	Ac	2.9–3.8	o-vp	66–67

LV-BA – Baltezers Mire Nature Reserve (Latvia); LT-PU – Pūsčia peatland (Lithuania).
* Spontaneous revegetation of abandoned peat quarry.

VEGETATION

Occurring plant species (Figure 18)**:**

LV: *Rhynchospora alba, Trichophorum alpinum, Vaccinium oxycoccus, Carex flava,* *C. dioica, C. echinata, C. lasiocarpa, C. limosa, C. nigra, C. rostrata, Dactylorhiza cruenta, D. baltica, D. fuchsii, D. maculata, Drosera anglica, D. rotundifolia, Epipactis palustris, Eriophorum latifolium, E. vaginatum, Juniperus communis, Menyanthes trifoliata, Phragmites australis, Platanthera bifolia, Pinguicula vulgaris, Trichophorum cespitosum, Sphagnum warnstorfii, Calliergon giganteum, Campylium stellatum, Cinclidium stygium, Fissidens adianthoides, Scorpidium scorpioides, Tomentypnum nitens.*

LT: *Rhynchospora alba*, *Trichophorum alpinum*, *Eriophorum vaginatum, Drosera rotundifolia, Calluna vulgaris, Andromeda polifolia, Vaccinium uliginosum, Pinus sylvestris* (dwarf forms), *Betula pendula, B. pubescens, Salix* spp., *Polytrichum strictum, Sphagnum capillifolium, S. magellanicum, S. fallax.*


A
Rhynchospora alba


B
Trichophorum alpinum

Sphagnum warnstorfii

Vaccinium oxycoccos

Dactylorhiza cruenta

Dactylorhiza maculata

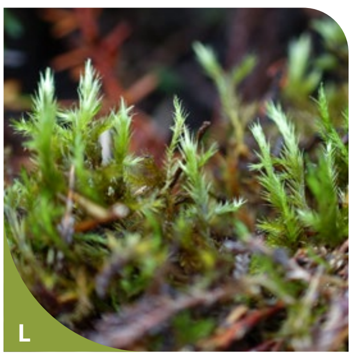
Platanthera chlorantha

Eriophorum latifolium

Menyanthes trifoliata

Campylium stellatum

Scorpidium scorpioides



Tomentypnum nitens

Preissia quadrata

Figure 18. Plant species occurring in GEST *Wet meadows and forbs*. Photos: M. Pakalne (A–H, J), J. Sendžikaitė (I) and L. Strazdiņa (K–M).

Vegetation communities:
LV and **LT:** *Rhynchospora alba-Eriophorum vaginatum, Rhynchospora alba-Trichophorum alpinum*, *Rhynchospora alba* communities.

Relation to habitats of EU importance:
LV: 7140 Transition mires and quaking bogs.
LT: 7150 Depressions on peat substrates of the *Rhynchosporion*.

GHG emissions:

Table 12. GHG emissions from GEST *Wet meadows and forbs*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
±0.0 (-3.9)	10.2	5.8 (7.4)	12.7	5.8 (3.5)	22.9

* Updated GEST catalogue (see *Annex 3*); values extrapolated from *Rewetted grassland*, values in brackets according to Reichelt, 2015.
** LV-BA. Measurement period 2019, modelled data. Data without tree related fluxes.

LIFE Peat Restore sites: LV-BA, LT-PU.

Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT) NEW 10.

Figure 19. *Very moist/Wet calcareous meadows, forbs and small sedges reeds* in Suursoo-Leidissoo project site (Estonia). Photos: R. Pajula.

GENERAL DESCRIPTION

Very moist/Wet calcareous meadows, forbs and small sedges reeds GEST unit with different drainage impact: open fen and fen in succession to the transitional mire (*Wet peat moss lawn*) occur in Suursoo-Leidissoo peatland, Estonia (Figure 19). In the best parts the water table is mostly close to the surface and drops no deeper than -30 cm in dry seasons (Table 13). With an increasing drainage impact, the water level continuously falls during dry periods and bryophyte coverage decreases. The mean water table for the GEST is -8 cm, but in sites with higher impact of drainage (for example, Lake Engure fen in Latvia) it lies deeper than -20 cm and sometimes during the dry seasons the water table can drop to -70 cm. Trees (*Betula pubescens, Pinus sylvestris*) and shrubs (*Frangula alnus*, *Myrica gale, Salix rosmarinifolia*) began intensively infiltrating the habitat. Perhaps 40–50 years ago *Sphagnum* patches began to form and development towards a bog trajectory proceeds in many parts of this GEST.

Tussocks of low-growing sedges (*Schoenus ferrugineus, Carex panicea*) and brown mosses (*Campylium stellatum, Drepanocladus* spp., *Calliergonella cuspidata, Fissidens adianthoides, Scorpidium scorpioides*) dominate the vegetation cover. *Carex lasiocarpa, C. elata, C. rostrata, Phragmites australis, Menyanthes trifoliata, Molinia caerulea* grow in the grass layer, *Myrica gale* spreads in the shrub layer.

Molinia caerulea dominates in sites with higher drainage impact. *Carex lasiocarpa, Trichophorum cespitosum, Peucedanum palustre, Carex davalliana, Vaccinium oxycoccos* are co-dominants. Shrub layer (*Myrica gale, Salix* spp.) height and coverage is higher than in the best-preserved sites. *Campylium stellatum* and *Fissidens adianthoides* dominate in the bryophyte layer but the coverage of fen mosses is significantly lower than in the previous group. *Sphagnum* (*S. capillifolium, S. angustifolium, S. fuscum*) occupies only small patches. Feather mosses

Hylocomium splendens and *Pleurozium schreberi* expand into fen vegetation around shrubs. Typical fen species *Dactylorhiza incarnata, D. ochroleuca, Eriophorum latifolium, Pinguicula vulgaris, Primula farinosa, Tofieldia calyculata, Trichophorum alpinum* grow sparsely in both groups.

In areas of Lake Engure fen, Latvia, where the vegetation is rather homogeneous and were earlier dominated by *Schoenus ferrugineus*, some places are gradually becoming overwhelmed by *Cladium mariscus* stands which represent stable communities composed of one strong competitor and low probability of establishment of new species.

Table 13. Water level and peat properties characteristic of GEST *Very moist/Wet calcareous meadows, forbs and small sedges reeds*

<table>
<tr><th rowspan="3">Project sites</th><th colspan="2">Water level</th><th colspan="4">Peat properties</th></tr>
<tr><th rowspan="2">Soil moisture class (Koska et al. 2001)</th><th rowspan="2">Mean, min and max WL, cm (LIFE Peat Restore)</th><th colspan="2">pH</th><th colspan="2">C:N</th></tr>
<tr><th>Based on plant indicators</th><th>LIFE Peat Restore</th><th>Based on plant indicators</th><th>LIFE Peat Restore</th></tr>
<tr><td>EE-SU</td><td>5+</td><td>-8, -44, +20</td><td rowspan="2">Alk</td><td>6.8</td><td>m-hm</td><td>20</td></tr>
<tr><td>LV-EN</td><td>6+/4+</td><td>-28, -47, +8</td><td>7.7</td><td>m-lm</td><td>nd</td></tr>
</table>

EE-SU – Suursoo-Leidissoo peatland (Estonia); LV-EN – Lake Engure Nature Reserve (Latvia).

VEGETATION

Occurring plant species (Figure 20)**:**

EE: ***Schoenus ferrugineus, Carex panicea*****,** ***Molinia caerulea*****,** ***Myrica gale, Drepanocladus*** **spp.**, ***Calliergonella cuspidata*****,** ***Fissidens adianthoides,*** *Carex lasiocarpa, C. elata, C. rostrata, Phragmites australis, Menyanthes trifoliata, Campylium stellatum, Scorpidium scorpioides, Trichophorum cespitosum, Peucedanum palustre, Carex davalliana, Vaccinium oxycoccos, Hylocomium splendens, Pleurozium schreberi, Sphagnum capillifolium, S. angustifolium, S. fuscum, Dactylorhiza incarnata, D. ochroleuca, Eriophorum latifolium, Pinguicula vulgaris, Primula farinosa, Tofieldia calyculata, Trichophorum alpinum.*

LV: ***Schoenus ferrugineus, Cladium mariscus, Carex panicea, Phragmites australis, Lycopus europaeus, Potentilla erecta, Salix rosmarinifolia, Epipactis palustris, Eupatorium cannabinum, Cirsium palustre, Drepanocladus revolvens, Scorpidium scorpioides, Fissidens adianthoides, Campylium stellatum****, Carex hostiana, C. flacca, C. lepidocarpa, C. dioica, Primula farinosa, Pinguicula vulgaris, Parnassia palustris, Equisetum variegatum, Sesleria caerulea, Molinia caerulea, Myrica gale, Linum catharticum, Gymnadenia conopsea, Triglochin palustre, Pedicularis palustris, Calliergonella cuspidata.*

Schoenus ferrugineus

Schoenus ferrugineus

Cladium mariscus

Scorpidium scorpioides

Myrica gale

Parnassia palustris

Primula farinosa

Pedicularis palustris

Fissidens adianthoides

Drepanocladus revolvens

Figure 20. Plant species occurring in GEST *Very moist/Wet calcareous meadows, forbs and small sedges reeds.* Photos: M. Pakalne (A–H) and L. Strazdiņa (I–J).

Vegetation communities:
EE and **LV:** *Myrica gale-Schoenus ferrugineus-Carex panicea*-fen mosses community, *Myrica gale-Molinia caerulea-Trichophorum cespitosum*-fen mosses community, *Myrica gale-Molinia caerulea-Sphagnum*, *Scorpidium scorpioides-Cladium mariscus*, *Primula farinosa-Schoenus ferrugineus* communities.

Relation to habitats of EU importance:
EE and **LV:** 7230 Alkaline fens, 7210* Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*.

GHG emissions

Table 14. GHG emissions from GEST *Very moist/Wet calcareous meadows, forbs and small sedges reeds*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
2.4	EE-SL**: 0.0	0.5	EE-SL**: 0.4	2.9	EE-SL**: 0.4
	LV-EN***: 3.4		LV-EN***: 2.7		LV-EN***: 6.1

* Updated GEST catalogue (see *Annex 3*).
** Mean of 2018–2020, modelled data.
*** Measurement period 2019, modelled data.

LIFE Peat Restore sites: EE-SU, LV-EN.

Very moist bog heath 11.

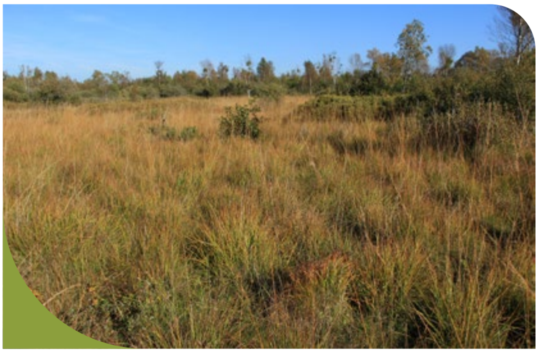


Figure 21. *Very moist bog heath* on Wielkie Bagno and Ciemińskie Błota in Słowiński National Park (Poland). Photos: K. Bociąg.

GENERAL DESCRIPTION

GEST *Very moist bog heath* occurs in drained raised bogs with oligotrophic-very poor and acidic peat soils (Table 15). *Eriophorum vaginatum* with *Erica tetralix* and *Calluna vulgaris* (Figure 21) dominate the vegetation in Ciemińskie Błota and Wielkie Bagno, Słowiński NP, Poland. *Andromeda polifolia, Vaccinium oxycoccos, Molinia caerulea* are common species. *Sphagnum* species (*S. capillifolium, S. fallax*) most often dominate the moss layer. Coverage of brown or feather mosses (i.e., *Hypnum cupressiforme*, *Pleurozium schreberi*)

Table 15. Water level and peat properties characteristic of GEST *Very moist bog heath*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al*. 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
PL-CB	4+	-14, -57, +15	Ac	nd	o-vp	nd
PL-WB		-35,-94, +1*				

PL-CB – Ciemińskie Błota, PL-WB – Wielkie Bagno (Poland).
* The water level at this point is lower than the values for this GEST unit presented by Koska *et al.* (2001). This is due to the specificity of the site, located in a small enclave of open peat bog vegetation overgrown with trees, on a slightly raised dry surface. Vegetation changes here follow the gradual decrease in the water level, but with a certain delay.

is usually lower. Due to drainage the area is overgrowing with *Betula pubescens* and *Pinus sylvestris*, which are periodically removed during the implementation of conservation measures. *Myrica gale* spreads in the shrub layer in Ciemińskie Błota, Poland.

Calluna vulgaris | *Erica tetralix* | *Eriophorum vaginatum*

Vaccinium oxycoccos | *Empetrum nigrum* | *Myrica gale*

Sphagnum fallax | *Hypnum cupressiforme* | *Pleurozium schreberi*

Figure 22. Plants occurring in GEST *Very moist bog heath.* Photos: K. Bociąg (A–G) and L. Strazdiņa (H–I).

VEGETATION

Occurring plant species (Figure 22)**:**

PL: ***Eriophorum vaginatum, Calluna vulgaris, Erica tetralix-Sphagnum nemoreum***, ***S. fallax,*** *S. magellanicum, Vaccinium oxycoccos, Rhododendron tomentosum* (sin. *Ledum palustre*), *Molinia caerulea, Myrica gale, Empetrum nigrum, Betula pubescens*, *Pinus sylvestris, Pleurozium schreberi, Polytrichum strictum, Hypnum cupressiforme*.

LT: ***Calluna vulgaris***, ***Eriophorum vaginatum***, ***Rhododendron tomentosum*** **(sin.** ***Ledum palustre*****),** ***Vaccinium uliginosum,*** *V. oxycoccos, Betula* spp., *Pinus sylvestris, Empetrum nigrum, Pleurozium schreberi*, *Polytrichum strictum, Sphagnum magellanicum*, *S. rubellum, Aulacomnium palustre, Dicranum polysetum.*

Vegetation communities:
PL: *Eriophorum vaginatum-Erica tetralix-Sphagnum* spp., *Erica tetralix-Calluna vulgaris-Myrica gale-Sphagnum* spp. communities.
LT: *Calluna vulgaris-Ledum palustre-Sphagnum* spp. community.

Relation to habitats of EU importance:
PL and **LT:** 7120 Degraded raised bogs still capable of natural regeneration.

GHG emissions:

Table 16. GHG emissions from GEST *Very moist bog heath*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
1.7 (4.7)	-1.8	3.0 (0.9)	0.03	4.6 (5.5)	-1.8

* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt, 2015.
** PL-WB, mean of 2018–2020, modelled data.

LIFE Peat Restore sites: PL-WB, PL-CB, LT-AM.

12. Very moist peat moss lawn

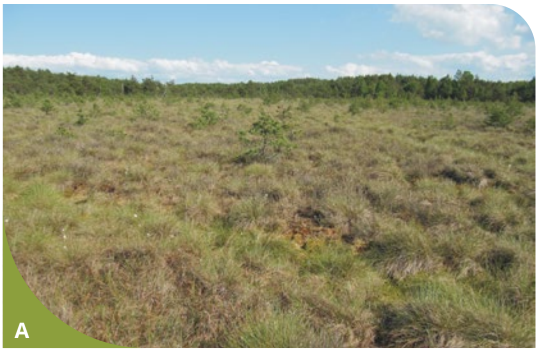


Figure 23. *Very moist peat moss lawn* on Wielkie Bagno (A) and Ciemińskie Błota (B) in Słowiński National Park (Poland). Photos: P. Pawlaczyk (A) and K. Bociąg (B).

GENERAL DESCRIPTION

Very moist peat moss lawn occurs in acidic oligotrophic-very poor raised bog habitats (Figure 23, Table 17). *Calluna vulgaris*, *Erica tetralix* and *Eriophorum vaginatum* are the dominant vascular plant species. *Vaccinium oxycoccos* and *Andromeda polifolia* are also abundant, *Molinia caerulea* occurs only locally. *Sphagnum* species (*S. fallax, S. magellanicum, S. nemoreum, S. rubellum*) dominate in the dense moss layer. Due to drainage the area is overgrown with *Betula pubescens* and *Pinus sylvestris*, which are periodically removed during the implementation of conservation measures (Słowiński NP, Poland).

Table 17. Water level and peat properties characteristic of GEST *Very moist peat moss lawn*

Water level				Peat properties	
Soil moisture class (Koska *et al.* 2001)	Project sites: Mean, min and max WL, cm (*LIFE Peat Restore*)			pH	C:N
4+(5+)	PL-WB: -24, -78, +7	PL-CB: -20, -62, +4	PL-KL: -10, -43, +7	Ac	o-vp

PL-WB – Wielkie Bagno, PL-CB – Ciemińskie Błota, PL-KL – Kluki (Poland).

VEGETATION

Occurring plant species (Figure 24)**:**

PL: ***Sphagnum fallax, S. magellanicum, S. capillifolium*, *S. rubellum*, *Eriophorum vaginatum, Erica tetralix, Calluna vulgaris,*** *Vaccinium oxycoccos, Andromeda polifolia*, *Molinia caerulea*.

Eriophorum vaginatum | *Vaccinium oxycoccos* (flowers) | *Vaccinium oxycoccos* (fruits)

Figure 24. Plants occurring in GEST *Very moist peat moss lawn*. Photos: J. Sendžikaitė (A, C) and Ž. Sinkevičius (B).

Vegetation communities:
PL: *Eriophorum vaginatum-Erica tetralix-Sphagnum* spp., *Molinia caerulea-Eriophorum vaginatum-Sphagnum fallax* communities.

Relation to habitats of EU importance:
PL: 7110 *Active raised bogs, 7120 Degraded raised bogs still capable of natural regeneration.

GHG emissions*:
CO_2 emissions – -1.1 (-4.3) t CO_2-eq./ha/year
CH_4 emissions – 3.4 (1.5) t CO_2-eq./ha/year
GWP estimate – 2.3 (3.0) t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: PL-WB, PL-CB, PL-KL.

13. Wet tall sedges reeds

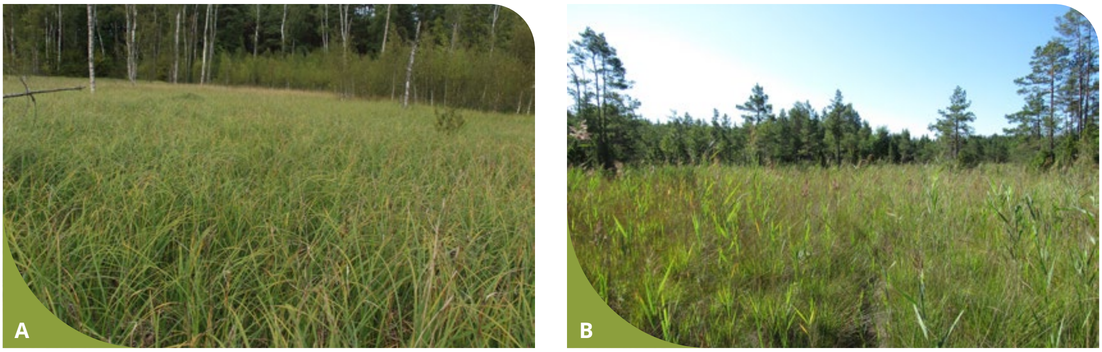


Figure 25. *Wet tall sedges reeds* on Wielkie Bagno (Poland) and Engure Nature Reserve (Latvia). Photos: K. Bociąg (A) and A. Priede (B).

GENERAL DESCRIPTION

GEST *Wet tall sedges reeds* (Figure 25) occurs in the margins of raised bogs, in transitional mires and fens with acidic mesotrophic-rather poor and mesotrophic-medium poor peat soils (Table 18; Słowiński NP, Poland). The herb layer is composed of tall sedges and/or common reeds. Moss coverage is quite diverse: from very scarce (<5%) to more developed (up to 20–30%); mostly formed by brown mosses (*Calliergonella cuspidata, Calliergon cordifolium*), less common *Sphagnum* mosses (*S. fimbriatum, S. squarrosum*). Tree and shrub layers are formed by *Betula pubescens*, *Alnus glutinosa*, *Myrica gale* and *Salix* spp.

Table 18. Water level and peat properties characteristic of GEST *Wet tall sedges reeds*

Water level		Peat properties			
		pH		C:N	
Soil moisture class (Koska *et al.* 2001)	Mean, min and max water level by *LIFE Peat Restore*, cm	Vegetation indication	*LIFE Peat Restore* (mean)	Vegetation indication	*LIFE Peat Restore* (mean)
5+ (4+)	nd	Ac	nd	m-lm, m-mr	nd

VEGETATION

Occurring plant species (Figure 26)**:**

LV and **PL:** ***Carex acutiformis, Phragmites australis,*** *Betula pubescens, Alnus glutinosa, Myrica gale, Salix* spp., *Calliergonella cuspidata, Calliergon cordifolium*, *Sphagnum fimbriatum, S. squarrosum.*

A *Phragmites australis*

B *Alnus glutinosa*

C *Calliergonella cuspidata*

D *Sphagnum squarrosum*

Figure 26. Plant species occurring in GEST *Wet tall sedges reeds*. Photos: J. Sendžikaitė (A–B) and L. Strazdina (C–D).

Vegetation communities:
PL: *Carex acutiformis*, *Phragmites australis-Carex* spp*.* communities.

Relation to habitats of EU importance: none.

GHG emissions*:
CO_2 emissions – -0.1 (-1.0) t CO_2-eq./ha/year
CH_4 emissions – 8.5 (9.5) t CO_2-eq./ha/year
GWP estimate – 8.4 (10.5) t CO_2-eq./ha/year
* Extrapolated from Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: PL-WB, PL-CB, LV-EN, LV-AU.

14. Wet small sedges reeds mostly with moss layer

Figure 27. *Wet small sedges reeds mostly with moss layer* in spontaneously regenerated part of an abandoned peat quarry in Sachara peatland (Lithuania). Photos: J. Sendžikaitė.

GENERAL DESCRIPTION

GEST *Wet small sedges and reeds mostly with moss layer* (Figures 27) occurs in natural or spontaneously regenerated peatlands, which are characterised by acid oligotrophic-very poor soils (Table 19) and comparably high-water levels. Tree layer is scarce. The herb layer is dominated by *Carex* spp. *Sphagnum* forms a dense moss layer.

Table 19. Water level and peat properties characteristic of GEST *Wet small sedges reeds mostly with moss layer*

<table>
<tr><th rowspan="3">Project sites</th><th colspan="2">Water level</th><th colspan="4">Peat properties</th></tr>
<tr><th rowspan="2">Soil moisture class (Koska et al. 2001)</th><th rowspan="2">Mean, min and max WL, cm (LIFE Peat Restore)</th><th colspan="2">pH</th><th colspan="2">C:N</th></tr>
<tr><th>Based on plant indicators</th><th>LIFE Peat Restore</th><th>Based on plant indicators</th><th>LIFE Peat Restore</th></tr>
<tr><td>LT-SA</td><td rowspan="2">4+/5+</td><td>nd</td><td rowspan="2">Ac</td><td>3.0</td><td>o-vp</td><td>74</td></tr>
<tr><td>PL-CB</td><td>-6, -57, +28</td><td>nd</td><td>o-p</td><td>nd</td></tr>
</table>

LT-SA – Sachara peatland (Lithuania); PL-CB – Ciemińskie Błota (Poland).

VEGETATION

Occurring plant species (Figure 28)**:**

LT and **PL:** ***Carex rostrata, C. lasiocarpa, Eriophorum vaginatum, E. angustifolium, Sphagnum cuspidatum, S. fallax,*** *Phragmites australis, Juncus effusus, Vaccinium oxycoccos, Polytrichum strictum.*

Carex rostrata — *Eriophorum vaginatum*

Eriophorum angustifolium — *Sphagnum fallax* — *Sphagnum cuspidatum*

Figure 28. Plant species occurring in GEST *Wet small sedges reeds mostly with moss layer*. Photos: J. Sendžikaitė (A, C-D), M. Pakalne (B) and L. Strazdiņa (E).

Vegetation communities:
LT: *Sphagnum* spp.-*Carex rostrata-Phragmites australis*, *Sphagnum* spp.-*Carex rostrata*, *Sphagnum* spp.-*Carex rostrata-Eriophorum vaginatum* communities.
PL: *Juncus effusus*, *Carex nigra-Calliergonella cuspidata* communities.

Relation to habitats of EU importance:
LT and **PL:** 7140 Transition mires and quaking bogs.

GHG emissions*:
CO_2 emissions – -3.5 (-2.0) t CO_2-eq./ha/year
CH_4 emissions – 6.8 (4.7) t CO_2-eq./ha/year
GWP estimate – 3.3 (2.5) t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: PL-WB, PL-CB, PL-KL, LT-SA.

15. Wet tall reeds

Figure 29. *Wet tall reeds* in the wet part of the peat quarry after the cessation of mining on the outskirts of the Aukštumala peatland (Lithuania). Photo: J. Sendžikaitė.

GENERAL DESCRIPTION

GEST *Wet tall reeds* (Figure 29) is usually found in peatlands characterised by mesotrophic-rather poor fen peat and high-water levels (Table 20). Vegetation cover is represented by very dense coverage of *Phragmites australis*, among them *Carex* spp. and/or shrubs of *Salix* spp. are quite abundant. Other plant species appear scarcely.

Table 20. Table 20. Water level and peat properties characteristic of GEST *Wet tall reeds*

Project sites	Water level		Peat properties			
			pH		C:N	
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LT-AU	5+	nd	Sub	5.3	m-lm	29
LT-PU				5.9		26

LT-AU – Aukštumala peatland, LT-PU – Pūsčia peatland (Lithuania).

VEGETATION

Occurring plant species (Figure 30)**:**

LT: ***Phragmites australis, Salix cinerea,*** *Comarum palustre*, *Lysimachia thyrsiflora, Carex rostrata, Lycopus europaeus, Juncus effusus.*

Phragmites australis — *Salix cinerea* — *Comarum palustre*

Lysimachia thyrsiflora — *Carex rostrata* — *Lycopus europaeus*

Figure 30. Plant species occurring in GEST *Wet tall reeds.* Photos: J. Sendžikaitė (A, C, E), A. Priede (B), Ž. Sinkevičius (D) and L. Šveistytė (F).

Vegetation communities:
LT: *Phragmites australis-Salix cinerea* community.

Relation to habitats of EU importance: none.

GHG emissions*:
CO_2 emissions – -2.3 (-0.2) t CO_2-eq./ha/year
CH_4 emissions – 6.3 (6.5) t CO_2-eq./ha/year
GWP estimate – 4.0 (6.5) t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: LT-AU, LT-PU, PL-WB, LV-AU, LV-BA.

16. Wet peat moss lawn

Figure 31. *Wet peat moss lawn* in Augstroze Nature Reserve (Latvia). Photo: M. Pakalne.

GENERAL DESCRIPTION

Dwarf shrubs (*Andromeda polifolia, Calluna vulgaris, Rhododendron tomentosum* (sin. *Ledum palustre*), *Vaccinium oxycoccos*), species of sedge family (*Eriophorum vaginatum, Rhynchospora alba, Trichophorum cespitosum*) and *Sphagnum* spp. (*S. capillifolium, S. cuspidatum, S. fuscum, S. magellanicum, S. rubellum, S. tenellum*) dominate in the GEST *Wet peat moss lawn* (Figure 31). Peat depth reaches 4–7 metres, pH value of water in the bog varies from 3.7 to 4.3, EC is 93.2–398.0 sm/cm^2 (Augstroze NR, Latvia). Water table fluctuates depending on the amount of precipitation (Table 21).

VEGETATION

Occurring plant species (Figure 32)**:**

LV: *Rhynchospora alba, Drosera anglica, Sphagnum flexuosum*, *S. magellanicum, S. rubellum*, *S. tenellum*, *Andromeda polifolia, Calluna vulgaris, Chamaedaphne calyculata, Drosera rotundifolia, Empetrum nigrum, Eriophorum vaginatum, Ledum palustre, Vaccinium oxycoccos, V. microcarpum, Rubus chamaemorus, Trichophorum cespitosum, Vaccinium uliginosum, V. vitis-idaea, Cladopodiella fluitans, Dicranum polysetum, Polytrichum commune, Sphagnum fuscum, S. capillifolium, S. fallax, Cladonia stellaris, C. stygia, Mylia anomala.*

Table 21. Table 21. Water level and peat properties characteristic of GEST *Wet peat moss lawn*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LV-AU	5+ (4+)	-24, -93, -34	Ac	4.0	o-vp	nd

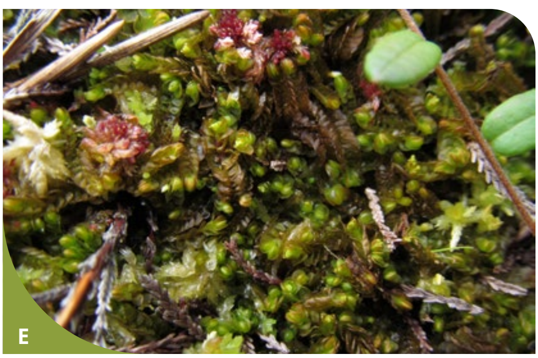
LV-AU – Augstroze Nature Reserve (Latvia).

Sphagnum rubellum and *S. fuscum*

Chamaedaphne calyculata

Sphagnum magellanicum

Drosera anglica



Mylia anomala

Cladonia stygia

Figure 32. Plant species occurring in GEST *Wet peat moss lawn.* Photos: M. Pakalne (A, C–F), K. Libauers (B) and L. Strazdiņa (E).

Vegetation communities:
Sphagnum magellanicum, Eriophorum vaginatum-Sphagnum recurvum communities.

Relation to habitats of EU importance:
LV: 7110 *Active raised bogs.
PL: 7120 Degraded raised bogs still capable of natural regeneration.

GHG emissions

Table 22. GHG emissions from GEST *Wet peat moss lawn*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
-0.5 (-3.0)	7.1	0.3 (5.3)	5.1	-0.3 (2.0)	12.2

* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.
** LV-AU, measurement period 2019, modelled data.

LIFE Peat Restore sites: LV-AU, PL-WB, LT-PU.

Peat moss lawn on former peat-cut off areas 17.

Figure 33. *Peat moss lawn on former peat-cut off areas* in Sachara peatland (A) and Plinkšiai peatland (B) (Lithuania), as well as on Wielkie Bagno (Poland; C–D). Photos: J. Sendžikaitė (A–B) and K. Bociąg (C–D).

GENERAL DESCRIPTION

GEST *Peat moss lawn on former peat-cut off areas* (Figure 33) occur in cut-over peatlands (usually bogs), which are characterised by spontaneous re-naturalization. Species composition is similar to the GEST *Wet peat moss lawn* and mainly dominated by *Sphagnum* mosses. *Rhynchospora alba* and *Eriophorum vaginatum* are commonly found in the herb layer, *Calluna vulgaris* is most common in the dwarf shrub layer. The tree layer is very scarce and mainly consists of dwarf forms of *Pinus sylvestris* and *Betula pendula*. Water level is generally high. If habitats occur on the remaining bog peat layer, chemical parameters of soils are usually assigned as acidic and oligotrophic-very poor (Table 23).

Eriophorum angustifolium, Eriophorum vaginatum, Rhynchospora alba, Molinia caerulea, Calla palustris are most common on former peat-cut areas in Słowiński NP, Poland. A dense moss layer is formed by dominating *Sphagnum cuspidatum* and *S. fallax*.

Table 23. Table 23. Water level and peat properties characteristic of GEST *Peat moss lawn on former peat-cut off areas*

<table>
<tr><th rowspan="3">Project sites</th><th colspan="2">Water level</th><th colspan="4">Peat properties</th></tr>
<tr><th rowspan="2">Soil moisture class (Koska et al. 2001)</th><th rowspan="2">Mean, min and max WL, cm (LIFE Peat Restore)</th><th colspan="2">pH</th><th colspan="2">C:N</th></tr>
<tr><th>Based on plant indicators</th><th>LIFE Peat Restore</th><th>Based on plant indicators</th><th>LIFE Peat Restore</th></tr>
<tr><td>LT-PL</td><td rowspan="4">5+/4+</td><td>nd</td><td rowspan="4">Ac</td><td>2.7–2.8</td><td rowspan="4">o-vp</td><td>59–67</td></tr>
<tr><td>LT-SA</td><td>nd</td><td>2.8</td><td>64</td></tr>
<tr><td>PL-CB</td><td>-11, -74, +4</td><td>nd</td><td>nd</td></tr>
<tr><td>PL-WB</td><td>-10, -47, +11</td><td>nd</td><td>nd</td></tr>
</table>

LT-PL – Plinkšiai peatland, LT-SA – Sachara peatland (Lithuania); PL-CB – Ciemińskie Błota, PL-WB – Wielkie Bagno (Poland).

VEGETATION

Occurring plant species (Figure 34)**:**

LT: ***Sphagnum cuspidatum, S. fallax, S. magellanicum, S. rubellum, Eriophorum vaginatum, Carex rostrata, Calluna vulgaris,*** *Rhododendron tomentosum* (sin. *Ledum palustre*), *Rhynchospora alba, Vaccinium oxycoccos, Andromeda polifolia, Betula pendula, Pinus sylvestris*, *Drosera rotundifolia, Empetrum nigrum, Rubus chamaemorus, Vaccinium uliginosum, Pleurozium schreberi, Sphagnum fuscum, S. tenellum.*

PL: ***Eriophorum angustifolium, Molinia caerulea, Calla palustris*** are common.

Vegetation communities:

LT: *Eriophorum vaginatum-Calluna vulgaris-Sphagnum* spp., *Eriophorum vaginatum-Rhynchospora alba-Sphagnum* spp. communities.

PL: *Eriophorum vaginatum-Molinia caerulea-Sphagnum* spp., *Eriophorum vaginatum-Eriophorum angustifolium-Molinia caerulea-Sphagnum* spp., *Eriophorum angustifolium-Rynhospora alba-Molinia caerulea-Sphagnum cuspidatum*, *Eriophorum angustifolium-Molinia caerulea-Sphagnum* spp., *Eriophorum angustifolium-Calla palustris-Sphagnum* spp. communities.

Relation to habitats of EU importance:
LT and **PL:** 7110 *Active raised bogs, 7120 Degraded raised bogs still capable of natural regeneration, 7140 Transition mires and quaking bogs.

Sphagnum fallax *Sphagnum rubellum* *Calla palustris*

Figure 34. Plant species occurring in GEST *Peat moss lawn on former peat-cut off areas*. Photos: S. Sprainaitytė (A–B) and K. Bociąg (C).

GHG emissions*:
CO_2 emissions – 1.5 (2.8) t CO_2-eq./ha/year
CH_4 emissions – 0.4 (37.3) t CO_2-eq./ha/year
GWP estimate – 1.9 (40.0) t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: LT-PL, LT-SA, PL-WB, PL-CB, PL-KL.

18. Wet peat moss lawn with pine trees NEW

Figure 35. *Wet peat moss lawn with pine tree*s in Suursoo-Leidissoo peatland (Estonia). Photo: R. Pajula.

GENERAL DESCRIPTION

GEST *Wet peat moss lawn with pine trees* (Figure 35) can be identified in different successional levels from *Wet peat moss lawn* (with increasing coverage of *Sphagnum*) to *Very moist forests and shrubberies* (with increasing volume of *Sphagnum* mat). *Sphagnum angustifolium*, *S. fuscum*, *S. magellanicum*, *S. rubellum* lies on fen peat, and its thickness varies from 20 cm up to 40 cm. A mixture of vascular plants (*Eriophorum vaginatum*, *Empetrum nigrum, Andromeda polifolia, Betula nana, Calluna vulgaris, Rhododendron tomentosum* (sin. *Ledum palustre*)*, Vaccinium oxycoccos, V. vitis-idaea*) occur in the bog moss carpet. Vascular plants (*Carex lasiocarpa, Menyanthes trifoliata, Phragmites australis*) set root in minerotrophic fen peat in Suursoo-Leidissoo peatland, Estonia. Small *Pinus sylvestris* and *Betula pubescens* trees (1–2 m) and some dwarf shrubs (*Empetrum nigrum, Calluna vulgari*s) occur. The water level is close to the surface in wet seasons but drops down 40–50 cm (from the top of *Sphagnum*) in dry seasons (Table 24).

Wet peat moss lawn with pine trees can also occur in the wet places of heavily drained peatlands (Lithuania) on acid oligotrophic-poor or oligotrophic-very poor peat (Table 24). Dense bryophyte cover (80–100%) is formed by *Sphagnum* (55–100%) and other mosses

(*Polytrichum strictum*, *Pleurozium schreberi*). The very dense dwarf shrub layer (60–90%) is dominated by *Calluna vulgaris*, *Rhododendron tomentosum* (sin. *Ledum palustre*), *Vaccinium uliginosum, V. oxycoccos.* The tree layer (max 6 m high; trees and dwarf forms of *Pinus sylvestris*, as well as trees of *Betula pendula* and *B. pubescens*) cover up to 30%.

Table 24. Water level and peat properties characteristic of GEST *Wet peat moss lawn with pine trees*

<table>
<tr><th rowspan="3">Project sites</th><th colspan="2">Water level</th><th colspan="4">Peat properties</th></tr>
<tr><th rowspan="2">Soil moisture class (Koska et al. 2001)</th><th rowspan="2">Mean, min and max WL, cm (LIFE Peat Restore)</th><th colspan="2">pH</th><th colspan="2">C:N</th></tr>
<tr><th>Based on plant indicators</th><th>LIFE Peat Restore</th><th>Based on plant indicators</th><th>LIFE Peat Restore</th></tr>
<tr><td>EE-SU</td><td rowspan="4">4+</td><td>-14, -47, +5</td><td>Sub</td><td>5.6</td><td>m-lm</td><td>29</td></tr>
<tr><td>LT-SA</td><td rowspan="3">nd</td><td rowspan="3">Ac</td><td>2.8</td><td rowspan="2">o-vp</td><td>65</td></tr>
<tr><td>LT-PU</td><td>3.0</td><td>45</td></tr>
<tr><td>LT-AM</td><td>2.9</td><td>o-p</td><td>40</td></tr>
</table>

EE-SU – Suursoo-Leidissoo peatland (Estonia); LT-SA – Sachara peatland, LT-PU – Pūsčia peatland, LT-AM – Amalva peatland (Lithuania).

VEGETATION

Occurring plant species (Figure 36)**:**

EE: *Sphagnum angustifolium, S. fuscum, S. magellanicum, S. rubellum*, ***Eriophorum vaginatum***, ***Pinus sylvestris***, ***Empetrum nigrum, Menyanthes trifoliata****, Andromeda polifolia, Betula nana, Calluna vulgaris, Ledum palustre, Vaccinium oxycoccos, V. vitis-idaea*, *Carex lasiocarpa, Phragmites australis*. *Liparis loeselii* (EU Directive species) was inventoried in the Suursoo-Leidissoo peatland.

LT: *Sphagnum angustifolium, S. magellanicum, S. rubellum, Polytrichum strictum, Pinus sylvestris* (trees and dwarf forms), ***Calluna vulgaris, Rhododendron tomentosum* (sin. *Ledum palustre*), *Eriophorum vaginatum, Vaccinium uliginosum,*** *V. oxycoccos, Andromeda polifolia, Sphagnum tenellum, Pleurozium schreberi, Dicranum polysetum*, etc.

Vegetation communities:

EE: *Betula nana-Eriophorum vaginatum-Sphagnum* spp., *Myrica gale-Empetrum nigrum-Sphagnum* spp. communities.

LT: *Sphagnum* spp.-*Ledum palustre-Pinus sylvestris* community.

Pinus sylvestris

Betula nana

Andromeda polifolia

Eriophorum vaginatum

Sphagnum tenellum

Sphagnum fuscum

Figure 36. Plant species occurring in GEST *Wet peat moss lawn with pine tree*s. Photos: K. Libauers (A), M. Pakalne (B–D) and L. Strazdiņa (E–F).

Relation to habitats of EU importance:
EE: 7140 Transition mires and quaking bogs.
LT: 7110 *Active raised bogs, 91D0 *Bog woodland.

GHG emissions

Table 25. GHG emissions from GEST *Wet peat moss lawn with pine trees*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
3.9	0.2	0.2	4.0	4.1	4.2

* Updated GEST catalogue (see *Annex 3*); data without woods.
** EE-SU, measurement period 2018–2020, modelled data. Data without tree related fluxes.

LIFE Peat Restore sites: EE-SU, LT-AM, LT-PU, LT-SA.

19. Wet peat moss hollows resp. flooded peat moss lawn

Figure 37. *Wet peat moss hollows resp. flooded peat moss lawn* in Augstroze Nature Reserve, Latvia. Photo: M. Pakalne.

GENERAL DESCRIPTION

The GEST *Wet peat moss hollows resp. flooded peat moss lawn* (Figure 37) develops in natural or minimally affected parts of raised bogs (Table 26). The wet hollows are usually well defined with open water areas, the vegetation is dominated by floating *Sphagnum* mats, often with reeds and sedges, vegetation typical for poor mires. Scarce tree and dwarf shrub layer develops on dryer hummocks. The water level fluctuates due to natural precipitation-evapotranspiration processes.

Table 26. Water level and peat properties characteristic of GEST *Wet peat moss hollows resp. flooded peat moss lawn*

Project sites	Water level		Peat properties			
			pH		C:N	
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LV-AU	5+	nd	Ac	nd	o-vp	nd

LV-AU – Augstroze Nature Reserve (Latvia).

VEGETATION

Occurring plant species (Figure 38)**:**

LV: ***Sphagnum cuspidatum, Calla palustris, Carex limosa, Rhynchospora alba, Scheuchzeria palustris,*** *Carex rostrata, Comarum palustre, Sphagnum fallax, Carex elata, C. lasiocarpa, Chamaedaphne calyculata, Drosera rotundifolia, D. anglica, Equisetum fluviatile, Eriophorum vaginatum, E. latifolium, Menyanthes trifoliata, Naumburgia thyrsiflora, Vaccinium oxycoccos, Succisa pratensis, Thelypteris palustris, Calliergonella cuspidata, Sphagnum magellanicum, S. teres, Utricularia* sp.

PL: ***Sphagnum cuspidatum, Calla palustris, Carex limosa, C. rostrata, Rhynchospora alba, Sphagnum fallax, Eriophorum angustifolium****, Comarum palustre, Drosera rotundifolia, Menyanthes trifoliata.*

Sphagnum cuspidatum

Rhynchospora alba

Sphagnum magellanicum

Scheuchzeria palustris

Carex limosa

Drosera rotundifolia

Menyanthes trifoliata

Calla palustris

Figure 38. Plant species occurring in *Wet peat moss hollows resp. flooded peat moss lawn*. Photos: M. Pakalne (A, C–G), L. Šveistytė (B) and K. Libauers (H).

Vegetation communities: *Sphagnum cuspidatum-Carex limosa*, *Sphagnum recurvum-Carex limosa* community.

Relation to habitats of EU importance:
LV: 7140 Transition mires and quaking bogs.

GHG emissions*:
CO_2 emissions – -3.1 (-4.6) t CO_2-eq./ha/year
CH_4 emissions – 12.0 (11.8) t CO_2-eq./ha/year
GWP estimate – 8.9 (7.0) t CO2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: LV-AU, PL-WB.

Open water/ditches 20.

Figure 39. GEST *Open water/ditches* as post-excavation water basin on Wielkie Bagno (A, Poland), old peat pit filled by water in Sachara peatland (B, Lithuania) and drainage ditche in Pūsčia peatland (C, Lithuania). Photos: K. Bociąg (A) and J. Sendžikaitė (B–C).

GENERAL DESCRIPTION

Natural dystrophic lakes and ponds, drainage ditches as well as post-excavation basins with variable water level in peatlands are united by GEST *Open water/ditches* (Figure 39). Water acidity and trophicity in these water reservoirs depends on the peatland type (Table 27). Water is rich in organic matter (humic substances). Water transparency varies, in post-mining reservoirs and drainage ditches water is often brown in colour (due to high concentrations of humic acid fractions). Vegetation is rather poor. Underwater mats of *Sphagnum* or *Warnstorfia* species characteristic to clear water of dystrophic lakes. *Nitella,* *Chara* and *Potamogeton* species occur in the ponds of alkaline calcium-rich peatlands. Quite often *Nuphar lutea* and *Nymphaea alba* occur too. In the flooded post-excavation areas (artificial water reservoirs) plants are found only in the shallowest zones, in the scarce submerged forms of *Sphagnum* (mostly *S. cuspidatum*), *Warnstorfia exannulata* and *Juncus bulbosus.* In the drainage ditches floating plants, such as *Lemna minor, Spirodela polyrhiza* or *Hydrocharis morsus-ranae,* are common.

Table 27. Water level and properties characteristic to GEST *Open water/ditches*

Project sites	Water level	Water properties (pH)	
	Soil moisture class (Koska *et al.* 2001)	*LIFE Peat Restore* (mean)	
PL-KL	6+	Ac, Sub	5.0
PL-WB		Ac	4.6
LV-AU			3.7
LV-BA		Sub-Alk	5.1

PL-KL – Kluki, PL-WB – Wielkie Bagno (Poland); LV-AU – Augstroze Nature Reserve, LV-BA – Baltezers Mire Nature Reserve (Latvia).

VEGETATION

Occurring plant species (Figure 40)**:**

LV: ***Sphagnum cuspidatum,*** *Nymphaea alba, Nuphar* spp., *Nitella* spp., *Chara* spp., *Potamogeton* spp., *Juncus bulbosus, Lemna* spp., *Stratiotes aloides.*

PL: ***Sphagnum cuspidatum****, Juncus bulbosus, Warnstoria exannulata.*

LT: ***Sphagnum cuspidatum,*** *Lemna minor, Spirodela polyrhiza, Hydrocharis morsus-ranae, Utricularia minor, Potamogeton* spp.

Vegetation communities:

LV: *Nuphar lutea-Nymphaea alba*, *Sphagnum cuspidatum* underwater community, S*phagnum denticulatum* underwater community, *Warnstorfia exannulata* underwater community, *Chara* spp., *Potamogeton* spp. communities.
PL: vegetation communities not formed.
LT: sometimes *Sphagnum cuspidatum* underwater, *Potamogeton* spp. communities.

Nymphaea alba — *Warnstorfia exannulata*

Sphagnum cuspidatum — *Sphagnum denticulatum*

Figure 40. Plant species occurring in GEST *Open water/ditches*. Photos: M. Pakalne (A, C), L. Strazdiņa (B) and K. Bociąg (D).

Relation to habitats of EU importance:
LV and **PL:** 3160 Natural dystrophic lakes and ponds, 7120 Degraded raised bogs still capable of natural regeneration, can also be part of 7110 *Active raised bogs, 7140 Transition mires and quaking bogs, 7230 Alkaline fens.
LT: none.

GHG emissions*:
CO_2 emissions – nd (+-0) t CO_2-eq./ha/year
CH_4 emissions – 2.8 (3.2) t CO_2-eq./ha/year
GWP estimate – nd (3.0) t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); values in brackets according to Reichelt 2015.

LIFE Peat Restore sites: PL-KL, PL-WB, LV-AU, LV-BA, LT-AM, LT-SA, LT-PU.

FORESTED PEATLANDS

OLIGOTROPHIC PEATLANDS

21. Dry forest and shrubberies (OL) NEW

Figure 41. *Dry forest and shrubberies (OL)* GEST in Amalva peatland (Lithuania). Photo: Ž. Sinkevičius.

GENERAL DESCRIPTION

GEST *Dry forest and shrubberies (OL)* occur in peatlands severely damaged by drainage or peat mining activities (Figure 41). Characterised by oligotrophic-very poor and acidic soils and low water level values (Table 28). Tree layer coverage is very dense (up to 80%) and mainly consists of *Betula* spp. Because of the unfavourable hydrologic conditions, *Sphagnum* mosses are almost absent and replaced by other bryophyte species: *Dicranum polysetum, Pleurozium schreberi*, *Polytrichum commune* and etc.

In the Polish sites, that were heavily drained in the first half of the 20th century (before the establishment of the Słowiński NP), *Picea abies* was planted as a part of forest management.

Table 28. Water level and peat properties characteristic of GEST *Dry forest and shrubberies (OL)*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska et al. 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LT-AM	2-/3-	-65; -110; -23	Ac	2.9–3.4	o-vp	45–50
LT-PU		-63; -119; -17		3.1–4.5		38–48

LT-AM – Amalva peatland, LT-PU – Pūsčia peatland (Lithuania).

VEGETATION

Occurring plant species (Figure 42) **:**

LT: ***Betula pendula, B. pubescens, Frangula alnus, Pinus sylvestris, Calluna vulgaris, Ledum palustre, Molinia caerulea, Vaccinium uliginosum, Vaccinium vitis-idaea, Dicranum polysetum, Pleurozium schreberi, Polytrichum commune***, *Calamagrostis epigejos, Lycopodium annotinum, Lysimachia vulgaris.*

PL: ***Picea abies, Vaccinium myrtillus, Molinia caerulea, Pleurozium schreberi,*** *Betula pendula, B. pubescens, Vaccinium vitis-idaea, Dicranum polysetum, D. scoparium.*

Vegetation communities:

LT: *Betula* spp.-*Frangula alnus-Molinia caerulea* community.
PL: *Picea abies* community (planted).

Relation to habitats of EU importance: none.

GHG emissions*:
CO_2 emissions – 26.0 t CO_2-eq./ha/year
CH_4 emissions – 0.0 t CO_2-eq./ha/year
GWP estimate – 26.0 t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); extrapolated from *Picea abies* stands in temperate Germany; data without woods.

LIFE Peat Restore sites: LT-AM, LT-PU, PL-WB, PL-KL.

Betula pubescens

Frangula alnus

Calluna vulgaris

Vaccinium vitis-idaea

Vaccinium uliginosum

Lycopodium annotinum

Figure 42. Plant species occurring in GEST *Dry forest and shrubberies (OL)*. Photos: J. Sendžikaitė (A–B, F), M. Pakalne (C–D) and K. Libauers (E).

Moderately moist forest and shrubberies (OL) 22.

Figure 43. GEST *Moderately moist forest and shrubberies (OL)* in Pūsčia (A) and Sachara (B) peatlands (Lithuania), as well as on Ciemińskie Błota and Wielkie Bagno (Poland; C-D). Photos: J. Sendžikaitė (A), Ž. Sinkevičius (B) and K. Bociąg (C–D).

GENERAL DESCRIPTION

GEST *Moderately moist forest and shrubberies (OL)* occurs on oligotrophic peatlands which have been damaged by drainage (Figure 43), but the impact of drainage is being mitigated through the process of self-regeneration (Sachara, Pūsčia, Amalva and Plinkšiai peatlands, Lithuania) on the edges of former peat quarries (near main ditches) and in areas with slightly higher elevation. Compared to *Dry forest and shrubberies (OL)*, water level values are a bit higher. The tree layer mainly consists of *Betula pendula*, *Pinus sylvestris* and *Picea abies.* On oligotrophic-very poor and acidic soils (Table 29) dwarf shrubs of *Calluna vulgaris*, *Vaccinium myrtillus*, *V. vitis-idaea* grow, in wetter places *Rhododendron tomentosum* (sin. *Ledum palustre*), and *Vaccinium uliginosum* occur. In the herb layer *Lycopodium annotinum* and *Eriophorum vaginatum* are quite common. Coverage of bryophytes varies depending on peatland state: from very scarce (up to 15%; in Sachara and Pūsčia peatlands) to very dense (up to 70–90%; in Plinkšiai and Amalva peatlands) with *Pleurozium schreberi, Dicranum polysetum* and *Polytrichum commune.* Small patches of *Sphangum magelanicum* and *S. capilifolium* are very rare.

In Polish sites, *Molinia caerulea dominate* in the herb layer and is frequent in *Molinia caerulea-Pinus sylvestris* and *Molinia caerulea-Betula pubescens* communities. *Picea abies* is typical and dominant in the moss layer of more degraded pine or birch forests (*Pleurozium schreberi-Pinus sylvestris*, *Pleurozium schreberi-Betula pubescens* communities).

Table 29. Table 29. Water level and peat properties characteristic of GEST *Moderately moist forest and shrubberies (OL)*

<table>
<tr><th rowspan="3">Project sites</th><th colspan="2">Water level</th><th colspan="4">Peat properties</th></tr>
<tr><th rowspan="2">Soil moisture class (Koska et al. 2001)</th><th rowspan="2">Mean, min and max WL, cm (LIFE Peat Restore)</th><th colspan="2">pH</th><th colspan="2">C:N</th></tr>
<tr><th>Based on plant indicators</th><th>LIFE Peat Restore</th><th>Based on plant indicators</th><th>LIFE Peat Restore</th></tr>
<tr><td>LT-SA</td><td rowspan="7">2+</td><td>-41; -127, +16</td><td rowspan="7">Ac</td><td>2.9–3.2</td><td rowspan="2">o-p–o-vp</td><td>35–58</td></tr>
<tr><td>LT-PU</td><td rowspan="3">nd</td><td>3.1–4.5</td><td>35–48</td></tr>
<tr><td>LT-AM</td><td>2.9–3.4</td><td rowspan="5">o-vp</td><td>45–50</td></tr>
<tr><td>LT-PL</td><td>2.6–3.1</td><td>48–84</td></tr>
<tr><td>PL-WB</td><td>-30; -86; +7</td><td rowspan="3">nd</td><td rowspan="3">nd</td></tr>
<tr><td>PL-CB</td><td>-30; -94; +10</td></tr>
<tr><td>PL-KL</td><td>-35; -126, +20</td></tr>
</table>

LT-SA – Sachara peatland, LT-PU – Pūsčia peatland, LT-AM – Amalva peatland, LT-PL – Plinkšiai peatland (Lithuania); PL-CB – Ciemińskie Błota, PL-WB – Wielkie Bagno, PL-KL – Kluki (Poland).

VEGETATION

Occurring plant species (Figure 44)**:**

LT and **PL:** ***Betula pendula, B. pubescens, Picea abies, Vaccinium myrtillus, V. vitis-idaea, Pleurozium schreberi, Pinus sylvestris, Lycopodium annotinum, Calluna vulgaris, Frangula alnus, Dicranum polysetum, Polytrichum commune, Molinia caerulea***, *Vaccinium uliginosum, Populus tremula, Eriophorum vaginatum, Rhododendron tomentosum* (sin. *Ledum palustre*), *Rubus chamaemorus*, *R. idaeus*, *Pyrola rotundifolia*, etc.

Picea abies

Vaccinium vitis-idaea

Vaccinium myrtillus

Lycopodium annotinum

Dicranum polysetum

Figure 44. Plant species occurring in GEST *Moderately moist forest and shrubberies (OL)*. Photos: J. Sendžikaitė (A, C) and L. Strazdiņa (B, D–E).

Vegetation communities:

LT: *Vaccinium myrtillus-Betula pendula-Picea abies*, *Lycopodium annotinum-Betula pendula*, *Eriophorum vaginatum*-bare peat-*Betula pendula*, *Vaccinium vitis-idaea*-bare peat-*Betula pendula*, *Calluna vulgaris-Pinus sylvestris*, *Molinia caerulea-Salix cinerea-Betula pendula*, *Pleurozium schreberi-Betula pubescens* communities.

PL: *Molinia caerulea-Pinus sylvestris*, *Pleurozium schreberi-Pinus sylvestris, Molinia caerulea-Betula pubescens*, *Pleurozium schreberi-Betula pubescens* communities.

Relation to habitats of EU importance:
LT: 7120 Degraded raised bogs still capable of natural regeneration.
PL: 91D0* Bog woodland.

GHG emissions

Table 30. Table 30. GHG emissions from GEST *Moderately moist forest and shrubberies (OL)*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
20.0 [-3.1]	49.3	0.0 [-0.1]	-0.2	20.0 [-3.2]	49.1

* Updated GEST catalogue (see *Annex 3*), values without considering wood biomass, extrapolated from GEST Moderately moist (forbs) meadows; values in square brackets consider wood biomass.
** LT-AM, measurement period 2019, modelled data. Data without tree related fluxes.

LIFE Peat Restore sites: LT-SA, LT-PU, LT-AM, LT-PL, PL-WB, PL-KL.

Moist forests and shrubberies (OL) 23.

Figure 21. *GEST Moist forest and shrubberies (OL)* with dense shrub and dwarf shrub layer on the border of Baltezers transition mire (Latvia, A), Pūsčia peatland (Lithuania, B) and on Wielkie Bagno, Słowiński National Park (Poland, C–D). Photos: A. Priede (A), J. Sendžikaitė (B) and K. Bociąg (C–D).

GENERAL DESCRIPTION

GEST *Moist forest and shrubberies (oligotrophic)* usually develops on natural but drained peatlands (Figure 45, Table 31), especially along both sides of old drainage ditches (Baltezers Mire, Latvia; Kluki, Ciemińskie Błota, Wielkie Bagno, Poland) and spontaneously overgrown parts of abandoned (for last 3–6 decades) peat quarries (Sachara and Pūsčia peatlands, Lithuania; Kluki, Ciemińskie Błota, Wielkie Bagno, Poland), where the drainage system was accidentally and naturally clogged. Slow hydrology stabilisation followed the drainage system failure and made it possible for trees to adapt and establish a forest stand. Undrained areas, where *Moist forest and shrubberies (OL)* occur are rare and only occupy small areas in Kluki, Ciemińskie Błota and Wielkie Bagno (Poland).

Shrub and dwarf-shrub layers are similar to bog woodland, however due to drained soil *Vaccinium* spp. and *Rhododendron tomentosum* (sin. *Ledum palustre*) cover has increased density. In contrary to bog woodland, *Sphagnum* cover in the bryophyte layer in Baltezers

Mire is almost absent (the species composition is more similar to Western Taiga), while in Lithuanian sites it can vary widely (from 2% to 80%).

Shrub and dwarf-shrub layers consist of *Rhododendron tomentosum* (syn. *Ledum palustre*), *Vaccinium* spp., *Andromeda polifolia*, in Poland also *Calluna vulgaris* and *Erica tetralix* are common. The shrub and dwarf-shrub layer is most abundantly developed on drained surfaces. *Eriophorum vaginatum* is a typical species in the undergrowth. The coverage of the bryophyte layer is varied. In the least dry areas in Poland and Lithuania, it is well developed (50–100%), composed of *Sphagnum* species with an admixture of brown mosses. Less preserved areas have a scarce bryophyte cover (20–50%), with predominant brown mosses. Part of the surface has a poor bryophyte layer (2–20% coverage). In Baltezers Mire, Latvia, peat mosses are almost absent in the *Moist forest and shrubberies (OL)* the species composition is more similar to Western Taiga.

Table 31. Water level and peat properties characteristic of GEST *Moist forests and shrubberies (OL)*

<table>
<tr><th rowspan="3">Project sites</th><th colspan="2">Water level</th><th colspan="4">Peat properties</th></tr>
<tr><th rowspan="2">Soil moisture class (Koska et al. 2001)</th><th rowspan="2">Mean, min and max WL, cm (LIFE Peat Restore)</th><th colspan="2">pH</th><th colspan="2">C:N</th></tr>
<tr><th>Based on plant indicators</th><th>LIFE Peat Restore</th><th>Based on plant indicators</th><th>LIFE Peat Restore</th></tr>
<tr><td>LT-SA</td><td rowspan="5">3+</td><td>33; -120; +14</td><td rowspan="5">Ac</td><td>2.5–2.8</td><td>o-vp</td><td>53–72</td></tr>
<tr><td>LT-PU</td><td>nd</td><td>2.9</td><td rowspan="2">o-p</td><td>35</td></tr>
<tr><td>PL-CB</td><td>-19; -60; +10</td><td rowspan="3">nd</td><td rowspan="3">nd</td></tr>
<tr><td>PL-WB</td><td>-24; -109; +22</td><td rowspan="2">o-vp</td></tr>
<tr><td>PL-KL</td><td>-23; -110; +17</td></tr>
</table>

LT-SA – Sachara peatland, LT-PU – Pūščia peatland (Lithuania); PL-CB – Ciemińskie Błota, PL-WB – Wielkie Bagno, PL-KL – Kluki (Poland).

VEGETATION:

Occurring plant species (Figure 46)**:**

LT: ***Betula pubescens, Pinus sylvestris, Picea abies,*** *Rhododendron tomentosum* (sin. *Ledum palustre*), *Vaccinium uliginosum, V. oxycoccos, Andromeda polifolia, Carex echinata, C. nigra, C. rostrata, Eriophorum vaginatum, Rubus chamaemorus, Molinia caerulea, Hylocomium splendens.* Moss cover includes *Dicranum polysetum*, *Pleurozium schreberi*, *Sphagnum fallax, S. magellanicum, S. rubellum, S. capillifolium.*

PL: also C*alluna vulgaris, Erica tetralix, Eriophorum angustifolium, Myrica gale, Sphagnum palustre, S. russowii, S. fimbriatum, Pseudoscleropodium purum, Polytrichum* spp.

Rhododendron tomentosum (syn. *Ledum palustre)*

Vaccinium uliginosum

Rubus chamaemorus

Vaccinium oxycoccos

Pinus sylvestris

Hylocomium splendens

Figure 46. Plant species occurring in GEST *Moist forest and shrubberies (oligotrophic).* Photos: M. Pakalne (A, C–E), J. Sendžikaitė (B) and L. Strazdiņa (F).

Vegetation communities:

LV: *Vaccinium uliginosum-Betula pubescens, Vaccinium uliginosum-Pinus sylvestris* communities.

PL: *Vaccinium uliginosum-Pinus sylvestris* (in the central parts of peat bogs), *Vaccinium uliginosum-Betula pubescens* (in peripheral parts) communities and single patches of *Myrica gale* community.

LT: *Vaccinium uliginosum-Betula pubescens, Eriophorum vaginatum-Pinus sylvestris*, *Sphagnum* spp.- *Eriophorum vaginatum-Pinus sylvestris* communities.

Relation to habitats of EU importance:
LV: 91D0 *Bog woodland, 9010 *Western taiga.
PL: 91D0 *Bog woodland.
LT: 91D0 *Bog woodland, 7120 Degraded raised bogs still capable of natural regeneration.

GHG emissions*:
CO_2 emissions – 9.4 [-2.2] t CO_2-eq./ha/year
CH_4 emissions – 0.0 [-1.8] t CO_2-eq./ha/year
GWP estimate – 9.4 [-4.0] t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); extrapolated from GEST *Moist bog heath*; values in square brackets consider wood biomass.

LIFE Peat Restore sites: LV-AU, LV-BA, LT-SA, LT-PU, PL-WB, PL-KL, PL-CB.

Very moist forests and shrubberies (OL) 24.

Figure 47. GEST *Very moist forests and shrubberies (OL)* in Suursoo-Leidissoo peatland (Estonia, A–B) and Kluki, Ciemińskie Błota and Wielkie Bagno (Poland, C–D). Photos: R. Pajula (A–B) and K. Bociąg (C–D).

GENERAL DESCRIPTION

Typically, GEST *Very moist forests and shrubberies (OL)* occur on wet substrates with persistently high-water levels (bogs and acidic fens). In the Boreal region, they are usually found in the periphery of mire complexes, in valleys, or on minerotrophic soils dominated by *Picea abies*.

Very moist forests and shrubberies (OL) occupy a small area in Kluki, Ciemińskie Błota and Wielkie Bagno, Poland. Stand is low (7–12 m), composed mainly of *Pinus sylvestris* with an admixture of *Betula pubescens.* The undergrowth layer is well developed and dominated by clumps of *Eriophorum vaginatum.* The bryophyte layer (100% coverage) is made of *Sphagnum fallax*, less often *Sphagnum cuspidatum.* Most of such forests on Polish sites are secondary forests. They developed as a result of the rising water level in post excavations areas, previously overgrown by moist forest. Less often, *Very moist forests and shrubberies (oligotrophic)* are young stages of a bog forest encroaching on an open bog.

In Suursoo-Leidissoo peatland, Estonia, the situation is exceptional (Figure 47), because *Very moist forests and shrubberies (OL)* developed from the GEST *Wet peat moss lawn* with increasing height and density of *Pinus sylvestris* on impacted by drainage fen (the main reclamation works were performed in the end of the 19th century, additional ditches were installed in the 1960s. Currently, the bog peat is just beginning to shape; the roots of the plants extend to the fen peat. *Pinus sylvestris* trees ranging between 10 and 15 m in height and *Betula pubescens* dominate in the tree layer (coverage is 20–25%). Some of them are older than 100 years, thus, they grew here before drainage. Dwarf shrubs *Rhododendron tomentosum* (sin. *Ledum palustre*), *Calluna vulgaris, Empetrum nigrum, Vaccinium oxycoccos* and ect.) spread widely. Some shrubs (*Myrica gale*, *Salix* spp.) are more characteristic to minerotrophic habitats. The peat surface is covered by a dense and thick (up to 50 cm) carpet of *Sphagnum* mosses (mainly *S. magellanicum, S. papillosum, S. capillifolium*). In the wet season, water lies on the surface between hummocks, but the water level can drop up to 50 cm depth in dry season (Table 32).

Table 32. Water level and peat properties characteristic of GEST *Dry forest and shrubberies (OL)*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska et al. 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
EE-SU	4+	-15; -52; +3	Sub	5.9	m-lm	29

EE-SU – Suursoo-Leidissoo peatland (Estonia).

VEGETATION

Occurring plant species (Figure 48)**:**

EE: ***Pinus sylvestris***, ***Betula pubescens***, ***Sphagnum magellanicum***, ***S. papillosum***, ***S. capillifolium***, ***Menyanthes trifoliata***, ***Eriophorum vaginatum***, *Andromeda polifolia, Betula nana, Calluna vulgaris, Rhododendron tomentosum* (sin. *Ledum palustre*), *Empetrum nigrum, Vaccinium oxycoccos*, *Myrica gale*, *Salix* spp., *Sphagnum angustifolium*, *S. fuscum*, *S. russowii.*

PL: ***Pinus sylvestris, Betula pubescens, Eriophorum vaginatum, Sphagnum fallax, S. cuspidatum,*** *S. palustre, Erica tetralix, Andromeda polifolia, Eriophorum angustifolium, Vaccinium oxycoccos, Molinia caerulea.*

Betula nana

Myrica gale

Eriophorum vaginatum

Rhododendron tomentosum (syn. *Ledum palustre*)

Andromeda polifolia

Calluna vulgaris

Figure 48. Plant species occurring in GEST *Very moist forest and shrubberies (oligotrophic)*. Photos: J. Sendžikaitė (A–B, E), K. Bociąg (C), L. Truus (D, F).

Vegetation communities:

EE: *Betula nana-Rhododendron tomentosum-Sphagnum angustifolium*, *Myrica gale-Menyanthes trifoliata-Sphagnum* spp. communities.

PL: *Eriophorum vaginatum-Pinus sylvestris* community.

Relation to habitats of EU importance:
EE: 91D0 *Bog woodland.

GHG emissions

Table 33. GHG emissions from GEST *Very moist forests and shrubberies (OL)*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
1.7 [-2.3]	-4.7	3.0 [1.75]	0.9	4.7 [-0.55]	-3.8

* Updated GEST catalogue (see *Annex 3*); extrapolated from GEST *Very moist bog heath*; values in square brackets consider wood biomass.

** EE-SL, measurement period 2018–2020, modelled data. Data without tree related fluxes.

LIFE Peat Restore sites: EE-SU, PL-WB, PL-CB, PL-KL.

25. Dry forests and shrubberies (ME/EU) NEW

Figure 49. *Dry forests and shrubberies (mesotrophic/eutrophic)* in Amalva peatland (Lithuania). Photo: L. Jarašius.

GENERAL DESCRIPTION

GEST *Dry forests and shrubberies (ME/EU)* occur in peatlands severely damaged by drainage or peat mining activities (Figure 49). They are characterised by mesotrophic-rather poor and acidic or sub-neutral soils and low water level values (Table 34). Tree and shrub layers are very dense (up to 90 and 70%, respectively) and mostly dominated by *Betula pendula* and *Populus tremula, Salix* spp., *Frangula alnus*, etc. Herb projective coverage up to 50–70%, moss coverage — 10–30%.

In Polish sites, extremely damaged by drainage, *Alnus glutinosa* was planted, less often *Picea abies*, as a part of forest management activities in the first half of the 20th century (before the establishment of Słowiński NP). Currently, they form mesotrophic *Alnus glutinosa* or *Picea abies* communities.

Table 34. Water level and peat properties characteristic of GEST *Dry forest and shrubberies (EU/ME)*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
LT-AM	2-/3-	-89; -112; -61	Ac	3.2	o-vp	46

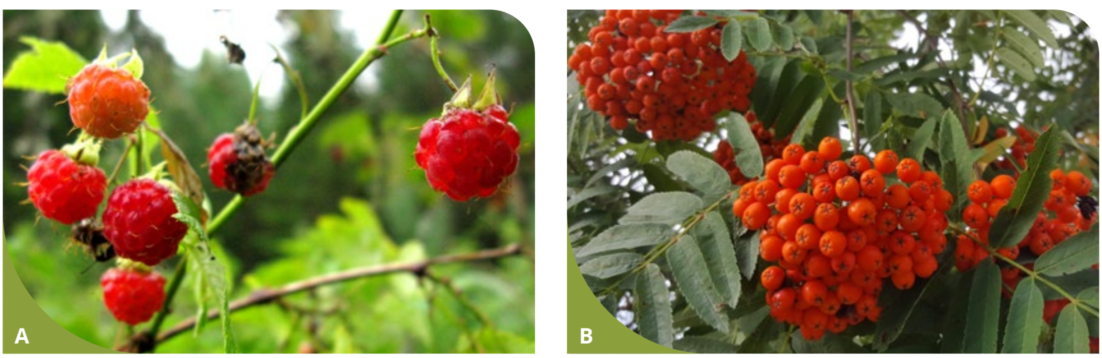
LT-AM – Amalva peatland (Lithuania).

VEGETATION

Occurring plant species (Figure 50)**:**

LT: ***Betula pendula, Frangula alnus, Populus tremula, Salix caprea, Sorbus aucuparia, Dryopteris expansa, Molinia caerulea*, *Mycelis muralis, Rubus idaeus, Pleurozium schreberi,*** *Galeopsis bifida, Geranium robertianum, Geum urbanum, Lycopodium annotinum, Lysimachia vulgaris, Urtica dioica, Polytrichum commune.*

PL: also common ***Alnus glutinosa, Picea abies*** and *Rubus* spp.



Rubus idaeus *Sorbus aucuparia*

Figure 50. Plants occurring in GEST Dry forests and shrubberies (ME/EU). Photos: L. Strazdiņa (A) and J. Sendžikaitė (B).

Vegetation communities:

LT: *Urtica dioica-Betula pendula-Populus tremula, Rubus idaeus-Frangula alnus-Populus tremula, Molinia caerulea-Rubus idaeus-Betula pendula* communities.

PL: *Alnus glutinosa* (planted)*, Picea abies* (planted) communities.

Relation to habitats of EU importance: none.

GHG emissions*:
CO_2 emissions – 43.4 t CO_2-eq./ha/year
CH_4 emissions – 0.0 t CO_2-eq./ha/year
GWP estimate – 43.4 t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); extrapolated from deciduous forests.

LIFE Peat Restore sites: LT-AM, PL-KL.

26. Moderately moist forests and shrubberies (ME/EU)

Figure 51. GEST *Moderately moist forests and shrubberies (ME/EU)*: degraded *Betula pubescens* forest in Biesenthaler Becken (Germany; A) and Słowiński National Park (Poland; with *Rubus fruticosus-Betula pubescens* and *Betula* sp.-*Quercus robur* communities; B–C) on eutrophic heavily drained peat; *Tilia cordata-Ulmus* spp. community on a slope in Augstroze Nature Reserve (Latvia; D). Photos: C. Schulz (A), K. Bociąg (B–C) and S. Ikauniece (D).

GENERAL DESCRIPTION

The GEST *Moderately moist forests and shrubberies (ME/EU)* is located in a small deeply drained and consequently heavily degraded kettlehole peatland in Biesenthaler Becken NR, Germany (Figure 51, A). *Betula pubescens* accompanied by *Padus serotina* dominate in the tree and shrub layer. *Molinia caerulea* agg. is common in the herb layer, *Vaccinium myrtillus* prevails in the dwarf shrub layer. The species assemblage indicates mesotrophic-rather poor acid and moderately moist ecological conditions (Table 35). Small patches of *Carex elongata*, *Sphagnum fimbriatum* and *S. squarrosum* hint towards the former mire state.

Moderately moist forests and shrubberies (ME/EU) occur in peripheral parts of project sites in the Słowiński NP, Poland (Figure 51, B–C). Species composition of the *Rubus fruticosus* agg.-

Betula pubescens community is similar as described above, except that *Padus serotina* is not frequent in Polish sites. *Betula* sp.-*Quercus robur* community is characteristic for marginal parts of Kluki peatland. Oak seedlings are abundant in shrub and grass layers, as well as young oak trees are common in the undergrowth. Old oak trees are quite rare. Depending on soil moisture and fertility, these forests range from bog forests (with *Molinia caerulea* agg. and mosses) to rich in herbaceous species forests with dominance of *Rubus* sp. and scarce coverage of mosses.

Moderately moist forests and shrubberies (ME/EU) were identified in the partly rewetted (2003) margins of Pūsčia peatland (Lithuania), which were abandoned after intensive peat mining more than 30 years ago. Forest stands (*Betula pendula*, *B. pubescens*, *Picea abies*, *Pinus sylvestris*) are up to 25 years old with a tree coverage of 60–70%. Shrubs (*Frangula alnus, Salix* spp.) and grass (*Molinia caerulea*, *Lysimachia vulgaris, Carex* spp., etc.) layers are quite dense (up to 60% and 40–80%, correspondingly). Coverage of the dwarf shrub layer (*Vaccinium myrtillus, V. vitis-idaea, Rubus idaeus*) varies from 10% to 80%. Bryophytes cover is scarce (up to 10%).

In Latvia, this type of forest has developed in both drained and natural places. In Baltezers Mire NR (Figure 51, D), these are 70–90-year-old forests that correspond to habitat 9010 *Western Taiga with atypical herb layer vegetation. The tree layer is dominated by *Populus tremula* mixed with *Betula pendula* and *Picea abies*. The herb layer has a spring aspect, the most common species being *Anemone* spp., *Hepatica nobilis*, *Aegopodium podagraria,* and also *Eurhynchium angustirete* and *Rhytidiadelphus triquetrus* in moss layer. In the Augstroze NR, these forests are mainly found on bog islands or have developed in a wooded meadow landscape during the secondary succession after the cessation of grazing. Forest plots are fragmented and occupy a small area. Forests correspond to the nemoral habitats (9020*, 9160, 9180*), which are dominated by *Ulmus* spp., *Quercus robur, Tilia cordata, Acer platanoides*, but with a significant admixture of boreal species (*Picea abies, Populus tremula*). The ground layer is covered by *Anemone* spp., *Gagea lutea, Mercurialis perennis, Corydalis* spp.

VEGETATION

Occurring plant species (Figure 52)**:**

PL: ***Betula pendula, Rubus idaeus, Frangula alnus, Calamagrostis epigejos, Betula pubescens, Molinia caerulea, Salix cinerea, Populus tremula, Brachythecium rutabulum, Lycopodium annotinum, Pinus sylvestris, Lysimachia vulgaris, Padus serotina, Vaccinium myrtillus,*** *Dryopteris carthusiana, Polytrichum formosum, Scleropodium purum, Quercus robur, Rubus caesius, R. nessensis, Pyrola rotundifolia, Carex hartmanii, C. vaginata, C. hirta, Fragaria vesca, Dicranum scoparium, Brachythecium oedipodium, Salix aurita, Artemisia vulgaris, Calamagrostis canescens, Urtica dioica, Polytrichum juniperinum, Pteridium aquilinum.*

LV: ***Fraxinus excelsior*, *Populus tremula, Picea abies, Quercus robur, Sorbus aucuparia, Tilia cordata, Ulmus glabra, Aegopodium podagraria, Anemone* spp., *Hepatica nobilis, Eurhynchium angustirete,*** *Acer platanoides, Corylus avellana, Padus avium, Asarum europaeum, Campanula latifolia, Convallaria majalis, Galium odoratum, Galeobdolon luteum, Lathyrus vernus, Oxalis acetosella, Paris quadrifolia, Stellaria holostea, Atrichum undulatum, Plagiomnium undulatum, Rhytidiadelphus triquetrus.*

DE: ***Betula pubescens, Padus serotina, Vaccinium myrtillus, Dryopteris carthusiana, Scleropodium purum,*** *Frangula alnus, Molinia caerulea, Deschampsia flexuosa, Festuca rubra, Luzula pilosa, Rubus fruticosus* agg., *Polytrichum formosum, Dicranum scoparium, Mnium hornum.*

LT: ***Betula pendula, B. pubescens, Frangula alnus, Salix cinerea, Rubus idaeus, Calamagrostis epigejos, Molinia caerulea, Lycopodium annotinum, Pinus sylvestris, Picea abies, Lysimachia vulgaris, Vaccinium myrtillus, Populus tremula,*** *Carex* spp., *C. hirta, Fragaria vesca, Calamagrostis canescens, Urtica dioica, Polytrichum juniperinum, Pteridium aquilinum.*

Table 35.

Table 35. Water level and peat properties characteristic of GEST *Moderately moist forests and shrubberies (ME/EU)*

<table>
<tr><th rowspan="3">Project sites</th><th colspan="2">Water level</th><th colspan="4">Peat properties</th></tr>
<tr><th rowspan="2">Soil moisture class (Koska et al. 2001)</th><th rowspan="2">Mean, min and max WL, cm (LIFE Peat Restore)</th><th colspan="2">pH</th><th colspan="2">C:N</th></tr>
<tr><th>Based on plant indicators</th><th>LIFE Peat Restore</th><th>Based on plant indicators</th><th>LIFE Peat Restore</th></tr>
<tr><td>PL-WB</td><td rowspan="7">2+</td><td>-36; -112; +11</td><td rowspan="5">Ac</td><td rowspan="4">nd</td><td rowspan="4">m-lm</td><td rowspan="3">nd</td></tr>
<tr><td>PL-CB</td><td>-26; -76; -5</td></tr>
<tr><td>PL-KL</td><td>nd</td></tr>
<tr><td>DE-BB-3</td><td>-95; -127; -46</td><td>22</td></tr>
<tr><td>LT-PU</td><td rowspan="3">nd</td><td>3.8–4.0</td><td>e-mr–m-lm</td><td>18-33</td></tr>
<tr><td>LV-BA</td><td rowspan="2">Sub</td><td rowspan="2">nd</td><td rowspan="2">m</td><td rowspan="2">nd</td></tr>
<tr><td>LV-AU</td></tr>
</table>

PL-WB – Wielkie Bagno, PL-CB– Ciemińskie Błota, PL-KL – Kluki (Poland); DE-BB-3 – fen near Lake Plötzensee (Biesenthaler Becken Nature Reserve, Germany), LV-BA – Baltezers Mire Nature Reserve, LV-AU – Augstroze Nature Reserve (Latvia); LT-PU – Pūsčia peatland (Lithuania).

Vegetation communities:

DE: *Rubus fruticosus-Betula pubescens* community.
PL: *Rubus fruticosus-Betula pubescens*, *Betula* sp.*-Quercus robur* communities.
LV: *Rubus fruticosus-Frangula alnus, Rubus fruticosus-Betula pubescens, Molinia caerulea-Quercus robur, Milium effusum-Alnus glutinosa-Fraxinus excelsior, Urtica dioica-Sambucus nigra-Alnus glutinosa-Fraxinus excelsior* communities.
LT: *Frangula alnus-Betula pendula* community.

Brachythecium rutabulum — *Lycopodium annotinum*

Molinia caerulea — *Betula pendula*

Figure 52. Plants occurring in GEST *Moderately moist forests and shrubberies (ME/EU)*. Photos: L. Strazdiņa (A, C, D) and L. Ķeire (B).

Relation to habitats of EU importance:

DE: 91D1 *Sphagnum* birch woods.

PL: 9190 Old acidophilous oak woods with *Quercus robur* on sandy plains.

LV: 9010 *Western Taiga, 9020 *Fennoscandian hemiboreal natural old broad-leaved deciduous forests (*Quercus*, *Tilia*, *Acer*, *Fraxinus* or *Ulmus*) rich in epiphytes, 9160 Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*, 9180 **Tilio-Acerion* forests of slopes, screes, and ravines.

LT: none.

GHG emissions*:

CO_2 emissions – 20.0 [1.0] t CO_2-eq./ha/year

CH_4 emissions – 0.0 [nd] t CO_2-eq./ha/year

GWP estimate – 20.0 [1.0] t CO_2-eq./ha/year

* Updated GEST catalogue (see *Annex 3*); extrapolated from GEST *Moderately moist (forb) meadows*; values in square brackets consider wood biomass.

LIFE Peat Restore sites: DE-BB-3, PL-WB, PL-CB, PL-KL, EE-SL, LT-PU, LT-AM, LT-AU.

27. Moist forests and shrubberies (ME/EU)

Figure 53. GEST *Moist forests and shrubberies* in (MZ/EU) Biesenthaler Becken Nature Reserve (A; Germany) and Suursoo-Leidissoo peatland (B; Estonia). Photos: C. Schulz (A) and L. Truus (B).

GENERAL DESCRIPTION

This GEST occupies the largest area (approx. 6.5 ha) of the *LIFE Peat Restore* project sites in Biesenthaler Becken NR, Germany (Figure 53, A). It occurs on fens heavily affected by drainage. *Alnus glutinosa* is dominating, partly accompanied by *Betula pubescens, Fraxinus excelsior* or *Salix cinerea*, as well as *Humulus lupulus*, *Ribes nigrum*, and *Urtica dioica* in case of BB-1, or in case of BB-2 with *Athyrium filix-femina* and *Carex acutiformis* in the bush and herb layers, accordingly. The species assemblage indicates eutrophic-rich, sub-neutral calcareous and moist conditions (Table 36).

In Suursoo-Leidissoo peatland (Figure 53, B), Estonia, this GEST spreads on most substantially drained sites, occurring in 50 to 150 m wide belts on both sides of the drainage ditches. The soil surface has subsided and the topmost part of the peat deposit is compressed, the water level is the deepest among these GESTs sites. The dense tree layer is formed by *Betula pubescens*, *Pinus sylvestris* and *Picea abies*. Surface and ground vegetation is sparse with dominating dwarf shrubs (*Vaccinium myrtillus, V. vitis-idaea*), and plants not typical for mires (*Trientalis europaea, Pyrola chlorantha, Rhytidiadelphus triquetrus, Hylocomium splendens*).

In Lithuania, this GEST (approx. 1 ha in size) was inventoried in effectively rewetted (in 2003) margins of Pūsčia peatland, which was abandoned after intensive peat mining more than 30 years ago. Forest stands (*Betula pendula*, *B. pubescens*) are up to 25 years old with a tree coverage of 50–70%. *Salix* spp. dominate in the shrub layer (coverage – 30–60%), *Phragmites australis* and *Carex* spp. are abundant in the grass layer (up to 70%). Bryophytes cover is very scarce (up to 5%).

Table 36. Water level and peat properties characteristic of GEST *Moist forests and shrubberies (ME/EU)*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
DE-BB-1	3+	-9; -29; +1	sub-alk	nd	e-mr	nd
DE-BB-2		-12; -58; +5		5.3		13
EE-SL		-24; -67; -6	sub	5.9	m-hm	20

DE-BB-1 – fen at the mouth of the *Pfauenfließ*, DE-BB-2 – fen at Lake *Hellsee* (Biesenthaler Becken Nature Reserve, Germany), EE-SL – Suursoo-Leidissoo peatland (Estonia).

VEGETATION

Occurring plant species (Figure 54)**:**

DE: ***Alnus glutinosa, Salix cinerea, Athyrium filix-femina, Urtica dioica, Carex acutiformis, Plagiomnium undulatum, Brachythecium rutabulum, Mnium hornum,*** *Fraxinus excelsior, Betula pubescens, Sorbus aucuparia, Ribes nigrum, Impatiens parviflora, Myosoton aquaticum, Galium aparine, Poa trivialis, Agrostis stolonifera, Geranium robertianum***,** *Geum rivale, Carex elongata, Cirsium oleraceum, Humulus lupulus, Plagiomnium ellipticum, Calliergonella cuspidata.*

EE: ***Pinus sylvestris, Picea abies, Betula pubescens, Vaccinium myrtillus, V. vitis-idaea***, *Betula pubescens, Vaccinium vitis-idaea*, *Trientalis europaea, Pyrola chlorantha, Pleurozium schreberi, Hylocomium splendens.*

LT: ***Salix cinerea, Phragmites australis, Betula pendula, B. pubscens, Carex* spp.**, *Frangula alnus, Salix aurita, Lythrum salicaria, Lysimachia thyrsiflora*, *Betula humilis* (red listed) etc.

PL: ***Betula pubescens, Carex acutiformis,*** *Alnus glutinosa, Betula pendula, Frangula alnus, Lysimachia thyrsiflora, Carex* spp.

Vegetation communities:

DE: *Carex remota-Alnus glutinosa-Fraxinus excelsior*, *Carex acutiformis-Salix cinerea*-communities.
EE: *Vaccinium myrtillus-Pleurozium schreberi-Hylocomium splendens*, *Vaccinium vitis-idaea-Trientalis europaea* communities.
PL: *Carex acutiformis-Betula pubescens* community.
LT: *Salix cinerea-Phragmites australis* community.

Related to habitats of EU importance:
PL and **DE** (partly, where contributing *Betula pubescens*)**:** 91D0 *Bog woodland.
EE and **LT:** none.

Alnus glutinosa

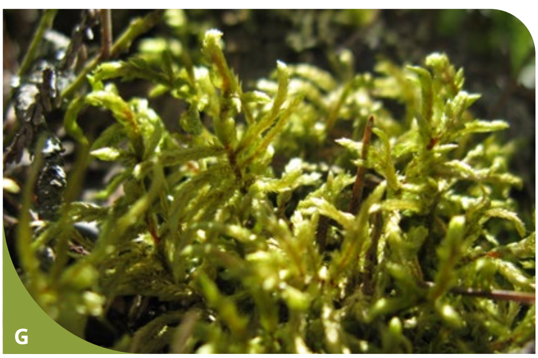
Picea abies

Stellaria nemorum

Chrysosplenium alternifolium

Filipendula ulmaria

Hylocomium splendens



Pleurozium schreberi

Plagiomnium undulatum

Figure 54. Plant species occurring in GEST *Moist forests and shrubberies (ME/EU).* Photos: L. Strazdiņa (A, F–H), L. Ķeire (B), K. Libauers (C) and M. Pakalne (D–E).

GHG emissions

Table 37.

Table 37. GHG emissions from GEST *Moist forests and shrubberies (EU/ME)*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
4.6 [21.59–24.98]	EE-SL**: 23.1	7.5 [0.00-5.35]	EE-SL**: 1.0	12.2 [21.59–30.33]	EE-SL**: 24.1
	DE-BB-2***: 35.7		DE-BB-2***: 0.4		DE-BB-2***: 36.1

* According to Updated GEST catalogue (see *Annex 3*); extrapolated from GEST *Moist reeds and (forb) meadows*; values in square brackets consider wood biomass.
** Mean of 2018–2020, modelled data. Data without tree related fluxes.
*** Measurement period 2018–2020, modelled data. Data without tree related fluxes.

LIFE Peat Restore sites: DE-BB-1, DE-BB-2, EE-SL, PL-CB, LT-PU.

28. Very moist forests and shrubberies (ME/EU)

Figure 55. GEST *Very moist forests and shrubberies* (*ME/EU)* in Biesenthaler Becken Nature Reserve (Germany, A–B) and Suursoo-Leidissoo peatland (Estonia, C–D). Photos: C. Schulz (A–B) and R. Pajula (C–D).

GENERAL DESCRIPTION

In case of Germany this GEST is represented by the second largest contribution, covering almost 5.4 ha. *Alnus glutinosa* dominates the tree layer (Figure 55, A–B). *Carex acutiformis* prevailing in the herb layer. *Lythrum salicaria* and *Scirpus sylvaticus,* as well as mosses *Calliergonella cuspidata* and *Climacium dendroides.* The species assemblage indicates very moist, eutrophic-rich, subneutral or alkaline habitat conditions (Table 38).

In Suursoo-Leidissoo peatland, Estonia, this GEST occurs at the edge of an open fen (Figure 55, C–D). The area is fed by mineral-rich groundwater, flooded in wet season and dries out in dry season. It can be natural or developed from GEST *Very moist/Wet calcareous meadows, forbs and small sedges reeds* after the cessation of management activities. *Betula pubescens, Alnus glutinosa* and solitary *Pinus sylvestris* grow in the tree layer. *Myrica gale, Frangula alnus, Salix* spp. as well as young trees of *Picea abies* growing in the shrub layer. Surface and ground vegetation is mosaic and lush, consisting of high-growing sedges (*Carex acutiformis, C. appropinquata, C. irrigua, C. nigra), Phragmites* *australis, Calamagrostis canescens*, ferns (*Dryopteris expansa, D. cristata, Thelypteris palustris*), *Potentilla palustris, Angelica sylvestris, Succisa pratensis*. *Sphagnum angustifolium, S. capillifolium, S. magellanicum, Pleusozium schreberi, Calliergon stramineum* form bryophytes cover. *Maianthemum bifolium* and *Trientalis europaea* grow on old stumps of trees.

Table 38. Water level and peat properties characteristic of GEST V*ery moist forests and shrubberies (ME/EU)*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
DE-BB-1 DE-BB-2	4+	nd	sub-alk	5.1	e-r	16
EE-SL		-9; +20; -80		5.9	e-mr	19

DE-BB-1 and DE-BB-2 – Biesenthaler Becken Nature Reserve (Germany), EE-SL – Suursoo-Leidissoo peatland (Estonia).

VEGETATION

Occurring plant species (Figure 56)**:**

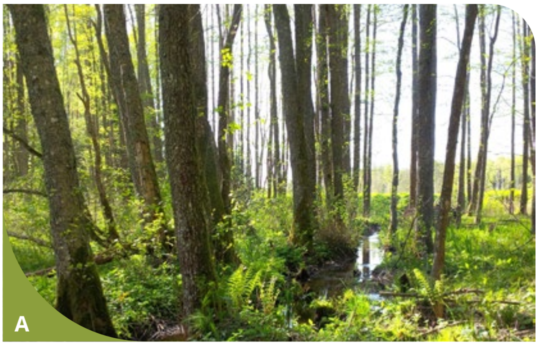
EE: ***Phragmites australis***, ***Dryopteris expansa***, ***Sphagnum angustifolium, Myrica gale, Carex acutiformis, S. magellanicum***, ***Pleurozium schreberi***, *Carex appropinquata, C. irrigua, C. nigra, Frangula alnus, Calamagrostis canescens*, *Dryopteris cristata, Thelypteris palustris*, *Potentilla palustris, Angelica sylvestris, Succisa pratensis, Maianthemum bifolium, Trientalis europaea, Sphagnum capillifolium, Calliergon stramineum*.

DE: ***Alnus glutinosa***, ***Carex acutiformis, Mnium hornum, Brachythecium rutabulum, Plagiomnium ellipticum***, *Betula pubescens, Equisetum fluviatile, Iris pseudacorus, Thelypteris palustris, Caltha palustris, Cardamine amara, Carex elongata, Carex remota, Dryopteris dilatata, Galium palustre, Lysimachia thyrsiflora, Lycopus europaeus, Mentha aquatica.*

Vegetation communities:

EE: *Carex lasiocarpa-Phragmites australis-Vaccinium oxycoccos*, *Calamagrostis canescens-Maianthemum bifolium-Trientalis europaea*, *Carex acutiformis, Dryopteris expansa* communities.

DE and **PL:** *Carex elongata-Alnus glutinosa* community (partly with *Betula pubescens*).



Alnus glutinosa

Thelypteris palustris

Calliergon stramineum

Sphagnum angustifolium

Figure 56. Plant species occurring in GEST *Very moist forests and shrubberies (ME/EU)*. Photos: L. Strazdiņa (A, C–D) and J. Sendžikaitė (B).

Relation to habitats of EU importance:
EE: 9080 *Fennoscandian deciduous swamp woods.
DE: 91D0 *Bog woodland (with contribution of *Betula pubescens*).
PL: none.

GHG emissions

Table 39. GHG emissions from GEST *Very moist forests and shrubberies (ME/EU)*

CO_2 emissions (t CO_2-eq./ha/year)		CH_4 emissions (t CO_2-eq./ha/year)		GWP estimate (t CO_2-eq./ha/year)	
Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***	Emissions/ Source*	*LIFE Peat Restore***
-0.5 [-10.72–-5.97]	-1.0	2.1 [0.81–4.27]	-0.1	1.6 [-9.91–-1.7]	-1.1

* Updated GEST catalogue (see *Annex 3*); extrapolated from GEST *Very moist meadows, forbs and small sedges reeds*; values in square brackets consider wood biomass.
** EE-SL, measurement period 2018–2020, modelled data. Data without tree-related fluxes.

LIFE Peat Restore sites: DE-BB-1, DE-BB-2, EE-SL, PL-CB.

Wet forests and shrubberies (ME/EU) 29.

Figure 57. GEST *Wet forests and shrubberies* (*ME/EU*) in Biesenthaler Becken site (A; Germany; *Sphagnum-Betula pubescens-Alnus glutinosa* community) and Ciemińskie Błota (B; Poland; *Alnus glutinosa-Salix cinerea* community). Photos: C. Schulz (A) and K. Bociąg (B).

GENERAL DESCRIPTION

This GEST occurs in a forested fen area (approx. 2 ha in size) of Biesenthaler Becken DE-BB-1 project site (Germany; Figure 57, A). *Betula pubescens*, *Pinus sylvestris* and *Alnus glutinosa* dominate in the tree layer. *Carex acutiformis* prevail in the herb layer, amongst others *Carex rostrata*, *Epilobium palustre*, *Potentilla palustris*, *Scirpus sylvaticus*, *Valeriana dioica* and *Veronica beccabunga* are also abundant. *Sphagnum fimbriatum* and *S. palustris* occur in the moss layer. The species assemblage indicates wet, mesotrophic-medium and acid conditions (Table 40).

In Słowiński National Park, Poland, the GEST *Wet forests and shrubberies (mesotrophic/ eutrophic)* occurs in the youngest, well hydrated and mesotrophic lake side part of the Ciemińskie Błota (Figure 57, B). *Alnus glutinosa* and *Salix* spp. dominate in the tree and shrub layers, *Betula pubescens* and *Pinus sylvestris* are quite abundant as well. *Salix cinerea, S. aurita* and *Myrica gale* are the dominant elements of shrubberies, *Carex* species prevail in the herb layer. *Thelypteris palustris* and *Phragmites australis* are common.

Table 40. Water level and peat properties characteristic of GEST *Wet forests and shrubberies (MZ/EU)*

Project sites	Water level		Peat properties			
	Soil moisture class (Koska *et al.* 2001)	Mean, min and max WL, cm (*LIFE Peat Restore*)	pH		C:N	
			Based on plant indicators	*LIFE Peat Restore*	Based on plant indicators	*LIFE Peat Restore*
DE-BB-1	5+	-7; -48; +10	Ac	nd	m-lm	nd
PL-CB		-9; -57; +28				

DE-BB-1 – Biesenthaler Becken Nature Reserve (Germany), PL-CB – Ciemińskie Błota (Poland).

VEGETATION

Occurring plant species (Figure 58)**:**

DE: ***Betula pubescens, Alnus glutinosa, Carex acutiformis, Thelypteris palustris, Mnium hornum, Brachythecium rutabulum,*** *Equisetum arvense, Equisetum fluviatile, Geum rivale, Lysimachia thyrsiflora, Valeriana dioica, Carex elongata, Deschampsia cespitosa, Crepis paludosa, Sphagnum fimbriatum, Sphagnum squarrosum, Calliergonella cuspidata, Plagiomnium ellipticum.*

PL: ***Salix cinerea, Salix aurita, Myrica gale, Alnus glutinosa,*** *Betula pubescens, Betula pendula, Pinus sylvestris, Frangula alnus, Carex spp., Comarum palustre, Equisetum fluviatile, Phragmites australis,Thelypteris palustris, Lysimachia vulgaris, Sphagnum squarrosum, Sphagnum palustre, Sphagnum teres, Calliergonella cuspidata.*

Carex limosa

Sphagnum teres

Figure 58. Plant species occurring in GEST W*et forests and shrubberies (ME/EU).* Photos: K. Libauers (A) and L. Strazdiņa (B).

Vegetation communities:

DE: *Sphagnum-Betula pubescens-Alnus glutinosa* community.
PL: *Alnus glutinosa-Salix cinerea*, *Myrica gale-Salix aurita*, *Carex elongata-Alnus glutinosa* communities.

Relation to habitats of EU importance:
DE: 91D0 *Bog woodland (subtype Pal. 44.A1 – *Sphagnum* birch woods).
PL: none.

GHG emissions*:
CO_2 emissions – -3.5 [-4.89] t CO_2-eq./ha/year
CH_4 emissions – 6.8 [0.04–11.46] t CO_2-eq./ha/year
GWP estimate – 3.3 [-4.85–6.57] t CO_2-eq./ha/year
* Updated GEST catalogue (see *Annex 3*); extrapolated from GEST 14. *Wet small sedges reeds mostly with moss layer*, values in square brackets consider woods.

LIFE Peat Restore sites: DE-BB-1, PL-CB.

Table 41. Summarised data on water level and peat properties characteristic of GESTs identified in *LIFE Peat Restore* project

Water level		Soil moisture class*	Water table Average, min/max, cm					Peat properties							
								pH					C:N ratio		
			EE	LV	LT	PL	DE	EE	LV	LT	PL	DE	EE	LT	DE
1		*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
OPEN PEATLAND AREAS															
1.	*Moderately moist (forb) meadows*	2+	-	-	-	-54 -138/+1	-	-	-	4.4	-	-	-	24.8	-
2.	*Moderately moist/dry bog heath* NEW	2+/2-	-	-	-	-	-	-	-	2.4	-	-	-	42.1	-
3.	*Moist reeds and (forb) meadows*	3+	-	-	-	-	-	-	-	3.2–6.4	-	-	-	57.3–98.0	-
4.	*Moist bog heath*	3+	-	-	-	-	-	-	-	3.0	-	-	-	33.2	-
5.	*Bare peat dry (oligotrophic)*	2-/3-	-	-	-52 -92/+6	-	-	-	-	4.4	-	-	-	30.4	-
6.	Bare peat moist *(oligotrophic)*	3+	-	-	-35 -64/-6	-	-	-	-	2.6–4.2	-	-	-	59.4–91.0	-
7.	*Bare peat wet*	4+(5+)	-	-	-	-	-	-	-	-	-	-	-	-	-
8.	*Very moist meadows, forbs and small sedges reeds*	4+(5+)	-	-	-	-	-	-	-	4.0–4.7	-	-	-	33.1–34.3	-
9.	*Wet meadows and forbs*	5+	-	-	-8 -32/+30	-	-	-	5.8–6.5	2.9–3.8	-	-	-	66.0–67.2	

Table 41 (continued)

Water level		**Soil moisture class***	**Water table** Average min/max, cm					**Peat properties**							
								pH					**C:N ratio**		
			EE	**LV**	**LT**	**PL**	**DE**	**EE**	**LV**	**LT**	**PL**	**DE**	**EE**	**LT**	**DE**
1		*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
OPEN PEATLAND AREAS															
10.	*Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT)* NEW	5+ 6+/4+	-8 -44/+20	-28 -47/+8	-	-	-	6.8	7.7	-	-	-	20.0	-	-
11.	*Very moist bog heath*	4+	-	-	-	-25 -76/+8	-	-	-	-	-	-	-	-	-
12.	*Very moist peat moss lawn*	4+(5+)	-	-	-	-18 -61/+6	-	-	-	-	-	-	-	-	-
13.	*Wet tall sedges reeds*	5+(4+)	-	-	-	-	-	-	-	-	-	-	-	-	-
14.	*Wet small sedges reeds mostly with moss layer*	5+(4+)	-	-	-	-6 -57/+28	-	-	-	3.0	-	-	-	74.2	-
15.	*Wet tall reeds*	5+	-	-	--	-	-	-	-	5.3–5.9	-	-	-	26.2–29.1	-
16.	*Wet peat moss lawn*	5+(4+)	-	-24 -93/-34	-	-	-	-	4.0	-	-	-	-	-	-
17.	*Peat moss lawn on former peat-cut off areas*	5+(4+)	-	-	-	-11 -61/+8	-	-	-	2.7–2.8	-	-	-	58.5–66.8	-
18.	*Wet peat moss lawn with pine trees* NEW	4+	-14 -47/+5	-	--	-	-	5.6	-	2.8–3.0	-	-	29.0	40.0–65.0	-
19.	*Wet peat moss hollows resp. flooded peat moss lawn*	5+	-	-	-	-	-	-	-	-	-	-	-	-	-
20.	*Open water/ditches*	6+	-	-	-	-	-	-	3.7– 5.1**	-	4.6– 5.0**	-	-	-	-

FORESTED PEATLANDS															
Oligotrophic peatlands															
21.	*Dry forest and shrubberies* NEW	2-/3-	-	-	-64 -115/ -20	-	-	-	-	2.9–4.5	-	-	-	38.2–49.7	-
22.	*Moderately moist forest and shrubberies*	2+	-	-	-41 -127/ +16	-32 -102/ +12	-	-	-	2.6–4.5	-	-	-	34.8–83.6	-
23.	*Moist forests and shrubberies*	3+	-	-	-33 -120/ +14	-22 -93/ -16	-	-	-	2.5-2.9	-	-	-	35.0–71.8	-
24.	*Very moist forests and shrubberies*	4+	-15 -52/ +3	-	-	-	-	5.9	-	-	-	-	29.0	-	-
Mesotrophic and eutrophic peatlands															
25.	*Dry forests and shrubberies* NEW	2-/3-	-	-	-89 -112/ -61	-	-	-	-	3.2	-	-	-	46.2	-
26.	*Moderately moist forests and shrubberies*	2+	-	-	-	-31 -94/ +3	-95 -127/ -46	-	-	3.8–4.0	-	-	-	18.2–32.7	22.3
27.	*Moist forests and shrubberies*	3+	-24 -67/-6	-	-	nd	-11 -44/ +3	5.9	-	-	-	5.3	20.0	-	12.7
28.	*Very moist forests and shrubberies*	4+	-9 -80/ +20	-	-	nd	nd	5.9	-	-	-	5.1	19.1	-	16.2
29.	*Wet forests and shrubberies*	5+	-	-	-	-9 -57/ +28	-7 -48/ +10	-	-	-	-	-	-	-	-

* Koska et al. 2001
** – water properties

Index of plant species with photographs


NABU
LITHUANIAN FUND FOR NATURE
TALLINN UNIVERSITY
UNIVERSITY OF LATVIA
KLUB PRZYRODNIKÓW