



# Handbook for Assessment of Greenhouse Gas Emissions from Peatlands

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







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### 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<sub>2</sub> change. While pristine peatlands sequester carbon, peatland degradation by drainage and land-use leads to significant CO<sub>2</sub> 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,):**

A colourless, odourless and nonpoisonous 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,-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:**

 The process of removing carbon from the atmosphere and storing it in a reservoir (peat), as a natural process in growing peatlands;
 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<sub>2</sub>-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<sub>2</sub>-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<sub>4</sub>)\*:

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<sub>2</sub> exchange between a particular ecosystem and the atmosphere – characterised by the difference between gross photosynthesis (P<sub>g</sub>, negative values) or gross primary production

#### Nitrous oxide (N,O)\*:

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
- CH₄ methane
- **CO**<sub>2</sub> carbon dioxide
- **CO**<sub>2</sub>**-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	<b>nd</b> – no data			
<b>Gt</b> – gigatons = 1 000 000 000 tons	NEE – Net Ecosystem Exchange			
GPP – gross primary production	<b>NP</b> – National Park			
GWP – Global Warming Potential	NR – Nature Reserve			
HA – Humic Acid	N <sub>2</sub> O – nitrous oxide			
IPCC – Intergovernmental Panel on Climate Change	NDC – Nationally Determined Contributions defined by the Paris Agreement			
LAI – leaf area index is one-sided green	OL – oligotrophic			
leaf area per unit ground surface area that has been developed to characterise	PAR – Photosynthetically Active Radiation			
plant canopies	<b>P</b> <sub>g</sub> – gross photosynthesis			
LIDAR – Light Detection and Ranging	R <sub>eco</sub> – ecosystem respiration			
LULUCF – Land Use, Land-Use Change and Forestry	T <sub>air</sub> – air temperature			
ME/EUT – mesotrophic/eutrophic	UNFCCC – United Nations Framework Convention on Climate Change			
<b>n/a</b> – not available	VCC Varified Carbon Standard			

- thetically Active Radiation synthesis n respiration rature ted Nations Framework 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), 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),
  - (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.

# PEATLAND-RELATED GREENHOUSE GASES AND POSSIBILITIES FOR THEIR ESTIMATION

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.

Peatland-related GHGs

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<sub>2</sub> 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<sub>2</sub> exchange correlates rather well with vascular plant cover and leaf area, a higher leaf area leads to higher CO<sub>2</sub> 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).

1.1.



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<sub>2</sub> fluxes, CH<sub>4</sub> and especially N<sub>2</sub>O fluxes are strongly related with microbial activity. With rising water levels and higher abundance in herbaceous vegetation, especially aerenchymatous shunt species, methane (CH<sub>4</sub>) 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<sub>4</sub>, environmental variables impacting the N<sub>2</sub>O fluxes are less known, but general trends reported in the scientific literature show that fertilisation of peatlands increases N<sub>2</sub>O emissions (Gong et al. 2019; Minkkinen et al. 2020). Drainage leads to deeper water levels and also increases N<sub>2</sub>O fluxes (Minkkinen et al. 2020).





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  $CH_{A}$  and  $N_{2}O$ . 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.

# 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.



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 micrometeorological 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 timeinterval 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.

hoto: R. Pajul

# Methodology of GEST approach 2.1.

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<sub>2</sub> exchange, by supplying organic matter (incl. root exudates) for CO<sub>2</sub> and CH<sub>4</sub> 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.).



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.



# Determination of the vegetation form 2.1.1.

First, a differentiation of homogeneous vegetation units, which are related to physiognomicstructural 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,





Field work for vegetation assessments in the *LIFE Peat Restore* project sites: A – Plant cover estimation in Suursoo-Leidissoo site (Estonia).  $10 \times 10$  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 <sup>2</sup>				
3- Dry	WD: 60–100 l/m <sup>2</sup>				
4- Very dry	WD: 100-140 l/m <sup>2</sup>				
5- Extremely dry	WD: >140 l/m <sup>2</sup>				

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	о-р	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 <sub>KCI</sub> <4.8							
Sub-neutral	Sub	рН <sub>ксі</sub> 4.8–6.4							
Alkaline	Alk	рН <sub>ксі</sub> >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).







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.





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.

## 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).



- Wet peat moss lawn with pine trees (ME)
- Very moist forests and shrubberies (OL)
- Very moist forests and shrubberies (EUT)
- Moist forests and shrubberies (ME)



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 *Spontaneous 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					GEST s	cenarios		
			GWP estimate, t CO <sub>2</sub>	, BASELINE		PROJECT (RESTORATION)		SPONTANEOUS SUCCESSION	
			eq./ ha/ yr*	Area, ha	Total GWP, t CO <sub>2</sub> eq./yr	Area, ha	Total GWP, t CO <sub>2</sub> eq./yr	Area, ha	Total GWP, t CO <sub>2</sub> 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).

# DIRECT GHG MEASUREMENT METHODS IN THE *LIFE PEAT RESTORE* PROJECT

3.

noto: 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*.



## GHG measurement plots Very moist/Wet calcareous meadows, forbs and small Wet peat moss lawn with

- Very moist forest and
- Very moist forests and





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.



Examples of different measurement plots in the LIFE Peat Restore project sites: A - Wielkie Figure 13. 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.).



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<sub>4</sub> and N<sub>2</sub>O 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  $R_{\text{Ero}}$  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<sub>4</sub> and N<sub>2</sub>O 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  $\pm 2$  °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<sub>2</sub>O, as well as controlling these variables for conducting more sophisticated experiments.

In the Estonian site,  $CH_{A}$  and  $N_{2}O$  were measured on the site with a separate IRGA Gasmet DX-4030 (Gasmet Technologies Inc, Vantaa, Finland). This IRGA's detection limits for CO is <10 ppm, CH<sub>4</sub> is 0.06 ppm, and  $N_2O$  is 0.02 ppm. Although this IRGA is also suitable for CO<sub>2</sub> 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O 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<sub>2</sub> concentration (detection limit 1  $\mu$ g) and an Electron Capture Detector (ECD) for analysing the N<sub>2</sub>O 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 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<sub>vasc</sub>) 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<sub>vasc</sub> 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:

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

#### Where:

- $\mathsf{LAI}_{\max}$  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<sub>vasc</sub> 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.







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<sub>vaer</sub> (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.

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

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

where:

- $F = GHG Flux [mg CO_2, CH_4 m^{-2} day^{-1} or \mu g N_2O m^{-2} day^{-1} for Eq.1; and \mu g CO_2-C, CH_4-C, N_2O-N m^{-2} h^{-1} for Eq. 2];$
- $M = molar mass of the gas [g \times mol<sup>-1</sup>];$
- P = atmospheric pressure [Pa];
- V = volume of the chamber headspace and the collar [m<sup>3</sup>];
- $\Delta c$  = 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<sup>3</sup> × 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<sub>2</sub> by photosynthesis processes, whereas positive fluxes (efflux) show an increase of CO<sub>2</sub> by respiration (Figure 16). Positive and negative fluxes can also occur for both methane and nitrous oxide. In case of CO<sub>2</sub> fluxes, gross primary production (GPP; negative) was calculated by subtracting Ecosystem Respiration (R<sub>eco</sub>; positive) from the NEE (can be positive or negative; NEE= P<sub>g</sub> + R<sub>eco</sub>; P<sub>g</sub>=NEE-R<sub>eco</sub>; 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:





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



Figure 17. Ca

Calculated  $\rm CO_2$  fluxes in Suursoo-Leidissoo in 2019 fulfilling the flux quality criteria.

variation of PAR during the flux measurement should not be more than  $\pm 15\%$ , inside temperature of the chamber should not vary more than  $\pm 5^{\circ}$ C and the determination coefficient (R<sup>2</sup>) of the measured flux at least 0.9. Very low fluxes ( $\pm 0.2$  ppm s<sup>-1</sup>) were accepted regardless of their R<sup>2</sup> 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<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>), 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  $T_{Soll}/T_{Air}$ , because of different availability of data or because of a better model fitting result.

$$R_{eco} = R_{ref} \times exp \left(E_{0} \times \left(\left(\frac{1}{T_{ref} - T_{0}}\right)\right) - \left(\frac{1}{T_{Soil/Air} - T_{0}}\right)\right) \quad (Eq. 4)$$

where:

 $R_{ero}$  = Ecosystem Respiration [g CO<sub>2</sub>-C × m<sup>-2</sup> × h<sup>-1</sup>];

R<sub>ref</sub> = respiration rate at reference temperature;

 $E_0$  = activation energy [K];

T<sub>ref</sub> = reference temperature; 283.15 [K];

 $T_0$  = temperature, where biological processes are possible; 227.13 [K];  $T_{Soil/Air}$  = soil or air temperature [K].

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

#### where:

 $r_0$  is the respiration rate (mg CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>) 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<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>) the non-linear model was parameterized based on the saturating response to PAR and in Estonia also taking into account the changes in LAI<sub>vasc</sub> 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.

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

where:

 $P_g$  = Gross Primary Production [µmol CO<sub>2</sub> \* m<sup>-2</sup> \* s<sup>-1</sup>];  $P_{gmax}$  = maximum gross primary production at full light; alpha = initial quantum yield; PPFD = Photosynthetic photon flux density.

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

Where:

 $P_{max}$  is the maximum hourly  $P_g$  at light saturation (mg CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>); k is the PAR value, when  $P_g$  reaches half its maximum (µmol m<sup>-2</sup> s<sup>-1</sup>); s is the value of LAI<sub>vasc</sub> (m<sup>2</sup> m<sup>-2</sup>) 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<sub>4</sub> values against GWL, and N<sub>2</sub>O 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.





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):

$$E_r = \sqrt{\sum_{i=1}^{n} \frac{(F_{obs} - F_{mod})^2}{(n-1) \times n}}$$
 (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:

$$E_{r} = \sqrt{E_{r(P_{g})}^{2} + E_{r(R_{ECO})}^{2}}$$
(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.



# 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 (continued)



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) <sup>NEW</sup>	-	-	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) <sup>NEW</sup>	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		
	FORES	TED PEA	TLANDS						
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) a	nd eutro	ophic (El	JT) peat	lands				
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		

State of peatlands in 2018:

\* - damaged by draining,

29. Wet forests and shrubberies

\*\* - severely damaged by draining and/or destroyed by peat extraction

36.4

2.0

38.4

# **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 sedgebrown 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 (Amalva peatland, Lithuania).



Management area and GWP reduction in t  $CO_2$ -eq/ha/yr on *LIFE Peat Restore* project areas. State of peatlands in 2018:



\*\* - severely damaged by draining and/or destroyed by peat extraction.



Summarised GWP for *Baseline* and *Project (restoration) scenarios* given in t CO<sub>2</sub>-eq/ha/yr and all project sites, calculation for management area

	Project	Mana- gement area, ha	GEST GWF scena t CO <sub>2</sub> -eq	P balance prios, j./ha/yr	GWP reduction in project	GWP reduction per 1 ha in
Project site	area, ha		Baseline	Project (Resto- ration)	area, t CO <sub>2</sub> -eq./ ha/yr	manage- ment area, t CO <sub>2</sub> -eq./ ha/yr
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.

Figure 19.

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<sub>2</sub>-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 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<sub>2</sub> reduction is expected in Kluki site (1158.3 t CO,-eq./yr), a little lower – from Wielkie Bagno (914.0 t CO,-eq./yr) and significantly lower from Ciemińskie Błota (220.4 t CO<sub>2</sub>-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 *Postrestoration scenario* GHG emission sequestration would almost double as the main emissions caused by drainage would have been significantly decreased (*Table 6*).

### Results of direct measurements and comparison with the Updated GEST catalogue

4.2.

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 <sub>2</sub> (t CO <sub>2</sub> -eq./ ha/yr)	CH₄ (t CO₂ -eq./ ha/yr)	N <sub>2</sub> O (t CO <sub>2</sub> -eq./ ha/yr)	Total emission (t/CO <sub>2</sub> -eq./ ha/yr)
				2018	-3.3	0.3	0.0	-3.0
	10.	Very moist/Wet calcareous meadows, forbs and small sedges reeds (FUT) New	2019	1.8	0.9	0.0	2.7	
	EE-SU		Scuges recus (201)	2020	1.5	0.1	0.0	1.6
				2018	1.1	0.0	0.0	1.1
		18.	Wet peat moss lawn with pine trees <sup>NEW</sup>	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
		24.		2019	-0.9	2.3	-0.0	1.4
				2020	-11.2	0.3	-0.0	-10.9
				2018	27.1	0.1	0.0	27.2
		27.	Moist forests and shrubberies (ME/EUT)	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
		28.		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

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T-AM	22.	Moderately moist forest and shrubberies (OL)	2019	49.3	-0.2	0.1	49.2
T-PU	6.	Bare peat moist (OL)	2019**	14.4	1.4	0.1	15.9
)E-BB		27. Moist forests and shrubberies (ME/EUT)	2018	38.4	0.63	2.6	41.6
	27.		2019	36.4	0.38	5.0	41.8
			2020	32.3	0.2	3.4	35.9
	11.	11. Very moist bog heath	2018	-1.7	0.07	1.1	-0.5
L-WB			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

Table 7 (continued)

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**<sub>2</sub>**O** emissions were very small in most of the studied GESTs. N<sub>2</sub>O fluxes were closely related to nitrogen deposition (Leip *et al.* 2011) – being lowest in Estonia and increased towards Western Europe. N<sub>2</sub>O emissions were highest in the Biesenthaler Becken project site in Germany. Addition of nitrogen to peatlands, through atmospheric deposition or fertilisation, increases N<sub>2</sub>O emissions (Gong *et al.* 2019). The N<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub> and CH<sub>4</sub> 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.

			GWP (t CO <sub>2</sub> -eq./ha/yr)		
	GESTS	Site	Catalogue, data with trees	Catalogue, data without trees	LIFE Peat Restore direct measurements reconstructed
5.	Bare peat dry (OL) <sup>NEW</sup>	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) <sup>NEW</sup>	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	-9.91.7	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<sub>2</sub> emissions (Fenner & Freeman, 2011; Lund et al. 2012; Purre et al. 2019, Koebsch et al. 2020) and decrease CH, 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<sub>2</sub> 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<sub>2</sub> 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%.



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 <sup>NEW</sup>.

				GHG emission data			
GESTs		Area (ha)	In the Updated GEST catalogue (t CO <sub>2</sub> -eq./ha/ yr)	Modelled from measurements, means of three year (2018–2020) data (t CO <sub>2</sub> -eq./ha/ yr)	In the Updated GEST Catalogue (t CO <sub>2</sub> -eq./per site area/yr)	Measurements (transparent chamber), reconstructed	
	10.	Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT) <sup>NEW</sup>	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.

# Benefits and drawbacks of direct measurements and GEST approach



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.

4.3.

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 recom- mended: 1. automatic water level loggers or 2. manually.		
Other ecologi- cal parameters	Air and peat temperatures, PAR, LAI or vegetation height.	Peat depth, peat properties (pH, C:N ratio), timber volume assess- ment (in forested GEST units).		
Measured GHGs	$CO_{2^{\prime}}$ $CH_4$ , $N_2O$ and other gases if deemed necessary.	CO <sub>2</sub> , CH <sub>4</sub>		
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 vege- tation reflects environmental pa- rameters 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 through- out the year) on the basis of at least 3-year measurements. The sufficient spatial fre- quency 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 adapt- ed to wetter conditions.		
Skills	Specific equipment for measurements, scientific knowledge and general geobotanical education needed.	Vegetation and habitat investiga- tions experience as well as spatial assessment (mapping) skills re- quired.		
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.

# CHALLENGES AND 5. SOLUTIONS


# 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*.

# 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.

# 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.

# 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<sub>2</sub> 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).

# CONCLUSIONS AND RECOMMENDATIONS





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.*).

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.

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.).

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.*).

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.

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.

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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*.

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.

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.

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.*).

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ANNEX 1

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

#### Equation 1: $C = [V \times D \times BEF] \times (1+R) \times CF$

- 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]



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		1.3 (1.15–4.2)	1.15 (1-1.3)
Pine	0-12.5	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	raxinus excelsior		0.60
Populus	Populus spp. Pinus sylvestris		0.38
Pinus			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**:  $C = [V \times D_s + V \times (BEF-1) \times D_h] \times (1+R) \times CF$ 

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	
	<50	0.46	±0.21	
Conifer forest/ Plantation	50-150	0.32	±0.08	
	>150	0.23	±0.09	
Oak forest	>75	0.35	±0.25	
	<75	0.43	±0.24	
Other broadleaf forest	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		8.4	
	Growing season (May-October) average temperature (°C)	13.7	nd	14.5	nd
	Annual precipitation (mm)		nu	610	nu
	Growing season (May–October) precipitation (mm)	373		347	

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Site	Variable	Long- term	2018	2019	2020
LV-EN	Annual average temperature (°C)	5.7		8.3	
	Growing season (May–October) average temperature (°C)	13.7		13.8	
	Annual precipitation (mm)	13.7	na	552	na
	Growing season (May–October) precipitation (mm)	600		349	
LV-AU	Annual average temperature (°C)	6.5		8.0	
	Growing season (May–October) average temperature (°C)	13.6		13.8	
	Annual precipitation (mm)	743	na	814	na
	Growing season (May–October) precipitation (mm)	470		525	
LT-AU	Annual average temperature (°C)	8.2		10.2	
	Growing season (May–October) average temperature (°C)	13.9		16.1	
	Annual precipitation (mm)	733	na	683	na
	Growing season (May–October) precipitation (mm)	508		448	
LT-AM	Annual average temperature (°C)	9.4		9.1	
	Growing season (May–October) average temperature (°C)	16.2		15.3	
	Annual precipitation (mm)	650	na	398	na
	Growing season (May-October) precipitation (mm)	433		221	
LT-PU	Annual average temperature (°C)	9.4		7.9	
	Growing season (May–October) average temperature (°C)	16.2		14.1	
	Annual precipitation (mm)	650	na	625.5	na
	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)

<b>GEST /</b> Corresponding vegetation form	Occuring plant species		
OPEN PEATLANDS			
<ul> <li><b>1. Moderately moist (forb) meadows</b></li> <li>Cirsium oleraceum-Arrhenatherum elatius-community</li> <li>Molinia caerulea-Daucus carota-Deschampsia cespitosa- community</li> <li>Cirsium oleraceum-Urtica dioica-community</li> <li>Phragmites australis-Aegopodium podagraria-Urtica diocia- community</li> <li>Juncus effusus-Deschampsia cespitosa- community</li> <li>Pteridium aquilinum-Molinia caerulea-community</li> <li>Molinia caerulea-community</li> </ul>	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	<b>Calluna vulgaris, Pleurozium schreberii,</b> 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		
<b>4. Moist bog heath</b> Calluna vulgaris-community Calluna vulgaris-Molinia caerulea-community	<b>Calluna vulgaris, Eriophorum vaginatum,</b> 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<sub>2</sub>/CH<sub>4</sub> emissions/GWP" – Values used in *LIFE Peat Restore* 

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

[Value] in columns "CO<sub>2</sub>/CH<sub>4</sub> emissions/GWP" – Data considering wood biomass

(Value) in columns "CO<sub>2</sub>/CH<sub>4</sub> emissions/GWP" – Accord. to Reichelt 2015

Water level	CO <sub>2</sub> emissions (t CO <sub>2</sub> -eq./ ha/year)	CH₄ emissions (t CO₂-eq./ ha/year)	GWP estimate (t CO <sub>2</sub> eq./ ha/year)	Aim/Remarks	References
2+	20.0	0.0	20.0	Gapfilling Extrapolated from GEST Moderately moist grassland	Couwenberg <i>et al.</i> 2011
2+/2-	nd	nd	nd	Gapfilling New GEST (suggested to use a bit higher values as for the GEST <i>Moist bog heath</i> )	No references
3+	<b>4.6</b> (-2.8)	<b>7.5</b> (0.0)	<b>12.2</b> (3.0)	Calibration	Koch <i>et al.</i> 2014 Fortuniak <i>et al.</i> 2017 Wilson <i>et al.</i> 2016
3+	<b>9.4</b> (12.3)	<b>0</b> (0.2)	<b>9.4</b> (12.5)	Calibration	Drösler <i>et al.</i> 2013
2-/3-	7.0	0.4	7.5		Maljanen <i>et al.</i> 2010 Couwenberg <i>et al.</i> 2011

<b>GEST /</b> 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
<b>10. Very moist/Wet calcareous meadows,</b> <b>forbs and small sedges reeds (eutrophic)</b> 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 <sub>2</sub> emissions (t CO <sub>2</sub> -eq./ ha/year)	CH₄ emissions (t CO₂-eq./ ha/year)	GWP estimate (t CO <sub>2</sub> eq./ ha/year)	Aim/Remarks	References
3+	<b>6.2</b> (9.0)	<b>0.0</b> (0.0)	<b>6.2</b> (9.0)	Calibration	Vanselow-Algan <i>et al.</i> 2015 Wilson <i>et al.</i> 2009 Wilson <i>et al.</i> 2016
4+ (5+)	<b>1.5</b> (1.3)	<b>0.1</b> (0.2)	<b>1.6</b> (1.5)	No target GEST	Bortoluzzi <i>et al.</i> 2006 Wilson <i>et al.</i> 2016
4+ (5+)	<b>-0.5</b> (12.6)	<b>2.3</b> (0.3)	<b>1.9</b> (13.0)	Calibration	Tauchnitz <i>et al.</i> 2008 Audet <i>et al.</i> 2013 Drösler <i>et al.</i> 2013 Rinne <i>et al.</i> 2007
5+	<b>±0.0</b> (-3.9)	<mark>5.8</mark> (7.4)	<mark>5.8</mark> (3.5)	Gapfilling/Calibration Extrapolated from rewetted grassland	Audet <i>et al.</i> 2013
4+/5+	2.4	0.5	2.9	Gapfilling New GEST	Drösler <i>et al.</i> 2013

#### Annex 3 (continued)

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

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

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Annex 3 (continued)
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<b>GEST /</b> Corresponding vegetation form	Occuring plant species
<b>16. Wet peat moss lawn</b> 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 sppcommunity	<b>Sphagnum spp., Sphagnum cuspidatum,</b> S. fallax, Eriophorum vaginatum, E. angustifolium, Molinea
Eriophorum angustifolium-Calla palustris-Sphagnum spp community	caerulea, Dicranella cerviculata, Phragmites australis, Carex rostrata
Eriophorum angustifolium-Molinia caerulea-Sphagnum spp community	
Eriophorum angustifolium-Rynchospora alba-Molinia caerulea-Sphagnum cuspidatum-community	
<b>18. Wet peat moss lawn with pine trees NEW</b> Pinus sylvestris-Sphagnum magellanicum-community	<b>Pinus sylvestris, Sphagnum</b> <b>magellanicum, sphagnum spp.</b> <b>S. rubellum, S. medii,</b> Eriophorum vaginatum, Rhododendron tomentosum (syn. Ledum palustre), Calluna vulgaris, Menyanthes trifoliata, Vaccinium uliginosum, Sphagnum fallax
<b>19. Wet peat moss hollows resp. flooded peat moss lawn</b> Sphagnum cuspidatum-Carex limosa-community Sphagnum recurvum-Carex limosa-community	<b>Sphagnum cuspidatum</b> , 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 <sub>2</sub> emissions (t CO <sub>2</sub> -eq./ ha/year)	CH <sub>4</sub> emissions (t CO <sub>2</sub> -eq./ ha/year)	GWP estimate (t CO <sub>2</sub> eq./ ha/year)	Aim/Remarks	References
5+ (4+)	<b>-0.5</b> (-3.0)	<b>0.3</b> (5.3)	<b>-0.3</b> (2.0)	Calibration	Drösler 2013, 3 sites
5+ (4+)	<b>1.5</b> (2.8)	<b>0.4</b> (37.3)	<b>1.9</b> (40)	Calibration	Drösler 2005 Drösler <i>et al.</i> 2013 Bortoluzzi <i>et al.</i> 2006
4+	3.9	0.2	4.1	Gapfilling/Calibration New GEST Data without woods	Drösler <i>et al.</i> 2013
5+	<b>-3.1</b> (-4.6)	<b>12.0</b> (11.8)	<b>8.9</b> (7)	Calibration	Drösler 2005 Drösler 2013, 2 sites Vanselow-Algan <i>et al.</i> 2015
6+	<b>nd</b> (+-0)	<b>2.8</b> (3.2)	<b>nd</b> (3.0)	Gapfilling	Van den Pol-van Dasselaar <i>et al.</i> 1999, 3 sites

Annex 3 (continued)

<b>GEST /</b> Corresponding vegetation form	Occuring plant species		
FORESTED PEATLANDS Oligotrophic peatlands			
<b>21. Dry forest and shrubberies NEW</b> Picea abies (planted)-community	<b>Picea abies,</b> 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		
<b>22. Moderately moist forest and shrubberies</b> 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		
<b>23. Moist forests and shrubberies</b> 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		
<b>24. Very moist forests and shrubberies</b> Eriophorum vaginatum-Betula pubescens-community Eriophorum vaginatum-Pinus sylvestris-community	<b>Eriophorum vaginatum, Betula pubescens,</b> Pinus sylvestris, Empetrum nigrum, Rhododendron tomentosum (syn. Ledum palustre), Myrica gale, Sphagnum spp.		
Mesotrophic and eutrophic peatlands			
<b>25. Dry forests and shrubberies NEW</b> Picea abies (planted)-community Alnus glutinosa (planted)-community	<b>Populus tremula</b> , 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 <sub>2</sub> emissions (t CO <sub>2</sub> -eq./ ha/year)	CH₄ emissions (t CO₂-eq./ ha/year)	GWP estimate (t CO <sub>2</sub> eq./ ha/year)	Aim/Remarks	References
2-/3-	26.02	0.0	26.0	Gapfilling New GEST Data without woods extrapolated from <i>Picea</i> abies stands in temperate Germany, no peat	Matteucci <i>et al.</i> 2000
2+	<b>20.0</b> [-3.1]	<b>0.0</b> [-0.11]	<b>20.0</b> [-3.22]	<b>Gapfilling</b> <b>Data without woods</b> extrapolated from GEST <i>Moderately Moist (forb)</i> <i>meadows</i> [Data with woods]	Ojanen <i>et al.</i> 2014, 2 sites Meyer <i>et al.</i> 2013 calculated for <i>Picea</i> <i>abies</i> stands
3+	<b>9.4</b> [-2.2]	<b>0.0</b> [-1.8]	<b>9.4</b> [-4.0]	Gapfilling Data without woods extrapolated from GEST <i>Moist bog heath</i> [Data with woods]	Ojanen <i>et al.</i> 2014, 2 sites Hommeltenberg <i>et al.</i> 2014 (similar vegetation but different water level)
4+	<b>1.7</b> [-2.3]	<b>3.0</b> [1.75]	<b>4.7</b> [-0.55]	Calibration Data without woods extrapolated from GEST Very moist bog heath [Data with woods]	Hommeltenberg <i>et al.</i> 2014
2-/3-	43.4	0.0	43.4	Gapfilling New GEST Data without woods extrapolated from deciduous forests in Wisconsin	Bolstad <i>et al.</i> 2004

26. Moderately moist forests and shrubberies Rubus fruticosus-Frangula alnus-community	species
Rubus fruticosus-Frangula alnus-community Frangula alnus, Calamag	bus ida
Rubus fruticosus-Betula pubescens-communityBetula pubescens, Molinea a cinerea, Populus tremula, B rutabulum, Lycopodium annot sylvestris, Lysimachia vulgaris, 	rostis caeruled rachythe inum, Pin Padus so hum forr n myrtillu tundifolic caria vesc achythec isia vulgo chirta, Uu dium aqu

#### 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

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

Rubus idaeus, agrostis epigejos, a caerulea, Salix Brachythecium otinum, Pinus r**is,** Padus serotina, richum formosum, ium myrtillus, Quercus rotundifolia, Carex agaria vesca, Dicranum Brachvthecium emisia vulgaris, rex hirta, Urtica dioica, ridium aquilinum

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

Alnus glutinosa, Carex acutiformis, Betula pubescens. Sphagnum sauarrosum. 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 <sub>2</sub> emissions (t CO <sub>2</sub> -eq./ ha/year)	CH <sub>4</sub> emissions (t CO <sub>2</sub> -eq./ ha/year)	GWP estimate (t CO <sub>2</sub> eq./ ha/year)	Aim/Remarks	References
2+	<b>20.0</b> [1.0]	<b>0.0</b> [nd]	<b>20.0</b> [1.0]	Gapfilling Data without woods extrapolated from GEST Moderately moist (forb) meadows [Data with woods]	Ojanen <i>et al.</i> 2014
3+	<b>4.6</b> [21.59- 24.98]	<b>7.5</b> [0.004- 5.35]	<b>12.2</b> [21.59- 30.33]	<b>Gapfilling</b> <b>Data without woods</b> extrapolated from GEST <i>Moist reeds and (forb)</i> <i>meadows</i> [Data with woods]	Schäfer & Joosten 2005
4+	<b>-0.5</b> [-10.72- -5.97]	<b>2.1</b> [0.81- 4.27]	<b>1.6</b> [-9.91- -1.7]	<b>Gapfilling</b> <b>Data without woods</b> extrapolated from GEST Very moist meadows, forbs and small sedges reeds [Data with woods]	Schäfer & Joosten 2005

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Annex 3 (continued)
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<b>GEST /</b> 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-Salix pentandra-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 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 <i>LIFE Peat Restore</i> 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 australia			
community			
schoenopiectus lacustris-Priragmites 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-			

Water level	CO <sub>2</sub> emissions (t CO <sub>2</sub> -eq./ ha/year)	CH₄ emissions (t CO₂-eq./ ha/year)	GWP estimate (t CO <sub>2</sub> eq./ ha/year)	Aim/Remarks	References
5+	-3.5 [-4.89]	<b>6.8</b> [0.04- 11.46]	<b>3.3</b> [-4.85- 6.57]	<b>No Target GEST</b> <b>Data without woods</b> extrapolated from GEST Wet small sedges reeds mostly with moss layer [Data with woods]	Schäfer & Joosten 2005
5+ (4+)	<b>3.1</b> (0.0)	<b>21.6</b> (17.8)	<b>24.7</b> (18.0)	Calibration	Vanselow-Algan <i>et al.</i> 2015
4+	<b>0.5</b> (10.7)	<b>6.9</b> (1.6)	<b>7.4</b> (12.5)	No target GEST	Sommer <i>et al.</i> 2004, 2 sites Günther <i>et al.</i> 2014, 2 sites Drösler <i>et al.</i> 2013
6+/5+	<b>1.2</b> (-1.1)	<b>14.6</b> (6.8)	<b>15.8</b> (5.5)	No target GEST	Günther <i>et al.</i> 2014 Minke <i>et al.</i> 2015, 3 sites
5+/6+	<b>-15.7</b> (-12.4)	<b>13.0</b> (12.4)	<b>-2.7</b> (0.0)	No target GEST	Minke <i>et al.</i> 2015
6+	<b>-2.9</b> (2.4)	<b>37.0</b> (40.9)	<b>34.0</b> (43.5)	No target GEST	Gelbrecht <i>et al.</i> 2008 Drösler <i>et al.</i> 2013, 2 sites
6+	<b>-32.8</b> (-32.7)	<b>33.6</b> (26.2)	<b>0.8</b> (-6.5)	No target GEST	Minke <i>et al.</i> 2015

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# 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) <sup>NEW</sup>
- 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 NEW26. Moderately moist forests and shrubberies27. Moist Forests and shrubberies28. 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 mesotrophicmedium 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

Proje		Wa	ter level	Peat properties			
	Project sites	Soil moisture	Mean, min and max WL, cm ( <i>LIFE Peat Restore</i> )	рН		C:N	
		class (Koska <i>et al.</i> 2001)		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

Calamagrostis epigejos





Deschampsia cespitosa



Rubus caesius

Aegopodium podagraria

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.

Juncus effusus

**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 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	Wa	ter level	Peat properties			
	Soil moisture class (Koska <i>et al.</i> 2001)	Mean, min and max WL, cm ( <i>LIFE Peat Restore</i> )	рН		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)





Dicranum polysetum



Vaccinium vitis-idaea



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	Wa	ter level	Peat properties			
	Soil moisture	Mean, min and max WL, cm ( <i>LIFE Peat Restore</i> )	рН		C:N	
	class (Koska <i>et al.</i> 2001)		Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
DE-BB-1	- 3+		Sub-Alk	nd	e-r	nd
LT-PU		nd	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



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

#### Moist bog heath 4.



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 oligotrophicpoor 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%.



Water level and peat properties characteristic of GEST Moist bog heath

Project sites	Wa	ter level	Peat properties			
	Soil moisture class (Koska <i>et al.</i> 2001)	Mean, min and max WL, cm ( <i>LIFE Peat Restore</i> )	рН		C:N	
			Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
LT-PU	3+	nd	Ac	3.0	о-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







Polytrichum strictum

Betula sp.



Rhododendron tomentosum

(syn. *Ledum palustre*)





Drosera rotundifolia

Campylopus introflexus – alien species



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.



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).



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

	Wa	ter level	Peat properties			
Project sites	Soil moisture class (Koska <i>et al.</i> 2001)	Mean, min and max WL, cm ( <i>LIFE Peat Restore</i> )	рН		C:N	
			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-lm	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

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. GH

GHG emissions from GEST Bare peat dry (OL)

CO <sub>2</sub> emissions		CH <sub>4</sub> em	nissions	GWP e	stimate
(t CO <sub>2</sub> -eq./ha/year)		(t CO <sub>2</sub> -eq	./ha/year)	(t CO <sub>2</sub> -eq	./ha/year)
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat
Source*	Restore**	Source*	Restore**	Source*	Restore**
7.0	16.7	0.4	11.5	7.5	

\* Updated GEST catalogue (see Annex 3).

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

LIFE Peat Restore site: LT-AU.







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)

	Water level		Peat properties				
Project sites	Soil moisture	Mean, min and	pH C:N				
5105	class (Koska <i>et al.</i> 2001)	max WL, cm ( <i>LIFE Peat Restore</i> )	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore	
PL-WB		nd	Ac	nd	- o-vp	nd	
LT-SA	2,	-35, -64, -6		2.7		66-85	
LT-PL	3+	ad		2.6		91	
LT-PU		na		2.6-4.2		59-72	

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 Dr

Drosera intermedia





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)

UIII GEST DUIE	peul moist (OL)

CO <sub>2</sub> emissions		CH <sub>4</sub> em	issions	GWP es	stimate
(t CO <sub>2</sub> -eq./ha/year)		(t CO <sub>2</sub> -eq.	/ha/year)	(t CO <sub>2</sub> -eq.	/ha/year)
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat
Source*	Restore**	Source*	Restore**	Source*	Restore**
6.2 (9.0)	14.4	0.0 (0.0)	1.4	6.2 (9.0)	

\* 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)





*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*.



Water level and peat properties characteristic of GEST Bare peat wet (OL)

	Water level		Peat properties			
Project sites	Soil moisture class (Koska <i>et al.</i> 2001)	Mean, min and	pH C:N			
		max WL, cm ( <i>LIFE Peat Restore</i> )	Based on plant indicators	Based on plant LIFE Peat indicators 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



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



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

	Wa	ter level	Peat properties			
Project sites	Soil moisture	Mean, min and	рН	C:N		
	class (Koska <i>et al.</i> 2001)	max WL, cm ( <i>LIFE Peat Restore</i> )	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
LT-PU	4+(5+)		Ac	4.0-4.7	о-р	33-34
DE-BB-1	4+	na	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 Iasiocarpa, 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 acutiformis



Carex lasiocarpa

Carex nigra







Carex pseudocyperus

Lythrum salicaria

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.

Equisetum fluviatile

#### Relation to habitats of EU importance:

**LT** and **LV:** 7140 Transition mires and quaking bogs. **DE:** none.

#### **GHG emissions\***:

Figure 16.

 $CO_2$  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 subneutral (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

	Wa	ter level	Peat properties			
Project sites	Soil moisture class (Koska <i>et al.</i> 2001)	Mean, min and	рН		C:N	
		max WL, cm ( <i>LIFE Peat Restore</i> )	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
LV-BA	E+	nd	Sub-Alk	5.8-6.5	nd	nd
LT-PU*	T	-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.



Rhynchospora alba



Trichophorum alpinum





Sphagnum warnstorfii

Vaccinium oxycoccos







Dactylorhiza cruenta

Dactylorhiza maculata







Platanthera chlorantha

Eriophorum latifolium



Scorpidium scorpioides





Preissia quadrata



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 e

GHG emissions from GEST Wet meadows and forbs

CO <sub>2</sub> emissions		emissions CH <sub>4</sub> emissions		GWP estimate		
(t CO <sub>2</sub> -eq./ha/year)		eq./ha/year) (t CO <sub>2</sub> -eq./ha/year)		(t CO <sub>2</sub> -eq./ha/year)		
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat	
Source*	Restore**	Source*	Restore**	Source*	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





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* 

	Wa	ter level		Peat pr	operties	
Project sites	Soil moisture class (Koska <i>et al.</i> 2001)	Mean, min and	рН		C:N	
		max WL, cm ( <i>LIFE Peat Restore</i> )	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
EE-SU	5+	-8, -44, +20	Alle	6.8	m-hm	20
LV-EN	6+/4+	-28, -47, +8	AIK	7.7	m-lm	nd

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





Scorpidium scorpioides

Cladium mariscus



Myrica gale





Primula farinosa

Pedicularis palustris





Fissidens adianthoides

Drepanocladus revolvens



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 <sub>2</sub> emissions (t CO <sub>2</sub> -eq./ha/year) Emissions/ Source* <i>LIFE Peat</i> <i>Restore**</i>		CH <sub>4</sub> emissions (t CO <sub>2</sub> -eq./ha/year)		GWP estimate (t CO <sub>2</sub> -eq./ha/year)	
		Emissions/ Source*	LIFE Peat Restore**	Emissions/ Source*	LIFE Peat Restore**
2.4	EE-SL**: 0.0	0.5	EE-SL**: 0.4	2.0	EE-SL**: 0.4
2.4	LV-EN***: 3.4	0.5	LV-EN***: 2.7	2.9	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

		Water level		Peat properties				
	Project sites Class (Koska <i>et al.</i> 2001)	Soil moisture	Mean, min and max WL, cm ( <i>LIFE Peat Restore</i> )	рН	C:N			
		et al. 2001)		Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore	
	PL-CB PL-WB	-14, -57, +15	A	a d		a d		
		4+	-35,-94, +1*	AC	na	о-vp	na	

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





Vaccinium oxycoccos







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:



GHG emissions from GEST Very moist bog heath

CO <sub>2</sub> emissions		sions CH <sub>4</sub> emissions			GWP estimate		
(t CO <sub>2</sub> -eq./ha/year)		a/year) (t CO <sub>2</sub> -eq./ha/year)			(t CO <sub>2</sub> -eq./ha/year)		
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat		
Source*	Restore**	Source*	Restore**	Source*	Restore**		
1.7 (4.7)	-1.8	3.0 (0.9)	0.03	4.6 (5.5)			

\* 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

	Peat pro	operties			
Soil moisture class (Koska <i>et al.</i> 2001)	Project sites: Mean, min ai	nd max WL, cm ( <i>LIF</i>	E Peat Restore)	рН	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)



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



*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.

Figure 25.

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

Wate	er level		Peat pro	operties	
Soil moisture	Mean, min and	р	Н	C:N	
class (Koska <i>et al.</i> 2001)	max water level by <i>LIFE Peat</i> <i>Restore</i> , 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.* 





Phragmites australis

Alnus glutinosa





Calliergonella cuspidata

Sphagnum squarrosum

Figure 26. Plant specie L. Strazdina

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.



# 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

Project sites	Water level		Peat properties			
	Soil moisture	Mean, min and	рН		C:N	
	class (Koska et al. 2001)	max WL, cm (LIFE Peat Restore)	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
LT-SA	4+/5+	nd	A -	3.0	o-vp	74
PL-CB		-6, -57, +28	AC	nd	о-р	nd

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 cuspidatum



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.



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 mesotrophicrather 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			
	Soil moisture	Mean, min and	рН		C:N	
	class (Koska et al. 2001)	(LIFE Peat Restore)	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
LT-AU	- 5+	_	Cub	5.3		29
LT-PU		na	Sub	5.9	i m-im	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



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.





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<sup>2</sup> (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

	Wa	ter level		Peat properties		
Project sites	Soil moisture class (Koska <i>et al.</i> 2001)	Mean, min and max WL, cm ( <i>LIFE Peat Restore</i> )	рН		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).





Chamaedaphne calyculata



Sphagnum rubellum and S. fuscum



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 <sub>2</sub> emissions		CH <sub>4</sub> em	nissions	GWP estimate		
(t CO <sub>2</sub> -eq./ha/year)		(t CO <sub>2</sub> -eq	./ha/year)	(t CO <sub>2</sub> -eq./ha/year)		
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat	
Source*	Restore**	Source*	Restore**	Source*	Restore**	
-0.5 (-3.0)	7.1	0.3 (5.3)	5.1	-0.3 (2.0)		

\* 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* 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* 

	Water level		Peat properties				
Project sites	Soil moisture class (Koska <i>et al.</i> 2001)	Mean, min and	рН		C:N		
0.000		max WL, cm (LIFE Peat Restore)	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore	
LT-PL		nd		2.7-2.8	o-vp	59–67	
LT-SA	E . (4)	nd	Ac	2.8		64	
PL-CB	- 5+/4+	-11, -74, +4		nd		nd	
PL-WB		-10, -47, +11		nd		nd	

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.



#### **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.



### Wet peat moss lawn with pine trees <sup>N</sup>



Figure 35.

Wet peat moss lawn with pine trees 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 vulgaris) 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%.

Water level and peat properties characteristic of GEST Wet peat moss lawn with pine trees

	Water level		Peat properties				
Project sites	Soil moisture	Mean, min and	рН		C:N		
	class (Koska et al. 2001)	max WL, cm (LIFE Peat Restore)	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore	
EE-SU		-14, -47, +5	Sub	5.6	m-lm	29	
LT-SA	4			2.8		65	
LT-PU	4+	nd	Ac	3.0	0-vp	45	
LT-AM			-	2.9	o-p	40	

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



Sphagnum tenellum



Plant species occurring in GEST *Wet peat moss lawn with pine trees*. 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



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

CO <sub>2</sub> emissions		CH₄ em	iissions	GWP estimate		
(t CO <sub>2</sub> -eq./ha/year)		(t CO₂-eq	/ha/year)	(t CO <sub>2</sub> -eq./ha/year)		
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat	
Source*	Restore**	Source*	Restore**	Source*	Restore**	
3.9	0.2	0.2	4.0	4.1		

\* 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.

Eriophorum vaginatum



Sphagnum fuscum

## 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	
	10010 20.	

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

	Wa	ter level		Peat pr	operties	
Project sites	Soil moisture	Mean, min and	рН		C:N	
	class (Koska <i>et al.</i> 2001)	max WL, cm ( <i>LIFE Peat Restore</i> )	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



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**.







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.



Water level and properties characteristic to GEST Open water/ditches

Project sites	Water level	Water properties (pH)		
	Soil moisture class (Koska <i>et al.</i> 2001)	LIFE Peat Restore (mean)		
PL-KL		Ac, Sub	5.0	
PL-WB	6+		4.6	
LV-AU		AC	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, Sphagnum 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 Plant species occurrir Sphagnum denticulatum

Figure 40. Plant L. Stra

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**

Dry forest and shrubberies (OL)

Figure 41.

**21**.

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 20<sup>th</sup> 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	Mean, min and	рН		C:N	
	class (Koska et al. 2001)	max WL, cm ( <i>LIFE Peat Restore</i> )	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
LT-AM	2-/3-	-65; -110; -23	۵c	2.9-3.4	0-1/0	45-50
LT-PU	2-/3-	-63; -119; -17	AC	3.1-4.5	σνμ	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<sub>2</sub> emissions – 26.0 t CO<sub>2</sub>-eq./ha/year CH emissions – 0.0 t CO<sub>2</sub>-eq./ha/year GWP estimate – 26.0 t CO<sub>2</sub>-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 uliginosum

Figure 42.





Vaccinium vitis-idaea



Lycopodium annotinum

# Moderately moist forest and shrubberies (OL) 22.





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 oligotrophicvery poor and acidic soils (Table 29) dwarf shrubs of *Calluna vulgaris, Vaccinium myrtillus, V. vitisidaea* 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.	
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Table 29. Water level and peat properties characteristic of GEST Moderately moist forest and shrubberies (OL)

	Water level		Peat properties			
Project sites	Soil moisture	Soil moisture Mean, min and		рН		
	class (Koska et al. 2001)	max WL, cm (LIFE Peat Restore)	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
LT-SA		-41; -127, +16		2.9-3.2	o-p-o-vp	35-58
LT-PU				3.1-4.5		35-48
LT-AM	-	nd	Ac	2.9-3.4		45-50
LT-PL	2+			2.6-3.1		48-84
PL-WB	_	-30; -86; +7		o-vp	o-vp	
PL-CB		-30; -94; +10		nd		nd
PL-KL		-35; -126, +20				

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. vitisidaea, 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.





Vaccinium vitis-idaea



Picea abies





Lycopodium annotinum

Dicranum polysetum



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

CO <sub>2</sub> emissions		CH₄ emissions		GWP estimate	
(t CO <sub>2</sub> -eq./ha/year)		(t CO₂-eq./ha/year)		(t CO <sub>2</sub> -eq./ha/year)	
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat
Source*	Restore**	Source*	Restore**	Source*	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.





*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)* 

Project sites	Water level		Peat properties			
	Soil moisture class (Koska <i>et al.</i> 2001)	Mean, min and	рН		C:N	
		max WL, cm (LIFE Peat Restore)	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
LT-SA		33; -120; +14		2.5-2.8	o-vp	53-72
LT-PU	3+	nd		2.9	- о-р	35
PL-CB		-19; -60; +10	Ac			
PL-WB		-24; -109; +22		nd		nd
PL-KL		-23; -110; +17			o-vp	

LT-SA – Sachara peatland, LT-PU – Pūsčia 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 Calluna 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





Pin

Figure 46.

Hylocomium splendens

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<sub>2</sub> emissions – 9.4 [-2.2] t CO<sub>2</sub>-eq./ha/year CH<sub>4</sub> emissions – 0.0 [-1.8] t CO<sub>2</sub>-eq./ha/year GWP estimate – 9.4 [-4.0] t CO<sub>2</sub>-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.**





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 19<sup>th</sup> 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 ( <i>LIFE Peat Restore</i> )	рН		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



Eriophorum vaginatum

Rhododendron tomentosum (syn. Ledum palustre)





Andromeda polifolia

Calluna vulgaris

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:**

Figure 48.

**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	
	Table 55.	

GHG emissions from GEST Very moist forests and shrubberies (OL)

CO <sub>2</sub> emissions		CH <sub>4</sub> em	nissions	GWP estimate		
(t CO <sub>2</sub> -eq./ha/year)		(t CO <sub>2</sub> -eq	./ha/year)	(t CO <sub>2</sub> -eq./ha/year)		
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat	
Source*	Restore**	Source*	Restore**	Source*	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.

# MESOTROPHIC AND EUTROPHIC PEATLANDS





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.



Water level and peat properties characteristic of GEST Dry forest and shrubberies (EU/ME)

Project sites	Water level		Peat properties			
	Soil moisture M class (Koska <i>et al.</i> 2001) (Ll	Mean, min and max WL, cm ( <i>LIFE Peat Restore</i> )	рН		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.



Sorbus aucuparia



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<sub>2</sub> emissions – 43.4 t CO<sub>2</sub>-eq./ha/year CH<sub>4</sub> emissions – 0.0 t CO<sub>2</sub>-eq./ha/year GWP estimate – 43.4 t CO<sub>2</sub>-eq./ha/year \* Updated GEST catalogue (see Annex 3); extrapolated from deciduous forests.

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



# 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)* 

	Water level		Peat properties			
Project sites	Soil moisture	Mean, min and	рН	рН		
	class (Koska et al. 2001)	max WL, cm (LIFE Peat Restore)	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
PL-WB		-36; -112; +11			m-lm	
PL-CB		-26; -76; -5		nd		nd
PL-KL		nd	Ac			
DE-BB-3	2+	-95; -127; -46				22
LT-PU				3.8-4.0	e-mr–m-lm	18-33
LV-BA	-	nd	Sub	nd	~	nd
LV-AU				na	m	na

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



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.



### 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, subneutral 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)* 

	Wa	ter level		Peat pr	operties	
Project sites	Soil moisture	Mean, min and	рН		C:N	
	class (Koska <i>et al.</i> 2001)	max WL, cm ( <i>LIFE Peat Restore</i> )	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
DE-BB-1		-9; -29; +1		nd	o mr	nd
DE-BB-2	3+	-12; -58; +5	SUD-AIK	5.3	e-mr	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



Chrysosplenium alternifolium



Stellaria nemorum



Filipendula ulmaria



Pleurozium schreberi



Plagiomnium undulatum

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). Figure 54.

#### **GHG** emissions

Table 37.

Table 37. GHG emissions from GEST Moist forests and shrubberies (EU/ME)

CO <sub>2</sub> el	missions	CH <sub>4</sub> er	nissions	GWP	estimate
(t CO <sub>2</sub> -el	q./ha/year)	(t CO <sub>2</sub> -ec	q./ha/year)	(t CO <sub>2</sub> -e	q./ha/year)
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat
Source*	Restore**	Source*	Restore**	Source*	Restore**
4.6	EE-SL**: 23.1	7.5	EE-SL**: 1.0	12.2	EE-SL**: 24.1
[21.59–24.98]	DE-BB-2***: 35.7	[0.00-5.35]	DE-BB-2***: 0.4	[21.59–30.33]	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.



Water level and peat properties characteristic of GEST Very moist forests and shrubberies (ME/EU)

	Wa	iter level		Peat pr	operties	
Project sites	Soil moisture	Mean, min and	рН		C:N	
	class (Koska <i>et al.</i> 2001)	max WL, cm ( <i>LIFE Peat Restore</i> )	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



GHG emissions from GEST Very moist forests and shrubberies (ME/EU)

CO <sub>2</sub> en	nissions	CH <sub>4</sub> em	nissions	GWP e	stimate
(t CO <sub>2</sub> -eq	./ha/year)	(t CO <sub>2</sub> -eq	./ha/year)	(t CO <sub>2</sub> -eq	./ha/year)
Emissions/	LIFE Peat	Emissions/	LIFE Peat	Emissions/	LIFE Peat
Source*	Restore**	Source*	Restore**	Source*	Restore**
-0.5 [-10.725.97]	-1.0	2.1 [0.81–4.27]	-0.1	1.6 [-9.911.7]	-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.





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)

	Wa	ter level		Peat pr	operties	
Project	Soil moisture	Mean, min and	рН		C:N	
sites	class (Koska <i>et al.</i> 2001)	max WL, cm ( <i>LIFE Peat Restore</i> )	Based on plant indicators	LIFE Peat Restore	Based on plant indicators	LIFE Peat Restore
DE-BB-1	F 1	-7; -48; +10	٨٥	nd	m lm	nd
PL-CB	5+	-9; -57; +28	AC	na	111-1111	na

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

and L. Strazdiņa (B).

Sphagnum teres

Figure 58.

#### **Vegetation communities:**

- **DE:** Sphagnum-Betula pubescens-Alnus glutinosa community.
- **PL:** Alnus glutinosa-Salix cinerea, Myrica gale-Salix aurita, Carex elongata-Alnus glutinosa communities.

Plant species occurring in GEST Wet forests and shrubberies (ME/EU). Photos: K. Libauers (A)

#### Relation to habitats of EU importance:

**DE:** 91D0 \*Bog woodland (subtype Pal. 44.A1 – *Sphagnum* birch woods). **PL:** none.

#### GHG emissions\*:

CO<sub>2</sub> emissions – -3.5 [-4.89] t CO<sub>2</sub>-eq./ha/year CH<sub>4</sub> emissions – 6.8 [0.04–11.46] t CO<sub>2</sub>-eq./ha/year GWP estimate – 3.3 [-4.85–6.57] t CO<sub>2</sub>-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.

lat	lie 41. Summarised data on	water level a	ind pear p	oroperties	cnaracter	Istic of GES	I S IGENT	ITIEd IN	μινε νεατ	kestore pr	oject				
				3	ater table					Pe	eat prop	erties			
	Water level	Soil moisture rlace*		Averag	e, min/ma	x, cm	1			Hd				C:N ratio	
		C C C C C C C C C C C C C C C C C C C	Ш	۲۸	5	ΡL	DE	Ш	L	5	Ч	DE	Ш	5	DE
	1	2	£	4	5	9	7	8	6	10	11	12	13	14	15
					OPEN PE	ATLAND A	REAS								
<del>.</del>	Moderately moist (forb) meadows	2+		ı		-54 -138/+1			ı	4.4	,	1		24.8	
5	Moderately moist/dry bog heath <sup>New</sup>	2+/2-	ı	ı		ı	ı		ı	2.4		ı	ı	42.1	
'n	Moist reeds and (forb) meadows	3+	ı	ı	ï	ı	ı	ı.	ı	3.2-6.4	ı	ī	ī	57.3-98.0	
4.	Moist bog heath	÷							1	3.0				33.2	
Ŀ.	Bare peat dry (oligotrophic)	2-/3-	ı		-52 -92/+6		ı		ı	4.4	ı	1		30.4	
6.	Bare peat moist (oligotrophic)	3+	ı	ı	-35 -64/-6	ı	I		ı	2.6-4.2	ı	ı	ı	59.4-91.0	ı
7.	Bare peat wet	4+(5+)	I	ı		ı	ı	ı	ı	ı	ı	ı	ı	ı	ı.
×.	Very moist meadows, forbs and small sedges reeds	4+(5+)	ı	ı	ı	ı	I	ı	I	4.0-4.7	ı	ı	1	33.1-34.3	ı.
.6	Wet meadows and forbs	5+	ı		-8 -32/+30	ı	I		5.8-6.5	2.9-3.8	ı			66.0-67.2	

(continue	
Table 41	
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able 4	11 (continued)														
		÷		3	/ater table	0				Pe	at prop	erties			
	Water level	soll moisture clace*		Avera	ge min/ma	x, cm				Н				C:N ratio	
			Ш	L	5	ЪГ	DE	出	L	5	Ы	DE	出	5	DE
	1	2	ω	4	5	6	7	~	6	10	11	12	13	14	15
					OPEN PE	ATLAND AI	REAS	-					-		
10.	Very moist/Wet calcareous meadows, forbs and small sedges reeds (EUT) <sup>NEW</sup>	5+ 6+/4+	-8 -44/+20	-28 -47/+8		1	1	6.8	7.7	1			20.0		
11.	Very moist bog heath	4+			ı	-25 -76/+8	1			ı	I				
12.	Very moist peat moss lawn	4+(5+)			ı	-18 -61/+6	ı			ı	ı				
13.	Wet tall sedges reeds	5+(4+)	ı	ı		ı	ı				ı			I	ı
14.	Wet small sedges reeds mostly with moss layer	5+(4+)	ı		ı	-6 -57/+28	ı	ı	ı	3.0	I		ı	74.2	ı
15.	Wet tall reeds	5+			:	1	1			5.3-5.9				26.2-29.1	
16.	Wet peat moss lawn	5+(4+)		-24 -93/-34	ı	ı	ı		4.0	ı	ı			,	
17.	Peat moss lawn on former peat-cut off areas	5+(4+)	ı	ı	ı	-11 -61/+8	I	ı	ı	2.7-2.8	ı	ı	I	58.5-66.8	I
18.	Wet peat moss lawn with pine trees <sup>NEW</sup>	4+	-14 -47/+5		ł	ı	I	5.6		2.8-3.0	ı	,	29.0	40.0-65.0	ı
19.	Wet peat moss hollows resp. flooded peat moss lawn	5+	ı		ı	ı	I	ı		ı	I	ı	ı	ı	ı
20.	Open water/ditches	+9	ı	,	ı		ı	I	3.7- 5.1**	·	4.6- 5.0**		I		

					FORESTE	D PEATLA	NDS								
					Oligotro	ohic peatl	ands								
21.	Dry forest and shrubberies <sup>NEW</sup>	2-/3-	1	I	-64 -115/ -20	ı	I	ı	ı	2.9-4.5	ı	ı	ı	38.2-49.7	ı
22.	Moderately moist forest and shrubberies	2+	1	I	-41 -127/ +16	-32 -102/ +12	I	ı	ı	2.6-4.5	ı	ı	ı.	34.8-83.6	,
23.	Moist forests and shrubberies	3+	1	I	-33 -120/ +14	-22 -93/ -16	I	I		2.5-2.9	1	1	ı	35.0-71.8	1
24.	Very moist forests and shrubberies	4+	-15 -52/ +3	I	I	ı	I	5.9	ı	ı	ı	ı	29.0	ı	,
				Mesot	rophic and	d eutroph	ic peatla	spue							
25.	Dry forests and shrubberies <sup>NEW</sup>	2-/3-	1	I	-89 -112/ -61	ı	I	I	ı	3.2	ı	ı	ı	46.2	1
26.	Moderately moist forests and shrubberies	2+	1	I	I	-31 -94/ +3	-95 -127/ -46	ı	,	3.8-4.0	ı	1	,	18.2-32.7	22.3
27.	Moist forests and shrubberies	3+	-24 -67/-6	ı	ı	pu	-11 -44/ +3	5.9			ı	5.3	20.0		12.7
28.	Very moist forests and shrubberies	4+	-9 -80/ +20	ı	·	pu	pu	5.9	ı		ı	5.1	19.1	ı	16.2
29.	Wet forests and shrubberies	5+	ı	I	ı	-9 -57/ +28	-7 -48/ +10	ı	ı	ı	I				ı

\* Koska et al. 2001 \*\* – water properties

### Index of plant species with photographs

Plant species	Figures No	Juncus effusus	2E
Fiant species		Lycopodium annotinum	42F, 44D, 52B
Aegopodium podagraria	2D	Lycopus europaeus	30F
Alnus glutinosa	26B, 54A, 56A	Lysimachia thyrsiflora	30D
Andromeda polifolia	36C, 48E	Lythrum salicaria	16F
Betula nana	36B, 48A	Menyanthes trifoliata	18I, 38G
Betula pendula	52D	Mvlia anomala	32E
Betula pubescens	42A	Mvrica gale	20E, 22F, 48B
Betula sp.	8F	Molinia caerulea	2A, 10A, 12A, 52C
Bidens tripartita	10C	Nymphaea alba	40A
Brachythecium rutabulum	52A	Parnassia palustris	20F
Calamagrostis epigeios	2C	Pedicularis palustris	20H
Calla palustris	34C, 38H	Phragmites australis	6A. 26A. 30A
Calliergon stramineum	560	Picea abies	44A, 54B
Calliergonella cuspidata	26A	Pinus svlvestris	8F. 36A. 46F
Calluna vulgaris	4A 4B 8A 22A 42C 48E	Plagiomnium undulatum	54H
Campylium stellatum	18	Platanthera chlorantha	186
Campylonus introflexus	8	Pleurozium schreheri	221 546
Carex acutiformis	6D 16B	Polytrichum strictum	8D
Carex lasiocarna	164	Preissia quadrata	18M
Carex limosa	38F 58A	Primula farinosa	20G
Carex nigra	160	Phynchospora alba	18A 28B
Carex nseudocynerus	16C 16D	Phododendron tomentosum	104, 300
Carex rostrata	28A 30E	(sup Ledum palustra)	8G 16A 18D
Chamandanhna calveulata	207, JUL 210	(Syll. Leadin parasite)	25
Chrysosplanium alternifolium	52D 54D	Rubus chamaamorus	2F 46C
Cladium mariscus	24D 20C	Rubus channelliorus	40C
Cladonia sp		Rubus Iuueus Saliy cinoraa	
Cladonia stygia		Schauchzaria palustris	200
Comarum palustra	52F 20C	Schoonus forruginous	204 208
Comunity pulastre		Schoenus jerrugineus	20A, 20B
Dactylorniza cruenta		Scirpus sylvulicus	
Daciyioriniza maculala Dacihampia cospitosa		Scorpialani scorpiolaes	10K, 20D
Discranolla conviculata	2D 12F	Sorbus aucuparia	
		Sphagnum angustijonum	
Dicrumum polysetum		Sphagnum cuspidulum	14A, 28E, 38A, 40C
Drepariociadus revolveris	20)	Sphagnum denticulatum	
Drosera anglica	32D 12C	Sphagnum fallax	22G, 28D, 34A
Drosera intermedia		Spnagnum Juscum	32A, 36F
Drosera rotunalfolia	38F, 8H	Spnagnum mageilanicum	320, 380
Empetrum nigrum		Sphagnum rubellum	32A, 34B
Epilopium palustre		Spnagnum squarrosum	26D
Epipactis palustris	6E	Sphagnum tenellum	36E
Equisetum fluviatile		Spnagnum teres	58B
		Spnagnum warnstorfli	180
Eriophorum angustifolium	12B, 28C	Stellaria nemorum	540
Eriophorum latifolium	18H	Thelypteris palustris	56B
Eriopnorum vaginatum	4C, 8B, 12F, 22C, 24A, 28B, 36D, 48C	Iomentypnum nitens	18L
Filipenaula ulmaria	6G, 54E	iricnophorum alpinum	6H,18B
Fissidens adiantholdes	201	Urtica dioica	6B
Frangula alnus	42B	vaccinium myrtillus	440
Hylocomium splendens	46F, 54F	Vaccinium oxycoccos	18D, 22D, 24B, 24C, 46D
Hypnum cupressiforme	22H	Vaccinium uliginosum	42E, 46B
Juncus alpino-articulatus	10B	Vaccinium vitis-idaea	4D, 42D, 44B
Juncus bulbosus	12D, 14B	Warnstorfia exannulata	40B







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