FIRST DATA ON APPLICATION OF GEST APPROACH IN THE BALTIC REGION: VEGETATION MAPPING OF PILOT PEATLANDS

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In the manuscript we are presenting first data on application of GEST approach in Baltics: vegetation mapping results with identified and described GEST vegetation types in three different pilot peatlands. All peatlands have different disturbance rates (from slightly drained fen and raised bog to totally drained, cutaway and left for spontaneous revegetation former raised bog) caused by drainage. Ecological restoration activities will be implemented in all these peatlands over the next few years. The efficiency of restoration activities in the project LIFE Peat Restore areas will be assessed using GEST approach.

Introduction

Greenhouse Gas Emission Sites Types (GEST) approach was developed for assessing greenhouse gas (GHG) emissions from degraded and rewetted peatlands using vegetation as a proxy. The concept was elaborated by the mire researchers' group at Greifswald University [5-7]. As direct measurements of GHG emissions are laborious, sophisticated and expensive, this approach gives a possibility to evaluate GHG fluxes by interlinking vegetation types, water table depth, peat properties and thickness. The approach [6, 7, 15] was justified by evaluation of comprehensive amount of literature data on GHG flux measurements and grouping them into GEST's depending on site parameters and vegetation features. In 2017, GEST was officially approved by the Verified Carbon Standard (VCS) as a method to estimate Global Warming Potential (GWP) of temperate peatlands. GEST approach since its initial establishment has been developed further, however, even more detailed investigations and additional data collection from various geographical regions is necessary to improve it, e.g. integrating climatic gradients, adjusting new vegetation types, etc. One of the tasks of the project LIFE Peat Restore is to calibrate GEST approach for Baltic countries. New data from three Baltic countries – Estonia, Latvia and Lithuania – would be a good supplement for the development of GEST approach considering geographic peculiarities of European continent. Ecological restoration activities (damming of ditches, cutting of trees and shrubs, etc.) will be implemented in all these peatlands over the next few years. The efficiency of restoration activities in the project LIFE Peat Restore areas will be assessed using GEST approach.

Study sites

Suursoo fen (Estonia), Madiešēnu mire (Latvia) and Pūščia peatland (Lithuania) are situated in the eastern part of the Baltic basin and the western part of East European Plain (between 59° N and 55° N). According to Köppen climate classification, Estonia, Latvia and Lithuania belongs to the same climatic type (Dfb), which is characterized by humid continental climates with warm summers and cold winters [16]. Meteorological data, e.g. air temperatures (mean annual, January and July) and annual precipitation do not differ much between the study sites (Suursoo fen: +5.9˚C, -3.3˚C, +17.2˚C, 696 mm/year [8]; Madiešēnu mire: +6.5˚C, -2,1˚C, +17.9˚C, 743 mm/year [13]; Pūščia peatland: +5.8-6.3˚C, -5.2 - -4.4˚C, +16.9-17.1˚C, 590-670 mm/year [3], correspondingly).

Suursoo fen in north-western Estonia is a part of the Läänemaa Suursoo complex of bogs, transitional mires, fens and different mire forests. Peat layer there is mostly up to 4.8 m deep. Several east-western directional streams are flowing through the site. Although drainage network is not very dense, the fen has been drained for very long period. Suursoo fen has been used for hay mowing and cattle pasturing previously, but abandoned after the World War II. In 1981, a part of the Läänemaa Suursoo mire complex was taken under protection as mire conservation area (9 713 ha). In 2005, the conservation status was changed and the Läänemaa Suursoo landscape protection area was established. At present, drained Suursoo fen has been protected as a nature reserve and is a part of Natura 2000 site (EE0040202) with several habitats of EU importance (Table 1).

The surface elevation is decreasing in east-western direction and has slope of about 1 m/km. All streams are dredged and straightened, first at the end of the 19th century, and partly in the 1960's. Additionally, ditches have been dug in different times. The old ditches are mostly about 0.5 m deep, but several ditches passing through the area are up to 1.5 m deep and 3-4 m wide, some of these have been deepened in the 1960's. This resulted in decrease of the water level up to 0.5-1.0 m. The influence of drainage differs depending on the distance from deep ditches and the ground slope (steeper in western part). Due to unusually rainy summer and autumn of 2017, our hydrological monitoring data don't characterize typical water table in the fen habitats. Water table depth varies between +10 cm to -50 cm depending of the distance from the ditches or streams.

Madiešēnu Mire in the north-eastern part of Latvia is a part of the Augstroze Nature Reserve with the total area of 1881 ha. Madiešēnu Mire is one of the five large mires in the Reserve. In 1995, the mire got status of Internationally Important Bird Area. In 1997, the Nature Reserve was included into the North Vidzeme Biosphere Reserve as landscape protection zone. It is a Natura 2000 site LV0000110, established in 1977 and protected since 2011. A total of eleven habitats of EU importance (Auniņš 2013) are represented (see Table 1). Madiešēnu Mire is a typical raised bog with hummock-hollow complex and bog pools, especially in the southern part of the mire. Transitional mire vegetation has developed in the lagg zone. Forest vegetation on mineral ground elevations is also characteristic of the mire.

Thickness of peat deposit differs between the habitats. In the raised bog, maximum thickness of peat layer is 4.8 m, but in some places reaches up to 10 m. In the transition mire, peat layer is thinner on average 1.6 m, maximum – 3.0 m. Drainage systems for forestry were established in different times in various parts of the mire. First ditches were dug between 1937 and 1940 in the eastern margin of the mire. However, these ditches are overgrown with forest vegetation and, therefore, restoration would not be efficient in this part of the mire. Other drainage system with total ditch length nearly 12 km was established between 1983 and 1989 in the northern part of the mire (see Table 1). Vegetation and habitat degradation, peat mineralization and decrease of water table depth is still ongoing along these ditches in 102 ha area.

Pūsčia peatland in the north-eastern part of Lithuania belongs to Gražutė Regional Park. In 2006, peatland was appointed as pSCI (LTZAR0030), since 2010 it has a status of Telmological Reserve (100.6 ha). Four habitats of EU importance were inventoried in 2017 (see Table 1). Drainage and industrial peat harvesting in Pūsčia peatland began in 1959 and lasted until 1990.

Peat thickness varies from 0.5 m on the edges to 4.5-6.0 m in the central part of the cutover peatland. Mineralized white peat dominates in the area. In 2017, a water level in Pūsčia peatland was quite high and ranged from -60 to +10 cm due to unusually rainy vegetation period. This site has been abandoned for more than 25 years. Although the first small-scaled restoration activities were implemented in 2000-2003, however, it had only marginal effect due to dense network of drainage ditches (see Table 1). Spontaneous succession towards typical bog communities is still very slow and was observed only in the lowest part of microrelief, near blocked ditches on the eastern and northern edges of the peatland. The central part of the peatland is characterized by woody vegetation, one third of the territory is still covered by bare peat with solitary individuals of *Calluna vulgaris*, *Eriophorum vaginatum*, *Equisetum arvense* or small *Pinus sylvestris* and *Betula* spp. trees. Some fragments of *Campylopus introflexus* lawn was indicated on bare peat in 1.5 ha area.

Methods

Investigations on vegetation cover and environmental parameters were carried out in 2017. All vegetation units were mapped at study sites (Figure 1) and assigned to vegetation forms [4, 11, 12, 15]. Smaller units were mapped by visual delineation and GPS. On areas with more complicated vegetation pattern and on large areas, remote sensing technologies were used for mapping. On Madiešēnu Mire, LiDAR and spectral data were used in collaboration with the Institute of Environmental Solutions (Latvia), on Suursoo fen – drone photos and different maps from Estonian Landboard (aerophotos, land cover map, etc.) were used for mapping. On each mapped unit, vegetation was analysed at least on three random 10×10 m relevés applying the principles of Zürich-Montpellier phytosociological vegetation rese-arch approach in open mire areas and 25×25 m in forested areas [2]. Peat thickness, coverage of bare peat, litter and open water were estimated in every relevé, soil moisture classes evaluated according to Koska et al. [11], biotic parameters (tree height and diameter, cover of shrubs, herbaceous plants and bryophytes) were estimated after Peet et al. [14]. The analyses of peat (dry mass, ash, Ca, Mg, Fe, N, P) and water (pH, EC, Ca, Mg, Fe) parameters were determined at Estonian site. It will support interpretation of direct GHG measurements at Estonian sites in the future. Peat pH and C:N ratio was analysed at Lithuanian site (Table 2).

Results and discussion

In **Suursoo fen,** five GEST types were classified, both eutrophic and oligotrophic peatlands (see Figure 1, Table 2). Three of these (Wet calcareous meadows, Very moist forests and shrubberies, minerotrophic and Moist forests and shrubberies) have no data or the data are very scarce in GEST catalogue [6, 7, 9, 15]. Peat is predominantly deep – 4.8 m (Soil map of Estonian Land Board), however in some of the vegetation types (Wet calcareous meadows, Moist and very moist forest and shrubberies) occur on shallow peat (0.2-0.3 m). Studies carried out in 2017 showed that oligotrophic vegetation forms lie on fen peat and have been developed recently because of drainage. The main effects of drainage: drop of mire water table; decline of ground surface on the ditch banks; spreading of *Sphagnum* mosses on fen area; aggravation and increase of height of trees and shrubs; and finally, extinction of mire plant species. The objective of rewetting is to stop peat decomposition and afforestation on that huge disturbed fen ecosystem, and to maintain the complex of open fen, transitional mire and some fen and transitional mire forests. This should be accompanied by a decrease in GHG emission.

In **Madiešēnu Mire,** nine GEST vegetation types were classified. Wet peat moss lawn (70% of the total site area) is located in the middle of the mire (peat depth reaches up to 10 m). It is surrounded by other types according to decreased peat thickness, ground elevation and drainage influence (see Figure 1, Table 2). Degradation of raised bog

Table 1 – General data on drainage and habitats of EU importance in pilot peatlands in the Baltic regions

Peatland	Area (ha)		Drainage history				Habitats of EU importance
	Total	Drained	Period	Drainage net (m/ha)	Purposes	Type of damage	
Suursoo fen, Estonia	3343	3188	End of the 19th century, some ditches in 1960's	20	Hay mowing (19th century – 1940's). Peat mining (not realized) in 1960's	Long-lasting medium or weak drainage	7230, 91D0*, 7140, 9080*, 7110*, 9010*
Madiešēnu Mire, Latvia	1881	102	1937-1940, 1983-1989	6 (in all mire)/ 117 (in drained area)	Forestry	Drained	6270*, 7110*, 7120, 7140, 9010*, 9020*, 9050, 9080*, 9160, 9180*, 91D0*
Pūsčia peatland, Lithuania	101	80	1959-1990	347 (in all peatland) / 438 (at study site)	Peat mining (white peat for bedding	Drained/cutaway. 1st rewetting efforts in 2000	7120, 7150, 91D0*, 7140

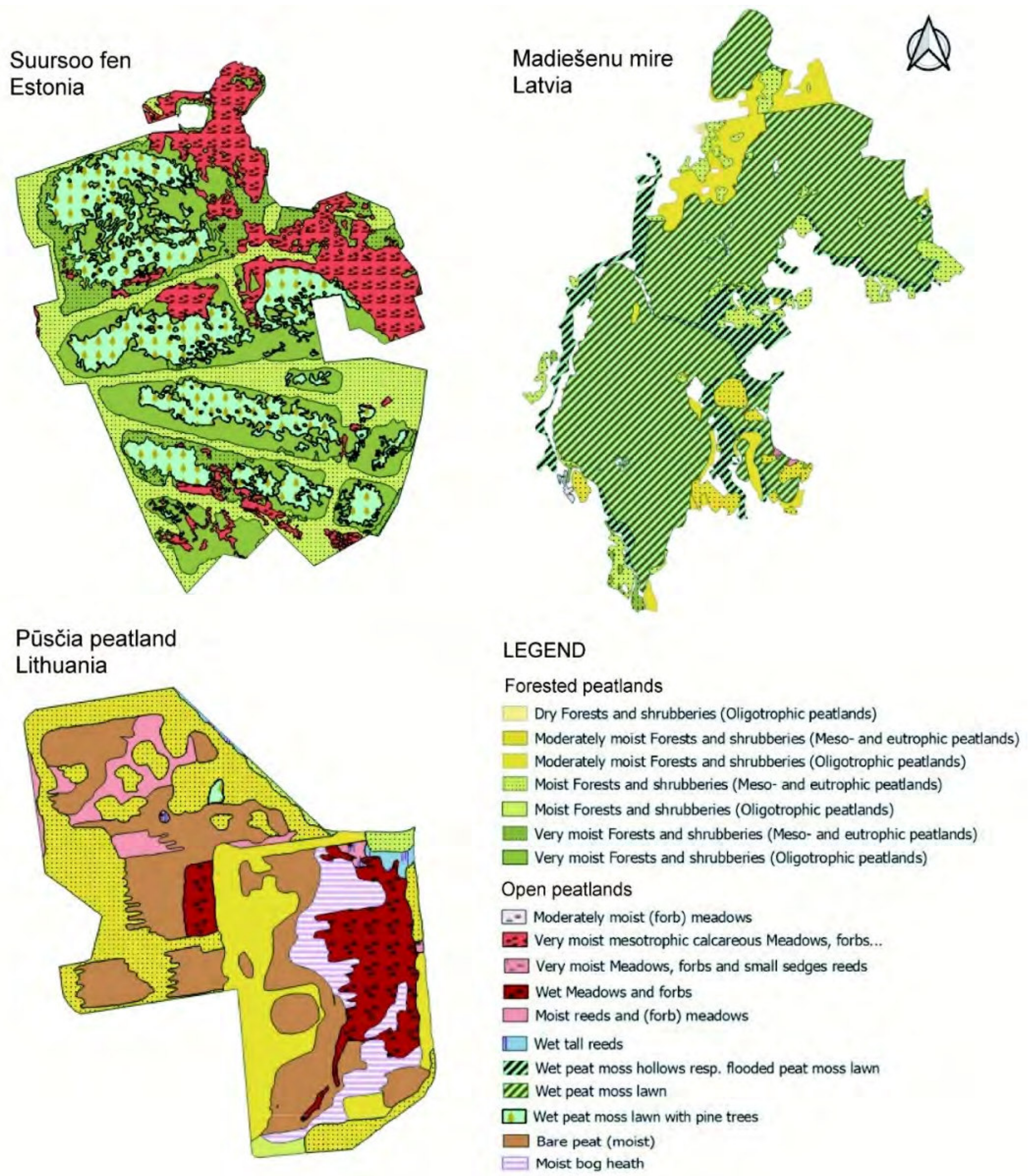

Figure 1 – Distribution of GEST types in pilot peatlands in the Baltic region (Project LIFE Peat Restore) in 2017

in the northern part of the mire for a period of 30 years has caused open-landscape GEST type modification into Moderately moist forests and shrubberies.

Pūsčia peatland is in the worst condition since the area is disturbed by drainage, peat mining activity and fire. Wide areas of bare peat and shrubby vegetation predominate in the landscape. Due to these circumstances and variable hydrological conditions in different parts of the peatland, the biggest variety of GEST vegetation types (eleven) has formed (see Figure 1, Table 2). Vegetation gradually changes from Moist eutrophic forests and shrubberies and Wet meadows and forbs on the edges towards Moist oligotrophic forests and Bare peat habitats in the middle of the peatland. Peat pH values vary from 2.9 to 6.4; thickness of peat deposit varies from 0.5 to 6.0 m. Wet tall reeds, Moist reeds and (forb) meadows, Moist mesotrophic forests and shrubberies occur on the thinnest peat deposit areas, whereas Wet meadow and forbs, Wet peat moss lawn with pine trees and Moist forests and shrubberies were recorded on the thickest peat with the lowest pH values (see Figure 1, Table 2).

GEST approach has been elaborated mainly for the measurements in peatlands of Germany and Belarus. In northern climate, plant growth and decomposition rate can differ from these resulting in different GHG emissions from drained peatlands. Also, GEST catalogue [9, 15] does not cover all vegetation forms occurring on drained peatlands, or there are only few measurements for some GEST types, e.g. types on meso- and eutrophic. We found eighteen GEST types at three project sites of the Baltic countries. Part of these need more detailed calibration, while another part need to be adjusted with additional information. New data from direct GHG measurements on Life Peat Restore project pilot sites can be a good supplement for further development of GEST approach and making it more precise and reliable.

Both peatland development and drainage history are variable and site-specific, also the impact of management measures can be variable. Investigations on vegetation cover development after restoration activities (damming of ditches, cutting of trees and shrubs, etc.) together with hydrological and GHG monitoring will provide the opportunity to evaluate the rate and intensity of vegetation (i.e. GEST type) changes in formerly degraded, but now under restoration peatlands. Assessment of GHG emissions before, during and after rewetting allows creating development models for several different vegetation forms and drainage situations.

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Table 2 – GEST vegetation types in pilot peatlands in the Baltic region (Project LIFE Peat Restore), in 2017

GEST types	Soil moisture classes	PEATLANDS								
		Suursoo fen, Estonia			Madiešēnu Mire, Latvia			Pusčia peatland, Lithuania		
		Area, ha	Peat depth, m (average, min-max)	Water pH	Area, ha	Peat depth, m (average, min-max)	Peat pH	Area, ha	Peat depth, m (average, min-max)	Peat pH (average, min-max)
OPEN PEATLAND AREAS										
Moderately moist (forb) meadows	2+	–	–	–	2.7	ND	ND	–	–	–
Moist reeds and (forb) meadows	3+	–	–	–	–	–	–	4.2	2.8 2.0-4.0	4.0 3.2-6.4
Moist bog heath	3+	–	–	–	–	–	–	6.4	4.5 3.3-6.0	3.0 2.9-3.0
Bare peat (moist)	3+	–	–	–	–	–	–	24.2	3.2 1.5-6.0	2.9 2.7-4.2
Very moist meadows, forbs and small sedges, reeds	4+(5+)	–	–	–	2.0	1.6 3.0	ND	0.5	3.4 1.2-5.0	4.5 4.0-4.7
Wet meadow and forbs	5+(4+)	–	–	–	–	–	–	9.8	5.5 4.5-6.0	3.2 2.9-3.8
*Wet calcareous meadows	5+	601.0	3.3 0.3-4.8	5.5	–	–	–	–	–	–
Wet tall reeds	5+	–	–	–	–	–	–	0.7	1.3 1.1-1.5	5.9
Wet peat moss lawn	5+(4+)	–	–	–	1136.9	4.8 10.0	3.8	–	–	–
Wet peat moss lawn with pine trees	4+	827	3.3 1.0-4.8	4.9	–	–	–	0.2	6.0	3.0
Wet peat moss hollows resp. flooded peat moss lawn	5+	–	–	–	182.4	1.6 3.0	ND	–	–	–
FORESTED PEATLANDS										
Oligotrophic peatlands										
*Dry forest and shrubberies	2-	–	–	–	2.3	ND	ND	–	–	–
Moderately moist forest and shrubberies	2+	–	–	–	129.5	4.0	3.8	11.6	2.7 0.5-5.0	4.2 3.1-6.1
Moist forests and shrubberies	3+	–	–	–	106.8	ND	6.1	0.6	5.0	2.9
Very moist forests and shrubberies	4+	860.0	2.7 0.5-4.8	4.9	9.8	ND	ND	–	–	–
Mesotrophic and eutrophic peatlands										
Moderately moist forest and shrubberies	2+	–	–	–	90	ND	ND	20.7	2.0 0.0-5.1	3.7 3.2-4.0
*Moist forest and shrubberies	3+	733.0	3.1 0.2-4.0	5.5	–	–	–	0.1	1.5	ND
*Very moist forests and shrubberies	4+	297.0	3.1 0.2-4.0	6.0	–	–	–	–	–	–

* – new GEST types; ND – no data

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ВЛИЯНИЕ УСЛОВИЙ ПРОИЗРАСТАНИЯ НА СОСТАВ ЛИПИДОВ СФАГНОВЫХ И ЗЕЛЕНЫХ МХОВ

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Методом хромато-масс-спектрометрии исследован состав липидов 16 разновидностей сфагновых и зеленых мхов, произрастающих при среднегодовой температуре от -9,1°С до 1,5°С. Определен индивидуальный состав и содержание во мхах н-алканов, н-жирных кислот и их эфиров, н-алкан-2-онов, альдегидов, токоферолов, стероидов, сескви-, ди- и тритерпеноидов. Показано, что наиболее зависимы от природных условий обитания циклические изопреноиды: соотношение в их составе углеводородов и кислородсодержащих структур, рядов пергидропицена и циклопентахризена, содержание сквалена, сескви- и дитерпеноидов.

Несмотря на свое разнообразие и широкую распространенность в растительном мире состав липидов мхов долгое время оставался мало изученным. Однако, исследования, проведенные в последнее время, показали, что мхи содержат многочисленные соединения с высокой биологической активностью [2]. Работы, посвященные изучению состава липидов мхов, касаются преимущественно отдельных районов Северной Европы [1-3] и ограниченно – юга Сибири [4]. Отсутствуют сведения о влиянии условий обитания на особенности их состава. Поэтому целью этого исследования был анализ состава липидов сфагновых и листостебельных мхов, произрастающих на территориях, отличающихся природно-климатическими условиями.

Образцы сфагновых и зеленых мхов отобраны на территориях, существенно различающихся температурой окружающей среды (таблица). Содержание и состав органических соединений определяли методом хромато-масс-спектрометрии с использованием магнитного хромато-масс-спектрометра DFS фирмы «Thermo Scientific» (Германия). Разделение осуществляли на кварцевой капиллярной хроматографической колонке фирмы «Agilent» с внутренним диаметром 0,25 мм, длиной 30 м и неподвижной фазой DB-35MS.

В зеленых (бриевых) мхах родов *Aulacomnium*, *Calliergon* и *Warnstorfia*, независимо от среднегодовой температуры, при которой они произрастали (от -9,1 до +0,3°С), сесквитерпеноиды отсутствуют, только мох рода *Polytrichum* (-7°С) содержит невысокое (0,03 мкг/г сухого мха) количество δ-кадинена (структура 1, рисунок 1).

В сфагновых мхах содержание и состав сесквитерпеноидов различается в зависимости от вида мха и от температурных условий его местообитания. Наблюдается увеличение содержания и существенного расширения набора сесквитерпеноидов во мхах вида *Sph. fuscum* от 0,3 до 4 мкг/г при увеличении температуры окружающей среды от -8,2 до +0,5-1,5°С. При температуре -8,2°С сесквитерпеноиды представлены единственным соединением (структура 2, см. рисунок 1), в районе со среднегодовой температурой -6,6°С во мхе присутствуют 2 сесквитерпеноида (структуры 1 и 2, см. рисунок 1). При переходе к району с положительной