Method for Assigning Emission Factors to Mapping Units Based on Modelling the Spatial Structure and Functions of Peatland Ecosystems

EGU25-20654, BG8-13

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How are peatland **rewetting** projects evaluated in line with VCM standards?

VCS Methodology

VM0036

Methodology for Rewetting Drained Temperate Peatlands

1. Project site Stratification.
2. Assigning GESTs to the land classes (no scale limits).
3. Assigning Emission Factors to GESTs.
4. Evaluating Area and Emissions by GESTs in two scenarios.
5. Calculating Emission Reductions between two scenarios.

Drainage - rewetting

Can we evaluate a peatland restoration project with available VCM standards?

1. Broader landscape regulation of peatland hydrology and biogeochemistry.

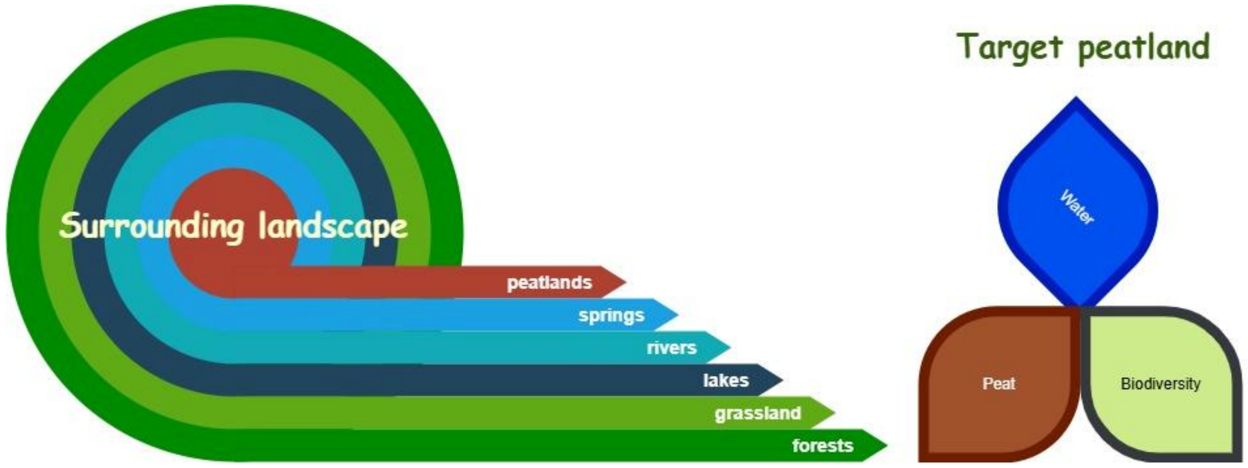
2. High peatland heterogeneity/ecosystem diversity across various spatial scales, but low higher plant species diversity.

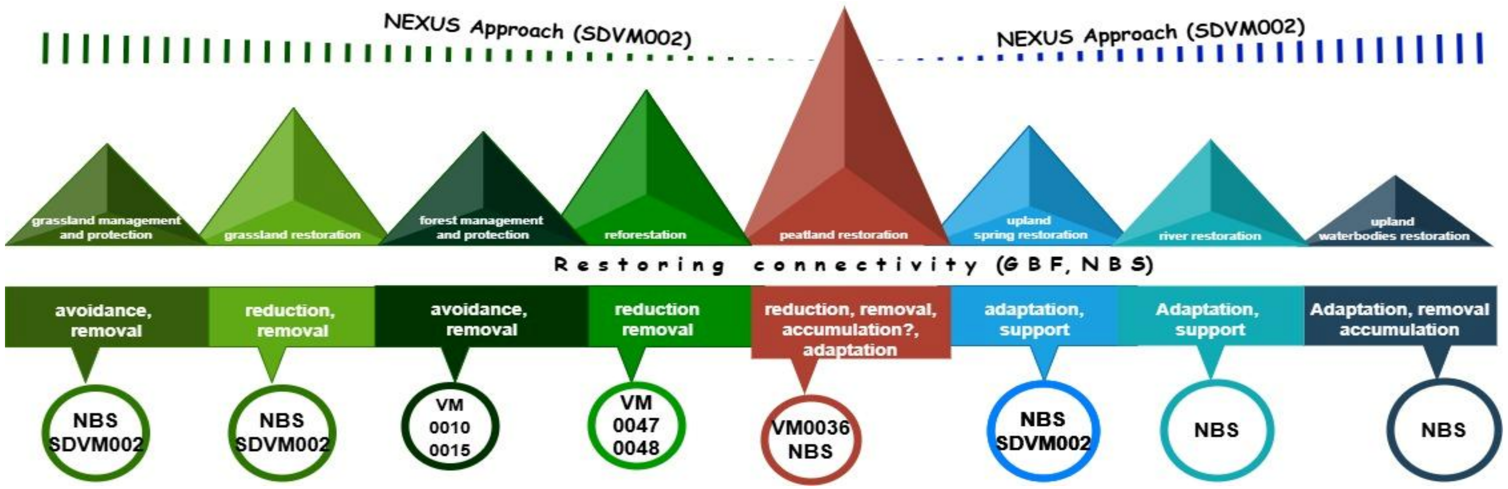
3. The GHG emission is controlled at the micro-level and must be evaluated at a larger scale.

Turning an ecosystem restoration project into a carbon project

Problem 1 Landscape Approach:

- **Project boundaries**
- **List of methodologies**
- **Absence of process-based indicators**





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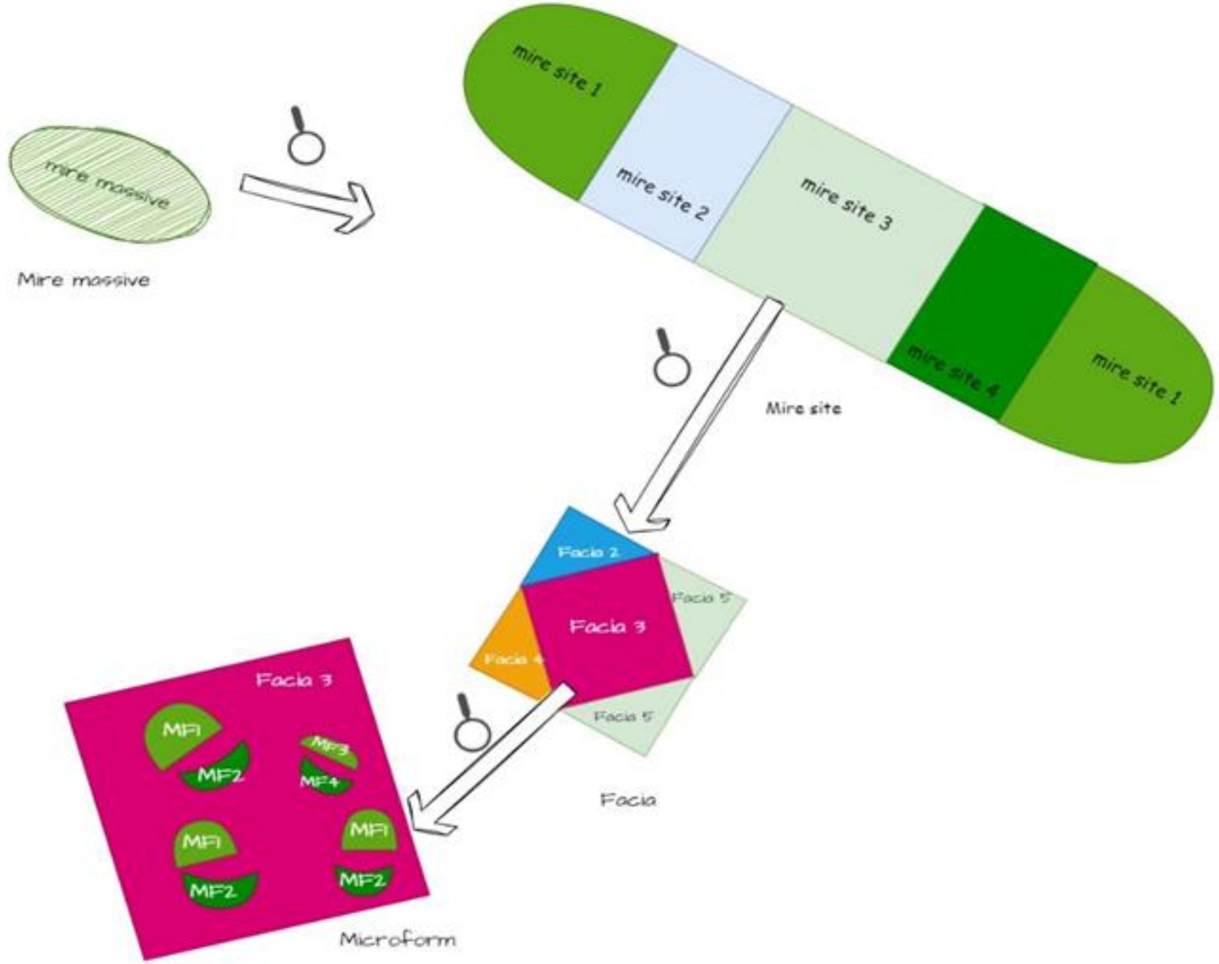
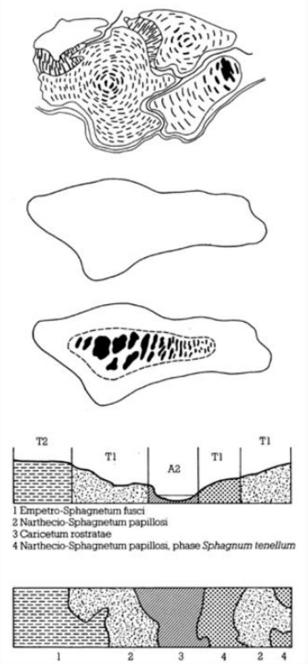
Turning an ecosystem restoration project into a carbon project

Problems 2 and 3: Heterogeneity and upscaling

- **Landscape functional units vs vegetation-driven classes**
- **Hierarchical classification of functional units**
- **Upscaling ecosystem characteristics from the measurement scale to the evaluation scale**

Hierarchical mire landscape classification



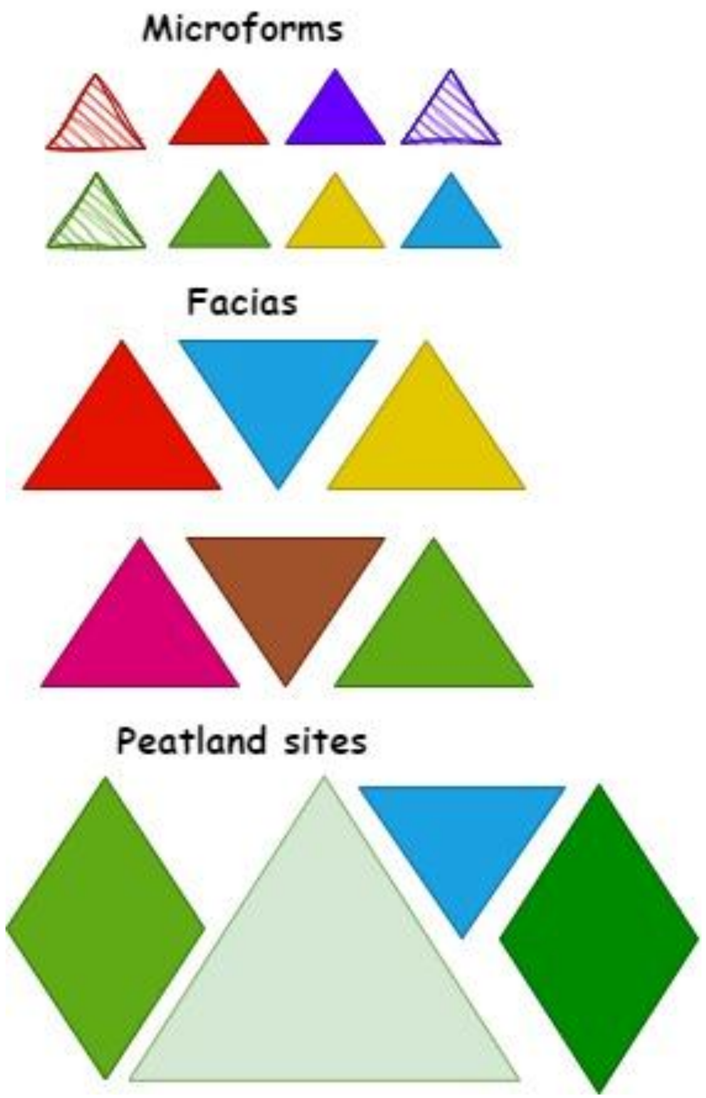


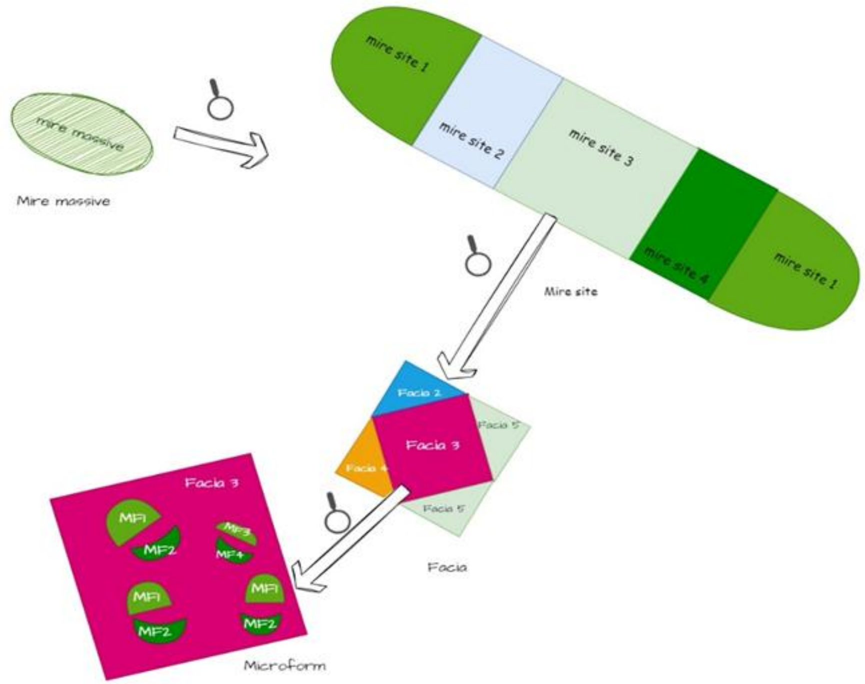
The landscape		Description	Vegetation unit	Scale (m^2)
	Macrotope	The mire complex (or system; several merged mire massifs)	Biogeographic zone	10^5–10^9
	Mesotope	The mire massif (separate raised bog, fen, *etc.*)	Mire massif type	10^2–10^7
	Microtope	Homogeneous element of landscape heterogeneity within the mire massif (hummock-hollow complex, margin, sedge mat, *Sphagnum* carpet)	Complex of phytocoenoses	10^2–10^6
	Microform (nanotope)	Hummock, hollow, pool, ridge	Phytocoenosis	10^{-1}–10^1
	Vegetation mosaic	Microcoenosis, tussock, *etc.*	Microcoenosis	10^{-2}–10^{-1}

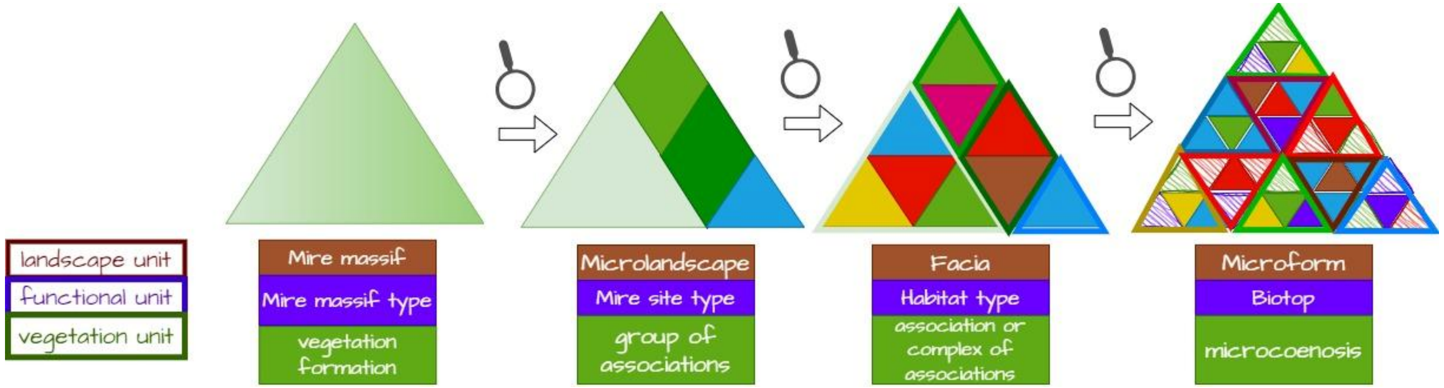
Figure 3. The elements of hierarchical mire classification (after Masing 1974 and Lindsay *et al.* 1988).

Mires and Peat, Volume 19 (2017), Article 01, 1–36, http://www.mires-and-peat.net/, ISSN 1819-754X
 DOI: 10.19189/MaP.2013.OMB.150

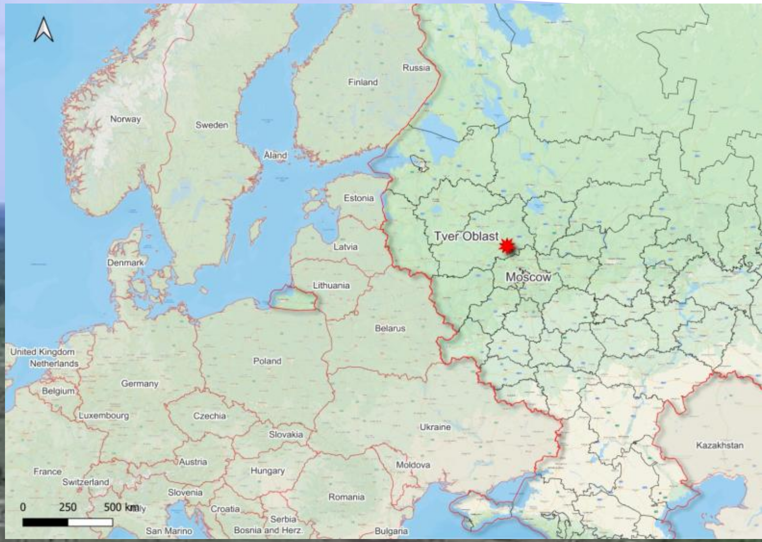
Hierarchical mire landscape classification – for upscaling







Orsha peatland, 650 sq. km, Tver, Russia



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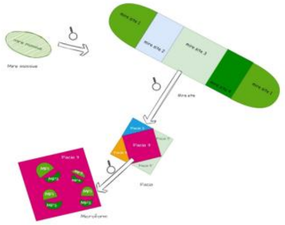
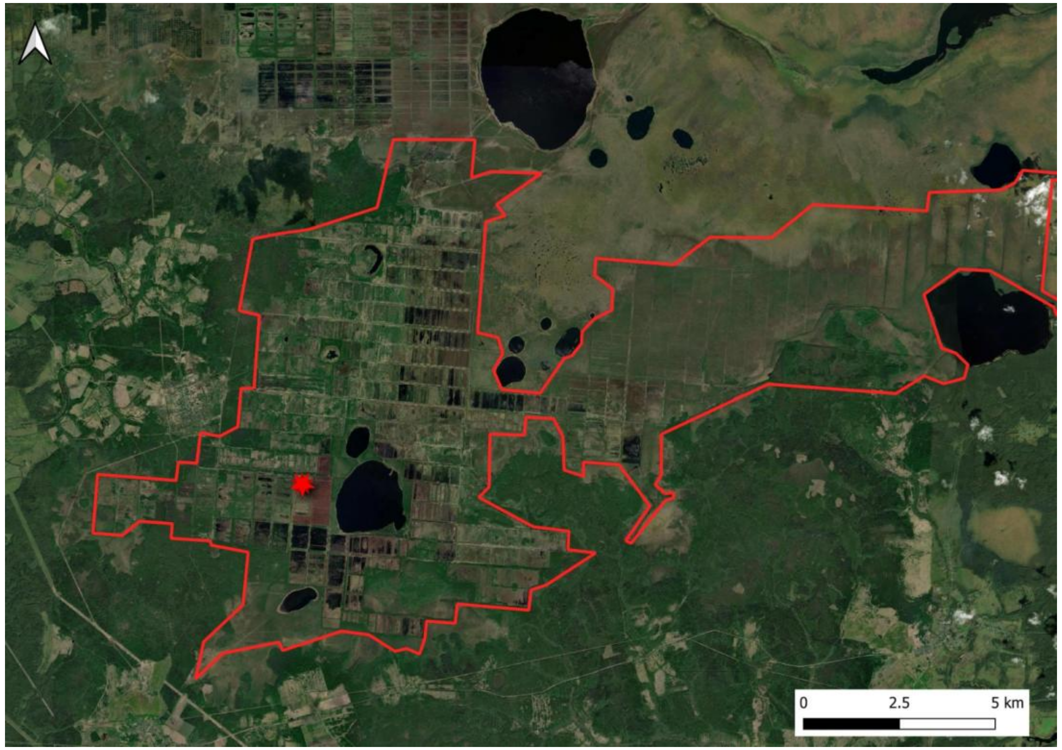
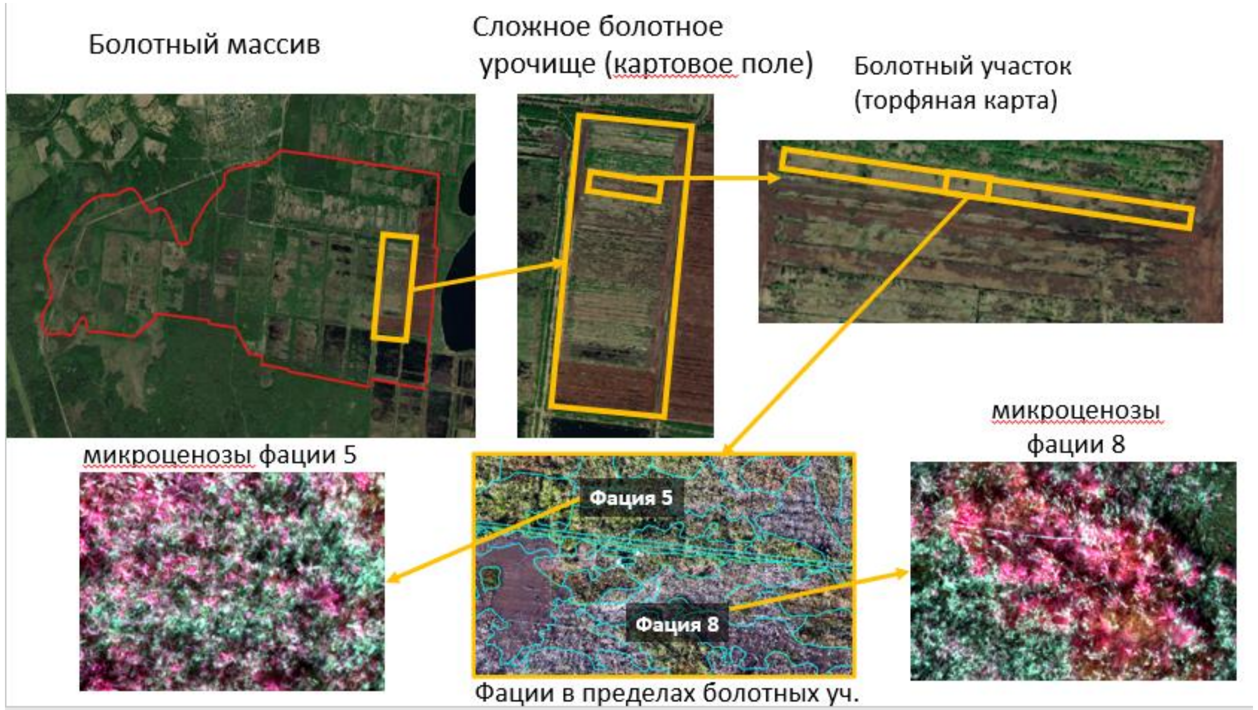
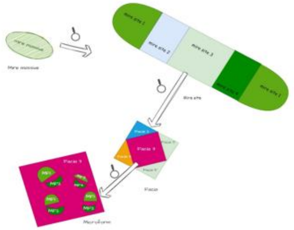
Experiment on Hierarchical Upscaling of Ecosystem Function Parameters: assigning the plot







Experiment on Hierarchical Upscaling of Ecosystem Function Parameters: mapping



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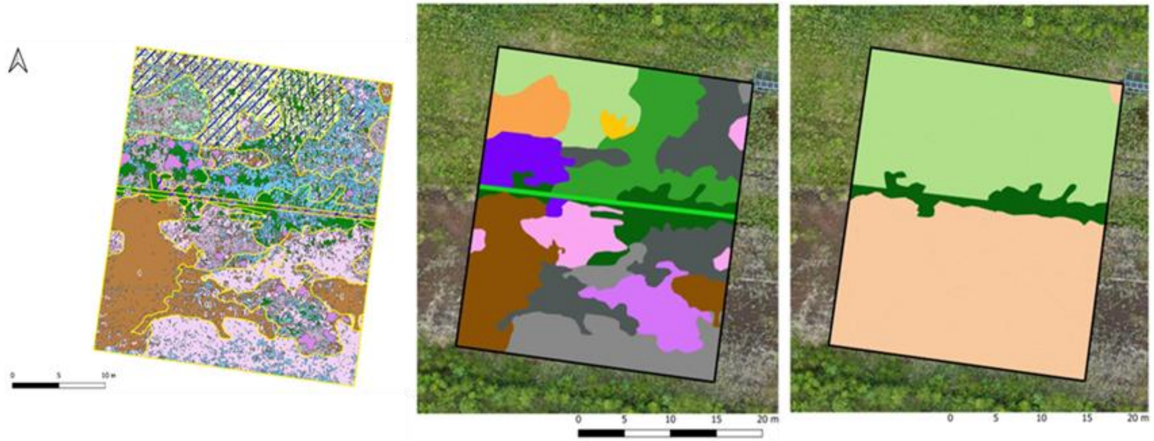
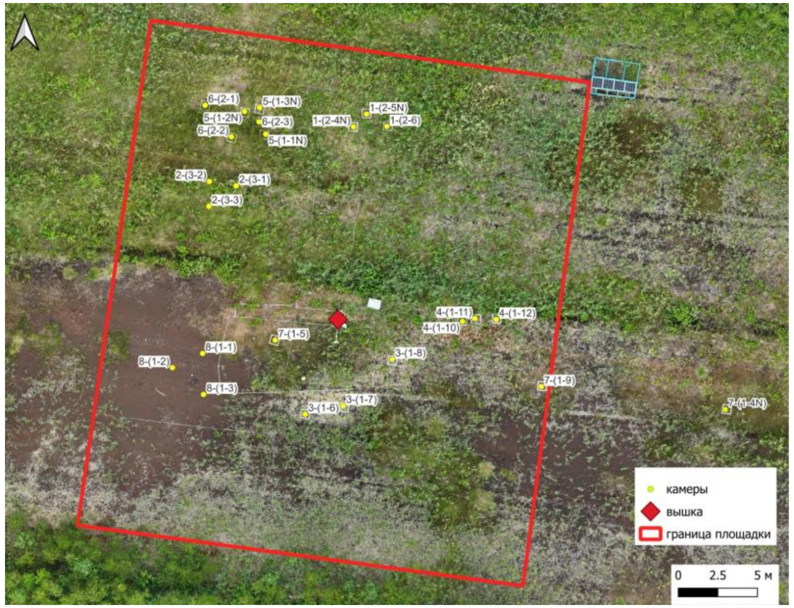
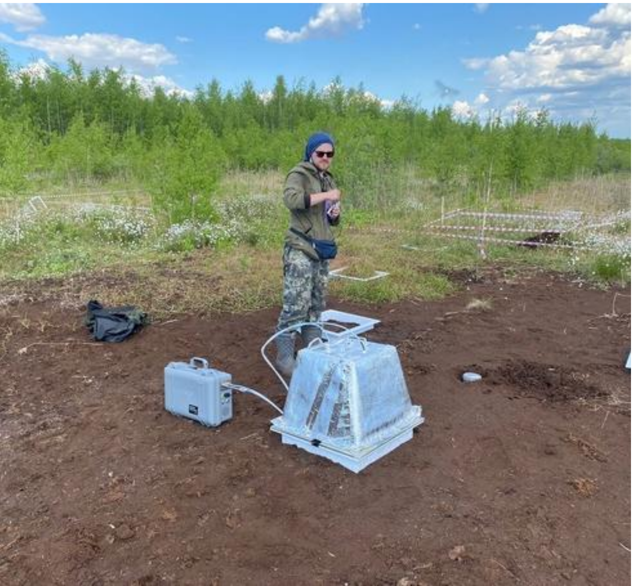


Seven types of microform, 12 types of facias, three types of peatland sites



Shooting:
DJI Mavic 3 multispectral

Classification:
Random forest – a machine learning algorithm for classification

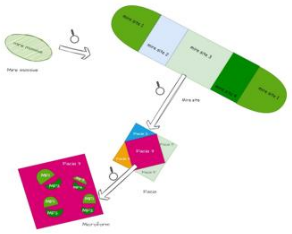


May 2024

July 2024

September 2024

Experiment on Hierarchical Upscaling of Ecosystem Function Parameters: measuring

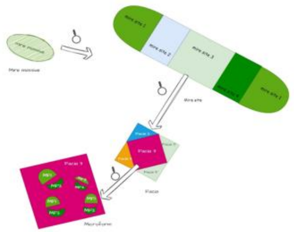


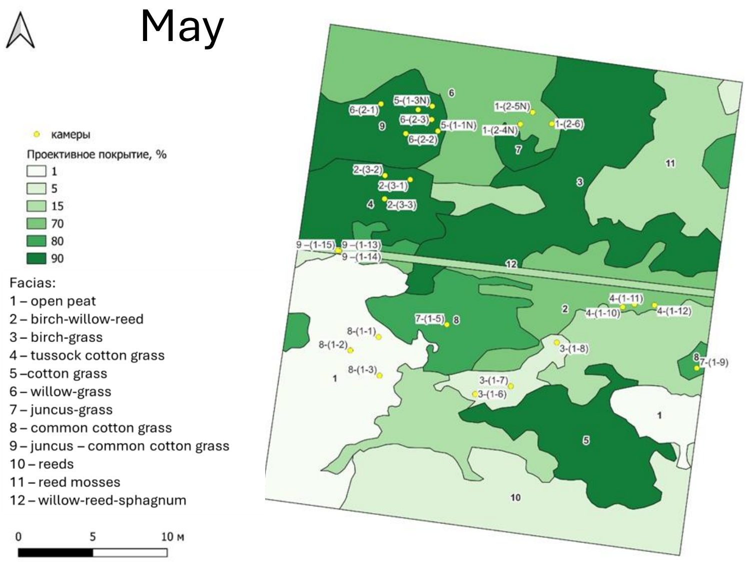
Seven types of microforms, three repetitions – 21 plots, four campaigns.

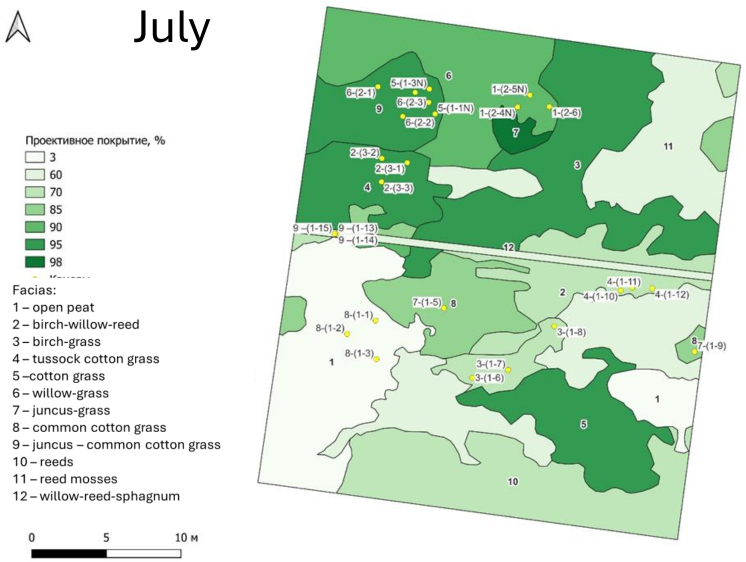
Measurements at the level of microforms:

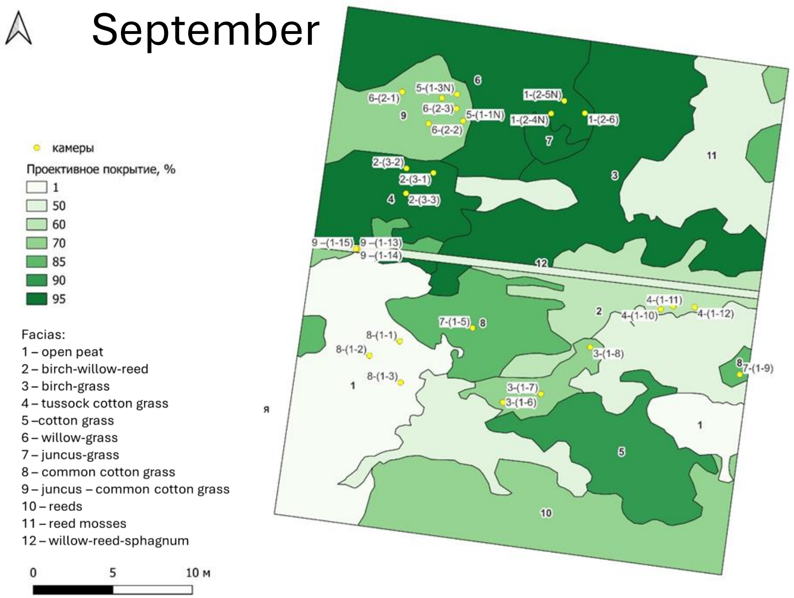
1. Vegetation species composition and cover.
2. AGB, BGB, litter, mortmass (July)
3. Gradient of soil temperature and moisture (0, 5, 10, 15 cm).
4. Water table
5. Photosynthetically Active Radiation (PAR), air temperature and humidity of air Minikin QTH (EMS Brno, Чехия)
6. CO2 and CH4 fluxes by chambers «LI-7810» (Li-Cor, США)

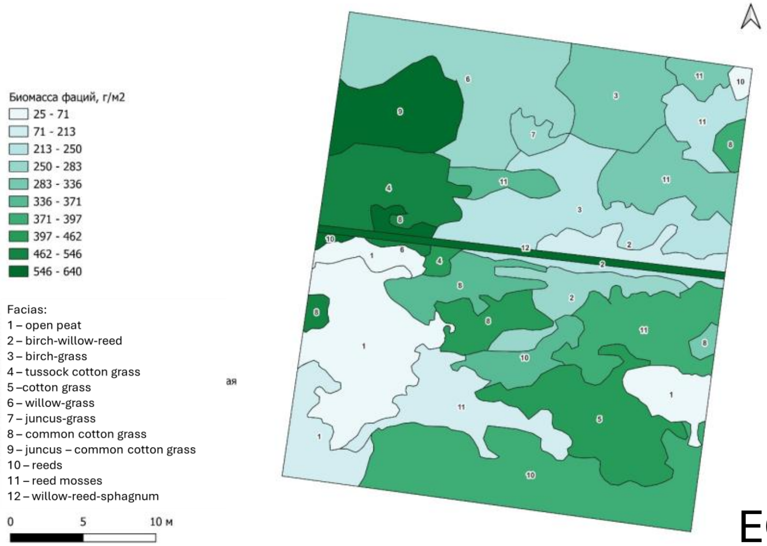
Experiment on Hierarchical Upscaling of Ecosystem Function Parameters: vegetation cover and phytomass



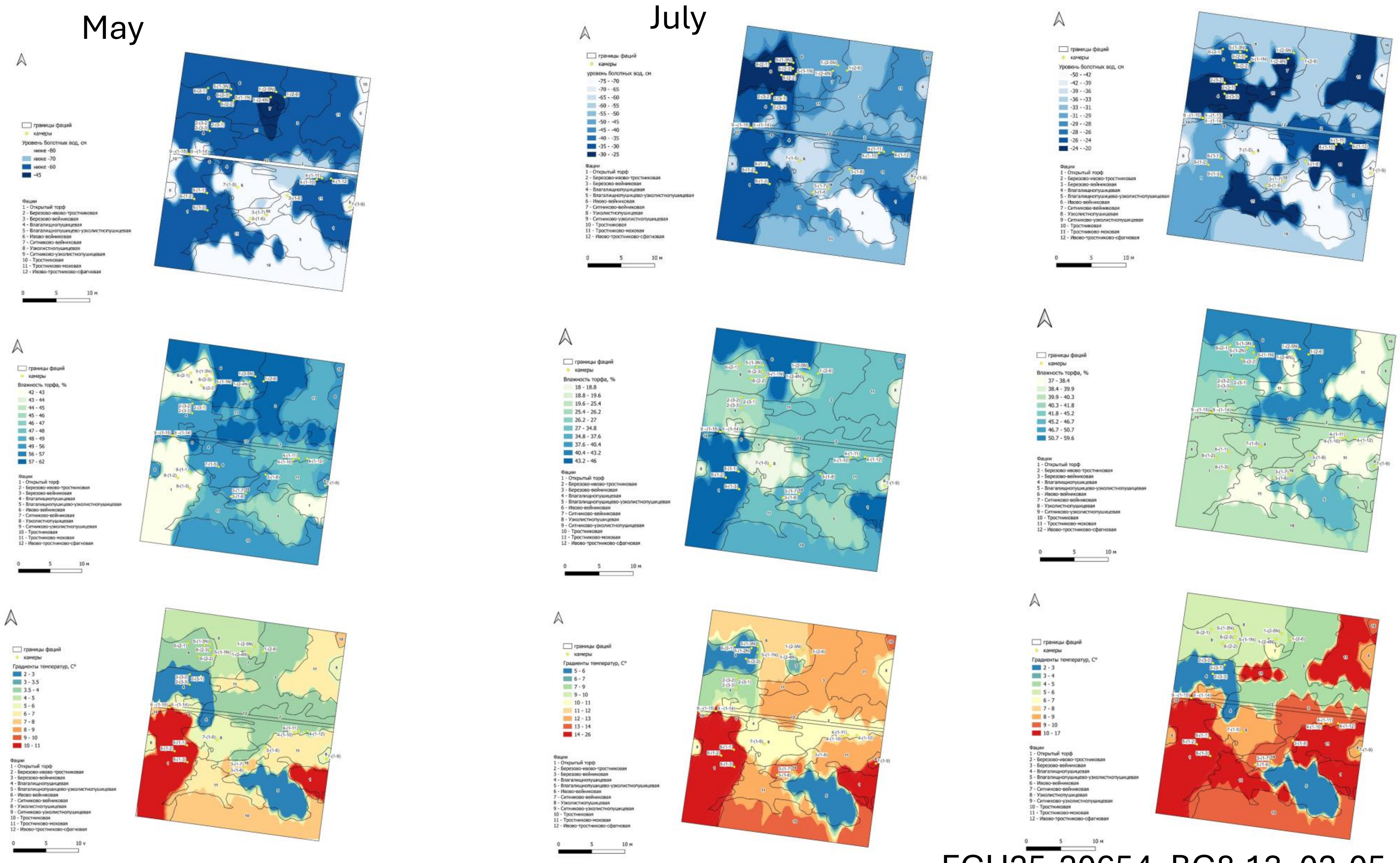








Experiment on Hierarchical Upscaling of Ecosystem Function Parameters: water table (cm), soil moisture (%), soil temperature 0/10 difference °C



Facias:
1 – open peat
2 – birch-willow-reed
3 – birch-grass
4 – tussock cotton grass
5 –cotton grass
6 – willow-grass
7 – juncus-grass
8 – common cotton grass
9 – juncus – common cotton grass
10 – reeds
11 – reed mosses
12 – willow-reed-sphagnum

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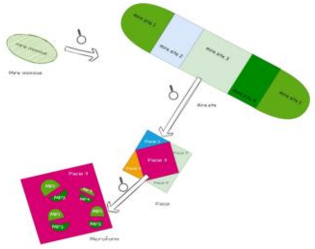
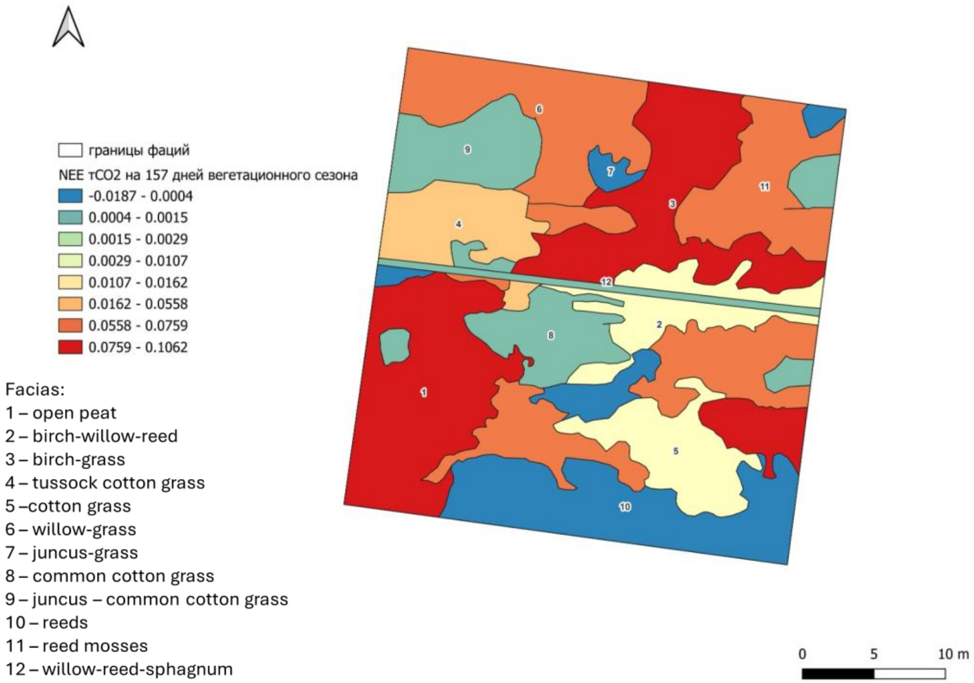
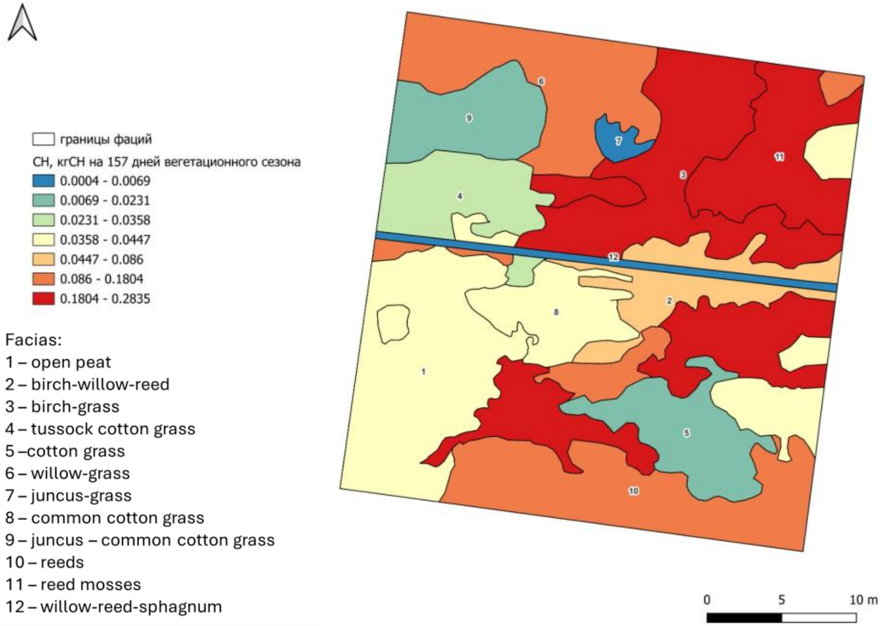
Experiment on Hierarchical Upscaling of Ecosystem Function Parameters: NEE tCO_2, and methane emission kg*ha for the growing season *157 days







Microcenosis number	1	2	3	4	5	6	7	8	9	
Microcenosis name	Juncus effusus - Calamagrostis epigeios	Eriophorum vaginatum	Phragmites australis	Betula spp.-Polytrichum spp.	Juncus effusus	Eriophorum angustifolium wet	Eriophorum angustifolium dry	Bare peat	ditch	EF for plot (tCO2-eq/ha /growing season)
Input of microcoenoses to the emission factor of the plot (tCO2-eq/ha /growing season)	0,65	0,23	1,13	0,84	0,04	-0,27	-0,57	0,84	0,00	2,89
IPCC emission factor for CO2 for peatland managed for extraction, t C-CO2 ha-1 year-1 (95% confidence interval 1.1-4.2)										2.8
Emission from ditches - not included in the plot, (tCO2-eq/ha /growing season)									7,59	7,59
Cumulative for peatland site type, including ditches										10,48

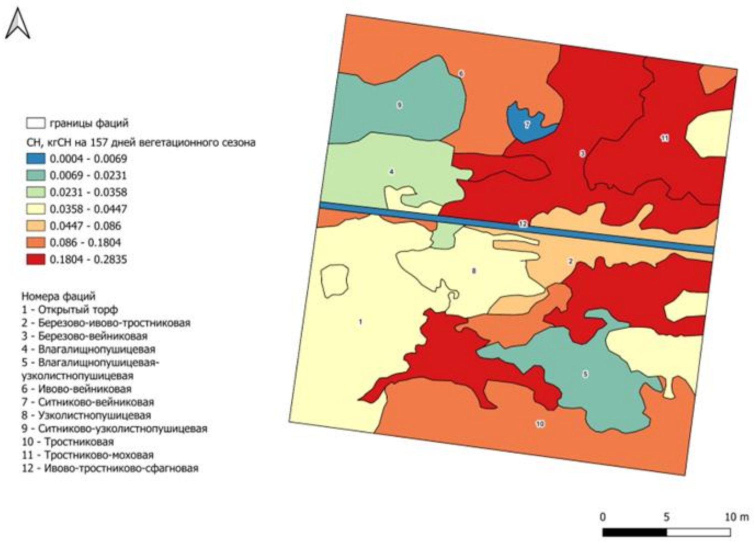
Comparing Eddy-covariance measurements with chamber measurements within the footprint

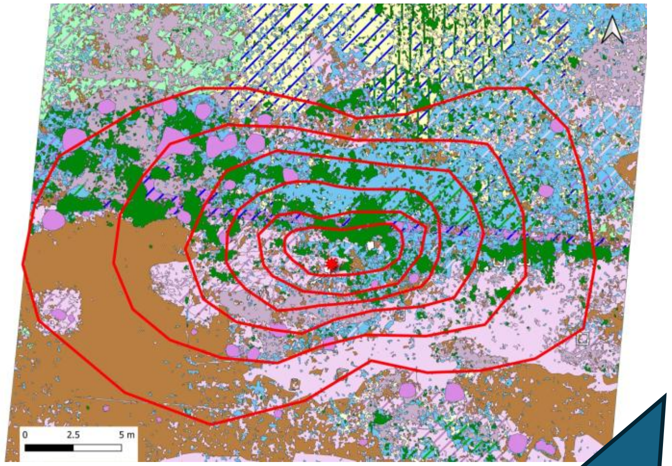
Parameter	Type of Equipment	Model and Country of Origin
CO_2 and H_2O Concentrations	Closed-path Gas Analyzer	LI-7200 (USA)
CH_4 Concentration	Open-path Gas Analyzer	LI-7700 (USA)
Photosynthetically Active Radiation (PAR)	Sensor	LI-190 (USA)
Wind Speed and Direction	3-D Sonic Anemometer	R3-50 (Gill Instruments, UK)
Soil Temperature	Sensor	Campbell (USA)
Soil Heat Flux	Sensor	HFP01SC (Hukseflux, Netherlands)

Footprint model calculated after: Kljun, N., P. Calanca, M.W. Rotach, H.P. Schmid, 2015: A simple two-dimensional parameterisation for Flux Footprint Prediction (FFP). Geosci. Model Dev., 8, 3695-3713. doi:10.5194/gmd-8-3695-2015

	growing season		winter		year		growing season		winter		year		EF
	tC-CO2/ha	kgCH4 ha	тC-CO2/га	кгCH4 га	TC-CO2*ha-1	kgCH4 га	TCO2eq*ha-1	CH4, TCO2-eq*ha-1	тCO2*ha-1	CH4, TCO2-eq*ha-1	тCO2*ha-1	CH4, TCO2-eq*ha-1	TCO2eq*ha-1*year-1
Tower	1,60	17,5	0,3	2,3	1,9	19,8	5,9	0,47	1,1	0,06	6,9	0,5	7,5
chambers (70% footprint)	0,9	10,0	0,3	2,3	1,2	12,3	3,5	0,27	1,1	0,06	4,5	0,3	4,8

What method should be chosen to develop a specific emission factor at a project level?





method	EF , TCO2eq*ha-1*year-1
Hierarchical extrapolation from microcoenoses to the random plot	**3,58**
Eddy-covariance	**7,5**
Hierarchical extrapolation from microcoenosis to the footprint	**4,8**
IPCC, managed for extraction peatlands	**2,8**

1. Improvement of chamber measurement techniques
2. Mapping and hierarchical extrapolation
3. Accurate interpretation of Eddy covariance data

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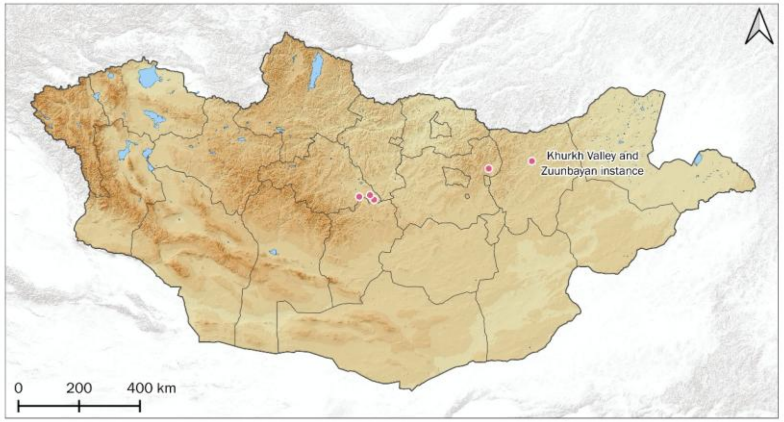
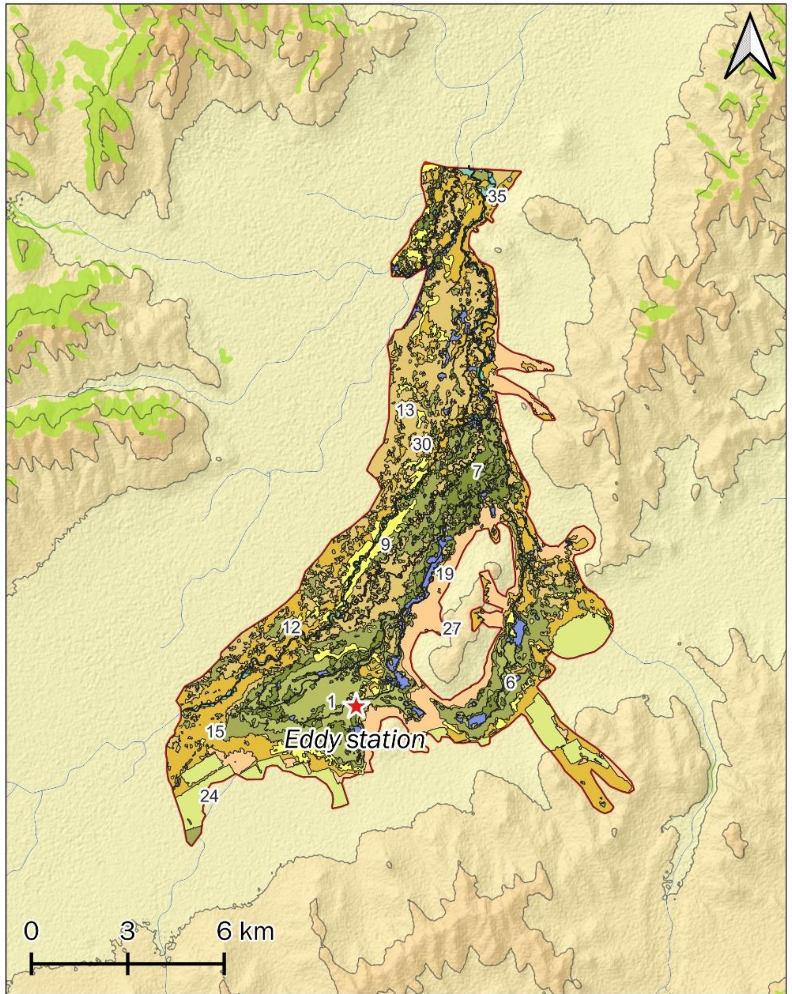
Upscaling approach to other projects: Mongolia and Peru



Legend

- National boundary
- Province boundary
- Project area
- Forest
- Lake
- River
- Project areas

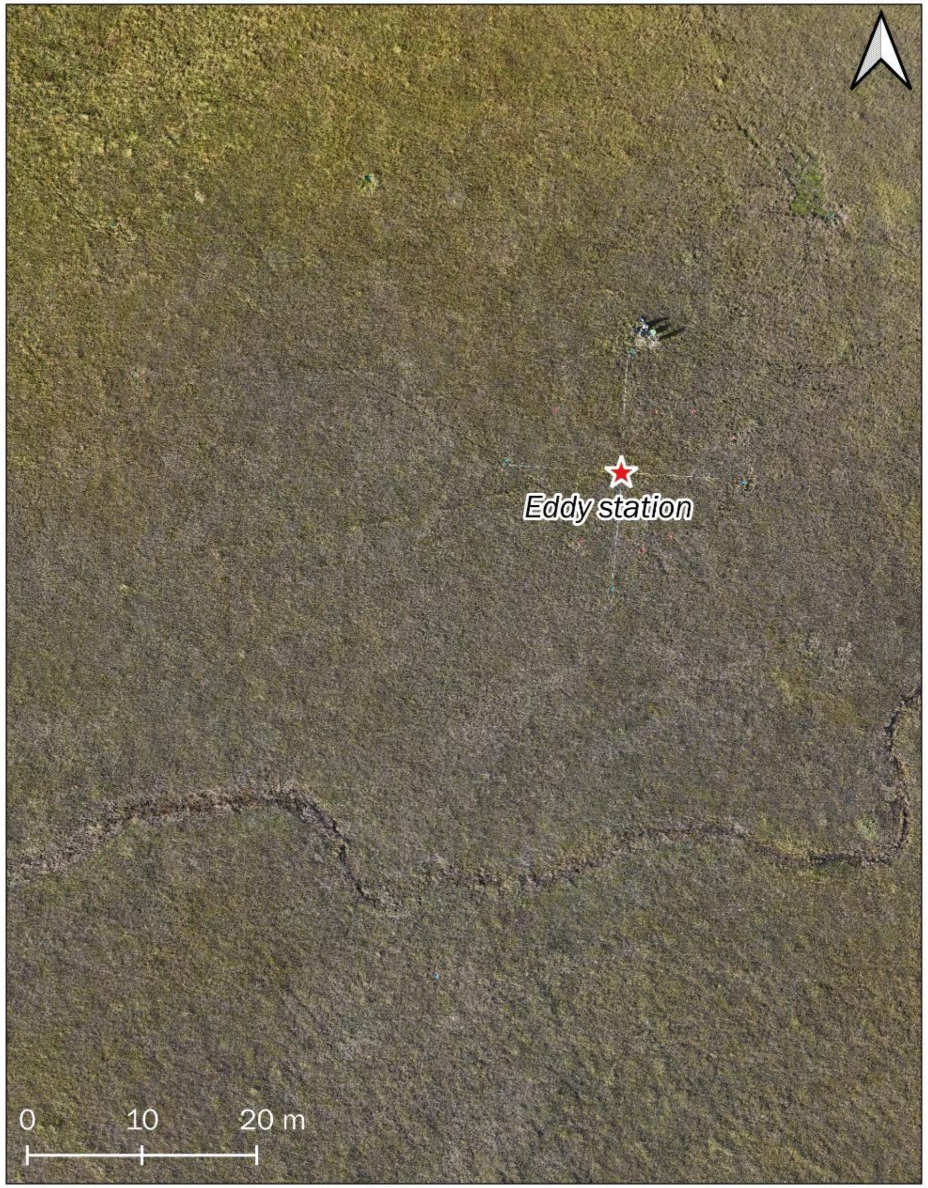


Legend

- Project area

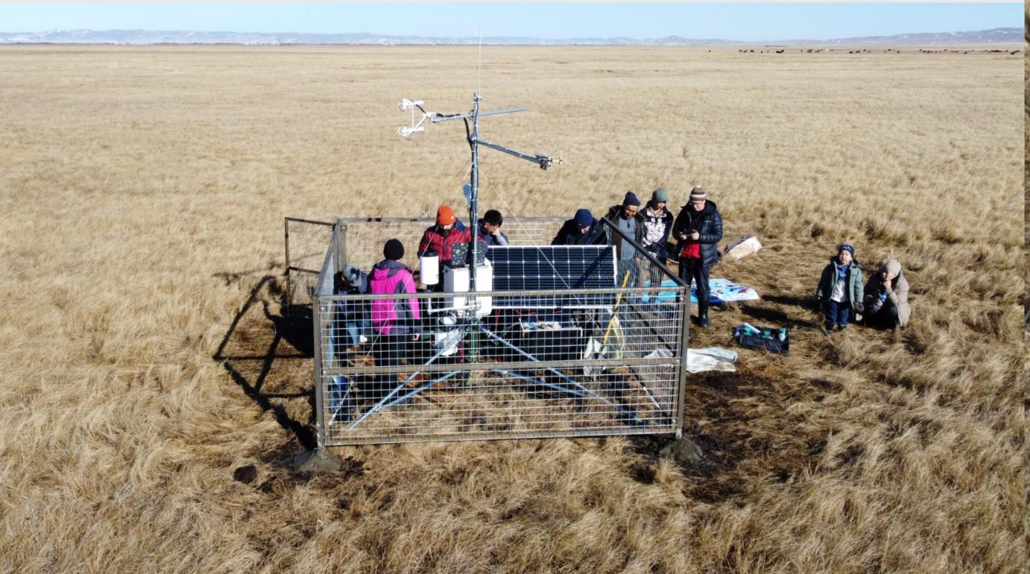
Vegetation classification

- 1. Fen on permafrost
- 6. Shalow peat wet meadows
- 7. Spring, riparian, lacustrian near water peatlands
- 8. Open water on peat
- 9. Overgrased fen with degraded or without permafrost
- 12. Deciduous forest on peat under degradation
- 13. Shalow peat wet meadows under degradation
- 15. Degraded wet meadows on sod-peaty soils
- 19. Flooded open peatlands
- 24. Arable lands on peat
- 25. Construction on peat
- 27. Meadow
- 30. Open water on mineral backgrounds
- 35. River and lake open and partly open mineral ground
- 34. Dried out fresh and salty lakes on mineral soil

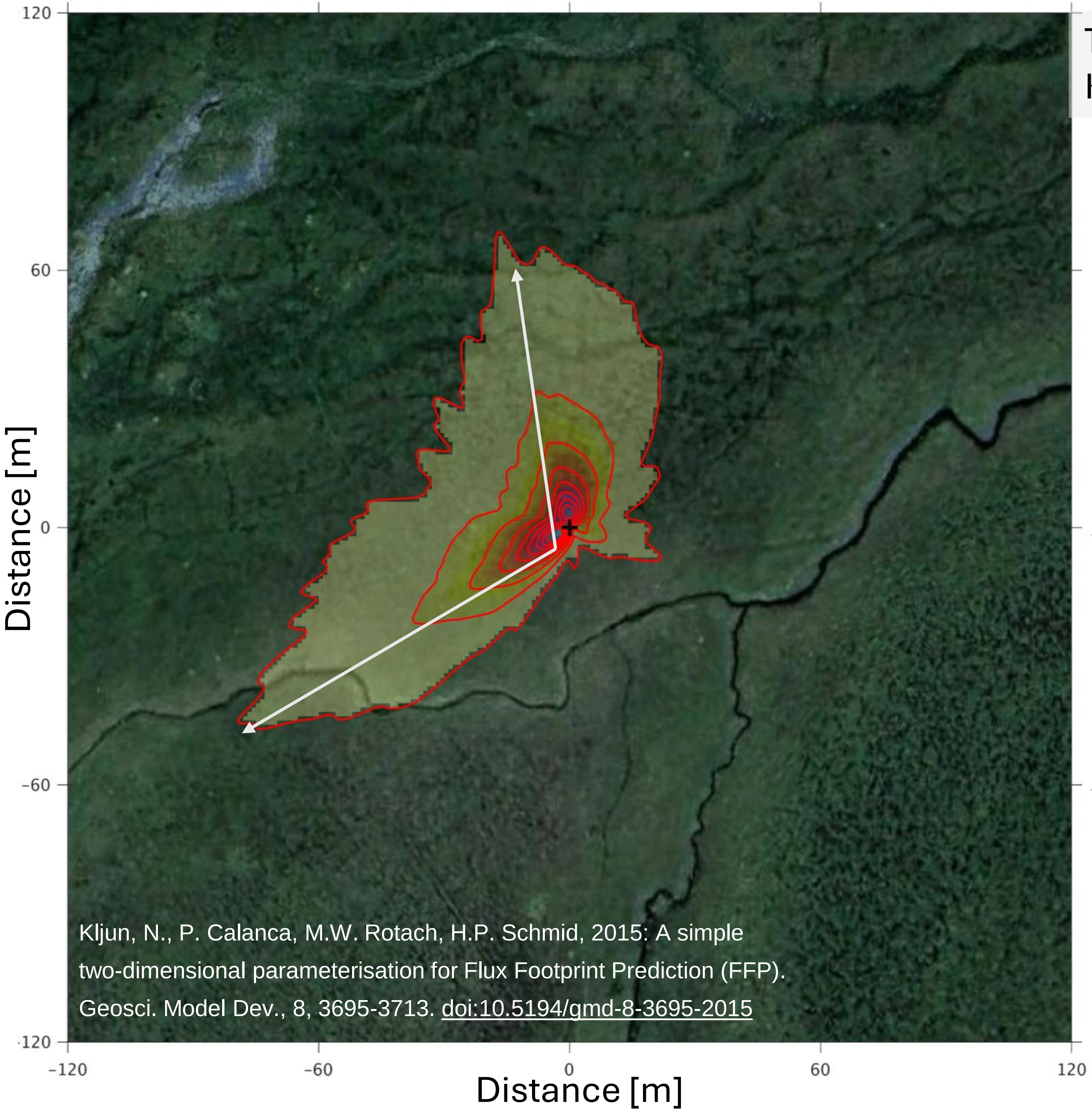


Khurkh EDDY station

The eddy covariance station was set up at 48°18'27.75" N, 110°20'43.12" E, on a representative peatland surface in Khurkh Valley. The primary eddy covariance system included an IGRASON Campbell Scientific, Inc., USA unit, which integrates a 3D sonic anemometer and an open-path infrared CO_2 H2O gas analyser, mounted at a height of 2.85 meters. To complement the atmospheric measurements, radiation and precipitation sensors were installed. Additionally, soil sensors were placed at depths of 5 cm, 20 cm, and 50 cm to monitor temperature and moisture levels.

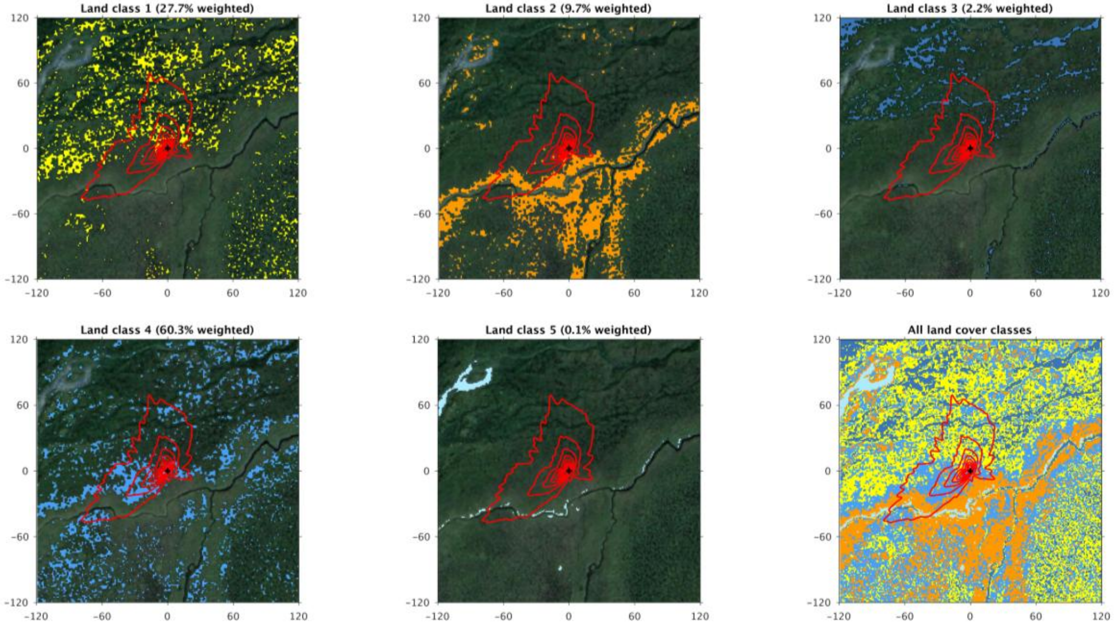


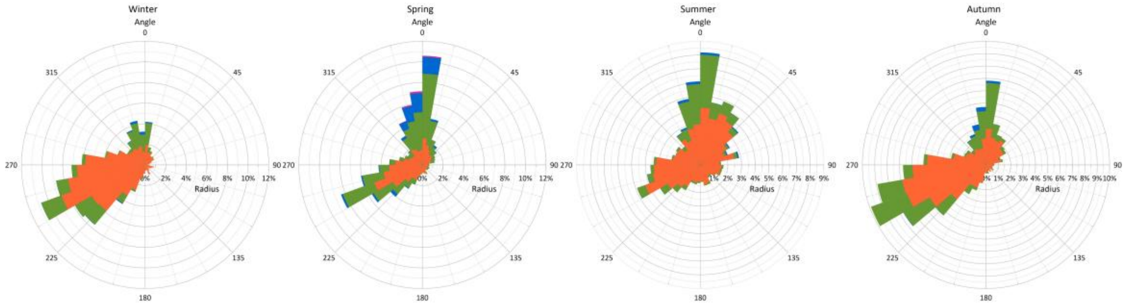
The footprint climatology for the Khurkh eddy station Khentii province, Mongolia, for Jan to April 2025



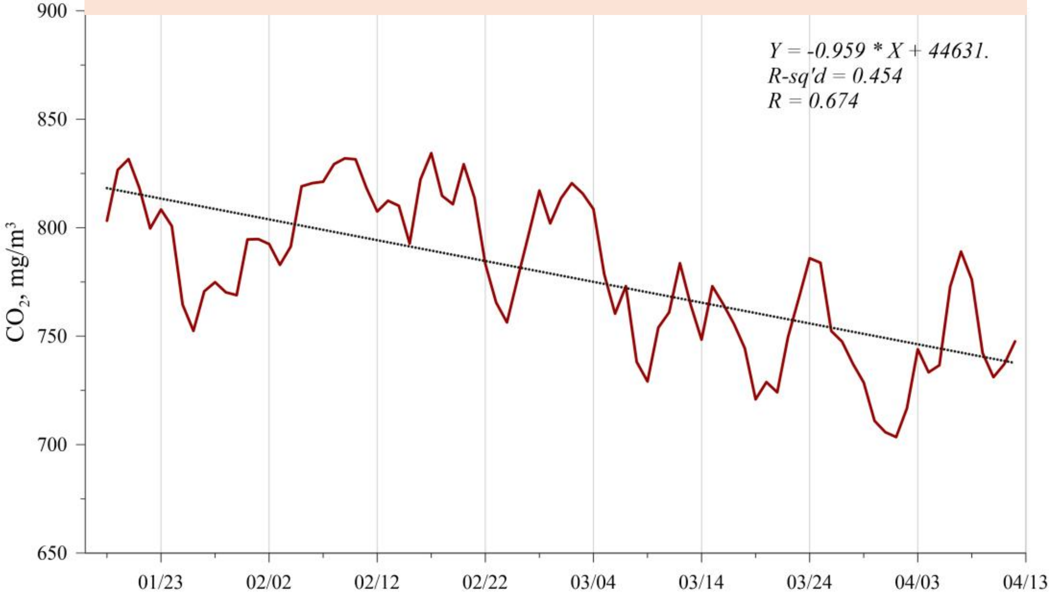
Kljun, N., P. Calanca, M.W. Rotach, H.P. Schmid, 2015: A simple two-dimensional parameterisation for Flux Footprint Prediction (FFP). Geosci. Model Dev., 8, 3695-3713. doi:10.5194/gmd-8-3695-2015

Cumulative footprint areas (50%, 70%, 80%, 90% contours) were mapped. Dominated by Land Class 4 (~60.3% contribution to fluxes).Small contributions from Land Class 1 (~27.7%) and other classes.

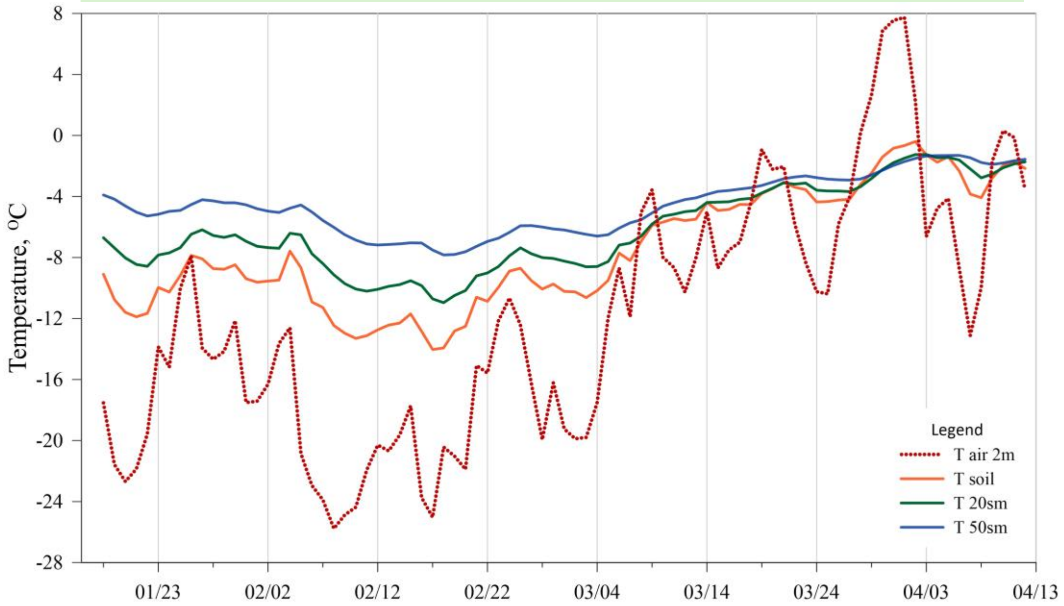




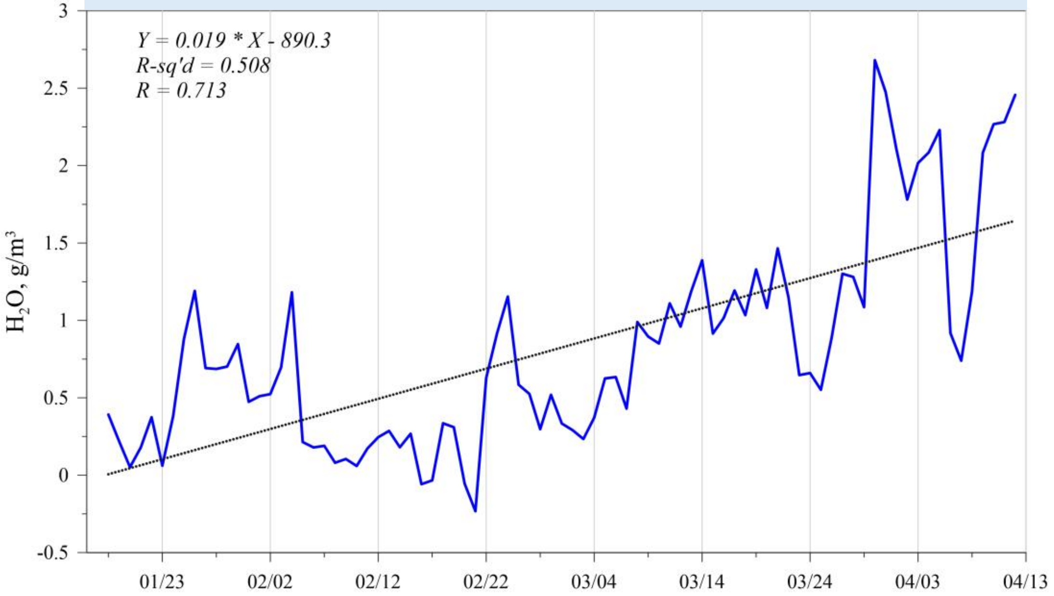
CO2 Mass Density



Air and soil temperature



H2O Mass Density



- The first graph illustrates a declining trend in daily average CO_2 concentration (mg/m^3) from late January to mid-April, with a regression line indicating a decrease of approximately 0.96 mg/m^3 per day (R^2 = 0.454), likely reflecting increased photosynthetic activity and seasonal warming.
- The second graph shows a clear upward trend in water vapor (H_2O) concentration (g/m^3), increasing by about 0.019 g/m^3 per day (R^2 = 0.508), suggesting rising humidity levels associated with warmer temperatures and possibly higher evapotranspiration.
- The third graph compares air temperature at 2 meters with soil temperatures at the surface, 20 cm, and 50 cm depths, all showing a gradual warming trend; the air and surface temperatures fluctuate more strongly than those at depth, indicating greater stability in subsurface thermal conditions.

Thank you!
Join us!

Tatiana.minayeva@care-for-ecosystems.net

Table 1 Catalogue of microforms (microcoenoses, used for large-scale mapping and chamber measurements)

	N Microcenosis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Microcenosis name	Juncus effusus - Calamagrostis epigeios	Eriophorum vaginatum	Phragmites australis	Betula spp.- Polytrichum spp.	Juncus effusus	Eriophorum angustifolium wet	Eriophorum angustifolium dry	Bare peat	ditch	
	Nanorelief	small tussoks and flat surface	hummok	flat surface	slight elevation of the canal edge	hummok	depression	flat surface	flat surface	Drainage channel	
	Disturbance type	Abandoned milled field	Abandoned milled field	Abandoned milled field	Abandoned milled field	Abandoned milled field	Abandoned milled field	Abandoned milled field	Abandoned milled field	Drainage channel	
	Peat depth	60	50	60	70	40	40	60	60	NA	
	Peat decomposition degree	50-60	50-60	50-60	50-60	50-60	50-60	50-60	50-60	NA	
Total cover,%	**Averaged for july**	53	98	27	47	67	79	60	0	NA	
Total cover,%	**Min**	40	98	15	10	60	60	40	0	NA	
Total cover,%	**Max**	70	98	35	80	80	98	70	0	NA	
Herb layer cover,%	**Averaged for july**	53	98	27	18	67	79	60	0	NA	
Herb layer cover,%	**Min**	40	98	15	10	60	60	40	0	NA	
Herb layer cover,%	**Max**	70	98	35	25	80	98	70	0	NA	
Herb layer hight,%	**Averaged for july**	70	65	62	73	72	62	32	0	NA	

	N Microcenosis	1	2	3	4	5	6	7	8	9	
Herb layer hight,%	**Min**	60	55	55	60	50	60	25	0	NA	
Herb layer hight,%	**Max**	80	70	70	100	85	65	40	0	NA	
Moss layer cover, %	**Averaged for july**	0	1	43	65	0	0	21	0	NA	
Moss layer cover, %	**Min**	0	1	40	55	0	0	1	0	NA	
Moss layer cover, %	**Max**	1	1	50	80	0	0	60	0	NA	
Litter cover, %	**Averaged for july**	90	60	37	42	73	57	62	0	NA	
Litter cover, %	**Min**	85	60	30	30	70	50	50	0	NA	
Litter cover, %	**Max**	95	60	40	50	80	60	70	0	NA	
Undrgrowth cover, %	**Averaged for july**	0	2	1	47	0	0	0	0	NA	
Undrgrowth cover, %	**Min**	0	0	0	30	0	0	0	0	NA	
Undrgrowth cover, %	**Max**	0	5	3	60	0	0	0	0	NA	
Open water, %	**Averaged for july**	0	0	0	0	0	20	0	0	NA	
Open water, %	**Min**	0	0	0	0	0	0	0	0	NA	
Open water, %	**Max**	0	0	0	0	0	60	0	0	NA	
Bare peat, %	**Averaged for july**	0	0	25	0	0	0	8	100	0	

	N Microcenosis	1	2	3	4	5	6	7	8	9	
Bare peat, %	**Min**	0	0	15	0	0	0	5	100	0	
Bare peat, %	**Max**	0	0	40	0	0	0	10	100	0	
Vascular plants biomass, g/sq.m	**Avg**	471,43	1895,50	118,67	261,95	1147,23	383,75	420,38	0,00	NA	
Vascular plants biomass, g/sq.m	**std**	131,82	751,96	35,38	152,08	360,43	115,17	153,02	0,00	NA	
Vascular plants biomass, g/sq.m	**Max**	675,2	2651,1	159,3	548,5	1577	574,7	611,4	0,00	NA	
Vascular plants biomass, g/sq.m	**Min**	289,8	1027,3	75,8	133,6	599,4	248,8	266,9	0,00	NA	
Mosses biomass, g/sq.m	**Avg**	0,00	7,22	82,60	234,63	4,25	1,06	1,91	0,00	NA	
Mosses biomass, g/sq.m	**std**	0,00	13,78	81,49	116,40	9,79	2,60	4,09	0,00	NA	
Mosses biomass, g/sq.m	**Max**	0	34,398	244,608	386,022	24,206	6,37	10,192	0,00	NA	

	N Microcenosis	1	2	3	4	5	6	7	8	9	
Mosses biomass, g/sq.m	**Min**	0	0	17,836	49,686	0	0	0	0,00	NA	
Mortmass, g/sq.m	**Avg**	168,40	1298,63	44,93	14,33	925,17	626,65	276,50	0,00	NA	
Mortmass, g/sq.m	**std**	111,79	539,57	26,72	13,14	363,70	203,07	132,38	0,00	NA	
Mortmass, g/sq.m	**Max**	379,4	2221,2	77,7	36,4	1315,7	1039,5	482	0,00	NA	
Mortmass, g/sq.m	**Min**	56,6	791,2	10,1	3,7	522,5	515	153,5	0,00	NA	
Litter, g/sq.m	**Avg**	625,75	416,39	171,99	271,57	390,69	397,91	171,99	0,00	NA	
Litter, g/sq.m	**std**	162,19	233,16	95,25	155,55	171,55	179,23	94,56	0,00	NA	
Litter, g/sq.m	**Max**	840,84	654,836	300,664	481,572	535,08	710,892	331,24	0,00	NA	
Litter, g/sq.m	**Min**	397,488	188,552	77,714	57,33	101,92	210,21	68,796	0,00	NA	
ΔR T0/10	**Averaged for the season**	-0,232745313	-0,232001	-0,3023396	-0,262000543	-0,219005	-0,277731464	-0,290093983	-0,374357329	NA	
ΔR T0/10	**Min**	-0,380697024	-0,450592	-0,4293973	-0,425046035	-0,31839	-0,427868484	-0,429153517	-0,611017101	NA	
ΔR T0/10	**Max**	-0,052820873	-0,132381	-0,1069294	-0,068559707	-0,112384	-0,157113997	-0,093499377	-0,137697557	NA	
BWL	**BWL averaged**	-35	-29,4	-37	-39,8	-24,6	-24,6	-43,4	-39,8	NA	
BWL	**Min**	-50	-50	-60	-70	-40	-40	-61	-70	NA	

	N Microcenosis	1	2	3	4	5	6	7	8	9	
BWL	Max	-20	-10	-10	-20	0	0	-11	-10	NA	
Peat density, g/cm3	Averaged for the season	0,3	0,3	0,3	0,2	0,3	0,3	0,2	0,3	NA	
Peat density, g/cm3	Min	0,3	0,2	0,3	0,2	0,2	0,2	0,2	0,3	NA	
Peat density, g/cm3	Max	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	NA	
Peat moisture, %	Averaged for the season	41,0	37,3	41,4	48,1	47,9	47,9	43,3	54,3	NA	
Peat moisture, %	Min	25,5	18,1	27,9	27,5	25,9	25,9	36,5	39,6	NA	
Peat moisture, %	Max	46,5	53,4	50,1	58,8	73,8	73,8	55,3	89,5	NA	
Ash content of peat, %	Averaged for the season	4,5	18,4	16,8	12,3	12,5	12,5	10,3	15,4	NA	
Ash content of peat, %	Min	4,5	18,4	16,8	12,3	12,5	12,5	10,3	15,4	NA	
Ash content of peat, %	Max	4,5	18,4	16,8	12,3	12,5	12,5	10,3	15,4	NA	
pH	Averaged for the season	4,9	4,8	5,3	5,2	4,6	4,6	4,6	4,4	NA	
pH	Min	4,0	4,2	5,2	4,7	4,2	4,2	4,1	4,1	NA	

	N Microcenosis	1	2	3	4	5	6	7	8	9	
pH	**Max**	5,4	6,1	5,5	5,5	5,2	5,2	5,2	4,8	NA	
Field Peat moisture, %	**Averaged for the season**	43,90	53,10	54,18	42,63	60,43	60,43	39,33	67,58	NA	
Field Peat moisture, %	**Min**	19,00	25,90	36,50	27,90	26,20	26,20	18,10	39,60	NA	
Field Peat moisture, %	**Max**	74,60	93,00	91,00	53,80	98,00	98,00	57,40	93,00	NA	
Square, m2		62,5	22,6	187,5	95,4	11,7	116,9	224,7	183,9	NA	
Share of the total area of the plot, %		6,9	2,5	20,7	10,5	1,3	12,9	24,8	20,3	NA	
CO2, tCO2-equiv /ha /grow seas	**avr**	9,38	9,12	5,00	7,35	3,31	-2,21	-2,53	4,14	6,93	
CO2, tCO2-equiv /ha /grow seas	**min**	-34,92	-16,03	-30,38	-56,77	-38,34	-44,50	-42,25	2,70	0,00	
CO2, tCO2-equiv /ha /grow seas	**max**	65,13	40,17	22,56	70,51	41,50	29,23	25,94	5,05	47,19	
CH4, tCO2-equiv /ha /grow seas	**avr**	0,05	0,00	0,45	0,63	0,01	0,08	0,24	0,00	0,67	
CH4, tCO2-equiv /ha /grow seas	**min**	-0,18	-0,06	0,13	0,13	-0,07	-0,07	-0,01	-0,01	-0,06	

	N Microcenosis	1	2	3	4	5	6	7	8	9	
CH4, tCO2-equiv /ha /grow seas	**max**	0,19	0,10	2,60	3,05	0,12	0,41	0,47	0,02	2,91	
GWP, tCO2-equiv /ha /grow seas	**avr**	9,43	9,13	5,45	7,98	3,32	-2,13	-2,29	4,14	7,59	
GWP, tCO2-equiv /ha /grow seas	**min**	-35,10	-16,09	-30,25	-56,63	-38,42	-44,57	-42,26	2,69	-0,06	
GWP, tCO2-equiv /ha /grow seas	**max**	65,31	40,27	25,16	73,56	41,62	29,65	26,42	5,08	50,09	

Table 2 EF of the peatland site type calculated from microform mapping, growing season and a year

Microcenosis number	**1,00**	**2,00**	**3,00**	**4,00**	**5,00**	**6,00**	**7,00**	**8,00**	**9,00**		
Microcenosis name	Juncus effusus - Calamagrostis epigeios	Eriophorum vaginatum	Phragmites australis	Betula spp.- Polytrichum spp.	Juncus effusus	Eriophorum angustifolium wet	Eriophorum angustifolium dry	Bare peat	ditch	EF for growing season	EF for year
Input of microcoenoses to the emission factor of the plot (tCO2-eq/ha /growing season)	0,65	0,23	1,13	0,84	0,04	-0,27	-0,57	0,84	0,00	2,89	3,58

Emission from ditches - not included in the plot, (tCO2-eq/ha /growing season)								ditches	7,59	7,59	
								Cummulative		10,48	

Table 3 Fluxes and emission factors calculated from microcoenoses within the 70 % footprint

	growing season		winter		year		growing season		winter		year		EF
	tC-CO2/ha	kgCH4 ha	тС-CO2/га	кгCH4 га	TC-CO2*ha-1	kgCH4 га	TCO2eq*ha-1	CH4, TCO2-eq*ha-1	тCO2*ha-1	CH4, TCO2-eq*ha-1	тCO2 *ha-1	CH4, TCO2-eq*ha -1	TCO2eq* ha-1*year-1
tower	1,60	17,5	0,3	2,3	**1,9**	**19,8**	5,9	0,47	1,1	0,06	**6,9**	**0,5**	**7,5**
chambers (70% footprint)	0,9	10,0	0,3	2,3	**1,2**	**12,3**	3,5	0,27	1,1	0,06	**4,5**	**0,3**	**4,8**

Emission factors for CO_2 for peatland Managed for extraction, t C-CO_2 ha-1 year-1 2.8 (95% confidence interval 1.1-4.2)

CH_4 EMISSION/REMOVAL FACTORS FOR DRAINED ORGANIC SOILS, kg CH_4 ha-1 year-1 среднее при доле канав 5% 32,895 (95% confidence interval 6.6-59.5)