Spatial variation of soil respiration on a drained peatland: A case study from Lettosuo-peatland, Finland

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Soil respiration (Rs), especially from drained peatland, has a significant role in the global carbon cycle. Drained peatland adds more CO_2 effluxes due to the aerobic condition and fast decomposition rate of organic matter. In such condition, peatlands are no more carbon sink rather than a source. However, soil respiration (Rs) is known to be markedly variable with time and space. Many ecological studies showed an exact measurement of Rs is critical. Even a spatial variability of Rs is less known at a plot scale. This study investigated the spatial variation of Rs and its relationship with some explanatory factors (soil temperature, water-table level, moss cover, drainage ditch distance, and vegetation cover) in Lettosuo-peatland, Tammela, Finland. Soil respiration (Rs), soil temperature (Ts), and water-table level (WTL) were measured at 98 sampling plots during May to August 2017. A closed chamber system is known as Environmental Gas Monitor (EGM) was used to measure soil respiration. Once at the end of the measurement in August, vegetation site type (St), ditch distance (Dd), field layer vegetation (FLV), and ground layer vegetation (peat moss (M_p), forest moss (M_f)) were measured. The results showed that the mean rate of CO_2 efflux was 0.49 ± 0.1 (± Std) g CO_2 m^{-2} h^{-1} at 13.51 ± 0.8 (± Std) °C (at 5 cm depth) ranging from 0.15 to 0.98 g CO_2 m^{-2} h^{-1}. A multiple linear model indicated (R^2 =0.18) that about 18% of the spatial variation of Rs could be explained by Ts, WTL, and Dd collectively, but only WTL (R^2 = 0.12) could explain 12% variation alone. The spatial variability of soil respiration was mainly driven by the variability in WTL.

Avainsanat – Nyckelord – Keywords
Soil respiration, spatial variation, drained peatland, soil temperature, water-table

Säilytyspaikka – Förvaringsställe – Where deposited

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Contents

Abbreviations

C	Carbon
CO_2	Carbon Dioxides
CV	Coefficient of variance
Dd	Ditch distance
Dn	Ditch network
ECT	Eddy Covariance Tower
EGM	Environmental Gas Monitor
FLV	Field layer vegetation
Fm	Forest moss
GHG	Greenhouse gas
OM	Organic matter
Pm	Peat moss
Ra	Autotrophic respiration
Rh	Heterotrophic respiration
Rs	Soil respiration
Std	Standard deviation
SMC	Soil moisture content
SOM	Soil organic matter
St	Site type
Ts	Soil temperature
WTL	Water-table level

1 INTRODUCTION

1.1 Background of the study

Peatlands are an important ecosystem that store carbon and act as a sink of atmospheric CO_2 (Bleuten et al. 2006) sustained by a humid climate with a high water table. Here in this ecosystem, organic matter (OM) becomes partially decomposed in the aerobic soil surface and deposited as peat. The lower part of this aerobic surface is anaerobic because of water-saturated conditions. In such conditions, the decomposition rate is much slower due to the lack of sufficient oxygen as well as low temperature and phenol toxicity. This anaerobic surface becomes aerated and subject to rapid decomposition after drainage. In peatlands, the growing vegetation provides soluble carbohydrates and cellulose-containing fresh litter which led decomposition rate faster rather than the less soluble lignin-containing old litters and debris, and as an outcome, it emits CO_2 to the atmosphere. In Finland, drainage of peatland is carried out for land conversion in term of land use for forestry, agriculture, peat extraction etc. Approximately 60% (6 million ha) of the original peatland area of 10 million ha, which is one third of the whole land area in Finland, has been drained and managed for agriculture and especially for forestry. Nowadays about 4.9 million ha of forest land is in drained, and 4 million ha is still in pristine condition (Minkkinen 2007).

Soil respiration process is strongly influenced by many abiotic factors (e.g., soil temperature and water table) and biotic factors (e.g., organic matter and living biomass) which are difficult to clutch because of their spatial and temporal changes. In term of spatial Rs, it is crucial to estimate representative Rs within an ecosystem where the distribution of the influencing factors and organisms are inconsistent (Liu 2016). It is already a burning research topic which increasingly demands further research. As such, the spatial variation in soil respiration considering the factors is still poorly known. In addition, research on soil respiration and its influencing factors is important not only to investigate the role of biological processes in ecosystem carbon efflux but also to evaluate of the status and function of the terrestrial ecosystem in the global carbon cycle (Huang et al. 2011). CO_2 emission through soil respiration (Rs, CO_2 efflux from soil) from a terrestrial ecosystem is the second largest carbon-cycling efflux. So, the drained peatland ds of Finland substantially contributes to CO_2 emissions (Alm et al. 2007).

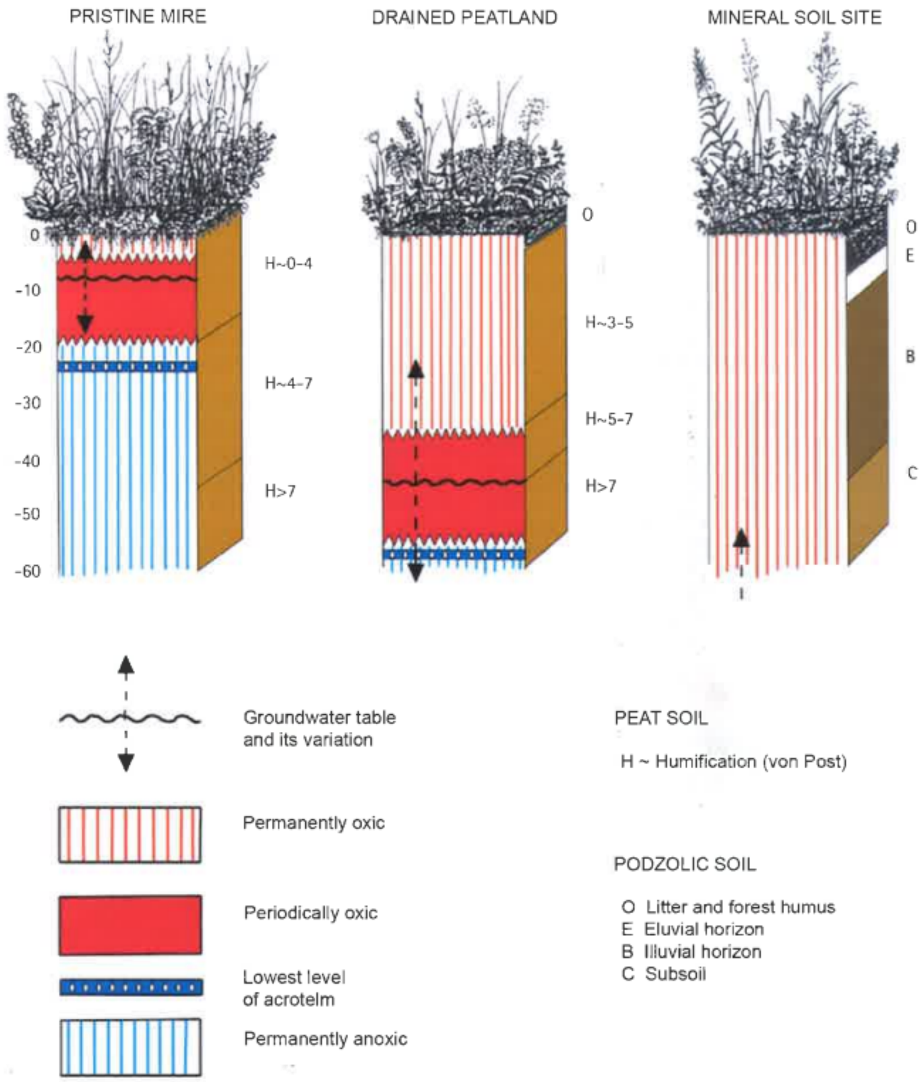


Figure 1: A schematic representation of surface soil profile (0-60 cm) in a pristine mire, peatland site drained for forestry, and mineral soil site (Päivänen and Hånell, 2012a).

1.2 Soil respiration

Soil contains almost two times as much carbon as the total of the atmosphere and the vegetation (Groenigen et al. 2015). The efflux of CO_2 to the atmosphere is known as soil respiration (Rs). This efflux is treated as a loss of C from the soil system through a process (Figure 2) to form soil organic matter (SOM) by microbial decomposition of organic residues (Yanardag 2015). Soil respiration is one of the important components of the terrestrial C cycle and it accounts for about 30 to 90% of the total ecosystem respiration in forest ecosystems (Zongda et al. 2016). In terrestrial ecosystems, Rs is estimated to be 50 to 75 Pg C year^{-1}. However, respiration of the soil is the sum of respiration of plant roots (autotrophic respiration, R_a) and organic matter (OM) decomposition (heterotrophic respiration, R_h) (Ishikura et al. 2017).

Many studies showed similar changes in Ra and Rh over a season, while Ra increases to some extent later in the growing season than Rh. The corresponding contribution of Ra and Rh varies greatly from 10 to 90% depending on the measurement season of the year, measurement technique, and the type of the ecosystem. Measurements revealed that Rh contributed 66 to 82% of Rs in a 26-year old longleaf pine forest in western Georgia, 52 to 56% in a Scots pine forest in northern Sweden (Daly 2016), and 50% in a deciduous forest in the Hudson Highlands of USA (Levy-Varon et al. 2012).

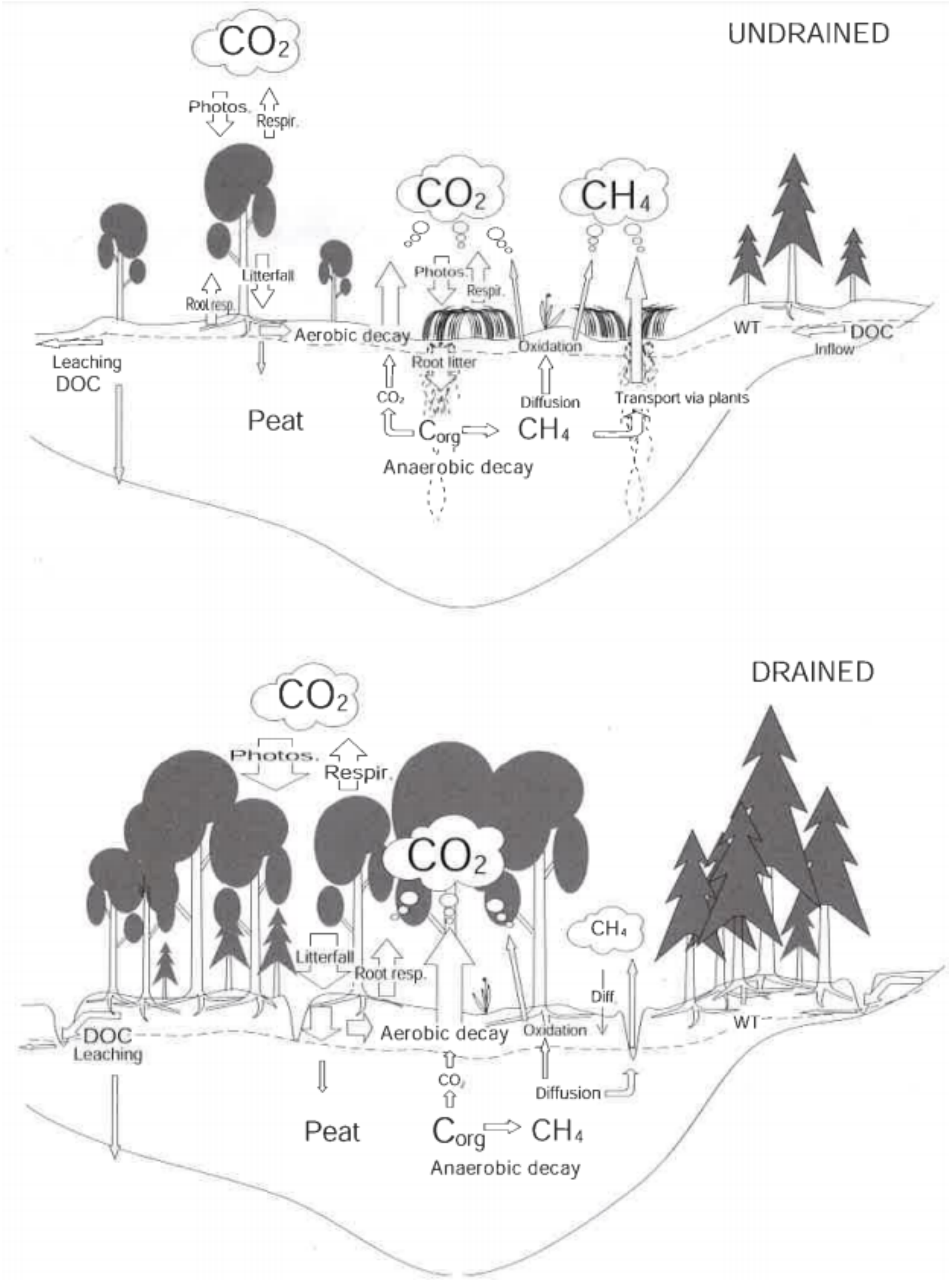


Figure 2: Carbon (C) cycle in undrained mires and peatlands drained for forestry. (Minkkinen 1999).

1.2.1 Autotrophic respiration

Photosynthesis is the process of C fixation by plants. The term "photosynthesis" refers to the amount of carbon fixed by gross photosynthesis minus the carbon lost by photorespiration. This loss by photorespiration is known as autotrophic respiration (Ra) which is almost 50% C that of fixed by plants (Kirschbau et al. 2001). Ra accounts for the respiration caused by plant roots and their associated mycorrhizae. Basically, the associated mycorrhizae are the fungi which expose a mutually beneficial relationship with roots (Figure 3). Because of the association, the plant roots get a wide surface area for absorption, growing the fungal hyphae about 5 to 15 cm farther around the roots (Brady & Weil 2008). This association provides survival capability during drought season by facilitating large mycorrhizal communities, thus absorbing water and nutrients from the soil (Van et al. 2011).

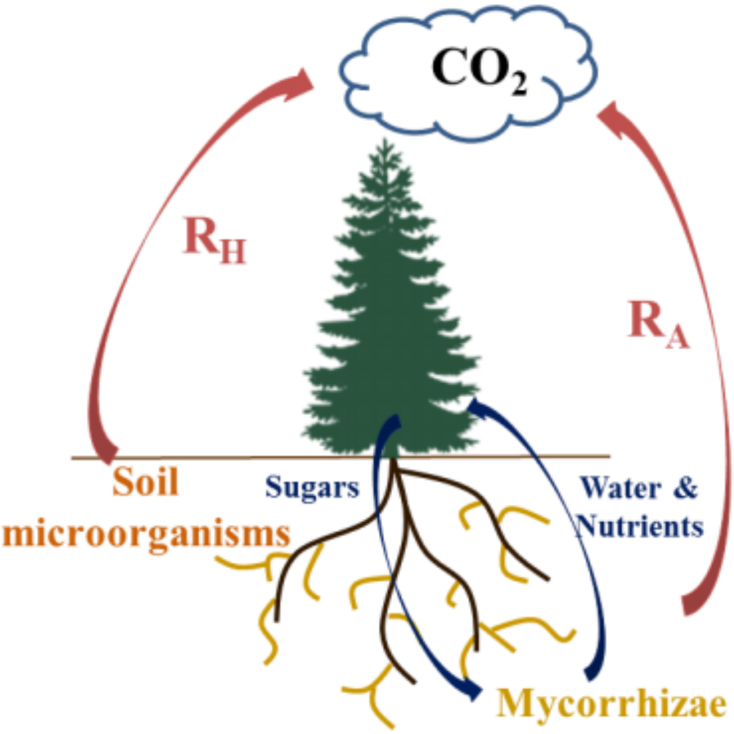


Figure 3. A simplified visualization of the autotrophic (Ra) and heterotrophic (Rh) respiration, along with the symbiotic relationship between roots and their associated mycorrhizae (Daly 2016).

In a forest ecosystem, autotrophic respiration (Ra) is an important component of the global C cycle. Only about 30 to 50 % of photosynthesis is used for maintenance and development of plant tissues, while the rest emits to the atmosphere as Ra. Annually, about 45 to 55 Pg C of CO_2 is produced from global forest Ra which is six to seven times of annual carbon released from fossil fuel combustion, and approximately one-fifteenth of total CO_2 in the atmosphere.

However, still, we do not have a clear understanding of Ra and its responses to environmental changes. A number of studies found that Ra was affected directly or indirectly by biotic and abiotic factors, such as age, temperature, nitrogen content etc. (Piao et al. 2010).

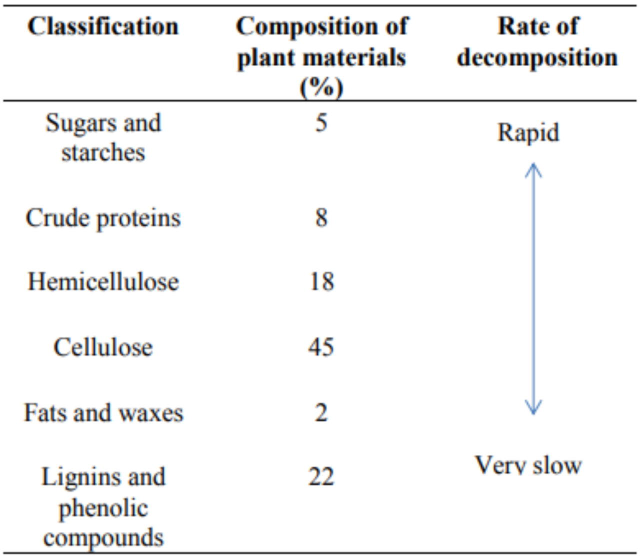
1.2.2 Heterotrophic respiration

Heterotrophic respiration (Rh) indicates C loss by the primary organisms (microbes) other than the plants in an ecosystem. It is consisted of the respiration from above-ground by animals, which is a minor constituent, and the below-ground litter layer along with decomposed OM influenced by litterfall, root turn-over, root exudation, dead organisms, and fecal matter. It also counts the loss of C through the decomposition of standing dead trees and coarse woody debris (Kirschbau et al. 2001).

Decomposition of OM is a process where OM breaks down into smaller molecules due to the activity of soil microbes. Soil microbes get energy (eq. 1) for their lives from breaking down the OM. Litter fall is the key component which undergoes decomposition by soil microorganisms. Actually, the rate of decomposition depends on the chemical composition if the litter (Table 1) (Thangarajan et al. 2013).

$$M + 2O_2 \xrightarrow{oxidation} CO_{2(g)} + H_2O + Energy \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Table 1. Organic compounds in plant tissues, organized into broad classes showing their relative percentage within typical green-plant material and relative rate of decomposition (Daly 2016).



Classification	Composition of plant materials (%)	Rate of decomposition
Sugars and starches	5	Rapid
Crude proteins	8	↕
Hemicellulose	18	
Cellulose	45	
Fats and waxes	2	
Lignins and phenolic compounds	22	Very slow

1.3 Soil respiration controlling factors

1.3.1 Soil temperature

Soil temperature (Ts) is considered as a most important abiotic factor which has a strong effect on temporal variation in Rs. The rapid decomposition rate of OM is influenced by high soil temperature and low water table (Jassal et al. 2008; Liu et al. 2009; Moyano et al. 2012). Basically, the decomposition rate is dominated by the influence of Ts through the regulation of the kinetics of microbial activities, diffusion of enzymes and substrate (Beng 2017).

Current studies have found Ts as a most significant explanatory factor to reveal the temporal variation in soil respiration, and up to 96% of Rs within a peatland can be explained by Ts (Mäkiranta et al. 2007, 2008). Another study has revealed a large spatial variation in Rs with changes in temperature within and between peatlands (Minkkinen et al. 2007b). Organic matter decomposition rate and the microbial community structure behind the decomposition bring out the spatial variation in soil respiration. The activities of different microorganisms might vary with temperature (Pietikäinen et al. 2005). However, many studies have indicated a positive relationship between soil respiration and temperature (Zongda et al 2016).

1.3.2 Water-table level (WTL)

Water table level (WTL) is often considered as a major controlling factor of heterotrophic soil respiration from a peatland. It affects soil carbon storage and loss in peatlands (Hirano et al. 2007). In a peatland ecosystem, it acts as an important source of soil moisture (Jauhiainen et al. 2012). Lowering water table level has increasing trend in soil respiration rate in peatlands (Silvola et al. 1996; Chimner and Cooper 2003) due to the higher oxygen content entering into unsaturated peat surfaces providing more active transportation and higher aerobic respiration (Li et al. 2007; IPCC 2013). It has also a controlling effect on Rs in term of OM decomposition rate in peatlands (Silvola et al. 1996) by regulating the volume of peat. In addition, a peat surface might be too dry out because of the deep water table level which limits the decomposition rate (Laiho et al. 2004). Sivola et al. in 1996 & von Arnold et al. in 2005, reported an increase in seasonal soil respiration after drainage in cases on Finnish and Swedish peatlands. They also found a linear relationship between soil respiration and the average water table level.

1.3.3 Ditch network

Water logging pristine peatlands are to drain through systematic artificial ditch network (D_n). It has a great influence on drainage of a peatland to prevent water table level (WTL) rising to a certain point which notably reduces tree growth. The ditching system aims to keep the WTL over 35 – 40 cm below the soil surface in ombrotrophic, and to over 55 – 60 cm in minerotrophic peats (Päivanen & Hånell 2012b).

1.3.4 Vegetation

A vegetation succession initiated by drainage in which typical mire plants are replaced gradually by forest vegetation (Laine et al. 1995). This forest vegetation composition has an utmost role in carbon (C) cycle through the production of organic matter (OM) and the further addition of new litters (Strack 2008b). Type of the vegetation is one of the most influencing factors of soil respiration rate which may vary significantly based on major plant biomes. However, the cause-effect argument of vegetation type and soil respiration is not clear always due to a complex correlation among environmental factors, vegetation distributions, and rates of soil respiration (Raich 1999). Both belowground and aboveground parts of the vegetation use CO_2 during photosynthesis (Lambrs et al. 2008) whereas, in the belowground, both vegetation roots and rhizosphere emit CO_2 through respiration (Le Mer and Rogers 2001) in an anoxic condition. In addition, dead biomass supplies more CO_2 as an outcome of decomposition in the presence of Oxygen (Brown 1998). Addition of plant debris, which feeds soil organisms, may influence soil respiration. Decomposition of litters on soil surface emits CO_2 into the atmosphere. A study from a relatively mature forest ecosystem showed that soil respiration increased with increasing litterfall (Nodelhoffer &Raich 1989).

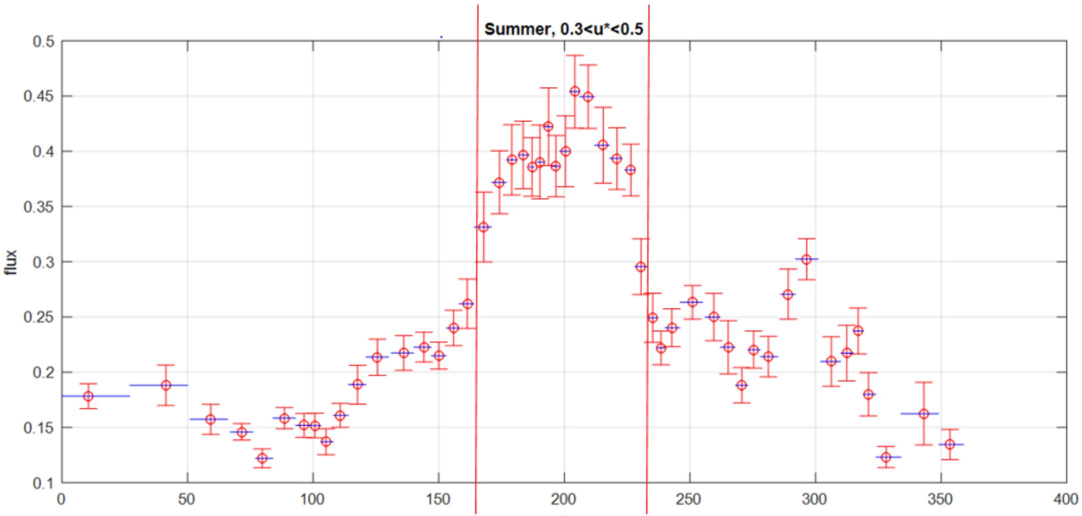
1.4 Significance of the study

In term of climate change and carbon emission, soil respiration from a drained peatland is an important research area. In Finland, already about 60% of original peatland has been drained and managed which possess a significant effect on climate due to GHG emissions (Minkkinen 2007c). According to the Kyoto protocol (UNFCC 1997), Finland is bound to report its anthropogenic greenhouse gas (GHG) emission annually. The report by the Intergovernmental Panel on Climate Change (IPCC) estimates that global mean surface temperature will increase by 3.7° to 4.8°C in 2100 if GHG emits like today. Additionally, studies suggest that climate will also change soil respiration (IPCC 2014), although the direction and extent of change are unclear yet due to the high spatial variability and difficulty in soil respiration measurement (Bond-Lamberty et al. 2010).

An Eddy Covariance (EC) measurement system, established at the Lettosuo-peatland, indicates differences in ecosystem respiration (Reco), the sum of heterotrophic respiration (Rh) from microbial decomposition from residues and autotrophic respiration (Ra) from plants, in different sectors around the EC tower**.** It measures the highest respiration from the partially harvested site at SW 170° to SE 230° (Unpublished data, Annalea Lohila, Finnish Meteorological Institute Helsinki). The differences in above ground autotrophic respiration and soil respiration in different sectors are the possible reasons behind this higher Reco due to the responses with different environmental factors. However, spatial variation in Rs here in Lettosuo-peatland is poorly known which might play an important role for high values in Reco. Now in this research, we are focusing on the spatial variation in Rs by formulating the following research questions:

i) Are there differences in soil respiration in different sectors of Lettosuo-peatland, and does the area at SW 170° to SE 230° show higher value than the other sectors?
ii) What are the environmental factors causing this difference? and finally
iii) How does the difference vary from partial harvested site to control site?

R_ECO from different directions, measured from EC mast



170-230°

Figure 4. Ecosystem respiration (Reco) at different directions (Unpublished data by Annalea Lohila, Finnish Meteorological Institute Helsinki, Finland).

1.5 Aims and objectives of this study

The main objective of this study was to investigate the changes of soil respiration in different sectors of Lettosuo-peatland by ascertaining the answers of a few specific questions: is soil respiration of SW 170° to SE 230° area is higher than other sectors, what are the untangling underlying abiotic and biotic drivers behind the changes, and how do the changes vary between partial-harvested site and control site.

The hypothesis of this study can be formulated as follows:

i) There are differences in Rs in different sectors around the EC tower.
ii) The area at SW 170° to SE 230° shows higher Rs than the other sectors? and
iii) Rs in partial harvested site is higher than the control site.

2 MATERIALS AND METHODS

2.1 Study site

The research took place at Lettosuo-peatland (N60°38', E23°57') which is an associated ecosystem site of Integrated Carbon Observation System (ICOS) located in Tammela area. It is one of the drained peatlands of southern Finland which was drained in early 1970 for forestry. Mean annual temperature and precipitation are 4.6 °C and 627 mm respectively. The soil type is classified as peat, originally herb-rich tall sedge birch-pine fen. Scots pine and downy birch dominated this site has a dense understorey of Norway spruce. According to the vegetation site type, this is classified as Vaccinium-myrtillus (MT) type (FMI).

In this peatland, an area was partially harvested by removing pine trees (75% of the tree biomass) in spring, 2016. After this partial harvest, the water level has been increased 15-20 cm due to reduced transpiration of trees. On the other hand, an area with untouched trees has been kept as a control site from where GHG exchange can be monitored with the automatic flux chambers (FMI). After harvesting branches and tree tops were left in the site as falling. The falling is still distinctly visible. A thick layer of litter and debris was distinct on the soil surface where it was not covered by understorey plants.

Figure 5. Map of the Lettosuo study site (map A is drawn with Python geoplot, and map B is from Minkkinen 2017).

Table 2. Climatological and vegetative characteristics of Lettosuo-peatland (FMI 2017).

Snow depth at mid-March	**Median snow cover**		**Mean vegetation height**	**Stand volume before harvest (m^3ha^{-1})**	**Tree density (ha^{-1}) before harvest**
	Start date	**End date**			
28 cm	Dec 13	Apr 8	20 m	230	2200

2.2 Experimental design

In the study site, ten line transects (marked as 0 to 9) were set up at ten directions by keeping the Eddy covariance tower (ECT) as a center (Fig. 6). Each line transect consisted of ten sampling plots and the last plot of 0 & 2 transects were in a clear-cut and on a road respectively. In such condition, they were not anymore valid based on our research objective. Total 98 circular plots(control site 13 plots, partially harvested site 85 plots) were established around the ECT within an area of 200–m radius which was considered as the potential source of major fluxes. Measurements were made from 98 plots, and the plots were shaped like roundish groove by using the metal measuring chamber (Collar). The grooves were made by inserting the Collar 2 to 3 cm into the soil.

Perforated tubes were installed near each sampling plot at the same elevation as a plot to measure the depth of the WTL. The study required a total 98 of tubes and the maximum distance between each well and the plot was one meter depending on the suitable position and elevation. All installations were completed one week ahead of measurements.

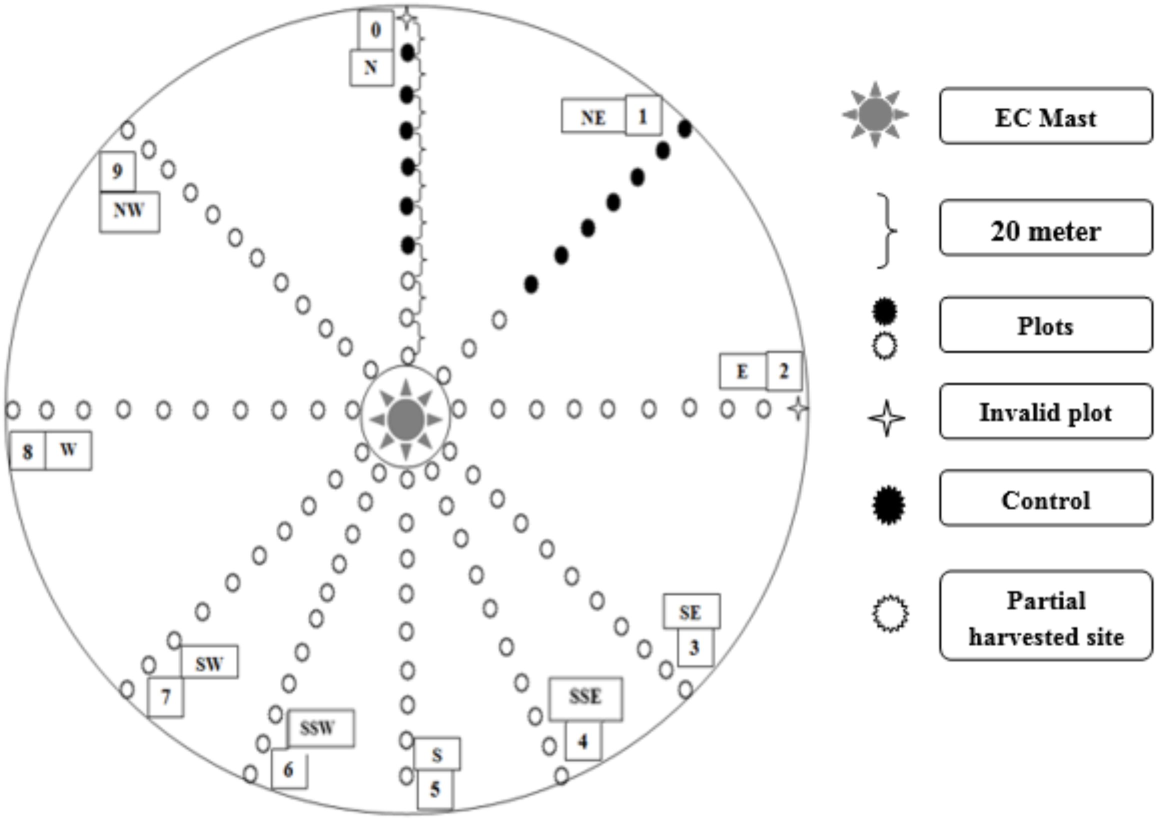


Figure 6. Direction wise plot distribution (Design of sample plots).

Table 3. Mean, minimum and maximum values of climate and site variables from Lettosuo-peatland study site. The variables are calculated from June 2017 to August 2017.

Variable	**Abbreviation**	**Unit**
Soil respiration (Flux)	Rs	$g\ m^{-2}\ h^{-1}$
Soil temperature at 5 cm depth	Ts	°C
Water table level	WTL	cm
Plot distance from a ditch	D_d	m
Plot direction	D_p	--
Peat moss cover	M_p	%
Forest moss cover	M_f	%
Litter cover	Li	%
Lichen cover	Lic	%
Field layer vegetation cover	FLV	%

2.3 Measurement of soil respiration and environmental factors

2.3.1 Soil respiration measurement using EGM

Rs were measured once a week from June to August using a portable infra-red Environmental gas monitor analyzer (EGM-4 model) connected with an automatic soil respiration chamber (SRC-1, PP systems Inc.). During measurement, gas circulates between chamber headspace and infra-red cell in the instrument, analyzing the CO_2 concentration. CO_2 flux is calculated automatically from a linear change in CO_2 concentration according to ideal gas law considering the measurement time, chamber volume, air temperature, and air pressure. The calculation results are recorded in the internal memory at each 4.8 seconds.

The measurements of R_s from all plots (98) were recorded always in a single day to minimize fluctuations in environmental conditions within one measurement tour. A systematical cycle was followed to start measuring for observing the fluxes from different plots at a different time. For example, if the measurements were started in the early morning from zero (0) line transect towards 1, 2, respectively then the next tours measurements were started from other than zero (0) line transect.

For the flux measurement, the chamber was flushed in the air for 15 seconds, and it was kept in a safe position to avoid CO_2 from breathing. After complete flushing, the collar was gently placed on the groove at a depth of 2 to 3 cm, to ensure proper sealing. A sampling period of 81 seconds at each sampling plot was used. Usually, a complete sampling from all plots used to require a long day from 8h to 18h.

2.3.2 Environmental factors measurement

The WTL depth was measured from perforated tubes once a week along with T_s & R_s measurements. Soil temperature (T_s) was monitored and recorded with R_s measurement using a thermocouple probe pushed in the soil to the depth of 5 cm near the sampling plot. The measurement was recorded at 81 seconds as of chamber measurement.

Vegetation measurement and site type were conducted through a survey in early August when the vegetation was highest in size. Every measuring plot was identified under a specific site type (Päivanen& Hånell 2012). The site type was categorized based on an abundance of specific plants within a 10-m radius around the plot. All the species, as well as the plant organ (dead or alive), were considered. Along with the listing the species, percentage (%) based coverage was recorded at each plot. Lichen, peat moss and forest moss amounts (%) were recorded by ocular assessment from the ground layer of the plots. Field layer vegetation (above ground vegetation) cover was calculated individual species basis as well as total species. Some of the cases the total coverage was more than 100% due to the overlapped coverage of the species. At the same time, the amount of litter on the ground surface was recorded. A perpendicular distance (in m) from the sampling plot to the nearest ditch was measured to understand the effect of ditch networks on Rs. A measuring tape (precision 1 m) was used to measure the shortest distance from the center of the ditch to the measurement plot.

Table 4. List of representative species for site type determination (Päivänen and Hånell, 2012a).

Site Type	**Representative species**
Herb-rich type (Rhtkg)	*Matteuccia struthiopteris, Athyrium filix-femina, Dryopteris expansa, Thelypteris phegopteris, Filipendula ulmaria, Repis paludosa, Pyrola spp., Oxalis acetosella, Rhytidiadelphus triquetrus, Climacium dendroides*
Vaccinium myrtillus type II (Mtkg II)	*Trientalis europaea, Maianthemum bifolium, Linnaea borealis, Orthilia secunda, Equisetum sylvaticum, Dryopteris carthusiana, Vaccinium myrtillus,Vaccinium vitis-idaea*
Vacciniumvitis-idaeatype II (Ptkg II)	*Ledum palustre, Vaccinium uliginosum* (occur) *Vaccinium myrtillus* (common), *V. vitis-idaea* (common) Herbs rare, *Dryopteris carthusiana* (may occur)
Dwarf shrub type (Vatkg)	*Ledum palustre, Vaccinium uliginosum, Empetrum nigrum, Cladonia spp.,* Very little *Vaccinium myrtillus,* some *V. vitis-idaea.* *Dryopteris carthusiana* (may occur) Herbs absent.

3 DATA PROCESSING AND STATISTICAL ANALYSIS

After downloading the recorded data in a computer, they were screened carefully and severe deviations from the linearity were corrected by removing the bad data points and re-calculating fluxes manually. Sometimes the whole measurements were deleted due to the high deviations and EGM malfunction. All recorded data were corrected using air temperature (at 2m height from soil) because the closed system (EGM + SRC) measured the fluxes at 25 °C by default.

The following equations were used for correcting temperature and removal of bad data points, respectively.

Flux correction $$\text{Measured flux} * \frac{273.15+25}{273.15+\text{Tair at 2m height from soil}} \quad (2)$$

Flux correction with Trend line $$\text{Measured flux} * \frac{\text{New Slope}}{\text{Old Slope}} \quad (3)$$

Here,

Measured flux = Amount of Flux (g CO_2 m^{-2} h^{-1}) measured by EGM from a plot

Tair = Air temperature measured by EC at 2m height from the soil surface

New slope = New slope from trend-line after correcting flux

Old slope = Existing slope from trend-line for measured flux

At the very beginning of a statistical analysis of Lettosuo-peatland dataset, it was screened on the basis of missing value and outlier removal. Outliers were identified by using Cook´s distance procedure and they were replaced by the mean values. After that, the normality of this dataset was tested through histogram, Shapiro tests, Q-Q plot. Multicollinearity, linear relationship, among the factors were checked before applying them into the linear model. A constant variance of error (homoscedasticity) was also checked across the observations.

The analysis of correlation was employed to determine the relationships between R_s and factors (environmental factors and biotic factors). The coefficient of variance (CV) was applied to signify the spatial variation of R_s and explanatory factors. After that, a multiple stepwise linear regression analysis was used to examine the spatial variation in soil respiration considering the effects of environmental factors.

Multiple linear regression models were formulated and carried out for each of the measurement campaigns to predict Rs using covariates. The following equation (eq. 7) is the full model to predict Rs.

$$\mathrm{Rs} = \mathrm{i} + \mathrm{a\,Ts} + \mathrm{b\;\;WTL} + \mathrm{c\,Dd} + \mathrm{e\,Mp} + \mathrm{f\,Mf} + \mathrm{g\,Li} + \mathrm{h\,FLV} + \;\varepsilon \qquad (4)$$

Where,

i = intercept of the model

a = coefficient of soil temperature (Ts)

b = coefficient of a water-table level (WTL)

c = coefficient of ditch distance (D_d)

d =coefficient of peat moss cover (M_p)

e = coefficient of forest moss cover (M_f)

f = coefficient litter cover (Li)

g = coefficient of field layer vegetation cover (FLV)

ε = standard error

Furthermore, a parametric one-way analysis of variance (ANOVA) was used to identify any difference in soil respiration (Rs) among the ten directions. Normality and homogeneous variances of the dataset (n=98) were tested before ANOVA test, and no data transformation was needed. If the ANOVA test showed a significant difference at $p<0.05$, a TukyHSD test was used to determine where differences lie. Apart from these, a rank test was also applied to analyses the means. In the statistical analysis especially modeling, R (3.5.1) and MS Excel (2016) were used. In the visualization of the results, Python (3.5) was used.

4 RESULTS

4.1 Spatial variations of soil respiration and explanatory factors

4.1.1 Spatial variations of soil respiration (Rs)

In the studied drained peatland (Lettosuo-peatland) CO_2 effluxes varied from 0.15 to 0.98 g CO_2 m^{-2} h^{-1} with an average 0.49 ± 0.13(± Std.) g CO_2 m^{-2} h^{-1} (Table. 5); while the corresponding mean at partial harvested site and control site were 0.49 ± 0.12 g CO_2 m^{-2} h^{-1} and 0.50 ± 0.14 g CO_2 m^{-2} h^{-1} , respectively. Across all plots, soil respiration deviated highly at most of the plots, especially at North and North-West directions (Fig. 7). The distribution showed the highest median flux with less variation at plot 26 (East direction) and relatively high fluxes were recorded at the easternmost (E) direction, where the efflux was on average 0.60 g CO_2 m^{-2} h^{-1}. The finding was expected since the water-table levels were deepest with the soil temperature at their highest at this plot (Fig. 7).

Table 5. Soil respiration (Rs, g CO_2 m^{-2} h^{-1}) across both sites of Lettosuo-peatlands. This table presents daily mean values including minimum (min.), maximum (max.) and standard deviation (Std.).

	Rs (Control site)				**Rs (Partial harvested site)**			
Measurement Days	**Mean**	**Min.**	**Max.**	**Std.**	**Mean**	**Min.**	**Max.**	**Std.**
6th June 2017	0.40	0.27	0.55	0.09	0.41	0.19	0.74	0.11
14th June 2017	0.38	0.23	0.58	0.10	0.45	0.24	0.87	0.14
21th June 2017	0.36	0.22	0.52	0.09	0.37	0.15	0.80	0.11
27th June 2017	0.44	0.21	0.64	0.11	0.47	0.27	0.97	0.13
18th July 2017	0.50	0.34	0.67	0.12	0.52	0.25	0.82	0.13
25th July 2017	0.55	0.31	0.74	0.14	0.51	0.29	0.84	0.13
1st August 2017	0.70	0.44	0.93	0.12	0.57	0.16	0.93	0.16
8th August 2017	0.67	0.34	0.90	0.16	0.60	0.32	0.98	0.16
Mean	0.50	0.29	0.69	0.12	0.49	0.23	0.87	0.14

4.1.2 Spatial variations of soil temperature (Ts)

A variation of soil temperature at 5 cm depth was found from 11.4 to 15.8 °C on an average with a total average 13.5 ± 1.15 °C at Lettosuo-peatland. The minimum and maximum mean Ts were recorded at plot 48 (SSE direction) and plot 34 (SE direction) respectively (Fig. 7). During the measurement period (June-August), partially harvested site had a slight higher mean Ts than the control site. Between the first (6th June) and last (8th August) measurement day, an increase in Ts was found. However, a clear seasonal rising (steady pattern) in soil temperature (Ts) was found from June to August when it was at highest. This pattern of Ts was found similar on both control and partially harvested sites (Table. 6).

Table 6. Soil temperature (Ts, °C) across both sites of Lettosuo-peatlands. This table presents daily mean values including minimum (min.), maximum (max.) and standard deviation (Std.).

	Ts (Control site)				**Ts (Partial harvested site)**			
Measurement days	**Mean**	**Min.**	**Max.**	**Std.**	**Mean**	**Min.**	**Max.**	**Std.**
6th June 2017	12.5	10.5	14.2	0.9	12.1	7.8	17.2	2.2
14th June 2017	11.5	10.2	13.5	0.8	12.2	8.8	17.3	2.1
21th June 2017	11.0	9.8	13.1	0.9	11.2	9.7	12.9	0.8
27th June 2017	12.2	11.1	13.7	0.8	12.6	10.7	15.3	1.1
18th July 2017	13.8	12.5	16.1	1.0	14.5	11.3	18.3	1.5
25th July 2017	14.4	13.5	15.6	0.6	14.6	12.0	17.6	0.9
1st August 2017	14.5	13.5	15.5	0.6	16.4	12.8	21.1	1.7
8th August 2017	14.9	14.0	16.4	0.7	14.9	12.1	19.5	1.7
Mean	13.1	11.9	14.8	0.8	13.6	10.7	17.4	1.5

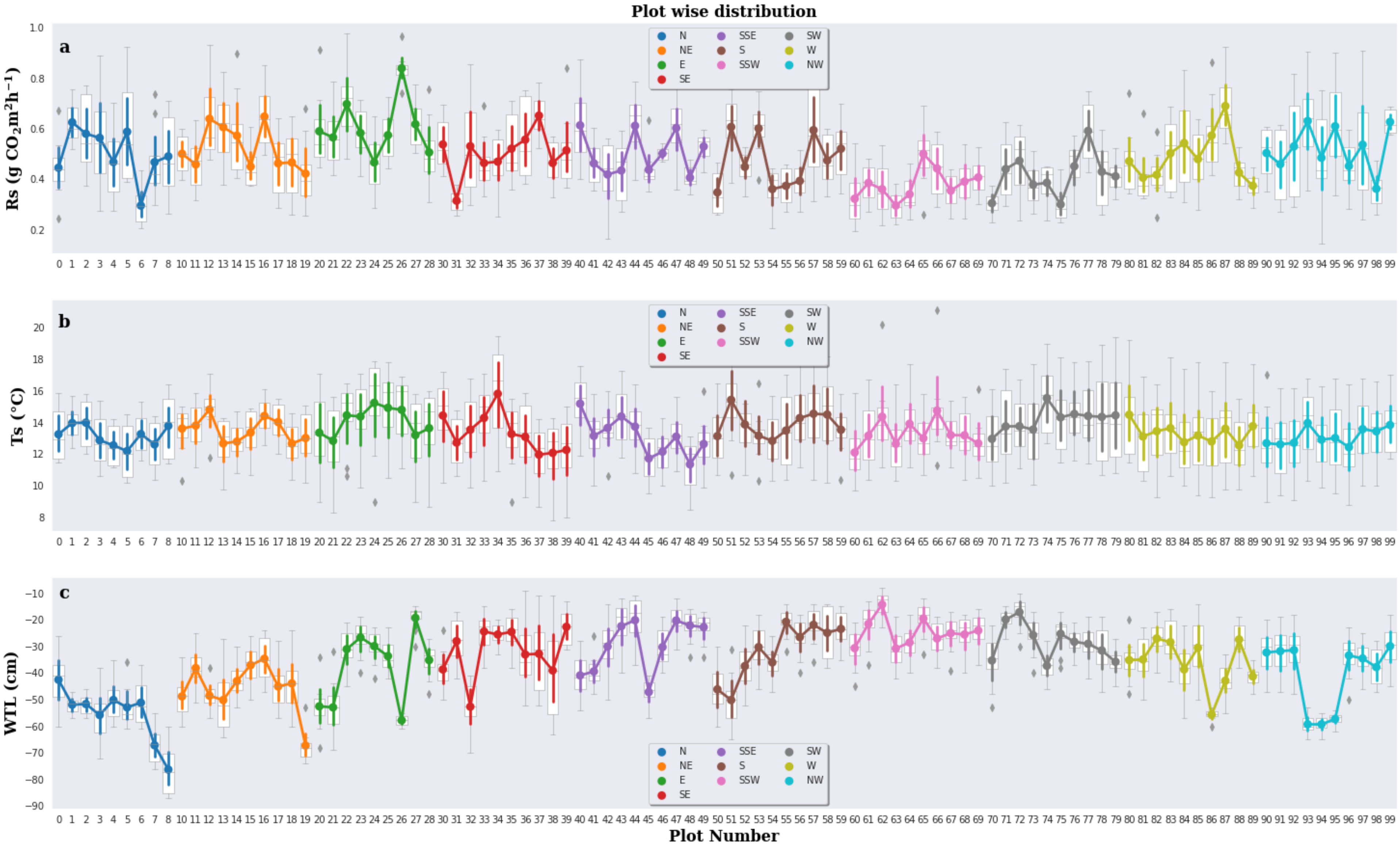


Figure 7. Spatial variation in instantaneous soil respiration, soil temperature at 5 cm and water-table level at Lettosuo-peatland (both control and partially harvested sites. n=98*8)

4.1.3 Spatial variations of water-table level (WTL)

There was a large spatial variability in summertime water-table level between and within the sites (Fig. 7), but concurrently no clear spatial pattern was found like soil temperature. The mean monthly WTL on both sites (control site and partial harvested site) were 52 cm and 34 cm deep respectively. A fluctuation was well noticeable after heavy rain falls. Lettosuo got moderate rainfall during the measurement period, the groundwater got recharged, and the water-table came upward to the peat surface. Due to the rainfall soil moisture deficit was mitigated. However, the control site was characterized by deeper water table level than the partial harvested site (Table. 7).

Table 7. Water-table level (WTL, cm) across both sites of Lettosuo-peatlands. This table presents daily mean values including minimum (min.), maximum (max.) and standard deviation (Std.).

Measurement days	**WTL (Control site)**				**WTL (Partial harvested site)**			
	Mean	**Min.**	**Max.**	**Std.**	**Mean**	**Min.**	**Max.**	**Std.**
6th June 2017	53	41	71	10	34	12	61	12
14th June 2017	36	24	60	12	23	8	56	11
21th June 2017	49	35	68	12	33	13	62	11
27th June 2017	46	26	73	14	26	9	57	12
18th July 2017	55	35	81	13	35	15	65	12
25th July 2017	60	42	85	12	42	20	68	11
1st August 2017	63	47	87	11	46	23	70	10
8th August 2017	53	27	85	16	30	11	58	12
Mean	52	35	76	13	34	14	62	11

4.1.4 Spatial variations in other factors

In site type (St) at Lettosuo-peatland, Mtkg II was most dominant (85%) site type while a small portion was occupied by Rhtkg (9%), Ptkg II (5%) and Vatkg (1%). Most of the sites were dominated by *Vaccinium myrtillus, Vaccinium vitis-idaea* and *Trientalis europaea.* Through a vegetation survey 11 plant species were found and identified on the plots, and one species was not identified due to the early stage growth. However, no lichen was found on any plot. Apart from these factors, a nearest ditch distance from every sampling plot was measured, and the measurement showed that most of the plots were in between 4 to 20 m (Fig. 8). There was no peat moss in the control site whereas 19 plots in the partial harvested site were found where 70% surface area of 12 plots was covered by peat moss. Most of these plots were more than 15 m far away from the nearest ditch. Oppositely, forest moss was frequently available at most of the plots (approximately 92% of plots). A distinctive abundance of field layer vegetation was found in the partially harvested site (Fig. 8). Furthermore, a comparative analysis between sites has been presented in figure 10.

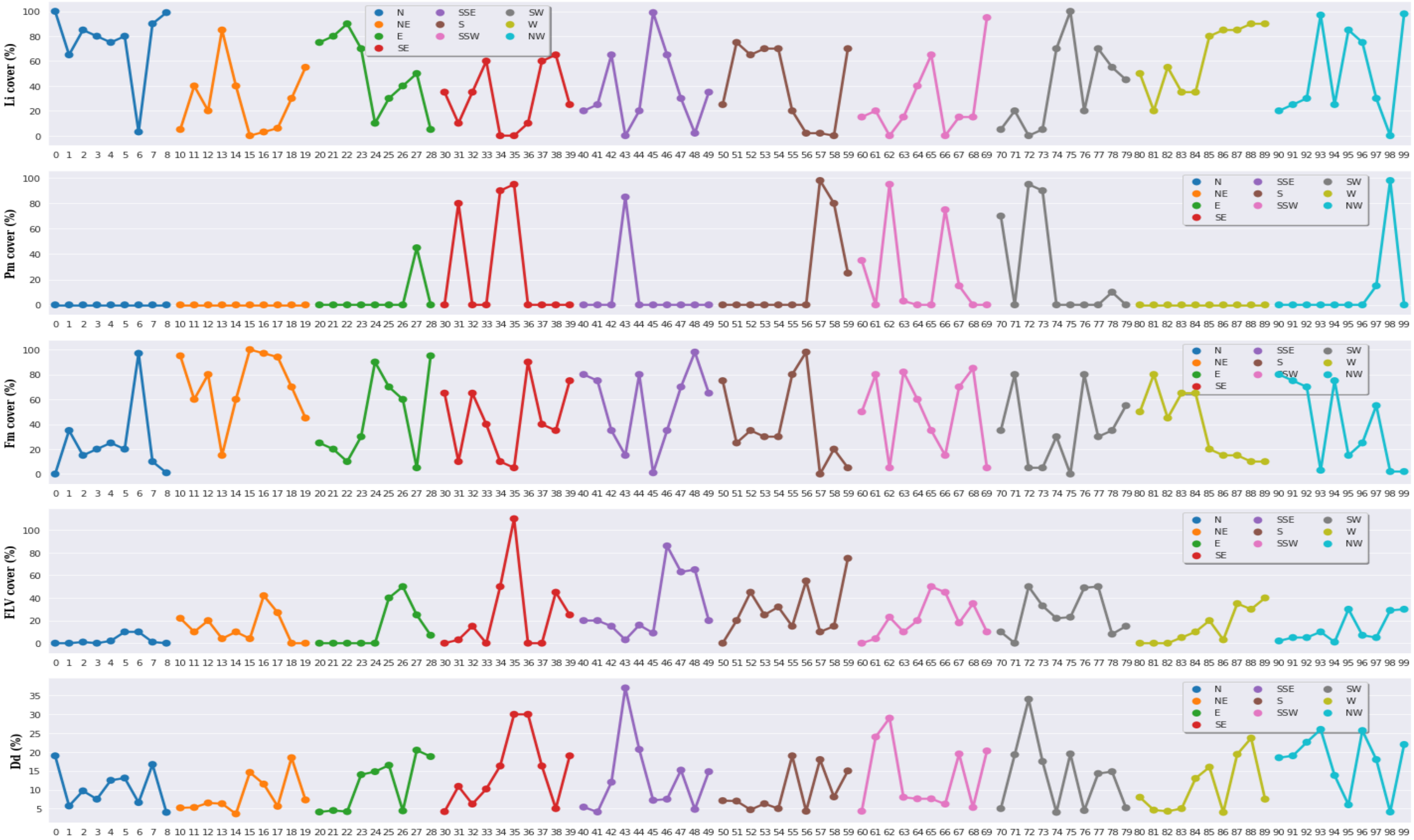


Figure 8. Plot wise distribution of litter cover (%), peat moss cover (%), forest moss cover (%), field layer vegetation (%) and ditch distance (m).

4.2 Direction wise comparison

A direction wise distribution of the response (Rs) and the explanatory factors (Fig. 9) showed that the highest efflux of CO_2 at east direction and the immediate next was from north-east direction. Along with highest fluxes, highest soil temperature (total mean) was measured at east direction. In the water-table level measurement, deepest WTL was found at N and NE directions whereas at rest of the directions WTL was close to peat surface. Field layer vegetation cover was close to zero (%) with a small amount (20%) of forest moss and large amount (80%) of litter cover. At the rest of the directions, a certain amount (> 15%) of FLV, Li, and Fm were found. Alongside, Pm was only found at south-east (SE), south (S), south-south-west (SSW) and west (W) directions.

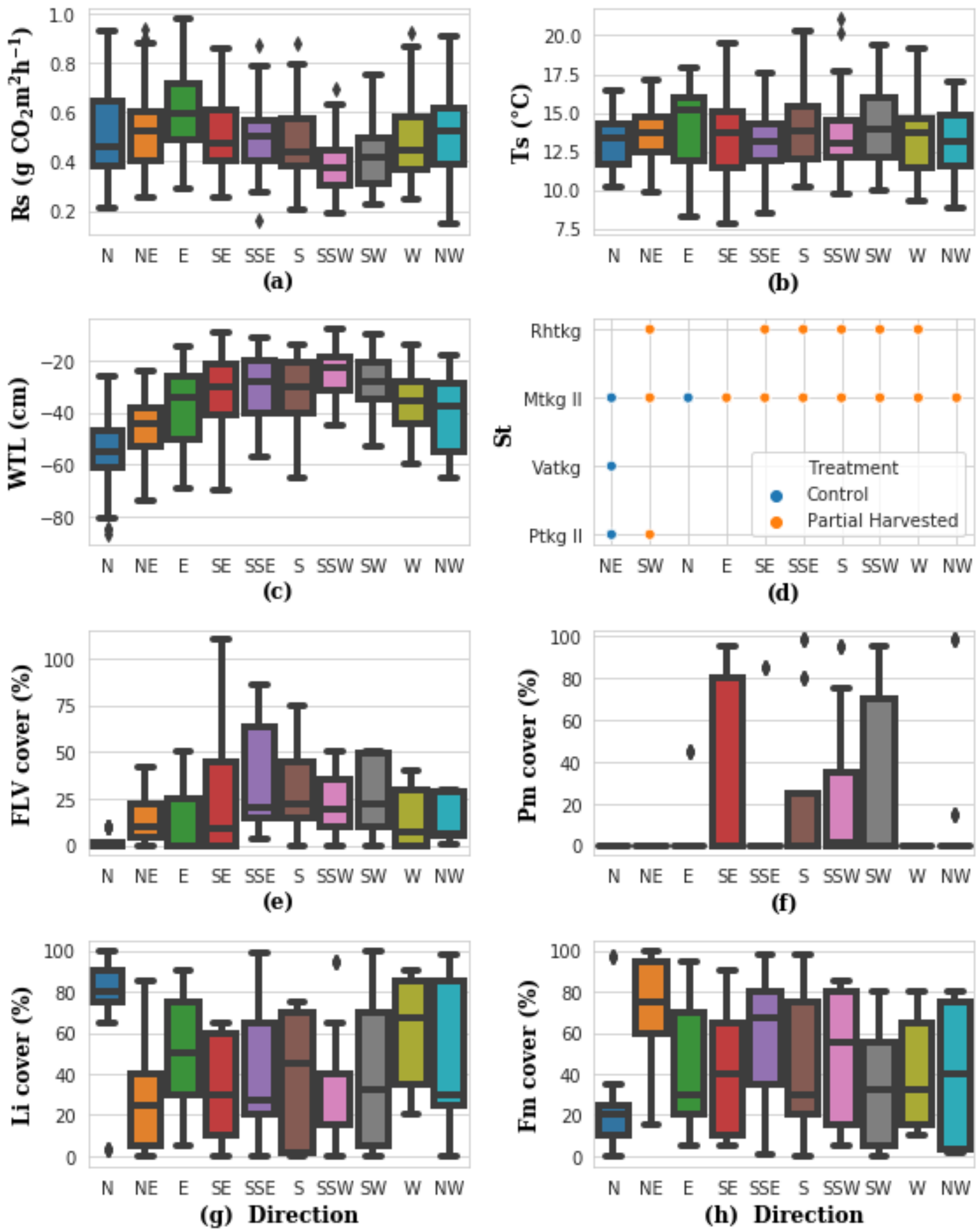


Figure 9. Direction wise distribution of explanatory factors (a. soil respiration, b. soil temperature, c. water table level, d. site type, e. field layer vegetation cover, f. peat moss, g. litter and h. forest moss.).

Furthermore, a statistical analysis of variance (one way ANOVA) on direction wise respiration means, p-value (9.429e-05) rejected the null hypothesis (same means of respiration from all directions). So, it was concluded that the mean fluxes in different directions were different. After that, multiple comparisons among means (TukeyHSD) was used to see which means or fluxes might differ from others. It conducted all possible pair-wise comparisons for analysis of variance fit (Appendix 10). It found the difference in means of all possible pairs at 95% confidence intervals. The projected p-value (< 2.2e-16) was less than the 0.05. Additionally, Kruskal-wallis test also rejected the null hypothesis (same means). Therefore, it concluded that the means of fluxes in different directions were not the same.

4.3 Comparison between the control site and partial harvested site

The calculated median values showed that the hourly median efflux from both sites was almost the same (Fig. 10), but the mean efflux in the partial harvested site was slightly high (Table 5). The median value of soil temperature at 5 cm depth of partial harvested site was slightly higher than the control site. Water-table level (WTL) was way higher in the control site than the partial harvested site. Around 29% of the sampling plots had a water table below 40 cm in the partial harvested site whereas almost 85% was above 40 cm in the control site was. According to the field layer vegetation (FLV) distribution, higher amount (%) was recorded from the partially harvested site where most of the sampling plots had more than 15% vegetation in respect to the area of the plot. No evidence of peat moss in control site while a small amount was found in partial harvested site. Apart from that, litter and forest moss coverage were higher in the control site than the partial harvested site. Additionally, the site type survey indicated that partial harvested site had most of the nutrient-rich plots (Fig. 9 (d)).

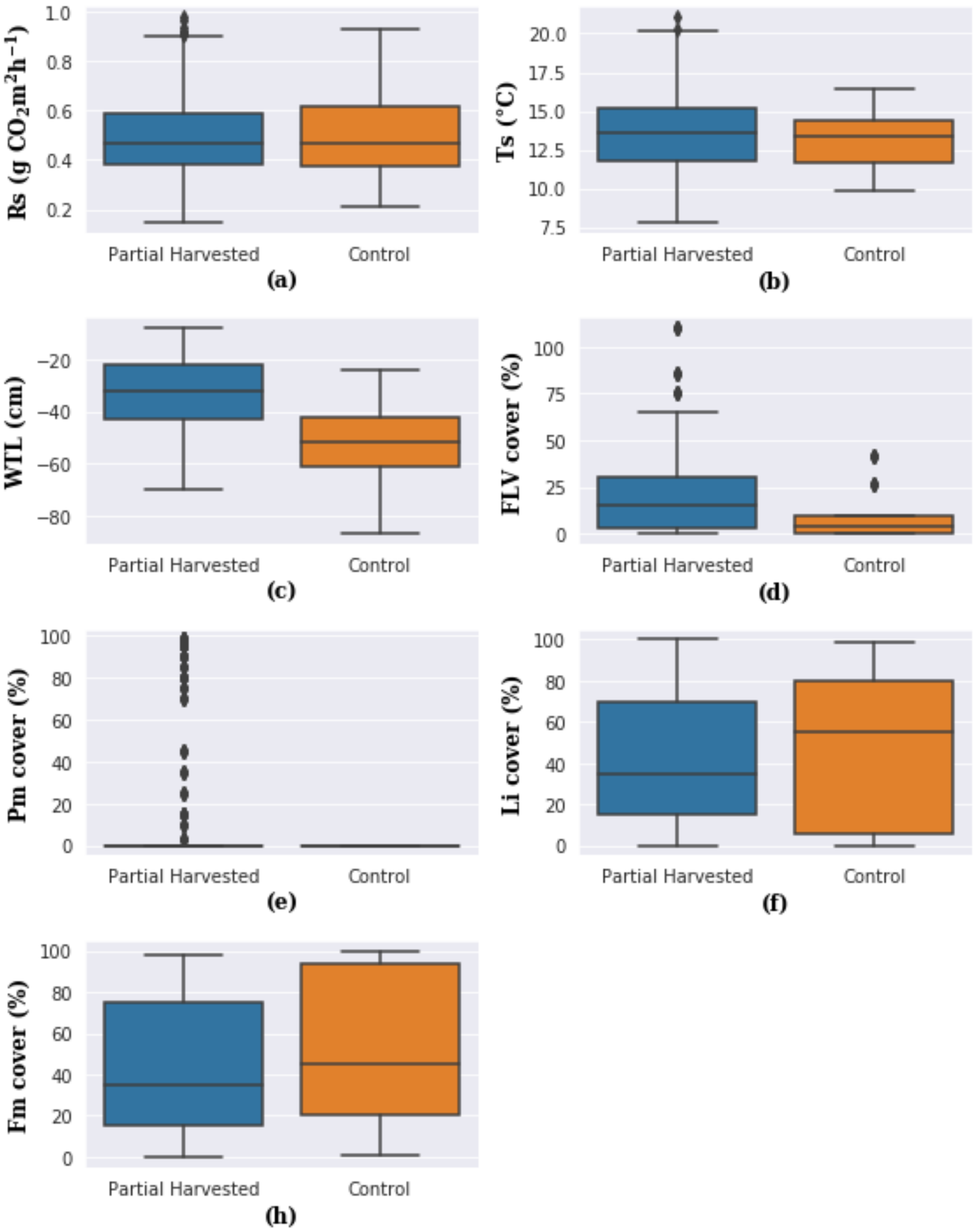


Figure 10. Comparison between Control and Partially harvested sites.

4.4 Effects of explanatory factors on Rs

A spatial variation in soil respiration was found from the measured data from 98 sample plots of both sites (control and partial harvested) in Lettosuo-peatlands, closely following (Pearson's correlation) the water-table level and soil temperature at 5 cm (Fig. 11). Fluxes of CO_2 were very low (0.15 g CO_2

$m^{-2} h^{-1}$) at both sites when the peat surface was frozen, and the highest instantaneous fluxes were up to a maximum of 0.98g CO_2 $m^{-2}h^{-1}$, when the Ts were at their highest with deeper WTL.

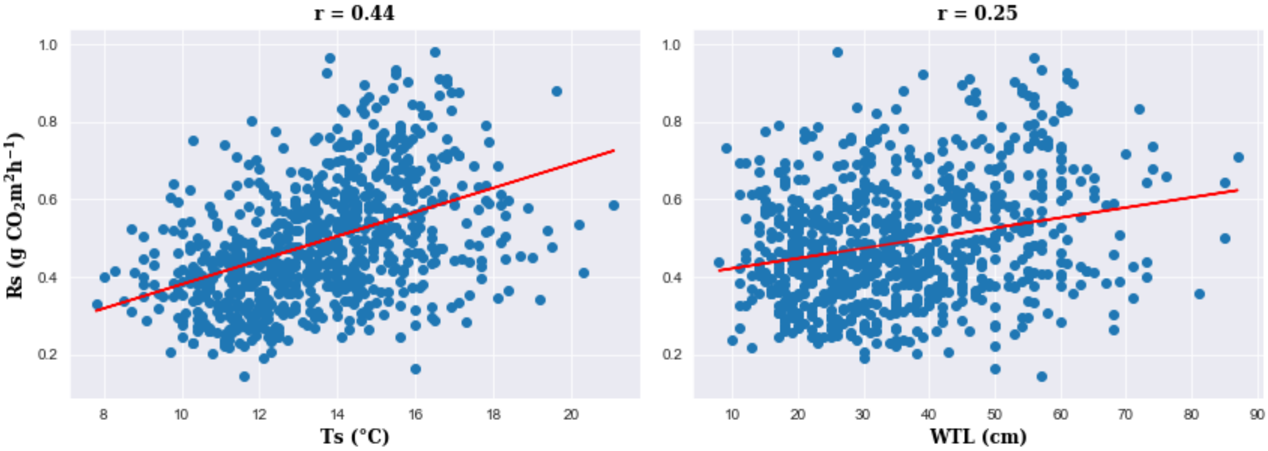


Figure 11. The relationships between soil respiration with soil temperature (r = 0.44, p = 8.64e-39), and water-table level (r = 0.25, p = 1.27e-12) at both sites of Lettosuo-peatland.

The daily patterns of mean CO_2 efflux were similar throughout the summer season (measurement period 2017). Lettosuo-peatland had an obvious seasonal rising pattern of CO_2 efflux (Figure 12) from the beginning of the measurement on 6th June and reached its highest value on the last measurement day 8th August. As shown in figure 12, CO_2 efflux began to raise around 11h and peaked at around 12-13 h. Then the efflux started dropping from 14 h. However, direction-wise changes in Rs showed also a common trend of gradual increase from June to August closely following the variation of topsoil surface temperature. Figure 12 showed the mean effluxes which indicated an increasing rate with summer days. But the average highest fluxes were measured at 26 number plot.

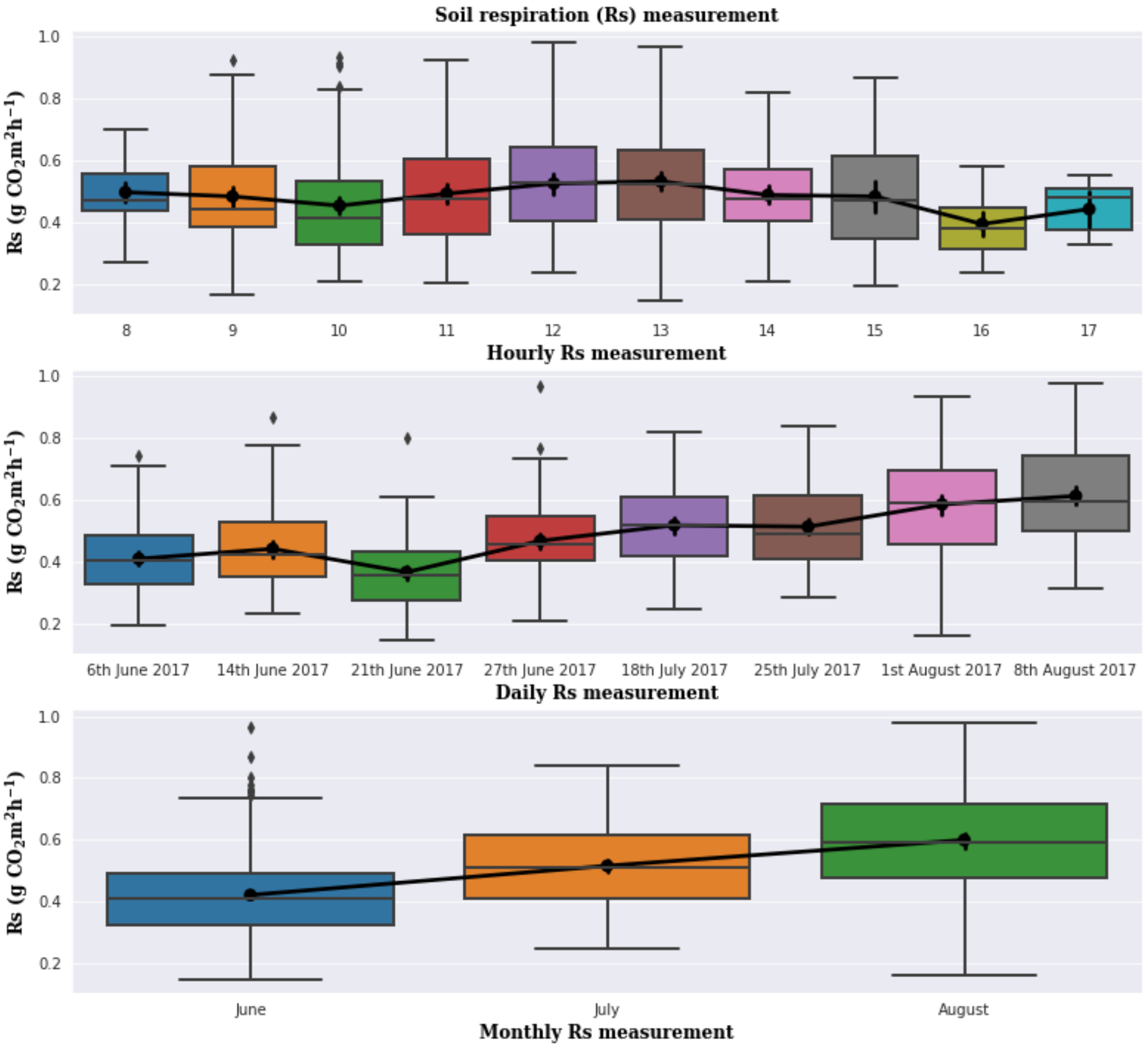


Figure 12. Daily and hourly CO_2 efflux from the soil surface at Lettosuo-peatland (summer 2017. n= 98*8)

Hourly soil CO_2 effluxes in the studied sites (partial harvested and control) varied on average from 0.37 to 0.60 g CO_2 m^{-2} $h^{-1}$and 0.35 to 0.72 g C m^{-2} h^{-1}at partial harvested and control sites respectively. However, an average hourly variation of the CO_2 effluxes on both control site (0.50 g CO_2 m^{-2} h^{-1}) and partial-harvested site (0.49 g CO_2 m^{-2} h^{-1}) was almost same (Table 3).

A correlation analysis (Pearson's correlation) was carried out on mean values measured from the partially harvested site. The analysis showed (Fig 13**)** water-table level (WTL) and litter cover (%) were positively correlated with soil respiration (Rs) while peat moss cover (%) showed a negative correlation.

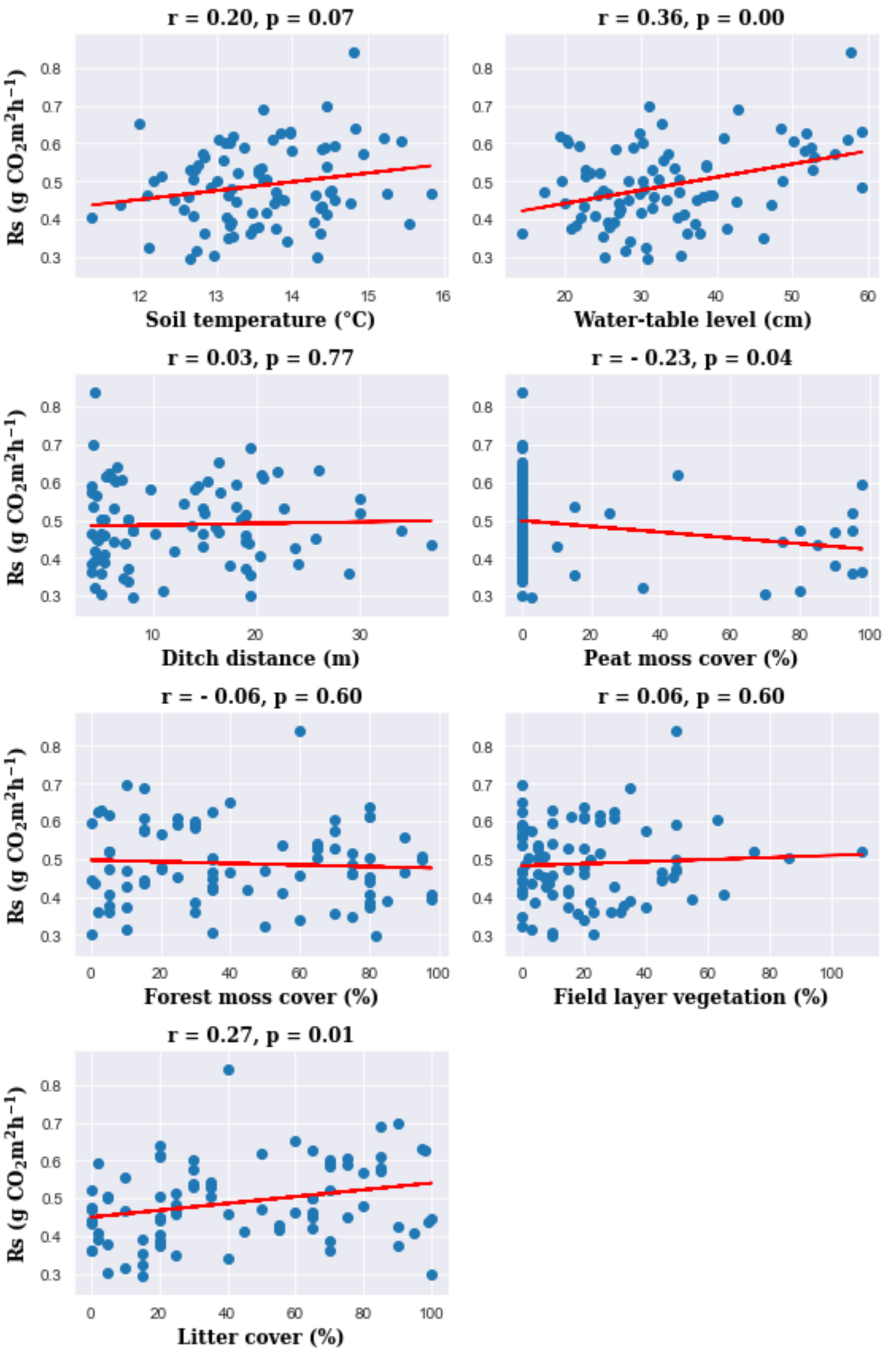


Figure 13. Scatter plots between Rs and explanatory factors with Pearson´s correlation values (r) and asymptotic significance levels (p at 95% confidence)are shown on top of the graphs.

4.5 Multiple linear modeling for soil respiration (RS)

Soil respiration (Rs) and all of the explanatory factors were fit into a multiple linear regression model. The summary of the model showed the median was close zero (0) which indicated the normality of the Lettosuo-peatland dataset. It showed that this model could explain about 24% ($R^2 = 0.24$) variation in soil respiration. According to this analysis, the following multiple linear regression model can be formulated.

$$\mathrm{Rs} = 0.36 + 0.027\ \mathrm{Ts} + .004\ \mathrm{WTL} + 0.004\ \mathrm{Dd} + (-)0.004\ \mathrm{Li} + (-)0.004\ \mathrm{Mf} + (-)0.005\ \mathrm{Mp} + 0.001\ \mathrm{FLV} + \varepsilon \qquad (5)$$

The equation (5) shows Rs is increased on average by 0.027 g CO_2 m^{-2} h^{-1} as Ts increases one unit while other factors are constant. This increasing trend applies also to WTL and Dd. On the other hand Rs is reduced on average by 0.005 g CO_2 m^{-2} h^{-1} as peat moss increases one unit while the other factors are constant. Pm, Fm and Li also showed a decrease in Rs.

A number of elimination steps were run for performing inference in the multiple regression setting. The explanatory variables were gradually removed from the model to measure the potential effect on Rs. The backward elimination showed, the model with significant factors Ts (p = 0.046), WTL (p = 7.5e-05)and Dd (p = 0.035) collectively at 95% confidence level explained 18% of the variation in Rs. However, WTL could explain 12% variation in Rs as an individual explanatory factor (Table. 8). Interestingly, the model also showed that Ts and Dd did not possess any individual effect at all on Rs (Appendix 5).

Table 8. Backward elimination in a multiple linear regression model.

LM	**Factors**	**Effective factors**	**p-value**	**Adjusted R squared**
1	TS+ WT_L + D_d+ M_p + M_f+ Li+FLV	TS,WTL, Dd	0.0001989	0.24
2	TS + WT_L + D_d	Ts, WTL, D_d	0.000231	0.18
3	WTL	WTL	0.000696	0.12

Finally, the analysis showed the following model which could explain most variation in Rs at Lettosuo-peatland.

$$\mathrm{Rs} = (-)0.01 + 0.02\ \mathrm{Ts} + 0.004\ \mathrm{WTL} + 0.002\ \mathrm{Dd} + \varepsilon \qquad (6)$$

$$\mathrm{Rs} = 0.372 + 0.003\ \mathrm{WTL} + \varepsilon \qquad (7)$$

5 DISCUSSION

The aim of this study was to measure soil respiration (Rs) in different sectors of Lettosuo-peatland along with revealing the controlling factors and their relationship with soil respiration. The installation of each plot and its respiration measure was measured very carefully without altering the ground composition i.e. vegetation, peat, and old litter. The measurement was the sum of heterogenic soil respiration (Rh) and autotrophic respiration (Ra). The amount of soil respiration (Rs) was quite low at the very beginning of June (summer 2017) due to frozen peat surface.

The first hypothesis in this study was that there were differences in soil respiration in different sectors of Lettosuo-peatland. On the question based on this hypothesis, this study found a noticeable variation within and among the different sectors. Statistically one-way ANOVA (p-value = 9.429e-05) indicated that there was variation in different sectors. This same phenomenon of spatial variation in Rs was described by Mäkiranta et al. (2007) in afforested organic croplands in Finland. The average measured soil respiration varied between 0.37 and 0.62 g CO_2 m^{-2} h^{-1}. The finding suggested us to accept the null hypothesis.

Spatial variation of in Lettosuo-peatland has led this study to rather unexpected findings: the highest respiration and the highest response to water-table level were found at the easternmost instead of southernmost. Interestingly, southernmost sectors showed the lowest respiration level with shallowest water-table. This clear finding leads this study to fail to accept the second hypothesis, area at SW 170° to SE 230° shows higher respiration. Hence, soil respiration (Rs) at southernmost direction (between SW 170° and SE 230°) is not the reason behind higher ecosystem respiration (Reco) measured by EC-mast.

Temporal variation of soil respiration was positively correlated with soil temperature (5 cm). However, a lot of spatial variation within the direction and between sites remained unexplained by temperature. Average soil respiration both from partial-harvested site (0.49 g CO_2 m^{-2} $h^{-}1$) and control site (0.51 g CO_2 m^{-2} h^{-1}) within the measurement period was almost same. But a rapid increase was noticed in control site on the last two measurement days (Table 6). There was no large variation in Rs between both sites except these two measurements. It happened due to the deepest water-table level and highest temperature those correlate vegetation growth during the growing season. At this point of the growing season, temperature affects the microbial community biomass and growth rate as well as the overall decomposition rate of organic matter under varying moisture condition. In a word microbial community is capable of growing and respiring fast in those plots with continuous deeper water-table. A similar study was reported by Vanhala et al. in 2008 for carbon mineralization.

In this studied peatland, water-table level (WTL) was the main explanatory factor controlling spatial variation in soil respiration (Rs). At the partial-harvested site, WTL could explain 18% of the variation in Rs. The explanatory power of WTL measurement over the measured Rs from the sectors of the partial harvested site in Lettosuo-peatland suggested that decomposition progressions in surface layer facing utmost WTL variations and having the most labile organic matter portions controlled the observed Rs. This significant influence on variations in WTL on observed Rs could be explained with the studies on peat soil by Moore and Knowles (1989) and Blodau and Moore (2003). In their studies, they showed that the dropping of water table and concomitant increase in the volume of aerated peat layer linearly increased peat decomposition rates.

The thickness of aerobic peat depends upon the variation of the water-table level. A close relationship between average water-table level and soil respiration was found by Silvola et al. in 1996. Our study found a moderate relationship (r = 0.25, n=98*8) (Fig. 11). In this studied site, 80% of the total measurements of the water-table level was above 20 cm underneath the peat surface. It means that this peat layer was aerobic with availability of labile carbon with high temperatures and a high concentration of nutrients. The significance of this peat surface in term of soil respiration has been reported by Mäkiranta (2012c) in research of heterotrophic soil respiration in drained peatlands.

Soil temperature at 5cm depth showed a negligible effect on the spatial variation of soil respiration (Rs). A weak relationship (r = 0.02) was found between water-table level and soil temperature during the measurement time. Instantaneous changes in water-table level (WTL) in deep peat layers with an intractable substrate (Bridgham and Richardson 1992) at low temperatures are likely to have had a less effect on the observed respirations which might happen due to the absence of WTL and Rs relationship. Studies from Chimner and Cooper (2003) and Silvola et al. (1996a) showed this observation had no further increases in soil respiration rate when WTL moved down below a certain depth (10-40 cm).

A statistical model was formulated to find and test the observed relationships between soil respiration (Rs) and the explanatory factors and their significance. Measured data only from the partial-harvested site was used in this model to Rs in response to a set of factors. The model showed that 24% (R^2 =0.24) variations in Rs can be explained by the explanatory factors but all of the factors were not statistically significant. After eliminating the insignificant factors, it was found that the variation in soil respiration (Rs) was significantly related with water table level (WTL), soil temperature (Ts) and ditch distance (Dd) (Table 8. eq. 6). Respiration is a cause of enzymatic reactions meaning that it is positively correlated with temperature in a forest-ecosystem (Zhang 2013). The respiration model showed about 18 % variation in soil respiration can be explained by soil temperature, water-table level, and ditch distance collectively whereas only water-table level explains individually 12% variation. However, soil temperature and ditch distance with other factors to the linear function increased the model R^2 (0.24), but their individual effect was not found. From the model a set of findings are apparent: i) Water-table level is statistically most significant factor which affects Rs both directly and indirectly. ii) Soil temperature (at 5 cm) indirectly affects Rs in the presence of other factors but independently it does not possess any significance. iii) Ditch distance has a significance with WTL and Ts but independently insignificant.

6 CONCLUSIONS

In this study, we demonstrated that there was a spatial variation of soil respiration (Rs) in different sectors of Lettosuo-peatland, and the highest efflux of CO_2 was recorded at easternmost (E, at 90°) direction instead of southernmost (SW to SE, at 170° to 230°). We further demonstrated that the efflux in the control site slightly higher than the partial harvested site. However, the spatial variation of soil respiration (Rs) at Lettosuo-peatland was explained well mainly by water-table level (WTL). This study also clearly indicated that soil temperature (Ts) and ditch distance (Dd) with water-table level (WTL) were collectively significant factors, but individually they (Ts and Dd) did not have any significance on Rs. Rises in temperature and peat thickness (deeper water-table) raise the decomposition rate of organic matter. Hence, this relationship is a concern of climate change (a rise in temperature) which has got the attention of some researchers. In 2005, Knorr et al. reported that a rise in temperature would increase the heterotrophic respiration from the soil organic matter to the atmosphere. In term of country scale forecasting, water-table level data from drained peatlands would play an important explanatory factor for soil respiration. The remained unexplained higher ecosystem respiration (Reco) from the southernmost sector measured by EC-mast needs further investigations to identify the reason.

Notwithstanding, this study broadens the knowledge of spatial variation of soil respiration and its explanatory factors and will provide a basement for future studies concerning draining any peatland in a boreal ecosystem.

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APPENDIX

Appendix 1. Descriptive statistics of soil respiration and its explanatory factors.

Statistics	**Rs** (g CO_2 $m^{-2}h^{-1}$)	**WTL** (cm)	**Ts** (°C)	**Pm** (%)	**Fm** (%)	**Li** (%)	**FLV** (%)
Mean	0.49	36	13.5	12	44	43	19
Std	0.16	15	2.2	29	32	32	21
Min.	0.15	8	7.8	0	0	0	0
25%	0.38	24	12	0	15	15	2
50%	0.47	35	13.5	0	35	35	10
75%	0.59	47	15.0	0	75	70	30
Max.	0.98	87	21.1	98	100	100	110
Other factors were measured once at the end of the measurement period. This descriptive statistics in from (98 plots * 8 days) 784 measurements.							

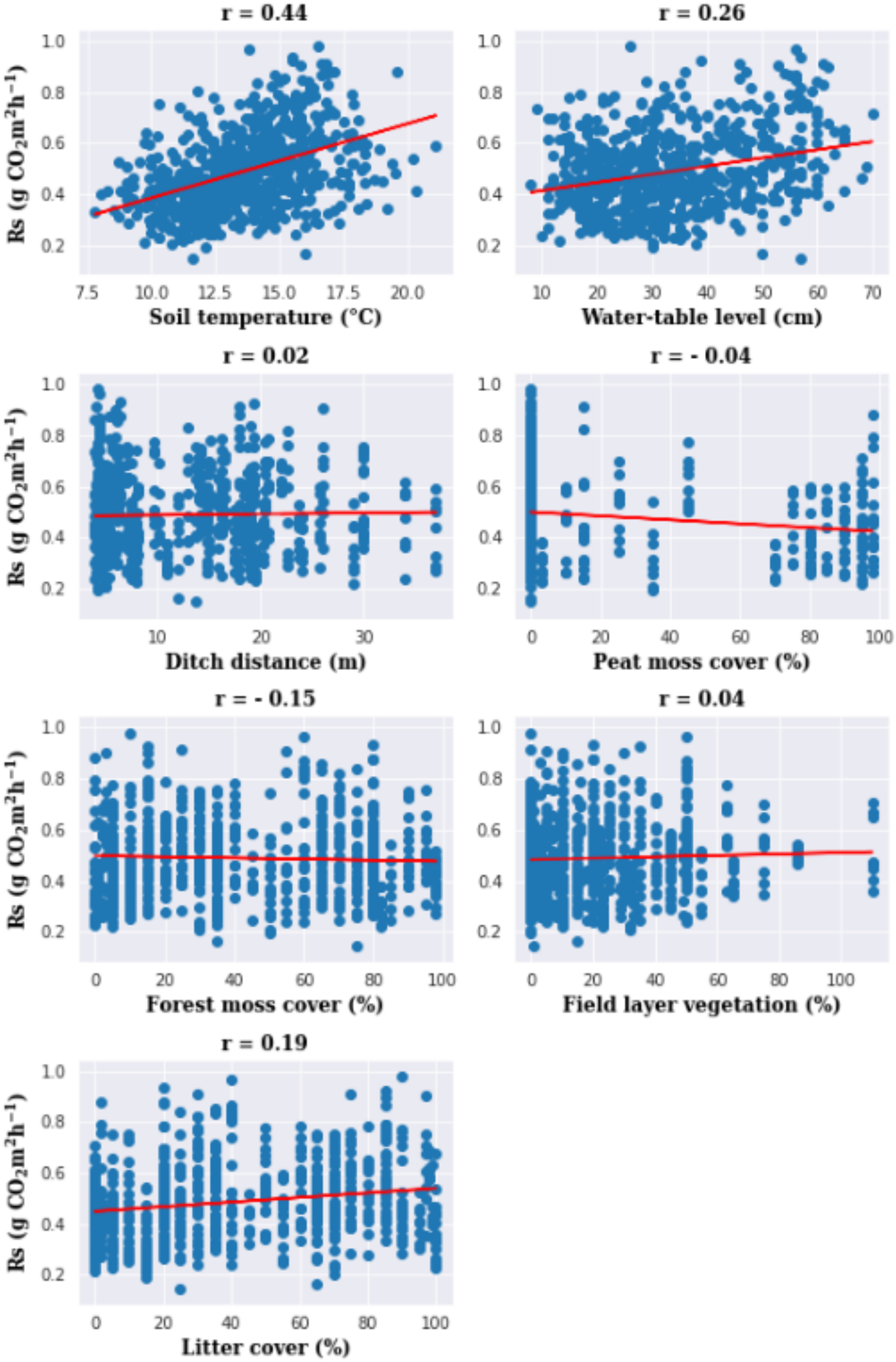
Appendix 2. Mean. Minimum and maximum value of fluxes from harvested and control sites.

Measurement days	**Rs (Mean)**		**Ts (Mean)**		**WTL (Mean)**		**Rs**	**Ts**	**WTL**
	C	**Ph**	**C**	**Ph**	**C**	**Ph**	**(Mean)**	**(Mean)**	**(Mean)**
6th June 2017	0.40	0.41	12.52	12.11	53	34	0.41	12.2	36
14th June 2017	0.38	0.45	11.54	12.22	36	23	0.44	12.1	25
21th June 2017	0.36	0.37	11.03	11.18	49	33	0.37	11.2	35
27th June 2017	0.44	0.47	12.17	12.60	46	26	0.47	12.5	29
18th July 2017	0.50	0.52	13.78	14.49	55	35	0.52	14.4	37
25th July 2017	0.55	0.51	14.42	14.62	60	42	0.51	14.6	44
1st August 2017	0.70	0.57	14.47	16.45	63	46	0.59	16.2	48
8th August 2017	0.67	0.60	14.92	14.93	53	30	0.61	14.9	33
Total Mean	**0.50**	**0.49**	**13.11**	**13.57**	**52**	**34**	**0.49**	**13.5**	**36**

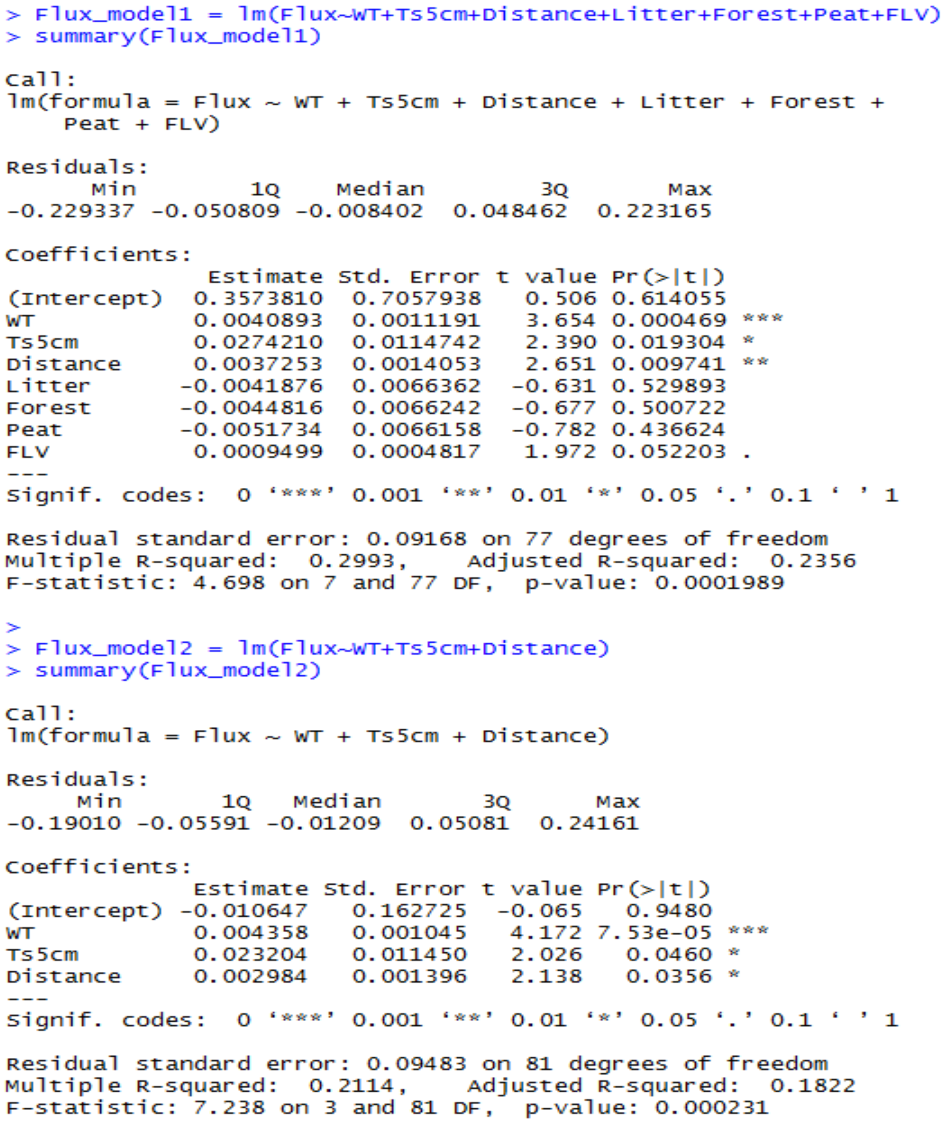
Appendix 3. Values for Pearson´s correlation

With Rs	**Both site (Ph+C)**		**Partial harvested (Ph)**		**Control (C)**	
	r	**p**	**r**	**p**	**r**	**p**
Ts	0.44	8.64e-39	0.44	1.385e-32	0.58	8.804e-11
WTL	0.25	1.26e-12	0.28	1.287e-13	0.18	0.080
Dd	0.01	0.684	0.02	0.570	-0.02	0.839
Li	0.18	3.00e-07	0.19	1.082e-06	0.15	0.122
Pm	- 0.14	6.31e-05	-0.04	0.267	--------	--------
Fm	- 0.06	0.101	-0.15	6.719e-05	- 0.15	0.122
FLV	0.04	0.214	0.04	0.309	0.18	0.591

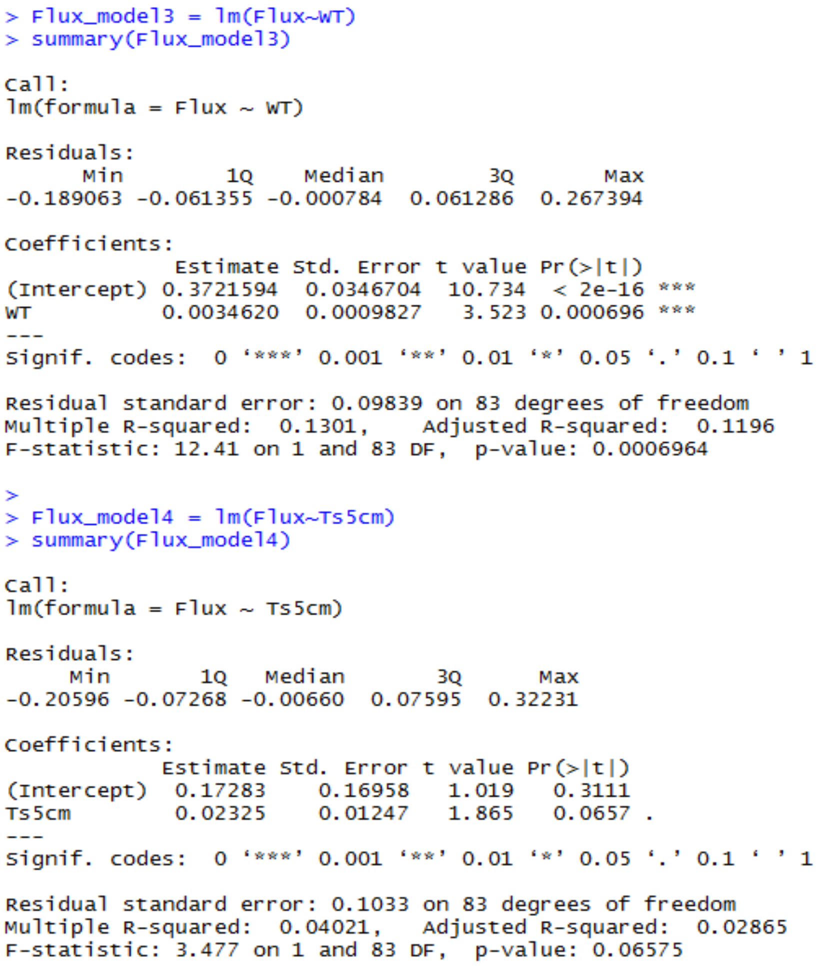
Appendix 4. Scatter plots between RS and explanatory factors (Partial harvested site) and Pearson´s correlation values (r) are shown on top of the graphs.(All measurements (98*8) have been considered here)



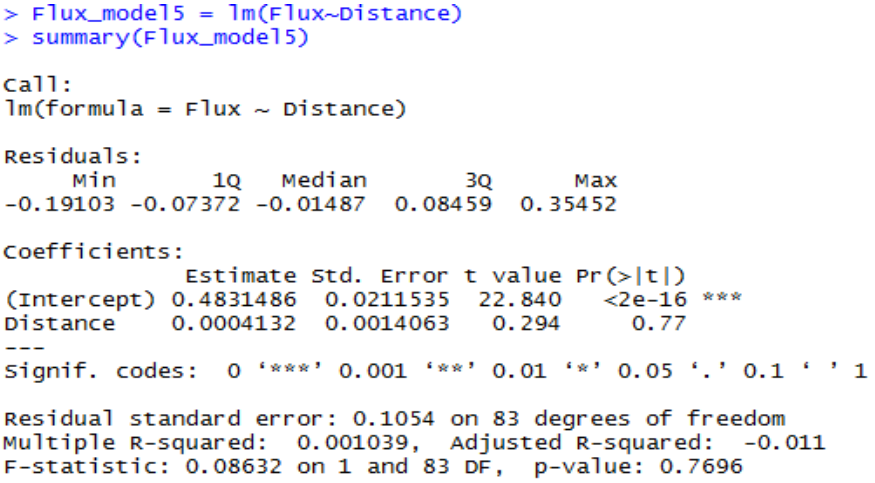
Appendix 5 . Multiple linear regression model in R (statistical tool)



```
> Flux_model1 = lm(Flux~WT+Ts5cm+Distance+Litter+Forest+Peat+FLV)
> summary(Flux_model1)

Call:
lm(formula = Flux ~ WT + Ts5cm + Distance + Litter + Forest +
    Peat + FLV)

Residuals:
      Min        1Q    Median        3Q       Max
-0.229337 -0.050809 -0.008402  0.048462  0.223165

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.3573810  0.7057938   0.506 0.614055
WT           0.0040893  0.0011191   3.654 0.000469 ***
Ts5cm        0.0274210  0.0114742   2.390 0.019304 *
Distance     0.0037253  0.0014053   2.651 0.009741 **
Litter      -0.0041876  0.0066362  -0.631 0.529893
Forest      -0.0044816  0.0066242  -0.677 0.500722
Peat        -0.0051734  0.0066158  -0.782 0.436624
FLV          0.0009499  0.0004817   1.972 0.052203 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.09168 on 77 degrees of freedom
Multiple R-squared:  0.2993,	Adjusted R-squared:  0.2356
F-statistic: 4.698 on 7 and 77 DF,  p-value: 0.0001989

>
> Flux_model2 = lm(Flux~WT+Ts5cm+Distance)
> summary(Flux_model2)

Call:
lm(formula = Flux ~ WT + Ts5cm + Distance)

Residuals:
     Min       1Q   Median       3Q      Max
-0.19010 -0.05591 -0.01209  0.05081  0.24161

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.010647   0.162725  -0.065   0.9480
WT           0.004358   0.001045   4.172 7.53e-05 ***
Ts5cm        0.023204   0.011450   2.026   0.0460 *
Distance     0.002984   0.001396   2.138   0.0356 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.09483 on 81 degrees of freedom
Multiple R-squared:  0.2114,	Adjusted R-squared:  0.1822
F-statistic: 7.238 on 3 and 81 DF,  p-value: 0.000231
```

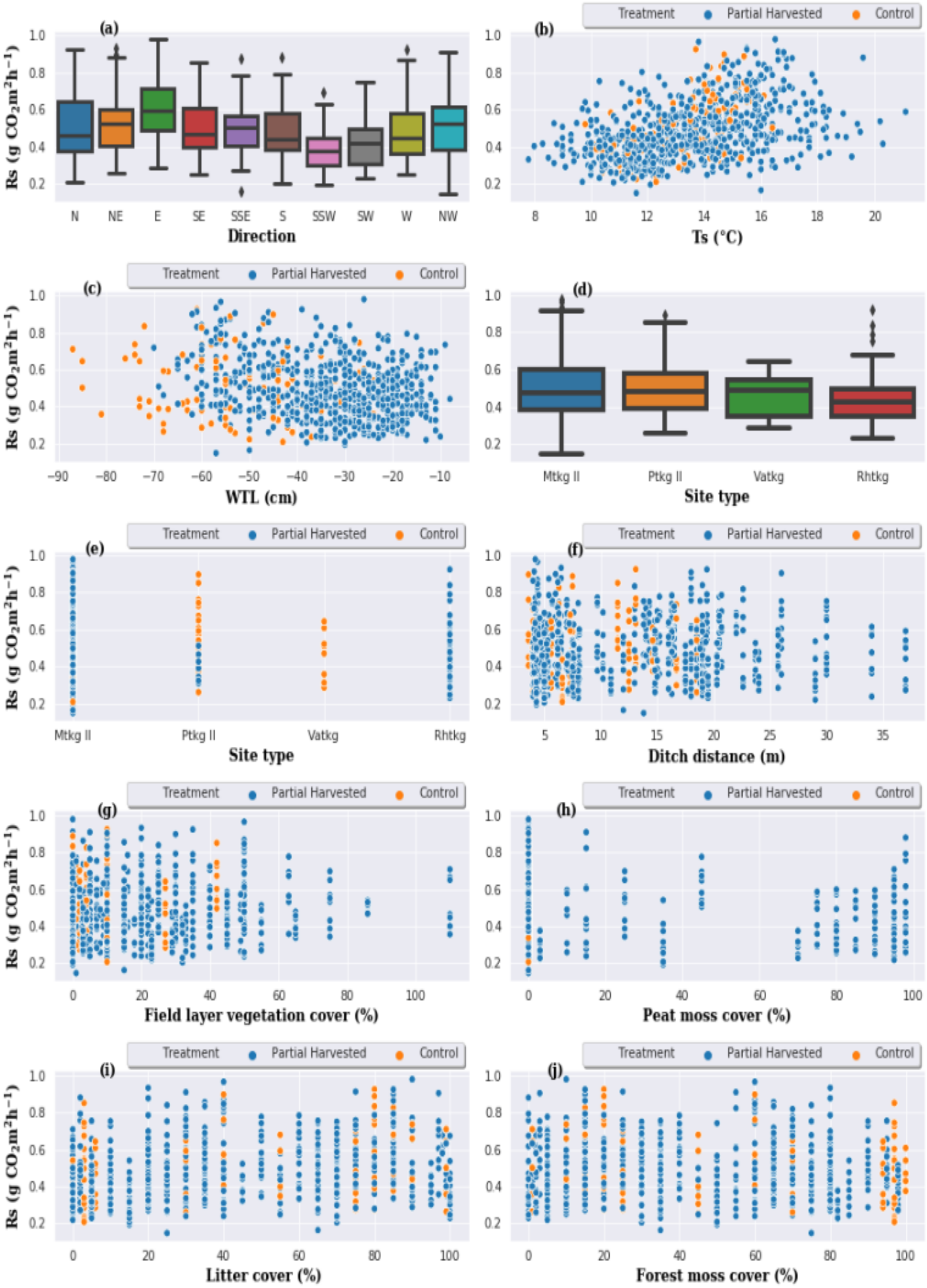


```
> Flux_model3 = lm(Flux~WT)
> summary(Flux_model3)

Call:
lm(formula = Flux ~ WT)

Residuals:
      Min        1Q    Median        3Q       Max 
-0.189063 -0.061355 -0.000784  0.061286  0.267394 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 0.3721594  0.0346704  10.734  < 2e-16 ***
WT          0.0034620  0.0009827   3.523 0.000696 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.09839 on 83 degrees of freedom
Multiple R-squared:  0.1301,	Adjusted R-squared:  0.1196 
F-statistic: 12.41 on 1 and 83 DF,  p-value: 0.0006964

> 
> Flux_model4 = lm(Flux~Ts5cm)
> summary(Flux_model4)

Call:
lm(formula = Flux ~ Ts5cm)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.20596 -0.07268 -0.00660  0.07595  0.32231 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)  
(Intercept)  0.17283    0.16958   1.019   0.3111  
Ts5cm        0.02325    0.01247   1.865   0.0657 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.1033 on 83 degrees of freedom
Multiple R-squared:  0.04021,	Adjusted R-squared:  0.02865 
F-statistic: 3.477 on 1 and 83 DF,  p-value: 0.06575
```



```
> Flux_model5 = lm(Flux~Distance)
> summary(Flux_model5)

Call:
lm(formula = Flux ~ Distance)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.19103 -0.07372 -0.01487  0.08459  0.35452 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 0.4831486  0.0211535  22.840   <2e-16 ***
Distance    0.0004132  0.0014063   0.294     0.77    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.1054 on 83 degrees of freedom
Multiple R-squared:  0.001039,	Adjusted R-squared:  -0.011 
F-statistic: 0.08632 on 1 and 83 DF,  p-value: 0.7696
```

Appendix 6. Relationship between Rs and explanatory factors (a. direction, b. soil temperature, c. water table level, d. site type e. site type, f. ditch distance, g. field layer vegetation cover, h. peat moss, i. litter and j. forest moss. All measurements (98*8) have been considered here).



Appendix 7. Fluxes of CO_2 (g $CO_2 m^{-2} h^{-1}$) (n=98*8)

Date	Median	Mean (0.49)	Min.	Max.	Std	SE	CV (%)
6th June	0.41	0.42	0.19	0.92	0.12	0.01	0.02
14th June	0.42	0.44	0.23	0.87	0.14	0.01	0.02
21st June	0.36	0.37	0.15	0.80	0.11	0.01	0.01
27th June	0.46	0.47	0.21	0.97	0.13	0.01	0.02
18th July	0.52	0.52	0.25	0.82	0.13	0.01	0.02
25th July	0.49	0.51	0.29	0.84	0.13	0.01	0.02
1st August	0.59	0.59	0.16	1.03	0.17	0.02	0.03
8th August	0.60	0.62	0.32	1.33	0.17	0.02	0.03

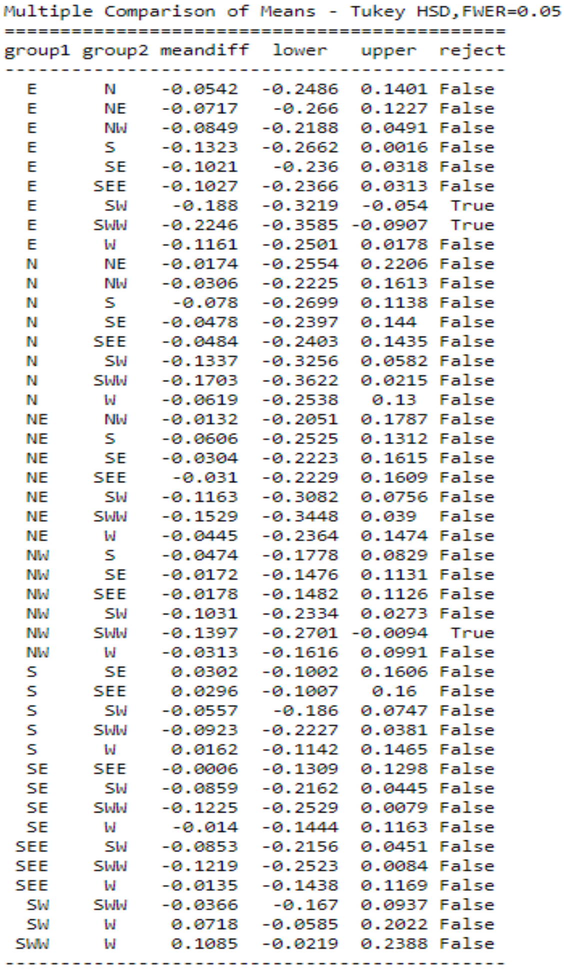
Appendix 8. Soil temperature at 5cm (°C) (n=98*8)

Date	Median	Mean (13.51)	Min.	Max.	Std	SE	CV (%)
6th June	12.00	12.16	7.80	17.20	2.10	0.21	4.41
14th June	11.85	12.13	8.80	17.30	1.95	0.20	3.81
21st June	11.20	11.16	9.70	13.10	0.80	0.08	0.64
27th June	12.40	12.54	10.70	15.30	1.08	0.11	1.16
18th July	14.25	14.39	10.30	18.30	1.48	0.15	2.19
25th July	14.50	14.59	12.00	17.60	0.88	0.09	0.77
1st August	16.20	16.19	12.80	21.10	1.71	0.17	2.94
8th August	14.80	14.93	12.10	19.50	1.57	0.16	2.48

Appendix 9. Water table level (cm) (n=98*8)

Date	Median	Mean (56.00)	Min.	Max.	Std	SE
6th June	55	56	32	91	14	1.36
14th June	41	45	28	80	12	1.22
21st June	53	55	33	88	12	1.23
27th June	43	49	29	93	14	1.44
18th July	55	57	35	101	14	1.42
25th July	63	64	40	105	13	1.27
1st August	67	68	43	107	12	1.21
8th August	45	53	31	105	15	1.47

Appendix 10. TukyHSD visualization for differences in mean levels at different directions



```
Multiple Comparison of Means - Tukey HSD,FWER=0.05
=============================================
group1 group2 meandiff  lower   upper  reject
---------------------------------------------
  E      N    -0.0542  -0.2486  0.1401 False
  E      NE   -0.0717   -0.266  0.1227 False
  E      NW   -0.0849  -0.2188  0.0491 False
  E      S    -0.1323  -0.2662  0.0016 False
  E      SE   -0.1021   -0.236  0.0318 False
  E     SEE   -0.1027  -0.2366  0.0313 False
  E      SW    -0.188  -0.3219  -0.054  True
  E     SWW   -0.2246  -0.3585 -0.0907  True
  E      W    -0.1161  -0.2501  0.0178 False
  N      NE   -0.0174  -0.2554  0.2206 False
  N      NW   -0.0306  -0.2225  0.1613 False
  N      S     -0.078  -0.2699  0.1138 False
  N      SE   -0.0478  -0.2397  0.144  False
  N     SEE   -0.0484  -0.2403  0.1435 False
  N      SW   -0.1337  -0.3256  0.0582 False
  N     SWW   -0.1703  -0.3622  0.0215 False
  N      W    -0.0619  -0.2538   0.13  False
  NE     NW   -0.0132  -0.2051  0.1787 False
  NE     S    -0.0606  -0.2525  0.1312 False
  NE     SE   -0.0304  -0.2223  0.1615 False
  NE    SEE    -0.031  -0.2229  0.1609 False
  NE     SW   -0.1163  -0.3082  0.0756 False
  NE    SWW   -0.1529  -0.3448  0.039  False
  NE     W    -0.0445  -0.2364  0.1474 False
  NW     S    -0.0474  -0.1778  0.0829 False
  NW     SE   -0.0172  -0.1476  0.1131 False
  NW    SEE   -0.0178  -0.1482  0.1126 False
  NW     SW   -0.1031  -0.2334  0.0273 False
  NW    SWW   -0.1397  -0.2701 -0.0094  True
  NW     W    -0.0313  -0.1616  0.0991 False
  S      SE    0.0302  -0.1002  0.1606 False
  S     SEE    0.0296  -0.1007   0.16  False
  S      SW   -0.0557   -0.186  0.0747 False
  S     SWW   -0.0923  -0.2227  0.0381 False
  S      W     0.0162  -0.1142  0.1465 False
  SE    SEE   -0.0006  -0.1309  0.1298 False
  SE     SW   -0.0859  -0.2162  0.0445 False
  SE    SWW   -0.1225  -0.2529  0.0079 False
  SE     W     -0.014  -0.1444  0.1163 False
 SEE     SW   -0.0853  -0.2156  0.0451 False
 SEE    SWW   -0.1219  -0.2523  0.0084 False
 SEE     W    -0.0135  -0.1438  0.1169 False
  SW    SWW   -0.0366   -0.167  0.0937 False
  SW     W     0.0718  -0.0585  0.2022 False
 SWW     W     0.1085  -0.0219  0.2388 False
---------------------------------------------
```

Appendix 11: Data set (Plot wise mean values)

Plot number	Flux (g CO_2 m^{-2} h^{-1})	Soil temperature (°C)	Ditch distance (m)	Water-table level (cm)	Litter cover (%)	Forest moss cover (%)	Peat moss (%)	Field layer vegetation (%)	Treatment site (Ph –partial harvest, C –Control)	Direction	Site type
0	0.45	13	19	43	100	0	0	0	Ph	N	Mtkg II
1	0.63	14	6	52	65	35	0	0	Ph	N	Mtkg II
2	0.58	14	10	52	85	15	0	1	Ph	N	Mtkg II
3	0.56	13	8	56	80	20	0	0	C	N	Mtkg II
4	0.47	13	13	50	75	25	0	2	C	N	Mtkg II
5	0.59	12	13	53	80	20	0	10	C	N	Mtkg II
6	0.30	13	7	51	3	97	0	10	C	N	Mtkg II
7	0.47	13	17	67	90	10	0	1	C	N	Mtkg II
8	0.59	14	4	76	99	1	0	0	C	N	Mtkg II
10	0.50	14	5	49	5	95	0	22	Ph	NE	Mtkg II
11	0.46	14	5	38	40	60	0	10	Ph	NE	Mtkg II
12	0.64	15	7	49	20	80	0	20	Ph	NE	Mtkg II
13	0.61	13	6	50	85	15	0	4	C	NE	Mtkg II
14	0.57	13	4	43	40	60	0	10	C	NE	Ptkg II
15	0.45	13	15	37	0	100	0	4	C	NE	Ptkg II
16	0.65	14	12	35	3	97	0	42	C	NE	Ptkg II
17	0.46	14	6	45	6	94	0	27	C	NE	Vatkg
18	0.47	13	19	44	30	70	0	0	C	NE	Ptkg II
19	0.42	13	7	67	55	45	0	0	C	NE	Mtkg II
20	0.59	13	4	53	75	25	0	0	Ph	E	Mtkg II
21	0.57	13	5	53	80	20	0	0	Ph	E	Mtkg II
22	0.70	14	4	31	90	10	0	0	Ph	E	Mtkg II

23	0.58	14	14	27	70	30	0	0	Ph	E	Mtkg II
24	0.47	15	15	30	10	90	0	0	Ph	E	Mtkg II
25	0.57	15	17	34	30	70	0	40	Ph	E	Mtkg II
26	0.84	15	4	58	40	60	0	50	Ph	E	Mtkg II
27	0.62	13	21	19	50	5	45	25	Ph	E	Mtkg II
28	0.51	14	19	35	5	95	0	7	Ph	E	Mtkg II
30	0.54	14	4	39	35	65	0	0	Ph	SE	Mtkg II
31	0.32	13	11	28	10	10	80	3	Ph	SE	Mtkg II
32	0.53	14	6	53	35	65	0	15	Ph	SE	Mtkg II
33	0.46	14	10	24	60	40	0	0	Ph	SE	Mtkg II
34	0.47	16	16	26	0	10	90	50	Ph	SE	Mtkg II
35	0.52	13	30	25	0	5	95	110	Ph	SE	Mtkg II
36	0.56	13	30	33	10	90	0	0	Ph	SE	Mtkg II
37	0.65	12	16	33	60	40	0	0	Ph	SE	Mtkg II
38	0.46	12	5	39	65	35	0	45	Ph	SE	Mtkg II
39	0.51	12	19	23	25	75	0	25	Ph	SE	Rhtkg
40	0.61	15	5	41	20	80	0	20	Ph	SSE	Mtkg II
41	0.46	13	4	39	25	75	0	20	Ph	SSE	Mtkg II
42	0.42	14	12	30	65	35	0	15	Ph	SSE	Mtkg II
43	0.43	14	37	22	0	15	85	3	Ph	SSE	Mtkg II
44	0.61	14	21	20	20	80	0	16	Ph	SSE	Mtkg II
45	0.44	12	7	47	99	1	0	9	Ph	SSE	Rhtkg
46	0.50	12	8	30	65	35	0	86	Ph	SSE	Mtkg II
47	0.60	13	15	20	30	70	0	63	Ph	SSE	Mtkg II
48	0.41	11	5	22	2	98	0	65	Ph	SSE	Mtkg II
49	0.53	13	15	23	35	65	0	20	Ph	SSE	Mtkg II
50	0.35	13	7	46	25	75	0	0	Ph	S	Mtkg II
51	0.61	15	7	50	75	25	0	20	Ph	S	MtkgII
52	0.45	14	5	37	65	35	0	45	Ph	S	Mtkg II
53	0.60	13	6	30	70	30	0	25	Ph	S	Mtkg II

54	0.36	13	5	36	70	30	0	32	Ph	S	Mtkg II
55	0.37	14	19	21	20	80	0	15	Ph	S	Rhtkg
56	0.39	14	4	27	2	98	0	55	Ph	S	Mtkg II
57	0.59	15	18	22	2	0	98	10	Ph	S	Mtkg II
58	0.47	15	8	25	0	20	80	15	Ph	S	Mtkg II
59	0.52	14	15	23	70	5	25	75	Ph	S	Mtkg II
60	0.32	12	4	31	15	50	35	0	Ph	SSW	Mtkg II
61	0.39	13	24	22	20	80	0	4	Ph	SSW	Mtkg II
62	0.36	14	29	14	0	5	95	23	Ph	SSW	Mtkg II
63	0.30	13	8	31	15	82	3	10	Ph	SSW	Mtkg II
64	0.34	14	8	29	40	60	0	20	Ph	SSW	Mtkg II
65	0.50	13	8	20	65	35	0	50	Ph	SSW	Mtkg II
66	0.44	15	6	27	0	15	75	45	Ph	SSW	Mtkg II
67	0.35	13	20	25	15	70	15	18	Ph	SSW	Mtkg II
68	0.39	13	5	26	15	85	0	35	Ph	SSW	Rhtkg
69	0.41	13	20	24	95	5	0	10	Ph	SSW	Mtkg II
70	0.31	13	5	35	5	35	70	10	Ph	SW	Mtkg II
71	0.44	14	19	20	20	80	0	0	Ph	SW	Mtkg II
72	0.47	14	34	17	0	5	95	50	Ph	SW	Mtkg II
73	0.38	14	18	26	5	5	90	33	Ph	SW	Ptkg II
74	0.39	16	4	37	70	30	0	22	Ph	SW	Mtkg II
75	0.30	14	20	25	100	0	0	23	Ph	SW	Rhtkg
76	0.45	15	5	28	20	80	0	49	Ph	SW	Rhtkg
77	0.59	14	14	29	70	30	0	50	Ph	SW	Mtkg II
78	0.43	14	15	32	55	35	10	8	Ph	SW	Mtkg II
79	0.41	14	5	36	45	55	0	15	Ph	SW	Mtkg II
80	0.47	15	8	35	50	50	0	0	Ph	W	Mtkg II
81	0.41	13	5	35	20	80	0	0	Ph	W	Mtkg II
82	0.42	13	4	27	55	45	0	0	Ph	W	Mtkg II
83	0.50	14	5	28	35	65	0	5	Ph	W	Mtkg II

84	0.54	13	13	39	35	65	0	10	Ph	W	Mtkg II
85	0.48	13	16	31	80	20	0	20	Ph	W	Mtkg II
86	0.57	13	4	56	85	15	0	3	Ph	W	Mtkg II
87	0.69	14	19	43	85	15	0	35	Ph	W	Rhtkg
88	0.43	13	24	27	90	10	0	30	Ph	W	Rhtkg
89	0.37	14	8	41	90	10	0	40	Ph	W	Rhtkg
90	0.50	13	19	32	20	80	0	2	Ph	NW	Mtkg II
91	0.46	13	19	32	25	75	0	5	Ph	NW	Mtkg II
92	0.53	13	23	31	30	70	0	5	Ph	NW	Mtkg II
93	0.63	14	26	59	97	3	0	10	Ph	NW	Mtkg II
94	0.49	13	14	59	25	75	0	1	Ph	NW	Mtkg II
95	0.61	13	6	57	85	15	0	30	Ph	NW	Mtkg II
96	0.45	12	26	33	75	25	0	7	Ph	NW	Mtkg II
97	0.54	14	18	35	30	55	15	5	Ph	NW	Mtkg II
98	0.36	13	4	38	0	2	98	29	Ph	NW	Mtkg II
99	0.63	14	22	30	98	2	0	30	Ph	NW	Mtkg II