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INFLUENCE OF MANAGEMENT AND RESTORATION ON GREENHOUSE GAS FLUXES OF A PREALPINE BOG

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Vorwort

Als ich im Sommer 2006 zu Prof. Dr. Jörg Pfadenhauer kam, um mich zu erkundigen, ob es denn bei ihm am Lehrstuhl für Vegetationsökologie die Möglichkeit gäbe, auch im Bereich des Klimaschutzes zu promovieren, hat er mich an seinen Mitarbeiter Dr. Matthias Drösler verwiesen. Dieser hatte gerade eine Förderung für ein bundesweites Projekt kurz vor der Genehmigung durch das Bundesministerium für Bildung und Forschung. Wie Matthias Drösler mir erzählt hat, gehe es in diesem Projekt unter anderem um die Erfassung von Spurengasflüssen aus Mooren verschiedener Nutzungen, Ausprägungen und Lage innerhalb Deutschlands. Ein Moorstandort sollte sich im Voralpenland südlich von München befinden, nahe dem Dorf Königsdorf – die Hochmoorflächen von Mooseurach.

Diese Aussage elektrisierte mich, denn die geplanten Messstandorte lagen kaum 20 km von meinem Heimatort Wolfratshausen entfernt und mit dem Fahrrad bin ich des Öfteren schon an diesen vorbeigefahren. Somit eröffnete sich mir mit diesem Angebot zur Promotion die Möglichkeit, in unmittelbarer Heimatnähe Daten für meine Doktorarbeit zu erheben und ansonsten unzugängliche Bereiche der heimatlichen Hochmoore besser kennen zu lernen.

Zuvor hatte ich allerdings noch die Gelegenheit, zu testen, ob mir denn der nicht unanstrengende Einsatz im Feld auch liegen würde. Dies konnte ich bei Spurengasmessungen ausprobieren, die meine ehemalige Kollegin Lindsey Bergmann auf Flächen des Benediktbeurer Klosterlandes durchführte. Wie auch sie, bei ihren Messkampagnen wurde auch ich, bei der Installation des stationären Messequipments (Stege, Lagerplätze, etc.) wie auch den in den folgenden zweieinhalb Jahren durchgeführten Spurengasmessungen von zahlreichen studentischen Hilfskräften, Zivildienstleistenden, Helfern von Ort und Kollegen vom Lehrstuhl für Vegetationsökologie unterstützt. Hierbei möchte ich besonders Marika Bernrieder erwähnen, die das Monitoring nach der Vernässung der Flächen seit Jahren durchführt und das Hochmoor wohl besser kennt, als kaum jemand anderer. Marika Bernrieder ist nahezu immer dann eingesprungen und hat sich Zeit genommen, bei den Messungen zu helfen, wenn mal wieder nicht genügend Helfer zur Verfügung standen.

Ebenso möchte ich mich bedanken bei Dr. Christof Bosch, dem Eigentümer der Flächen, ohne dessen Erlaubnis, Kooperation und auch inhaltlichem Interesse die Erhebung der Spurengasflüsse nicht möglich gewesen wäre. Einen herzlichen Dank richte ich auch an den dort zuständigen Förster Herrn Neustifter, dessen Flexibilität ich durch meine oft sehr spontan stattfindenden Messkampagnen arg strapaziert habe, wie auch an Herrn Schuller, Landwirt am Gut Mooseurach, der uns besonders in der Aufbauphase mit diversen Transportgeräten das Leben erleichterte.

Dank auch an meinen Kollegen Dr. Wolfram Adelmann, der zeitgleich mit mir die Spurengasmessungen auf Standorten des Freisinger Mooses durchgeführt hat, insbesondere für dessen Organisationstalent bei der Kampagnenabstimmung, seiner Mithilfe beim Aufbau sowie den Messungen und der Urlaubsvertretung.

Während meiner Zeit als wissenschaftlicher Angestellter bei Prof. Dr. Jörg Pfadenhauer hatte ich neben den Arbeiten für meine Promotion auch Gelegenheit, in Prüfungsbeisitzen und auf Exkursionen mein Wissen im Bereich der Vegetationsökologie aufzufrischen wie auch zu verbessern. Gleichwohl möchte ich mich bei Prof. Dr. Hans-Peter Schmid bedanken, der nach Ausscheiden von Prof. Dr. Jörg Pfadenhauer aus dem aktiven Universitätsbetrieb und dem Wechsel mit der Arbeitsgruppe um Dr. Drösler an die Hochschule Weihenstephan, bereit war, die Betreuung meiner Dissertation, die ich nunmehr als ‚Externer' anfertigte an der Technischen Universität München zu übernehmen.

Dank ebenso an Prof. Dr. Matthias Drösler, der mir neben enormem, fachlichem Input die Gelegenheit geboten hat, an verschiedensten Tagungen nationaler und internationaler Ebene teilzunehmen und in den letzten Jahren auch in mehreren regionalen und nationalen Projekten, teils an entscheidender Stelle mitzuwirken, was zudem die Finanzierung meiner Stelle ermöglichte. Die damit oft verbundene Absorption von Arbeitszeit führte jedoch auch hin und wieder zu gewissen Ruhezeiten der Promotion.

Ruhezeiten anderer Art war die Geburt meiner beiden Kinder Lukas und Simon, die in der letzten Zeit doch immer öfter und intensiver ihren Papa forderten, aber mir ebenso auch in Phasen eingeschränkter Produktivität Kraft und Zuversicht gegeben haben. Eine Quelle steter Unterstützung und Kraft ist zudem meine Frau Helga Förster, die mich seit Beginn der Promotion begleitet und bei der ich mich vor allem für ihre Geduld, nicht zuletzt bei der Fertigstellung dieser Arbeit, bedanken möchte.

Schließlich gilt mein Dank noch meinen Eltern und Großeltern, ohne deren Unterstützung in den Jahren vor, aber auch während der Promotion, diese wohl gar nicht möglich gewesen wäre.

Die nunmehr vorliegende Arbeit hat zunächst den Anschein einer kumulativen Dissertation. Die einzelnen Kapitel sind, sofern sie fachliche Ergebnisse beinhalten, weitestgehend in Form wissenschaftlicher Veröffentlichungen gehalten. Daher sind die Kapitel auch in englischer Sprache verfasst. Als Nicht-Muttersprachler ist es allerdings nicht immer möglich, umfangreiche Texte wie diese Arbeit in englischer Sprache ganz fehlerfrei zu verfassen; insofern möchte ich mich an dieser Stelle noch ganz herzlich bei Jessica Herron bedanken, die sich dazu bereit erklärt hat, diese Arbeit gegenzulesen und wo nötig, korrigierend Anmerkungen zu setzen.

Die angewandte Form hatte sich auch deswegen angeboten, da die Spurengasmessungen in einzelne Komponenten aufgeteilt waren, deren Ergebnisse nicht zuletzt der Übersichtlichkeit halber entsprechend dargestellt werden konnten und daher themenspezifisch unterschiedliche Zielgruppen ansprechen kann.

So umfasst Kapitel 2 eine allgemeine Beschreibung des Gebiets und allgemeiner verwendeten Methoden, sowie bereits die Ergebnisse der erfassten Umweltparameter. Daran schließt Kapitel 3 an, welches die Messung von CO_2 auf den unterschiedlichen Messvarianten behandelt. Die Trennung der Darstellung der CO_2 Ergebnisse und derer von CH_4 und N_2O, erfolgte aufgrund des Umfangs, den die CO_2 Messungen und Auswertungen hatten. Dem Kapitel zu den CH_4 und N_2O Messungen (Kapitel 4) folgen eine Synthese (Kapitel 5) aller erfassten Spurengase sowie ein Ausblick auf die zukünftige Entwicklung der Standorte (Kapitel 6).

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Units

a^{-1}	per year
b.p.	before present
cm	centimetre
°C	degree Celsius
g	gram
h	hour
ha	hectare
K	kelvin
kg	kilogram
km	kilometre
l	litre
min	minute
mm	millimetre
m^2	square meter
µmol	micromole
µS/cm	micro-Siemens per centimetre
s	second
t	ton
Tg	teragram

Abbreviations of used expressions

α	initial slope of GPP versus PAR regressions
ANOVA	analysis of variance
avg	average
C	carbon
CCA	canonical correspondence analysis
C_{eq}	carbon equivalents
CH_4	methane
CO_2	carbon dioxide
DCA	detrended correspondence analysis
EC	electrical conductivity
ECD	electron capture detector
E_0	activation energy like parameter
FID	flame ionisation detector
GHG	greenhouse gases
GP_{max}	maximum GPP for PAR versus infinite
GPP	gross primary production
GWP_{100}	global warming potential of GHG after 100 years
IRGA	infrared gas analyser
N	nitrogen

n	number
NEE	net ecosystem exchange
N_2O	dinitrogen monoxide / nitrous oxide
p	probability
PAR	photosynthetic active radiation
pH	pH value
R_{eco}	respiration of the ecosystem
rH	relative humidity
R_{ref}	respiration at reference temperature of 10°C
rest.	restored
r^2	coefficient of determination
StDev	standard deviation
SE	standard error
THG	Treibhausgase
V	volume
WT	water table

1 Introduction

The aim of this work is the elaboration of the exchange habitude of greenhouse gases (GHG) CO_2, CH_4 and N_2O of a bog in the Bavarian foreland of the Alps. DRÖSLER (2005) showed already the differences between natural, restored and degraded bogs concerning CO_2 resp. GHG of this region. But as mentioned in many studies especially in the nemoral zone, there is little data concerning greenhouse gas emissions and this work aims to be a step to fill this gap (BYRNE ET AL. (2004) or DRÖSLER (2005), HENDRIKS ET AL. (2007), WILSON ET AL. (2007) or COUWENBERG (2011)).

Surrounding conditions

This work was part of the research project 'Klimaschutz - Moornutzungsstrategien' (FKZ 01LS05046), funded by the German Ministry of Science and Research, which investigated greenhouse gas fluxes at six different areas all over Germany under different use and at different peatland types. Criterions for selection of specific testing areas were (1) representativeness of the areas concerning their uses, (2) their status as hot-spots for emissions and potential for future development and (3) a multiple presence at several areas to get a more distinct resolution of emission factors of peatlands (DRÖSLER ET AL. 2011 and 2013). The Lower-Saxonian bog area included intensively and extensively used grassland, bog heaths with different water tables, a peat cut area and a natural like bog. Four other testing areas were located on fens used as arable land with different crops, willows, intensive and extensive grassland, pasture and reeds with small and large sedges. For further details of the project 'Klimaschutz - Moornutzungsstrategien' see DRÖSLER ET AL. 2011 and 2013. The testing area of Mooseurach, regarded in this work, was probably the less disturbed one. Preliminary studies accompanied restoration activities, which took place in 1993 by faunistic and floristic investigations as well as water chemical analysis and analysis of nutrients from 1992 to 1999 (BOSCH UND PARTNER GMBH 2001). Thus, the success of restoration was proved by continuous investigations concerning biotic and abiotic compartiments of the single sites. But how the restoration of this bog influenced gas fluxes from the soil and plants was disregarded.
Thus, the intent of this work is to investigate small scale GHG differences of a relatively natural like and rarely disturbed bog, which has a widely intact peat body which can easily be pushed to restart to grow after rewetting and stopping oxidation. As Fig. 1 shows, natural peatlands are sinks for CO_2 but sources for CH_4. Being untouched, they are in total carbon sinks, which is noticeable in the growth of the peat body. Drainage and use of peatlands by humans led and still lead to a release of the stored carbon to the atmosphere by oxidative

processes, which partly peaked in a total destruction of these peatlands with no possibility to revitalise them. In addition to the dominating CO_2 efflux, N_2O release contributes to an enforced climate impact especially because the global warming potential (GWP_{100}) of N_2O after 100 years is 310 times more effective than CO_2 (IPCC 1995 and 2003).

Restoration of drained peatlands might reduce or stop these releases and can re-establish conditions for climate discharge and peat growth. But restoration has to be done with care to avoid large areas with flooding and enhanced CH_4 emissions, which cannot be compensated by CO_2 uptakes, because CH_4 is 21 times more destructive to the climate than CO_2 (IPCC 1995 and 2003). As Fig. 1 shows CH_4 emissions of restored peatlands can reach the level of natural peatlands (TUITTILA ET AL. (2000), SAARNIO ET AL. (2009) or WILSON ET AL. (2009) or even exceed them (LAINE ET AL. (2007). Small scale flooding is not a problem due to large areas with water tables below the surface, where bog typical vegetation can establish and accumulates carbon.

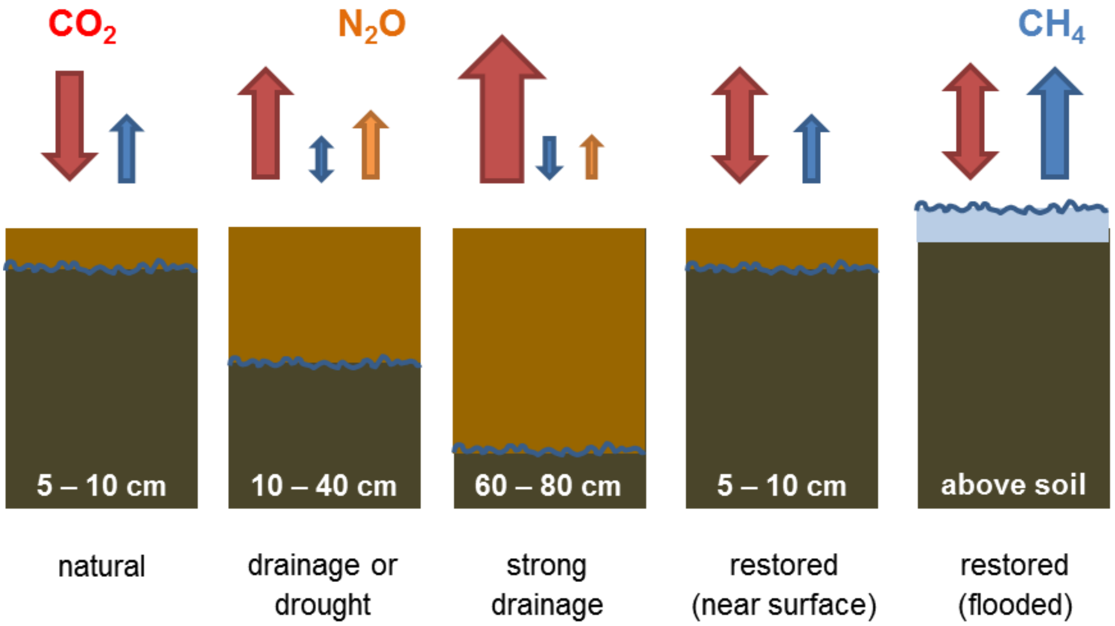

Fig. 1: Relation of greenhouse gas emissions and uptakes at different water tables
(after DRÖSLER ET AL. 2008; modified)
red arrows show CO_2 fluxes, blue arrows CH_4 fluxes and yellow arrows N_2O fluxes; curled blue lines indicate water tables, dark brown areas indicate waterlogged soils, light brown areas indicate not waterlogged soils

Thus, the questions which arise and which shall be answered with this work are:

- How the restoration of a drained bog heath with *Calluna vulgaris* (L.) Hull is visible referring to greenhouse gas fluxes after 15 years and is there a climate cooling effect visible even after short term restoration? (Chronosequence of restoration)

- How do water tables influence the gas fluxes of a bog meadow which is drained for decades? How big is the restoration potential concerning greenhouse gases after 15 years of restoration and after stopping any kind of management?

- How do CH_4 and N_2O fluxes change after rewetting of a bog meadow resp. a *Calluna* heath especially in comparison to CO_2 and how does this affect the total GHG balances?

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2 Site descriptions and general methods

2.1 Research area

2.1.1 Geographical and natural classification

The property Mooseurach is located 50 km south of Munich in the district of Bad Tölz Wolfratshausen between the commune Königsdorf in the northeast and the river Loisach in the west. Mooseurach is part of "Königsdorfer Moränen- und Moorplatte" which belongs to the "Moorlandschaft im südlichen Ammer-Loisach-Hügelland" (BFN 2009), which is, with a total area of 649 km² between Staffelsee, Tegernsee and the northern end of the former "Wolfratshauser See", one of the areas with the highest amount of peatlands in Middle Europe. As a typical example of the use at this area, the property Mooseurach shows a high percentage of grassland and needle wood (100 ha each). The remaining area is a composite of a drained, *Calluna* rich bog and a relatively untouched bog (BERNRIEDER 2003, BOSCH & PARTNER GMBH 2001). The research areas are located in the southeast of the property in the 'Breitfilz'.

Geology

The estate Mooseurach is located on a drumlin. These formations, which are typical for this region, were created at the end of the last ice age (Würm; 115.000 to 10.000 b.p.) when the glaciers retrenched. While they moved back to the Alps the glaciers smoothed small hills and boulder clays and created these streamlined erosion formations. Around these drumlins between the rivers Isar and Loisach are nowadays fluvial and limnic sediments which derived from the former Wolfratshauser See which existed till 8.000 b.p.. After the lake leaked within a few months via a river gate at Schäftlarn, many moist areas in its former basin remained. These were the base of the peatland areas of today. (MEYER ET AL. 2002)

Climate situation

The 'oberbayerische Vorland', where the community of Königsdorf is located, is characterized by cool-humid climate conditions with partly rich precipitation events (perhumid prealpid climate). The long-term average of precipitation of Königsdorf is 1244 mm; the long-term average air temperature is 7.5°C (BERNRIEDER 2003).

Due to relatively high variability in temperature within a year and a maximum of precipitation in summer, the climate of this region has a continental touch. (VAN EIMERN in JERZ 1968)
One typical phenomenon of the many mountain regions is also remarkable in the foreland of the Alps. The fan, a dry downslope wind based on equilibrated conditions of air pressure at both sides of a mountain system, results in intensive solar irradiation, high temperatures and low humidity and leads as consequence to drying occurrences of the upper soil.

2.1.2 Land use history

Mooseurach had three farms already in 1860. In 1870 a first estate was established which was bought by Robert Bosch in 1912. He planned to create a prospering farming enterprise and to remove the peat after having drained the peatland. Having been famous for livestock and grassland management, the estate got one of the most important employers in the region. After the Second World War, the farming use of the drained areas and the peat removal stopped because of inefficiency. Grassland use was forced now and big areas were afforested with *Picea abies* (L.) H. Karst., small areas with *Pinus sylvestris* L. (WWW.MOOSEURACH.DE)
Due to slow drainage and low productivity, the profitable efficiency of farming activities decreased. Stop of the use would have led to a fallow and would have promoted a forest with a fauna and flora, which would be relatively far away from a species composition of bog ecosystems. Restoration was the best procedure to protect these species. (BERNRIEDER 2003)
Thus in 1993 in some areas of forest and grassland and at the bog heath as well, a restoration project was undertaken including closure of drainages and ditches and construction of barriers to keep the water inside the area; details can be read in 'Laufener Seminarbeiträge' (1/03, p. 121-146 by BERNRIEDER 2003).

2.1.3 Description of the research areas

The so called 'Breitfilz' is a bog complex of around 100 ha (47° 47' N, 11° 26' E), which separates into three areas: a Pine forest and an associated tree-cut area in the east, which was not regarded in detail here (see. e.g. BERNRIEDER 2003), the Setzberger Feld in the west and the bog heath, which was surrounded by the first two areas and partly dominated by shrubs or pines.
The biotope mapping of Bavaria describes the bog complex of the Breitfilz in 1991 to be destroyed by drainage and as afforestation with *Pinus sylvestris* L. and mainly *Picea abies* (L.) H. Karst., which is located in the east; in the west, grasslands like the Setzberger Feld can be found.

The complex is surrounded by a fringe of trees composed by *Picea abies* (L.) H. Karst., *Pinus sylvestris* L. and *Acer platanoides* L. and by two circles of ditches, into which the drainages of the bog heath and the Setzberger Feld drained or still drain the complex. Additionally, draining ditches with a depth of one meter lead from the centre of the bog to these surrounding ditches. This lowering of ground water table lead to a stop of growth of the bog and on the other hand supported the growth of pines and birches. The central part is described to be settled with *Calluna* heath and typical species like *Vaccinium uliginosum* L. s. l., *Vaccinium oxycoccos* L. (s. l.), *Andromeda polifolia* L., *Eriophorum vaginatum* L. and *Rhynchospora alba* (L.) Vahl..

Due to the drainage, the biotope mapping regards the 'Breitfilz' to be damaged in a way that no regeneration would be possible; nevertheless the report recommends the re-establishment of natural like water levels by closure of ditches and destruction of drainages which was implemented during the restoration project in 1993.

In relation to the biotope types, 90% are described as bogs or transition mires and 10% as moist forest. (fisnat.bayern.de; April 2014)

Bog Heath

The bog heath with a total area of 28 ha was separated from the Setzberger Feld in the east by a small stripe of *Picea abies* (L.) H. Karst and *Betula pubescens* Ehrh. s.l.. In the 1920s, open-ditch drainages were installed every 10 m to drain the complex. Because of no further use, the bog heath was settled with *Pinus sylvestris* L., at more open areas mainly with *Calluna vulgaris* (L.) Hull and *Pinus x rotundata* Link. PFADENHAUER & KLÖTZLI (1996) described this state as a result of 'heathification', which lead to dominant *Calluna vulgaris* (L.) Hull, birch or pine communities.

The restoration of 1993 was limited to 4 ha of the bog heath because of protection of species. In 2005 a small stripe (0.25 ha) in the north of the already rewetted part was restored by closing the drainages and shifting off some trees. Therefore, the bog heath showed three steps of restoration (1993, 2005 and no restoration). Like at the Setzberger Feld there were still some differences in water tables due to the influence of the drainages (s. Fig. 2).

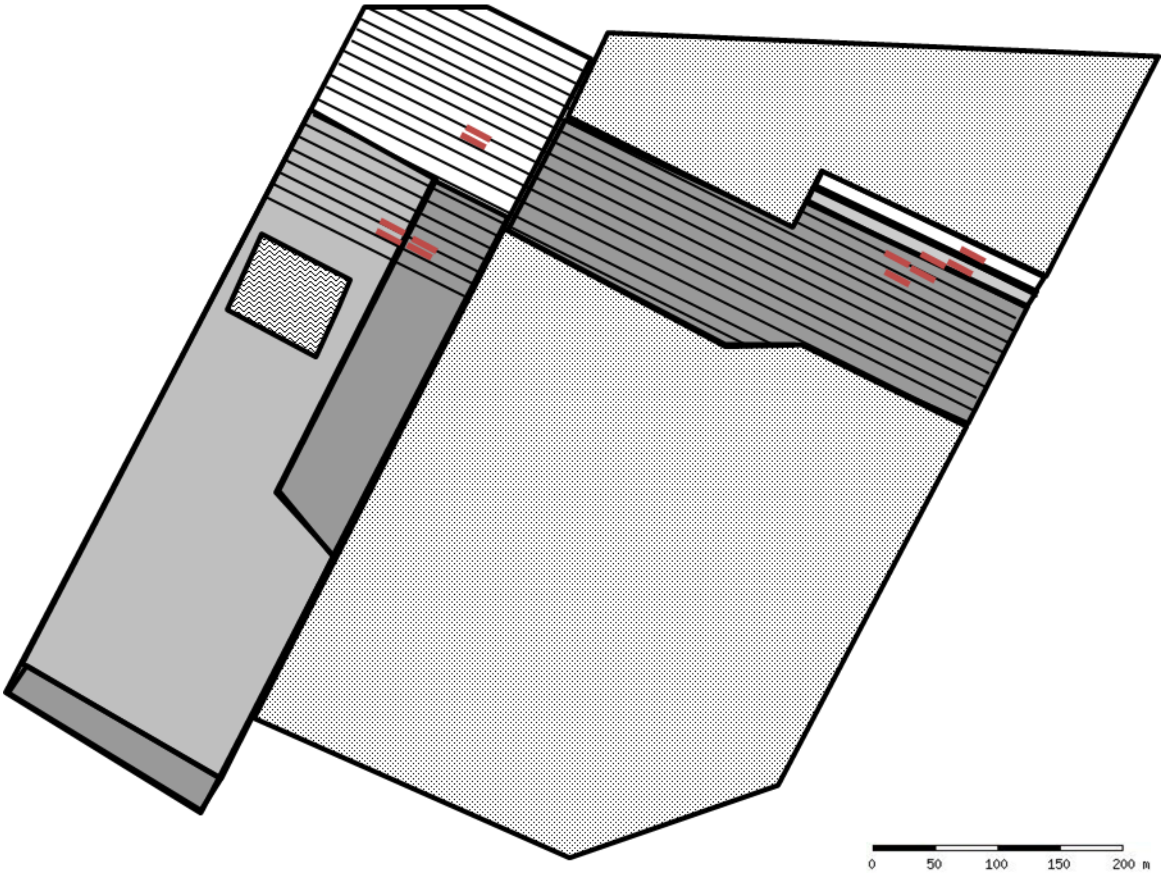

Fig. 2: Schematic overview of the testing areas at the 'Breitfilz'
small black stripes show drainages (displayed only where relevant); red stripes show investigation sites;
left: Setzberger Feld: white: drained and managed; light grey: rewetted 1993 and managed; dark grey: rewetted 1993 and not managed; curled: water basin with *Sphagnum* L.;
right: bog heath: dotted: dominated by *Pinus x rotundata* Link; white: no restoration; light grey: restored 2005; dark grey: restored 1993

Setzberger Feld

Until the beginning of the 1980s, this field of 12 ha was extensively used for grazing with low animal pressure, low donations of fertilizers and one cut per year. Now there is only one cutting event after the 15th of July every year. In 1993, an area of 7 ha was rewetted by destroying the drainages and filling the collector of the drainages at the western part. At this time, some drainages weren't even working anymore; thus some wet areas developed in the southern (shaded) and eastern part, where the field is in contact with the bog heath.

The surface of an area of 60 x 90 m² was removed and the now created water-covered area was filled with soil and *Sphagnum* mosses from the bog heath. These wet areas were excluded from the cutting events to avoid any disruption of the slowly developing bog specific vegetation. Therefore, the Setzberger Feld showed a mosaic of non-restored and rewetted areas with different water tables caused by the drainages. Additionally, the partial management lead to different developments of the vegetation under comparable conditions.

Site selection

In the middle of October 2006, the site selection was done by Matthias Drösler and the author. Every site consisted of three plots, which served as repetitions due to similarity in vegetation, water table and water supply; 18 plots were installed at the bog heath and a further 18 at the Setzberger Feld.

At the bog heath, one site with *Calluna* shrubs was not restored and was used as dry reference, two sites were recently restored (in 2005) and vegetated with *Calluna* shrubs (on the ridge) or *Sphagnum* mosses (on a drainage). The other three sites were located at the area, which was restored in 1993; one of these sites was located on a former drainage where *Eriophorum* hummocks established, while at the other two sites on ridges *Sphagnum* lawns with and without *Pinus x rotundata* Link could be found. Therefore, the selection of the sites at the bog heath was done along a succession with different restoration steps and water tables.

Tab. 1: Site description of the measurement sites and plots of Mooseurach

the description includes area, position on drainages or ridges, management, year of restoration and a rough characterisation of the vegetation; the installation of the additional plot 20b (site M7) was necessary due to destruction of the vegetation of plot 20 by *Meles meles* L.

Site	Plots	Area	Position	Management	Restoration	vegetation based site description
M1	1,2,3	bog heath	ridge	no	no	dry *Calluna vulgaris* (L.) Hull heath
M2	4,5,6	bog heath	ridge	no	2005	moist *Calluna vulgaris* (L.) Hull heath with sparse *Sphagnum* L. lawn
M3	7,8,9	bog heath	drainage	no	2005	*Sphagnum* L. hummocks
M4	10,11,12	bog heath	drainage	no	1993	*Eriophorum vaginatum* L. hummocks
M5	13,14,15	bog heath	ridge	no	1993	*Sphagnum* L. lawn with *Rhychospora alba* L.
M6	16,17,18	bog heath	ridge	no	1993	*Sphagnum* L. lawn with *Pinus x rotundata* Link and *Calluna vulgaris* (L.) Hull
M7	19,20,21,20b	Setzberger Feld	ridge	1 cut/a	no	dry bog-meadow with *Anthoxanthum odoratum* L. and *Climacium dendroides* Hedw.
M8	22,23,24	Setzberger Feld	drainage	1 cut/a	no	dry bog-meadow with *Anthoxanthum odoratum* L. and *Climacium dendroides* Hedw.
M9	25,26,27	Setzberger Feld	drainage	no	1993	*Sphagnum* L. lawn with *Carex* L. species
M10	28,29,30	Setzberger Feld	drainage	1 cut/a	1993	moist bog-meadow with *Carex* L. species
M11	31,32,33	Setzberger Feld	ridge	no	1993	*Sphagnum* L. lawn
M12	34,35,36	Setzberger Feld	ridge	1 cut/a	1993	moist bog-meadow with *Anthoxanthum odoratum* L. and *Climacium dendroides* Hedw.

Half of the plots at the Setzberger Feld were located at the top of former drainages; the other 9 were installed on ridges as comparisons with different water supply. Six plots were located at the managed and unrestored part, six at the managed and restored area and six plots at a stripe where the management was stopped and some *Sphagnum* communities already had established. Therefore, there was a mosaic of areas with different management, water table and restoration effects within a few square meters.

2.1.4 Characteristics of soils

Analyses of soils were done within the project by ZALF (Leibniz-Zentrum für Agrarlandschaftsforschung e.V., Müncheberg, Germany). Peat thickness in the research area was between two and five meters. Thus, minimum thickness for peat layers of 30 cm was fulfilled for the research area of Breitfilz (PFADENHAUER 1997). The soil sequence in the centre of the bog heath differed depending on the water saturation with a hHv (thickness of 10 cm) or a hHw (around 20 cm) followed by a hHr (more than 60 cm); description of soil horizons were according to German systematic of soils (DEUTSCHE BODENKUNDLICHE GESELLSCHAFT DBG 2006).

The degrees of decomposition varied from 8.5 ± 1.3 at areas with higher water tables to 4.0 ± 1.8 at waterlogged areas (according to VON POST 1924 in SUCCOW 1988). Soil type of the managed area was identified as a sapric ombric histosol (dystric), while at the natural or restored area there was fibric to hemic histosol (dystric). Generally, the spatial variability of soil in the testing area was regarded to be low.

At the bog meadow of the Setzberger Feld, a certain degree of humification was detectable in the first few centimeters of soil and a sagging of peat within the last century of one to two meters could be detected (BOSCH & PARTNER GMBH 2001). However, the level of soil cover differed even along a gradient of the Setzberger Feld, in which the side, which was closer to the bog heath, was 0.5 m higher than the averted side. Using this downward slope, the intact drainages of the Setzberger Feld drain the meadow to a surrounding ditch, which leads to the Zellwieser Mühlbach and from this to the river Loisach (topographical map of Bavaria 1:50.000; BAYERISCHE VERMESSUNGSVERWALTUNG 2013).

2.1.5 Climate situation

For comparisons of the individual weather station in the ‘Breitfilz’ to at least mid-term climate conditions of the region, it was necessary to choose a weather station close to the measurement area. The weather station Wettlkam was located around 40 km in the northeast of Mooseurach, was pursued by the 'Landesanstalt für Landwirtschaft' (LfL) and was in service from 1991 to 2008.

Although the weather situation in the foreland of the Alps can be very small scale, the distance to this reference weather station was estimated to be acceptable and therefore its data to be comparable to the individual weather station.

Tab. 2: Weather data for 2007 and 2008 and long term average data
annual data came from our weather station; average data (since 1991) and precipitation data came from the LfL weather station Wettlkam, south. Bavaria (LfL)

	Month	1	2	3	4	5	6	7	8	9	10	11	12	ø / Σ
Temp Air 200 [°C]	2007	4.2	4.2	4.8	10.5	13.9	17.0	17.3	15.8	11.0	6.6	0.6	-1.6	8.7
	2008	2.1	2.4	4.0	8.2	14.4	17.3	17.8	17.4	12.5	9.1	4.0	0.9	9.2
	AVG	-2.0	-0.8	2.8	7.1	12.0	15.0	16.4	16.0	11.7	7.7	1.8	-1.4	7.2
Temp Soil 20 [°C]	2007	4.5	4.6	4.8	8.0	11.7	14.6	15.7	15.6	12.7	10.4	6.0	3.6	9.4
	2008	3.4	2.9	4.1	7.0	11.4	15.0	16.9	17.3	15.7	12.3	8.5	5.4	10.0
	AVG	1.3	1.4	2.9	6.5	11.1	14.5	15.9	15.9	12.8	9.4	5.0	2.3	8.2
Rel Hum 200 [%]	2007	80.7	80.2	77.2	67.6	72.2	87.7	78.3	80.5	80.4	84.0	88.5	85.9	80.3
	2008	82.2	72.9	64.7	70.6	59.2	65.8	68.1	63.9	63.7	74.6	76.8	73.5	69.7
	AVG	90.1	87.4	87.4	83.7	80.3	79.2	79.7	80.5	82.5	89.4	92.9	92.5	85.4
Precipitation [mm]	2007	58.1	48.0	22.1	18.0	342.3	118.5	239.0	172.6	230.9	28.7	125.7	77.2	1481.1
	2008	55.6	35.0	106.4	182.7	78.7	124.8	187.2	199.0	64.1	64.3	45.3	26.6	1169.7
	AVG	49.5	60.6	79.4	67.4	122.0	119.2	141.0	138.1	101.7	74.6	81.7	64.4	1099.6

The monthly average air temperatures of 2007 and 2008 were most of the time higher than the mid-term-average (s. Tab. 2). The total difference for the annual average was +1.5°C in 2007 and in +2°C in 2008. While the soil temperatures from May 2007 to June 2008 were comparable to the average, the soil was much warmer before (> 3°C in winter) and in summer and autumn 2008. Thus, the difference to the mean soil temperature reached 1.8°C in 2008. In addition to the higher temperatures in 2008, this year was also dryer, especially during the growing season. The annual precipitation until September 2008 was more than 200 mm lower than it was in 2007, which had been a regular year in reference to the relative humidity and the precipitation.

Concerning the snow-cover the winter 2006 / 2007 was not a regular winter because of a lack of snow. In spite of a solid blanket of snow from end of November until begin of March with some interruptions due to less precipitation in wintertime, that winter showed only a few days with thin snow-layer (s. Tab. 3). In comparison to the preceding one, the winter 2007 / 2008 had a solid blanket of snow from middle of November 2007 to middle of March 2008.

Tab. 3: Overview of meteorologically important days in 2007, 2008 and 2009

hot days (T_{max} > 30°C), summer days (T_{max} > 25°C); vegetation days (T_{avg} > 5°C); frost days (T_{min} < 0°C) and ice days (T_{max} < 0°C) and days with snow

*: data collection stopped 07.04.09; average and maximum temperatures used as reference from weather station Rothenfeld (south. Bavaria, LfL)

	Month	1	2	3	4	5	6	7	8	9	10	11	12	Σ
Hot Days (T_{max} > 30°C)	2007	0	0	0	0	4	7	7	3	0	0	0	0	21
	2008	0	0	0	0	3	5	6	5	0	0	0	0	19
	2009	0	0	0	0*	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	0
	max. ø	0	1	0	3	2	3	7	9	0	0	0	0	25
Summer Days (T_{max} > 25°C)	2007	0	0	0	12	14	20	18	16	6	3	0	0	89
	2008	0	0	0	1	12	14	16	18	8	2	0	0	71
	2009	0	0	0	2*	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	0
	max. ø	0	1	0	8	11	18	23	23	6	0	0	0	90
Vegetation Days (T_{avg} > 5°C)	2007	15	8	13	29	31	30	31	31	30	18	3	3	242
	2008	4	10	12	27	31	30	31	31	30	28	13	2	249
	2009	0	0	4	7*	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	4
	AVG	4	5	13	21	30	28	30	31	29	24	11	4	230
Frost Days (T_{min} < 0°C)	2007	18	18	28	27	8	0	0	1	3	19	20	25	167
	2008	28	25	19	8	6	0	0	0	1	7	18	19	131
	2009	30	26	20	4*	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	76
	AVG	27	27	22	14	3	0	0	0	1	9	21	26	149
Ice Days (T_{max} < 0°C)	2007	1	0	0	0	0	0	0	0	0	0	0	1	2
	2008	0	0	0	0	0	0	0	0	0	0	1	2	3
	2009	7	0	0	0*	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	7
	AVG	11	7	2	0	0	0	0	0	0	0	3	10	34
Days with Snow	2007	10	3	5	2	0	0	0	0	0	0	16	23	59
	2008	16	0	20	0	0	0	0	0	0	0	7	27	70
	2009	26	28	16	0	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	70

Only from end of January 2008 to end of February was there a snow-free period. The soil was frozen from middle of December 2007 to middle of March 2008.

Concerning extreme temperatures in winter, both years were relatively moderate, which was indicated by almost no ice days. The number of days, having had temperatures for plant growth was higher than the long-term average, especially in January 2007.

2.2 General methods

2.2.1 Site equipment

In November 2006, the construction of the boardwalks started and was finished within one week with the powerful help of some co-workers. At the bog heath boardwalks, with a total length of around 100 m, were constructed in fixing them on wooden stems of 1 m to 1.5 m length to reduce swinging effects caused by footsteps. At the Setzberger Feld, boardwalks of 70 m length were built this way, that only at the not-managed part the boardwalks were fixed to the ground. To avoid impacts on cutting activities by the farmer, the big part of the boardwalks at the field were constructed in a moveable way. Because of the wetness of this field and the attended swinging effects we couldn't renounce the use of the boardwalks.

Every plot was equipped with a soil frame (PVC or PE; 0.75 x 0.75 m^2). Twelve frames with 5 cm-blades were constructed and, due to water tables which could cause flooding, six frames with 20 cm-blades were installed at the bog heath. Due to the cutting activities one time per year at the Setzberger Feld, twelve frames (PE) without aboveground blades were installed at the managed area. At the non-managed area six frames with 20 cm-blades were used. The measurement chambers were stored covered to be protected from sun, rain, snow and ice.

At the centre of the measurement sites of the bog heath, close to site M4, a weather station was installed, which collected data of photosynthetically active radiation (PAR), air temperatures at 2 m and 20 cm, relative humidity (rH) of the air and soil temperatures at 2 cm, 5 cm, 10 cm, 20 cm and 50 cm in half-hourly steps between 3rd of January 2007 and 7th of April 2009. For temperatures and relative humidity a T-mem-Logger (Version C1; Fa. Microdesign; Stefan Krause) with suitable sensors was used and for PAR a LICOR LI-1000 (LICOR) with a LICOR SA-190 sensor.

Because of the low spatial distance of the two measurement areas (< 400 m), it was possible to use the data of the weather station for all the sites as a reference and basis for further modelling steps (s. chapter 3).

2.2.2 Chamber system

The heterogeneity of the measurement sites with low distances to each other made it necessary to choose a measurement method for gas-flux measurements which was able to show small-scale differences between the variants. The use of closed chambers (DRÖSLER (2005) is an appropriate and established method for flux measurements of CO_2, CH_4 and N_2O (e.g. BEETZ ET AL. (2013), BEYER ET AL. (2014 and 2015).

Depending on the measured gases, different types of chambers were used: for the measurements of CH_4 / N_2O and the respiratory part of CO_2 (R_{eco}) an opaque chamber (PVC; 78 x 78 x 50 cm^3; 11 kg) covered with a reflective insulation and for the NEE (Net Ecosystem Exchange) a transparent chamber (Plexiglas ®; 78 x 78 x 50 cm^3; 8 kg). This size was chosen, to reduce possible edge effects (e.g. heating) by the chamber-walls and to avoid mechanical influence on the vegetation, whose maximum height was lower than 50 cm. All used chambers and frames were produced by PS Plastic (Eching, Bavaria) after the recommendation of DRÖSLER (2005).

All chambers were equipped with rubbers (Sahlberg, Bavaria) to tighten the chambers against air fluxes to or from the ambient when being placed on the frames. During the measurements, the chambers were fixed on the frames with some elastic bungees to equilibrate possible torsions of the frames and to prevent any kind of air exchange between the inside of the chambers and the atmospheric ambient.

To equilibrate pressure gradients between the chamber and the ambient that could appear when placing the chamber, a vent valve and a vent tube was installed. Because of the length of the used tubes (1.5 m), any air exchange during a measurement could be excluded. The valve was closed after the chamber was placed onto the frame and the installation of the bungees.

Each chamber also had a thermometer to control the inside temperature during a measurement which should not change more than 1.5°C for the CO_2 measurements (DRÖSLER 2005).

2.2.3 Water tables and physical parameters

Natural peatlands are highly dependent on water and restoration of degraded peatlands can only be fulfilled, if water regime is similar to natural peatlands. Furthermore, water table is one of the main driving parameters for greenhouse gases from (natural) peatlands. Thus, it was unavoidable to install a system for continuous measurements of water tables.

For this purpose, in the north-western corner of each plot, an observation well (PVC with perforations; length: 1 m; ø: 4 cm) was installed. The water tables were taken at every CO_2 and CH_4 / N_2O campaign; thus a measurement frequency of at least two to three weeks could be guaranteed. Differences of water tables should show annual dynamics for the single sites and characterize the water regimes between the different sites.

Using the same wells, electric conductivity (EC) and pH of the soil water were taken during the CO_2 campaigns (every three to four weeks). For pH measurements a WTW pH 191 was used, for EC a WTW LF 196. These physical parameters were taken as they are commonly used indicators for the state of a bog concerning degradation (pH) and nutrition supply (EC).

2.2.4 Vegetation analysis

Vegetation assessments

The determination of species and their frequencies on all the plots and additionally on plot-surrounding transects showing comparable vegetation and habitat conditions (water table, position on a drainage, restoration time) was done from May 2008 to August 2008. Although the measurements started nearly one and a half years before, a one-time analysis was regarded to be sufficient because of the slow development of the vegetation. Only the managed area of the Setzberger Feld has shown faster growth. For the determination of the species, coverages of a 100-grid cell frame (0.75 x 0.75 cm^2) was used, which fitted exactly to the size of the plots. The classification of the plants coverage was done after the scale of LONDO (1976). For the assessments, SCHMEIL-FITSCHEN (2000) and ROTHMALER (2000) were used for the plants determination and for sociological classification, OBERDORFER (2001) was applied. Another tool to describe the conditions of an area is the application of indicator values (ELLENBERG 1992) which is common in ecology, especially if further analysis of soil and ground water is not possible or too expensive. To get a fast overview of the sites conditions, the indicator values of ELLENBERG (1992) were applied to our vegetation assessments.

The inventory of vegetation was repeated in June 2012 to determine changes in the species' composition. To identify possible habitat types with protection according to Natura 2000 Guideline for habitat types (Habitats Directive; 92/43/EWG), we applied the descriptions of Natura 2000 habitat types to the vegetation assessments according to the Bavarian State Office for Environment (BAYLFU 2010), although the size of the assessments was often quite small scale due to the topography of the 'Breitfilz' with drainage and ridges. Where possible, we related the habitat types and conditions to the habitats of the vegetation assessments.

Aerenchymatic plants

Based on the plant species composition, two other analyses were done. Being an important transmitter for CH_4 coming from the soil, the percentages of plants with aerenchyma were determined. Results concerning the dependency between aerenchymatic plants, CH_4 balances and water tables are described in chapter 4.

Hemeroby

Additionally, the degree of human impact to the sites was determined in a post-hoc analysis, based on the vegetation. KLOTZ & KÜHN (2002) improved a method whereby they used the habitude of the plants to have ecological amplitudes, on whose bases plants can be situated close to or far from locations which were or are influenced by human beings. They assigned different hemerobic spans to plant species and calculated out of these values a hemerobic value for a single vegetation unit, which indicates the orientation by nature for this unit or, in the opposite case, the distance to a natural status. Due to the relatively low human impact to the testing areas, we expected for the bog heath and the Setzberger Feld hemerobic values, which indicated an oligo- to mesohemerobic status.

Seasonal development of vegetation

The continuous collection of phytomass at every CO_2 campaign was done to analyse functional differences of vegetation during the growing season. This was done by cutting squares of 20 x 20 cm² whose vegetation were representative for the plots. To avoid too much detracting of the slow growing bog vegetation, samples were only taken for the managed sites M7, M8, M10 and M12. Each vegetation sample was divided in physiological groups: green and brown leaves of herbaceous plants, green and brown mosses and aerenchymous plants. Therefore, the proportion of photosynthetically active plants could be defined as well as the proportion of the plants with aerenchymatic tissue. These plants are regarded as supporters of CH_4 exchange between soil and atmosphere (COUWENBERG 2009). To reduce anoxic conditions around their roots, aerenchymous plants transport CH_4 via roots, stems and leaves to the air and supply of their roots with air from the atmospheric ambient.

After having sorted the phytomass, the components were dried for 24 hours at 70°C and afterwards weighted to determine the dry weight. For the growing season, a rise of phytomass should have been detectable.

C/N ratio of vegetation

As well as the phytomass samples taken during every CO_2 campaign, phytomass samples for C/N ratio determination were only taken at the managed sites M7, M8, M10 and M12 to avoid any unnecessary damage of the slowly growing and expanding bog vegetation.

The analysis of the carbon and nitrogen content of vegetation samples was done by Institut Koldingen GmbH (AGROLAB Laborgruppe) according to DIN ISO 10694 (total-carbon) and DIN ISO 13878 (1998) (total-nitrogen).

Statistical analyses

Statistical analyses were done with Statistica 6.1 (StatSoft Inc., Tulsa USA). If normality was not taken for granted, normal distribution could be achieved by root-transformation for vegetation data. For water tables, electrical conductivity and pH, a normal distribution could not be achieved by any kind of transformation; thus, the non-parametric Mann-Whitney U-Test was used to compare these data. For a better comparability to ANOVA, results of Mann-Whitney U-Test were translated into this system by adding letters to the corresponding results.

Vegetation data and additional plot parameters (water table, electrical conductivity, pH, and CH_4 fluxes) were used for further analyses with PC-Ord 6 (MjM Software, Oregon, USA). The first step was a detrended correspondence analysis (DCA) to compare the single plots based on their vegetation. A cluster analysis was done (Ward's Method, Euclidean distance) for conclusions that were more detailed, including individual characteristics of plots. To identify the main parameters that explained differences in between the plots, a canonical correspondence analysis (CCA) was applied to vegetation data (main matrix) and parameter data (second matrix).

2.3 Results

2.3.1 Water tables and physical parameters

Water tables

Generally, the distributions of the water tables in 2007 and 2008 were similar. The degraded sites (M1 in the bog heath, M7 and M8 at Setzberger Feld) showed in both years the lowest mean water tables (-17.7 to -36.4 cm) and the widest spreads but also the restored managed sites M10 and M12 and the recently restored site M2 showed wide ranges in both years. Sites M5 and M6 had generally a similar behaviour and their mean water tables were comparable to those of M9, M11 and M12 (-12.8 to -15.8 cm). The standard deviations at all restored sites of the bog heath (M3 to M6 except of M2) were comparable.

The sites at the closed drainages (M3, M4, M9 and M10) had the highest mean water tables (-4.7 to -12.8 cm). In contrast to these, site M8 at the only still working drainage showed the lowest mean water tables (-35.8 and -36.4 cm). According to the sites M5 to M6, the standard deviations at sites M9 and M11 of the Setzberger Feld with no management were lower than at the managed ones (-13.0 to -15.8 cm).

Whereas the mean water tables in summer 2007 were similar to those of the total year (s. Tab. 4), the differences between the summer water tables of 2008 were remarkably lower than for the total year (s. Tab. 5). In contrast to the mean values, the standard deviations were similar in summer 2008 and in the total year 2008. In 2007, the summer oscillations of water tables were remarkably lower than in 2008.

Tab. 4: Water Tables of the Mooseurach sites in 2007

displayed are the numbers, median values, mean values and corresponding standard deviations for the total year, the summer and winter half-year and the span between extreme values (Max – Min); different n: s. text; letters show significant differences between the sites (Man-Whitney-U-Test; p<0.05)

Site	Water Table [cm]						
	n	Median	Mean ± StDev		Max-Min	Summer ± StDev	Winter ± StDev
M1	*86*	-26.5	-26.7 ± 7.3	b	34.5	-25.4 ± 5.4	-31.3 ± 7.5
M2	*87*	-20.0	-22.3 ± 6.5	c	26.5	-22.3 ± 5.8	-23.9 ± 7.1
M3	*84*	-4.4	-5.3 ± 4.3	g	20.5	-4.8 ± 3.0	-7.4 ± 5.3
M4	*87*	-10.0	-11.3 ± 4.8	f	21.0	-10.5 ± 3.2	-13.6 ± 6.2
M5	*90*	-14.4	-14.4 ± 4.2	de	22.5	-14.1 ± 3.2	-16.3 ± 4.7
M6	*89*	-14.4	-14.9 ± 4.3	d	20.5	-14.6 ± 3.4	-16.7 ± 4.9
M7	*90*	-23.5	-22.9 ± 8.4	c	37.0	-24.3 ± 7.0	-23.9 ± 7.3
M8	*90*	-36.4	-36.4 ± 9.8	a	50.0	-34.7 ± 8.0	-42.5 ± 8.5
M9	*90*	-13.5	-14.2 ± 5.8	de	30.0	-12.6 ± 3.5	-18.0 ± 7.5
M10	*90*	-4.0	-6.9 ± 8.1	g	35.0	-5.3 ± 4.7	-10.8 ± 11.5
M11	*90*	-14.5	-15.8 ± 5.9	d	28.0	-14.5 ± 2.8	-19.0 ± 8.7
M12	*90*	-13.6	-15.8 ± 8.0	d	30.1	-15.6 ± 6.9	-17.7 ± 9.5

Tab. 5: Water Tables of the Mooseurach sites in 2008

displayed are the numbers, median values, mean values and corresponding standard deviations for the total year, the summer and winter half-year and the span between extreme values (Max – Min); different n: s. text; letters show significant differences between the sites (Man-Whitney-U-Test; $p<0.05$)

Site	Water Table [cm]						
	n	Median	Mean ± StDev		Max-Min	Summer ± StDev	Winter ± StDev
M1	*117*	-30.0	-30.3 ± 8.1	b	31.0	-32.9 ± 7.5	-24.0 ± 7.8
M2	*117*	-19.5	-21.2 ± 6.8	c	36.0	-24.4 ± 7.2	-16.2 ± 3.7
M3	*117*	-4.0	-4.7 ± 4.9	i	19.5	-7.4 ± 5.1	-1.2 ± 2.5
M4	*114*	-9.5	-10.4 ± 5.4	h	23.0	-13.3 ± 5.1	-5.3 ± 1.6
M5	*114*	-12.5	-13.0 ± 4.5	ef	17.5	-15.2 ± 4.5	-9.3 ± 2.9
M6	*114*	-13.0	-13.7 ± 4.6	efg	17.0	-16.4 ± 4.4	-9.6 ± 2.3
M7	*132*	-16.8	-17.7 ± 9.3	d	43.0	-20.6 ± 9.7	-12.7 ± 8.3
M8	*116*	-38.0	-35.8 ± 9.8	a	60.5	-38.1 ± 7.4	-29.4 ± 12.7
M9	*114*	-12.5	-12.8 ± 6.8	ef	31.5	-16.7 ± 7.0	-8.4 ± 3.5
M10	*114*	-3.5	-6.4 ± 8.5	i	33.5	-11.6 ± 9.3	-1.0 ± 2.3
M11	*110*	-13.8	-15.5 ± 6.6	e	28.5	-19.1 ± 7.3	-11.8 ± 3.6
M12	*111*	-13.0	-15.4 ± 8.8	efg	35.6	-19.4 ± 9.2	-11.7 ± 7.1

The different measurement numbers were caused by site-specific differences, mainly by ice in the wells that could not be removed (thickness > 5 cm), due to an ice cover throughout a whole plot, an additional plot of site M7 or problems with the measurement instruments. The annual courses of the water tables of the sites from January 2007 until April 2009, displayed in the annex, showed anomalies during the year, especially during the growing season (from March to October), and separated the two years. While the water tables in 2007 were relatively constant, with the exception of a rainless period in April 2007, the water tables in 2008 differed around 15 cm within two weeks from May until September.

Electrical Conductivity (EC)

Electrical conductivity showed the opposite pattern of water tables and similar distributions in 2007 and 2008. The lowest mean contents of ions were recognizable at sites M9 to M12 (31.8 to 44.5 µS/cm), at the restored part of the Setzberger Feld. Comparable but slightly higher mean values (40.3 to 45.5 µS/cm) were reached at sites M3 and M4 at the former drainages in the bog heath. The conductivity of the not restored sites M7 and M8 and the recently restored M2 were also similar (47.5 to 65.3 µS/cm) as well as their standard deviations. Especially in 2007 site M6 (*Sphagnum* L. with *Pinus x rotundata* Link) was grouped with the preceding sites and showed in both years comparable standard deviations.

The highest mean values of electrical conductivity (82.7 and 83.1 µS/cm) were found at site M1. In contrast to 2007 site M5 was not grouped between site M4 and M6 (45.5 to 57.6 µS/cm) in 2008 but showed the lowest mean conductivity (31.7 µS/cm) and standard deviation.

The interannual comparison displayed higher mean values in 2007 but lower standard deviations by trend. The annual courses (s. annex Fig. 12 and Fig. 13) did not show a trend for 2007 but in 2008 there is a slight rise of conductivity.

Tab. 6: Electrical Conductivity and pH of all sites in 2007

displayed are the numbers, median values, mean values and corresponding standard deviations and the span between extreme values (Max – Min) of the electrical conductivity and pH; different n: s. text; letters show significant differences between the sites (Man-Whitney-U-Test; p<0.05)

Site	Electrical Conductivity [µS/cm]					pH				
	n	Median	Mean ± StDev		Max - Min	*n*	Median	Mean ± StDev		Max - Min
M1	*35*	84.0	82.8 ± 13.0	i	70.0	*35*	3.91	3.95 ± 0.19	a	0.87
M2	*36*	64.5	62.4 ± 11.2	g	52.0	*36*	3.94	3.94 ± 0.12	a	0.54
M3	*33*	45.0	45.0 ± 3.2	d	12.0	*33*	4.02	4.05 ± 0.10	c	0.43
M4	*36*	45.0	45.5 ± 6.1	d	26.0	*36*	4.00	3.99 ± 0.11	a	0.42
M5	*39*	50.0	51.1 ± 11.2	e	55.0	*39*	4.02	4.01 ± 0.16	ac	0.67
M6	*38*	55.5	57.6 ± 10.6	fg	48.0	*38*	3.98	3.96 ± 0.23	ab	1.26
M7	*39*	54.0	55.7 ± 15.3	efg	82.0	*39*	4.45	4.47 ± 0.18	df	0.93
M8	*39*	57.0	65.3 ± 21.7	fgh	91.0	*39*	4.38	4.34 ± 0.23	d	1.18
M9	*39*	35.0	35.6 ± 4.5	b	18.0	*39*	4.42	4.41 ± 0.16	de	0.73
M10	*39*	35.0	37.1 ± 7.9	b	41.0	*39*	4.45	4.46 ± 0.18	df	0.7
M11	*39*	33.0	32.5 ± 4.2	a	17.0	*39*	4.50	4.54 ± 0.25	ef	1.06
M12	*39*	41.0	41.0 ± 5.6	c	26.0	*39*	4.39	4.42 ± 0.18	de	0.79

Tab. 7: Electrical Conductivity and pH of all sites in 2008

displayed are the numbers, median values, mean values and corresponding standard deviations and the span between extreme values (Max – Min) of the electrical conductivity and pH; different n: s. text; letters show significant differences between the sites (Man-Whitney-U-Test; p<0.05)

Site	Electrical Conductivity [µS/cm]					pH				
	n	Median	Mean ± StDev		Max - Min	*n*	Median	Mean ± StDev		Max - Min
M1	*44*	76.0	83.1 ± 19.7	f	69.0	*39*	3.97	3.96 ± 0.24	a	1.06
M2	*45*	58.0	59.9 ± 18.1	e	74.0	*36*	3.93	3.91 ± 0.23	a	0.98
M3	*39*	44.0	42.6 ± 12.4	c	48.0	*33*	4.01	3.97 ± 0.28	a	1.29
M4	*39*	42.0	40.3 ± 10.5	ac	40.0	*36*	4.03	3.99 ± 0.26	a	1.46
M5	*45*	31.0	31.7 ± 8.6	a	32.0	*39*	4.18	4.18 ± 0.18	b	0.78
M6	*45*	43.0	47.5 ± 16.0	c	65.0	*38*	4.09	4.14 ± 0.27	b	1.11
M7	*43*	51.0	53.1 ± 21.2	cd	88.0	*26*	4.71	4.67 ± 0.25	d	0.87
M8	*44*	59.0	60.5 ± 16.9	e	87.0	*29*	4.46	4.45 ± 0.20	c	0.93
M9	*37*	36.0	35.3 ± 12.5	ab	53.0	*33*	4.46	4.43 ± 0.23	c	0.96
M10	*38*	34.5	33.7 ± 8.6	a	38.0	*32*	4.42	4.39 ± 0.31	c	1.32
M11	*39*	32.0	31.8 ± 9.9	a	43.0	*33*	4.57	4.54 ± 0.31	d	1.46
M12	*42*	42.0	44.5 ± 19.1	c	87.0	*28*	4.41	4.42 ± 0.24	c	1.14

pH

The pattern of mean pH values in 2007 and 2008 was similar. All the sites in the bog heath had a pH slightly below or above 4.00. The means ranged from 3.94 ± 0.02 to 4.05 ± 0.02 in 2007 and 3.91 ± 0.04 to 4.18 ± 0.03 in 2008. At the Setzberger Feld the pH values were on average 0.50 units higher than in the bog heath (4.34 ± 0.04 to 4.54 ± 0.04 in 2007; 4.39 ± 0.05 to 4.67 ± 0.05 in 2008). The highest average values were reached at site M7 and M11 (4.47 ± 0.18 to 4.67 ± 0.25). Although there were differences between the relatively undisturbed bog heath and the - in former times fertilised - Setzberger Feld, the mean pH values between 3.94 and 4.67 could be regarded as typical for a nutrient poor bog ecosystem.
The annual courses of pH (refer to Fig. 12 and Fig. 13 in the annex of this chapter) did not show any trend. The mean values of the single measurements were distributed around the annual mean values of 4.00 for the bog heath and 4.50 for the Setzberger Feld.

2.3.2 Vegetation analysis

Vegetation assessments

The species in the bog heath were distributed in relation to restoration degree (sites M1, M2, M5 and M6) and water tables (M3 and M4). Site M1 was dominated by degradation indicators like *Calluna vulgaris* (L.) Hull (>30%) and *Pleurozium schreberi* (Brid.) Mitt (25 to 50%). *Sphagnum rubellum* Wils. appeared in lower frequencies (0 to 20%). Site M2, still being in transition from the degraded status to a more moist one (s. water tables at page 19), showed the same species composition but there was a gradient from the dry plot 4 without any *Sphagnum* L. to the moist plot 6 with *Sphagnum magellanicum* Brid. (50%). Both *Sphagnum*-species also appeared at sites M3 and M4, located at former drainages and this therefore accounted for higher water tables. Especially site M3 was exclusively vegetated by three *Sphagnum*-species (>90%) while at site M4 *Sphagnum fallax* H. Klinggr. was replaced by *Eriophorum vaginatum* L. (40 to 65%) where *Sphagnum*-species appeared only in the second layer of the vegetation. The sites M5 and M6 differed only by the appearance of young pines (*Pinus x rotundata* Link) (< 10%) at site M6. Apart from that, *Calluna vulgaris* (L.) Hull formed the shrub-layer (2 to 35%) and the moss-layer was dominated by *Sphagnum rubellum* Wils. (>90%).
Management and restoration separated the vegetation of the Setzberger Feld. While *Anthoxanthum odoratum* L. s. str. was the dominant grass (20 to 60%) at the sites M7, M8 and M12 and *Climacium dendroides* (Hedw.) F. Weber. & Mohr formed the moss-layer (site M7: > 80%; site M8: 10 to 40%; site M12: 60 to 75%), these species were partly replaced at the

other sites M9, M10 and M11 by *Carex* and by *Sphagnum* -species. Especially *Sphagnum fallax* H. Klinggr. was the dominant moss at these three sites (> 75%).
The plots 27 of site M9 and plot 30 of site M10 were characterised by the absence of big moss-layers (< 2%). Here the vegetation cover was formed by *Carex canescens* L. (plot 27: > 50%) or by bare soil and litter (plot 30: > 90%). A *Juncus effusus* L. -aspect of 2007 with an abundance of 10 to 20% did not appear in 2008 at plot 30.

Plant sociological classification

According to OBERDORFER (1991), the vegetation of the sites was classified according to plant sociological units. The vegetation units of the bog heath were classified into the class *Oxycocco-Sphagnetea*. Although the sites M1 and M2 were dominated by species of the *Nardo-Callunetea* mainly caused by drainage, they could be classified as a *Calluna*-rich *Sphagnion magellanici*, due to the increasing number of *Sphagnum* L.. The plant-society on the former drainage (M3) was classified as *Sphagnetum magellanici* with a tendency to become an *Eriophorum vaginatum* L. –society within this community like site M4 indicates due to its development since 1993. The sites M5 and M6 were determined as *Sphagnetum magellanici* with low presence of *Calluna* Salisb. shrubs resp. *Pinus x rotundata* Link..
The vegetation of the bog meadow split the Setzberger Feld into two parts. The degraded sites M7, M8 and the restored but relatively dry site M12 with similar vegetation were classified as *Epilobio-Juncetum effusi* in the *Calthion* society. The two restored, not managed sites (M9, M11) and the wet, managed site M10 were described as *Caricetum fuscae* of the *Scheuchzerio - Caricetea fuscae* class with a dominant occurrence of *Sphagnum fallax* H. Klinggr.. This underlined the transition character of this area between the bog heath and the extensively managed bog meadow. (BEIERKUHNLEIN 1999, OBERDORFER 2001)

Application of the Habitats Directive

The degraded site of the bog heath M1 and the recently rewetted site M2 could be described as degraded bogs with restorability but in a relatively bad condition (7120 C) mainly due to number of species with no protection status. In contrast to these, the sites M5 and M6 with a longer period of rewetted conditions was described as living bog, but in a bad condition again (*7110 C). Here, the classification was caused by the presence of degradation indicators. The site on the drainage (M3) was described as *Sphagnum* L. hollow complex (7150 C) with a low number of target species. The Bavarian field mapping instructions (BAYLFU & BAYLWF 2010) sort these hollows into a tight complex with habitat type 7120. Only site M4 on the drainage with longer period after restoration reached status 7120 B due to the presence of target species for bogs.

In contrast to the bog heath, at the bog meadow of the Setzberger Feld, only the sites without management, low disturbances or relevant *Sphagnum* growth rates (M9, M10 and M11) were described as transition mires of bad condition (7140 C). The other three sites M7, M8 and M12 did not reach a status of the Habitats Directive. (BAYLFU 2010)

Indicator values and Hemeroby

Analysis of the indicator values of ELLENBERG (1992) showed only low differences between the two areas regarding light or temperature indicator values. L values indicated half- or full light conditions, T values at least cool conditions at the bog heath to moderate temperatures at the Setzberger Feld. The F value, showing the humidity of the sites, showed moist conditions at the bog heath and moist to wet conditions at the Setzberger Feld. The vegetation indicates more acid conditions at the bog heath (strong acidity) and extreme nitrogen poverty than at the bog meadow (acid conditions resp. nitrogen poverty).

Concerning the human impact to the sites, the vegetation showed a clear separation of the bog heath and the bog meadow Setzberger Feld. With hemerobic values from 1.98 to 2.31, the bog heath could be regarded to be oligohemerobic, but the more degraded sites M1 and M2 as well as the pine-settled site M6 had values in direction of mesohemerobic status which indicated a more intense human impact due to drainage. All sites of the Setzberger Feld (2.73 to 3.06) were classified as mesohemerobic with a tendency for the rewetted and not managed sites to approach an oligohemerobic status in future.

Tab. 8: Metadata of vegetation assessments

Number of species, German red list species, FFH Annex V species, hemerobic values and hemerobic status of the sites based on the their vegetation are displayed

Site	total species number	red list species number (red list 'cat. 3' number)	FFH Annex V species number	hemerobic value	hemerobic status
M1	9	4 (2)	1	2.13	oligohemerobic
M2	12	6 (3)	3	2.31	oligohemerobic
M3	10	8 (5)	3	1.98	oligohemerobic
M4	10	7 (5)	3	1.98	oligohemerobic
M5	10	6 (4)	3	1.98	oligohemerobic
M6	13	7 (4)	2	2.12	oligohemerobic
M7	7	1 (1)	0	2.96	mesohemerobic
M8	10	2 (2)	0	3.03	mesohemerobic
M9	8	1 (0)	1	2.84	mesohemerobic
M10	9	1 (0)	1	3.06	mesohemerobic
M11	7	1 (0)	1	2.73	mesohemerobic
M12	8	1 (0)	1	2.95	mesohemerobic

Detrended correspondance analysis (DCA) of plots and species

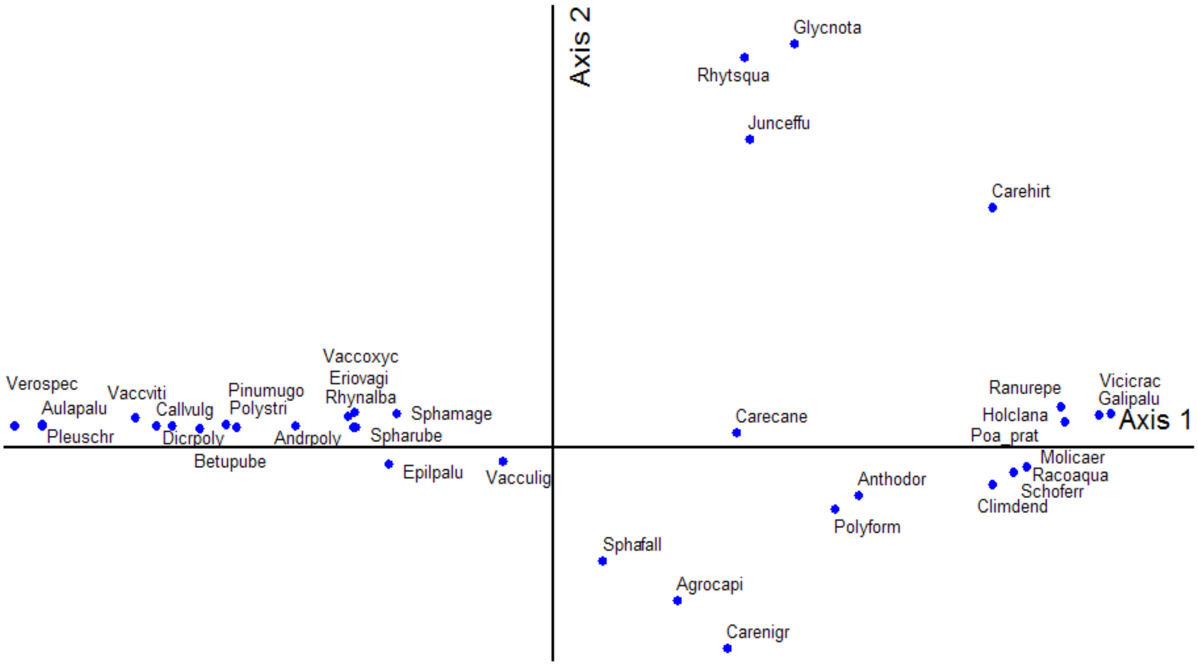

Fig. 3: Detrended correspondance analysis (DCA) of species
data are root transformed; labels show abbreviations for species

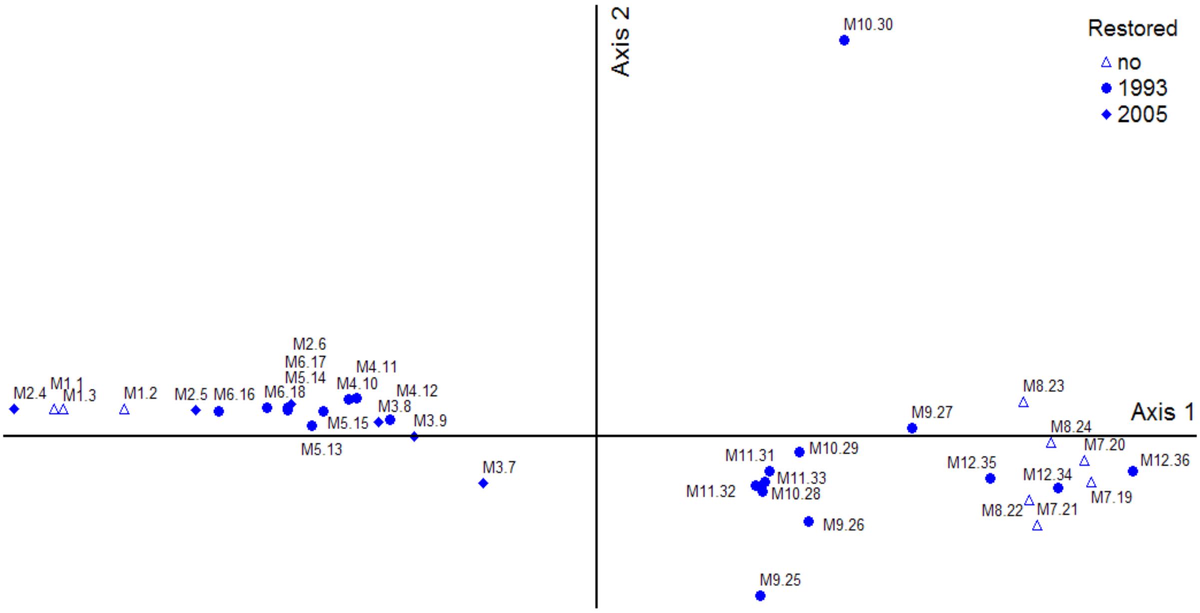

Fig. 4: Detrended correspondance analysis (DCA) of 36 plots
species cover data are root transformed; labels show site and plot numbers (M 'Site'.'Plot'); signs show different restoration times

In total, 24 vascular plants and 12 mosses were used for following analyses. Data of the species cover can be found in the annex in Tab. 11 and Tab. 12. The relationship between the species composition and cover of all the plots was analysed with a detrended correspondence analysis (DCA). The species data were root transformed to reach a normal distribution. Having had a total variance in the species data of 3.7336; the correspondence could be regarded unimodal. This was enforced by the eigenvalue of the first axis of 0.9374 whose length of gradient was 7.513. The second axis had an eigenvalue of 0.3621 and a length of gradient of 3.583, the third axis 0.1549 and 1.773.

The analysis separated the two areas of bog heath and Setzberger Feld along axis 1. Only plot 30 of site M10 was remarkably separated from all other plots along axis 2, mainly by indicators of very wet conditions (*Juncus effusus* L. and *Glyceria notata* Chevall.). Here it should be mentioned, that the removal of plot 30 as an outlier did not lead to another distribution in the DCA and to different results concerning the lengths of gradients or eigenvalues.

At the bog heath, the degraded and restored *Calluna* heath sites M1 and M2 sorted to the left, at which site M2 was very inhomogeneous in the plots' grading. The long-term restored sites M5 and M6, which differed in the absence of *Pinus x rotundata* Link at M5 sorted together. The sites on former drainages with *Eriophorum vaginatum* L. M4 and with *Sphagnum* species M3 assorted in direction to the centre, at which site the recently restored *Sphagnum* populated drainage had a wider span than the established M4. Generally, a degradation gradient was remarkable for the sites of the bog heath towards the centre of DCA.

This gradient was continued at the Setzberger Feld. The restored sites M10 and M11 were very homogenous - except for plot 30. An influence of mowing was not detectable here. In contrast to those, site M9, also dominated by *Sphagnum fallax* H. Klinggr., was much more heterogonous, indicating a gradient, which was not visible, when sites had been installed. Separated from the restored sites M9 to M11, the degraded sites M7 and M8 are slightly connected with recently restored site M12 via their vegetation with poor grassland species (*Anthoxanthum odoratum* L. s. str.) and a dominance of *Climacium dendroides* (Hedw.) F. Weber. & Mohr in the moss layer.

Cluster analyses of plant species and site factors

Given that vegetation is an indicator or a consequence of abiotic factors of an area, additionally to the DCAs, cluster analyses on the basis of plant species and in combination with site-factors were conducted. Site factors water table, standard deviation of water table, electrical conductivity, pH, CH_4 flux, were all used as well as species number, number of Red-List species of German Red-List, species cover with aerenchymatic tissue and hemerobic value of single plots. Cluster analyses were conducted using Ward's Method for linkage and Euclidean (Pythagorean) distance measuring.

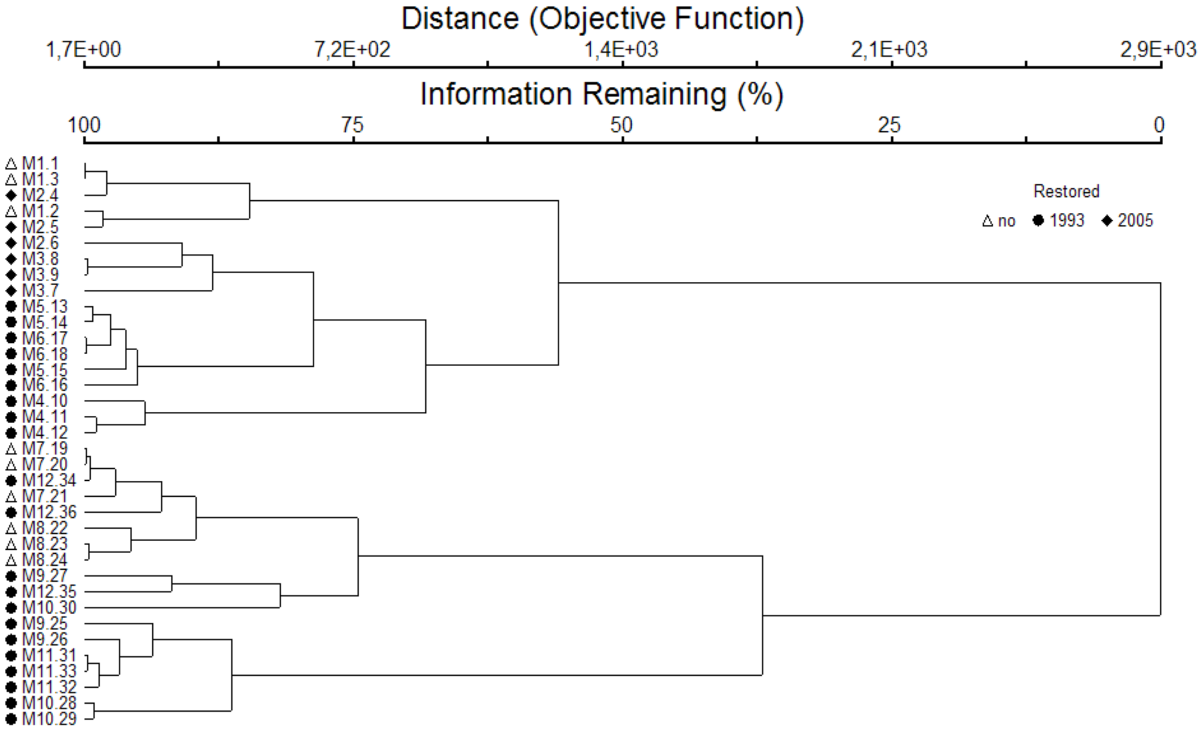

Fig. 5: Cluster analysis of plots based on species

data are root transformed; linkage: Ward's Method; distance: Euclidean; chaining 3.77%; signs show different restoration times

The species' cluster analysis (Fig. 5) separated the plots of the bog heath (1-18) and of the Setzberger Feld (19-36). In the bog heath, all the plots (1-3) of site M1 and plot 4 and 5 of site M2 were pooled together, while plot 6 of M2 was placed to site M3 (7-9). Sites M5 (13-15) and M6 (16-18) were mixed and had a relatively low distance to site M3. In contrast, the distance of site M4 (10-12) to the other restored sites was quite high.

The non-restored sites M7 (19-21) and M8 (22-24) of the Setzberger Feld were pooled together with two plots (34 and 36) of site M12, whereas site M8 was slightly separated. The restored non-managed sites M9 (25-26) and M11 (31-33) showed low distances to each other. Separated from these was site M10 with its plots 28 and 29. The plots 27 (M9), 30 (M10) and 35 (M12) had relatively long distances to all the other plots.

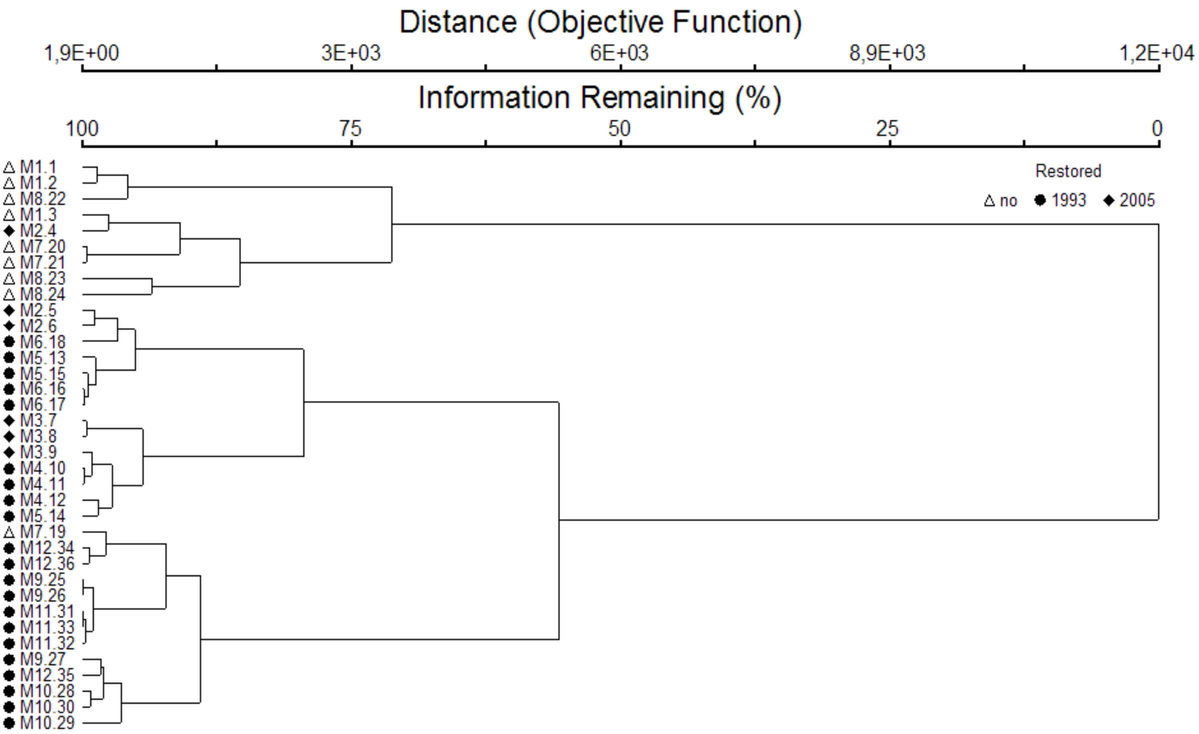

Fig. 6: Cluster analysis of plots based on plot parameters of the year 2007
linkage: Ward's Method; distance: Euclidean; chaining 2.52%;
signs show different restoration times

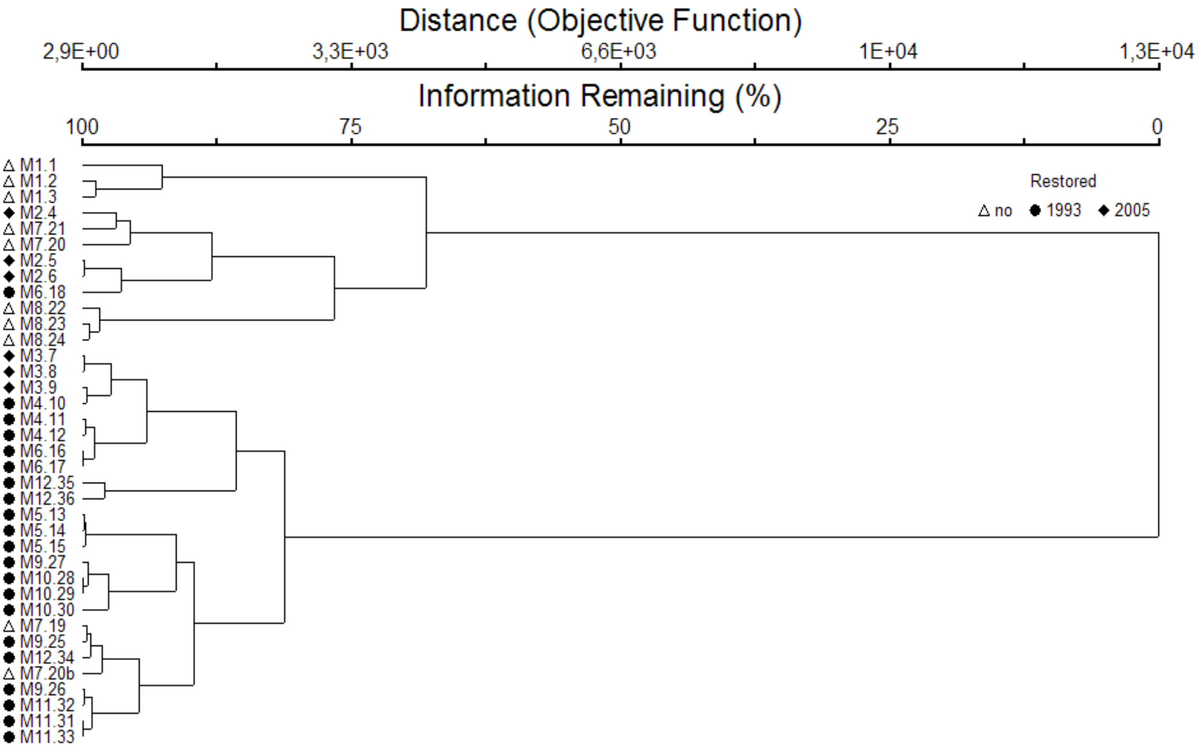

Fig. 7: Cluster analysis of plots based on plot parameters of the year 2008
linkage: Ward's Method; distance: Euclidean; chaining 2.17%;
signs show different restoration times

In contrast to the species' cluster analysis, the parameter-based analysis showed a higher distance (Fig. 6 and Fig. 7). The differentiation of the two areas bog heath and Setzberger Feld was broken up.

Dry conditions separated sites M1 / M2 (in 2008) of the bog heath and M7 / M8 of the Setzberger Feld from all other sites. At least in 2007, restored sites from bog heath (M3 to M6) and Setzberger Feld (M9 to M12) were segregated. Within the small clusters, there was also a junction of the wet sites M3 and M4, respectively the drier sites M5 and M6 at the bog heath. At the Setzberger Feld, separation was based on abandonment of management. Especially in 2007 sites without cutting M9 and M11 were closer, whereas these clusters were not well visible in 2008. Generally, plots were grouped together for most of the sites except for some single sites. To clarify the results of the cluster analyses, canonical correspondence analyses (CCA) were conducted for both years.

Canonical correspondence analysis (CCA)

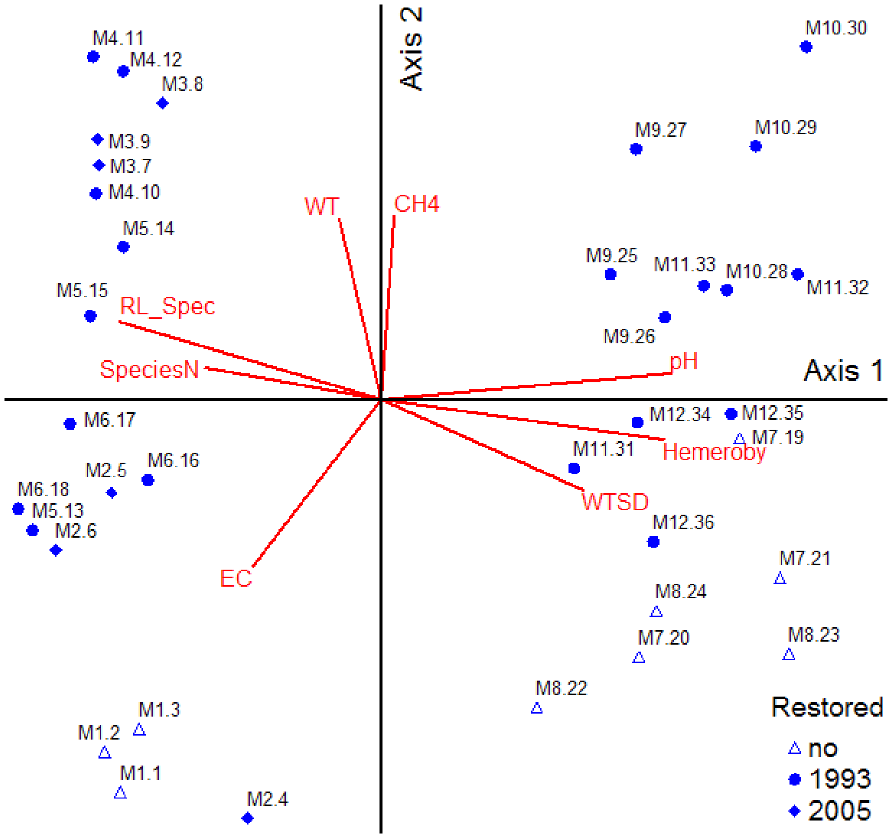

Fig. 8: Canonical correspondence analysis (CCA) of species (main matrix) and plot parameters 2007 (second matrix)

species data are root transformed; signs show different restoration times

The canonical correspondence analysis (CCA) divided the plots of the bog heath (left) and those of the Setzberger Feld (right) along axis 1 of Fig. 8. This was mainly driven by pH, which was 0.5 points lower at the bog heath, but also by water tables' standard deviation as an indicator for the amplitude of water tables. The impact of humans (via Hemeroby) was another parameter, being lower in the bog heath, as well as species or red list species number, which were higher in the bog heath.

The distribution of axis 2 separated the plots with low water tables and higher CH_4 emissions from the non-restored plots (1-3; 19-24) and the short-time restored plots 4 and 5 of site M2. Axis 1 was significantly correlated ($p<0.01$) with pH (0.94), Hemeroby (0.92), number of Red List species (-0.85) and water tables' standard deviation (0.66); axis 2 was significantly correlated ($p<0.01$) with water table (0.75), CH_4 flux (0.77) and EC (-0.70).

The first three axes with eigenvalues of 0.883, 0.476 and 0.249 had a cumulative explaining variance of 38.9% with single proportions of 21.3%, 11.5% and 6.0%. The Monte Carlo permutation test (998 runs) with real and randomised data for the eigenvalues were significant ($p<0.001$) for first axis (0.883/0.321), second axis (0.476/0.200) and third axis (0.249/0.135). Species-environment-correlation (Pearson-correlation) was also significant ($p<0.001$) for first axis (0.975/0.681), for second axis (0.916/0.644) and third axis (0.757/0.608).

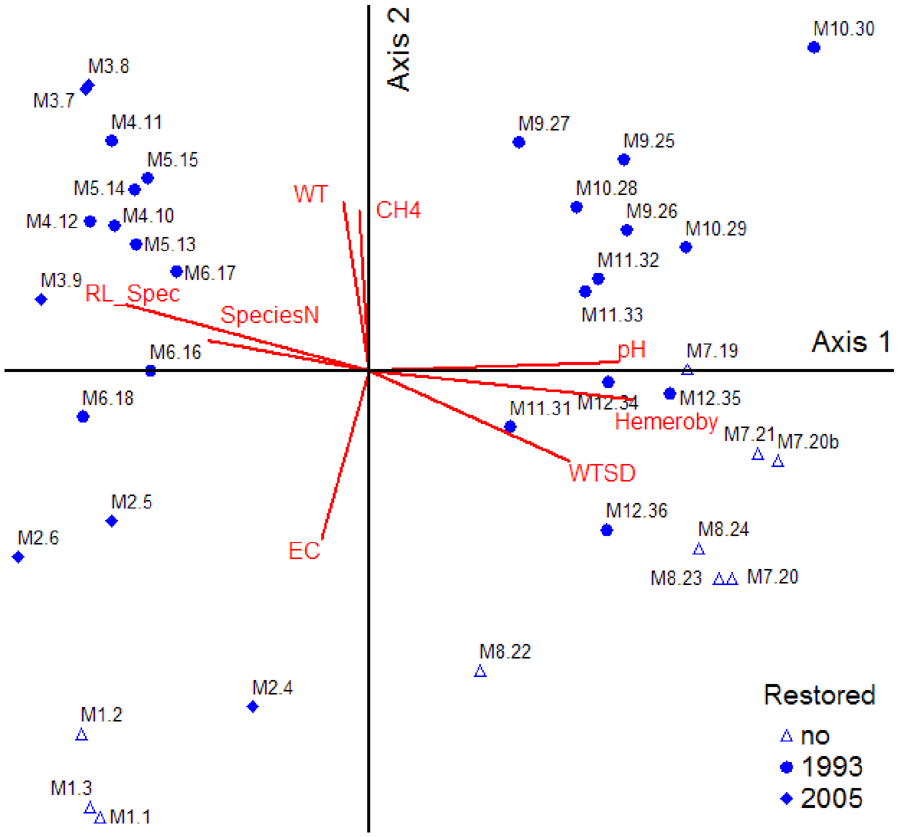

Fig. 9: Canonical correspondence analysis (CCA) of species (main matrix) and plot parameters 2008 (second matrix)

species data are root transformed; signs show different restoration times

Differing mainly in the plot parameters, distribution of plots (and sites) was almost comparable to that of 2007 (Fig. 9).

Significant correlation ($p<0.01$) of pH with axis 1 was lower than 2007 (0.879) but higher for standard deviation of water tables (0.706). Axis 2 was significant correlated ($p<0.01$) with EC (0.755), water table (-0.755) and CH_4 flux (-0.713). Opposite signs were caused by horizontal mirroring of the diagram to maintain comparability between the years.

39.1% of the cumulative variance was explained by the first three axes with single proportions of 21.2%, 11.3% and 6.7 and eigenvalues of 0.878, 0.467 and 0.276. Monte Carlo test (998 runs) was significant ($p<0.01$) with real and randomised date for the first axis (0.878/0.337), the second axis (0.467/0.213) and the third axis (0.276/0.145) as well as the species-environment correlations for axis 1 (0.971/0.690), axis 2 (0.907/0.654) and axis 3 (0.777/0.616).

In both years, degraded site M1 separated from other sites of the bog heath, whereas recently restored site M2 was located towards long-term restored sites M5 and M6 or overlapped with them in 2007. Wet sites M3 and M4 were pooled very closely in contrast to the drier ones. Separation was also visible at the Setzberger Feld, but variability inside the sites was larger. Thus, there was a gradient from the degraded sites M7 and M8, overlapping with M12 towards the moist site M11 to the sites on a drainage M9 and M10.

Seasonal development of vegetation

The results of the vegetation samples that were continuously taken during the measurements were used for statistical analyses to explain rates of photosynthesis or respiration. Due to high variations in results from one campaign to the next with no clear trend, it was not possible to find any relationship neither between green plant components and productivity nor between respiration or CH_4 fluxes and brown plant components.

C/N ratio of vegetation

The carbon content ranges from 49.9% to 51.4%; the nitrogen varied from 1.33‰ to 3.31‰. In total, the C/N ratio was mostly around 20%. Only in a few cases in 2008 did the ratio reach 30% to 40%, mainly where nitrogen content fell below 1.5‰. The reduction was not limited to a certain site and appeared randomly. Nevertheless, although the samples were taken from sites which were fertilized and lime washed until the 1980s, the ratios could be regarded as typical for a nutrient poor bog. (s. PFADENHAUER 1997)

For the sites M7 and M8, there was a small increase of this ratio with an increase of distance to the less disturbed bog heath whereas for site M10, there was a decrease and site M12 showed no gradient. To determine if these habitudes were random or functional appearances, more samples had to be taken as well as samples from soil to determine the distribution of the nutrient content of the soil close to the edges and in the middle of the Setzberger Feld.

Repetition of vegetation assessments

The repetition of plant species composition (s. annex Tab. 13 and Tab. 14) showed a certain growth of *Calluna vulgaris* (L.) Hull between 5 to 25% at drier sites M1 and M2 and restored sites M5 and M6, although *Calluna* Salisb. died at some places, which was remarkable by dry parts of plants. *Eriophorum vaginatum* (L.) abundance increased at all restored sites M3 to M6 from 10 to 50%. *Pinus x rotundata* Link grew at site M6, where it was already present in 2008, between 30 to 50% and appeared also at site M5. *Rhynchospora alba* (L.) Vahl could be found only at the recently restored drainage of site M3. *Pleurozium schreberi* (Brid.) Mitt. decreased nearly everywhere (20 to 50%), where it was found in 2008 (M1 and M2) as well as *Sphagnum rubellum* (Wils.) (up to 60%), which was replaced by *Sphagnum magellanicum* Brid. (up to 20%). In total, higher plants *Calluna vulgaris* (L.) Hull, *Eriophorum vaginatum* L. and *Pinus x rotundata* Link grew bigger, where present; *Sphagnum* L. species grew, where microhabitats were sufficient (water tables and oscillations) for their presence. In total, no elementary change in plants' composition was remarkable at any site.

At the Setzberger Feld, the number of species (13) was remarkably lower than in 2008 (20) but this is explainable by annual variances in appearance of plants, with differ according to microhabitats. *Anthoxanthum odoratum* L. s. str. increased not only at degraded sites M7 and M8 and recently restored site M12 (up to 60%) but also at the wet sites M10 and M11 (up to 20%). *Carex* L. species did not show a pattern concerning reduction or increase but varied on base of microhabitats (+/- 30%). *Climacium dendroides* (Hedw.) F. Weber. & Mohr decreased almost generally (up to 70%), whereas it was present only at the drier sites M7, M8 and M12. The number of *Juncus effusus* L. increased in contrast at almost all sites (up to 50%) as well as *Sphagnum fallax* H. Klinggr. at the restored sites M9 to M12. Especially increases of *Juncus effusus* L. as well as *Sphagnum* and *Carex* species and the reduction of *Climacium dendroides* (Hedw.) F. Weber. & Mohr were indicating an expansion of the vegetation of the bog - or at least vegetation which tolerates wet conditions - to the formerly used meadow. Influence of cutting to dispersal of *Sphagnum* fragments and thus, establishment of *Sphagnum* L. at a wider area of the meadow was not investigated, but remarked during several visits of this area.

Nevertheless, the plant sociological classifications of the sites did not change within these five years.

2.4 Discussion

Analyses of vegetation and pH were adequate to separate the sites of the managed Setzberger Feld and the sites of the bog heath. Electrical conductivity and water tables separated degraded or recently restored sites from long-term restored or natural sites.

Water tables of all sites were highly influenced by the topography of their locations. Thus, sites on ridges had in general water tables farther from the surface, but the differences between sites on drainages and ridges became smaller after rewetting, which also could be expected. Rewetting raised water tables closer to the surface and, due to dam of water, amplitudes of site water tables were remarkably buffered in comparison to those sites, where drainages were still working. Thus, significant differences of average water tables could be detected for degraded sites in comparison to restored sites, but even within the degraded resp. restored sites, significant differences of water tables were visible due to their position. Degraded sites M1, M2, M7 and M8 were significantly differing with one exception: The still working drainages of the Setzberger Feld made it impossible for the soil to store rainfalls. A comparable effect could be detected at the degraded part of the bog heath, although an increasing backwater effect of the surrounding restored area should not have been neglected. Almost flooded sites on drainages M3 and M10 were not significantly different from each other, as well as *Sphagnum* populated sites M5, M6, M9, M11 and M12, whose similar water tables probably made possible a re-establishment of *Sphagnum* mosses.

The abovementioned significant differences were even more distinct in summer due to buffering effects of restored and thus water saturated sites and the effect of water removal by drainages from areas which even suffered from summer evapotranspiration.

Nutrient status of sites was shown via electrical conductivity (EC in µS/cm). The degraded sites M1, M7, M8 and the moist site M2 were partly significantly separated from the restored or wet sites. Where significance was not given, a transitional position of the site (M12) with a vegetation's composition, which resembled to degraded sites M7 and M8, but with water table of restored sites (M9 to M11) could be supposed. The restored sites of the bog heath M3 to M6 showed almost always slightly higher values of conductivity than the restored sites M9 to M11 of the Setzberger Feld. This can be explained by the influence of H^+-ions at ranges of low pH values (SJÖRS 1950, ZIMMERLI 1988). For a more detailed explanation, a more specified analysis of water samples would have been necessary. Regarding the annual courses of EC there seemed to be a reduction of conductivity at the *Sphagnum* lawn sites M5 and M6, which indicated a reduction of total ions per time. In contrast to the sites M9 to M11 with fast growing *Sphagnum fallax* H. Klinggr., which could be responsible for low EC values around 35 µS/cm, *Sphagnum* lawns M5 and M6 of the bog heath were not as productive and fixed fewer ions. A proof of this hypothesis would have been possible by an analysis of water in a laboratory. But the applied approach was sufficient to notice, that almost all means of EC, except for degraded site M1, were in ranges of a nutrient poor bog (40 to 80 µS/cm) (FRANKL 1996, SLIVA 1997) and the differences between the degraded and restored sites imply a reduction of EC in time after rewetting. Even the sites of the Setzberger Feld showed these values, indicating poor nutrient status due to soil degradation by mowing. BOSCH & PARTNER (2001) found for the Setzberger Feld conductivities from 40 to 80 µS/cm, which decreased with time after rewetting. The electrical conductivity of the bog heath was between 30 and 45 µS/cm, which corresponded largely with data from this study.

In comparison to water tables and electrical conductivity, pH separated the two areas bog heath (pH around 4.0) and Setzberger Feld (pH around 4.5) significantly. A more detailed reflection within the areas did not make sense, although statistical analyses showed significant differences, but no pattern in between the sites was visible. A separation of *Sphagnum* lawns M5 and M6 with slightly elevated pH values was detectable only in 2008, but regarding the amplitudes of pH during the year, these elevations were inside the standard deviations and thus neglected. For the waterlogged sites of the bog heath, pH values were similar to those, which were found by POSCHLOD (1990) for bogs in the foreland of the Alps. LÜTT (1992) identified a relationship between enlargement of oxidative soil space and increase of H^+-ions in the pore water, which could explain the low pH of the degraded site M1 and recently restored site M2. However, the bog heath was never fertilised nor had nutrients been introduced of any kind, which would have provoked raised pH values.

For the Setzberger Feld, former fertilisation was remarkable in elevated pH, but BOSCH & PARTNER (2001) showed a tendency of reduction of pH from 5.0 to 4.5 or even less for the whole meadow, notably close to the transitional area towards the bog heath. pH values around or slightly below 4.0 were typical for testing areas of the bog heath in this study.

Concerning Calcium contents (Ca^{2+}) BOSCH & PARTNER (2001) found for the rewetted part of the bog heath Ca^{2+} contents of 1.0 to 0.5 mg/l with a decreasing tendency per time; the degraded part had Ca^{2+} values between 1.0 and 1.5 mg/l. Ca^{2+} contents reported by FRANKL (1996) and DRÖSLER (2005) for natural bog areas were in the same range. The rewetted areas of the Setzberger Feld also showed reduction of Ca^{2+} ions from 15 mg/l, indicating mesotrophic conditions, to 5 mg/l, which was also detected at the not restored part of this meadow, indicating an influence of restoration to the not restored area (BOSCH & PARTNER (2001)).

Site selection was done based on preliminary studies of this area ((BOSCH & PARTNER (2001), LUBOSCH (2005)). The vegetation of the sites was regarded to be representative for bog ecosystems with different use types and degradation levels. The dry area of the bog heath (M1) was used as reference in comparison to recently restored site M2 and long-term restored sites M5 and M6. According to their water tables, mainly the percentage of *Calluna vulgaris* (L.) Hull decreased with the length of the period since restoration. The community of mosses changed from indicators for dry conditions with *Pleurozium schreberi* (Brid.) Mitt. to moist or wet conditions with *Sphagnum rubellum* Wils. and *Sphagnum magellanicum* Brid.. On the former drainages, the time series was expressed by *Sphagnum rubellum* Wils. at the recently restored site M3 with presence of some shrubs and their replacement by *Eriophorum vaginatum* L. at site M4, which was even visible at site M3 at the end of the measurement activities.

At the Setzberger Feld, the degraded sites M7 and M8 represented the references for further steps of rewetting (sites M10 and M12) and ending of management after rewetting and establishment of plants, which are regarded typical for peatlands. Here, indicators for poor habitats like *Anthoxanthum odoratum* L. s. str. dominated the degraded sites, but were present also at the restored sites, especially at areas with water tables farther from the surface (M12). Indicators for common grasslands like *Holcus lanatus* L. or *Poa* species in general disappeared within the last few years and indicators for wet, poor habitats like *Juncus effusus* L. and *Carex* species replaced them. The moss flora showed this transition in a more intense way with *Climacium dendroides* (Hedw.) F. Weber. & Mohr and *Rhytidiadelphus squarrosus* (Hedw.) Warnst.. These species were still present at the drier sites (M7, M8 and M12), whereas *Sphagnum fallax* H. Klinggr. replaced them at the wet sites (M9, M10 and M11). AERTS ET AL. (1992) found that a good N-supply result in fortified growth of *Sphagnum* in comparison to areas with low N-supply. This might have been the case at the Setzberger Feld. To quantify the growth rates of *Sphagnum*, the cranked-wire method (AERTS ET AL. 1992) is a common approach, which was unfortunately not applied in this study.

The analysis of the plants composition was adequate to separate the two research areas. The human impact, calculated from hemerobic spans of plant species (s. Tab. 8) distinguished the sites of the bog heath with status oligohemerobic and the sites of the Setzberger Feld with status mesohemerobic. The cluster analysis of species and the correspondence analyses DCA and CCA led to comparable but more detailed results. Indirect gradient analysis (DCA) of species (s. Fig. 3) was done to show possible groupings of plots and sites (s. Fig. 4). Indicated by dry conditions, plots of the degraded site M1 were sorted with restored site M2 along a gradient towards plots of moist areas (site M5 and M6) and wet conditions (site M4 and M3). Thus, plots with 15 years after restoration were pooled together (M4, M5, M6), whereas recently restored sites showed wide spans of plots, indicating transition to another more natural like status.

These spans and transitions were even more expressive at the Setzberger Feld. The *Sphagnum fallax* populated sites M9, M10 and M11 were generally pooled together, but spans within the sites could be enormous due to flooding of plot 27 (M9) and plot 30 (M10). Especially, plot 30 separated from all other sites with its semiaquatic aspect. In between the degraded sites M7 and M8, which were assorted very close together, the drier restored site M12 was located, but with a wide span, similar to site M2 of the bog heath. Thus, especially the recently restored sites of the bog heath were in transition because of change in their vegetation's composition driven by higher water tables. These were also the main reason for transitions at the Setzberger Feld but also for differences within the sites.

These differences were also visible at the species cluster analysis, which showed a clear separation of the areas. Plots with established vegetation had low distances to each other (plots 10 to 18 and plots 25, 26, 28, 29, 31 to 32). Plots in transition, mainly of site M2 and M12, were sorted in between other sites. The cluster analyses of plot-parameters separated the drier sites (degraded sites, recently restored sites, sites on ridges) from the sites with low fluctuating water tables, which were additionally close to the surface. Separations on lower levels could be explained by site positions on former drainages and similar oscillation of water tables.

The canonical correspondence analysis (CCA) was adequate to explain the main driving parameters for differences between plots and sites and their specific grouping. PH, species number and human impact drove the split of the areas along first axis, water tables and CH_4 balances drove separation along the second axis. Sites M3, M4, M9 and M10 with water tables closest to the surface were displayed on top. Electrical conductivity divided the degraded or recently restored sites M1 and M2 additionally to water tables from the restored sites M3, M4, M5 and M6. At the Setzberger Feld, this division was supported by respiration rates and water tables' standard deviation, but was more along a continuous water table or CH_4 gradient from the degraded sites M7 and M8 via M12 to the rewetted sites M9, M10 and M11.

Thus, the main explaining parameters were pH (decreasing with natural like status), species number (increasing with natural like status) and annual mean water tables linked with CH_4 balances, which were highest at the plots with water tables close to the surface, representative for natural like conditions of a bog. However, oscillations of water tables and electrical conductivity were also suitable for separation of the degraded and the restored areas.

2.5 Perspectives

With the development history of the sites in mind, a possible future process can be derived. Especially because of the development after closure of the drainages and settlement of *Sphagnum* species, the first steps towards natural like conditions (M3 to M6; M9 and M11) can be regarded as assured for the corresponding areas.

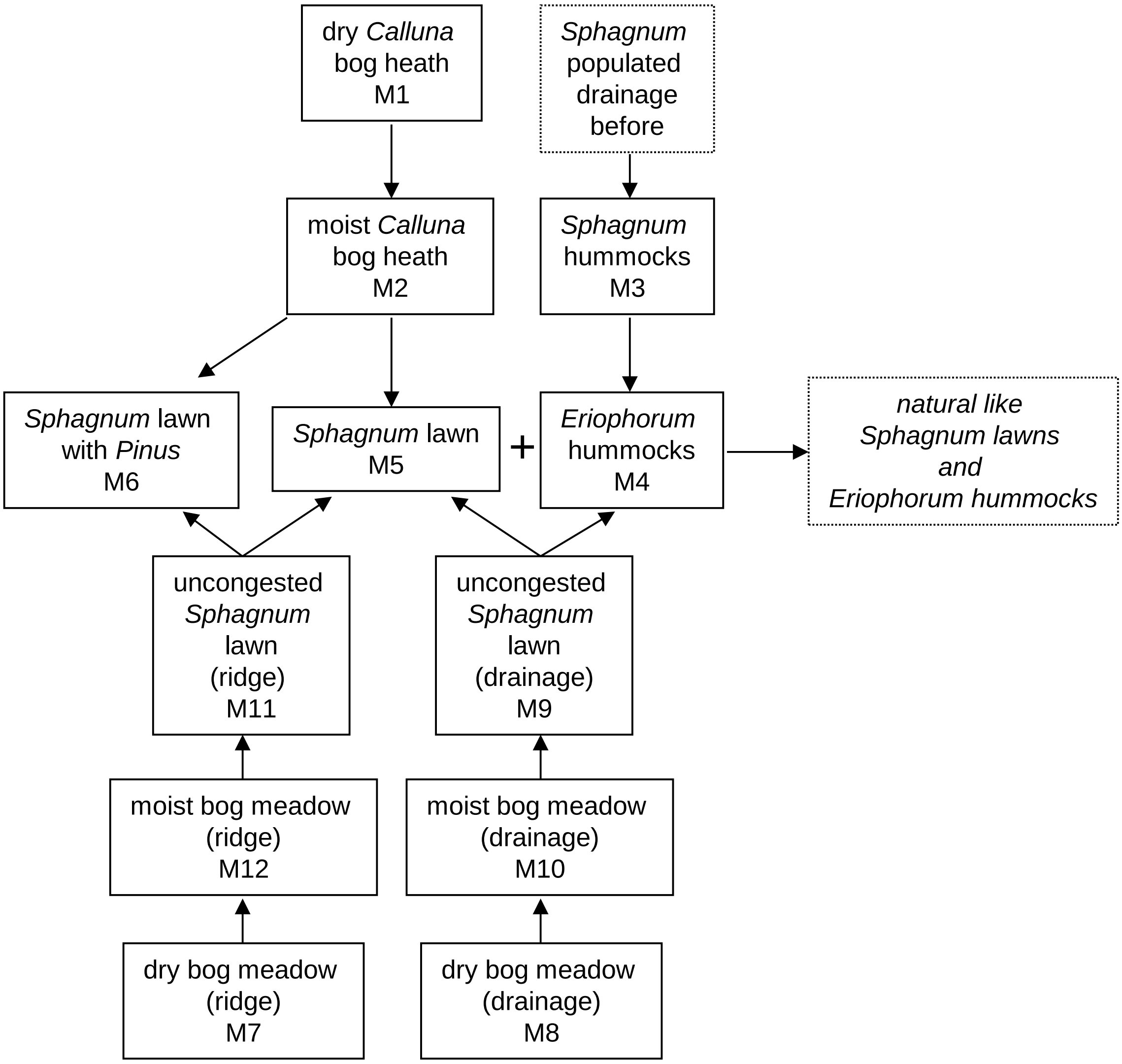

Fig. 10: Succession scheme of the sites of Mooseurach
arrows show possible developments of the sites after rewetting resp. restoration; sites in the upper part are located at the bog heath, sites in the lower part are at the Setzberger Feld

The sites of the Setzberger Feld have a bigger potential of development towards natural like conditions due to their recent distance to an undisturbed bog. As already remarked, the drained, managed sites M7 and M8 will get moist after closure of the drainages similar to sites M10 and M12. After ending the management, some uncongested *Sphagnum* communities are supposed to dominate the vegetation as can be seen at sites M9 and M11. The succession under undisturbed conditions might lead to *Eriophorum* hummocks (M4) and *Sphag-*

num lawns (M5), partly equipped with *Pinus x rotundata* Link (M6), where the water table is far enough from the surface to facilitate their establishment (around 15 cm).

At the bog heath, the dry *Calluna* heath (M1) will get moist in a few years as at site M2. This way, *Calluna* abundance will decrease and a *Sphagnum* lawn can develop (M5 or M6). On *Sphagnum* dominated former drainages like at site M3, *Eriophorum* hummocks will develop (M4). In the final period of this development, *Sphagnum* lawns and hummocks will replace some of these *Eriophorum* hummocks and displace shrubs to the edges of the central part of the bog. Only where *Eriophorum* hummocks reach adequate sizes a re-establishment of single examples of *Calluna vulgaris* (L.) Hull*, Pinus x rotundata* Link or *Betula pubescens* Ehrh. s. l. will be expected.

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Annex Environmental Parameters

Tab. 9: Water Tables, Electrical Conductivity, and pH in 2007
data show numbers, annual mean values and related standard deviations of measurement plots

Site	Plot	Water Table [cm]				Electrical Conductivity [µS/cm]				pH			
		n	Mean		StDev	*n*	Mean		StDev	*n*	Mean		StDev
M1	1	*29*	-30.4	±	7.4	*11*	88.5	±	8.7	*11*	3.91	±	0.15
	2	*28*	-25.4	±	7.0	*12*	85.6	±	7.5	*12*	3.95	±	0.23
	3	*29*	-24.3	±	6.3	*12*	74.7	±	16.8	*12*	4.01	±	0.17
M2	4	*29*	-25.9	±	6.5	*12*	70.1	±	12.1	*12*	3.97	±	0.13
	5	*29*	-19.7	±	5.9	*12*	56.1	±	9.7	*12*	3.95	±	0.13
	6	*29*	-21.2	±	5.6	*12*	61.2	±	7.0	*12*	3.90	±	0.11
M3	7	*28*	-3.8	±	4.1	*11*	45.9	±	2.4	*11*	4.02	±	0.09
	8	*28*	-4.4	±	3.8	*11*	41.8	±	1.7	*11*	4.10	±	0.11
	9	*28*	-7.6	±	4.1	*11*	47.4	±	2.3	*11*	4.02	±	0.08
M4	10	*29*	-11.6	±	4.9	*12*	45.5	±	5.2	*12*	3.98	±	0.11
	11	*29*	-11.8	±	4.8	*12*	49.2	±	6.8	*12*	3.98	±	0.11
	12	*29*	-10.4	±	4.7	*12*	41.8	±	3.8	*12*	4.00	±	0.13
M5	13	*30*	-14.4	±	2.8	*13*	57.5	±	10.8	*13*	3.95	±	0.16
	14	*30*	-16.1	±	4.4	*13*	42.7	±	7.1	*13*	4.07	±	0.17
	15	*30*	-12.8	±	4.5	*13*	53.0	±	10.4	*13*	4.01	±	0.14
M6	16	*30*	-14.4	±	3.7	*13*	53.8	±	4.5	*13*	4.03	±	0.12
	17	*29*	-15.5	±	5.2	*12*	56.3	±	9.2	*12*	3.91	±	0.33
	18	*30*	-14.8	±	4.1	*13*	62.7	±	14.2	*13*	3.92	±	0.19
M7	19	*30*	-20.4	±	7.1	*13*	43.5	±	7.9	*13*	4.58	±	0.22
	20	*30*	-25.5	±	8.8	*13*	60.6	±	9.9	*13*	4.33	±	0.12
	21	*30*	-22.7	±	8.5	*13*	63.0	±	18.2	*13*	4.49	±	0.10
M8	22	*30*	-31.8	±	8.7	*13*	82.2	±	19.3	*13*	4.33	±	0.20
	23	*30*	-41.3	±	10.4	*13*	63.2	±	14.6	*13*	4.37	±	0.18
	24	*30*	-36.1	±	8.1	*13*	50.4	±	18.8	*13*	4.33	±	0.30
M9	25	*30*	-16.0	±	5.8	*13*	34.9	±	4.4	*13*	4.41	±	0.22
	26	*30*	-15.3	±	5.6	*13*	34.6	±	4.3	*13*	4.43	±	0.09
	27	*30*	-11.4	±	5.1	*13*	37.2	±	4.6	*13*	4.39	±	0.14
M10	28	*30*	-7.0	±	5.7	*13*	39.9	±	5.0	*13*	4.52	±	0.19
	29	*30*	-7.7	±	8.0	*13*	32.2	±	5.9	*13*	4.42	±	0.12
	30	*30*	-5.9	±	10.0	*13*	39.0	±	10.0	*13*	4.45	±	0.21
M11	31	*30*	-17.3	±	5.7	*13*	31.9	±	3.7	*13*	4.40	±	0.27
	32	*30*	-13.7	±	5.8	*13*	32.8	±	4.0	*13*	4.67	±	0.20
	33	*30*	-16.4	±	5.9	*13*	32.8	±	5.1	*13*	4.55	±	0.21
M12	34	*30*	-17.5	±	6.5	*13*	38.2	±	4.5	*13*	4.41	±	0.17
	35	*30*	-10.8	±	7.1	*13*	42.5	±	6.9	*13*	4.53	±	0.20
	36	*30*	-18.9	±	8.1	*13*	42.4	±	4.1	*13*	4.34	±	0.13

Tab. 10: Water Tables, Electrical Conductivity, and pH in 2008

data show numbers, annual mean values and related standard deviations of measurement plots

Site	Plot	Water Table [cm]				Electrical Conductivity [µS/cm]				pH			
		n	Mean		StDev	*n*	Mean		StDev	*n*	Mean		StDev
M1	1	*39*	-33.3	±	7.6	*14*	93.8	±	22.4	*13*	3.92	±	0.26
	2	*39*	-26.1	±	6.9	*15*	80.5	±	19.7	*13*	3.99	±	0.23
	3	*39*	-31.4	±	8.3	*15*	75.6	±	12.7	*13*	3.98	±	0.23
M2	4	*39*	-24.4	±	6.6	*15*	67.7	±	23.2	*12*	3.93	±	0.23
	5	*39*	-18.7	±	7.2	*15*	55.4	±	13.2	*12*	3.93	±	0.21
	6	*39*	-20.3	±	5.4	*15*	56.5	±	14.6	*12*	3.88	±	0.26
M3	7	*39*	-2.2	±	4.6	*14*	42.5	±	12.4	*12*	3.94	±	0.27
	8	*39*	-4.3	±	4.2	*12*	40.5	±	12.2	*10*	3.98	±	0.26
	9	*39*	-7.7	±	4.4	*13*	44.5	±	13.1	*11*	4.00	±	0.34
M4	10	*38*	-10.4	±	5.2	*13*	43.1	±	11.8	*12*	4.00	±	0.36
	11	*38*	-10.3	±	5.6	*14*	37.7	±	10.1	*12*	4.00	±	0.20
	12	*38*	-10.4	±	5.4	*12*	40.3	±	9.5	*12*	3.96	±	0.20
M5	13	*38*	-12.6	±	3.4	*15*	31.1	±	9.3	*13*	4.18	±	0.15
	14	*38*	-14.5	±	4.5	*15*	31.4	±	8.6	*13*	4.19	±	0.19
	15	*38*	-11.8	±	5.1	*15*	32.5	±	8.6	*13*	4.16	±	0.22
M6	16	*38*	-13.3	±	4.3	*15*	39.2	±	6.2	*13*	4.17	±	0.27
	17	*38*	-14.1	±	5.1	*15*	40.1	±	12.9	*12*	4.15	±	0.24
	18	*38*	-13.7	±	4.3	*15*	63.3	±	14.1	*13*	4.10	±	0.31
M7	19	*39*	-16.3	±	8.4	*13*	37.6	±	12.3	*8*	4.75	±	0.19
	20	*35*	-17.6	±	8.7	*8*	74.8	±	25.5	*5*	4.74	±	0.25
	20b	*19*	-14.4	±	12.7	*7*	41.0	±	8.4	*7*	4.52	±	0.25
	21	*39*	-20.7	±	8.5	*15*	60.7	±	15.5	*6*	4.66	±	0.29
M8	22	*39*	-36.0	±	9.7	*15*	64.3	±	15.4	*11*	4.47	±	0.19
	23	*39*	-38.1	±	9.7	*15*	58.0	±	17.2	*9*	4.38	±	0.22
	24	*38*	-33.3	±	9.6	*14*	59.1	±	18.6	*9*	4.50	±	0.20
M9	25	*38*	-15.1	±	6.3	*11*	38.1	±	14.7	*11*	4.58	±	0.22
	26	*38*	-14.4	±	6.9	*12*	33.9	±	10.5	*11*	4.47	±	0.12
	27	*38*	-8.9	±	5.5	*14*	34.2	±	12.9	*11*	4.23	±	0.17
M10	28	*38*	-6.7	±	7.0	*13*	32.5	±	7.1	*11*	4.31	±	0.27
	29	*38*	-7.8	±	8.2	*13*	31.0	±	9.1	*11*	4.39	±	0.21
	30	*38*	-4.7	±	10.0	*12*	37.9	±	8.6	*10*	4.46	±	0.42
M11	31	*36*	-16.3	±	6.3	*12*	30.6	±	10.7	*11*	4.47	±	0.19
	32	*37*	-13.3	±	6.2	*12*	32.3	±	13.0	*11*	4.61	±	0.37
	33	*37*	-17.0	±	6.9	*15*	32.3	±	6.7	*11*	4.53	±	0.34
M12	34	*37*	-17.8	±	8.3	*15*	38.7	±	6.4	*12*	4.44	±	0.17
	35	*37*	-10.6	±	7.1	*12*	50.1	±	28.7	*4*	4.72	±	0.24
	36	*37*	-17.7	±	9.1	*15*	45.8	±	17.6	*12*	4.31	±	0.23

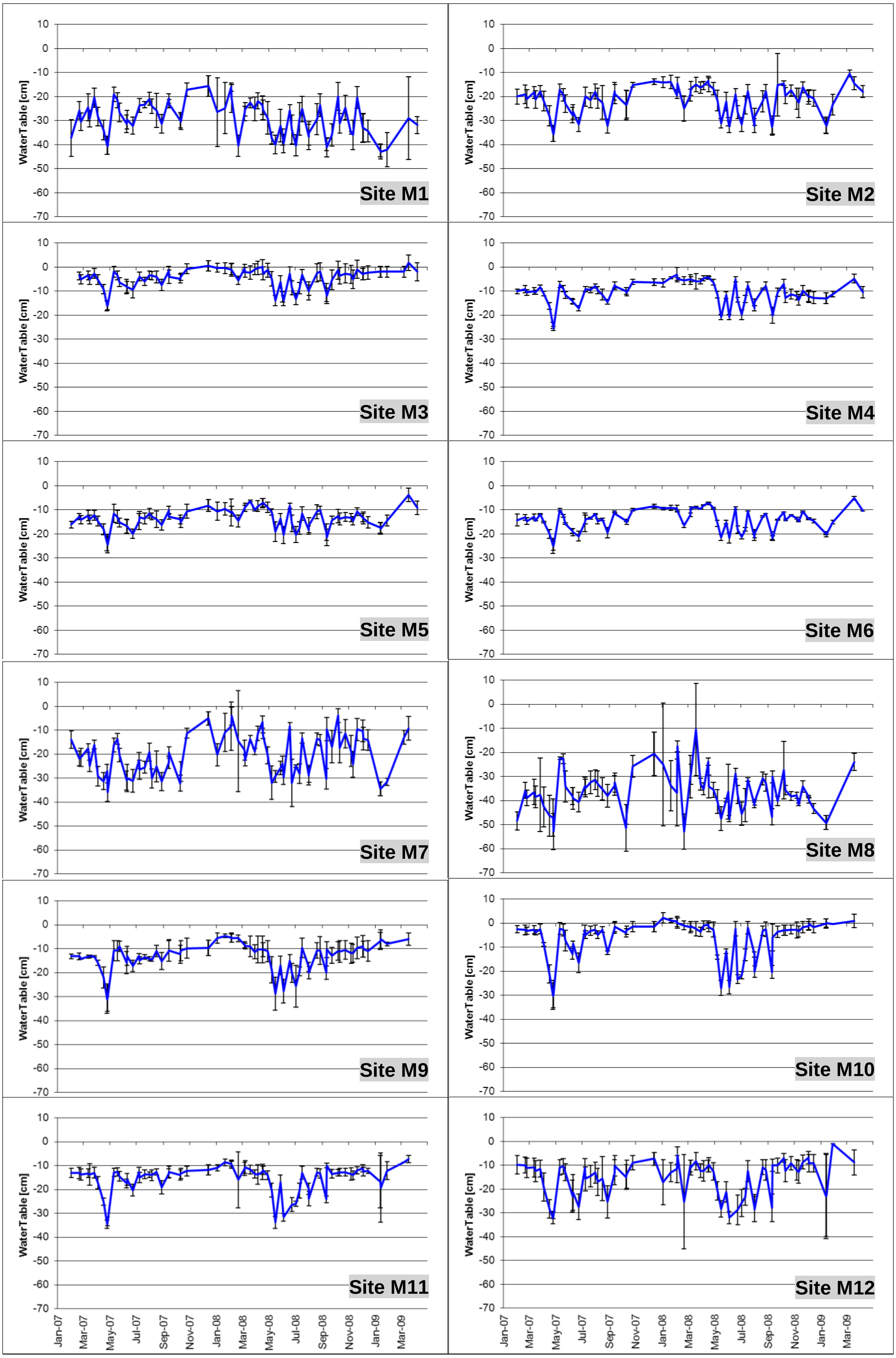


Fig. 11: **Courses of water tables of all sites between January 2007 and April 2009**
error bars show standard deviations based on three-plot measurements

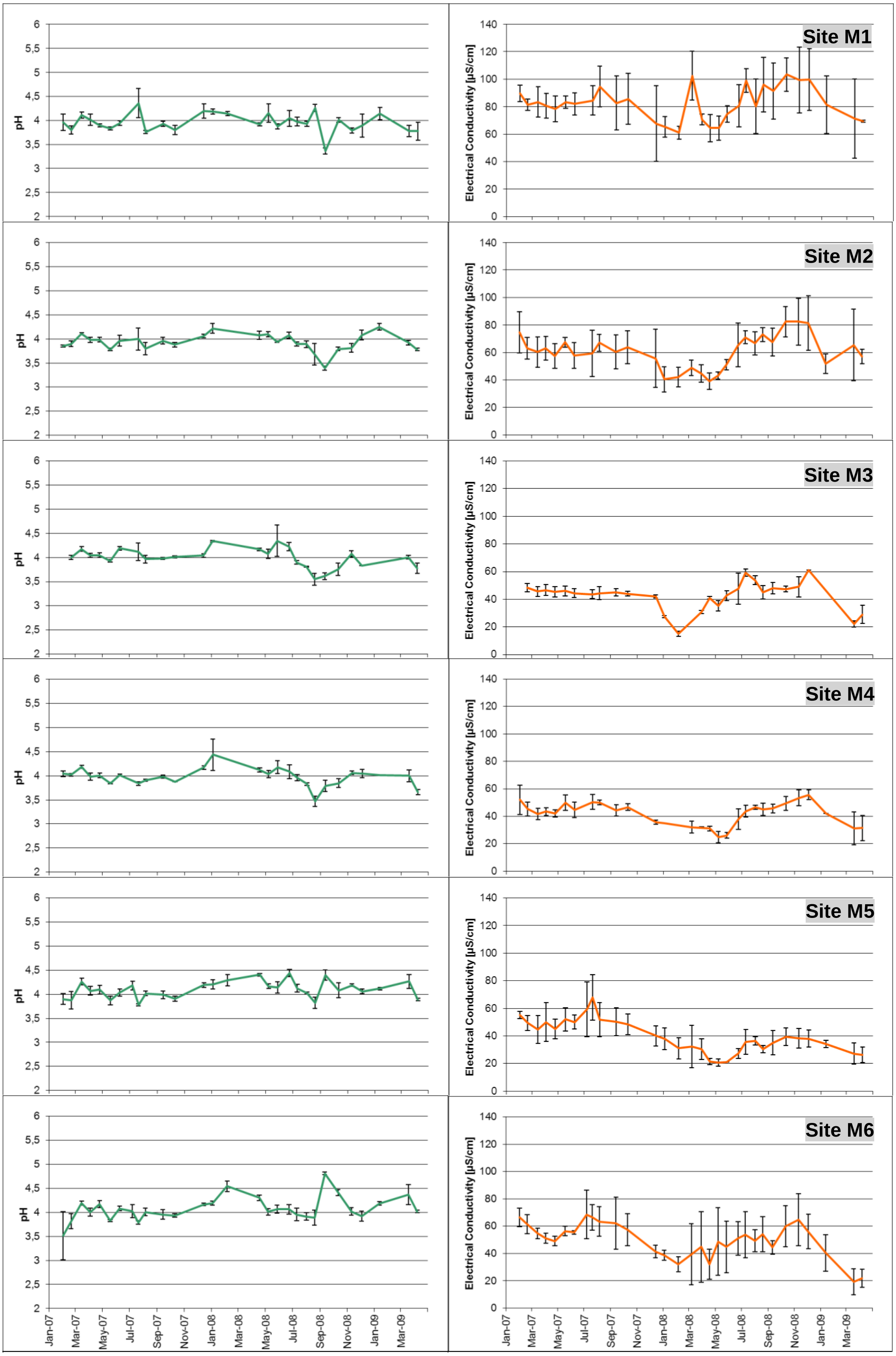


Fig. 12: **Courses of pH (left) and Electrical Conductivity (right) of sites M1 to M6 between January 2007 and April 2009**
error bars show standard deviations based on three-plot measurements

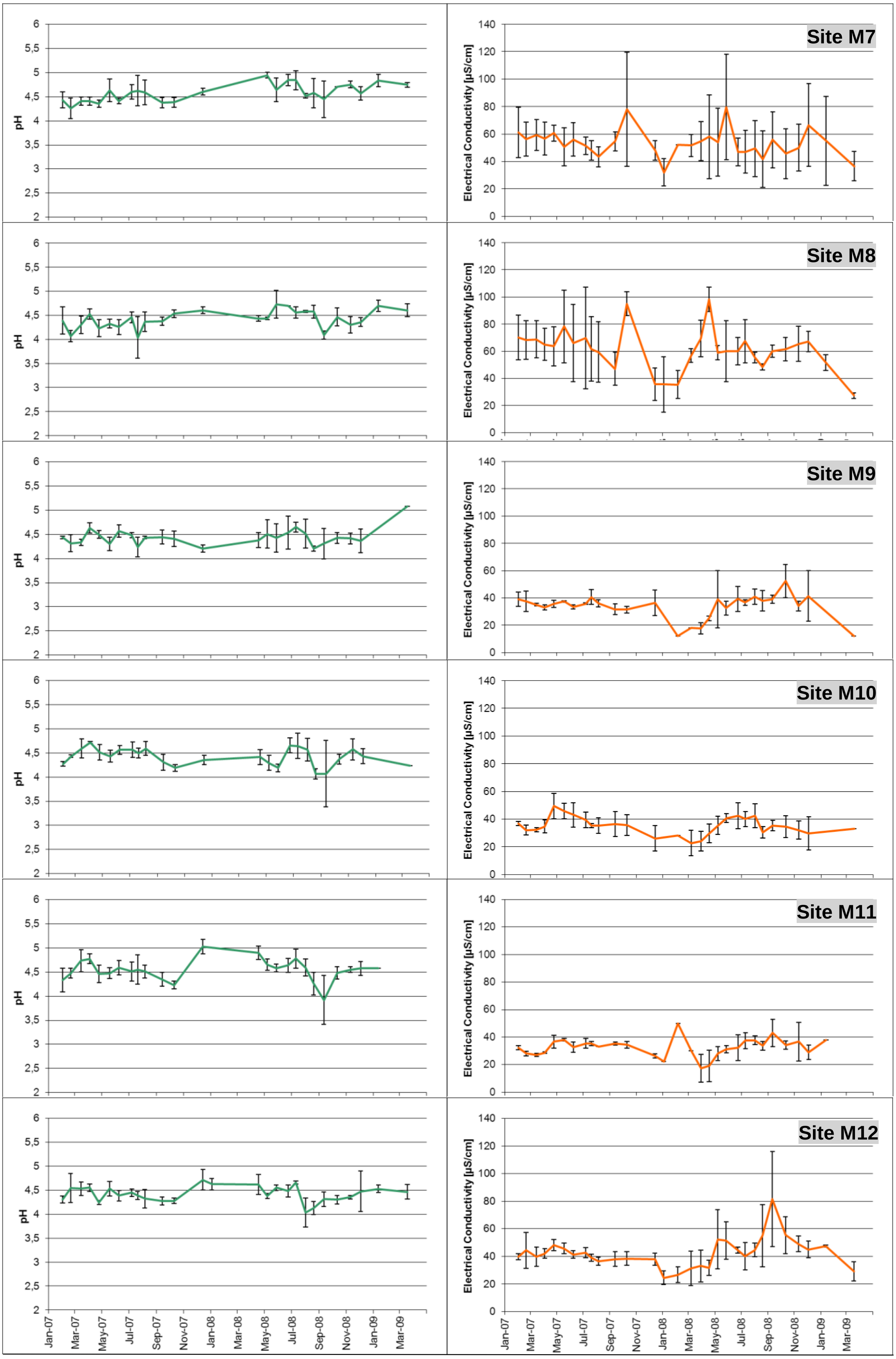


Fig. 13: **Courses of pH (left) and Electrical Conductivity (right) of sites M7 to M12 between January 2007 and April 2009**
error bars show standard deviations based on three-plot measurements

Tab. 11: Vegetation of the bog heath in 2008

numbers are abundances in % according to scale of Londo (1976)
abundances were estimated with a 100-grid frame

Site	Plot	Andromeda polifolia L.	Aulacomnium palustre (Hedw.) Schwaegr.	Betula pubescens Ehrh. s. l.	Calluna vulgaris (L.) Hull	Dicranum polysetum Sw.	Epilobium palustre L.	Eriophorum vaginatum L.	Pinus x rotundata Link	Pleurozium schreberi (Brid.) Mitt.	Polytrichum strictum Menz. ex. Brid.	Rhynchospora alba (L.) Vahl	Sphagnum fallax H. Klinggr.	Sphagnum magellanicum Brid.	Sphagnum rubellum Wils.	Vaccinium oxycoccos L. (s. l.)	Vaccinium uliginosum L. s. l.	Vaccinium vitis-idaea L.
M1	1		0.1		32					52	0.1				4			0.1
M1	2		0.1		42				0.1	27	7				22			
M1	3	0.1			37	0.1			0.1	32	0.1				2			
M2	4				67	0.1				82								
M2	5				27	0.1		1		22	4		0.1	1	72	0.1		
M2	6				27	0.1			0.1		0.1			50	45	2	0.1	0.1
M3	7							0.1			0.1	0.1	45	0.1	50	0.1	2	
M3	8	0.1			0.1			1			0.1	0.1	3	20	75	0.1		
M3	9							0.1			0.1	0.1	10	30	60	0.1		
M4	10				0.1			65				0.1		17	77	4		
M4	11				0.1			40			0.1	1		70	30	2		
M4	12	0.1			0.1			57	0.1			0.1	10	55	35	2		
M5	13				15		5				0.1	1	2	0.1	97	0.1		
M5	14				10			2			0.1	0.1		0.1	97	0.1		
M5	15				2			2	0.1		0.1	15	0.1	0.1	95	0.1		
M6	16	0.1		0.1	37	2			10	2	1	0.1	0.1		95	0.1	0.1	
M6	17	0.1			7	0.1		3	5		0.1		0.1		92	2	0.1	
M6	18	0.1			12			3	10			0.1			97	0.1		

Tab. 12: Vegetation of the Setzberger Feld in 2008

numbers are abundances in % according to scale of Londo (1976)
abundances were estimated with a 100-grid frame

Site	Plot	Agrostis capillaris L.	Anthoxanthum odoratum L. s. str.	Carex canescens L.	Carex hirta L.	Carex nigra (L.) Reichard	Climacium dendroides (Hedw.) F. Weber. & Mohr	Galium palustre L. s. l.	Glyceria notata Chevall.	Holcus lanatus L.	Juncus effusus L.	Molinia caerulea (L.) Moench s. str.	Poa pratensis L. s. str.	Polytrichum formosum Hedw.	Racomitrium aquaticum (Schrad.) Brid.	Ranunculus repens L.	Rhytidiadelphus squarrosus (Hedw.) Warnst.	Schoenus ferrugineus L.	Sphagnum fallax H. Klinggr.	Vicia cracca L. s. str.
M7	19		25			0.1	90			0.1	0.1				0.1					
M7	20		35			0.1	87			0.1	1					2				
M7	21		20			15	87				0.1									
M8	22		60			0.1	10					0.1	0.1	5	1			0.1		
M8	23		45		0.1		37				10			0.1						
M8	24		27				37				2			0.1						
M9	25		5			30					0.1			0.1					82	
M9	26		35	2		5					1			1			0.1		77	
M9	27			55		1	22				3								2	
M10	28		2	30		3								0.1			4		87	
M10	29		1	45			4				2			0.1			2		82	
M10	30			2					2		3						42			
M11	31		10			1					10			0.1					92	
M11	32	0.1	2	10		2					5								82	
M11	33		10	2							4								87	
M12	34		40	1			67							0.1					0.1	
M12	35		30	30			62	0.1						4		0.1			2	
M12	36		15				72	25						0.1		1				0.1

Tab. 13: Vegetation of the bog heath in 2012

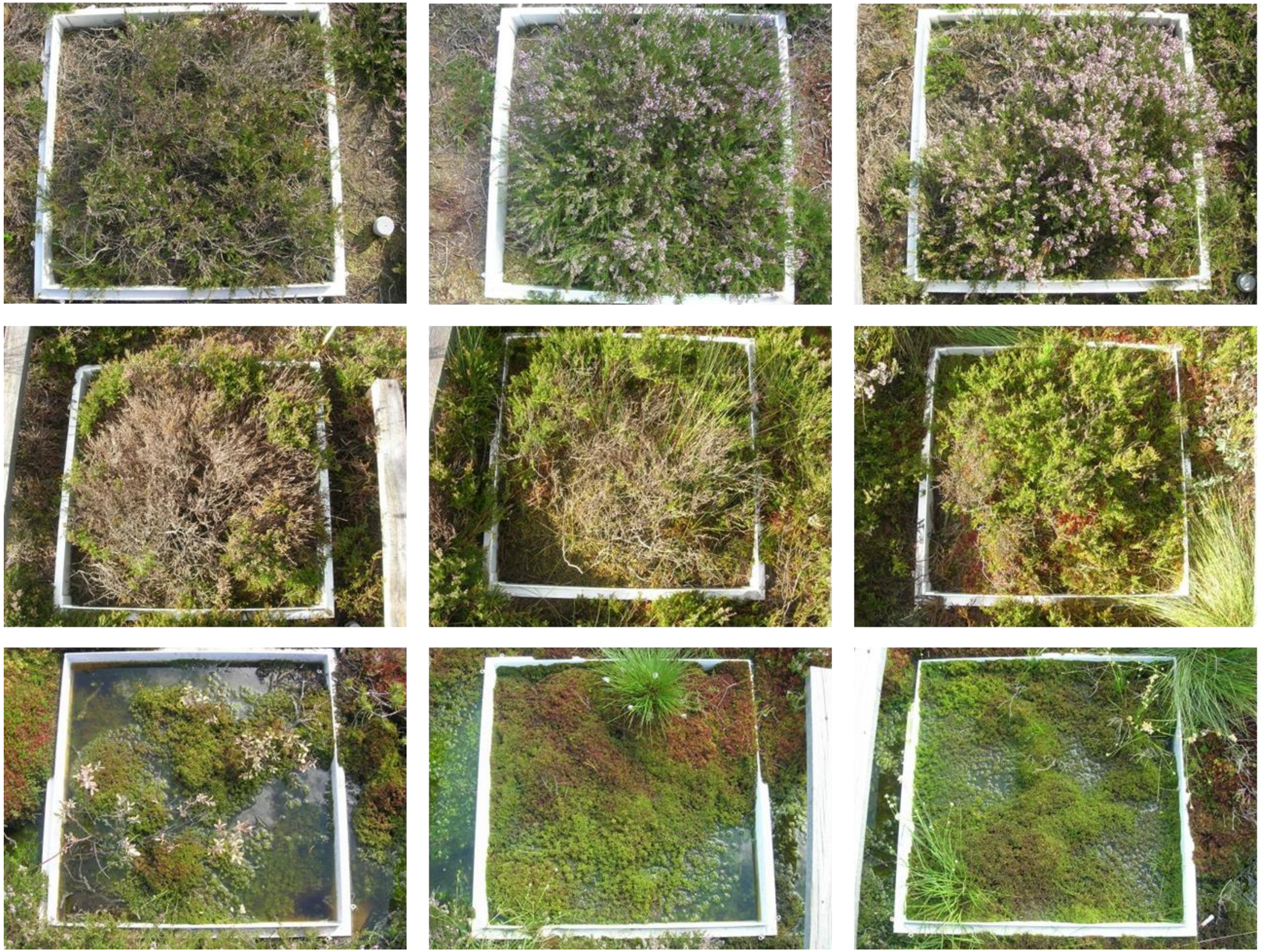
numbers are abundances in % according to scale of Londo (1976)
abundances were estimated with a 100-grid frame

Site	Plot	Andromeda polifolia L.	Aulacomnium palustre (Hedw.) Schwaegr.	Betula pubescens Ehrh. s. l.	Calluna vulgaris (L.) Hull	Calluna vulgaris (L.) Hull [died]	Dicranum polysetum Sw.	Drosera rotundifolia L.	Eriophorum vaginatum L.	Pinus x rotundata Link	Pinus sylvestris L.	Pleurozium schreberi (Brid.) Mitt.	Polytrichum strictum Menz. Ex. Brid.	Rhynchospora alba (L.) Vahl	Sphagnum magellanicum Brid.	Sphagnum rubellum Wils.	Vaccinium oxycoccos L. (s. l.)	Vaccinium uliginosum L. s. l.	Vaccinium vitis-idaea L.
M1	1		2		70	20						20				7			2
M1	2		0.1		33	50	0.1				7	23	2			4			
M1	3	0.1			90						4	7				2			
M2	4				70	30						30							
M2	5				50				7			7	0.1		0.1	70	0.1		
M2	6				77						0.1		7		20	70	0.1	0.1	0.1
M3	7													10					
M3	8								30					0.2	2	20	0.1		
M3	9								7				0.1	30			0.1		
M4	10	2							70						30	17	7		
M4	11	0.1							47						27	70	10		
M4	12	7							67						30	60	7		0.1
M5	13				37				47					0.1	10	87	0.1		
M5	14				30				47				0.1		2	87	0.1		
M5	15	0.1			20				47	7				0.1	10	90	2		
M6	16	4		7	37			0.1		30		17	7	0.1	0.1	37	0.1	2	
M6	17	0.1			17		0.1		40	37					2	67	2		
M6	18	0.1			17				13	57					2	70	2		

Tab. 14: Vegetation of the Setzberger Feld in 2012

numbers are abundances in % according to scale of Londo (1976)
abundances were estimated with a 100-grid frame

Site	Plot	Anthoxanthum odoratum L. s. str.	Carex canescens L.	Carex nigra (L.) Reichard	Climacium dendroides (Hedw.) F. Weber. & Mohr	Epilobium palustre L.	Galium palustre L. s. l.	Juncus effusus L.	Molinia caerulea (L.) Moench s. str.	Polytrichum formosum Hedw.	Racomitrium aquaticum (Schrad.) Brid.	Ranunculus repens L.	Rhytidiadelphus squarrosus (Limpr.) Warnst.	Sphagnum fallax Klinggr.
M7	19	27			57	0.1	47	0.1			7	0.1		
M7	20	30			57	2	30	2		7	2	4		
M7	21	30			30	0.1	10	17		40				
M8	22	47		0.1	17			27					30	
M8	23	77			20			2					17	
M8	24	60			30			0.1					17	
M9	25	0.1		17				7		0.1				87
M9	26	7	17	27				7		7				70
M9	27		37					2						90
M10	28	0.1	17											100
M10	29	10	20											97
M10	30	2	17					2						100
M11	31	7	7					47						90
M11	32	2	30					27	0.1					77
M11	33	17	27					20						97
M12	34	17		50	5								2	0.1
M12	35	67		7	4		0.1	2				2	27	
M12	36	57	17		2		0.1			20				27



Site M1
(plots 1-3)

dry bog heath
dominated by
Calluna vulgaris;
degraded

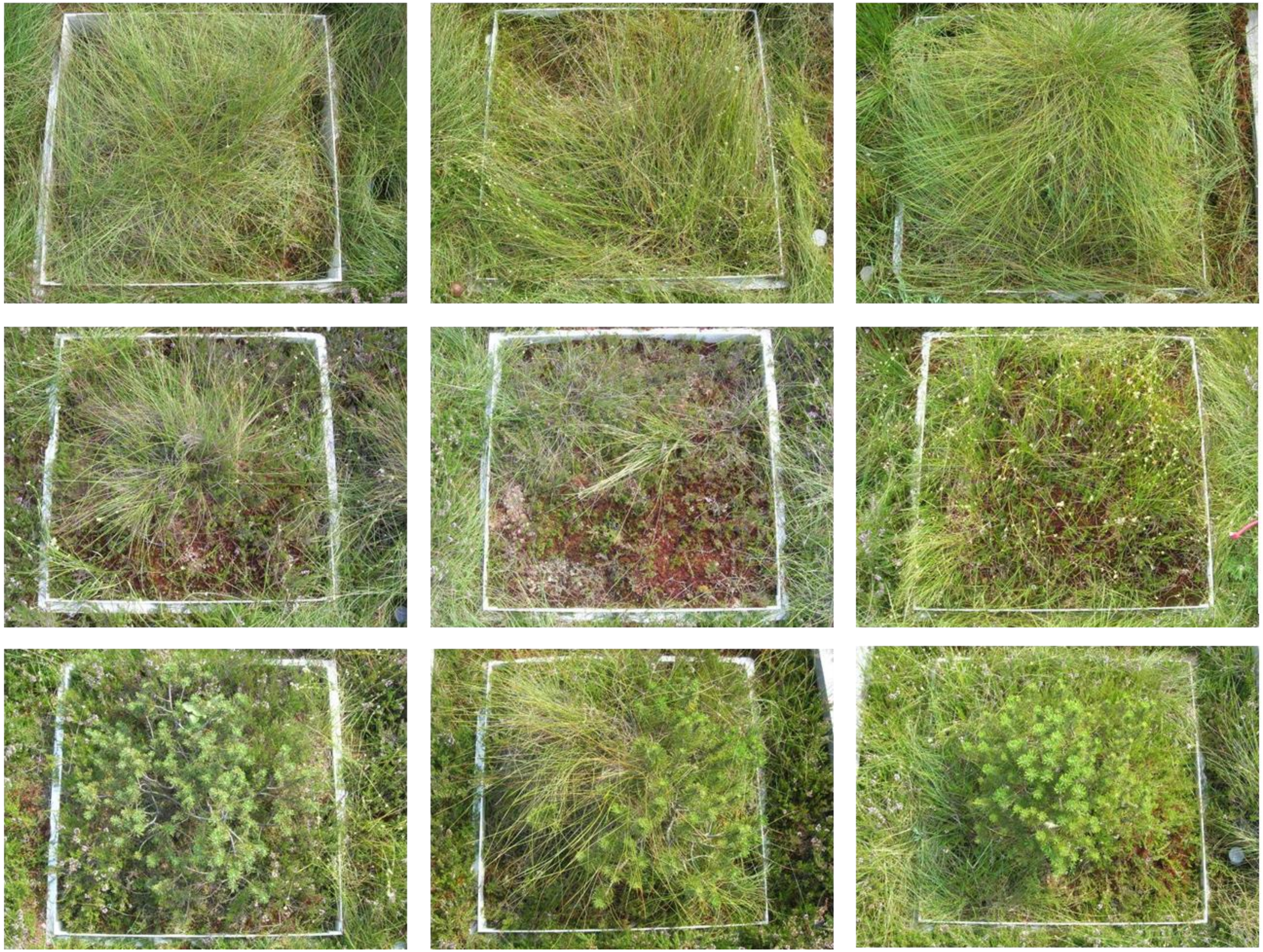
Site M2
(plots 4-6)

moist bog heath
dominated by
Calluna vulgaris;
restored 2005

Site M3
(plots 7-9)

Sphagnum
hummocks;
located on a
former drainage;
restored 2005

Fig. 14: Pictures of plots 1-3 (Site M1), 4-6 (Site M2) and 7-9 (Site M3) taken 2008/08/19 by Christoph Förster



Site M4
(plots 10-12)

Eriophorum vaginatum hummocks; located on a former drainage; restored 1993

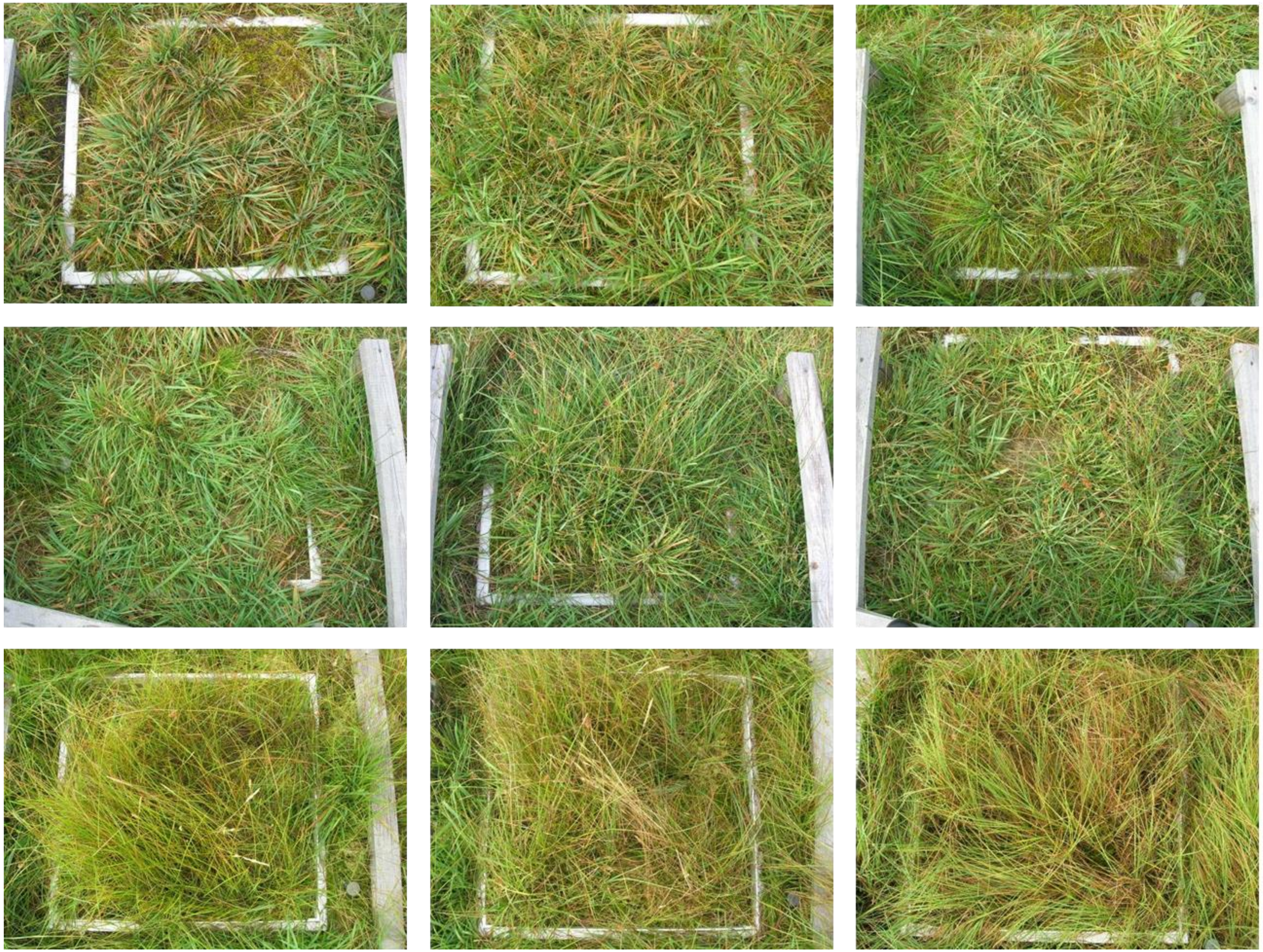
Site M5
(plots 13-15)

Sphagnum lawn with *Rhynchospora alba*; restored 1993

Site M6
(plots 16-18)

Sphagnum lawn with *Pinus x rotunddata*; restored 1993

Fig. 15: Pictures of plots 10-12 (Site M4), 13-15 (Site M5) and 16-18 (Site M6) taken 2008/08/19 by Christoph Förster



Site M7
(plots 19-21)

dry bog meadow with *Anthoxanthum odoratum;* located on a ridge; degraded

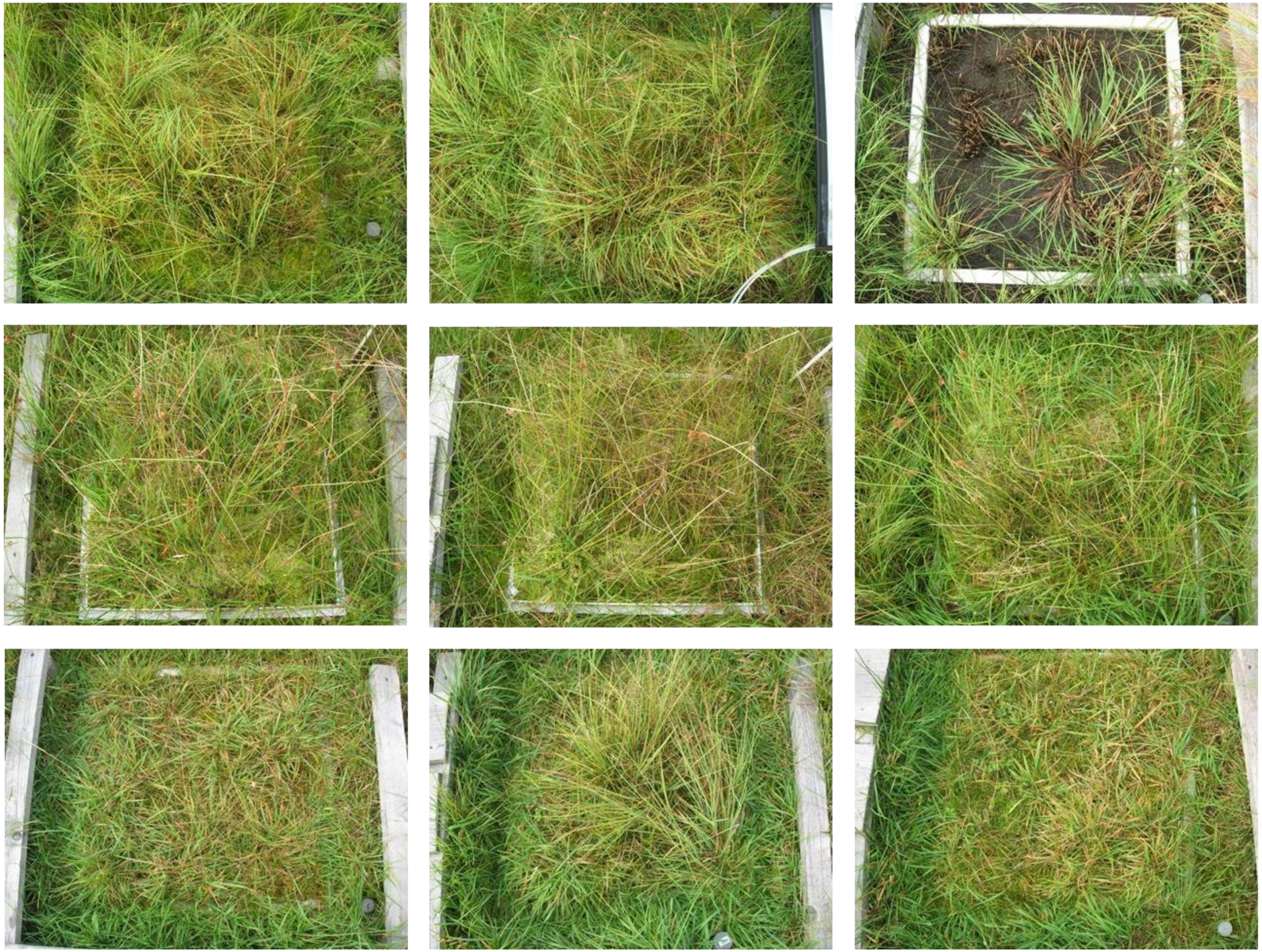
Site M8
(plots 22-24)

dry bog meadow with *Anthoxanthum odoratum;* located on a drainage; degraded

Site M9
(plots 25-27)

Sphagnum lawn with *Carex* species; located on a former drainage; rewetted 1993

Fig. 16: Pictures of plots 19-21 (Site M7), 22-24 (Site M8) and 25-27 (Site M9) taken 2008/07/31 by Christoph Förster



Site M10
plots (28-30)
moist bog
meadow with
Carex species;
located on a
former drainage;
rewetted 1993

Site M11
plots (31-33)
Sphagnum lawn
with *Carex*
species; located
on a ridge;
rewetted 1993

Site M12
plots (34-36)
moist bog
meadow with
Carex species;
located on a
ridge;
rewetted 1993

Fig. 17: Pictures of plots 28-30 (Site M10), 31-33 (Site M11) and 34-36 (Site M12) taken 2008/07/31 by Christoph Förster

3 Respiration (R_{eco}) and net ecosystem exchange (NEE) measurements

3.1 Abstract

Undisturbed bogs are sinks for CO_2 but emit CH_4 in a mentionable amount. The utilisation of almost 95% of global peatlands (HÖPER 2007) eliminated these CH_4 emissions. But now, CH_4 was oxidised and the former water logged peat was mineralised to CO_2. Additional agricultural use leads to N fertilisation with enhanced N_2O emissions. Restoration or rewetting of formerly used peatlands can at least reduce the total balance of these three greenhouse gases up to a status when the restored bog becomes a sink for C again. The results of the CH_4 and N_2O measurements can be found in chapter 4.

The investigated bog close to the village Mooseurach (BY, Germany) was drained in the 1920s. Due to restoration events in 1993 and 2005 at the bog heath, small stripes with typical vegetation could develop surrounded by the not restored bog. At the bog meadow we investigated a not restored and a rewetted area, and a stripe without management, where a *Sphagnum fallax* H. Klinggr. community established. To determine the CO_2 exchange of these varieties, measurement campaigns took place every three to four weeks using the chamber method developed by DRÖSLER (2005). Additionally meteorological physical and vegetation parameters were collected.

At the bog heath, the respiration (R_{eco}) ranged from 192 g C m^{-2} a^{-1} to 1091 g C m^{-2} a^{-1} in 2007 and 267 g C m^{-2} a^{-1} to 1324 g C m^{-2} a^{-1} in 2008. The gross primary production (GPP) ran from -317 g C m^{-2} a^{-1} to -1062 g C m^{-2} a^{-1} in 2007 and -503 g C m^{-2} a^{-1} to 1087 g C m^{-2} a^{-1} in 2008. The proportions of the spring balances were for R_{eco} and GPP up to four times higher in 2007 than in 2008.

The net ecosystem exchange (NEE) ranged from -160 g C m^{-2} a^{-1} to 381 g C m^{-2} a^{-1} in 2007 and from -237 g C m^{-2} a^{-1} to 552 g C m^{-2} a^{-1} in 2008. Highest releases of CO_2 were found at not and short term restored sites, whereas long term restored sites could show small uptakes. Permanent sinks for CO_2 were the *Sphagnum* dominated sites with water tables close to the surface. Interannual differences were caused by vegetation dynamics, seasonal influences as well as by oscillation of water tables.

Respiration (R_{eco}) of the six sites of the bog meadow ranged from 825 g C m^{-2} a^{-1} to 1981 g C m^{-2} a^{-1} in 2007 and from 789 g C m^{-2} a^{-1} to 1788 g C m^{-2} a^{-1} in 2008. The gross primary production (GPP) was between -1039 g C m^{-2} a^{-1} and -1496 g C m^{-2} a^{-1} in 2007 resp. -798 g C m^{-2} a^{-1} and -1206 g C m^{-2} a^{-1} in 2008. In spring 2007, the proportions of R_{eco} and GPP to total balances were up to four times higher than in spring 2008.

Net ecosystem exchange (NEE) ran from -246 g C m^{-2} a^{-1} to 485 g C m^{-2} a^{-1} in 2007 and -157 g C m^{-2} a^{-1} to 582 g C m^{-2} a^{-1} in 2008. While the degraded sites were CO_2 sources, rewetting reduced the emissions of around 20 to 80% or turned the sites into sinks for CO_2, depending on the water tables. Confident sinks for CO_2 could be found where management stopped and *Sphagnum* communities established.

3.2 Specific methods for gas exchange measurements of R_{eco} and NEE

3.2.1 Chamber system

The manual chamber system developed by DRÖSLER (2005) was applied for the gas exchange measurements at the 12 investigated sites. For further details see chapter 2.2.2. The advantage of this method was and still is to cover a small scale diversity of habitats in a high resolution shown in the number of measurements per day with few people. Therefore, this method is established for years and applied by other research groups (BEETZ ET AL. 2013), BEYER ET AL. (2014 and 2015). Due to practicability and different analysing methods, the measurements were split into a CO_2 part, which is described here, and a CH_4 / N_2O part (s. chapter 4). For the CO_2 measurements two types of chambers were used: Opaque chambers were used to quantify the respiratoric part of CO_2 exchanges (R_{eco}); transparent chambers made of acrylic glass were used for the quantification of total exchange of CO_2 (NEE) including uptake (via photosynthesis) and release (via respiration).

3.2.2 CO_2 measurements and analysis

R_{eco} can be distinguished in the respiration of plants and other autotrophic organisms and the respiration of heterotrophic organisms, which are not able to absorb CO_2 by photosynthesis. With the applied measurement method, it was not possible to separate the heterotrophic from the autotrophic respiration. But that was not necessary to get annual balances for the respiration of the different investigated sites in the end. The assimilation of CO_2 via photosynthesis could not be measured directly either. With the transparent chambers we were able to measure the net ecosystem exchange (NEE), which is the combination of efflux via respiration (R_{eco}) and uptake via photosynthesis (= gross primary production; GPP). With a simple approach (s. also Equation 3) we calculated the GPP from the NEE and R_{eco}.

The CO_2 field measurements took place from 19th of February 2007 to 7th of April 2009 every three weeks during the vegetation period (March to September). During the remaining time of both years, a four week rhythm was sufficient due to extremely reduced biological processes in autumn and winter. One measurement campaign lasted two days, whereas two teams with two to three persons each were responsible for two to four sites with six to twelve plots, depending on the location and the site combination (s. Fig. 2, chapter 2.1.3).

The measurements started before sunrise at the lowest temperatures of a day to get flux data which were comparable to the night fluxes, where respiration was equal to NEE (s. also DRÖSLER 2005). During a day, NEE and R_{eco} measurements altered to catch a homogenous change of fluxes driven by PAR (Photosynthetically Active Radiation) for NEE and by air or soil temperatures for R_{eco}. All these parameters should remain constant during the single measurements. The end of a measurement day was indicated by the decline of the upper soil temperatures which led to diminishing R_{eco} fluxes.

PAR was measured with a LICOR LI-250A light meter and a LI-190 terrestrial quantum sensor, for air temperatures at 20 cm in- and outside the chamber some control-thermometers (Fa. TFA, Wertheim) were used, for soil temperatures at 2 cm, 5 cm and 10 cm of every site some cut-in-thermometers (Voltcraft DET1R).

During the measurements, an ambient-like air flow inside the chamber was created by a pair of fans (Igaraschi, 3V). Often it was necessary to control the chamber-temperatures actively to avoid a rise or decrease of temperature of more than ± 1.5 K and to avoid a too big difference between the temperatures in and outside the chamber. Therefore ice packs were used in combination with the fans so that a moderate (rise of) temperature in the chamber could be guaranteed. Correlations between the outside air temperature and the chamber air temperature ranged from $r^2 = 0.990^{***}$ to 0.995^{***} for R_{eco} measurements and from $r^2 = 0.915^{***}$ to 0.994^{***} for NEE measurements.

For the CO_2 measurements the chambers (opaque or transparent) were connected via tubes (BEV-A-LINE, 15 m, LICOR) to a LICOR LI-820 IRGA or LI-800 (internal default ± 2 ppm). The intake of the air was done by a membrane pump (KMF; 12 V; max. 2 l / min). Every R_{eco} measurement took three minutes with time steps of 20 s, the NEE measurement time differed from one and a half to three minutes with time steps between 10 s to 20 s. The adaptation for the NEE had to be done due to different analysis methods (s. flux calculation below).

Some good indicators for the condition of peatlands in general were some physical parameters and the water tables of each plot were taken at each campaign; for pH a WTW pH 191 was used, for the Electric Conductivity (EC) a WTW LF 196.

3.2.3 Flux calculation

Depending on the measurement type (R_{eco} or NEE), different analysis methods were used to get fluxes. For both types, a quality criterion was a linear regression of the CO_2 concentration per time with $r^2 > 0.95$. The slopes of the R_{eco} regressions were linear and had their maxima at least after one minute. Possible non-linear relationships or jumping values were caused by the plants' reaction, which had to adapt themselves to darkness. Therefore, the first measurement-points had to be rejected sometimes. In contrast to R_{eco}, the first part of each measurement had to be used for the NEE regressions, because the initial slopes were linear and the most constant ones during a measurement. This was done to avoid an increase of humidity or temperature which could occur in the end under certain conditions (fast PAR increase, cold and moist surface). These changes of CO_2 concentrations per time were inserted in Equation 1.

$$F_{CO_2} = k_{CO_2} \times (273.15K / T_{in}) \times (V / A) \times (dc / dt)$$

Equation 1

F_{CO2} = CO_2 flux [mg C m^{-2} h^{-1}]
k_{CO2} = gas-constant at 273.15 K (= 0.536 g C l^{-1})
T_{in} = initial temperature inside the chamber [K]
V = volume of the chamber [l]
A = area of one plot within the frame [m^2]
dc / dt = change of CO_2 concentration per time [ml C l^{-1} h^{-1}]

The chamber volume V was 309 l, but had to be corrected by topographical differences of each plot. This correction volume was determined with a 100-cell grid.

The fluxes of each day and site were divided in R_{eco} and GPP fluxes and inserted in the graph-calculation program TableCurve 2D 5.01 (CRANES SOFTWARE). For the campaign-specific R_{eco} temperature regressions the values were imported in the respiration equation (Equation 2) after LLOYD & TAYLOR (1994) and mostly the correlation with the best fit was used for further calculations. As a result R_{ref} and E_0 were taken as driving parameters for the single daily regressions and inserted into the model of the annual fluxes using Equation 2.

Respiration equation (LLOYD & TAYLOR 1994):

$$R_{eco} = R_{ref} \times e^{E_0 x((1/T_{ref} - T_0) - 1/(T_{soil} - T_0))}$$

Equation 2

R_{ref} = respiration at the reference temperature [CO_2 [µmol m^{-2} s^{-1}]]
E_0 = activation energy like parameter [K]
T_{ref} = reference temperature [283.15 K]
T_0 = temperature constant for the start of biological processes [227.13 K]
T_{soil} = soil temperature at the depth of best fit with the dataset [K]

Sometimes the fitting (r^2) between R_{eco} fluxes and two (or more) temperatures (air 20 cm, soil 2 cm, soil 5 cm or soil 10 cm) was quite similar, so that a confident choice could only be guaranteed, when the measured fluxes were compared with the modelled fluxes, which could differ in a high degree although the r^2 were similar. Generally, the test of the modelled versus measured data was done, also for NEE regressions, to verify the best fitting model and to identify possible problematic campaigns. Tab. 21 to Tab. 26 show the r^2 of the applied regressions for the single campaigns. The validations of the models are displayed in Tab. 29 and Tab. 30 by facing the measured and corresponding modelled flux data with linear regressions.

The rectangular hyperbola equation (MICHAELIS & MENTEN 1913) used the result of R_{eco} model and two parameters α and GP_{max} of GPP which were elaborated by having used the best-fitting and thus tested R_{eco} model to calculate GPP fluxes with the measured NEE fluxes.

$$GPP_{cal} = NEE_{measured} - R_{eco\,modelled}$$ **Equation 3**

GPP_{cal} = calculated GPP fluxes [CO_2 [µmol m^{-2} s^{-1}]]
$NEE_{measured}$ = NEE measured during the field-campaigns [CO_2 [µmol m^{-2} s^{-1}]]
$R_{eco\ modelled}$ = modelled R_{eco} [CO_2 [µmol m^{-2} s^{-1}]]

Having used this intermediate step it was possible to use the rectangular hyperbola equation of Michaelis & Menten (1913). The pairs of values of GPP fluxes and PAR per site and campaign were inserted in TableCurve and the GPP flux curves were calculated using Equation 4. The results, α and GP_{max}, were inserted into the model for the annual fluxes having used Equation 4.

Rectangular hyperbola equation (Michaelis & Menten 1913):

$$NEE = (GP_{max} \times \alpha \times PAR)/((\alpha \times PAR) + GP_{max}) - R_{eco}$$ **Equation 4**

PAR = photon flux density of the photosynthetic active radiation [µmol m^{-2} s^{-1}]
GP_{max} = maximum gross photosynthetic fixation of CO_2 for PAR infinite [µmol m^{-2} s^{-1}]
α = initial / maximum slope of NEE versus PAR
R_{eco} = respiration model [CO_2 [µmol m^{-2} s^{-1}]]

3.3 R_{eco} and NEE measurements along a time gradient of restoration at the bog heath

3.3.1 Results

Accompanying parameters

DRÖSLER (2005) identified the increase of chamber temperature as a quality criterion for the gas flux measurements which should not raise more than 1.5 K. Otherwise the conditions inside the chambers would drift from the ambient conditions regarding temperature and humidity. Additionally, the temperature difference between the chamber and the ambient should be less than 1.5 K. Sometimes this criterion could not be achieved. In this case, when temperature rose above 1.5 K, the concerned fluxes were intensively checked and compared to fluxes with low temperature changes and also used for parameterisation if their attitude showed no irregularities. Correlations between outside air temperatures and chamber air temperatures had r^2 between 0.990*** and 0.995*** for R_{eco} measurements and r^2 between 0.988*** and 0.994*** for NEE measurements.

R_{eco} parameters for the models

In 2007, the used R_{eco} regressions (s. annex Tab. 21 and Tab. 22) showed a significant r^2 between 0.344 and 0.928. R^2 in 2008 ranged from 0.320 to 0.994. Sometimes it was necessary to combine the flux values of at least two campaigns due to missing significance of all the regressions (R_{eco} vs. Temp) of one single campaign or if the single r^2 were worse than 0.300. In some cases, the best-fitting regression did not lead to the best result (validated by modelled versus measured), thus another R_{eco} temperature regression had to be chosen. An adoption of parameters from one campaign to the following one was done in half-hourly steps.

The main driving and thus reference temperature in summer 2007 for all the sites except for M3 and M4 was air temperature. Respiration of sites M3 and M4, located on former drainages, was mainly driven by soil temperature at 2 cm.

Differences in respiration of the sites were linked to the R_{eco} parameters R_{ref} (= reference temperature at 283 K and E_0 (= activation energy). R_{ref} ranged from 0.276 µmol m^{-2} s^{-1} to 5.255 µmol m^{-2} s^{-1} in 2007 and from 0.021 µmol m^{-2} s^{-1} to 6.435 µmol m^{-2} s^{-1} in 2008. Highest R_{ref} were determined for sites M1, M2 and M6. Site M3 showed lowest values for both years. In 2007, E_0 was lowest for the sites M1 and M2, ranged from 65.9 K to 510.4 K for all the sites and was highest for site M3. In 2008, E_0 varied from -351.6 K (70.0 K) to 1032.3 K. The distribution was equivalent to that of 2007. Use of negative E_0 was sometimes necessary when no other reference temperature was significantly fitting and after having tested the model versus the measured data. The appearance of negative E_0 could be explained by the fact that the activation energy, elaborated with our methods, was sometimes superposed with other (bio-)chemical reactions, whose parameters we did not determine. Big differences in E_0 from one campaign to the next were caused by changes in reference temperatures.

In both years, there were significant relationships between R_{ref} and water tables (2007: 0.4310***; 2008: 0.5267***). For E_0, a significant relationship with water tables (-0.5449***) was only remarkable in 2007.

In winter (C14 to C16 plus C13 for M6), parameters were set zero, due to no detectable fluxes or fluxes below the internal default of the analyser (< 2 ppm per three minutes).

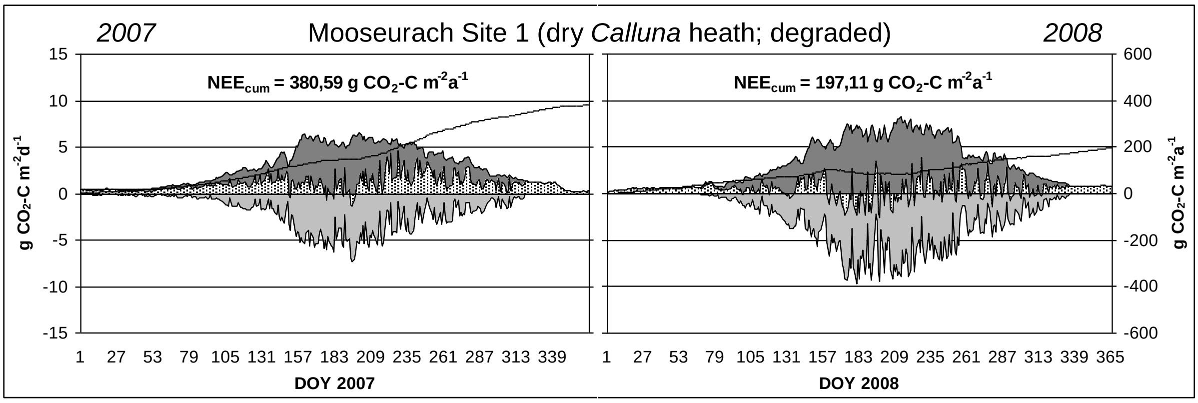
GPP parameters for the models

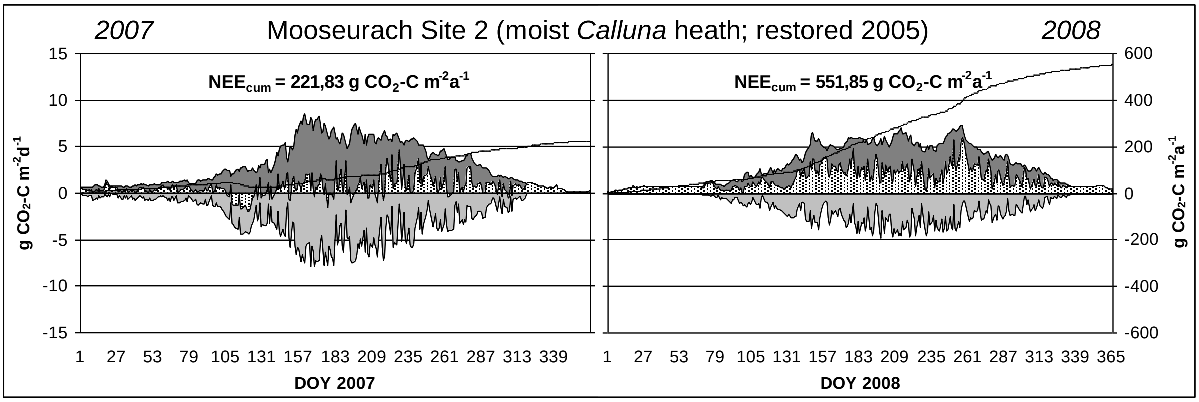
The GPP vs. PAR regressions had a significant r^2 between 0.589 and 0.993 for 2007 and 0.749 to 0.984 for 2008 (s. annex Tab. 23 and Tab. 24). As with R_{eco} modelling, it was sometimes necessary to combine two campaigns to get significant relationships. Depending on productivity and vegetation of the sites, the initial slopes (α) reached from -0.002 to -0.101 in 2007 and from -0.002 to -0.058 in 2008. Largest differences in α values in between the years had been detected for site M2. GP_{max} ranged from -1.36 µmol m^{-2} s^{-1} to -35.98 µmol m^{-2} s^{-1} in 2007 and from -1.24 µmol m^{-2} s^{-1} to -50.50 µmol m^{-2} s^{-1} in 2008, whereas by far the lowest values were detected for site M3 with a maximum of -6.32 µmol m^{-2} s^{-1} in 2007 and -14.69 µmol m^{-2} s^{-1} in 2008. For campaigns with ice and snow (C12 to C16 and C28), there was no measurable difference between R_{eco} and NEE fluxes and therefore no GPP fluxes. In these cases, parameters were set to zero.

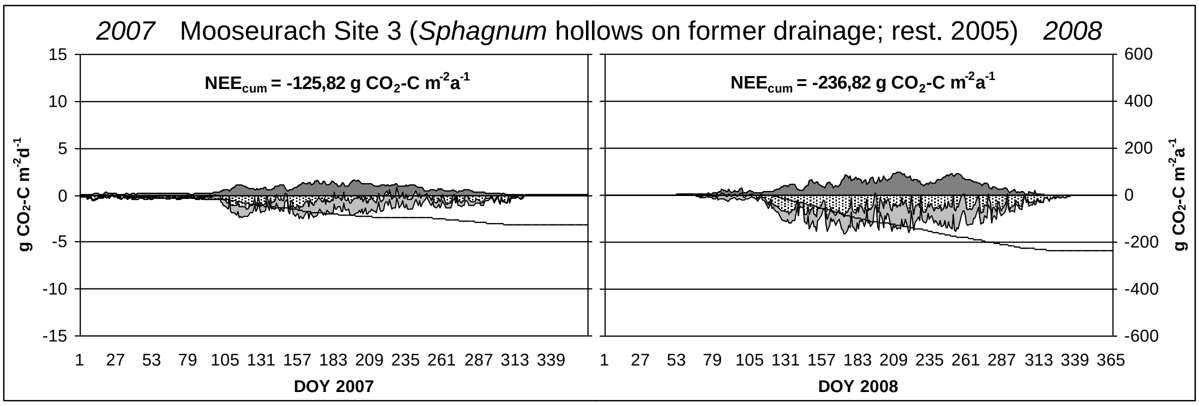
Significant relationships were detected for GP_{max} and water tables in 2007 (-0.2752*) and 2008 (-0.4584***), for α and water tables only in 2008 (-0.2320*).

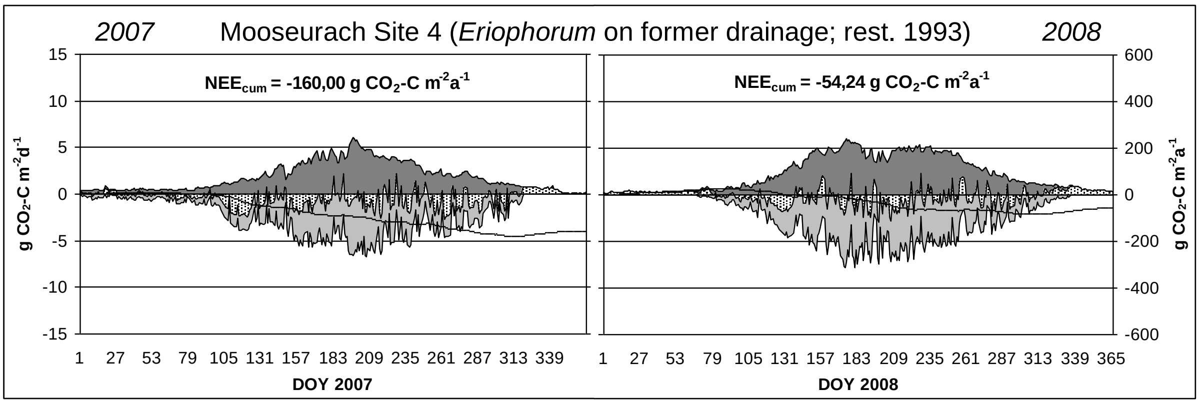
Annual courses of R_{eco}, GPP and NEE

In 2007, data from 13 campaigns were used for the models. Having started the CO_2 measurements on the 19th of February 2007, as for the preceding period no data were available. Due to a very warm winter with short snow-covered periods, the parameters were regarded stable and therefore the models were extrapolated from the first campaign to the 1st of January. The basis of the R_{eco} models were temperatures, logged in half-hourly steps, from a weather station, located in the bog heath and very close to all the sites. This station also collected PAR for the GPP and thus NEE models.


2007
Mooseurach Site 1 (dry Calluna heath; degraded)
2008
NEE$_{cum}$ = 380,59 g CO$_2$-C m^{-2}a^{-1}
NEE$_{cum}$ = 197,11 g CO$_2$-C m^{-2}a^{-1}
g CO$_2$-C m^{-2}d^{-1}
g CO$_2$-C m^{-2}a^{-1}
15 10 5 0 -5 -10 -15
600 400 200 0 -200 -400 -600
1 27 53 79 105 131 157 183 209 235 261 287 313 339
1 27 53 79 105 131 157 183 209 235 261 287 313 339 365
DOY 2007
DOY 2008


2007
Mooseurach Site 2 (moist Calluna heath; restored 2005)
2008
NEE$_{cum}$ = 221,83 g CO$_2$-C m^{-2}a^{-1}
NEE$_{cum}$ = 551,85 g CO$_2$-C m^{-2}a^{-1}
g CO$_2$-C m^{-2}d^{-1}
g CO$_2$-C m^{-2}a^{-1}
15 10 5 0 -5 -10 -15
600 400 200 0 -200 -400 -600
1 27 53 79 105 131 157 183 209 235 261 287 313 339
1 27 53 79 105 131 157 183 209 235 261 287 313 339 365
DOY 2007
DOY 2008


2007
Mooseurach Site 3 (Sphagnum hollows on former drainage; rest. 2005)
2008
NEE$_{cum}$ = -125,82 g CO$_2$-C m^{-2}a^{-1}
NEE$_{cum}$ = -236,82 g CO$_2$-C m^{-2}a^{-1}
g CO$_2$-C m^{-2}d^{-1}
g CO$_2$-C m^{-2}a^{-1}
15 10 5 0 -5 -10 -15
600 400 200 0 -200 -400 -600
1 27 53 79 105 131 157 183 209 235 261 287 313 339
1 27 53 79 105 131 157 183 209 235 261 287 313 339 365
DOY 2007
DOY 2008


2007
Mooseurach Site 4 (Eriophorum on former drainage; rest. 1993)
2008
NEE$_{cum}$ = -160,00 g CO$_2$-C m^{-2}a^{-1}
NEE$_{cum}$ = -54,24 g CO$_2$-C m^{-2}a^{-1}
g CO$_2$-C m^{-2}d^{-1}
g CO$_2$-C m^{-2}a^{-1}
15 10 5 0 -5 -10 -15
600 400 200 0 -200 -400 -600
1 27 53 79 105 131 157 183 209 235 261 287 313 339
1 27 53 79 105 131 157 183 209 235 261 287 313 339 365
DOY 2007
DOY 2008

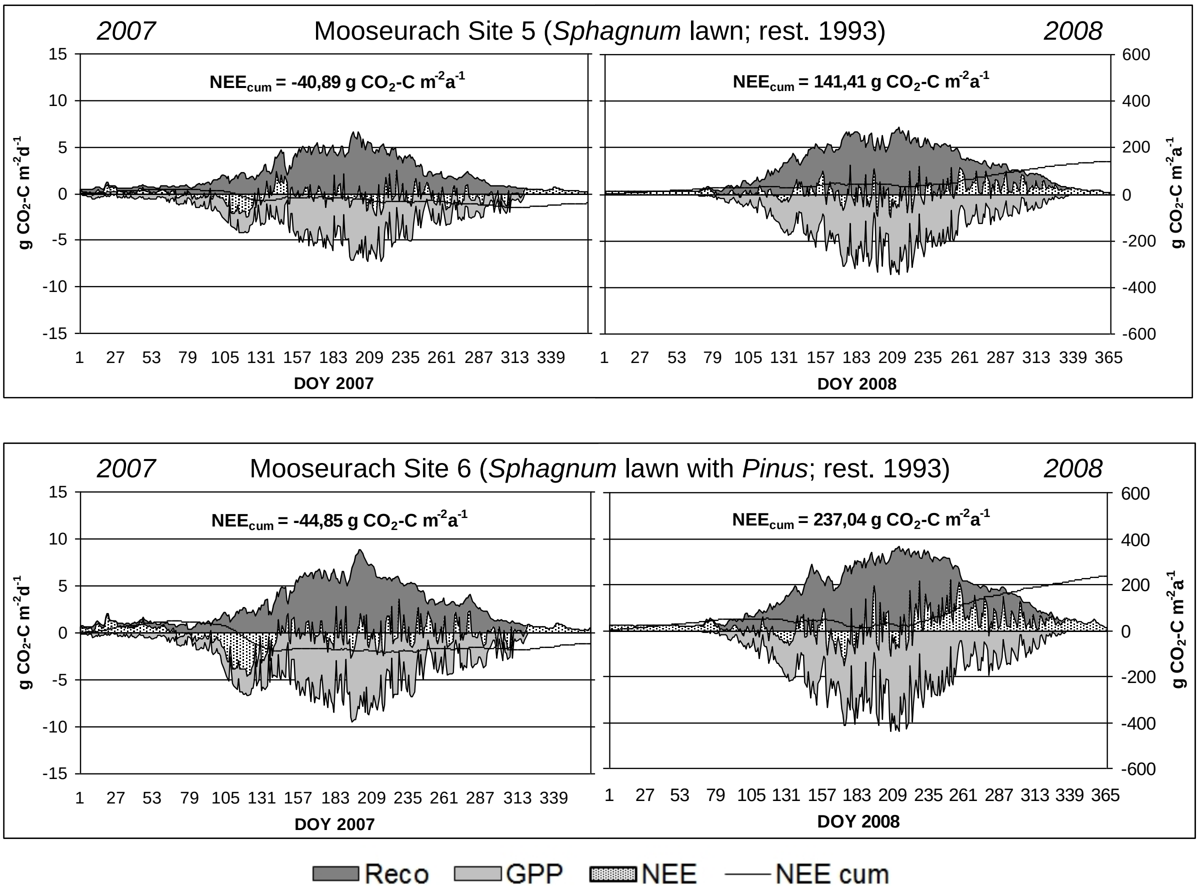


Fig. 18: Annual courses of R_{eco}, GPP, NEE and cumulative NEE of the sites M1 to M6 of the years 2007 and 2008
courses show daily balances which based on half-hourly modelled steps

The degraded, dry sites M1 (not restored) and M2 (restored 2005) showed a similar behaviour of R_{eco} and GPP, whereas site M2 had generally higher fluxes. In total, the release of site M1 with 381 g CO_2-C m^{-2} a^{-1} was higher than at site M2 with 222 g CO_2-C m^{-2} a^{-1}. Site M3 (former drainage with *Sphagnum* mosses; restored 2005) had much lower fluxes than all the other sites. Nevertheless, the NEE balance was negative (-126 g CO_2-C m^{-2} a^{-1}) as well as for site M4 (-160 g CO_2-C m^{-2} a^{-1}), which was restored 12 years before and was also located on a former drainage. Its' daily fluxes of R_{eco} and GPP were much more distinct than at site M3, comparable to site M5, which was restored the same year as M4, but located on a ridge. Concerning their vegetation, the sites M5 and M6 differed only by the appearance of *Pinus x rotundata* Link trees at site M6. Their annual NEE balances are very close with -41 g CO_2-C m^{-2} a^{-1} at site M5 and -45 g CO_2-C m^{-2} a^{-1} at site M6, whereas the R_{eco} and GPP daily balances were elevated at site M6. The first snowfall was on 15th of November 2007. Comparisons of R_{eco} and NEE fluxes with snow-coverage showed no differences any more. Therefore, GPP was set zero after this day.

In 2008 the snow- and ice-cover was persistent until end of March. Many flux measurements of this period were below the internal default of the CO_2 analyser. Even after three minutes of measurement time the values did not change more than 2 ppm in any direction, thus the fluxes were set to zero. Even when fluxes were remarkable, corresponding temperatures did not change during the measurement time. Therefore, no regressions were calculable for single measurement days and all parameters (R_{ref}, E_0, α and GP_{max}) were set to zero. Nevertheless, it was possible to calculate winter regression for R_{eco} for all the sites, after having pooled all winter fluxes from single sites. These models were also checked by comparing them with the measured data. In 2008, data of 15 campaigns were used for calculations.

Tab. 15: Annual balances 2007 of R_{eco}, GPP and NEE of the bog heath sites
summer balances are added; no export was taken from these sites;
different letters show significant differences according to ANOVA (Tukey-Test; $p<0.05$)

Site	Reco ± SE				GPP ± SE				NEE ± SE					r^2
	g CO_2-C m^{-2} a^{-1}			summer	g CO_2-C m^{-2} a^{-1}			summer	g CO_2-C m^{-2} a^{-1}			incl. Export	summer	md vs ms
M1	995	+ 125 - 111	de	816	-615	+ 198 - 193	f	-556	381	+ 87 - 68	f	381	260	0.9195
M2	1091	+ 246 - 200	e	894	-869	+ 249 - 246	cde	-733	222	+ 49 - 0	e	222	161	0.9311
M3	192	+ 65 - 50	a	156	-317	+ 88 - 80	g	-245	-126	+ 39 - 15	bc	-126	-89	0.8637
M4	665	+ 156 - 126	b	553	-825	+ 121 - 117	def	-693	-160	+ 39 - 5	ab	-160	-140	0.9511
M5	757	+ 220 - 168	bc	615	-798	+ 128 - 125	ef	-652	-41	+ 96 - 40	cd	-41	-37	0.9386
M6	1017	+ 171 - 146	de	832	-1062	+ 207 - 201	bc	-874	-45	+ 62 - 30	cd	-45	-41	0.9104

Tab. 16: Annual balances 2008 of R_{eco}, GPP and NEE of the bog heath sites
summer balances are added; no export was taken from these sites;
different letters show significant differences according to ANOVA (Tukey-Test; $p<0.05$)

Site	Reco ± SE				GPP ± SE				NEE ± SE					r^2
	g CO_2-C m^{-2} a^{-1}			summer	g CO_2-C m^{-2} a^{-1}			summer	g CO_2-C m^{-2} a^{-1}			incl. Export	summer	md vs ms
M1	1150	+ 227 - 195	de	968	-953	+ 332 - 315	bcd	-878	197	+ 137 - 88	de	197	90	0.9138
M2	1102	+ 240 - 199	cd	903	-550	+ 288 - 283	e	-483	552	+ 89 - 44	g	552	420	0.8541
M3	267	+ 100 - 68	a	243	-503	+ 143 - 131	e	-466	-237	+ 75 - 31	a	-237	-223	0.9111
M4	820	+ 135 - 117	b	703	-875	+ 160 - 151	bcd	-796	-54	+ 43 - 16	bc	-54	-93	0.9553
M5	986	+ 195 - 170	bcd	850	-844	+ 143 - 140	cd	-776	141	+ 55 - 27	d	141	74	0.9486
M6	1324	+ 186 - 165	e	1127	-1087	+ 245 - 238	ab	-995	237	+ 80 - 52	def	237	132	0.9521

In contrast to 2007, site M1 had a lower total NEE balance (197 g CO_2-C m^{-2} a^{-1}) due to an uptake 50% higher in 2008, whereas site M2 released more CO_2 (552 g CO_2-C m^{-2} a^{-1}) than in 2007, driven by a lower GPP (s. Tab. 15 and Tab. 16). The *Sphagnum* dominated site M3 had generally elevated fluxes, which led to an uptake of -237 g CO_2-C m^{-2} a^{-1}. The daily R_{eco} balances rose from site M4 to M6 while the GPP balances were comparable for site M4 and M5. As in 2007, site M6 showed in 2008 the highest CO_2 uptake via GPP. While site M4 had a negative NEE-balance (-54 g CO_2-C m^{-2} a^{-1}), site M5 released 141 g CO_2-C m^{-2} a^{-1} and site M6 237 g CO_2-C m^{-2} a^{-1}.

The differences in standard errors of every site and the CO_2 component are a consequence of the use of the exponential LLOYD & TAYLOR function (1994) for R_{eco} and the rectangular-hyperbolic function of MICHAELIS & MENTEN (1913) for GPP.

In 2008, total R_{eco} and GPP fluxes rose at all sites except of M2. Site M2 was characterized by a decline of GPP of more than 300 g CO_2-C m^{-2} a^{-1} while R_{eco} was more or less stable. The highest increases of GPP were remarkable for site M1 (> 330 g CO_2-C m^{-2} a^{-1}) and M3 (> 180 g CO_2-C m^{-2} a^{-1}) while the change of GPP for the other sites was minimal (< 50 g CO_2-C m^{-2} a^{-1}). In total, the sites M4 to M6, restored in 1993, released in 2008 between 100 and 250 g CO_2-C m^{-2} a^{-1} more than the year before. A NEE increase of more than 250 g CO_2-C m^{-2} a^{-1} was also given for site M2. Corresponding to GPP increase, a reduction of NEE was shown by site M1 (-180 g CO_2-C m^{-2} a^{-1}) and M3 (-110 g CO_2-C m^{-2} a^{-1}).

A difference in the relation between summer and annual fluxes of 2007 and 2008 was remarkable for R_{eco} and GPP. In 2007, summer R_{eco} had a proportion of 81% to 83% of the annual R_{eco}, GPP ranged from 77% to 90%. In 2008, summer R_{eco} rate was between 86% and 92% and GPP between 88% and 92%. While in 2007, the proportions of the spring R_{eco} balances were two to four times higher than those in autumn and winter, the rates of spring and autumn/winter were almost equilibrated the following year. For GPP, the rates of spring and autumn/winter 2008 were quite similar, while the spring ratios of 2007 were up to ten times higher than those of autumn and winter.

The NEE balances of site M1 and M2 in spring and autumn 2007 were comparable, while for the sites M4 to M6 the spring balance was negative and the autumn positive. Only site M3 showed an uptake for all seasons, whereas autumn ratio of NEE was negligible.

3.3.2 Discussion

Parameters for Modelling

For the parameters R_{ref}, α and GP_{max} (s. Tab. 21 to Tab. 24), seasonality could be regarded as it was also found by Drösler (2005), Beetz et al. (2013) and Beyer et al. (2014). For E_0, this was not visible, in contrast to the characteristics of the activation energy, being an indicator of buffering potential of soil-ecosystems for respiration processes. This potential decreased with the degree of human impact by degradation. The long-term restored sites generally showed the highest E_0 values as well as the *Sphagnum* dominated flooded site M3, whose buffering potential was high due to water tables at the soil surface. High standard errors of E_0 were also remarkable at the restored sites which could be explained by the sensitivity of vegetation to drought stress, even at low fluctuating water tables. While there was a significant relationship between E_0 and water table in 2007 (-0.5449***) this could not be regained in 2008. The use of negative E_0 was motivated by tests of the modelled versus measured data, which led to relationships (r^2=0.384** to r^2=0.799***) similar to those with positive E_0 (r^2=0.320*** to 0.994***). For those campaigns, models with positive E_0 were tested but had to be rejected due to an overestimation of R_{eco} fluxes for the concerning periods. Any pattern of weather driven reactions of respiration visible at the other sites was only visible having used negative E_0. This similarity in reaction of adjacent sites was regarded as proof for using these parameters.

At the degraded or still relatively dry sites M1, M2 and M6, a big pore space led to elevated R_{eco} values which were already visible at the R_{ref} values. Water tables closer to the surface at the former drainages M3 and M4 and the relatively moist M5 diminished this pore space. Therefore, R_{ref} and R_{eco} were reduced in comparison to the dryer sites.

The initial slope α of the GPP vs. PAR regressions was an indicator of vegetation's activity even at low radiation. Due to low temperatures at low radiation conditions in the early morning, some plants, mainly mosses, were adapted to these conditions and could do a photosynthesis which exceeded R_{eco} very early. A high frequency of mosses at all the sites led to similar α values. Only a sparse vegetation (M3 in 2007) or dying vegetation (M2 in 2008) reduced α, but had also an effect on GP_{max}. For the *Sphagnum* dominated site M3, lower GP_{max} values were explainable by the light-saturation effect of *Sphagnum* mosses which is reached for many species between PAR of 500 and 700 µmol m^{-2} s^{-1} (Clymo & Hayward 1982 or McNeil and Waddington 2003).

For the dry sites, the maximum rate of photosynthesis at a theoretical PAR of infinity (GP_{max}) was more distinct concerning the plants composition and the water tables. While degraded M1 and short-time restored M2 had similar GP_{max} in 2007, the dying of *Calluna* of M2 made its photosynthesis via the mosses *Pleurozium schreberi* (Brid.) Mitt and *Sphagnum rubellum* Wils. more common with the long-term restored M4 and M5. The productivity of M6 could be explained by the presence of *Sphagnum magellanicum* Brid. and *Pinus x rotundata* Link. In future, the productivity of these *Sphagnum* populated sites might even be enhanced by rising CO_2 supply (HEIJMANS ET AL. 2001).

Annual flux courses

Generally, the annual balances of R_{eco} and GPP had a similar pattern for both years. Winter balances were much lower than the annual, but in combination (NEE) the amount of winter CO_2 exchanges was relevant especially when NEE balances were close to zero (AURELA ET AL. 2002). The non-restored site M1 and the short term restored site M2 changed their CO_2 emissions less than the sites M4 to M6, which were restored in 1993, and site M3 on a former drainage with water tables close to the surface. This could be explained with the adoption of the dry sites to fast changing and low water tables. BUBIER ET AL. (2003) found relatively stable NEE balances for sites dominated with *Ericaceous* shrubs even for years with dry summers. For other sites BUBIER ET AL. (2003) described a lower CO_2 uptake, comparable to almost all our sites, which could lead to a loss of the sink function of some sites.

Although the mean water tables of these sites (-21.2 ± 0.63 cm to -30.3 ± 0.75 cm) let a big pore space for oxidative processes (CH_4 oxidation, denitrification), soil and root respiration, these processes were at their maxima in both years. Even lower water tables and its fast change as in summer 2008 (M1: -32.9 ± 0.97 cm; M2: -24.4 ± 0.93 cm) did not provoke a higher R_{eco} summer balance compared to the total year as with the other sites. The percentage of summer R_{eco} for all the sites was between 86.5% and 92.3%. While site M1 emitted 10% more CO_2 in 2008, emissions of site M2 were reduced around -4%. The oxidative pore space of these sites led to increased emissions of sites M4 to M6 (20% to 28%) and site M3 (38%). The vegetation of these sites was not able to acclimatise to the fast changing water tables which were present especially in summer 2008 (s. chapter 2). LAFLEUR ET AL. (2003) described the importance of precipitation for an ombrotrophic bog in Canada, which lost 90% of its carbon storage capacity in a year with reduced precipitation.

Nevertheless, the balances for R_{eco}, GPP and NEE of the sites M5 and M6 were comparable to balances of HOMMELTENBERG ET AL. (2014) measured with Eddy covariance technique at a natural bog-pine site in the south of Starnberger See. The results of a BEETZ ET AL. (2013) or DRÖSLER ET AL. (2005) for natural like bog sites were comparable for all components R_{eco}, GPP and the total balance NEE.

The reduced adaptation led in 2008 to a total release of CO_2 via NEE for the sites M4 to M6 due to low rising of GPP of these sites (2.3% to 5.9%). This is according to some studies which described to dependency of *Sphagnum* productivity and water levels (SILVOLA 1991 or MCNEIL & WADDINGTON 2003). TUITTILA ET AL. (2004) found a maximum photosynthesis of *Sphagnum* dominated sites at water levels around -12 cm, which is according to our results.
In contrast to them, the GPP of site M3 rose about 58%, in summer 2008 even 90%. For the *Sphagnum* mosses of site M3, the change of water tables (2007: -5.3 ± 0.47 cm; 2008: -4.7 ± 0.45 cm; summer 2008: -7.4 ± 0.65) was positive. More plant surface above the water level led to more photosynthetic active plants and therefore more uptake of CO_2. GPP of Site M1 was enhanced by about a half in 2008, while GPP balance was reduced for site M2 of about -37%. Both sites, covered with *Calluna vulgaris* (L.) Hull and *Pleurozium schreberi* (Brid.) Mitt. in the ground layer, differed in the vitality of their plants. Especially *Calluna* was more vital at site M1, whereas some *Calluna* shrubs died at site M2. Different vitalities could be explained by the more moist conditions at site M2 (-21.2 ± 0.63 cm in 2008) in comparison to the not restored M1 (-30.3 ± 0.75 cm in 2008). The combination of less productive plant biomass (less GPP) and destructive aerobic processes (more R_{eco}) at site M2 led to a change in NEE from a moderate to a high source, caused by the first restoration step.

The development in the next ten years will intensify the growth of *Sphagnum* mosses, appearance of *Rhynchospora alba* (L.) Vahl hummocks and the reduction of *Calluna vulgaris* (L.) Hull, which could be seen at sites M5 and M6. Depending on a settlement with pine trees and the constancy of the water table on the dryer areas, the total CO_2 emissions will be reduced between 0 and 400 g CO_2-C m^{-2} a^{-1}.
For the drainages, R_{eco} and GPP will increase due to more plant biomass and soil formation processes with factor 1.5 to 3. Net uptake rates will be stable or will decline, depending on the constancy of the water table again. CO_2 balances around zero or certain emissions MARINIER ET AL. (2004) identified for some *Eriophorum* populated restored peatlands in Canada as well. In contrast to the dryer sites M5 and M6, there will be a net uptake at sites M3 and M4, as far as the development to a natural like bog will not be disturbed. Even dry periods and oscillating water tables cannot turn these sites into CO_2 sources, due to the larger plant surface and more GPP at lower water tables.

Concerning the seasonal fluxes, there was neither a characteristic pattern for single sites nor a specific habitude of the sites in 2007 in comparison to 2008.

3.3.3 Conclusion

The biennial R_{eco} and NEE flux measurements at the former drained bog of Mooseurach had a clear result that restoration of a bog led to a reduction of CO_2 emissions. Although the two years 2007 and 2008 were different concerning their vegetation period (snowless winter 2006 / 2007) and water regime (oscillating water table in 2008 during summer), the pattern of fluxes did not differ with some limitations. After the first step of restoration (M1 to M2) the fitness of vegetation was reduced, which led to an increase of CO_2 emission between +30% and +350%. The development of bog specific vegetation stopped this process and turned the site to a smaller source than without restoration (-30% to -60%) even after a period of 15 years. Under ideal conditions, the sites became sinks for CO_2 (around -50 g CO_2-C m^{-2} a^{-1}). If the difference between before and after restoration is big, like at the sites on the (former) drainages, the success of restoration would be even bigger. Although the situation before restoration was not part of this work, a deeply drained area can be regarded as a source for CO_2. The short time restoration period of three years was sufficient to turn this area into an effective sink for CO_2 with uptakes between -120 and -240 g CO_2-C m^{-2} a^{-1}. Even if there was a reduction of uptake during the natural development, such a drained stripe will stay a sink for CO_2 with rates between -80 and -160 g CO_2-C m^{-2} a^{-1}.

3.4 Influence of rewetting and management on R_{eco} and NEE balances at a bog meadow

3.4.1 Results

R_{eco} parameters for the models

The r^2 of the used R_{eco} regressions (s. annex Tab. 25 and Tab. 26) ranged from 0.338 to 0.920 in 2007 and from 0.415 to 0.967 in 2008. If there was no significant correlation between R_{eco} and any temperature of one campaign, data of at least two campaigns were combined or, if this did not lead to a result, the parameters were interpolated between the preceding and following campaigns. If the regression with the best fit did not have the best final result, proved by the modelled versus the measured R_{eco} and NEE values, the regression with the best checked result was chosen.

In 2007, the main driving temperature for all the sites was air temperature. For 2008, the reference temperature for the R_{eco} models of site M7, M10 and M12 switched between air, soil at 2 cm and soil at 5 cm, while the main driving temperature for sites M8, M9 and M11 was still air temperature with some interruptions.

R_{ref} ranged in 2007 from 0.559 µmol m^{-2} s^{-1} to 8.770 µmol m^{-2} s^{-1}, E_0 from 59.7 K to 539.9 K. In 2008, R_{ref} ran from 0.479 µmol m^{-2} s^{-1} to 14.617 µmol m^{-2} s^{-1}, E_0 from -196.4 K to 853.0 K. Regressions with negative E_0 were compared with interpolated variances of R_{eco} models, but they led to the most confident results. The interpolated models showed jumps in annual R_{eco} models, which were not explainable by measured abiotic factors. Furthermore, the surrounding sites did not show such extreme reactions.

R_{ref} was highest for site M8 in both years, while the other sites showed similar respiration rates at 10°C. The activation energy did not differ for the investigated sites in 2007; in 2008 there was a differentiation between site M8 with lowest E_0 (maximum: 314.7 K) and M10 with highest values (maximum 853.0 K). The other sites sorted themselves in between.

The courses of R_{ref} (= respiration at 283 K) were highly significant correlated with water tables in 2007 (0.4857***) and 2008 (0.5337***). E_0 did not correlate with any other parameter taken during the measurements. Big differences in R_{ref} and E_0 from one campaign to the next were caused by changes in reference temperatures.

In winter (C13 to C16), parameters were set to zero due no detectable fluxes or fluxes below the internal default of the analyser (< 2 ppm per three minutes).

GPP parameters for the models

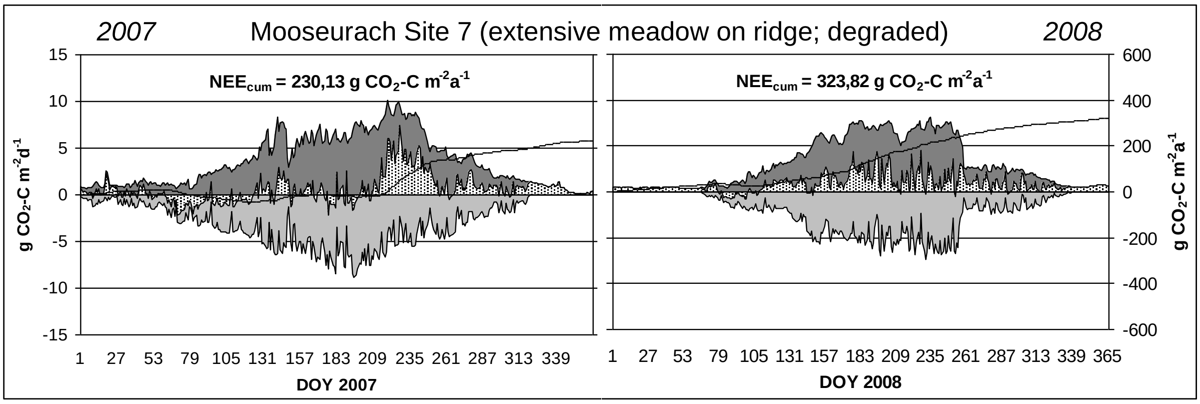
The regressions of GPP versus PAR were significantly correlated with an r^2 of 0.761 to 0.997 in 2007 and r^2 of 0.758 to 0.978 in 2008 (s annex Tab. 27 and Tab. 28). Due to non-significant correlations in 2008, it was necessary to combine the data of two campaigns to get significant relationships. If this did not lead to any results, the parameters α and GP_{max} were interpolated from the preceding to the subsequent campaign. The initial slopes (α) ranged in 2007 from -0.004 to -0.114 and in 2008 from -0.005 to -0.134. For all the sites, the annual courses of α were similar in both years. GP_{max} was lowest for site M7 (2007: -22.99 µmol m^{-2} s^{-1}; 2008: -23.95 µmol m^{-2} s^{-1}). The maximum GPP (GP_{max}) ranged from -2.51 µmol m^{-2} s^{-1} to -45.69 µmol m^{-2} s^{-1} in 2007 and from -4.63 µmol m^{-2} s^{-1} to -42.26 µmol m^{-2} s^{-1} in 2008. In wintertime (C12 to C16 and C28), when the vegetation was covered with snow or ice, parameters were set zero due to no detectable plants activity.

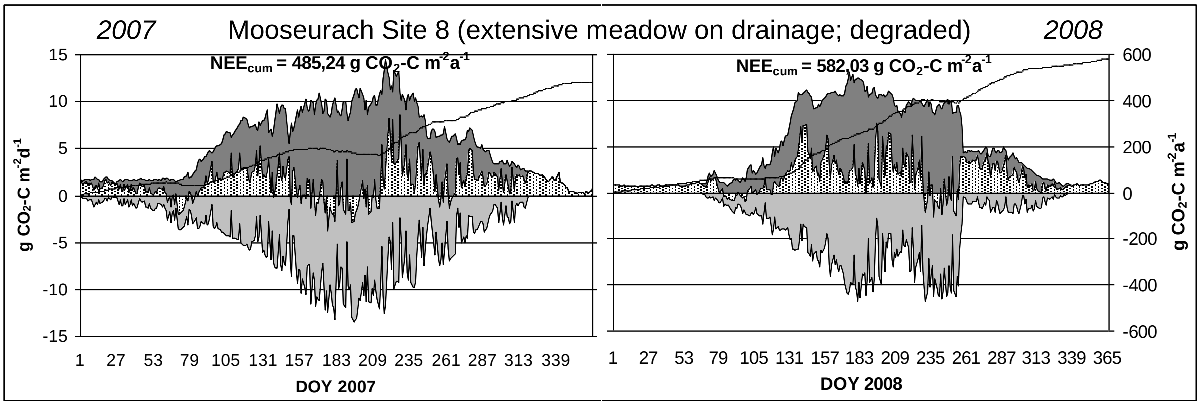
GP_{max} was significantly correlated to water tables in 2007 (-0.2253*) and 2008 (-0.3022**); a correlation of α and water tables was remarkable only in 2008 (-0.4013***).

Annual courses of R_{eco}, GPP and NEE

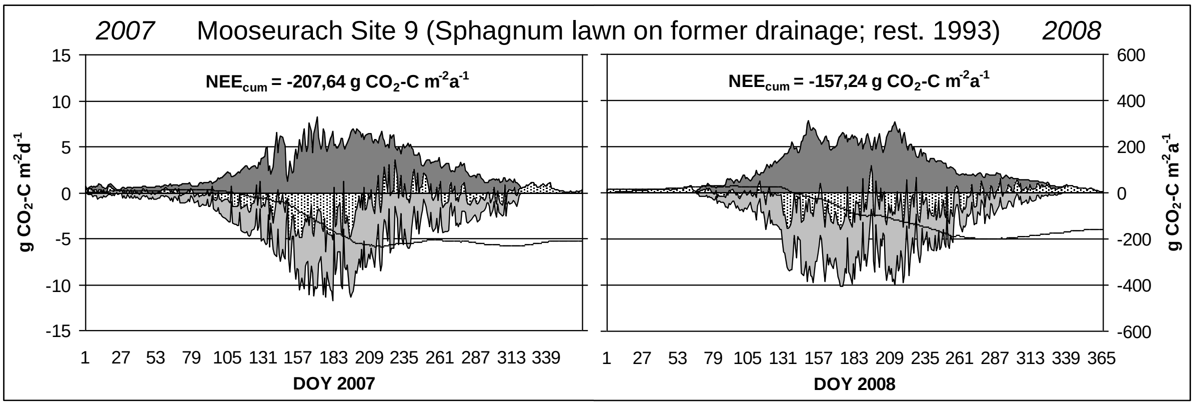
The measurements at the Setzberger Feld started on the 20th of February 2007. For the preceding period, starting on the 1st of January, parameters were extrapolated forwards from the first campaign. This was necessary due to missing data for this period and was possible due to a warm, snowless winter 2006 / 2007.

Temperatures of air and soil (at 2 cm, 5 cm and 10 cm) were basis for the R_{eco} models. These data were logged in half-hourly steps by a weather station, which was close to all the sites. This station also collected PAR for the GPP and thus NEE models. Data of 13 campaigns were used for modelling. Mowing took place at sites 7, 8, 10 and 12 on 10th of October 2007 and 15th of September 2008.

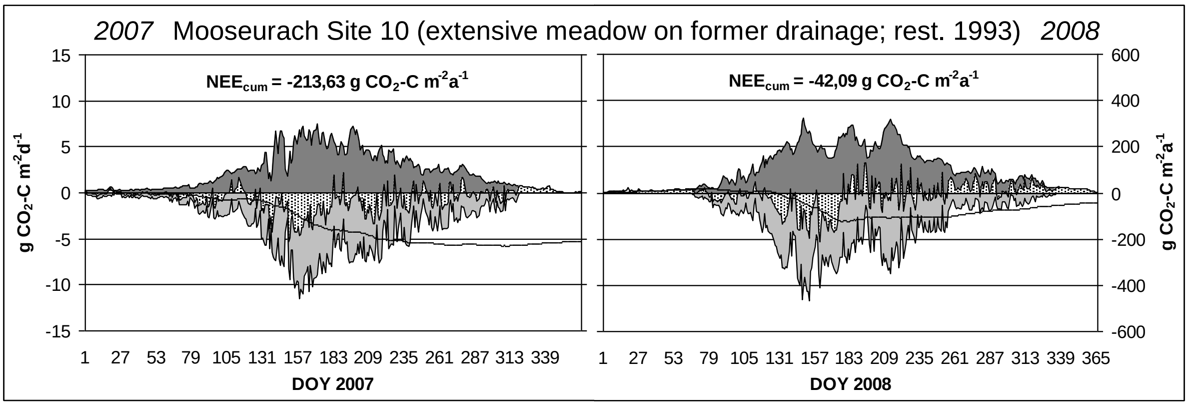




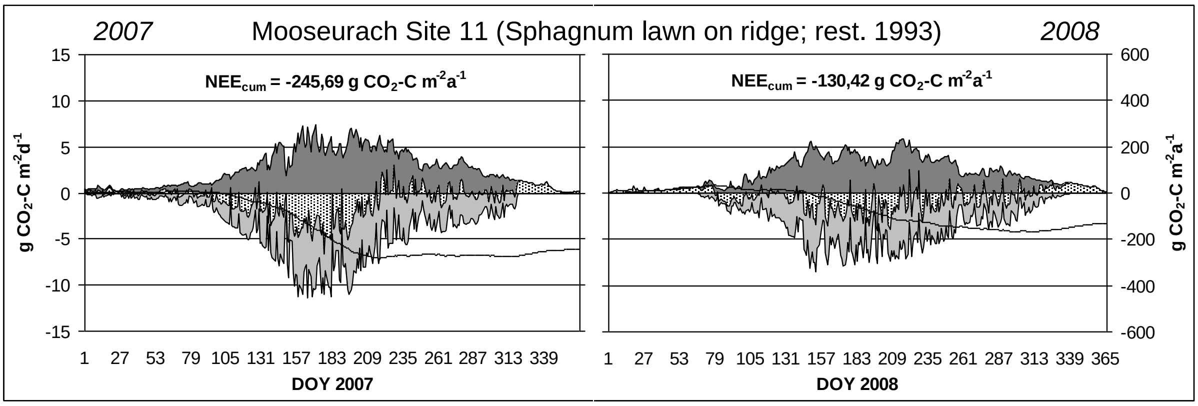
2007 Mooseurach Site 8 (extensive meadow on drainage; degraded) *2008*



2007 Mooseurach Site 9 (Sphagnum lawn on former drainage; rest. 1993) *2008*



2007 Mooseurach Site 10 (extensive meadow on former drainage; rest. 1993) *2008*



2007 Mooseurach Site 11 (Sphagnum lawn on ridge; rest. 1993) *2008*

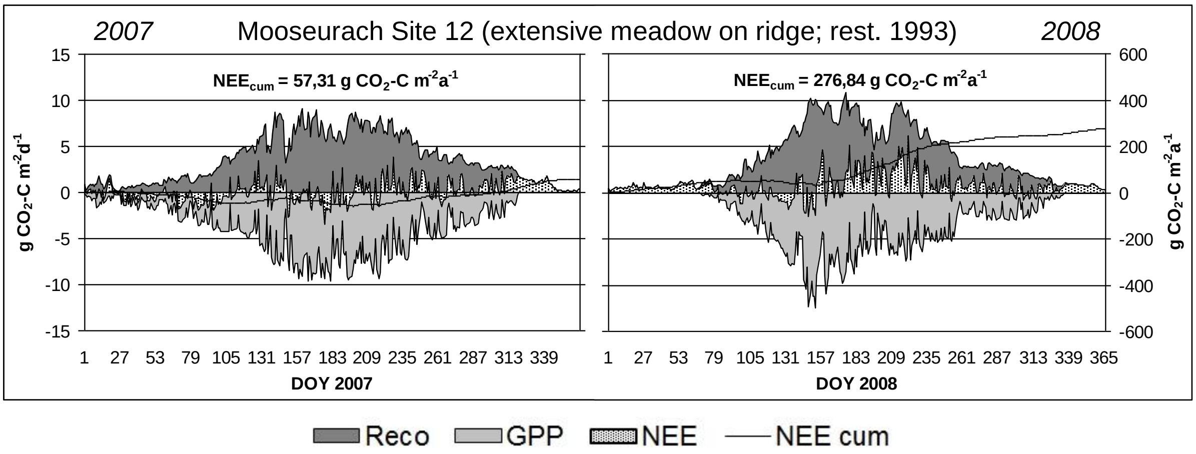


Fig. 19: Annual courses of R_{eco}, GPP, NEE and cumulative NEE of the sites M7 to M12 of the years 2007 and 2008
courses show daily balances which based on half-hourly modelled steps

The annual courses in 2007 of the degraded, managed sites M7 (on a ridge) and M8 (on a drainage) were quite similar, whereas daily fluxes of site M8 were higher than those of site M7. Totally, site M8 had the highest emissions of CO_2 (472 g CO_2-C m^{-2} a^{-1}), while they were reduced for site M7 (223 g CO_2-C m^{-2} a^{-1}). With a cumulative NEE of 47 g CO_2-C m^{-2} a^{-1}, the restored, managed site M12 (on a ridge) had an intermediate balance, whereas its R_{eco} and GPP courses were more comparable to sites M7 and M8 than to the surrounding ones.

The restored, non-managed sites M9 (on a drainage) and M11 (on a ridge) and the restored, managed site M10 (on a drainage) had NEE balances below -200 g CO_2-C m^{-2} a^{-1}. The NEE for sites M9 (-212 g CO_2-C m^{-2} a^{-1}) and M10 (-216 g CO_2-C m^{-2} a^{-1}) were almost the same, while site M11 showed the highest total uptake (-250 g CO_2-C m^{-2} a^{-1}).

Effects of mowing were visible in 2008 for sites M7 and M8 by reduced R_{eco} and GPP daily balances and, with less intensity, for sites M10 and M12. In 2007, the date of mowing was later during snowfall and with no effect on daily balances.

Corresponding to the balances of the bog heath, the differences in standard errors of every site and CO_2 flux components are a consequence of the use of the exponential function of LLOYD AND TAYLOR (1994) for R_{eco} and the rectangular-hyperbolic function of MICHALIS & MENTEN (1913) for GPP.

Tab. 17: Annual balances 2007 of R_{eco}, GPP and NEE of the sites of the Setzberger Feld
summer balances are added; export was taken from sites M7, M8, M10 and M12
different letters show significant differences according to ANOVA (Tukey-Test; $p<0,05$)

Site	Reco ± SE				GPP ± SE				NEE ± SE					r²
	g CO_2-C m^{-2} a^{-1}			summer	g CO_2-C m^{-2} a^{-1}			summer	g CO_2-C m^{-2} a^{-1}			incl. Export	summer	md vs ms
M7	1305	+ 352 - 264	f	1057	-1075	+ 180 - 163	bc	-837	230	+ 189 - 84	e	287	220	0.8973
M8	1981	+ 310 - 272	g	1514	-1496	+ 263 - 251	a	-1236	485	+ 60 - 9	f	537	279	0.9177
M9	942	+ 383 - 275	cde	780	-1150	+ 318 - 291	b	-994	-208	+ 92 - 43	ab	-208	-214	0.9413
M10	825	+ 392 - 265	bcd	693	-1039	+ 250 - 234	bcd	-896	-214	+ 157 - 15	ab	-120	-203	0.9356
M11	918	+ 257 - 205	cde	757	-1163	+ 249 - 229	b	-1002	-246	+ 44 - 29	a	-246	-246	0.9439
M12	1316	+ 263 - 221	f	1044	-1259	+ 250 - 241	b	-999	57	+ 28 - 22	d	88	45	0.9576

Tab. 18: Annual balances 2008 of Reco, GPP and NEE of the sites of the Setzberger Feld
summer balances are added; export was taken from sites M7, M8, M10 and M12
different letters show significant differences according to ANOVA (Tukey-Test; $p<0,05$)

Site	Reco ± SE				GPP ± SE				NEE ± SE					r²
	g CO_2-C m^{-2} a^{-1}			summer	g CO_2-C m^{-2} a^{-1}			summer	g CO_2-C m^{-2} a^{-1}			incl. Export	summer	md vs ms
M7	1122	+ 166 - 146	cde	956	-798	+ 164 - 154	d	-701	324	+ 18 - 13	f	437	255	0.9110
M8	1788	+ 346 - 290	f	1547	-1206	+ 324 - 301	a	-1078	582	+ 45 - 34	g	649	468	0.9028
M9	923	+ 217 - 182	bc	774	-1081	+ 364 - 339	ab	-990	-157	+ 182 - 123	ab	-157	-216	0.8896
M10	923	+ 463 - 311	bc	776	-965	+ 259 - 246	bcd	-855	-42	+ 217 - 52	c	22	-79	0.9094
M11	789	+ 301 - 216	b	638	-919	+ 297 - 284	bcd	-815	-130	+ 81 - 17	bc	-130	-177	0.8713
M12	1334	+ 606 - 408	e	1113	-1057	+ 274 - 268	abc	-917	277	+ 338 - 134	ef	353	195	0.8924

R_{eco} and GPP balances declined at almost all sites of the Setzberger Feld in 2008. Only for site M10, a higher respiration was detectable. While the NEE balances of the restored, non-managed sites M9 and M11 were relatively stable – the uptake was reduced by roughly less than 100 g CO_2-C m^{-2} a^{-1} – as well as for the degraded sites M7 and M8 with increased uptakes of 50 g CO_2-C m^{-2} a^{-1}, the managed and restored sites M10 and M12 showed differences in their NEE balances of more than 150 g CO_2-C m^{-2} a^{-1}.

The proportion of summer fluxes to annual balances differed in 2007 and 2008 for R_{eco} and GPP. In 2007, summer R_{eco} fluxes ranged from 77% to 84% of the total fluxes, while the proportion ranged from 85% to 91% in 2008. GPP had a summer proportion of 78% to 87% in 2007 and from 87% to 92% in 2008.

Spring R_{eco} and GPP fluxes were two to four times higher in 2007 than in 2008. In 2007, spring NEE balances showed an uptake for all sites except of M8, whereas this uptake was detectable in 2008 only for sites M10 and M11. At all other sites, spring NEE balances were equilibrated. In autumn, all sites released CO_2. The amount of spring and autumn CO_2 was comparable in 2007, whereas site M8 emitted 200 g CO_2-C m^{-2} a^{-1} in this time period. In 2008, autumn NEE balances were two times higher for the sites M9, M10 and M11, equal for sites M7 and M12 and about half for site M8.

3.4.2 Discussion

Parameters for modelling

Parameters R_{ref}, α and GP_{max} showed annual courses in 2007 and 2008 for all sites, as was also found in other studies with continuous GHG measurements (DRÖSLER 2005, BEETZ ET AL. 2013 and BEYER ET AL. (2014). E_0 did not (s. Tab. 25 to Tab. 28). Even after cutting at sites M7, M8, M10 and M12, there was no reaction detectable to parameters and thus, to the calculated R_{eco} or GPP. This was highly depending on the very late cutting in October 2007 and September 2008. In contrast to our results, BEETZ ET AL. (2013) found no effect of cutting events to R_{eco}, but to GPP for extensive peatland meadows, which can be explained by earlier cutting and regrowth of vegetation afterwards.

Elevated R_{ref} of site M8 was influenced by its plants composition with *Anthoxanthum odoratum* L. s. str. (frequency: 30% to 60%) and *Climacium dendroides* (Hedw.) F. Weber. & Mohr (frequency: 10 to 40%) and the position of M8 on the top of a still working drainage. A big amount of brown biomass from the year before led to a faster heating of the surface and the enhanced soil pore space due to draining enforced the heterotrophic soil respiration even in spring and early summer and led to R_{ref} which were twice as much as at the other sites. Jumps for R_{ref} were mainly caused by negative E_0, especially for sites M7 and M8 in summer 2008. High respiration rates were the consequence of low activation energies. As driving factor could be identified some relatively cold days (T_{air} max. 20°C) with low oscillating soil temperatures (dT ~ 5 K) before the measurement days, which were hot days (T_{air} max. 30°C) with enforced soil temperature oscillation (dT ~ 10 K) and thus soil respiration. A verification could be done by use of an automatic chamber system, which is able to measure fluxes with a higher resolution and under all weather conditions. The application of Eddy covariance technique, which was used for GHG balancing of a spruce forest in the north of Mooseurach and a bog-pine forest (HOMMELTENBERG 2014), was not applied here due to the relatively small size of this meadow. Sites M7 and M12 having shown a comparable plants composition, also had elevated R_{ref} in comparison to the sites M9 and M11, which had been out of management, and the very similar site M10 with management. Bigger pore space led to higher respiration rates of the unrestored sites and site M12. The differentiation to site M11 with identical water tables was via an expanding, uncongested *Sphagnum* community which released less CO_2, than the *Anthoxanthum-Climacium* complex of site M12. The use mainly of air temperature as best fitting driving temperature in 2007 for all the sites supported the thesis, that differences in respiration were mainly caused by plants and not by soil. Missing differences in E_0 in 2007 were also caused by the use of air temperatures, which did not differ between the sites. In 2008, a separation of site M10 was caused by a more frequent use of soil temperatures, especially at 5 cm, which led to significantly higher E_0 than for the other sites, where air temperatures were used.

For the models of GPP, the initial slopes α did not differ significantly in both years. Therefore, even the *Sphagnum* dominated sites M9 and M11 did not show an earlier photosynthetic activity during a day in comparison to the other, also moss-populated sites. For GP_{max} some contrast between the sites could be regarded. The separation of degraded site M8 to the others is clearer in 2007, where also the GPP balance is more separated from the other sites especially to the neighboured degraded M7, whose plant community was less adapted to the more moist conditions.

Annual flux courses

The similar patterns of balances, like those of the modelling parameters, were a proof of the measurement method. Although the conditions changed much from 2007 to 2008 with a warm winter and spring 2007 and altering water tables in 2008, CO_2 balance only differed in their total height but not in between the sites. The drier sites, especially the degraded sites M7 and M8 with water tables of -22.9 ± 0.81 cm and -36.4 ± 1.04 cm in 2007 and -17.7 ± 0.81 cm and -35.8 ± 0.91 cm in 2008 showed the highest R_{eco} balances. But this was not exclusively caused by water tables but also by the plants, whose composition could be found as well at the restored site M12. The neighboured non managed site M11, which had identical water tables in both years (M11: -15.8 ± 0.63 cm; M12: -15.8 ± 0.85 cm in 2007 and M11: -15.5 ± 0.63 cm; M12: -15.4 ± 0.84 cm in 2008) had significantly lower R_{eco} balances, similar to those of the moist sites M9 (2007: -14.2 ± 0.61 cm; 2008: -12.8 ± 0.64 cm) and M10 (2007: -6.9 ± 0.85 cm; 2008: -6.4 ± 0.80 cm). Here the oxidative space in the soil was reduced by water tables close to the surface. In 2008, R_{eco} balances were reduced mainly at the degraded sites M7, M8 and the restored site M12 due to a spring respiration in 2008 (up to 9%) of around the half of spring 2007 (up to 19%). The percentage of the *Sphagnum* populated sites M9, M10 and M11 was already lower in 2007 (up to 13%), thus a reduction in spring 2008 (up to 9%) did not have such a high influence to total balances. Thus, in 2008 total R_{eco} balances were mainly created by summer balances, while in a snowless winter, like in the Bavarian pre-alps in 2007, a poor cut grassland with *Anthoxanthum odoratum* L. s. str. and mosses in the ground layer was even productive, concerning respiration and photosynthesis, before the regular vegetation period started. This could also be seen for the GPP balances. Nevertheless, winter balances were relevant for these sites whose NEE balances were around zero (AURELA ET AL. 2002).

In spring 2007, the percentage of GPP was up to 21% of annual GPP for the sites M7, M8 and M12, at the *Sphagnum* populated sites up to 12%. In 2008, the spring GPP balances were between 7% and 10% without clear differences between the sites. The highest balance of site M8 in both years could be explained by the adaptation of the plants to the dry conditions, which was reduced for moister site M7. The similar productivity of restored sites M9 to M12 was influenced by the long term adaptation of the plants to water tables closer to the surface.

The location of sites M9 and M10 on the top of former drainages led to a better water supply during dry periods, although the oscillations did not differ from the neighboured sites M11 and M12 on a ridge. But the combination of water tables and oscillations led sometimes to better buffered situations and therefore similar annual balances (< 80 g CO_2-C m^{-2} a^{-1}) in 2007 and 2008. On the ridge, the balances of the sites differed much more (> 200 g CO_2-C m^{-2} a^{-1}) which could be explained by their water tables in summer 2008 of around -19 cm. The water supply during the vegetation period was worse than for sites on the former drainages. Generally the more oscillating water table in summer 2008 resulted in a lower productivity in 2008, while the respiration was relatively stable for both years at the restored sites. This reduced productivity of *Sphagnum* dominated sites is described by several studies (e.g. SILVOLA 1991 or MCNEIL & WADDINGTON 2003).

The reduction of R_{eco} and GPP led only to a small increase of NEE at the degraded sites M7 and M8, whose position on a still working drainage was responsible for the highest emissions of all the sites. Compared to these, restoration decreased the emissions depending on the position, on a former drainage or on a ridge. The reduction for the sites on the ridges (M7, M11 and M12) was relatively low after rewetting due to slow settlement of *Sphagnum* mosses even after 15 years of restoration time. Thus, the restored, cut site M12 was still a source for CO_2. Plant communities shifted after stop of management (M11). In consequence, fluxes, mainly R_{eco}, were reduced, which improved the NEE balance enormously and turned site M11 into a sink for CO_2, although water tables were identical. Only their oscillations were reduced. A comparable reaction could be seen for the sites on the drainages (M8, M9 and M10), but mitigation effects were sorted differently. Rewetting of the sites (M10) supported the development of vegetation, tolerating even wet conditions, like *Sphagnum* mosses and *Juncus effusus* L.. Thus, rewetting turned the dry sites into neutral areas or even small sinks for CO_2. HENDRICKS ET AL. (2007) described an abandoned peat meadow as a sink for CO_2.

But rewetting cannot guarantee that a peat meadow remains a carbon sink (MALJANEN ET AL. 2010). Only multi-year investigations can equilibrate interannual uncertainties and thus clarify, if a rewetted peat meadow is a source or a sink (ROULET ET AL. 2007).

In our case, the full mitigation effect could be seen after ending the management at sites M9 and M11, whereby the annual disturbance of developing *Sphagnum* layer was stopped. The uncongested structure of mainly *Sphagnum fallax* H. Klinggr. created a bigger photosynthetical active surface in comparison to the neighboured managed sites M10 and M12. The combination with reduced R_{eco} balances led to highest uptake rates of CO_2 of all the sites.

For both years 2007 and 2008, the comparison of the related sites showed similar habitudes, although the absolute balances differed due to different vegetation periods and weather events.

3.4.3 Conclusion

The CO_2 flux measurements at the Setzberger Feld showed as result that the amount of CO_2 mitigation depended on the topographical location of the sites on a drainage or on a ridge. The balances of the sites on the ridges (+280 to -250 g CO_2-C m^{-2} a^{-1}) did not differ as much as the sites on the drainages (+570 to -220 g CO_2-C m^{-2} a^{-1}). The closure of the drainages also led to moister conditions on the ridges, but the highest reduces of NEE were detected for the sites on the drainages (ridge: -80 to -200 g CO_2-C m^{-2} a^{-1}; drainage: -560 to -640 g CO_2-C m^{-2} a^{-1}; phytomass export included). After ending the management all the sites became sinks for CO_2. The mitigation potential was lower at the drainages (-90 to -180 g CO_2-C m^{-2} a^{-1}) than at the ridges (-330 to -470 g CO_2-C m^{-2} a^{-1}). Thus, for sites on drainages with high water table differences before and after restoration, rewetting showed the biggest success by turning a high CO_2 source into a neutral area up to a moderate sink, while the sites on the ridges remained sources for CO_2. Their biggest success was detected after ending management and the development of vegetation, which could be considered typical for bogs. In both cases, only the combination of rewetting and ending management led to a climate-friendly balance of the sites.

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Annex CO_2

Tab. 19: Mean fluxes of R_{eco} and NEE measurements 2007 and 2008 of plots at the bog heath

Standard deviations of mean fluxes are added; different numbers of measurements (*n*) are caused by different measurement intensities at the single plots

Site	Plot	Reco 2007 [µmol m^{-2}s^{-1}]		NEE 2007 [µmol m^{-2}s^{-1}]		Reco 2008 [µmol m^{-2}s^{-1}]		NEE 2008 [µmol m^{-2}s^{-1}]	
		n	Mean StDev	*n*	Mean StDev	*n*	Mean StDev	*n*	Mean StDev
M1	1	*38*	3.29 ± 2.57	*33*	-0.96 ± 3.18	*50*	3.09 ± 2.61	*29*	-0.32 ± 3.66
	2	*72*	3.91 ± 2.35	*117*	-1.85 ± 2.97	*111*	4.47 ± 3.65	*106*	-2.56 ± 4.69
	3	*36*	3.34 ± 2.80	*22*	-1.40 ± 2.56	*51*	4.43 ± 3.81	*27*	-3.88 ± 3.77
M2	4	*37*	3.54 ± 2.92	*26*	-3.10 ± 3.85	*53*	2.96 ± 2.64	*30*	0.23 ± 2.96
	5	*72*	4.77 ± 3.11	*126*	-1.63 ± 3.00	*111*	4.34 ± 3.15	*113*	0.13 ± 3.40
	6	*38*	3.04 ± 2.82	*25*	-3.02 ± 3.50	*49*	3.43 ± 2.81	*24*	-3.32 ± 4.38
M3	7	*37*	0.34 ± 0.60	*23*	-0.50 ± 0.60	*50*	0.74 ± 0.79	*27*	-1.56 ± 1.37
	8	*69*	0.95 ± 0.87	*112*	-1.91 ± 1.47	*112*	1.22 ± 1.14	*112*	-2.69 ± 2.00
	9	*39*	0.20 ± 0.52	*23*	-1.09 ± 0.82	*47*	1.04 ± 1.11	*27*	-3.41 ± 2.33
M4	10	*79*	3.06 ± 1.77	*122*	-4.36 ± 3.54	*104*	3.27 ± 2.27	*136*	-3.86 ± 3.79
	11	*39*	2.09 ± 1.74	*36*	-3.31 ± 3.03	*50*	2.58 ± 2.47	*39*	-3.18 ± 3.77
	12	*38*	2.48 ± 2.26	*33*	-4.17 ± 3.90	*54*	3.02 ± 2.62	*34*	-3.89 ± 3.81
M5	13	*39*	3.17 ± 2.83	*31*	-2.73 ± 2.96	*54*	4.00 ± 3.50	*37*	-3.05 ± 3.91
	14	*38*	2.73 ± 2.16	*36*	-2.20 ± 2.21	*51*	2.99 ± 2.71	*37*	-2.54 ± 2.80
	15	*80*	3.39 ± 2.26	*124*	-2.93 ± 2.74	*104*	4.35 ± 3.26	*134*	-3.06 ± 3.40
M6	16	*40*	3.46 ± 2.96	*33*	-2.50 ± 3.20	*54*	4.18 ± 3.74	*39*	-2.34 ± 4.06
	17	*39*	3.43 ± 2.56	*36*	-2.19 ± 3.02	*49*	4.04 ± 3.80	*36*	-2.71 ± 3.73
	18	*78*	4.92 ± 3.02	*126*	-3.91 ± 4.30	*104*	5.68 ± 3.99	*133*	-3.84 ± 4.77

Tab. 20: Mean fluxes of R_{eco} and NEE measurements of 2007 and 2008 of the plots at the Setzberger Feld

Standard deviations of mean fluxes are added; different numbers of measurements (*n*) are caused by different measurement intensities at the single plots;
after having been destroyed, plot 20 was replaced in May 2008 by plot 20b

Site	Plot	Reco 2007 [µmol m^{-2}s^{-1}]		NEE 2007 [µmol m^{-2}s^{-1}]		Reco 2008 [µmol m^{-2}s^{-1}]		NEE 2008 [µmol m^{-2}s^{-1}]	
		n	Mean StDev	*n*	Mean StDev	*n*	Mean StDev	*n*	Mean StDev
M7	19	*50*	4.65 ± 3.30	*51*	-1.21 ± 2.51	*68*	3.24 ± 2.61	*66*	-0.59 ± 3.41
	20	*105*	4.92 ± 2.81	*170*	-2.59 ± 2.49	*20*	1.06 ± 1.15	*10*	-0.02 ± 1.17
	20b		installed in 2008		installed in 2008	*36*	5.41 ± 3.50	*43*	-2.06 ± 3.81
	21	*48*	4.13 ± 3.02	*41*	-2.12 ± 3.05	*108*	4.49 ± 3.06	*121*	-1.35 ± 3.74
M8	22	*49*	7.65 ± 5.45	*50*	-1.14 ± 5.10	*55*	7.06 ± 5.84	*51*	2.47 ± 5.83
	23	*101*	6.80 ± 3.94	*158*	-2.75 ± 4.39	*126*	6.47 ± 4.66	*151*	-0.68 ± 5.13
	24	*50*	7.05 ± 4.74	*43*	-3.04 ± 4.45	*50*	5.59 ± 4.62	*51*	0.62 ± 4.84
M9	25	*37*	3.58 ± 3.12	*16*	-4.93 ± 4.96	*45*	3.29 ± 3.45	*27*	-2.92 ± 5.98
	26	*65*	4.25 ± 3.12	*108*	-4.23 ± 3.96	*86*	3.63 ± 2.83	*94*	-2.17 ± 5.39
	27	*39*	2.38 ± 2.26	*20*	-4.01 ± 2.69	*45*	2.09 ± 2.05	*29*	-3.25 ± 2.12
M10	28	*36*	3.00 ± 3.02	*19*	-4.48 ± 4.80	*47*	2.78 ± 2.79	*34*	-3.97 ± 4.00
	29	*69*	3.93 ± 3.05	*107*	-6.03 ± 3.84	*84*	3.76 ± 2.98	*89*	-4.44 ± 4.30
	30	*53*	2.53 ± 2.68	*57*	-3.13 ± 3.08	*43*	2.15 ± 2.80	*24*	-0.06 ± 2.34
M11	31	*36*	3.35 ± 3.09	*18*	-5.49 ± 3.96	*48*	2.78 ± 2.38	*25*	-3.21 ± 5.96
	32	*66*	3.55 ± 2.80	*99*	-4.58 ± 4.08	*85*	2.76 ± 2.22	*89*	-1.01 ± 6.02
	33	*38*	3.86 ± 3.41	*21*	-4.16 ± 3.13	*46*	3.27 ± 2.71	*27*	-1.10 ± 5.06
M12	34	*37*	4.40 ± 3.55	*17*	-3.06 ± 2.30	*46*	3.84 ± 3.04	*32*	-1.86 ± 3.77
	35	*68*	5.32 ± 3.50	*99*	-4.00 ± 3.39	*83*	4.91 ± 3.59	*91*	-3.33 ± 4.28
	36	*39*	4.87 ± 4.04	*19*	-3.37 ± 2.47	*44*	4.56 ± 4.26	*24*	-2.24 ± 2.79

Tab. 21: R_{eco} modelling parameters 2007 of the bog heath

numbers of used measurements and references temperatures, coefficients of determination and significances of the used regressions are added

Site	Date	used Campaign	k/n	$Temp_{ref}$	R_{ref} ± SE [µmol m^{-2} s^{-1}]	E_0 ± SE [K]	r^2	Sig
M1	19.02.07	C1	8/9	soil 2cm	**0.564** ± 0.034	**70.7** ± 22.1	**0.668**	**
	16.03.07	C2	6/8	soil 2cm	**1.390** ± 0.069	**167.6** ± 32.3	**0.881**	***
	11.04.07	C3	8/8	soil 2cm	**1.789** ± 0.090	**132.1** ± 34.4	**0.743**	***
	24.04.07	C3-C5	29/31	soil 5cm	**2.207** ± 0.152	**282.3** ± 36.7	**0.693**	***
	19.05.07	C5	12/14	soil 5cm	**2.178** ± 0.411	**292.6** ± 84.1	**0.656**	***
	09.06.07	C6	11/11	air 20cm	**4.699** ± 0.545	**83.5** ± 26.8	**0.559**	***
	08.07.07	C7	16/16	air 20cm	**4.478** ± 0.348	**68.3** ± 17.9	**0.543**	***
	20.07.07	C7-C9	40/40	air 20cm	**4.767** ± 0.290	**71.1** ± 13.9	**0.446**	***
	05.08.07	C9	13/15	air 20cm	**4.760** ± 0.296	**68.0** ± 15.6	**0.668**	***
	13.09.07	C10	13/14	air 20cm	**3.595** ± 0.272	**106.0** ± 23.2	**0.746**	***
	10.10.07	C10+C11	25/26	soil 2cm	**2.713** ± 0.216	**241.4** ± 40.0	**0.641**	***
	20.11.07	C11+C12	17/21	soil 2cm	**2.226** ± 0.185	**210.2** ± 58.6	**0.569**	***
	14.12.07	C13+C14	18/18	air 20cm	**0.541** ± 0.066	**145.3** ± 58.1	**0.304**	**
M2	19.02.07	C1+C2	18/20	soil 2cm	**1.687** ± 0.091	**271.2** ± 35.8	**0.809**	***
	16.03.07	C2	11/11	air 20cm	**1.483** ± 0.098	**101.8** ± 27.7	**0.672**	***
	11.04.07	C3	8/8	soil 2cm	**2.285** ± 0.357	**195.3** ± 92.1	**0.557**	*
	24.04.07	C3+C5	20/20	air 20cm	**1.671** ± 0.396	**222.9** ± 61.1	**0.588**	***
	19.05.07	C5	12/12	air 20cm	**2.171** ± 0.535	**167.2** ± 59.9	**0.623**	***
	09.06.07	C6	9/11	air 20cm	**5.255** ± 0.877	**133.2** ± 37.2	**0.735**	***
	08.07.07	C7	14/16	air 20cm	**4.411** ± 0.504	**123.3** ± 28.1	**0.692**	***
	20.07.07	C8	12/12	air 20cm	**3.043** ± 0.712	**193.7** ± 44.9	**0.732**	***
	05.08.07	C9	14/14	air 20cm	**4.597** ± 0.599	**119.5** ± 31.6	**0.657**	***
	13.09.07	C10	14/14	soil 2cm	**3.069** ± 0.304	**248.4** ± 51.3	**0.727**	***
	10.10.07	C10+C11	26/26	soil 2cm	**2.900** ± 0.207	**249.6** ± 42.6	**0.590**	***
	20.11.07	C11+C12	18/21	soil 5cm	**2.569** ± 0.220	**296.4** ± 92.4	**0.498**	***
	14.12.07	C13+C14	18/18	air 20cm	**0.639** ± 0.057	**311.8** ± 70.5	**0.684**	***
M3	19.02.07	C1-C14	155/155	soil 2cm	**0.395** ± 0.064	**397.8** ± 55.8	**0.412**	***
	16.03.07	C1-C14	155/155	soil 2cm	**0.395** ± 0.064	**397.8** ± 55.8	**0.412**	***
	11.04.07	C1-C14	155/155	soil 2cm	**0.395** ± 0.064	**397.8** ± 55.8	**0.412**	***
	24.04.07	C4	8/9	air 20cm	**0.820** ± 0.050	**175.3** ± 26.7	**0.928**	***
	19.05.07	C1-C14	155/155	soil 2cm	**0.395** ± 0.064	**397.8** ± 55.8	**0.412**	***
	09.06.07	C1-C14	155/155	soil 2cm	**0.395** ± 0.064	**397.8** ± 55.8	**0.412**	***
	08.07.07	C7	13/16	soil 2cm	**0.572** ± 0.150	**353.5** ± 79.8	**0.630**	***
	20.07.07	C1-C14	155/155	soil 2cm	**0.395** ± 0.064	**397.8** ± 55.8	**0.412**	***
	05.08.07	C1-C14	155/155	soil 2cm	**0.395** ± 0.064	**397.8** ± 55.8	**0.412**	***
	13.09.07	C1-C14	45/49	soil 2cm	**0.276** ± 0.057	**580.1** ± 196.6	**0.486**	***
	10.10.07	C1-C14	45/49	soil 5cm	**0.318** ± 0.047	**552.3** ± 130.3	**0.496**	***
	20.11.07	C1-C14	45/49	soil 5cm	**0.318** ± 0.047	**552.3** ± 130.3	**0.496**	***
	14.12.07	C1-C14	45/49	soil 5cm	**0.318** ± 0.047	**552.3** ± 130.3	**0.496**	***

Site	Date	used Campaign	k/n	$Temp_{ref}$	R_{ref} ± SE [µmol m^{-2} s^{-1}]	E_0 ± SE [K]	r^2	Sig
M4	19.02.07	C1+C2	15/15	soil 2cm	**1.064** ± 0.070	**323.9** ± 51.0	**0.804**	***
	16.03.07	C2	9/9	air 20cm	**0.574** ± 0.093	**275.2** ± 61.0	**0.876**	***
	11.04.07	C3	9/9	soil 2cm	**0.991** ± 0.105	**195.2** ± 51.5	**0.776**	***
	24.04.07	C3+C5	21/22	soil 2cm	**1.117** ± 0.190	**323.0** ± 72.4	**0.648**	***
	19.05.07	C5	12/13	soil 2cm	**1.350** ± 0.191	**306.8** ± 57.4	**0.816**	***
	09.06.07	C6	14/14	air 20cm	**2.068** ± 0.484	**152.5** ± 50.6	**0.506**	***
	08.07.07	C7	15/15	soil 2cm	**1.811** ± 0.373	**388.1** ± 85.8	**0.687**	***
	20.07.07	C7+C8	31/31	soil 2cm	**2.960** ± 0.394	**172.5** ± 38.8	**0.440**	***
	05.08.07	C9	18/18	soil 5cm	**2.346** ± 0.256	**214.0** ± 37.9	**0.680**	***
	13.09.07	C10	15/15	air 20cm	**1.736** ± 0.148	**160.5** ± 25.0	**0.871**	***
	10.10.07	C10+C11	19/21	soil 2cm	**1.679** ± 0.137	**275.3** ± 74.6	**0.542**	***
	20.11.07	C11+C12	19/21	soil 2cm	**1.679** ± 0.137	**275.3** ± 74.6	**0.542**	***
	14.12.07	C13+C14	18/18	air 20cm	**0.625** ± 0.057	**390.3** ± 68.0	**0.778**	***
M5	19.02.07	C1+C2	15/18	soil 5cm	**2.052** ± 0.241	**484.3** ± 73.2	**0.753**	***
	16.03.07	C2	9/9	soil 2cm	**1.226** ± 0.112	**245.5** ± 111.2	**0.512**	**
	11.04.07	C3	8/8	air 20cm	**1.513** ± 0.252	**139.3** ± 51.2	**0.735**	***
	24.04.07	C3+C5	23/23	air 20cm	**0.809** ± 0.295	**364.8** ± 92.9	**0.673**	***
	19.05.07	C5	15/15	soil 2cm	**1.407** ± 0.386	**390.5** ± 112.0	**0.668**	***
	09.06.07	C6	14/14	air 20cm	**2.879** ± 0.432	**153.6** ± 35.2	**0.698**	***
	08.07.07	C7	13/15	air 20cm	**3.517** ± 0.480	**125.7** ± 35.5	**0.592**	***
	20.07.07	C8	15/16	air 20cm	**3.103** ± 0.736	**180.1** ± 50.0	**0.633**	***
	05.08.07	C9	18/18	air 20cm	**3.353** ± 0.437	**144.9** ± 34.0	**0.637**	***
	13.09.07	C10	14/15	air 20cm	**1.501** ± 0.184	**192.1** ± 34.2	**0.853**	***
	10.10.07	C11+C12	19/21	soil 5cm	**1.391** ± 0.114	**399.1** ± 98.3	**0.655**	***
	20.11.07	C11+C12	19/21	soil 5cm	**1.391** ± 0.114	**399.1** ± 98.3	**0.655**	***
	14.12.07	C13+C14	18/18	soil 2cm	**1.084** ± 0.456	**355.8** ± 115.0	**0.587**	***
M6	19.02.07	C1+C2	15/19	soil 5cm	**4.263** ± 0.444	**510.4** ± 52.9	**0.880**	***
	16.03.07	C2	11/11	air 20cm	**0.902** ± 0.269	**323.6** ± 133.1	**0.639**	***
	11.04.07	C3	8/9	air 20cm	**1.212** ± 0.141	**241.8** ± 37.8	**0.918**	***
	24.04.07	C3+C5	21/23	air 20cm	**1.299** ± 0.268	**278.3** ± 51.3	**0.746**	***
	19.05.07	C5	13/14	air 20cm	**1.881** ± 0.302	**213.3** ± 37.6	**0.901**	***
	09.06.07	C6	13/14	air 20cm	**4.935** ± 0.507	**65.9** ± 25.5	**0.424**	**
	08.07.07	C7	21/21	air 20cm	**4.397** ± 0.549	**137.2** ± 32.4	**0.631**	***
	20.07.07	C7-C9	47/47	soil 5cm	**4.893** ± 0.480	**184.9** ± 37.9	**0.344**	***
	05.08.07	C9+C10	32/32	soil 2cm	**3.818** ± 0.294	**161.7** ± 31.1	**0.472**	***
	13.09.07	C10	13/14	air 20cm	**2.485** ± 0.322	**137.4** ± 39.3	**0.697**	***
	10.10.07	C11+C12	16/21	soil 5cm	**2.573** ± 0.162	**418.4** ± 93.0	**0.738**	***
	20.11.07	C11+C12	16/21	soil 5cm	**2.573** ± 0.162	**418.4** ± 93.0	**0.738**	***
	14.12.07	winter	134/134	soil 5cm	**2.666** ± 0.140	**440.2** ± 36.5	**0.568**	***

Tab. 22: R$_{eco}$ modelling parameters 2008 of the bog heath

numbers of used measurements and references temperatures, coefficients of determination and significances of the used regressions are added

Site	Date	used Campaign	k/n	Temp$_{ref}$	**R$_{ref}$** ± SE [µmol m^{-2} s^{-1}]	**E$_0$** ± SE [K]	**r^2**	Sig
M1	08.01.08	C13+C14	18/18	air 20cm	**0.541** ± 0.066	**145.3** ± 58.1	**0.304**	**
	05.02.08	winter	142/142	soil 5cm	**2.311** ± 0.109	**389.2** ± 32.3	**0.563**	***
	06.03.08	winter	142/142	soil 2cm	**1.919** ± 0.100	**312.7** ± 31.3	**0.378**	***
	29.03.08	C17	20/22	air 20cm	**1.301** ± 0.071	**116.6** ± 31.0	**0.470**	***
	17.04.08	C18	18/22	soil 2cm	**1.877** ± 0.138	**232.1** ± 64.0	**0.446**	***
	07.05.08	C18+C19	40/44	soil 2cm	**2.369** ± 0.156	**172.0** ± 32.9	**0.419**	***
	27.05.08	C20	9/9	air 20cm	**3.669** ± 0.628	**128.3** ± 36.1	**0.689**	***
	23.06.08	C20+C22	24/25	air 20cm	**4.410** ± 0.626	**132.4** ± 31.6	**0.477**	***
	10.07.08	C22	15/16	air 20cm	**4.311** ± 0.577	**155.6** ± 30.1	**0.741**	***
	31.07.08	C22+C23	27/30	air 20cm	**4.973** ± 0.809	**130.4** ± 35.2	**0.424**	***
	19.08.08	C24	9/11	air 20cm	**5.263** ± 0.903	**112.2** ± 37.8	**0.632**	**
	11.09.08	C25+C26	22/23	air 20cm	**3.997** ± 0.620	**158.8** ± 39.8	**0.506**	***
	11.10.08	C26	8/8	air 20cm	**3.576** ± 0.260	**124.3** ± 37.0	**0.618**	**
	10.11.08	C27	7/12	air 20cm	**1.758** ± 0.079	**70.0** ± 18.3	**0.769**	**
	03.12.08	C28	7/10	air 20cm	**0.610** ± 0.039	**-66.5** ± 15.8	**0.756**	***
M2	08.01.08	C13+C14	18/18	air 20cm	**0.639** ± 0.057	**311.8** ± 70.5	**0.684**	***
	05.02.08	winter	143/143	soil 5cm	**2.000** ± 0.096	**313.6** ± 28.9	**0.498**	***
	06.03.08	winter	143/143	soil 5cm	**2.000** ± 0.096	**313.6** ± 28.9	**0.498**	***
	29.03.08	C17	21/21	air 20cm	**1.283** ± 0.070	**122.2** ± 29.0	**0.517**	***
	17.04.08	C18+C19	44/44	air 20cm	**2.070** ± 0.226	**164.8** ± 39.0	**0.320**	***
	07.05.08	C18+C19	44/44	air 20cm	**2.070** ± 0.226	**164.8** ± 59.6	**0.320**	***
	27.05.08	C20	9/9	air 20cm	**3.476** ± 0.997	**163.2** ± 59.6	**0.574**	**
	23.06.08	C19-C21	47/54	soil 5cm	**3.514** ± 0.386	**174.6** ± 37.6	**0.376**	***
	10.07.08	C22	17/17	air 20cm	**4.321** ± 0.421	**92.9** ± 22.3	**0.594**	***
	31.07.08	C22+C23	28/31	air 20cm	**4.140** ± 0.611	**132.1** ± 31.1	**0.482**	***
	19.08.08	C24	10/11	air 20cm	**3.421** ± 0.602	**123.2** ± 36.5	**0.702**	***
	11.09.08	C25+C26	20/23	soil 5cm	**3.796** ± 0.430	**255.8** ± 59.4	**0.527**	***
	11.10.08	C26	8/8	soil 2cm	**3.035** ± 0.213	**255.3** ± 101.3	**0.533**	**
	10.11.08	C26+C27	19/20	soil 2cm	**2.803** ± 0.139	**325.7** ± 51.3	**0.703**	***
	03.12.08	C28	9/12	air 20cm	**0.519** ± 0.043	**-59.9** ± 15.5	**0.668**	***
M3	08.01.08	winter	142/142	soil 2cm	**0.327** ± 0.035	**342.6** ± 63.1	**0.172**	***
	05.02.08	winter	142/142	soil 2cm	**0.327** ± 0.035	**342.6** ± 63.1	**0.172**	***
	06.03.08	winter	142/142	air 20cm	**0.133** ± 0.027	**453.4** ± 87.8	**0.171**	***
	29.03.08	C17	18/21	air 20cm	**0.264** ± 0.044	**-351.6** ± 97.1	**0.536**	***
	17.04.08	C18	19/21	air 20cm	**0.238** ± 0.048	**-290.2** ± 87.2	**0.384**	***
	07.05.08	C19	20/21	air 20cm	**0.446** ± 0.176	**365.0** ± 125.0	**0.612**	**
	27.05.08	C20	9/9	air 20cm	**0.370** ± 0.067	**367.8** ± 35.7	**0.971**	***
	23.06.08	C20+C22	24/26	air 20cm	**0.722** ± 0.189	**266.9** ± 57.6	**0.571**	***
	10.07.08	C22	15/17	air 20cm	**0.679** ± 0.224	**275.4** ± 74.6	**0.640**	***
	31.07.08	C23	15/15	air 20cm	**1.565** ± 0.263	**118.8** ± 36.8	**0.488**	***
	19.08.08	C24	9/11	air 20cm	**0.694** ± 0.163	**174.3** ± 49.7	**0.762**	***
	11.09.08	C25	13/15	air 20cm	**1.932** ± 0.189	**70.9** ± 24.0	**0.491**	**
	11.10.08	C26	8/8	air 20cm	**0.490** ± 0.063	**223.5** ± 46.8	**0.775**	***
	10.11.08	C27+C28	19/23	air 20cm	**0.021** ± 0.022	**1032** ± 390.5	**0.756**	*
	03.12.08	C27+C28	19/23	air 20cm	**0.021** ± 0.022	**1032** ± 390.5	**0.756**	*

Site	Date	used Campaign	k/n	Temp$_{ref}$	**R$_{ref}$** ± SE [µmol m^{-2} s^{-1}]	**E$_0$** ± SE [K]	**r^2**	Sig
M4	08.01.08	C13+C14	18/18	air 20cm	**0.625** ± 0.057	**390.3** ± 68.0	**0.778**	***
	05.02.08	winter	136/136	soil 2cm	**1.527** ± 0.067	**453.7** ± 32.8	**0.622**	***
	06.03.08	winter	136/136	soil 2cm	**1.527** ± 0.067	**453.7** ± 32.8	**0.622**	***
	29.03.08	C17	15/17	air 20cm	**0.738** ± 0.049	**178.0** ± 33.3	**0.734**	***
	17.04.08	C18	18/18	air 20cm	**0.952** ± 0.058	**237.2** ± 33.2	**0.837**	***
	07.05.08	C19	17/18	air 20cm	**1.610** ± 0.180	**192.3** ± 33.1	**0.819**	***
	27.05.08	C20	15/15	soil 2cm	**2.497** ± 0.209	**238.1** ± 26.3	**0.903**	***
	23.06.08	C21	17/20	soil 2cm	**3.739** ± 0.386	**147.1** ± 29.4	**0.669**	***
	10.07.08	C22	16/16	air 20cm	**2.506** ± 0.329	**192.0** ± 28.2	**0.856**	***
	31.07.08	C22+C24	30/32	air 20cm	**2.746** ± 0.320	**157.0** ± 25.1	**0.698**	***
	19.08.08	C24	14/16	soil 2cm	**2.539** ± 0.435	**283.2** ± 66.7	**0.664**	***
	11.09.08	C25	13/14	air 20cm	**3.624** ± 0.243	**70.8** ± 17.5	**0.638**	***
	11.10.08	C26	7/7	air 20cm	**1.755** ± 0.024	**142.2** ± 4.9	**0.994**	***
	10.11.08	C27	11/12	air 20cm	**1.125** ± 0.069	**92.8** ± 25.2	**0.675**	***
	03.12.08	C27+C28	18/22	air 20cm	**1.141** ± 0.048	**90.2** ± 15.0	**0.771**	***
M5	08.01.08	C13+C14	18/18	soil 2cm	**1.084** ± 0.456	**355.8** ± 115.0	**0.587**	***
	05.02.08	winter	133/133	soil 5cm	**1.504** ± 0.076	**445.0** ± 35.9	**0.590**	***
	06.03.08	winter	133/133	soil 5cm	**1.504** ± 0.076	**445.0** ± 35.9	**0.590**	***
	29.03.08	C17	14/17	air 20cm	**0.771** ± 0.024	**247.4** ± 19.7	**0.949**	***
	17.04.08	C18	17/18	soil 2cm	**1.398** ± 0.070	**363.1** ± 49.8	**0.845**	***
	07.05.08	C19	18/19	air 20cm	**1.721** ± 0.319	**270.6** ± 57.8	**0.765**	***
	27.05.08	C20	15/15	soil 2cm	**2.526** ± 0.386	**253.1** ± 40.6	**0.827**	***
	23.06.08	C20+C21	35/35	soil 2cm	**3.483** ± 0.434	**190.0** ± 31.9	**0.605**	***
	10.07.08	C22	15/16	air 20cm	**3.255** ± 0.399	**194.7** ± 26.5	**0.875**	***
	31.07.08	C22+C23	32/34	air 20cm	**3.683** ± 0.591	**170.4** ± 34.0	**0.578**	***
	19.08.08	C24	15/16	air 20cm	**3.927** ± 0.535	**132.5** ± 29.3	**0.743**	***
	11.09.08	C25	13/14	air 20cm	**3.866** ± 0.408	**78.9** ± 24.0	**0.567**	***
	11.10.08	C25+C26	20/21	soil 2cm	**2.594** ± 0.307	**227.2** ± 39.8	**0.708**	***
	10.11.08	C26+C27	18/19	soil 5cm	**2.193** ± 0.115	**328.0** ± 55.3	**0.697**	***
	03.12.08	C28	8/10	air 20cm	**0.522** ± 0.058	**-75.4** ± 15.7	**0.799**	***
M6	08.01.08	winter	134/134	soil 5cm	**2.666** ± 0.140	**440.2** ± 36.5	**0.568**	***
	05.02.08	winter	134/134	soil 5cm	**2.666** ± 0.140	**440.2** ± 36.5	**0.568**	***
	06.03.08	winter	134/134	soil 5cm	**2.666** ± 0.140	**440.2** ± 36.5	**0.568**	***
	29.03.08	C17	16/16	air 20cm	**1.031** ± 0.080	**206.8** ± 37.6	**0.745**	***
	17.04.08	C18	16/17	air 20cm	**1.722** ± 0.060	**152.4** ± 20.9	**0.840**	***
	07.05.08	C19	15/17	air 20cm	**2.436** ± 0.287	**169.3** ± 37.7	**0.720**	***
	27.05.08	C20	15/15	air 20cm	**4.075** ± 0.690	**140.1** ± 35.3	**0.658**	***
	23.06.08	C19-C22	47/49	air 20cm	**3.333** ± 0.447	**183.3** ± 29.1	**0.569**	***
	10.07.08	C22	17/17	air 20cm	**5.829** ± 0.708	**105.1** ± 27.7	**0.558**	***
	31.07.08	C22+C24	32/33	air 20cm	**6.435** ± 0.363	**84.9** ± 13.4	**0.629**	***
	19.08.08	C24	15/16	soil 2cm	**5.834** ± 0.392	**175.5** ± 24.9	**0.808**	***
	11.09.08	C24-C26	21/21	soil 2cm	**4.550** ± 0.468	**202.1** ± 40.5	**0.464**	***
	11.10.08	C26+C27	18/19	soil 5cm	**3.574** ± 0.145	**242.3** ± 34.5	**0.763**	***
	10.11.08	C27	11/12	air 20cm	**2.177** ± 0.114	**70.6** ± 22.5	**0.554**	**
	03.12.08	C27+C28	18/19	soil 5cm	**6.225** ± 1.119	**581.7** ± 88.8	**0.741**	***

Tab. 23: GPP modelling parameters 2007 of the bog heath

numbers of used measurements, coefficients of determination and significances of the used regressions are added

Site	Date	used Campaign	k/n	α ± SE	**Gp_{max}** ± SE [µmol m^{-2} s^{-1}]	**r^2**	Sig
M1	19.02.07	C1	13/17	**-0.002** ± 0.001	**-4.17** ± 6.78	**0.898**	***
	16.03.07	C1+C3	22/29	**-0.002** ± 0.001	**-3.09** ± 1.60	**0.714**	***
	11.04.07	C3	9/12	**-0.002** ± 0.001	**-6.13** ± 10.66	**0.869**	***
	24.04.07	C4	12/12	**-0.012** ± 0.005	**-3.68** ± 0.56	**0.866**	***
	19.05.07	C5	21/21	**-0.004** ± 0.004	**-8.72** ± 12.07	**0.651**	***
	09.06.07	C6	21/21	**-0.039** ± 0.008	**-12.72** ± 0.85	**0.950**	***
	08.07.07	C7	23/25	**-0.039** ± 0.009	**-17.84** ± 1.33	**0.935**	***
	20.07.07	C8	20/22	**-0.015** ± 0.003	**-30.59** ± 7.18	**0.959**	***
	05.08.07	C9	15/19	**-0.014** ± 0.004	**-32.50** ± 12.95	**0.952**	***
	13.09.07	C10	12/13	**-0.014** ± 0.009	**-19.33** ± 14.62	**0.806**	***
	10.10.07	C11	12/13	**-0.012** ± 0.004	**-15.56** ± 6.63	**0.935**	***
	20.11.07	winter	14/14	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.
M2	19.02.07	C1+C2	38/39	**-0.006** ± 0.001	**-4.74** ± 1.01	**0.852**	***
	16.03.07	C2	16/17	**-0.004** ± 0.001	**-7.26** ± 3.54	**0.927**	***
	11.04.07	C3	10/13	**-0.007** ± 0.002	**-7.25** ± 1.60	**0.982**	***
	24.04.07	C4	12/12	**-0.022** ± 0.009	**-14.87** ± 7.69	**0.948**	***
	19.05.07	C5	21/22	**-0.009** ± 0.003	**-15.77** ± 6.66	**0.856**	***
	09.06.07	C6	20/20	**-0.046** ± 0.014	**-19.03** ± 1.88	**0.904**	***
	08.07.07	C7	24/26	**-0.025** ± 0.007	**-30.02** ± 7.35	**0.882**	***
	20.07.07	C7+C8	46/47	**-0.019** ± 0.005	**-32.08** ± 8.51	**0.833**	***
	05.08.07	C7+C9	44/46	**-0.019** ± 0.004	**-35.98** ± 9.18	**0.864**	***
	13.09.07	C10	13/15	**-0.028** ± 0.010	**-14.39** ± 2.88	**0.923**	***
	10.10.07	C11	13/13	**-0.015** ± 0.004	**-20.64** ± 7.76	**0.926**	***
	20.11.07	winter	14/14	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.
M3	19.02.07	C1	11/11	**-0.009** ± 0.007	**-1.52** ± 0.22	**0.817**	***
	16.03.07	C1+C2	28/28	**-0.004** ± 0.003	**-1.36** ± 0.35	**0.589**	***
	11.04.07	C3	11/12	**-0.001** ± 0.001	**-2.62** ± 3.57	**0.747**	***
	24.04.07	C4	12/13	**-0.026** ± 0.008	**-5.53** ± 0.45	**0.941**	***
	19.05.07	C5	21/21	**-0.005** ± 0.002	**-4.72** ± 0.70	**0.909**	***
	09.06.07	C6	21/21	**-0.017** ± 0.004	**-6.32** ± 0.49	**0.942**	***
	08.07.07	C7	21/25	**-0.017** ± 0.005	**-4.16** ± 0.38	**0.926**	***
	20.07.07	C8	15/19	**-0.012** ± 0.004	**-5.56** ± 0.64	**0.944**	***
	05.08.07	C9	14/17	**-0.006** ± 0.003	**-5.96** ± 1.85	**0.909**	***
	13.09.07	C10	11/13	**-0.009** ± 0.004	**-4.83** ± 0.96	**0.951**	***
	10.10.07	C10+C11	23/27	**-0.010** ± 0.004	**-4.87** ± 1.10	**0.837**	***
	20.11.07	winter	14/14	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.
M4	19.02.07	C1	10/10	**-0.005** ± 0.001	**-4.65** ± 1.22	**0.993**	***
	16.03.07	C2	16/16	**-0.005** ± 0.001	**-8.03** ± 3.61	**0.955**	***
	11.04.07	C3	16/17	**-0.004** ± 0.001	**-8.51** ± 2.44	**0.972**	***
	24.04.07	C4	12/12	**-0.029** ± 0.012	**-12.66** ± 2.36	**0.947**	***
	19.05.07	C5	24/24	**-0.010** ± 0.002	**-11.41** ± 1.93	**0.945**	***
	09.06.07	C6	28/28	**-0.037** ± 0.009	**-13.72** ± 0.87	**0.928**	***
	08.07.07	C7	24/24	**-0.039** ± 0.007	**-12.68** ± 0.84	**0.953**	***
	20.07.07	C8	25/27	**-0.048** ± 0.008	**-16.29** ± 0.90	**0.961**	***
	05.08.07	C9	26/26	**-0.040** ± 0.008	**-15.88** ± 0.94	**0.960**	***
	13.09.07	C10	18/18	**-0.024** ± 0.002	**-21.12** ± 1.67	**0.992**	***
	10.10.07	C11	11/12	**-0.023** ± 0.002	**-22.45** ± 2.73	**0.993**	***
	20.11.07	winter	14/14	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.
M5	19.02.07	C1	10/11	**-0.006** ± 0.002	**-2.51** ± 0.48	**0.957**	***
	16.03.07	C2		**-0.007**	**-5.84**	**interpolated**	n.s.
	11.04.07	C2+C4	33/37	**-0.009** ± 0.004	**-9.16** ± 3.29	**0.684**	***
	24.04.07	C4	14/14	**-0.033** ± 0.010	**-11.01** ± 0.86	**0.949**	***
	19.05.07	C5	23/23	**-0.006** ± 0.002	**-12.68** ± 4.44	**0.933**	***
	09.06.07	C6	27/27	**-0.029** ± 0.005	**-14.28** ± 0.85	**0.958**	***
	08.07.07	C7	23/24	**-0.037** ± 0.006	**-17.43** ± 1.06	**0.964**	***
	20.07.07	C8	23/27	**-0.033** ± 0.005	**-21.51** ± 1.27	**0.968**	***
	05.08.07	C9	25/26	**-0.036** ± 0.006	**-20.13** ± 1.20	**0.968**	***
	13.09.07	C10	17/17	**-0.015** ± 0.002	**-17.46** ± 2.10	**0.988**	***
	10.10.07	C11	11/12	**-0.021** ± 0.003	**-12.86** ± 1.91	**0.985**	***
	20.11.07	winter	14/14	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.
M6	19.02.07	C1	10/10	**-0.003** ± 0.001	**-4.36** ± 3.09	**0.937**	***
	16.03.07	C2	15/20	**-0.007** ± 0.004	**-10.09** ± 10.23	**0.894**	***
	11.04.07	C3	16/20	**-0.010** ± 0.005	**-12.31** ± 6.94	**0.837**	***
	24.04.07	C4	12/12	**-0.101** ± 0.021	**-17.92** ± 0.86	**0.982**	***
	19.05.07	C5	23/23	**-0.014** ± 0.003	**-17.59** ± 3.12	**0.941**	***
	09.06.07	C6	27/27	**-0.034** ± 0.007	**-18.55** ± 1.30	**0.949**	***
	08.07.07	C7	22/22	**-0.042** ± 0.007	**-27.80** ± 2.00	**0.969**	***
	20.07.07	C8	27/27	**-0.047** ± 0.012	**-27.25** ± 2.22	**0.911**	***
	05.08.07	C9	24/26	**-0.054** ± 0.013	**-19.76** ± 1.34	**0.937**	***
	13.09.07	C10	17/17	**-0.018** ± 0.003	**-26.57** ± 5.70	**0.975**	***
	10.10.07	C11	13/13	**-0.023** ± 0.005	**-23.08** ± 6.61	**0.951**	***
	20.11.07	winter	14/14	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.

Tab. 24: GPP modelling parameters 2008 of the bog heath

numbers of used measurements, coefficients of determination and significances of the used regressions are added

Site	Date	used Campaign	k/n	α ± SE	**Gp_{max}** ± SE [$\mu mol\ m^{-2}\ s^{-1}$]	r^2	Sig	Site	Date	used Campaign	k/n	α ± SE	**Gp_{max}** ± SE [$\mu mol\ m^{-2}\ s^{-1}$]	r^2	Sig
M1	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.	M4	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.
	05.02.08	winter	9/9	**0.000**	**-1.00**		n.s.		05.02.08	winter	9/9	**0.000**	**-1.00**		n.s.
	06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.		06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.
	29.03.08	C17	11/15	**-0.004** ± 0.002	**-3.14** ± 0.85	**0.881**	***		29.03.08	C17	17/18	**-0.006** ± 0.002	**-4.42** ± 0.67	**0.927**	***
	17.04.08	C18	13/16	**-0.007** ± 0.001	**-11.56** ± 2.25	**0.979**	***		17.04.08	C18	21/21	**-0.010** ± 0.003	**-7.75** ± 1.11	**0.939**	***
	07.05.08	C19	14/19	**-0.006** ± 0.002	**-20.72** ± 15.21	**0.949**	***		07.05.08	C19	23/23	**-0.013** ± 0.003	**-15.19** ± 2.56	**0.939**	***
	27.05.08	C20	14/18	**-0.021** ± 0.016	**-14.33** ± 4.93	**0.761**	***		27.05.08	C20	19/19	**-0.027** ± 0.004	**-15.28** ± 0.81	**0.985**	***
	23.06.08	C21	16/18	**-0.043** ± 0.009	**-26.05** ± 2.52	**0.959**	***		23.06.08	C21	28/28	**-0.039** ± 0.010	**-20.39** ± 1.89	**0.903**	***
	10.07.08	C22	16/18	**-0.037** ± 0.013	**-29.13** ± 5.23	**0.930**	***		10.07.08	C22	25/27	**-0.037** ± 0.011	**-19.54** ± 1.99	**0.928**	***
	31.07.08	C23	22/23	**-0.033** ± 0.021	**-32.97** ± 12.05	**0.749**	***		31.07.08	C23	22/25	**-0.031** ± 0.005	**-22.68** ± 1.72	**0.975**	***
	19.08.08	C24	16/17	**-0.048** ± 0.015	**-20.04** ± 2.14	**0.938**	***		19.08.08	C24	24/24	**-0.056** ± 0.017	**-14.46** ± 1.31	**0.889**	***
	11.09.08	C25	13/19	**-0.024** ± 0.010	**-35.34** ± 19.90	**0.927**	***		11.09.08	C25	21/22	**-0.042** ± 0.012	**-16.38** ± 1.87	**0.923**	***
	11.10.08	C26	21/21	**-0.025** ± 0.003	**-29.74** ± 5.70	**0.981**	***		11.10.08	C25+C26	39/43	**-0.025** ± 0.005	**-23.64** ± 4.15	**0.915**	***
	10.11.08	C27	16/16	**-0.020** ± 0.010	**-13.36** ± 6.66	**0.867**	***		10.11.08	C27	13/16	**-0.020** ± 0.013	**-5.99** ± 2.14	**0.892**	***
	03.12.08	winter	16/16	**0.000**	**-1.00**		n.s.		03.12.08	winter	17/17	**0.000**	**-1.00**		n.s.
M2	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.	M5	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.
	05.02.08	winter	9/9	**0.000**	**-1.00**		n.s.		05.02.08	winter	9/9	**0.000**	**-1.00**		n.s.
	06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.		06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.
	29.03.08	C17	16/18	**-0.008** ± 0.003	**-2.95** ± 0.45	**0.873**	***		29.03.08	C17	17/19	**-0.004** ± 0.001	**-3.83** ± 0.73	**0.925**	***
	17.04.08	C18	15/18	**-0.005** ± 0.002	**-10.28** ± 7.39	**0.852**	***		17.04.08	C18	21/21	**-0.008** ± 0.002	**-6.41** ± 1.13	**0.894**	***
	07.05.08	C19	17/19	**-0.006** ± 0.004	**-10.79** ± 8.24	**0.749**	***		07.05.08	C19	23/23	**-0.010** ± 0.002	**-18.37** ± 4.80	**0.944**	***
	27.05.08	C20	10/10	**-0.009** ± 0.008	**-23.92** ± 28.87	**0.820**	***		27.05.08	C20	18/18	**-0.025** ± 0.005	**-14.05** ± 1.23	**0.965**	***
	23.06.08	C21	15/18	**-0.008** ± 0.003	**-22.68** ± 17.74	**0.871**	***		23.06.08	C21	25/28	**-0.034** ± 0.005	**-22.08** ± 1.23	**0.978**	***
	10.07.08	C22	18/22	**-0.017** ± 0.007	**-15.55** ± 3.92	**0.901**	***		10.07.08	C22	26/27	**-0.034** ± 0.007	**-22.43** ± 1.76	**0.967**	***
	31.07.08	C23	16/23	**-0.014** ± 0.008	**-20.59** ± 10.45	**0.811**	***		31.07.08	C23	25/25	**-0.028** ± 0.006	**-35.52** ± 5.61	**0.953**	***
	19.08.08	C24	13/17	**-0.015** ± 0.008	**-22.16** ± 11.82	**0.919**	***		19.08.08	C24	22/24	**-0.037** ± 0.007	**-19.36** ± 1.28	**0.960**	***
	11.09.08	C25	16/19	**-0.018** ± 0.008	**-18.74** ± 7.86	**0.841**	***		11.09.08	C25	21/21	**-0.025** ± 0.005	**-19.95** ± 2.71	**0.958**	***
	11.10.08	C26	18/21	**-0.019** ± 0.006	**-17.65** ± 6.09	**0.903**	***		11.10.08	C26	18/18	**-0.024** ± 0.007	**-13.18** ± 2.32	**0.927**	***
	10.11.08	C27	14/15	**-0.016** ± 0.009	**-12.43** ± 7.98	**0.856**	***		10.11.08	C27+C28	20/26	**-0.019** ± 0.007	**-8.64** ± 2.41	**0.943**	***
	03.12.08	winter	20/20	**0.000**	**-1.00**		n.s.		03.12.08	winter	17/17	**0.000**	**-1.00**		n.s.
M3	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.	M6	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.
	05.02.08	winter	9/9	**0.000**	**-1.00**		n.s.		05.02.08	winter	9/9	**0.000**	**-1.00**		n.s.
	06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.		06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.
	29.03.08	C17	18/18	**-0.010** ± 0.005	**-1.49** ± 0.20	**0.805**	***		29.03.08	C17	20/20	**-0.005** ± 0.001	**-4.46** ± 0.70	**0.969**	***
	17.04.08	C18	11/16	**-0.002** ± 0.001	**-1.24** ± 0.50	**0.846**	***		17.04.08	C18	19/22	**-0.009** ± 0.001	**-18.17** ± 4.01	**0.967**	***
	07.05.08	C19	14/17	**-0.007** ± 0.002	**-13.50** ± 4.59	**0.966**	***		07.05.08	C19	20/23	**-0.012** ± 0.003	**-21.91** ± 5.93	**0.950**	***
	27.05.08	C20	18/18	**-0.015** ± 0.005	**-11.53** ± 1.83	**0.929**	***		27.05.08	C20	19/19	**-0.031** ± 0.013	**-23.13** ± 4.64	**0.890**	***
	23.06.08	C21	17/17	**-0.024** ± 0.006	**-9.75** ± 0.85	**0.949**	***		23.06.08	C21	24/29	**-0.040** ± 0.009	**-32.29** ± 3.78	**0.920**	***
	10.07.08	C22	18/19	**-0.021** ± 0.008	**-8.10** ± 0.93	**0.916**	***		10.07.08	C22	26/26	**-0.041** ± 0.009	**-25.46** ± 2.22	**0.957**	***
	31.07.08	C23	18/22	**-0.012** ± 0.005	**-14.69** ± 4.70	**0.917**	***		31.07.08	C23	21/25	**-0.034** ± 0.007	**-50.50** ± 9.30	**0.955**	***
	19.08.08	C24	15/17	**-0.029** ± 0.019	**-6.80** ± 1.14	**0.839**	***		19.08.08	C24	23/24	**-0.042** ± 0.009	**-25.67** ± 2.62	**0.939**	***
	11.09.08	C25	19/20	**-0.058** ± 0.025	**-9.25** ± 1.08	**0.851**	***		11.09.08	C25	20/22	**-0.020** ± 0.005	**-36.06** ± 14.31	**0.938**	***
	11.10.08	C25+C26	38/42	**-0.017** ± 0.004	**-12.89** ± 2.55	**0.897**	***		11.10.08	C26	18/18	**-0.034** ± 0.004	**-23.06** ± 2.39	**0.984**	***
	10.11.08	C27	12/16	**-0.011** ± 0.005	**-4.64** ± 1.64	**0.917**	***		10.11.08	C27	15/18	**-0.016** ± 0.009	**-28.42** ± 44.83	**0.837**	***
	03.12.08	winter	18/18	**0.000**	**-1.00**		n.s.		03.12.08	winter	17/17	**0.000**	**-1.00**		n.s.

Tab. 25: R_{eco} modelling parameters 2007 of the Setzberger Feld

numbers of used measurements and references temperatures, coefficients of determination and significances of the used regressions are added

Site	Date	used Campaign	k/n	$Temp_{ref}$	R_{ref} ± SE [µmol m^{-2} s^{-1}]	E_0 ± SE [K]	r^2	Sig
M7	20.02.07	C1	12/12	soil 2cm	**3.014** ± 0.495	**539.9** ± 94.7	**0.841**	***
	15.03.07	C2	15/18	air 20cm	**0.952** ± 0.129	**423.1** ± 60.5	**0.828**	***
	03.04.07	C3	9/9	air 20cm	**2.469** ± 0.108	**97.2** ± 17.1	**0.862**	***
	25.04.07	C3+C4	21/24	air 20cm	**2.430** ± 0.209	**144.0** ± 24.8	**0.772**	***
	18.05.07	C5	21/21	air 20cm	**3.937** ± 0.327	**213.3** ± 33.6	**0.779**	***
	08.06.07	C6	18/20	air 20cm	**2.567** ± 0.739	**243.8** ± 60.6	**0.664**	***
	07.07.07	C6+C8	34/39	air 20cm	**4.839** ± 0.313	**104.5** ± 14.0	**0.688**	***
	26.07.07	C8	19/19	air 20cm	**4.669** ± 0.346	**120.5** ± 19.1	**0.786**	***
	06.08.07	C9	13/15	soil 5cm	**4.045** ± 1.132	**339.4** ± 110.8	**0.471**	***
	14.09.07	C10	13/16	air 20cm	**3.743** ± 0.200	**105.7** ± 14.5	**0.871**	***
	11.10.07	C11+C12	27/28	soil 2cm	**2.522** ± 0.116	**313.7** ± 45.2	**0.816**	***
	21.11.07	C11+C12	27/28	soil 2cm	**2.522** ± 0.116	**313.7** ± 45.2	**0.816**	***
	14.12.07	winter	147/147	air 20cm	**0.847** ± 0.099	**334.6** ± 41.0	**0.374**	***
M8	20.02.07	C1	12/12	air 20cm	**1.751** ± 0.080	**59.7** ± 19.1	**0.531**	***
	15.03.07	C1+C2	26/29	air 20cm	**1.926** ± 0.146	**161.2** ± 38.4	**0.541**	***
	03.04.07	C3	9/11	air 20cm	**4.831** ± 0.285	**63.6** ± 24.7	**0.572**	**
	25.04.07	C3+C4	24/26	soil 2cm	**6.352** ± 0.304	**210.7** ± 30.4	**0.696**	***
	18.05.07	C5	20/20	air 20cm	**5.914** ± 0.488	**145.4** ± 27.6	**0.697**	***
	08.06.07	C6	18/20	air 20cm	**5.908** ± 1.250	**145.8** ± 40.5	**0.551**	***
	07.07.07	C6+C8	33/38	air 20cm	**7.141** ± 0.672	**115.5** ± 21.4	**0.543**	***
	26.07.07	C8	18/18	air 20cm	**6.184** ± 0.529	**134.2** ± 19.9	**0.841**	***
	06.08.07	C9	14/15	air 20cm	**8.770** ± 1.238	**152.3** ± 35.0	**0.684**	***
	14.09.07	C10	13/15	air 20cm	**5.082** ± 0.415	**117.3** ± 23.6	**0.747**	***
	11.10.07	C11+C12	27/27	soil 2cm	**4.420** ± 0.200	**268.5** ± 39.5	**0.767**	***
	21.11.07	C11+C12	27/27	soil 2cm	**4.420** ± 0.200	**268.5** ± 39.5	**0.767**	***
	14.12.07	winter	147/147	air 20cm	**1.448** ± 0.166	**303.4** ± 40.6	**0.297**	***
M9	20.02.07	C1	10/10	air 20cm	**0.712** ± 0.100	**183.9** ± 79.4	**0.557**	**
	15.03.07	C2	9/10	air 20cm	**1.073** ± 0.162	**181.1** ± 67.0	**0.668**	***
	03.04.07	C3+C4	18/21	soil 2cm	**1.485** ± 0.243	**393.5** ± 87.9	**0.637**	***
	25.04.07	C3+C4	18/21	soil 2cm	**1.485** ± 0.243	**393.5** ± 87.9	**0.637**	***
	18.05.07	C5+C6	20/21	air 20cm	**1.788** ± 0.480	**360.9** ± 62.2	**0.772**	***
	08.06.07	C6	14/14	air 20cm	**1.176** ± 0.634	**451.7** ± 119.0	**0.780**	***
	07.07.07	C7+C8	19/25	air 20cm	**4.192** ± 0.501	**119.0** ± 29.6	**0.484**	***
	26.07.07	C8	11/14	air 20cm	**4.618** ± 0.803	**101.6** ± 44.4	**0.388**	**
	06.08.07	C9	11/11	air 20cm	**3.708** ± 0.962	**186.7** ± 62.9	**0.584**	***
	14.09.07	C10	13/13	air 20cm	**2.621** ± 0.557	**150.9** ± 60.9	**0.517**	***
	11.10.07	C11+C12	18/21	air 20cm	**1.765** ± 0.149	**225.2** ± 52.2	**0.676**	***
	21.11.07	C11+C12	18/21	air 20cm	**1.765** ± 0.149	**225.2** ± 52.2	**0.676**	***
	14.12.07	winter	130/130	air 20cm	**0.618** ± 0.073	**337.8** ± 42.9	**0.355**	***

Site	Date	used Campaign	k/n	$Temp_{ref}$	R_{ref} ± SE [µmol m^{-2} s^{-1}]	E_0 ± SE [K]	r^2	Sig
M10	20.02.07	C1+C2	20/21	soil 2cm	**0.755** ± 0.046	**351.5** ± 42.5	**0.850**	***
	15.03.07	C2	10/11	air 20cm	**0.866** ± 0.055	**218.9** ± 34.7	**0.917**	***
	03.04.07	C3+C4	16/20	soil 2cm	**1.527** ± 0.260	**289.1** ± 67.0	**0.653**	***
	25.04.07	C4	10/12	soil 2cm	**2.036** ± 0.422	**198.3** ± 76.4	**0.559**	**
	18.05.07	C5	13/14	air 20cm	**1.130** ± 0.384	**454.5** ± 140.4	**0.700**	***
	08.06.07	C6	16/16	air 20cm	**3.192** ± 0.465	**236.1** ± 30.4	**0.894**	***
	07.07.07	C7	9/13	soil 2cm	**1.781** ± 0.246	**367.7** ± 51.9	**0.873**	***
	26.07.07	C8	12/16	air 20cm	**2.551** ± 0.960	**183.9** ± 81.7	**0.420**	***
	06.08.07	C9	13/13	air 20cm	**2.166** ± 1.235	**257.6** ± 128.6	**0.441**	**
	14.09.07	C10	14/14	air 20cm	**1.887** ± 0.504	**161.3** ± 66.9	**0.504**	***
	11.10.07	C11+C12	21/22	soil 2cm	**1.601** ± 0.159	**307.5** ± 58.9	**0.750**	***
	21.11.07	C11+C12	21/22	soil 2cm	**1.601** ± 0.159	**307.5** ± 58.9	**0.750**	***
	14.12.07	winter	128/128	air 20cm	**0.485** ± 0.074	**439.3** ± 54.7	**0.393**	***
M11	20.02.07	C1	6/10	air 20cm	**0.559** ± 0.085	**259.0** ± 115.9	**0.671**	**
	15.03.07	C2	8/10	air 20cm	**1.176** ± 0.122	**153.2** ± 48.7	**0.718**	***
	03.04.07	C3	7/8	soil 2cm	**1.235** ± 0.139	**337.3** ± 130.7	**0.726**	**
	25.04.07	C4	9/12	air 20cm	**1.811** ± 0.291	**169.6** ± 41.9	**0.825**	***
	18.05.07	C5	5/7	air 20cm	**2.405** ± 0.392	**228.8** ± 63.6	**0.904**	**
	08.06.07	C6	14/14	air 20cm	**2.004** ± 0.470	**356.2** ± 51.9	**0.902**	***
	07.07.07	C7+C8	25/25	air 20cm	**3.309** ± 0.482	**175.2** ± 37.9	**0.581**	***
	26.07.07	C8	14/14	air 20cm	**2.833** ± 0.713	**221.0** ± 61.0	**0.704**	***
	06.08.07	C9	11/11	air 20cm	**3.323** ± 0.463	**196.8** ± 33.1	**0.863**	***
	14.09.07	C10	12/13	air 20cm	**2.186** ± 0.415	**180.4** ± 54.2	**0.655**	***
	11.10.07	C11+C12	19/21	soil 2cm	**2.332** ± 0.159	**289.5** ± 68.5	**0.670**	***
	21.11.07	C11+C12	19/21	soil 2cm	**2.332** ± 0.159	**289.5** ± 68.5	**0.670**	***
	14.12.07	winter	135/135	air 20cm	**0.726** ± 0.090	**400.8** ± 42.4	**0.429**	***
M12	20.02.07	C1	10/10	air 20cm	**1.057** ± 0.103	**428.9** ± 69.2	**0.906**	***
	15.03.07	C2	10/10	air 20cm	**1.981** ± 0.184	**275.4** ± 50.2	**0.900**	***
	03.04.07	C3	8/9	soil 2cm	**2.243** ± 0.294	**272.3** ± 101.3	**0.713**	**
	25.04.07	C4	11/11	air 20cm	**3.539** ± 0.535	**147.0** ± 41.3	**0.712**	***
	18.05.07	C5	11/12	air 20cm	**4.150** ± 0.431	**222.1** ± 41.9	**0.849**	***
	08.06.07	C6	14/14	air 20cm	**3.283** ± 0.674	**286.8** ± 46.3	**0.864**	***
	07.07.07	C7	11/11	air 20cm	**4.633** ± 0.403	**132.9** ± 25.9	**0.764**	***
	26.07.07	C8	14/14	air 20cm	**4.637** ± 0.833	**163.7** ± 44.4	**0.669**	***
	06.08.07	C9	11/11	air 20cm	**4.998** ± 0.434	**166.2** ± 21.4	**0.911**	***
	14.09.07	C10	13/13	air 20cm	**3.196** ± 0.444	**182.0** ± 40.0	**0.781**	***
	11.10.07	C11	20/20	air 20cm	**3.117** ± 0.124	**107.1** ± 22.5	**0.730**	***
	21.11.07	C11+C12	20/21	soil 2cm	**2.665** ± 0.112	**291.3** ± 33.0	**0.920**	***
	14.12.07	winter	126/126	air 20cm	**1.043** ± 0.113	**350.2** ± 39.7	**0.451**	***

Tab. 26: R_{eco} modelling parameters 2008 of the Setzberger Feld

numbers of used measurements and references temperatures, coefficients of determination and significances of the used regressions are added

Site	Date	used Campaign	k/n	$Temp_{ref}$	R_{ref} ± SE [µmol m^{-2} s^{-1}]	E_0 ± SE [K]	r^2	Sig
M7	08.01.08	winter	147/147	soil 5cm	**2.537** ± 0.080	**522.3** ± 32.1	**0.763**	***
	07.02.08	winter	147/147	soil 5cm	**2.537** ± 0.080	**522.3** ± 32.1	**0.763**	***
	06.03.08	winter	147/147	soil 5cm	**2.537** ± 0.080	**522.3** ± 32.1	**0.763**	***
	30.03.08	C17	11/11	air 20cm	**1.035** ± 0.129	**219.0** ± 37.7	**0.867**	***
	18.04.08	C18	26/29	air 20cm	**1.866** ± 0.127	**244.4** ± 31.6	**0.809**	***
	08.05.08	C19	29/29	soil 2cm	**2.359** ± 0.131	**181.4** ± 22.1	**0.722**	***
	28.05.08	C19-C21	62/66	soil 5cm	**2.498** ± 0.212	**329.7** ± 27.4	**0.747**	***
	25.06.08	C19-C21	62/66	soil 5cm	**2.498** ± 0.212	**329.7** ± 27.4	**0.747**	***
	11.07.08	C21+C23	20/23	soil 2cm	**3.941** ± 0.547	**179.8** ± 38.8	**0.415**	***
	01.08.08	C23	11/13	air 20cm	**9.064** ± 0.816	**-196.4** ± 36.0	**0.794**	***
	21.08.08	C24	15/16	soil 2cm	**2.775** ± 0.240	**350.4** ± 31.7	**0.912**	***
	17.09.08	C25	10/10	air 20cm	**2.491** ± 0.041	**134.6** ± 9.7	**0.967**	***
	21.10.08	C26	15/15	air 20cm	**2.231** ± 0.081	**147.3** ± 10.7	**0.960**	***
	11.11.08	C27+C28	17/22	soil 5cm	**1.502** ± 0.092	**328.0** ± 38.4	**0.850**	***
	04.12.08	C28	9/9	air 20cm	**0.659** ± 0.054	**107.4** ± 44.9	**0.478**	**
M8	08.01.08	winter	147/147	soil 5cm	**4.176** ± 0.111	**515.3** ± 25.3	**0.825**	***
	07.02.08	winter	147/147	soil 5cm	**4.176** ± 0.111	**515.3** ± 25.3	**0.825**	***
	06.03.08	winter	147/147	soil 2cm	**3.893** ± 0.120	**452.4** ± 24.6	**0.772**	***
	30.03.08	C17	10/11	air 20cm	**1.213** ± 0.285	**238.2** ± 73.6	**0.666**	***
	18.04.08	C18	30/32	air 20cm	**2.652** ± 0.118	**222.8** ± 21.7	**0.856**	***
	08.05.08	C18+C19	55/60	soil 2cm	**3.827** ± 0.266	**314.7** ± 30.9	**0.637**	***
	28.05.08	C20	10/10	soil 2cm	**14.62** ± 2.939	**-191.4** ± 77.9	**0.441**	**
	25.06.08	C20+C21	32/37	soil 2cm	**5.756** ± 0.972	**221.2** ± 48.4	**0.397**	***
	11.07.08	C22	16/22	air 20cm	**8.759** ± 0.662	**74.8** ± 16.5	**0.638**	***
	01.08.08	C23	12/13	air 20cm	**13.60** ± 1.169	**-160.7** ± 28.7	**0.750**	***
	21.08.08	C22+C24	28/38	air 20cm	**6.921** ± 0.754	**114.4** ± 25.5	**0.450**	***
	17.09.08	C25	10/10	air 20cm	**4.293** ± 0.168	**107.5** ± 22.9	**0.756**	***
	21.10.08	C26	15/15	air 20cm	**3.981** ± 0.257	**100.7** ± 19.0	**0.748**	***
	11.11.08	C27	10/13	air 20cm	**1.444** ± 0.092	**-56.5** ± 15.2	**0.621**	***
	04.12.08	C28	9/9	air 20cm	**1.340** ± 0.169	**239.7** ± 87.6	**0.578**	**
M9	08.01.08	winter	130/130	soil 2cm	**1.614** ± 0.084	**456.0** ± 48.0	**0.524**	***
	07.02.08	winter	130/130	soil 2cm	**1.614** ± 0.084	**456.0** ± 48.0	**0.524**	***
	06.03.08	winter	130/130	air 20cm	**0.618** ± 0.073	**337.8** ± 42.9	**0.355**	***
	30.03.08	C17	9/11	soil 2cm	**2.075** ± 0.216	**371.9** ± 79.9	**0.753**	***
	18.04.08	C18	17/17	air 20cm	**1.704** ± 0.199	**199.7** ± 55.6	**0.597**	***
	08.05.08	C19	16/16	soil 2cm	**2.749** ± 0.389	**276.5** ± 64.8	**0.675**	***
	28.05.08	C20	11/11	air 20cm	**4.704** ± 0.773	**131.1** ± 35.0	**0.671**	***
	25.06.08	C19-C21	39/42	air 20cm	**3.696** ± 0.519	**138.4** ± 31.9	**0.437**	***
	11.07.08	C22			**3.511** ±	**174.4** ± **interpolated**		n.s.
	01.08.08	C23	7/10	air 20cm	**3.269** ± 0.610	**221.7** ± 53.0	**0.809**	***
	21.08.08	C24			**2.698** ±	**160.5** ± **interpolated**		n.s.
	17.09.08	C25+C26	17/18	air 20cm	**1.928** ± 0.132	**78.0** ± 22.6	**0.463**	***
	21.10.08	C26	10/11	air 20cm	**1.746** ± 0.213	**106.1** ± 34.6	**0.615**	**
	11.11.08	C27	12/14	air 20cm	**1.166** ± 0.078	**-47.8** ± 19.7	**0.339**	**
	04.12.08	C27+C28	20/23	soil 10cm	**2.199** ± 0.446	**518.7** ± 126.3	**0.588**	***
M10	08.01.08	winter	128/128	air 20cm	**0.485** ± 0.074	**439.3** ± 54.7	**0.393**	***
	07.02.08	winter	128/128	air 20cm	**0.485** ± 0.074	**439.3** ± 54.7	**0.393**	***
	06.03.08	winter	128/128	soil 5cm	**1.526** ± 0.081	**485.1** ± 44.4	**0.571**	***
	30.03.08	C17+C18	22/28	air 20cm	**1.552** ± 0.244	**257.4** ± 67.7	**0.628**	***
	18.04.08	C18	14/17	air 20cm	**1.644** ± 0.251	**346.1** ± 74.3	**0.826**	***
	08.05.08	C19	16/16	air 20cm	**3.441** ± 0.532	**144.0** ± 48.4	**0.560**	***
	28.05.08	C20	11/11	air 20cm	**4.161** ± 1.098	**177.3** ± 55.7	**0.605**	**
	25.06.08	C21+C22	27/31	soil 5cm	**0.933** ± 0.315	**639.4** ± 115.4	**0.528**	***
	11.07.08	C22	16/16	soil 5cm	**0.479** ± 0.225	**853.0** ± 152.9	**0.710**	**
	01.08.08	C23	10/10	air 20cm	**5.455** ± 0.720	**101.2** ± 39.1	**0.505**	**
	21.08.08	C24	12/15	soil 5cm	**1.152** ± 0.388	**450.1** ± 144.1	**0.488**	**
	17.09.08	C24+C25	18/21	soil 2cm	**1.216** ± 0.202	**382.5** ± 67.6	**0.707**	***
	21.10.08	C26	9/11	air 20cm	**1.069** ± 0.258	**288.5** ± 68.6	**0.875**	***
	11.11.08	C26+C27	19/23	soil 2cm	**2.313** ± 0.192	**577.2** ± 115.3	**0.635**	***
	04.12.08	C27+C28	20/21	soil 2cm	**1.836** ± 0.456	**454.5** ± 137.7	**0.430**	***
M11	08.01.08	winter	135/135	air 20cm	**0.726** ± 0.090	**400.8** ± 42.4	**0.429**	***
	07.02.08	winter	135/135	air 20cm	**0.726** ± 0.090	**400.8** ± 42.4	**0.429**	***
	06.03.08	winter	135/135	soil 5cm	**2.824** ± 0.214	**434.0** ± 48.5	**0.386**	***
	30.03.08	C17	15/15	air 20cm	**0.671** ± 0.161	**447.7** ± 79.2	**0.914**	***
	18.04.08	C18	15/17	air 20cm	**1.589** ± 0.147	**295.3** ± 48.8	**0.869**	***
	08.05.08	C19	16/16	soil 2cm	**2.177** ± 0.327	**271.0** ± 54.1	**0.820**	***
	28.05.08	C20	9/11	air 20cm	**2.946** ± 0.677	**175.2** ± 45.5	**0.783**	***
	25.06.08	C20+C21	21/24	air 20cm	**2.731** ± 0.629	**167.3** ± 47.7	**0.516**	***
	11.07.08	C20-C22	32/38	air 20cm	**1.993** ± 0.467	**209.3** ± 50.8	**0.424**	***
	01.08.08	C23+C24	36/40	soil 10cm	**0.635** ± 0.218	**821.6** ± 132.6	**0.703**	***
	21.08.08	C23+C24	36/40	soil 10cm	**0.635** ± 0.218	**821.6** ± 132.6	**0.703**	***
	17.09.08	C25	6/7	air 20cm	**1.917** ± 0.066	**239.3** ± 30.3	**0.967**	***
	21.10.08	C25+C26	16/18	air 20cm	**2.307** ± 0.294	**144.0** ± 37.2	**0.578**	***
	11.11.08	C27	11/14	air 20cm	**1.457** ± 0.088	**66.6** ± 23.4	**0.529**	**
	04.12.08	C27+C28	18/23	soil 2cm	**1.715** ± 0.111	**155.9** ± 27.6	**0.635**	***
M12	08.01.08	winter	126/126	air 20cm	**1.043** ± 0.113	**350.2** ± 39.7	**0.451**	***
	07.02.08	winter	126/126	air 20cm	**1.043** ± 0.113	**350.2** ± 39.7	**0.451**	***
	06.03.08	winter	126/126	air 20cm	**1.043** ± 0.113	**350.2** ± 39.7	**0.451**	***
	30.03.08	C17	12/12	air 20cm	**1.705** ± 0.177	**229.4** ± 34.7	**0.907**	***
	18.04.08	C18	15/16	air 20cm	**3.020** ± 0.184	**280.2** ± 36.4	**0.893**	***
	08.05.08	C19	15/15	air 20cm	**3.973** ± 0.330	**175.3** ± 25.4	**0.888**	***
	28.05.08	C20	9/11	air 20cm	**6.644** ± 0.940	**116.1** ± 30.6	**0.719**	***
	25.06.08	C20+C22	23/26	soil 2cm	**1.965** ± 0.694	**484.0** ± 107.8	**0.500**	***
	11.07.08	C22	14/15	soil 2cm	**1.514** ± 0.677	**528.7** ± 136.4	**0.537**	**
	01.08.08	C22+C24	28/29	soil 5cm	**1.143** ± 0.309	**655.0** ± 94.7	**0.614**	***
	21.08.08	C22+C24	28/29	soil 5cm	**1.143** ± 0.309	**655.0** ± 94.7	**0.614**	***
	17.09.08	C24+C25	22/22	air 20cm	**2.585** ± 0.366	**170.1** ± 41.8	**0.589**	***
	21.10.08	C26	10/11	air 20cm	**2.717** ± 0.378	**95.2** ± 37.0	**0.521**	**
	11.11.08	C27	9/12	air 20cm	**1.642** ± 0.135	**105.4** ± 35.3	**0.586**	**
	04.12.08	C27+C28	19/23	soil 2cm	**3.703** ± 0.272	**547.9** ± 54.2	**0.906**	***

Tab. 27: GPP modelling parameters 2007 of the Setzberger Feld

numbers of used measurements, coefficients of determination and significances of the used regressions are added

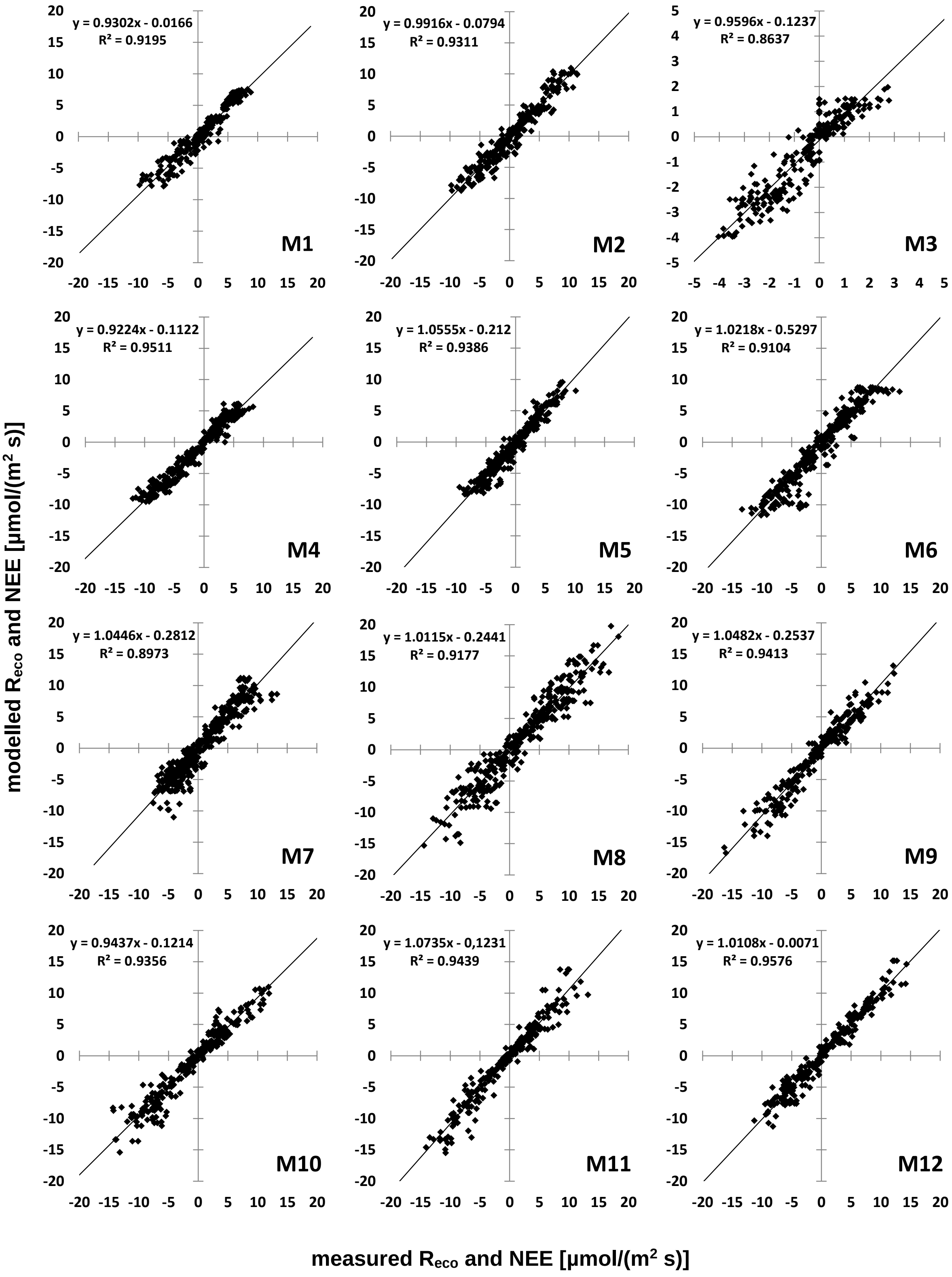
Site	Date	used Campaign	k/n	α ± SE	Gp$_{max}$ ± SE	r^2	Sig
					[µmol m^{-2} s^{-1}]		
M7	20.02.07	C1	23/23	**-0.009** ± 0.003	**-11.22** ± 5.51	**0.783**	***
	15.03.07	C2	18/18	**-0.031** ± 0.011	**-10.37** ± 1.22	**0.961**	***
	03.04.07	C3	21/21	**-0.015** ± 0.003	**-14.37** ± 2.32	**0.963**	***
	25.04.07	C4	21/27	**-0.050** ± 0.030	**-8.38** ± 0.87	**0.762**	***
	18.05.07	C5	37/37	**-0.043** ± 0.004	**-15.46** ± 0.39	**0.981**	***
	08.06.07	C6	20/20	**-0.027** ± 0.008	**-18.75** ± 2.55	**0.921**	***
	07.07.07	C7	27/27	**-0.058** ± 0.008	**-22.99** ± 1.24	**0.966**	***
	26.07.07	C8	28/32	**-0.050** ± 0.012	**-18.30** ± 1.11	**0.930**	***
	06.08.07	C9	29/33	**-0.058** ± 0.016	**-14.18** ± 1.02	**0.892**	***
	14.09.07	C10	22/22	**-0.057** ± 0.014	**-13.27** ± 0.87	**0.947**	***
	11.10.07	C11	21/22	**-0.027** ± 0.006	**-9.09** ± 0.56	**0.956**	***
	21.11.07	winter	18/18	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.
M8	20.02.07	C1	20/21	**-0.008** ± 0.001	**-15.10** ± 4.96	**0.962**	***
	15.03.07	C2	16/16	**-0.034** ± 0.009	**-12.97** ± 1.17	**0.977**	***
	03.04.07	C3	15/19	**-0.023** ± 0.012	**-10.54** ± 2.14	**0.761**	***
	25.04.07	C4		**-0.024**	**-15.45**	**interpolated**	n.s.
	18.05.07	C5	31/33	**-0.034** ± 0.006	**-21.60** ± 1.53	**0.957**	***
	08.06.07	C6	20/20	**-0.041** ± 0.010	**-34.78** ± 5.55	**0.931**	***
	07.07.07	C7	28/28	**-0.083** ± 0.015	**-36.36** ± 2.54	**0.928**	***
	26.07.07	C8	31/34	**-0.063** ± 0.009	**-29.77** ± 1.28	**0.972**	***
	06.08.07	C9	28/32	**-0.043** ± 0.007	**-45.69** ± 4.70	**0.966**	***
	14.09.07	C10	19/20	**-0.044** ± 0.013	**-30.53** ± 4.99	**0.935**	***
	11.10.07	C11	19/19	**-0.028** ± 0.008	**-20.01** ± 2.65	**0.943**	***
	21.11.07	winter	18/18	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.
M9	20.02.07	C1	14/14	**-0.006** ± 0.003	**-3.97** ± 1.47	**0.804**	***
	15.03.07	C2	13/13	**-0.006** ± 0.003	**-6.55** ± 3.48	**0.865**	***
	03.04.07	C3	8/11	**-0.006** ± 0.001	**-12.03** ± 2.63	**0.997**	***
	25.04.07	C4		**-0.018**	**-15.21**	**interpolated**	n.s.
	18.05.07	C5	23/23	**-0.030** ± 0.008	**-18.39** ± 1.32	**0.935**	***
	08.06.07	C6	23/24	**-0.059** ± 0.016	**-28.18** ± 2.43	**0.930**	***
	07.07.07	C7	11/11	**-0.066** ± 0.013	**-34.18** ± 3.53	**0.964**	***
	26.07.07	C8	20/20	**-0.033** ± 0.009	**-25.51** ± 3.22	**0.934**	***
	06.08.07	C9	14/14	**-0.027** ± 0.008	**-32.49** ± 7.39	**0.941**	***
	14.09.07	C10	9/9	**-0.023** ± 0.015	**-17.95** ± 7.60	**0.909**	***
	11.10.07	C11	10/10	**-0.041** ± 0.034	**-11.01** ± 3.85	**0.852**	***
	21.11.07	winter	14/14	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.

Site	Date	used Campaign	k/n	α ± SE	Gp$_{max}$ ± SE	r^2	Sig
					[µmol m^{-2} s^{-1}]		
M10	20.02.07	C1	16/16	**-0.007** ± 0.003	**-2.51** ± 0.57	**0.864**	***
	15.03.07	C2	12/13	**-0.009** ± 0.003	**-6.03** ± 1.55	**0.947**	***
	03.04.07	C3	13/13	**-0.014** ± 0.003	**-13.98** ± 2.90	**0.971**	***
	25.04.07	C4	12/18	**-0.005** ± 0.002	**-11.06** ± 8.13	**0.907**	***
	18.05.07	C5	35/35	**-0.045** ± 0.013	**-16.07** ± 1.39	**0.839**	***
	08.06.07	C6	22/27	**-0.114** ± 0.034	**-24.32** ± 1.69	**0.934**	***
	07.07.07	C7	18/18	**-0.052** ± 0.022	**-17.19** ± 2.80	**0.813**	***
	26.07.07	C8	28/28	**-0.040** ± 0.014	**-20.04** ± 2.22	**0.890**	***
	06.08.07	C9	17/17	**-0.031** ± 0.009	**-24.02** ± 3.30	**0.948**	***
	14.09.07	C10	14/14	**-0.018** ± 0.004	**-22.53** ± 5.63	**0.979**	***
	11.10.07	C11	11/13	**-0.023** ± 0.009	**-11.76** ± 3.11	**0.939**	***
	21.11.07	winter	16/16	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.
M11	20.02.07	C1	13/15	**-0.004** ± 0.001	**-8.87** ± 6.88	**0.917**	***
	15.03.07	C2	13/13	**-0.005** ± 0.002	**-14.61** ± 15.77	**0.901**	***
	03.04.07	C3	11/13	**-0.005** ± 0.001	**-15.35** ± 9.23	**0.981**	***
	25.04.07	C4		**-0.018**	**-17.50**	**interpolated**	n.s.
	18.05.07	C5	16/17	**-0.030** ± 0.009	**-20.38** ± 2.36	**0.924**	***
	08.06.07	C6	14/14	**-0.068** ± 0.016	**-28.46** ± 2.15	**0.974**	***
	07.07.07	C7	11/11	**-0.066** ± 0.014	**-30.33** ± 3.09	**0.973**	***
	26.07.07	C8	18/18	**-0.027** ± 0.003	**-30.98** ± 2.51	**0.986**	***
	06.08.07	C9	14/14	**-0.031** ± 0.005	**-23.47** ± 2.32	**0.980**	***
	14.09.07	C10	10/11	**-0.030** ± 0.011	**-13.75** ± 2.14	**0.962**	***
	11.10.07	C11	10/10	**-0.066** ± 0.039	**-9.74** ± 1.93	**0.875**	***
	21.11.07	winter	14/14	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.
M12	20.02.07	C1	15/15	**-0.011** ± 0.004	**-16.52** ± 7.74	**0.914**	***
	15.03.07	C2	12/13	**-0.015** ± 0.004	**-23.84** ± 12.53	**0.941**	***
	03.04.07	C3	12/12	**-0.015** ± 0.006	**-24.27** ± 13.94	**0.914**	***
	25.04.07	C4	13/17	**-0.022** ± 0.006	**-12.67** ± 1.58	**0.966**	***
	18.05.07	C5	18/18	**-0.028** ± 0.004	**-24.94** ± 2.47	**0.979**	***
	08.06.07	C6	24/24	**-0.060** ± 0.013	**-22.84** ± 1.21	**0.960**	***
	07.07.07	C7	12/12	**-0.049** ± 0.009	**-28.00** ± 3.46	**0.974**	***
	26.07.07	C8	21/21	**-0.029** ± 0.005	**-26.13** ± 2.71	**0.970**	***
	06.08.07	C9	13/13	**-0.074** ± 0.019	**-20.71** ± 1.53	**0.964**	***
	14.09.07	C10	11/11	**-0.028** ± 0.009	**-21.64** ± 4.94	**0.963**	***
	11.10.07	C11	10/10	**-0.036** ± 0.007	**-14.07** ± 1.48	**0.985**	***
	21.11.07	winter	14/14	**0.000**	**-1.00**		n.s.
	14.12.07	winter	9/9	**0.000**	**-1.00**		n.s.

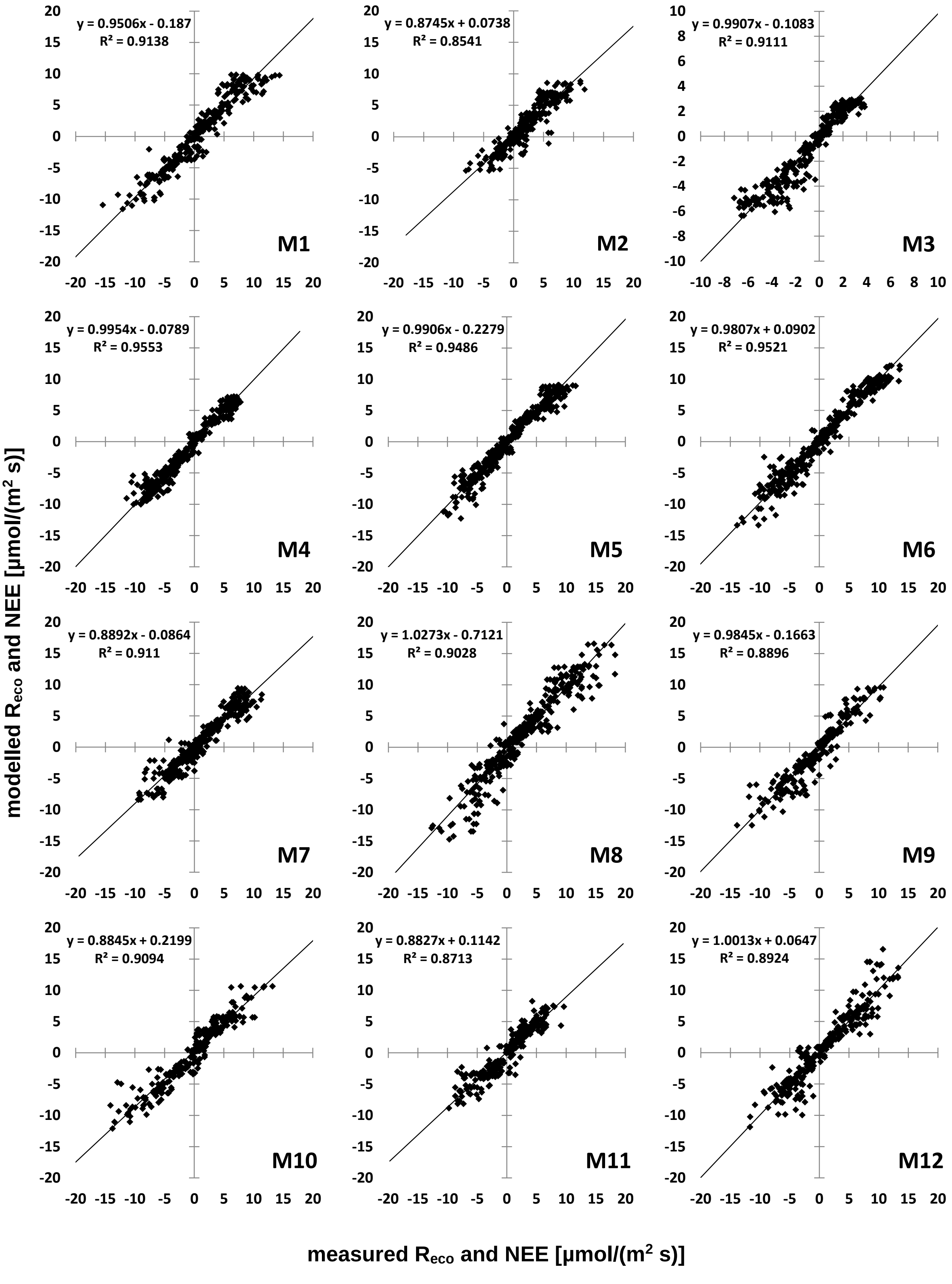
Tab. 28: GPP modelling parameters 2008 of the Setzberger Feld
numbers of used measurements, coefficients of determination and significances of the used regressions are added

Site	Date	used Campaign	k/n	α ± SE	**Gp$_{max}$** ± SE [µmol m^{-2} s^{-1}]	**r^2**	Sig
M7	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.
	07.02.08	winter	9/9	**0.000**	**-1.00**		n.s.
	06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.
	30.03.08	C17+C18	31/37	**-0.028** ± 0.012	**-4.63** ± 0.43	**0.856**	***
	18.04.08	C18	21/24	**-0.025** ± 0.007	**-5.72** ± 0.45	**0.934**	***
	08.05.08	C19	19/26	**-0.005** ± 0.002	**-5.93** ± 1.53	**0.888**	***
	28.05.08	C20	8/10	**-0.067** ± 0.027	**-11.50** ± 1.62	**0.974**	***
	25.06.08	C21	28/28	**-0.075** ± 0.024	**-9.49** ± 0.71	**0.908**	***
	11.07.08	C22	30/36	**-0.057** ± 0.017	**-13.52** ± 1.03	**0.890**	***
	01.08.08	C23	20/25	**-0.014** ± 0.004	**-23.95** ± 6.97	**0.923**	***
	21.08.08	C24	28/28	**-0.054** ± 0.014	**-19.54** ± 1.76	**0.905**	***
	17.09.08	C25	21/21	**-0.015** ± 0.002	**-8.52** ± 1.04	**0.971**	***
	21.10.08	C26	23/24	**-0.017** ± 0.005	**-15.13** ± 3.71	**0.927**	***
	11.11.08	C27	27/28	**-0.017** ± 0.005	**-10.37** ± 2.59	**0.882**	***
	04.12.08	winter	12/12	**0.000**	**-1.00**		n.s.
M8	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.
	07.02.08	winter	9/9	**0.000**	**-1.00**		n.s.
	06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.
	30.03.08	C17+C18	40/44	**-0.036** ± 0.014	**-5.62** ± 0.52	**0.793**	***
	18.04.08	C18	30/30	**-0.034** ± 0.012	**-6.68** ± 0.59	**0.848**	***
	08.05.08	C19	20/26	**-0.009** ± 0.003	**-23.71** ± 15.62	**0.853**	***
	28.05.08	C20	10/10	**-0.066** ± 0.040	**-16.18** ± 4.46	**0.926**	***
	25.06.08	C21	28/28	**-0.134** ± 0.061	**-22.08** ± 2.40	**0.799**	***
	11.07.08	C22	31/36	**-0.053** ± 0.016	**-28.48** ± 3.37	**0.878**	***
	01.08.08	C23	19/25	**-0.020** ± 0.008	**-27.35** ± 10.55	**0.807**	***
	21.08.08	C24	30/31	**-0.080** ± 0.015	**-34.70** ± 2.58	**0.950**	***
	17.09.08	C25	21/22	**-0.009** ± 0.003	**-5.80** ± 2.20	**0.856**	***
	21.10.08	C26	22/24	**-0.014** ± 0.002	**-23.55** ± 6.54	**0.970**	***
	11.11.08	C27	25/29	**-0.019** ± 0.007	**-12.08** ± 3.77	**0.823**	***
	04.12.08	winter	12/12	**0.000**	**-1.00**		n.s.
M9	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.
	07.02.08	winter	9/9	**0.000**	**-1.00**		n.s.
	06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.
	30.03.08	C17+C18	30/36	**-0.019** ± 0.009	**-4.72** ± 0.60	**0.783**	***
	18.04.08	C18	19/19	**-0.017** ± 0.004	**-6.66** ± 0.68	**0.937**	***
	08.05.08	C19	13/18	**-0.008** ± 0.003	**-35.14** ± 44.53	**0.926**	***
	28.05.08	C20	11/12	**-0.093** ± 0.041	**-20.06** ± 3.13	**0.924**	***
	25.06.08	C21	23/26	**-0.070** ± 0.025	**-22.79** ± 2.13	**0.887**	***
	11.07.08	C22	14/20	**-0.029** ± 0.017	**-25.11** ± 8.94	**0.758**	***
	01.08.08	C23	14/18	**-0.033** ± 0.014	**-42.26** ± 16.81	**0.856**	***
	21.08.08	C24	16/17	**-0.037** ± 0.012	**-21.77** ± 3.49	**0.926**	***
	17.09.08	C24+C25	25/26	**-0.026** ± 0.005	**-26.03** ± 4.75	**0.929**	***
	21.10.08	C26	13/14	**-0.010** ± 0.004	**-20.25** ± 19.70	**0.933**	***
	11.11.08	C26+C27	27/30	**-0.009** ± 0.002	**-7.55** ± 2.20	**0.972**	***
	04.12.08	winter	12/12	**0.000**	**-1.00**		n.s.
M10	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.
	07.02.08	winter	9/9	**0.000**	**-1.00**		n.s.
	06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.
	30.03.08	C17+C18	24/35	**-0.022** ± 0.007	**-7.58** ± 0.73	**0.920**	***
	18.04.08	C18	18/18	**-0.014** ± 0.006	**-9.04** ± 2.24	**0.858**	***
	08.05.08	C19	15/17	**-0.015** ± 0.003	**-31.82** ± 8.33	**0.978**	***
	28.05.08	C20	11/13	**-0.067** ± 0.013	**-30.85** ± 3.52	**0.975**	***
	25.06.08	C21	21/26	**-0.078** ± 0.032	**-16.21** ± 1.58	**0.865**	***
	11.07.08	C22	17/19	**-0.021** ± 0.012	**-15.77** ± 4.29	**0.885**	***
	01.08.08	C23	17/17	**-0.029** ± 0.009	**-37.91** ± 8.93	**0.901**	***
	21.08.08	C24	15/16	**-0.019** ± 0.005	**-18.71** ± 3.90	**0.937**	***
	17.09.08	C25	8/9	**-0.016** ± 0.005	**-6.79** ± 1.70	**0.961**	***
	21.10.08	C26+C27	26/29	**-0.011** ± 0.005	**-16.56** ± 12.33	**0.812**	***
	11.11.08	C27	14/16	**-0.013** ± 0.008	**-8.48** ± 4.68	**0.788**	***
	04.12.08	winter	12/12	**0.000**	**-1.00**		n.s.
M11	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.
	07.02.08	winter	9/9	**0.000**	**-1.00**		n.s.
	06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.
	30.03.08	C17+C18	25/29	**-0.016** ± 0.003	**-7.46** ± 0.55	**0.971**	***
	18.04.08	C18	17/18	**-0.015** ± 0.003	**-8.20** ± 0.73	**0.971**	***
	08.05.08	C18+C19	27/35	**-0.008** ± 0.002	**-15.72** ± 4.78	**0.931**	***
	28.05.08	C20	9/13	**-0.042** ± 0.015	**-23.37** ± 6.22	**0.950**	***
	25.06.08	C21	19/27	**-0.028** ± 0.015	**-24.13** ± 6.79	**0.802**	***
	11.07.08	C22		**-0.031**	**-23.00**	**interpolated**	n.s.
	01.08.08	C23	9/16	**-0.035** ± 0.011	**-21.51** ± 3.44	**0.874**	***
	21.08.08	C24	13/17	**-0.039** ± 0.018	**-18.21** ± 4.05	**0.881**	***
	17.09.08	C24+C26	30/30	**-0.028** ± 0.010	**-15.37** ± 3.11	**0.862**	***
	21.10.08	C26	11/13	**-0.033** ± 0.017	**-18.94** ± 6.83	**0.946**	***
	11.11.08	C27		**-0.017**	**-9.90**	**extrapolated**	n.s.
	04.12.08	winter	12/12	**0.000**	**-1.00**		n.s.
M12	08.01.08	winter	9/9	**0.000**	**-1.00**		n.s.
	07.02.08	winter	9/9	**0.000**	**-1.00**		n.s.
	06.03.08	winter	9/9	**0.000**	**-1.00**		n.s.
	30.03.08	C17	12/14	**-0.007** ± 0.003	**-12.67** ± 7.50	**0.907**	***
	18.04.08	C18	19/19	**-0.034** ± 0.007	**-11.50** ± 0.73	**0.970**	***
	08.05.08	C19	16/16	**-0.019** ± 0.007	**-23.21** ± 6.41	**0.903**	***
	28.05.08	C20	11/13	**-0.067** ± 0.016	**-34.06** ± 4.21	**0.962**	***
	25.06.08	C21	24/26	**-0.033** ± 0.009	**-28.56** ± 3.89	**0.937**	***
	11.07.08	C22	14/20	**-0.017** ± 0.006	**-31.65** ± 14.28	**0.922**	***
	01.08.08	C23	12/17	**-0.019** ± 0.006	**-36.37** ± 12.32	**0.954**	***
	21.08.08	C24	17/17	**-0.038** ± 0.013	**-15.84** ± 1.96	**0.926**	***
	17.09.08	C25	10/10	**-0.021** ± 0.006	**-9.97** ± 2.64	**0.957**	***
	21.10.08	C26	14/14	**-0.037** ± 0.014	**-12.89** ± 2.40	**0.945**	***
	11.11.08	C27	16/16	**-0.019** ± 0.006	**-23.05** ± 11.41	**0.928**	***
	04.12.08	winter	12/12	**0.000**	**-1.00**		n.s.

Tab. 29: R_{eco}- and NEE-model validation of the year 2007 (modelled versus measured)
scale for site M3 was modified due to low fluxes
possible larger spans are caused by flux variations of the single plots of each site



Tab. 30: R_{eco}- and NEE-model validation of the year 2008 (modelled versus measured)
scale for site M3 was modified due to low fluxes
possible larger spans are caused by flux variations of the single plots of each site



4 CH_4 and N_2O exchange of a bog heath and a bog meadow

4.1 Abstract

The investigated bog close to the village Mooseurach (BY, Germany) is spilt into two parts. The bog heath was drained in the 1920s and widely restored in 1993. Except for a small stripe, the missing part was restored in 2005. Thus, three different restoration steps could be found here. The second part, the Setzberger Feld, is a meadow of 12 ha, which exists since the drainage in the 1920s. In 1993, 7 ha were rewetted by closing the drainages but management (1 cut per year) remained except of a small stripe, where *Sphagnum* mosses already established. Gas flux measurements were done with closed chambers after DRÖSLER (2005). N_2O was mainly released at the degraded sites of the Setzberger Feld (481.6 ± 165.4 to 757.6 ± 123.1 mg N m^{-2} a^{-1}), while at the restored sites, the N_2O balance was between -9.6 ± 37.9 and 86.5 ± 48.4 mg N m^{-2} a^{-1}. An intermediate position (125.6 ± 118.7 to 174.4 ± 67.2 mg N m^{-2} a^{-1}) was taken by a restored site, with resembled in the vegetation's composition more to the degraded sites. In the bog heath, N_2O balances were between -46.5 ± 97.4 and +103.1 ± 124.0 mg N m^{-2} a^{-1} without a separation in degraded or restored sites. CH_4 releases were highest on former drainages, where water tables were closest to the surface (5.93 ± 1.62 to 12.09 ± 2.83 g C m^{-2} a^{-1}). Releases of the restored sites on ridges of the Setzberger Feld ranged from 0.63 ± 0.46 to 3.16 ± 1.02 g C m^{-2} a^{-1}, at the bog heath from 1.61 ± 0.53 to 4.60 ± 1.50 g C m^{-2} a^{-1}. Sites, showing degradation or at least disturbances, had balances from -0.18 ± 0.21 to 0.34 ± 0.25 g C m^{-2} a^{-1}. In both years of measurements in 2007 and 2008, the sites showed a similar pattern in balances, although weather conditions were different.

4.2 Introduction

Restoration of peatlands leads commonly to rising CH_4 emissions, which are characteristic for undisturbed peatlands (ASELMANN AND CRUTZEN 1989, GORHAM 1991). N_2O disappears in contrast after closure of drainages and raise of water tables. While N_2O emissions are relevant only for drained peatlands, the role of CH_4 increases after rewetting. The total GHG efflux can be similar to the fluxes of drained conditions due to the radiative forcing of CH_4. CH_4 is 21-times and N_2O is 310-times more climate-charging than CO_2 (FORSTER 2007). In Germany, CH_4 contributes 5% and N_2O 6.3% to total GHG (greenhouse gas) emissions (UBA

2010). Having signed the Kyoto-Protocol, Germany committed to reducing the emissions of GHG, compared with the reference-year 1990 (UNFCCC 2007). Because balances of natural wetlands are not taken into account for GHG reports, the remaining 8% of the bogs and 3.8% of the fens do not contribute to these emissions (UNFCCC 2007, HÖPER 2007). GHG emissions of used peatlands are regarded to be 3.7 to 4.5% of the total German emissions (UBA 2010). Peatlands, which are under use, emit mainly CO_2. CH_4 coming from anoxic layers in the soil, is oxidised to CO_2 due to water tables which allow these chemical processes. Depending on the use intensity and kind of use, N_2O is emitted after the use of fertilizers. At natural peatlands, having water tables close to the surface, this oxidative soil layer is missing and CH_4 can reach the atmosphere directly. But also restored peatlands, where the water tables were raised by closing drainages or even flooding, CH_4 is to be emitted, while the N_2O emissions decrease or disappear due to the lack of oxygen. Depending on the level of the water table after restoration, the amount of CO_2, which is not emitted any more, can exceed the amount of CH_4 release.

4.3 Material and Methods

CH_4 and N_2O measurements

Measurements of CH_4 and N_2O took place every two weeks from 31st of January 2007 to 18th of March 2009. To get gas samples, opaque chambers (PVC; 78 x 78 x 50 cm^3; 11 kg), covered with a reflective insulation were let for one hour on the 36 measurement plots. A group of three plots formed a site. Thus, there were 12 sites with different water tables, restoration times and vegetation types existed, whereas six sites were located in the bog heath (M1 to M6) and six sites at the Setzberger Feld (M7 to M12) (s. chapter 2). Using six opaque chambers per area (12 in total) it was possible to measure all the sites by two persons within half a day, including preparation time. One measurement cycle needed one hour, within which four samples per plot were taken (0 min, 20 min, 40 min and 60 min). The sampling air in the chambers was drawn into evacuated glass vials (20 ml) via a removable cannula situated in a valve, which was equipped with a septum, at the top of each chamber. The evacuation of the vials was done the day before; the pressure inside the vials was measured and compared to the air-pressure before the measurement and should not have differed more than 40 mbar. After each measurement, pressure was checked again to control if the sample was taken.

Analysis of CH_4 and N_2O

Analysis of the samples, using gas chromatography, was done by the Max-Planck-Institute of Biogeochemistry (MPI-BGC) in Jena, Germany. For CH_4, a FID (flame ionisation detector) and for N_2O, an ECD (electron capture detector) was used. Additionally, CO_2 was analysed with FID, which was used due to low CO_2 concentrations. This was done, being a certain quality check for each measurement vial, because ambient CO_2 concentration was known by CO_2 gas flux measurements. For calibrations, four standards of each gas were used (s. Tab. 31).

	CH_4 [ppm]	CO_2 [ppm]	N_2O [ppb]
s1	0.50 ± 5%	300 ± 1%	301.0 ± 5%
s2	1.00 ± 5%	700.3 ± 1%	702.4 ± 5%
s3	5.02 ± 5%	1499.2 ± 1%	1004.9 ± 5%
s4	99.97 ± 5%	2997.8 ± 1%	1289.7 ± 5%
sn	*1.96*	*398*	*321*

Tab. 31: Concentrations of used calibration standards for gas analyses

s1 to *s4* show gas concentrations of the standards for CH_4, CO_2 and N_2O including standard errors; *sn* shows ambient concentrations

Flux calculation

For calculation of fluxes, a linear approach (Equation 5) with at least three points was used. Negative values were defined as uptake into the ecosystem, positive values showed enrichment in the atmosphere. As quality criterion for flux acceptation, a minimum r^2 of 0.70 was defined for CH_4 and N_2O. For CO_2 a flux was accepted with an r^2 of 0.95. Comparisons of numbers of significant CH_4 fluxes with different r^2 showed comparable proportions of more than 80% significant fluxes for r^2 of 0.6, 0.7 and 0.8. A second quality criterion was the proportion of the calculated fluxes and the ranges (max – min) of the measurement points. Tests of the used linear and non-linear approach, using the HUTCHINSON-MOSIER Regression (1981), showed no significant differences. (FREIBAUER 2010, personal communication)

$$F_{gas} = k_{gas} \times (273.15K / T_{in}) \times (V / A) \times (dc / dt) \qquad \textbf{Equation 5}$$

F_{gas} = flux of CH_4 [mg C m^{-2} h^{-1}] or N_2O [µg N m^{-2} h^{-1}]
k_{gas} = gas-constant at 273.15K (= 0.536 g C l^{-1} for CH_4 and 1.25 g N l^{-1} for N_2O)
T_{in} = initial temperature inside the chamber [K]
V = volume of the chamber [l]
A = area of one plot within the frame [m^2]
dc / dt = change of concentration per time [µl gas l^{-1} h^{-1}]

The result of the flux calculations were gas fluxes per hour. For annual balances, comparisons with CO_2 fluxes and further calculations concerning total GHG balance, the hourly balances had to be extrapolated linearly.

Environmental parameters

At the start and at the end of each measurement cycle, the temperatures of the soil at 2 cm, 5 cm and 10 cm (cut-in-thermometers; Voltcraft DET1R) and of the air inside the chamber (car-thermometers; Fa. TFA, Wertheim) were taken. Using observation wells, which were installed in the north-western corner of each frame, the water tables (WT) of each plot were taken. Electric conductivity (EC) and pH were only measured during CO_2 campaigns. Phytomass samples were collected only for the managed sites M7, M8, M10 and M12 to avoid any disturbance of the slow developing bog typical vegetation. Here, vegetation was separated into green and brown higher plants and mosses and aerenchymous plants, which are known as transporters of CH_4 via plant tissue from the roots to the atmosphere (e.g. GREENUP ET AL. (2000), SHANNON ET AL. (1994), SHANNON ET AL. (1996) FRENZEL & RUDOLPH (1998) or WHALEN (2005)). Especially *Eriophorum vaginatum* L. might be able with its below-ground biomass to act as a conductor for CH_4 realease from surrounding *Sphagnum* lawns. FRENZEL & RUDOLPH (1998). A detailed analysis of vegetation, including species cover and composition of all the sites was done from May to July 2008.

Statistical analysis

STATISTICA 6.1 was used for statistical analysis. Due to no normal distribution of data, which could not be achieved by any kind of transformation, a non-parametric test was used for comparisons between the sites. The Mann-Whitney-U-Test was done for all the site combinations and the result was transferred into the output style of ANOVA.

4.4 Results

In the bog heath, the highest mean CH_4 fluxes and balance 2007 of more almost 11 g C m^{-2} a^{-1} were detected at the *Eriophorum* dominated site M4 and the *Sphagnum* dominated formerly drained site M3 of around the half. The two other long term restored sites M5 and M6 had a low emission of less than 3 g C m^{-2} a^{-1}, while the balances of the recently restored site M2 and the not restored site M1 were around zero. M1 showed CH_4 uptakes for almost the whole year, whereas the span was similar for sites M1, M2 and M6. ALM ET AL. (1999) found comparable low fluxes or uptakes for degraded peatlands. Site M5 had an intermediate span of CH_4 and the sites on the former drainages M3 and M4 had the biggest differences between maximum and minimum fluxes. Summer balances were comparable to those of the total year for all sites and thus indicated that most of the CH_4 was emitted between May and October.

Tab. 32: CH_4 and N_2O fluxes, annual and summer balances 2007 of all sites

shown are numbers of measurements, median and mean values with referring standard deviations; letters indicate significant differences according to non-parametric test (Mann-Whitney-U-Test; p<0.05); annual balances are displayed with their standard errors and summer balances are added; different numbers of measurements were caused by rejection fluxes which did not fulfil the criteria of quality (s. 4.3 – Flux calculation)

Site	CH_4 [mgC m^{-2} h^{-1}]				CH_4 [gC m^{-2} a^{-1}]		N_2O [µgN m^{-2} h^{-1}]				N_2O [mgN m^{-2} a^{-1}]	
	n	Median	Mean ± StDev		Balance ± SE	summer	*n*	Median	Mean ± StDev		Balance ± SE	summer
M1	*51*	0.00	-0.03 ± 0.09	a	-0.18 ± 0.21	-0.10	*49*	0.0	-9.8 ± 37.9	a	-38.2 ± 82.6	-30.0
M2	*53*	0.01	0.04 ± 0.13	bc	0.29 ± 0.45	0.26	*51*	5.2	5.9 ± 45.9	ab	41.8 ± 150.9	36.3
M3	*51*	0.21	0.79 ± 1.56	d	5.93 ± 1.62	5.48	*48*	-0.1	-6.0 ± 34.5	ac	-39.2 ± 111.4	-19.4
M4	*56*	0.79	1.38 ± 1.54	e	10.89 ± 2.98	9.53	*51*	1.9	6.8 ± 34.6	ab	71.4 ± 61.7	75.0
M5	*55*	0.26	0.33 ± 0.42	d	2.82 ± 0.94	2.38	*52*	0.0	9.3 ± 60.6	a	103.1 ± 124.0	139.8
M6	*50*	0.15	0.20 ± 0.17	d	1.61 ± 0.53	1.15	*51*	0.9	3.3 ± 32.5	a	19.3 ± 75.9	23.7
M7	*52*	0.01	0.03 ± 0.08	bc	0.31 ± 0.21	0.28	*51*	32.1	66.3 ± 99.2	d	526.8 ± 188.8	427.1
M8	*54*	0.01	0.03 ± 0.07	b	0.29 ± 0.26	0.14	*52*	56.0	92.4 ± 128.6	d	666.4 ± 167.7	513.5
M9	*56*	0.66	1.45 ± 1.53	e	11.04 ± 2.60	9.94	*49*	5.0	11.5 ± 45.3	ab	84.0 ± 98.0	86.1
M10	*56*	0.79	1.18 ± 1.08	e	9.18 ± 2.24	7.25	*46*	4.9	0.9 ± 38.9	a	-1.9 ± 45.1	-12.7
M11	*56*	0.16	0.40 ± 0.54	d	3.16 ± 1.02	2.81	*49*	0.0	4.9 ± 61.1	a	45.9 ± 116.5	38.6
M12	*49*	0.03	0.09 ± 0.21	c	0.74 ± 0.60	0.67	*51*	8.8	14.3 ± 44.8	bc	140.7 ± 138.5	106.5

At the Setzberger Feld, the restored sites M9 and M10 on a former drainage had the highest mean CH_4 fluxes and total emissions, comparable to site M4. Restored site M11 also showed a certain CH_4 release while those of the degraded sites M7 and M8 and of managed site M12 were negligible. Also the spans of CH_4 fluxes were lowest for these sites. Similar to the bog heath, the sites on the former drainages showed the largest spans.

N_2O was mainly emitted by the degraded managed sites M7 and M8, which also had the highest ranges. All the other sites had moderate (M5, M9 and M12) or low N_2O emissions up to a moderate uptake of sites M1 and M3. Like for CH_4, also for N_2O the main part of the balances was limited on summer.

Tab. 33: CH_4 and N_2O fluxes, annual and summer balances 2008 of all sites

shown are numbers of measurements, median and mean values with referring standard deviations; letters indicate significant differences according to non-parametric test (Mann-Whitney-U-Test; $p<0.05$); annual balances are displayed with their standard errors and summer balances are added; different numbers of measurements were caused by rejection fluxes which did not fulfil the criteria of quality (s. 4.3 – Flux calculation)

Site	CH_4 [mgC m^{-2} h^{-1}]				CH_4 [gC m^{-2} a^{-1}]		N_2O [µgN m^{-2} h^{-1}]				N_2O [mgN m^{-2} a^{-1}]	
	n	Median	Mean ± StDev		Balance ± SE	summer	*n*	Median	Mean ± StDev		Balance ± SE	summer
M1	*66*	0.00	0.00 ± 0.03	a	-0.03 ± 0.08	0.00	*69*	5.0	6.5 ± 13.1	b	47.9 ± 40.4	38.5
M2	*67*	0.02	0.04 ± 0.06	c	0.34 ± 0.25	0.23	*68*	0.8	2.6 ± 8.2	ab	23.1 ± 28.5	22.5
M3	*70*	0.33	0.70 ± 1.33	ef	6.20 ± 3.50	5.41	*72*	0.0	0.6 ± 7.2	a	4.8 ± 28.9	9.2
M4	*71*	0.68	0.86 ± 0.74	g	7.58 ± 1.57	5.86	*72*	4.6	3.7 ± 8.5	b	30.5 ± 34.2	19.1
M5	*71*	0.29	0.51 ± 0.55	e	4.60 ± 1.50	3.69	*72*	3.9	5.1 ± 6.5	b	45.5 ± 22.7	35.6
M6	*70*	0.22	0.31 ± 0.35	de	2.69 ± 1.19	2.06	*72*	4.8	5.4 ± 7.3	b	47.8 ± 23.2	39.1
M7	*70*	0.01	0.03 ± 0.07	c	0.30 ± 0.18	0.24	*72*	32.0	56.3 ± 65.9	d	482.1 ± 165.6	203.7
M8	*71*	0.00	0.01 ± 0.04	b	0.09 ± 0.14	0.05	*70*	50.9	76.9 ± 81.6	d	646.9 ± 256.5	366.3
M9	*72*	0.84	1.32 ± 1.15	h	12.09 ± 2.84	9.66	*72*	3.8	5.1 ± 11.5	b	46.7 ± 42.0	40.9
M10	*71*	0.71	0.92 ± 0.86	gh	8.28 ± 2.71	6.53	*72*	2.6	2.9 ± 9.0	b	26.0 ± 30.9	28.5
M11	*72*	0.14	0.25 ± 0.38	d	2.31 ± 1.04	1.98	*72*	4.2	0.8 ± 26.2	a	4.5 ± 58.0	-1.8
M12	*70*	0.02	0.07 ± 0.12	c	0.63 ± 0.46	0.59	*72*	12.8	19.1 ± 21.7	c	174.2 ± 67.5	133.5

In 2008, the distribution of fluxes (CH_4 and N_2O) was confirmed, although there were some differences of total values, especially for sites M3 and M4, which showed similar fluxes and balances in contrast to the year before. We also detected the highest CH_4 efflux of the bog heath here, followed by the also restored sites M5 and M6 while the degraded sites M1 and M2 did not have remarkable fluxes. At the Setzberger Feld, highest CH_4 releases were detectable for the restored sites M9 and M10 on former drainages, followed by the restored, non-managed site M11. The degraded sites M7, M8 and the restored site M12 on the ridge showed the lowest mean fluxes (< 0.1 mg C m^{-2} h^{-1}) and annual balances (< 1.0 g C m^{-2} a^{-1}). Generally, CH_4 fluxes were lower in 2008 than in 2007 for most of the sites.

N_2O fluxes did not show such a reduction. Their habitude was more accidental, but there were no sites with uptakes as in 2007. Highest releases and ranges were reached by the degraded sites M7, M8 and reduced by the restored site M12, while the mean fluxes for all other sites were below 10.0 µg N m^{-2} h^{-1} and annual releases were below 50.0 mg N m^{-2} a^{-1}. Compared to the spans of the CH_4 fluxes, which were similar in both years, the N_2O fluxes had a much lower span; partly four times lower than the year before. This could also be recognized at the single plots.

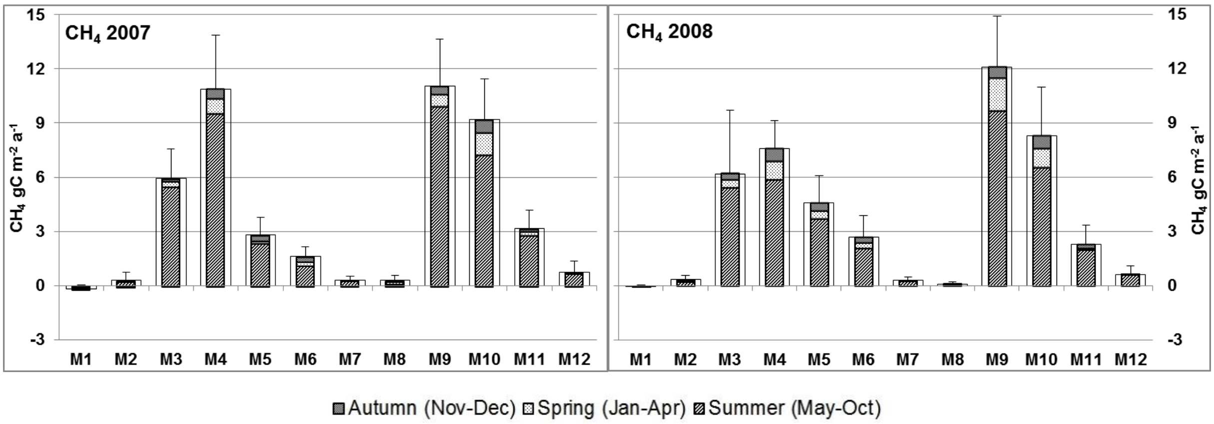


Fig. 20: **CH_4 balances 2007 and 2008 with seasonal proportions**
spring period: 1st of January until 30th of April
summer period: 1st May until 31st of October; wide bars show annual balances
autumn period: 1st of November until 31st of December

At the sites with remarkable CH_4 effluxes of more than 2 g C m^{-2} a^{-1}, the proportion of the winter CH_4 balances had a span of 6% to 20% in both years (s. Fig. 20, annex Fig. 29 and Fig. 30). ALM ET AL. (1999) found winter proportions of around 22% of annual CH_4 emissions for Finnish peatlands. For the other sites with no continuous fluxes, the proportions of winter and summer balances were distributed randomly. While differences in CH_4 fluxes were relatively high for the sites M3 / M4 to M5 / M6 in 2007, there seems to be a flux gradient from the sites on the drainages M3 (rest. 2005) and M4 to those on the ridges M5 and M6 (all rest. 1993). A second gradient was visible for sites M9 to M10 and M11 to M12, which separated the managed and non-managed restored sites.

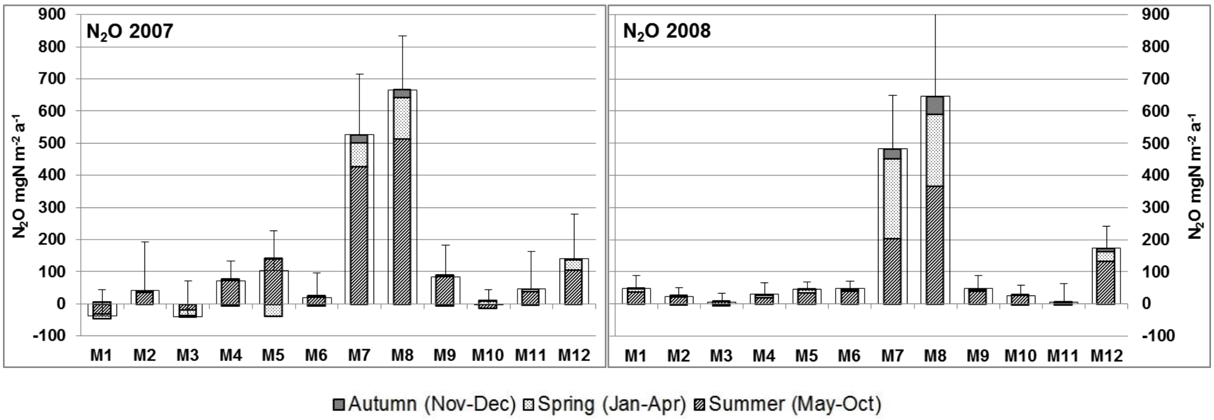


Fig. 21: **N_2O balances 2007 and 2008 with seasonal proportions**
spring period: 1st of January until 30th of April
summer period: 1st May until 31st of October; wide bars show annual balances
autumn period: 1st of November until 31st of December

In contrast to the CH_4 balances, which showed a more distinguished distribution, N_2O was present in relevant concentrations only at the managed degraded sites M7 and M8 and, with deductions, at site M12 in both years and all seasons (s. Fig. 21). Remarkable uptakes of N_2O were detectable only in 2007 at the degraded site M1, limited to summer, and the short-term restored site M3 for the whole year. The other sites did not show relevant, continuous fluxes.

In 2008, there was no remarkable uptake at any site and any time. While the seasonal N_2O emissions of site M12 were similar in both years, sites M7 and M8 showed a different pattern of seasonal balances. The proportions of winter N_2O effluxes were highly elevated in 2008 (43% to 58% in spite of 19% to 23% in 2007), especially for months March and April (see also Fig. 29 and Fig. 30). Thus, the N_2O summer balances exceeded those of winter with two exceptions, site M7 and site M11 in 2008, but total emissions of this site was negligible.

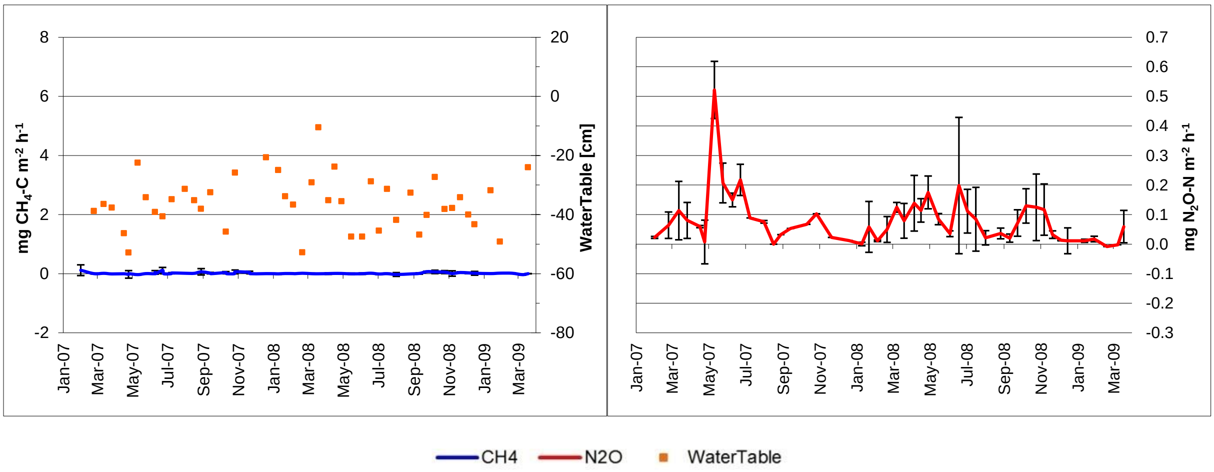


Fig. 22: Campaign based mean CH_4 and N_2O fluxes and water tables of the degraded site M8
error bars show site variability based on plot measurements

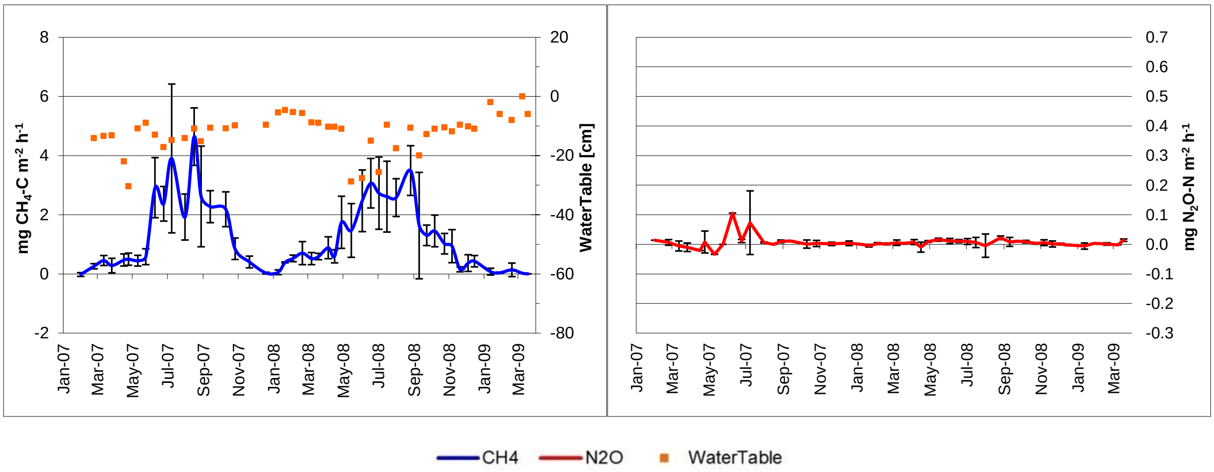


Fig. 23: Campaign based mean CH_4 and N_2O fluxes and water tables of the restored, non-managed site M9
error bars show site variability based on plot measurements

The chronological sequences of the sites M8 and M9 are displayed in Fig. 22 and Fig. 23 because they mark the edges of the possible flux characteristics. The degraded site M8 on a drainage with mean water tables below -20 cm had no CH_4 emissions, whereas N_2O was emitted nearly all over the year. N_2O fluxes were highest between May and July and lowest between December and February in both years. In contrast to this site, N_2O fluxes were detected at the restored, non-managed site M9 from June to September, but on a low level. This site, having had water tables around -10 cm, was a constant source for CH_4. Highest effluxes were detected between June and September / October, depending on the year. Almost no emissions were found from December until March. In between these periods, there was a slow rise of fluxes in spring and a similar decline in autumn.

4.5 Discussion

The most important driving factor for CH_4 emissions was the water table. In 2007 and 2008, CH_4 was emitted at those sites with water tables around -15 cm or closer to the surface (s. Fig. 24). In both years, there was a significant ($p<0.05$) relationship between CH_4-C balances and mean water tables. In a depth of around 15 cm, CH_4 started to be emitted. The highest emissions were detectable between 10 cm and 15 cm. The plotwise comparison of the mean fluxes and the water tables showed also significant relationships (2007: $r^2=0.360$***; 2008: $r^2=0.447$***).

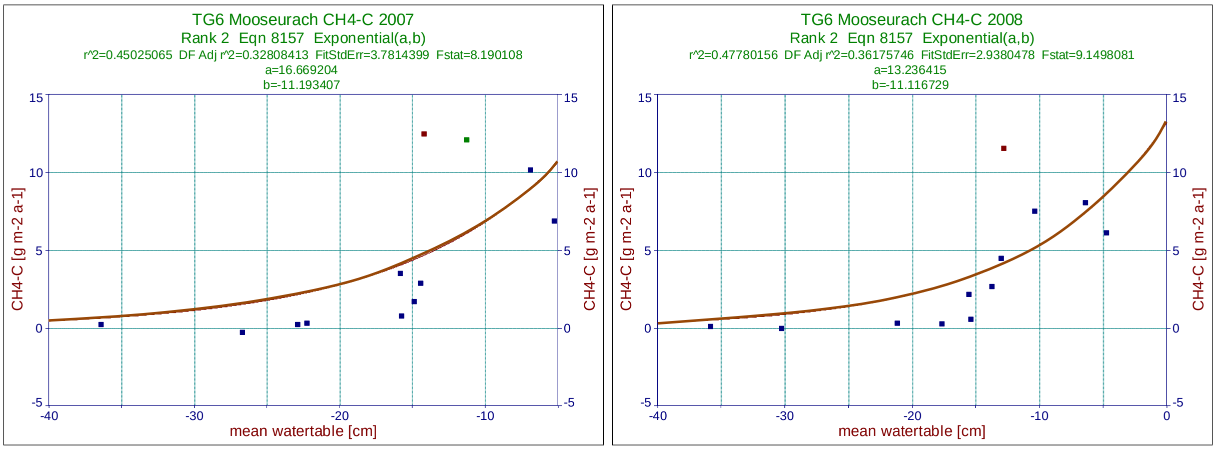


Fig. 24: Exponential relationship between CH_4-C balances and annual mean water tables in 2007 and 2008

$p<0.001$; fitting was done with TableCurve 2D

As DINSMORE ET AL. (2009) mentioned soil temperature is another driving factor for CH_4 fluxes. SHANNON ET AL. (1994) also found a strong correlation between CH_4 fluxes and peat temperatures. In both years, there were found exponential dependencies from 0.3587*** to 0.5853*** between CH_4 fluxes and soil temperatures. These results suggest a multiple dependency between water tables, soil temperatures and CH_4 fluxes, which could be found for the sites with relevant CH_4 emissions (s. Fig. 25). Multiple R (CH_4 / water table and soil temperature) ranged from 0.4835*** to 0.7467***.

Other dependencies in comparable ranges were found between CH_4 and CO_2, which was sampled instantly with CH_4 and N_2O, and water table resp. soil temperature. Multiple R for CH_4, CO_2 and water table had a span from 0.4825*** to 0.8035***, for CH_4, CO_2 and soil temperature from 0.5308*** to 0.8215***.

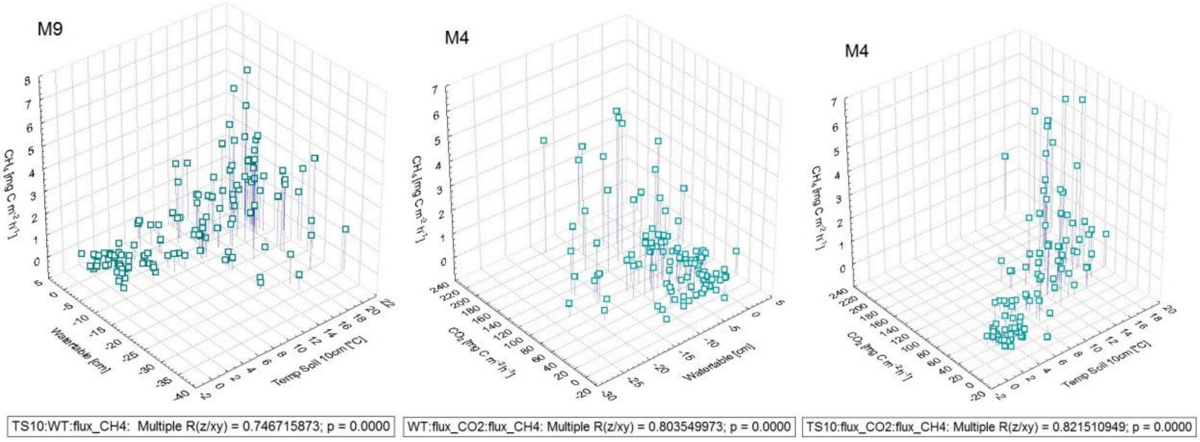


Fig. 25: Multiple relationships between CH_4 fluxes (z-axes) with WT and soil temperature (l), WT and CO_2 fluxes (m) and CO_2 fluxes and soil temperature (r)
fitting was done with Statistica 6.1

Whiting and Chanton (1993) found also a dependency of CH_4 emissions and primary production. The analysis of daily CH_4 balances and corresponding gross primary production (GPP) balances had as results correlations of -0.4084*** to -0.7534*** (Pearson) at the sites with remarkable CH_4 emissions. The correlation coefficients were even higher for the maximum GPP (GP_{max}) at indefinite photosynthetically active radiation (PAR) with -0.5962*** to -0.7995***. Multiple analyses were applied to include soil temperatures or water tables, whose influences were shown above. The multiple R (z/xy) ranged from 0.6026*** to 0.8383*** for CH_4, GPP and soil temperatures and from 0.4023*** to 0.8292*** for CH_4, GPP and water tables.

As another CH_4 driving parameter the percentage of plants with aerenchymatic tissue could be identified (s. Fig. 26 and chapter 2.2.4). This corresponded to Couwenberg et al. (2009), who called gas conductive plant tissue the best proxy for CH_4 emissions at high water tables.

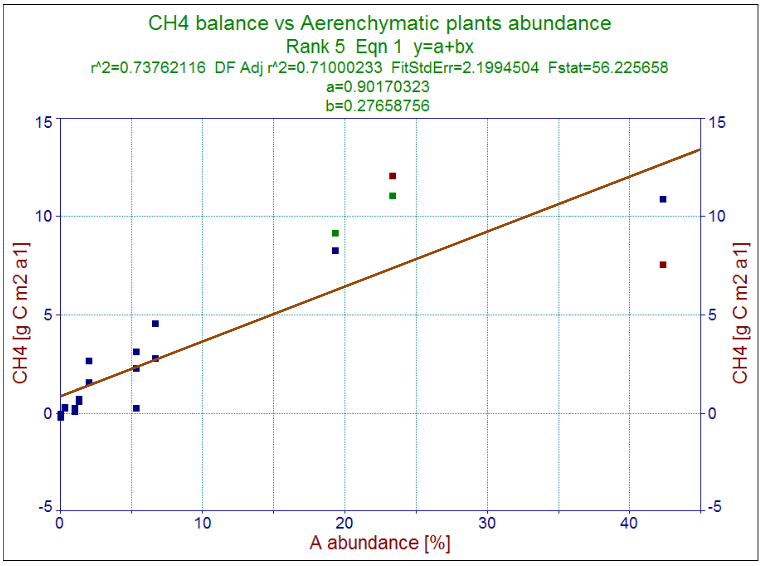


Fig. 26: Annual CH_4-C balances in dependency of abundance of plants with aerenchymatic tissues
$p<0.001$; fitting was done with TableCurve 2D

Sites with the highest CH_4-C balances and aerenchymatic content was *Eriophorum* dominated site M4 followed by restored sites on former drainages M9 and M10, dominated by *Sphagnum fallax* H. Klinggr.. BEYER AND HÖPER (2014) identified CH_4 balances between 16 and 24 g CH_4-C m^{-2} a^{-1} for some *Eriophorum* sites of a flooded restored bog in Lower Saxony which were Hot Spots for CH_4 releases due to *Eriophorum* dominance and almost permanent water overflow. GREENUP (2000) identified comparable mean CH_4 fluxes for *Eriophorum* dominated sites. DRÖSLER (2005) found similar fluxes close to zero for some degraded bog sites but even three times higher fluxes and annual balances for natural like *Sphagnum* hollows, restoration led to risen water tables and remarkable CH_4 emissions similar to our transitional sites. In general, the measured fluxes were in the same scale like those many other studies identified for bog ecosystems (BUBIER ET AL. 1993 and 1995, ROULET & MOORE 1995, NYKÄNEN ET AL. 1998, BELLISARIO ET AL. 1999, CHRISTENSEN ET AL. 2000 or JOABSSON & CHRISTENSEN 2001, HENDRICKS ET AL. 2007).

As explanation parameter for CH_4 releases, water tables are commonly used but often they are not sufficient to explain variances between sites with similar water tables. Thus, we created two three-dimensional models (Fig. 27) with mean water tables and abundance of plants with aerenchymatic tissue as explanation factors for CH_4 balances of the measurement plots and sites.

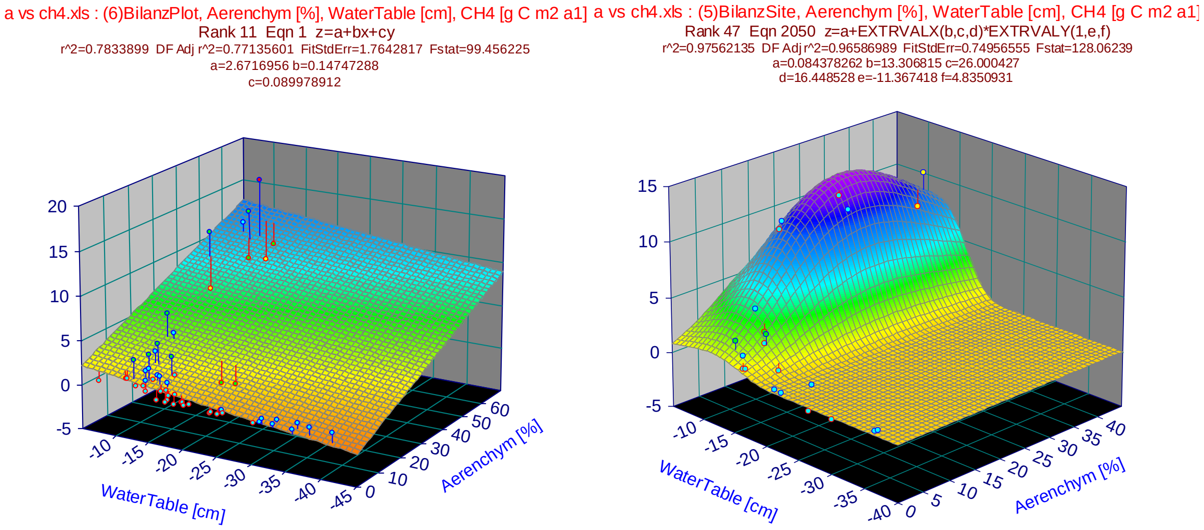


Fig. 27: Annual CH_4-C balances in dependency of abundance of plants with aerenchymatic tissues and annual mean water tables

CH_4 balances of plots (left) rise linear with lower water tables and rising numbers of aerenchymatic plants; the dependency of CH_4 balances of the sites (right) follow a more complex function

$p<0.001$; fitting was done with TableCurve 2D

This very simple approach showed a significant dependency ($r^2 = 0.7834^{***}$) between annual CH_4 balances of the plots, annual mean water tables and the content of aerenchymatic vegetation, dominated by fen-sedges. The second approach based on annual CH_4 balances of the sites showed a more distinct dependency ($r^2 = 0.9756^{***}$) with CH_4 appearing at water tables above -15 cm and maximum balances when the abundance of aerenchymatic plants was between 25% and 45%.

The degraded sites M7 and M8 of the Setzberger Feld and the sites M1 (degraded) and M2 (rest. 2005) of the bog heath had no remarkable CH_4 emissions. The soil's pore space was large enough to allow oxidation of upwelling CH_4 from the peat at these sites. DUECK ET AL. (2007) showed that under aerobic conditions, plants cannot emit CH_4 in a remarkable amount, and such conditions were given most of the time at these four sites. A certain uptake, mainly detected for site M1 in 2007, could also be explained by oxidation processes of CH_4 (ALM ET AL. 2007), which were even enforced by the specific structure with ditches and ridges. SHANNON ET AL. (1994) identified at shrub sites consumption rates from -0.2 to 1.5 mg CH_4 m^{-2} d^{-1}. The restored managed site M12 showed a similar behaviour as the sites M7 and M8. This was caused by the range of its water table, which reached depths of -30 to -40 cm, similar to site M2. Additionally, the vegetation composition with *Anthoxanthum odoratum* L. s. str. and *Climacium dendroides* (Hedw.) F. Weber. & Mohr was more similar to those of sites M7 and M8 than to site M10, which differed at the start of the project only by water table, being closer to the surface, but not by vegetation. Site M10 was populated during the measurement period by *Sphagnum fallax* H. Klinggr., which was already established at the non-managed sites M9 and M11. *Carex* species were found at all four sites M9 to M12. CH_4 emissions rose therefore due to a combination of water tables close to the surface with low ranges and a vegetation mainly composed by *Sphagnum fallax* H. Klinggr., *Carex canescens* L. and *Carex nigra* (L.) Reichard. SEBACHER ET AL. (1985) detected the highest CH_4 emissions (> 1 mg d^{-1}) and contents in their stems for aquatic plants with soft epidermal tissues, but still remarkable emission (< 1 mg d^{-1}) and contents for plants with hard epidermic tissues like *Juncus effusus* L. Especially *Carex* species, like other aerenchymous plants, are able to transport CH_4 actively from their root space via the plants body to the air (e.g. SEBACHER ET AL. 1985, DINSMORE ET AL. 2008). The sites M3 and M4 were comparable to the sites M9 and M11 due to their position on former drainages and therefore water tables close to the surface. Site M4 was the most important CH_4 emitter, being nearly full covered with *Eriophorum vaginatum* L. and *Sphagnum* mosses in the ground layer, which empowered the CH_4 release. Being populated by *Sphagnum* mosses after restoration in 2005, site M3 emitted less CH_4 than M4 but was one of the most important sources of the bog heath, followed by the sites M5 and M6 on the ridges of the bog. The separation of big (M3 and M4) and small (M5 and M6) CH_4 emitters was more distinct in 2007 than in 2008 due to a better separation of water tables and much lower ranges in 2007. Vecherskaya et al. (1993) or Whalen et al. (1996) reported high rates of CH_4 oxidation in *Sphagnum* moss layers, which was not proved in this study, but lower emission rates at site M3 in comparison to site M4 suggest that an oxidative effect might be possible. Basiliko et al. 2004 identified highest CH_4 oxidation rates for such locations with water table at moos layers. Larmola et al. (2010) found reduced oxidation rates after times with missing precipitation which was remarkable in spring 2007. The reduction of CH_4 release of site M4 in 2008 was driven by lower and more fluctuating water tables while the sites M5 and M6 benefited from buffered water tables on the ridges, which led to higher CH_4 releases in 2008.

Generally, the *Sphagnum* populated sites with mean water tables less than -15 cm were CH_4 sources, whereas the amount of gas emissions depended on the vitality of the vegetation, especially the *Sphagnum* mosses and the aerenchymous plants, and fluctuations in water tables.

For N_2O it was not possible to find such a well explainable dependency. This was caused by extremely low fluxes and hence calculated balances, which are common for undisturbed peatlands. Comparable low emissions or small uptakes were found by Martikainen et al. (1993), Drösler (2005), Hendricks et al. (2007) or Beyer et al. (2014). N_2O-N balances for both years showed a significant correlation with water tables, but having had only two sites with fluxes significantly differing from zero, these two mean fluxes created an exponential dependency in both years (2007: $r^2=0.76^{***}$; 2008: $r^2=0.45^{*}$) while all other fluxes ranged around the base line. A plotwise comparison did not have significant relationships due to big spans between the fluxes of the plots (Fig. 28).

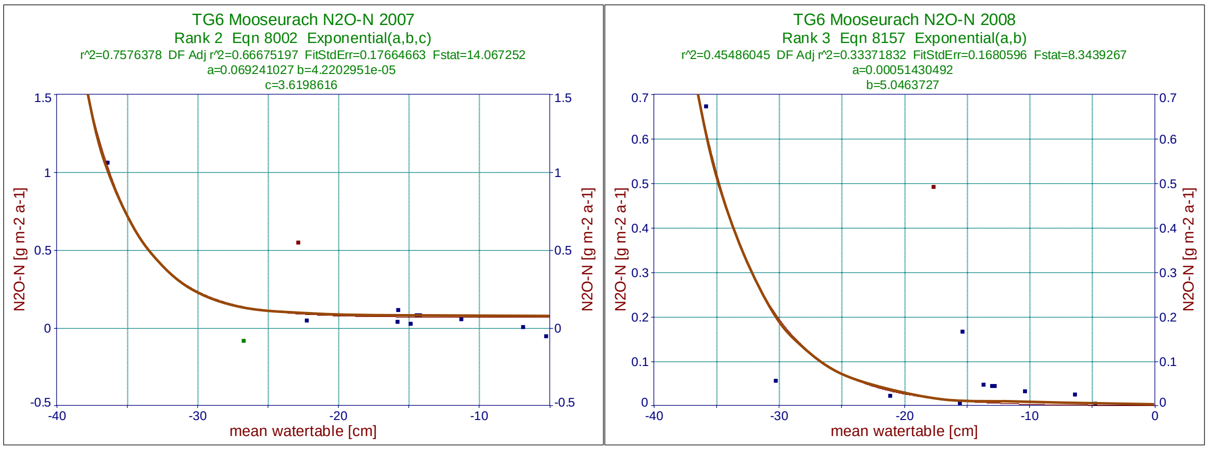


Fig. 28: Exponential relationship between mean N_2O-N fluxes and water tables in 2007 (left) and 2008 (right)

$p<0.001$; fitting was done with TableCurve 2D

Three dimensional analyses of N_2O fluxes and their dependencies to CO_2 fluxes and water tables had multiple R from 0.2648* to 0.5491***. Further analyses with soil temperatures were at the same range with multiple R between 0.2469* and 0.5324***.

N_2O, emitted mainly by the degraded sites M7 and M8 of the Setzberger Feld, was negligible for all other sites. Values were remarkable higher than those of some degraded sites found by DRÖSLER (2005) in another Bavarian bog. Only the emissions of the managed restored site M12 were comparable to the emissions at DRÖSLER (2005). Even mean winter emissions were higher for these sites than mean annual emissions for the other sites. Uptake of N_2O, which was detected several times in 2007, can be explained by the process of denitrification by anaerobic prokaryotes to release energy in a nutrient poor environment of a bog. Due to more fluctuating water tables in 2008, the anaerobic soil space changed faster than in 2007 and therefore, anaerobic conditions could not be guaranteed for these bacteria. Significant correlations of mean N_2O fluxes and water tables (2007: 0.223**; 2008: 0.334***) indicated that a bigger pore space led to higher N_2O emissions. Especially after a very dry spring in 2007 with water tables ¼ lower than the annual average, N_2O was also emitted from nearly all sites. For degraded site M1 this had to be denied where a bigger pore space, caused by a lower water table, led to a higher N_2O uptake. Site M1 was populated with a vital *Calluna vulgaris* (L.) Hull, whose symbiosis with mycorrhiza guaranteed their N supply. Additionally, the soil was compressed by soil settlements, which caused anaerobic areas. N uptake by mycorrhiza led to N deficit which was compensated by denitrification processes of prokaryotes. Also the soil of the *Calluna* populated site M2 was not as compressed as it was at site M1, where the vitality of prokaryotes was possibly reduced in 2008 due to a water table farther from the surface. Therefore, there was no N_2O uptake at site M2 and at site M1 in 2008. Winter uptakes, which appeared only at the *Sphagnum* populated sites in 2007, were caused by deposition effects during a warm, snowless winter.

4.6 Conclusion

CH_4 emissions of the degraded sites were negligible in both years with balances between -0.18 ± 0.21 g C m^{-2} a^{-1} and 0.31 ± 0.21 g C m^{-2} a^{-1}. In the bog heath and at the Setzberger Feld, highest CH_4 emissions were measured at the sites whose water tables were close to the surface (0 to -15 cm). All these sites were populated *Sphagnum rubellum* Wils., which is regarded as a symbiosis with methanotrophic bacteria, like all other *Sphagnum* species (LARMOLA ET AL. 2010). Differences in CH_4 balances were mainly caused by their plants composition and not by their water tables. Sites with similar water tables differed nevertheless in their CH_4 balances. *Carex* populated sites (M9 and M10) at the Setzberger Feld emitted slightly more CH_4 (8.28 ± 2.70 to 12.09 ± 2.83 g C m^{-2} a^{-1}) than sites M3 and M4 of the bog heath with *Eriophorum vaginatum* L. or different *Sphagnum* species (5.93 ± 1.62 to 10.89 ± 2.98 g C m^{-2} a^{-1}). Differences were more intense when water table oscillations were higher, like in 2008.

N_2O emissions greater than 100 mg N m^{-2} a^{-1} in both years, were only detectable for degraded cut sites and one restored cut site, whose plants composition was very similar to the degraded sites and which somehow benefited from fertilization until the 1980s (BERNRIEDER 2009, oral communication). The moister sites had N_2O fluxes and balances comparable to the sites of the bog heath which did not show significant differences ($p>0.05$) in fluxes and annual balances in 2007 and 2008. At the bog heath, N_2O fluxes could be regarded as negligible due to no preceding fertilization.

Generally the number of sites with relevant N_2O fluxes was too low to deduce driving parameters from the results found. But N_2O was not the main focused GHG. N_2O fluxes were taken to get annual balances for GHG balances, which are discussed in chapter 5. The much more relevant greenhouse gas was CH_4.

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Annex CH_4 and N_2O

Tab. 34: Mean CH_4 and N_2O fluxes per plot of 2007 and 2008

Standard deviations are added; different numbers of measurements (*n*) are caused by insignificant fluxes, which had to be rejected;
plot 20 was omitted after May 2008 due to destruction and replaced by plot 20b

Site	Plot	CH_4 2007			N_2O 2007			CH_4 2008			N_2O 2008		
		[mg C $m^{-2}h^{-1}$]			[µg N $m^{-2}h^{-1}$]			[mg C $m^{-2}h^{-1}$]			[µg N $m^{-2}h^{-1}$]		
		n	Mean	StDev	*n*	Mean	StDev	*n*	Mean	StDev	*n*	Mean	StDev
M1	1	*18*	-0.04	± 0.09	*16*	-14.4	± 41.7	*23*	0.00	± 0.02	*23*	4.1	± 8.2
	2	*15*	-0.02	± 0.12	*16*	-2.0	± 36.2	*22*	0.00	± 0.03	*23*	13.0	± 19.0
	3	*18*	-0.03	± 0.08	*17*	-13.0	± 36.7	*21*	0.00	± 0.02	*23*	2.3	± 5.8
M2	4	*17*	0.05	± 0.18	*16*	7.3	± 51.0	*23*	-0.01	± 0.02	*22*	-0.1	± 7.9
	5	*19*	0.02	± 0.09	*18*	-0.1	± 37.5	*21*	0.09	± 0.06	*23*	4.3	± 9.0
	6	*17*	0.04	± 0.12	*17*	11.1	± 50.8	*23*	0.04	± 0.04	*23*	3.5	± 7.2
M3	7	*15*	0.46	± 0.62	*15*	-4.6	± 17.2	*24*	0.90	± 1.12	*24*	1.8	± 7.7
	8	*17*	0.75	± 1.90	*16*	4.8	± 39.5	*24*	1.06	± 1.42	*24*	2.6	± 6.0
	9	*19*	1.07	± 1.75	*17*	-17.4	± 38.9	*22*	0.10	± 1.29	*24*	-2.7	± 6.8
M4	10	*19*	0.98	± 1.00	*17*	6.0	± 35.5	*24*	0.75	± 0.70	*24*	2.0	± 8.7
	11	*19*	1.66	± 1.94	*17*	2.2	± 32.6	*24*	0.94	± 0.85	*24*	5.2	± 9.5
	12	*18*	1.52	± 1.54	*17*	12.2	± 36.8	*23*	0.89	± 0.67	*24*	4.0	± 7.3
M5	13	*18*	0.20	± 0.31	*19*	30.9	± 86.4	*24*	0.43	± 0.31	*24*	5.5	± 5.7
	14	*19*	0.27	± 0.36	*16*	-13.2	± 33.0	*23*	0.34	± 0.34	*24*	3.3	± 5.8
	15	*18*	0.53	± 0.51	*17*	6.3	± 34.7	*24*	0.77	± 0.77	*24*	6.5	± 7.7
M6	16	*16*	0.15	± 0.21	*18*	4.9	± 39.9	*23*	0.13	± 0.27	*24*	6.2	± 7.3
	17	*18*	0.25	± 0.17	*18*	10.0	± 34.1	*24*	0.49	± 0.43	*24*	5.4	± 8.1
	18	*16*	0.19	± 0.13	*15*	-6.7	± 16.3	*23*	0.29	± 0.20	*24*	4.7	± 6.8
M7	19	*18*	0.01	± 0.09	*18*	76.9	± 95.1	*23*	0.01	± 0.03	*24*	75.0	± 74.0
	20	*16*	0.02	± 0.04	*15*	29.2	± 50.1	*9*	0.00	± 0.01	*9*	89.8	± 101.2
	20b		installed in 2008			installed in 2008		*15*	0.07	± 0.04	*15*	21.9	± 16.6
	21	*18*	0.06	± 0.10	*18*	86.7	± 126.8	*23*	0.05	± 0.10	*24*	46.6	± 50.4
M8	22	*17*	0.04	± 0.08	*16*	118.7	± 136.1	*23*	-0.01	± 0.03	*24*	128.8	± 105.5
	23	*19*	0.02	± 0.04	*18*	86.0	± 137.3	*24*	0.03	± 0.03	*23*	46.5	± 43.3
	24	*18*	0.03	± 0.08	*18*	75.5	± 115.9	*24*	0.02	± 0.03	*23*	53.1	± 53.4
M9	25	*19*	1.44	± 1.39	*17*	10.9	± 54.2	*24*	1.65	± 1.41	*24*	8.5	± 9.1
	26	*19*	1.00	± 1.11	*17*	12.8	± 49.9	*24*	1.00	± 0.81	*24*	3.4	± 15.4
	27	*18*	1.93	± 1.95	*15*	10.6	± 28.8	*24*	1.31	± 1.11	*24*	3.5	± 8.6
M10	28	*18*	0.87	± 0.81	*15*	-6.5	± 50.0	*24*	0.92	± 0.75	*24*	6.1	± 8.8
	29	*19*	1.34	± 1.13	*16*	6.5	± 24.3	*23*	0.58	± 0.34	*24*	1.1	± 10.7
	30	*19*	1.31	± 1.24	*15*	2.2	± 40.5	*24*	1.25	± 1.17	*24*	1.5	± 6.6
M11	31	*19*	0.20	± 0.29	*18*	13.2	± 76.5	*24*	0.08	± 0.15	*24*	-6.1	± 44.0
	32	*19*	0.55	± 0.67	*14*	1.0	± 46.1	*24*	0.44	± 0.55	*24*	4.3	± 7.3
	33	*18*	0.46	± 0.54	*17*	-0.7	± 56.0	*24*	0.22	± 0.24	*24*	4.3	± 7.2
M12	34	*17*	0.13	± 0.29	*18*	25.4	± 32.4	*23*	0.07	± 0.10	*24*	26.0	± 31.5
	35	*18*	0.13	± 0.16	*16*	14.4	± 47.9	*24*	0.13	± 0.15	*24*	10.8	± 9.0
	36	*14*	-0.01	± 0.12	*17*	2.4	± 52.2	*23*	0.00	± 0.04	*24*	20.6	± 16.1

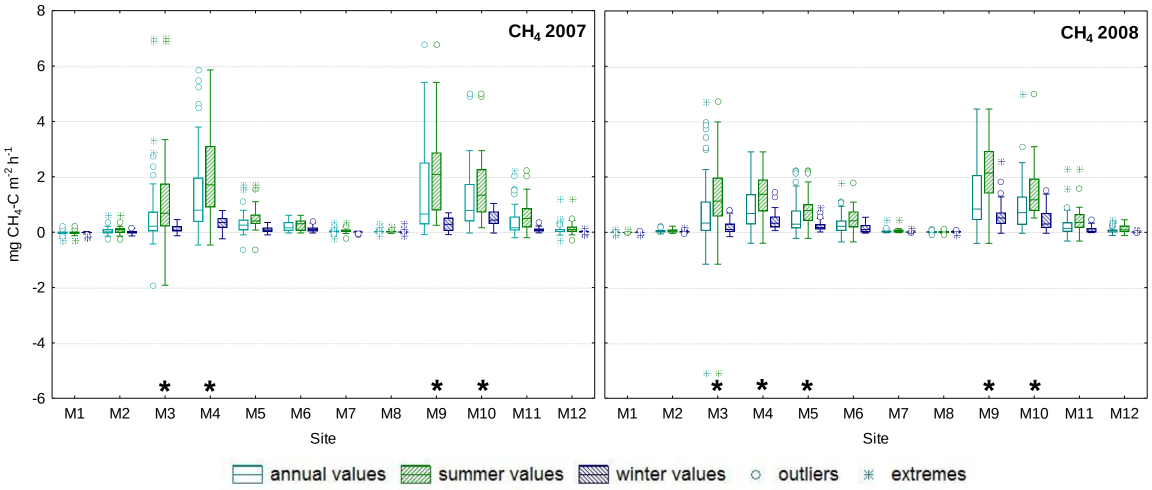

Fig. 29: Box Plots of CH_4 fluxes of the total years, summer and winter half-year

summer month were from May until October; winter month were from November until April; *: significant differences (Bonferroni; p<0.001) between winter and summer

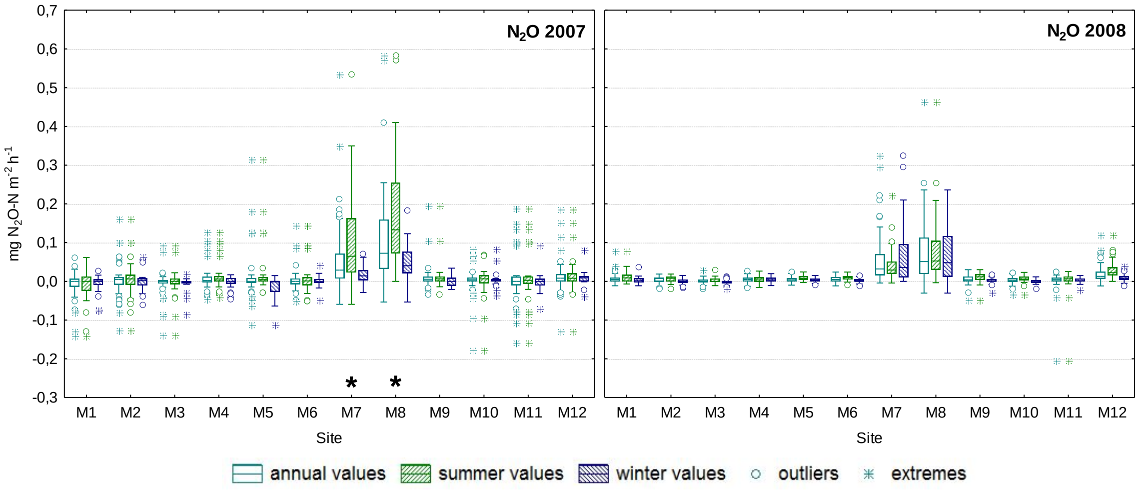

Fig. 30: Box Plots of N_2O fluxes of the total years, summer and winter half-year

summer month were from May until October; winter month were from November until April; *: significant differences (Bonferroni; p<0.001) between winter and summer; extreme values in 2007 were mainly caused by long time gap between sample taking and analysis; in 2008 no significant difference could be detected at any site

5 The greenhouse gas balance of a bog heath and a bog meadow in the foreland of the Bavarian Alps

5.1 Abstract

Whether peatlands are sinks or sources for GHG depend on their water tables, the land-use history and the vegetation. With decreasing intensity of use, GHG emissions go down in most of the time. Ending the use and / or rewetting are able to reduce these emissions up to neutral conditions or to turn peatlands into sinks for GHG again. This shift of use goes along with a change in vegetation.

The investigated bog areas of Mooseurach separated into two types concerning their land-use history, their vegetation and thus, their GHG fluxes. The gas flux measurements were done continously for two years. At the relatively undisturbed bog heath, we analysed a chronosequence in restoration which already led to different water tables and vegetation types. The degraded *Calluna* heath site emitted 203 to 374 g CO_2- C_{eq} m^{-2} a^{-1}, the short term rewetted site with few *Sphagnum* and *Calluna* heath emitted 230 to 557 g CO_2-C_{eq} m^{-2} a^{-1}; the long term restored sites with established *Sphagnum* lawns emitted 182 to 264 g CO_2- C_{eq} m^{-2} a^{-1} the one year and had almost neutral balances in the other year with lower water table oscillations. Balances around zero were detected for an *Eriophorum* dominated site on a former ditch, too. A recently restored site on another ditch with *Sphagnum* hummocks was the most effective sink for GHG (-86 to -189 g CO_2-C_{eq} m^{-2} a^{-1}). CH_4 emissions on the ditches were almost double (45 to 83 g CO_2-C_{eq} m^{-2} a^{-1}) than on the sites with *Sphagnum* lawns.

At the second area, a bog meadow, a rewetting- and management-gradient was analysed. The most elevated emissions were measured at the degraded sites (359 to 736 g CO_2-C_{eq} m^{-2} a^{-1}). Differences between the sites of almost 50% GHG were caused by their position on ridges or drainages, which highly influenced their water tables. Rewetting reduced the emissions on the ridges (112 to 380 g CO_2-C_{eq} m^{-2} a^{-1}) but reduction was much more effective on the former drainages (-51 to +88 g CO_2-C_{eq} m^{-2} a^{-1}) due to rises of water tables up to the surface. Here CO_2 releases were reduced dramatically but replaced by certain CH_4 releases (63 to 70 g CO_2-C_{eq} m^{-2} a^{-1}). Ending the management led to an establishment of a fast expanding *Sphagnum fallax* H. Klinggr. community and GHG uptakes from -59 to -216 g CO_2-C_{eq} m^{-2} a^{-1}. On the ridges CH_4 emissions were three times lower than on the drainages, whereas the CO_2 balances were comparable. Thus, GHG uptakes were most elevated for the sites on the ridges but detectable for all rewetted sites, where the management ended and a *Sphagnum* community established.

5.2 Introduction

Peatlands cover around 3% of global terrestrial land surface but store 20% of the terrestrial carbon (TURUNEN ET AL. (2002), JOOSTEN (2010). In Germany, almost 75% of peatlands are fens and less than 25% are bogs. But only 5% are still undisturbed or restored. (HÖPER 2007) Assuming German emissions from peatlands of 8.4 Mio t per year, German peatlands contribute 2.8% to the German anthropogenic GHG emissions.

Drainage, agricultural use and peat-cutting reduced the amount of carbon stored in the peatlands for centuries. On the other hand, the human impact on climate change which will lead to higher temperatures and changes in precipitation. Changes in regional climate can affect peatlands and turn them into sources for GHG (e.g. STRACK 2008). Thus, whether they were influenced by men or not, peatlands contribute to the atmospheric GHG budget in a mentionable amount (KETTUNEN ET AL. 1999, DRÖSLER ET AL. 2008 or OJANEN ET AL. 2010). Restored peatlands contribute mentionable amounts to total GHG emissions via CH_4 releases. On the other hand, oxidative processes are reduced by natural like water tables.

We wanted to investigate with this study in which amount rewetting of a bog heath and a bog meadow of the Bavarian pre-alps influences the single GHG fluxes and the GHG balances. Additionally, we investigated the influence of management on GHG balances before and after rewetting of some bog meadow sites.

5.3 Material and Methods

The measurements of the fluxes of the three greenhouse gases CO_2, CH_4 and N_2O were performed with closed chambers according to DRÖSLER (2005). The CO_2 measurements took place every three to four weeks, CH_4 and N_2O measurements were done bi-weekly. Additionally, water tables, electrical conductivity and pH of all 36 plots were taken every measurement day. A weather station, located close to the measurement sites, collected data of air temperatures (2 m and 20 cm), soil temperatures (2 cm, 5 cm, 10 cm, 20 cm and 50 cm), relative humidity of the air and PAR. These data were used for the creation of annual models of CO_2. For further details see chapter 3 and 4.

For CO_2 balances, the combination of annual R_{eco} and annual GPP (=NEE) including export (where phytomass was taken) ran into the calculation. For CH_4 and N_2O, only fluxes (mg gas m^{-2} h^{-1}) were available, but were interpolated to annual balances by a linear approach. Due to different contributions of the three gases to the GHG, their balances were converted to C_{eq} with multiplication factors according to the IPCC Guidelines 2007 (FORSTER ET AL. 2007). Summer fluxes were calculated from May 1st to October 31st. This period was chosen due to long term mean air and soil temperatures, which were higher for October than for April. Different ranges of standard errors (SE) were traced back to the way of calculating them (s. chapter 3 and 4) having used the exponential Lloyd & Taylor (1913) (R_{eco}) and the hyperbolic Michaelis & Menten (1994) (NEE) functions.

5.4 Results

Tab. 35: Annual balances 2007 of CO_2, CH_4, N_2O and sum of GHG

GWP$_{100}$ calculation factors according to IPCC Assessment Report 4 2007 (Forster et al. 2007) were applied to calculate GHG balances in C_{eq}; CO_2 balances include phytomass exports; different standard errors (SE) are based on CO_2 models (s. text)

Site	CO_2 ± SE g CO_2-C m^{-2} a^{-1}	CH_4 ± SE g CO_2-C_{eq} m^{-2} a^{-1}	N_2O ± SE g CO_2-C_{eq} m^{-2} a^{-1}	GHG ± SE g C_{eq} m^{-2} a^{-1}
M1	381^{+87}_{-68}	-1 ± 2	-5 ± 11	374^{+100}_{-81}
M2	222^{+49}_{-0}	2 ± 3	6 ± 20	230^{+73}_{-24}
M3	-126^{+39}_{-15}	45 ± 12	-5 ± 15	-86^{+66}_{-42}
M4	-160^{+39}_{-5}	83 ± 23	9 ± 8	-68^{+70}_{-35}
M5	-41^{+96}_{-40}	21 ± 7	14 ± 16	-6^{+119}_{-63}
M6	-45^{+62}_{-30}	12 ± 4	3 ± 10	-30^{+76}_{-44}
M7	287^{+189}_{-84}	2 ± 2	70 ± 25	359^{+216}_{-111}
M8	537^{+60}_{-9}	2 ± 2	89 ± 22	628^{+84}_{-34}
M9	-208^{+92}_{-43}	84 ± 20	11 ± 13	-113^{+125}_{-76}
M10	-120^{+157}_{-15}	70 ± 17	0 ± 6	-51^{+180}_{-38}
M11	-246^{+44}_{-29}	24 ± 8	6 ± 15	-216^{+67}_{-52}
M12	88^{+28}_{-22}	6 ± 5	19 ± 18	112^{+51}_{-45}

Generally, the most important GHG of the three measured gases was CO_2; the other gases had contributions in different fractions. In 2007, there was a separation of the sites of the bog heath. The highest emissions were detected for the not yet or recently restored dry sites M1 and M2, mainly driven by CO_2. The long-term restored sites M5 and M6 showed an equilibrated balance with a small uptake via CO_2 and a small release via CH_4 and N_2O. The short time restored site M3 and the long-term restored site M4, both located on former drainages, showed a comparable pattern, with a certain release of CH_4 and a higher uptake of CO_2, so that their total balances were negative. The restored sites on the former drainages M3 and

M4 were therefore small sinks for GHG, the long-term restored sites on the ridges M5 and M6 were neutral and the degraded, *Calluna* dominated sites M1 and M2 moderate sources for GHG. At the Setzberger Feld, there was a similar but more distinct separation in 2007. The non-restored sites M7 and M8 showed high releases of CO_2 and N_2O, whereas the releases of M8 were almost 50% higher than those of site M7. The restored managed site M12 showed a certain release of CO_2, but much lower than those of M7 and M8, while site M10, also restored and managed, was a sink for CO_2 but a source for CH_4. A comparable CH_4 release was detected for the non-managed site M9, which showed an even higher CO_2 uptake, similar to site M11 but with a low CH_4 release. Therefore, M11 (on a ridge) had the best GHG balance with a sequestration of more than -200 g C m^{-2} a^{-1} which is almost double than at the comparable site M9 on a drainage.

In 2008, the GHG balances were similar to those of 2007 with some exceptions and differences. Especially in the bog heath, site M1 showed ⅓ lower CO_2 emissions than 2007 whereas the CO_2 emissions of site M2 were two times higher than in 2007. The long-term restored sites of the bog heath changed into certain CO_2 sources (M5 and M6) with elevated CH_4 emissions or had a lower CO_2 fixation and similar CH_4 emissions (M4). Only the *Sphagnum*-dominated site M3 showed a doubled CO_2 uptake with stable CH_4 releases, which led to a GHG balance close to -200 g C_{eq} m^{-2} a^{-1}, whereas the other sites were neutral (M4), moderate (M1, M5 and M6) or big (M2) sources.

At the Setzberger Feld, the GHG distribution was equal in both years. Only the total balances differed in a way, that mainly the CO_2 emissions raised at the expense of N_2O (sites M7 and M8), or the uptake was reduced (sites M9 and M11). Site M10 changed from a CO_2 sink to a neutral CO_2 balance with constant CH_4 emissions. Like in 2007, the non-managed sites M9 and M11 had climate friendly, negative GHG balances (-112 to -59 g C_{eq} m^{-2} a^{-1}). The restored, managed sites M10 and M12 showed inhomogenous releases (90 to 381 g C_{eq} m^{-2} a^{-1}) of GHG, depending on their water tables. The degraded, managed sites remained elevated sources for GHG (503 to 736 g C_{eq} m^{-2} a^{-1}).

Tab. 36: Annual balances 2008 of CO_2, CH_4, N_2O and sum of GHG

GWP_{100} calculation factors according to IPCC Assessment Report 4 2007 (Forster et al. 2007) were applied to calculate GHG balances in C_{eq}; CO_2 balances include phytomass exports; different standard errors (SE) are based on CO_2 models (s. text)

Site	CO_2 ± SE g CO_2-C m^{-2} a^{-1}	CH_4 ± SE g CO_2-C_{eq} m^{-2} a^{-1}	N_2O ± SE g CO_2-C_{eq} m^{-2} a^{-1}	GHG ± SE g C_{eq} m^{-2} a^{-1}
M1	197 + 137 - 88	0 ± 1	6 ± 5	203 + 143 - 94
M2	552 + 89 - 44	3 ± 2	3 ± 4	557 + 95 - 49
M3	-237 + 75 - 31	47 ± 27	1 ± 4	-189 + 105 - 61
M4	-54 + 43 - 16	58 ± 12	4 ± 5	7 + 59 - 32
M5	141 + 55 - 27	35 ± 11	6 ± 3	182 + 69 - 42
M6	237 + 80 - 52	20 ± 9	6 ± 3	264 + 92 - 64
M7	437 + 18 - 13	2 ± 1	64 ± 22	503 + 41 - 36
M8	649 + 45 - 34	1 ± 1	86 ± 34	736 + 80 - 69
M9	-157 + 182 - 123	92 ± 22	6 ± 6	-59 + 209 - 150
M10	22 + 217 - 52	63 ± 21	3 ± 4	88 + 241 - 77
M11	-130 + 81 - 17	18 ± 8	1 ± 8	-112 + 97 - 33
M12	353 + 338 - 134	5 ± 4	23 ± 9	380 + 350 - 146

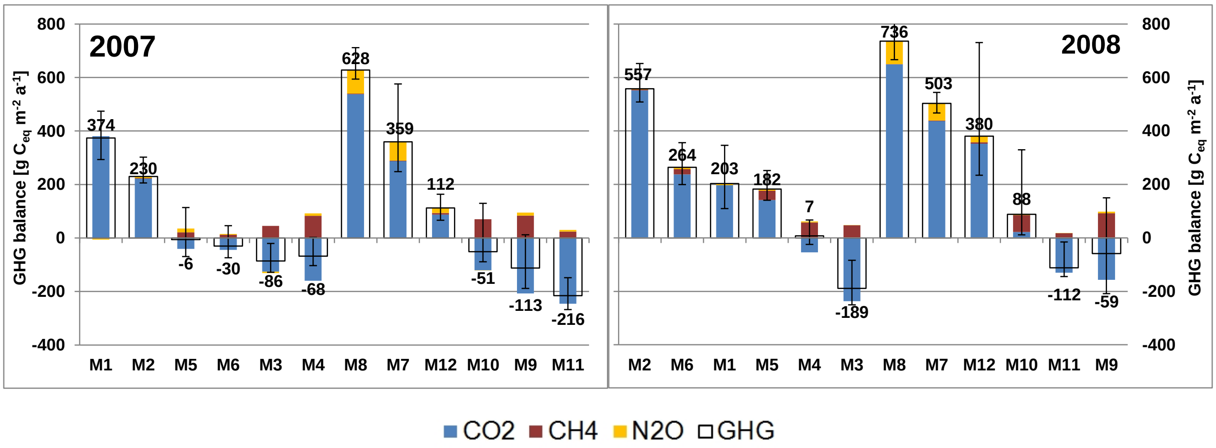

Fig. 31: Annual GHG balances separated for CO_2, CH_4 and N_2O and total annual GHG balances of 2007 (left) and 2008 (right)

bars show balances in C equivalents (GWP_{100}) according to IPCC 2007;
sites M1 to M6 are located at the bog heath, sites M7 to M12 at the Setzberger Feld

Carbon sequestration itself, shown at the x-Axis of Fig. 32, led to relative climate mitigation by extensification and rising water tables, which reduced CO_2 and N_2O emissions but enforced CH_4 emissions. Absolute climate mitigation could be achieved by reduction of the sum of all three climate relevant gases.

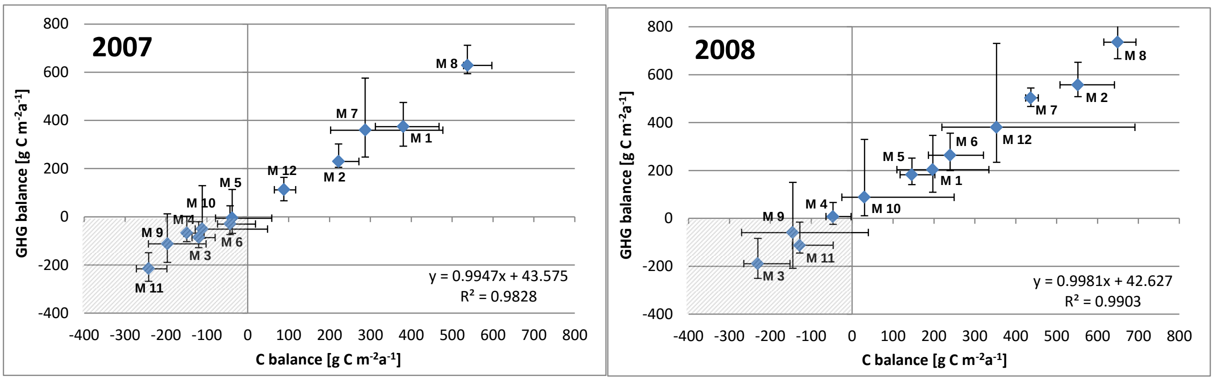

Fig. 32: Annual GHG balances (GWP_{100}) versus C balances of 2007 and 2008

graphs show balances incl. standard errors; lower C balance lead to higher carbon sequestration; lower GHG balance lead to higher C mitigation; shaped areas indicate C accumulation and thus climate cooling; unequal positive and negative SE are caused by CO_2 models

The balances of GHG versus C showed a linear distribution ($p<0.001$) for both years. Except for the degraded sites M7 and M8, N_2O never had a notable contribution to GHG balances. These degraded sites of the Setzberger Feld showed the highest balances in both years. The degraded site M1 and recently restored site M2 of the bog heath sorted in similar ranges. The long-time restored but managed site M12 showed moderate, but elevated positive balances in 2008, as well as the long-time restored sites M5 and M6 of the bog heath without management. In 2007, their balances were negative like for the long-time restored but managed site M10. The *Sphagnum* populated sites M3, M9, M11 and the *Eriophorum* dominated site M4 were GHG sinks in both years.

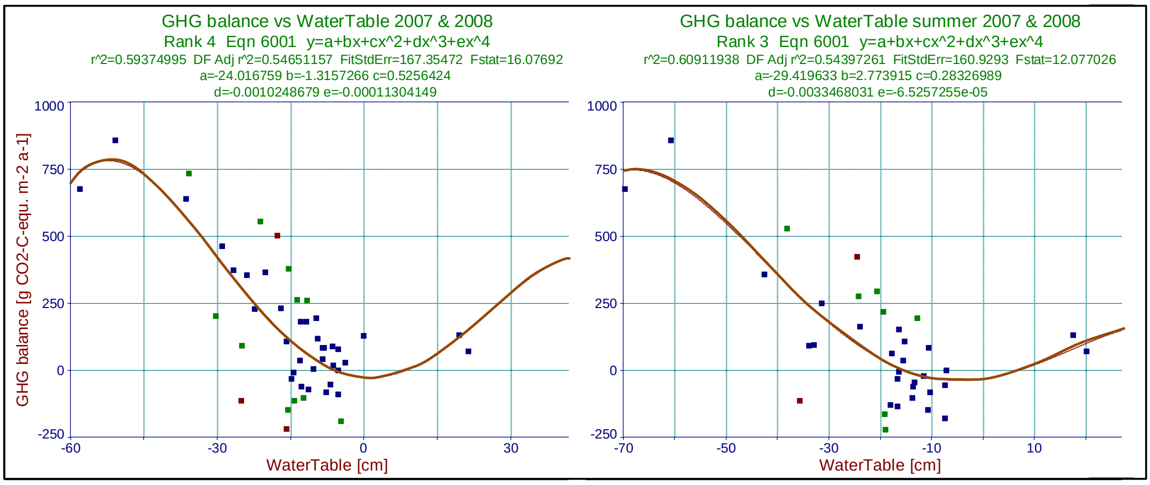

Fig. 33: Correlation of annual mean water tables and GHG balances (left) and summer mean water tables and summer GHG balances (right)

graphs show lowest emissions up to uptakes of C between -5 and -20 cm; flooding (> 0 cm) causes CH_4 driven emissions; higher emissions, driven by CO_2 and N_2O are detectable for water tables below -20 cm

In both years, GHG balances were significantly correlated to the mean water table (2007: 0,791***; 2008: 0,465*) as well as in combination of both years and in the summer periods (calculated from 1st of May to 31st of October) (Fig. 33). Highest GHG balances were detected for the degraded sites M8 and M7 of the Setzberger Feld, the degraded site M1 and the recently restored site M2 of the bog heath with water tables far from the surface. A clear separation was only visible for site M8. All other sites were more or less pooled together along a gradient.

Inserting data from other bog sites of the BMBF project and marking the edges of investigated consequences of land use led to a more complex function. Data were not available from all sites of the project for summer balance diagram.

5.5 Discussion

Greenhouse gas balances in years 2007 and 2008 showed a similar distribution between the sites, especially at the Setzberger Feld. Here, rewetting by closure of the drainages led to a significant reduction of GHG, mainly via CO_2. Different reduction potentials between the sites on the ridges and on the drainages were caused by the different reduction of aerobic pore space in the soil. Closure of the drainages raised the water table from -36.3 ± 9.9 cm to -6.3 ± 8.2 cm directly at the drainages. On the ridges, around 10 m away from the surrounding drainages, there was at least a certain influence of the closure, which raised the water table from -20.2 ± 9.6 cm to -15.6 ± 8.8 cm. The reduction of pore space diminished the oxidative peat decomposition and conversion of CH_4 coming from the catotelm, which reduced the CO_2 emissions much more on the drainages than on the ridges. Water tables closer to the surface also reduced the emission of N_2O, which were replaced by CH_4 due to a small oxidative layer, which let CH_4 pass from the soil. Additionally, CH_4 was actively transported by bog specific plants (mainly Cyperaceae) from their roots via their stems and leaves into the air to avoid reductive layers around their roots. Coming from the neighboured bog, a *Sphagnum fallax* H. Klinggr community expanded into the Setzberger Feld since management was stopped at some areas of the field in 1993. PFADENHAUER AND KLÖTZLI (1996) summarised, that restorations of bog ecosystems are successful mainly when green *Sphagnum* species established and thus, initialise a new peat forming process. The cutting events at the restored sites disturbed this vegetation and avoided a further expansion into the field. *Sphagnum fallax* H. Klinggr. and *Carex* species were able to establish at the sites without any disturbances.

At the bog heath, the pattern of GHG balances was not as homogenous. Especially the degrade and the short term restored sites were characterized by interannual variations of their balances, mainly driven by GPP (s. also chapter 3). The vitality of *Calluna* shrubs of site M1 raised in 2008, while plants died at site M2 during the summer of 2008. Having had a similar height in water table oscillation in both years, the two sites differed in their absolute water tables (M1: -25.4 ± 5.4 cm; M2: -22.3 ± 5.8 cm in summer 2007; M1: -32.9 ± 7.5 cm; M2: -24.4 ± 7.2 cm in summer 2008). Drier conditions supported the growth of *Calluna* shrubs at M1, while the conditions at site M2 changed from year to year after restoration in 2005 to the disadvantage of *Calluna vulgaris* (L.) Hull. The attribute of *Sphagnum* mosses being cation exchanger and reducing the pH of the soil actively, could not be regarded as a problem for *Calluna vulgaris* (L.) Hull (CLYMO 1967); furthermore *Calluna* is common to acidify soil itself (FALKENGREN-GRERUP 1987) and at the plot, at which around 75% of *Calluna* died, there were no *Sphagnum* in the moss layer. Also pH of site M2 did not differ significantly in either year (2007: 3.94 ± 0.12; 2008: 3.91 ± 0.23). While at these two sites CO_2 was the main GHG, at the long term restored sites (M4 to M6) and at the recently restored drainage (M3), CH_4 played a variable role in GHG balance. Especially at the former drainages with mean water tables between -4.7 ± 4.6 cm (M3) and -10.7 ± 5.0 cm (M4), CH_4 emissions reduced the success of CO_2 uptakes for total GHG balances. The improved GHG balance of M3 was mainly caused by a more dense *Sphagnum* cover in 2008 than in 2007, whose photosynthesis potential due to a larger surface was enhanced by more oscillating water tables in summer 2008 (-7.4 ± 5.1 cm) than in summer 2007 (-4.8 ± 3.0 cm). Water tables above -10 cm led to similar CH_4 balances in both years, in contrast to site M4. Here, especially in summer 2008 with a mean water table of -13.3 ± 5.1 cm, CH_4 summer balances were lower in 2008 (6.29 ± 1.19 g C m^{-2} $a^{-1/2}$) than in 2007 (9.86 ± 2.47 g C m^{-2} $a^{-1/2}$), but not significantly (p>0,08). The lower release of CH_4 in 2008 was driven by the closeness of the water table to the border of -15 cm. DRÖSLER (2011 and 2013) showed that CH_4 starts to be emitted between -15 cm and -10 cm. The reduced CO_2 fixation in the balance of 2008 was caused by enhanced CO_2 production in the air filled *Eriophorum* hummocks. The sites on the ridges (M5 and M6) had a lower CO_2 uptake in 2007 than the sites on the drainages due to water tables farther from the surface (M5: -13.5 ± 4.5 cm; M6: -14.2 ± 4.6 cm) and therefore a larger pore space for CO_2 releasing microbial processes. In 2008, the balances were worse due to higher summer R_{eco} which was higher than annual R_{eco} balances 2007. This was caused by lower water tables in summer 2008 (M5: -15.2 ± 4.5 cm; M6: -16.4 ± 4.4 cm). Having had similar respiration balances like the degraded site M1 and the short term restored M2, the long term restored sites differed in their GPP balances, which were more stable and lower in total (s. chapter 3). High R_{eco} balances and CH_4 releases, which did not differ in both years, led to relatively high GHG emissions in 2008, while in 2007 the sites had neutral GHG balances. The vegetation of the sites, mainly populated by *Sphagnum rubellum* Wils. and *Calluna vulgaris* (L.) Hull, did not change within the two years or suffer due to drought. Differences in between the sites were caused by the presence of *Pinus x rotundata* Link at M6. Thus, at the long term restored sites, GHG balances depended mainly on water tables in the vegetation period, while their vegetation was relatively resistant against rainless periods. The dry sites M1 and M2, whose development towards natural like conditions had just started, were in contrast stable in their R_{eco} balances, while their vegetation was undergoing a big change, which influenced their GPP balances negatively. N_2O was negligible at the bog heath because there was no impact from the outside.

This was also visible, in relation to the regressions of C balances versus the GHG balances. Due to low contributions of N_2O to total balances, the regressions were almost linear (2007: $r^2=0.9815$; 2008: $r^2=0.9902$). Additionally, the regressions were also gradients of degradation. The reduction of C emissions by rewetting (C sequestration) led to a certain C mitigation, but balances were still weighting the climate. The cessation of management in combination with water tables close to the surface, which reduced the pore space of the soil and kept CH_4 emissions at a moderate level, led finally to a real uptake into the ecosystem and therefore to a real mitigation of climate. This total C uptake is synonymous with a real prevention of peat loss which is remarkable when bog specific water tables throughout the year are present (PFADENHAUER & KLÖTZLI 1996).

Balances of all the sites of the project showed a good dependency with water tables. At the borders (under -50 cm and above 0 cm) the GHG balance reached their maxima. At low water tables, caused by deep drainage led to big aerobic soil areas, peat could be mineralized and other CO_2 producing processes could take place. When the area was flooded, CH_4 was released directly from the peat to the atmosphere and had the main proportion to GHG emissions.

5.6 Conclusion

In the bog heath and at the Setzberger Feld, CO_2 was the most important climate gas. N_2O emissions were relevant only at the degraded managed sites and were replaced by CH_4 at the restored sites. Where present, CH_4 releases were overcompensated by uptakes of CO_2, especially when oscillations in water tables were low (2007). Generally, water table influenced the steps of restoration and the success towards climate mitigation. At the Setzberger Feld rewetting resulted in the highest mitigation effects for the sites on the drainages (M8 to M10: -640 to -700 g C_{eq} m^{-2} a^{-1}) while the cessation of management (M10 to M9) reduced the emissions between -60 to -150 g C_{eq} m^{-2} a^{-1} and turned the sites into stable sinks for total GHG. The sites on the ridges with lower differences in water tables before and after restoration also had less reduction of GHG emissions (M7 to M12: -250 to -280 g C_{eq} m^{-2} a^{-1}); cessation of management on those sites had the more important effect with a mitigation between -320 to -490 g C_{eq} m^{-2} a^{-1}. Total uptakes of GHG were detected for the sites with *Sphagnum* communities, *Carex* species and *Juncus effusus* L., which were regarded as typical for areas developing towards natural like bogs.

At the more natural like bog heath, rewetting led to the dieback of *Calluna vulgaris* (L.) Hull and the replacement of *Pleurozium schreberi* (Brid.) Mitt. by *Sphagnum* species (M1 to M2) and may create a rise in GHG emissions. After the first few years, when vegetation typical for bogs had established (M2 to M5 or M6), GHG emissions were still possible but much lower (-50%) than for disturbed sites. In years with stable water supply in vegetation period, sites were even sinks for GHG (up to -30 g C_{eq} m^{-2} a^{-1}). The best results concerning mitigation effects could be regarded on the drainages. Even shortly after establishment of *Sphagnum* species (M3), sites became sinks for GHG (-90 to -190 g C_{eq} m^{-2} a^{-1}) and kept this status (M4) also after 15 years (-70 g C_{eq} m^{-2} a^{-1}). A more fluctuating water table led here, analogous to the drier sites M5 and M6, to the loss of the sink function for GHG via an enforced CO_2 release. A high sensitivity of CO_2 balances of former peatland ecosystems to annual and interannual changes in weather conditions, water tables and the vegetation period was identified by AUGUSTIN ET AL. (1996). But the results can be transmitted to more or less intact bog as well. Certain CO_2 releases due to oxidation processes can appear in natural bogs and, more intense, in degraded peatlands (LEIFELD ET AL. 2011).

Thus, if precipitation does not reduce too much, which would be negative for ombrotrophic peatlands and their vegetation (and could peak in mineralisation of peat in the worst case) the restored sites could be regarded as net sinks for GHG, from the perennial point of view, even if water table oscillates in some years. But simulations like WETTREG (UBA 2007) show for the prealpine region of Germany in summer a certain increase of temperature and a reduction of precipitation, whose intensities depend on the scenarios of the IPCC (FORSTER ET AL. 2007). LEIFELD ET AL. (2014) found increased emissions for agriculturally used peatlands due to enhanced peat decomposition which has been driven by enhanced fertiliser donations and increased annual mean temperatures. Although the investigated sites of Mooseurach have not been used with the intensity of many other German peatlands, the risk of augmented emissions driven by risen temperatures and drought periods is given. In winter, simulations predict an increase of temperatures and precipitation, which could improve the availability of water, at least for those plants which are photosynthetically active even at low temperatures like mosses including *Sphagnum* species. If they are able to equilibrate the dry periods in summer, as far as they are not too long and the mosses die, with the moister periods in winter, then the growth of peatlands in the foreland of the Alps could continue. In other regions of Germany with worse predictions concerning water supply, the existence of peatlands is perhaps more doubtful.

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6 Mitigation potential after rewetting – an outlook

Mitigation potential of the Mooseurach bog after rewetting, stopping management and development of a bog specific vegetation

The GHG balances of the drained but furthermore untouched bog depend highly on water table habitudes and development of a bog specific vegetation. Rewetting resulted in lower productivity of *Calluna* with could not be compensated by *Sphagnum* mosses of the below ground with could also be regarded in the balances of the following years (DRÖSLER ET AL. unpub.). Fig. 34 shows a possible development of the sites with corresponding changes in GHG balances.

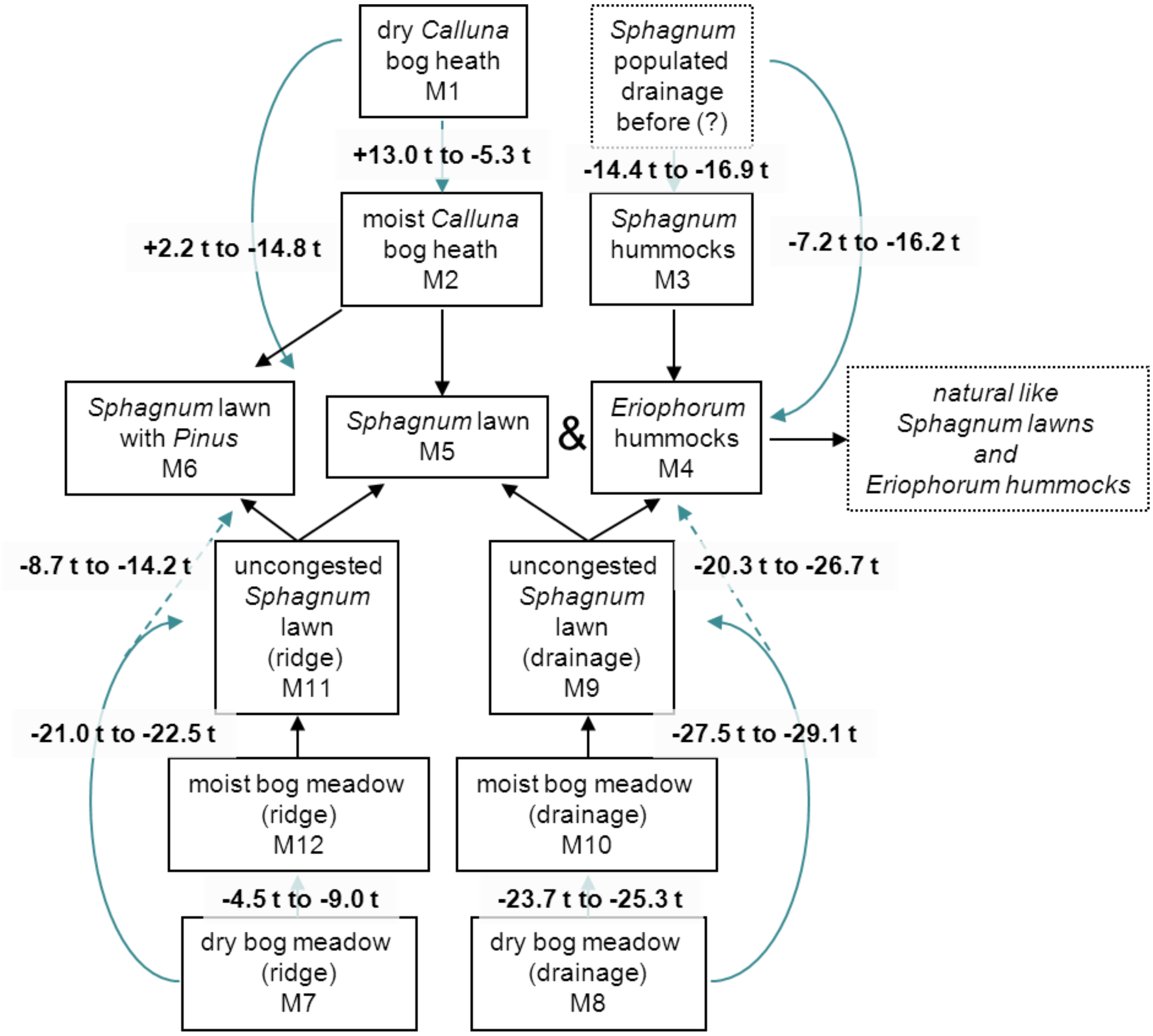

Fig. 34: Mitigation potentials of different restoration steps and vegetation dynamics of a bog heath (above) resp. a bog meadow (below)
values are shown in t CO_2 equivalents ha^{-1} a^{-1}

Whereas the short term effect of CO_2 balances varied between +13.0 and -5.3 t $CO_{2\ eq.}$ ha^{-1} a^{-1}, the long term mitigation effect was between +2.2 and -14.8 t $CO_{2\ eq.}$ ha^{-1} a^{-1}. The most intense improvements in GHG balances of the bog meadow appeared when cutting was stopped and *Sphagnum* lawns could establish (-12.0 to -18.0 t $CO_{2\ eq.}$ ha^{-1} a^{-1}) whereas rewetting changed emissions between -4.5 and -9.0 t $CO_{2\ eq.}$ ha^{-1} a^{-1}. Even bigger effects were visible at the drainages and the surrounding areas. Here, at these small stripes of around one meter, CO_2 mitigation was between -23.7 and -25.3 t $CO_{2\ eq.}$ ha^{-1} a^{-1}. Stopping management reduced the CO_2 balances additionally from -2.2 to -5.4 t $CO_{2\ eq.}$ ha^{-1} a^{-1}.

In total, the drainages showed the biggest mitigation potentials but when regarding bogs as a unit, the area of drainages is relatively low in comparison to the total bog. Therefore, their mitigation potentials cannot be transferred into the area nor be neglected. In the investigated bog of Mooseurach, the area of drainages is around 4 ha which means 10% of the total area. Supposedly, a development of the Setzberger Feld towards the conditions of the bog heath slightly reduces the mitigation potential of GHGs compared to the highly productive status of the not managed sites at the Setzberger Feld. The CO_2 mitigation at the drainage-stripes could diminish from -29.1 (max) to -20.3 (min) t $CO_{2\ eq.}$ ha^{-1} a^{-1}. The big remaining area reduces its CO_2 mitigation from -22.5 (max) to -8.7 (min) t $CO_{2\ eq.}$ ha^{-1} a^{-1}.

Tab. 37: Mitigation potential of different starting use types of the investigated prealpine bog close to Mooseurach

values are shown in t CO_2 equivalents ha^{-1} a^{-1};
big water table differences are traced back to positions on former drainages or ditches;
low water table differences to positions on ridges in between the drainages or ditches

* starting conditions at a ridge as reference

mitigation potential	areas with big water table differences			areas with low water table differences		
	size [ha]	[t CO_2 ha^{-1} a^{-1}] from	to	size [ha]	[t CO_2 ha^{-1} a^{-1}] from	to
starting as dry *Calluna* heath						
restoration (<5 years)	0.7	-14,4 *	-16,9 *	3.3	13	-5.3
restoration (>15 years)		-7,2 *	-16,2 *		2.2	-14.8
starting as bog meadow						
rewetting (>15 years)	0.25	-23.6	-25.3	2.25	-4.5	-9
+ without management	0.7	-27.5	-29.1	5.6	-21	-22.5
+ bog vegetation established	1.25	-20.3	-26.7	11.25	-8.7	-14.2

Based on the total areas, the *Calluna* populated part of the bog heath (4 ha) is able to store -29 t $CO_{2\ eq.}$ a^{-1}; rewetting of the bog meadow (12 ha), ending management and also population of a bog specific vegetation leads to uptake rates of around -160 t $CO_{2\ eq.}$ a^{-1}. How a rise of water table influences the vitality of *Pinus x rotundata* Link and *P. sylvestris* L. and thus the GHG balances of the other 22 ha of the central part of the bog, should be part of further researches including forest on peatlands.

7 Conclusion – Zusammenfassung

7.1 Final Conclusion

The aim of this work was to quantify the effect of restoration of a bog heath along a chronosequence after restoration took place and the influence of rewetting and management of a bog meadow concerning the changes of greenhouse gas emissions. To get greenhouse gas balances, closed chamber measurements took place from January 2007 to April 2009 for greenhouse gases CO_2, CH_4 and N_2O in campaigns every two to four weeks at 12 sites. Six sites were located at a bog heath and six at a bog meadow.

CO_2 was the most important GHG. CH_4 emissions were detected at sites with water tables close to the surface (0 to -15 cm). N_2O release was restricted to degraded or at least moist site of the bog meadow. To explain GHG flux changes, abiotic parameters like water tables (WT), electrical conductivity (EC) and pH were taken during the campaigns. A weather station collected data for air and soil temperatures, relative humidity of the air and photosynthetic active radiation (PAR), which were used for modelling the CO_2 balances. Changes of the sites after restoration were also described by vegetation assessments, which were used for vegetation analysis.

This vegetation analysis divided the two areas bog heath and bog meadow along a gradient of pH, water tables standard deviations, human impact (hemeroby) and number of plant species. The bog heath had a lower pH (4.0 in spite of 4.5). Here the oscillations of water tables were better buffered mainly by the less decomposed peat which kept its capability to store water. The species found at the bog heath corresponded widely to the species we expected at an area with a very low human impact; the species of the bog meadow had a composition which could be regarded as typical for poor grasslands without fertilisation and cuts to enhance soil impoverishment.

A second gradient was described by mean CH_4 fluxes and mean water tables. The sites with water tables close to the surface had the highest CH_4 fluxes. On the other hand, the peat decomposition of sites with water tables farther from the surface led to elevated concentrations of ions in the soil water (measured as electrical conductivity). Thus the first gradient could be regarded as an indicator for the naturalness of the sites, focused on an undisturbed bog, and the second gradient as indicator for the intensity of degradation.

Not surprisingly, the fluxes of all GHG were most elevated in summer (May to October) due to temperature driven higher microbial (R_{eco}, CH_4, N_2O) and plant activity (R_{eco} and GPP) but especially in spring the proportion of single GHG to annual balances could reach up to 50% (N_2O at the degraded bog meadow sites).

We hypothesised at the bog heath a reduction of greenhouse gas emissions with an increasing intensity up to an equilibrated status after restoration took place. Our results showed that the reality was more complex. Especially the water supply and the water table oscillations (in summer 2008) led to a lower productivity of most of the plants and thus worsened GHG balances in 2008 compared with 2007. Similar reactions were detected at the bog meadow where we expected a certain reduction of emissions after rewetting and a further reduction of GHG to a neutral balance or small sink function of the sites after stopping management.

At the bog heath, two years after closure of the drainages *Sphagnum* species settled at the now water filled ditches (site M3). Here respiration (R_{eco}) was reduced to a minimum (1/5 to 1/3) compared to the other sites but also the productivity (via photosynthesis) was relatively low (1/3 to 3/4) but a slightly fast growth of Sphagnum hummocks was detectable during the measurement period. In combination with moderate CH_4 emissions (~50 g C_{eq} m^{-2} a^{-1}), the recently restored *Sphagnum* ditches were steady sinks for total GHG due to their productivity (-189 to -86 g C_{eq} m^{-2} a^{-1}). After establishment of *Eriophorum vaginatum* L. like at site M4, respiration raised slightly more than the productivity but the total CO_2 balances still indicated an uptake (-160 to -50 g C_{eq} m^{-2} a^{-1}). The addition of CH_4 emissions (58 to 83 g C_{eq} m^{-2} a^{-1}) which were enhanced by the transport via the aerenchymatic tissue of *Eriophorum* (20% to 50% higher than at site M3) resulted in an at least neutral balance for the long term restored drainage (-68 to +7 g C_{eq} m^{-2} a^{-1}). Thus on the drainages, a more or less neutral status of GHG is to be expected after reestablishment of a bog specific vegetation.

The restoration of the sites on the ridges (comparison of sites M1 and M2) led, after a short term decrease of GHG (374 to 230 g C_{eq} m^{-2} a^{-1}) mainly driven by a higher productivity of *Calluna vulgaris* (L.) Hull, which was still detectable in 2007, to an abrupt increase (203 to 557 g C_{eq} m^{-2} a^{-1}) after the dieback of parts of *Calluna*, which was detectable also in halved productivity but comparable respiration. Although some *Sphagnum* species started to settle underneath, they were not able to compensate the death of *Calluna* in short term. But after 15 years and an establishment of a *Sphagnum* lawn with single *Calluna* shrubs and *Pinus x rotundata* Link like at sites M5 and M6, the conditions changed to neutral GHG balances with equilibrated R_{eco} and GPP balances in combination with CH_4 emissions of 12 to 35 g C_{eq} m^{-2} a^{-1}. In years with highly oscillating water tables (like in 2008) these sites can become temporary sources for total GHG (182 to 264 g C_{eq} m^{-2} a^{-1}), mainly by enhanced R_{eco} and surficial inactivity of *Sphagnum* by draught.

Particularly having climate change in mind and a possible reduced precipitation at some regions of Europe, where peatlands still can be found, we estimate that continuous drought in summer can lead to irreversible dieback of *Sphagnum* and other ombrotrophic species, which need a stable water supply. Peatlands in those regions will lose their ability to serve as climate coolers. But predictions in development of precipitation for the prealpine region lead to the conclusion that restored bogs like at the Breitfilz remain sinks for GHG or at least no steady sources.

A reduction of GHG emissions to an unequally larger amount, we detected at the bog meadow of the Setzberger Feld. Here we compared the influence of rewetting and management in dependency of water tables in six different variances. Depending on the location of the sites on top of drainages or ridges, the potentials of GHG reductions differed significantly. In general, after rewetting the respiration (R_{eco}) was partly reduced by half whereas the CO_2 uptake via photosynthesis remained similar to the degraded sites. In combination with an almost termination of N_2O releases after rewetting (before: 64 to 89 g C_{eq} m^{-2} a^{-1}; after: 0 to 23 g C_{eq} m^{-2} a^{-1}), pure rise of water tables by destruction of the drainages was most effective at the top of the drainages (site M8 to M10). Here, the total GHG reduction was between 648 to 679 g C_{eq} m^{-2} a^{-1} and led to balances from -51 to +88 g C_{eq} m^{-2} a^{-1}; the cessation of management at site M9 in combination with establishment of an uncongested *Sphagnum fallax* community, reduced the emissions again, but in a much lower amount, and turned the site to a low GHG sink (-113 to -59 g C_{eq} m^{-2} a^{-1}).
On the ridges (M7 to M12), the emissions were reduced from 123 to 247 g C_{eq} m^{-2} a^{-1}, corresponding to balances between 112 to 380 g C_{eq} m^{-2} a^{-1}. In contrast to the site on the drainage, the shift of vegetation was not detectable. *Anthoxanthum odoratum* L. s. str. remained the dominant vascular plant and *Climacium dendroides* (Hedw.) F. Weber. & Mohr the dominant moss as they have already been on sites M7 and M8. Ending management at site M11, accompanied by a shift of vegetation towards a *Sphagnum fallax* H. Klinggr. community like at site M9, reduced the emissions between -328 to -493 g C_{eq} m^{-2} a^{-1} and turned this site with water tables around -15 cm to the most effective climate cooler (-216 to -112 g C_{eq} m^{-2} a^{-1}).
The differences in the GHG reductions between the sites on drainages and ridges were caused by the differences in the reduction of aerobic soil pore space. Whereas the water table at the drainage site was raised from -36 cm to -6 cm, it was only from -20 cm to -15 cm at the site on a ridge. Hence at the sites on the former drainage CH_4 was released in an amount comparable to the sites M3 and M4 on the ditches of the bog heath (63 to 92 g C_{eq} m^{-2} a^{-1}). The CH_4 emissions of the sites on a ridges remained at the level of the bog heath sites M5 and M6 (5 to 24 g C_{eq} m^{-2} a^{-1}), even after ending management and a shift in vegetation with an increase of sedges.

Thus, this work finishes with three main results:

The closure of ditches in a relatively undisturbed bog where a vegetation, typical for bogs, is already present and expands easily by itself, cannot only lead to a reduction of GHG emission of this bog but can also turn this bog after a relatively short time of 15 to 20 years to a steady sink with a growing peat body in future.

Rewetting of bog meadows can be regarded as a first step towards a bog ecosystem in the (very) long-term, especially when management can hardly be done due to very moist conditions and high costs for maintenance of drainage systems. If a certain use shall be maintained due to any reason, rewetting with water tables around -10 to -15 cm below the surface can even result in almost equilibrated balances if a bog specific *Sphagnum* community might establish itself. In the first few years, cutting may even enhance the distribution of *Sphagnum* into meadows at the edges of expanding *Sphagnum* communities.

Nevertheless, the full climate mitigation effect cannot be achieved until the establishment of more bog specific plants, which will only take place if management stops and makes them possible to grow undisturbed.

7.2 Abschließende Zusammenfassung

Ziel der vorliegenden Arbeit war, den Renaturierungseffekt eines teilentwässerten Hochmoors entlang einer Chronosequenz nach dem Renaturierungszeitpunkt und den Einfluss von Vernässung und Managementaufgabe einer Hochmoorwiese in Form von Veränderung in den Treibhausgasbilanzen zu quantifizieren. Um Treibhausgasbilanzen der 12 Versuchsflächen zu erhalten wurden zwischen Januar 2007 und April 2009 Haubenmessungen für die Treibhausgase CO_2, CH_4 und N_2O in alle zwei bis vier Wochen stattfindenden Messkampagnen durchgeführt. Sechs der Versuchsflächen, im Folgenden auch Sites genannt, befanden sich auf einer Hochmoorweite, sechs weitere auf einer Hochmoorwiese.

CO_2 war das das Treibhausgas, das die Gesamtbilanzen am maßgeblichsten beeinflusste. CH_4 wurde auf den Sites in nennenswertem Umfang gemessen, deren Wasserstände sich im Bereich 0 bis -15 cm unter Flur befanden. Die N_2O Emissionen beschränkten sich auf die degradierten Sites sowie die feuchte, noch gemähte Fläche der Hochmoorwiese.

Um die Veränderungen der Treibhausgasflüsse erklären zu können, wurden abiotische Faktoren wie Wasserstände, elektrische Leitfähigkeit und pH Wert während der Messkampagnen aufgenommen. Eine Wetterstation, die auf der Hochmoorweite aufgestellt wurde, zeichnete halbstündlich Luft- und Bodentemperaturwerte, Luftfeuchte und die photosynthetisch aktive Strahlung (PAR) auf, die für die Modellbildung der CO_2 Bilanzen verwendet wurden.

Die Veränderung der Sites nach der Renaturierung wurde anhand von Vegetationsaufnahmen erfasst, wobei letztere auch für eine Vegetationsanalyse verwendet wurden. Diese Vegetationsanalyse trennte die beiden Gebiete der Hochmoorweite und der Hochmoormähwiese entlang eines Gradienten, der bestimmt wird durch den pH Wert, die Standardabweichung der Wasserstände, den menschlichen Einfluss, angegeben als Hemerobie, sowie die Anzahl der Pflanzenarten. Die Hochmoorweite wies pH Werte um 4,0 auf, während auf dem Setzberger Feld, der Mähwiese, pH Werte um 4,5 gemessen wurden. Die Oszillationen der Wasserstände wurden auf der Hochmoorweite besser abgepuffert, hauptsächlich aufgrund des weniger zersetzten Torfes, der seine Fähigkeit zur Wasserspeicherung noch beibehalten hat. Die Arten der Hochmoorweite entsprachen zudem weitestgehend den Erwartungen an einen Artenpool eines Standortes mit sehr geringem menschlichem Einfluss; die Arten der Mähwiese zeigten die typische Zusammensetzung eines nährstoffarmen Grünlands ohne Düngung mit Aushagerungsmahd.

Ein zweiter Gradient wurde durch die mittleren CH_4 Flüsse und die mittleren Wasserstände beschrieben. Die Sites mit oberflächennahen Wasserständen wiesen die höchsten CH_4 Flüsse auf. Andererseits führte die Torfzersetzung derjenigen Sites mit oberflächenfernen Wasserständen zu erhöhten Ionenkonzentrationen im Bodenwasser, aufgenommen als elektrische Leitfähigkeit. So konnte der erste Gradient als Indikator für Natürlichkeit mit Fokus auf ein intaktes Hochmoor sein und der zweite Gradient ein Indikator für den Grad der Degradierung.

Was die Treibhausgasflüsse angeht, war es nicht überraschend, dass diese im Sommerhalbjahr (Mai bis Oktober) diejenigen des Winterhalbjahres bei Weitem überstiegen aufgrund höherer mikrobieller Aktivität (R_{eco}, CH_4, N_2O) wie auch pflanzlicher Aktivität (R_{eco} und GPP). Insbesondere im Frühjahr konnte so der Anteil einzelner Treibhausgase bis zu 50% der Jahresbilanz ausmachen (u.a. N_2O auf den degradierten Sites der Hochmoorwiese).

Für die Hochmoorweite erwarteten wir einen Rückgang der THG Emissionen, der umso stärker ausfallen sollte, je länger die Renaturierung zurückliegt, bis schließlich eine für natürliche Hochmoore typische Senkenfunktion für THG wiederhergestellt ist. Unsere Ergebnisse zeigten, dass die Realität komplexer war. Besonders die Wasserversorgung und die Schwankungen der Wasserstände im Sommer 2008 führten zu einer geringeren Produktivität der Pflanzen und so zu schlechteren THG Bilanzen im Jahre 2008 im Vergleich zu 2007. Eine ähnliche Reaktion konnte auf der Hochmoorwiese festgestellt werden, bei der wir einen Rückgang der Emissionen nach der Wiedervernässung erwarteten, der nach Beendigung der Bewirtschaftung in einer ausgeglichenen THG Bilanz endet, wobei auch eine leichte Senkenfunktion der Sites hier nicht unerwartet gekommen wäre.

Auf der Hochmoorweite etablierten sich zwei Jahre nach dem Aufstau der Gräben Sphagnenarten im nun wassergefüllten Graben (Site M3). Verglichen mit den anderen Sites war die Atmung (R_{eco}) dort relativ gering (1/5 bis 1/3), doch auch die Produktivität (als Photosynthese angegeben) war vergleichsweise gering (1/3 bis 3/4) aber während der Messzeit war ein rasches Wachstum dieser Sphagnenbulte zu beobachten. Kombiniert mit moderaten CH_4 Emissionen von etwa 50 g C_{eq} m^{-2} a^{-1} waren die kürzlich renaturierten Gräben sichere Senken für die Summe der THG aufgrund deren Produktivität (-189 bis -86 g C_{eq} m^{-2} a^{-1}). Nach der Ansiedlung von *Eriophorum vaginatum* L. wie bei Site M4, stieg die Atmung in größerem Maße als die Produktivität, aber auch bei einer längeren Dauer nach der Renaturierung zeigten die CO_2 Bilanzen eine Aufnahme (-160 bis -50 g C_{eq} m^{-2} a^{-1}). Die Hinzunahme der CH_4 Emissionen (58 bis 83 g C_{eq} m^{-2} a^{-1}), die durch das aerenchymhaltige Gewebe von *Eriophorum* gefördert wurden (20% bis 50% höhere Emissionen als bei Site M3), führten mindestens zu einer ausgeglichenen Bilanz für die länger renaturierten Gräben (-68 bis +7 g C_{eq} m^{-2} a^{-1}). Folglich ist nach einer Renaturierung und der Wiederansiedlung einer hochmoortypischen Vegetation auf den Gräben eine mehr oder weniger ausgeglichene THG Bilanz zu erwarten.

Die Renaturierung der Sites auf den Rücken (Vergleich der Sites M1 und M2) führte nach einem kurzzeitigen Rückgang der THG (374 zu 230 g C_{eq} m^{-2} a^{-1}) aufgrund höherer Produktivität der dominierenden *Calluna vulgaris* (L.) Hull, was auch 2007 noch feststellbar war, zu einem plötzlichen Anstieg (203 zu 557 g C_{eq} m^{-2} a^{-1}) der THG nach dem teilweise Absterben der *Calluna*, was auch in einer Halbierung der Produktivität bei gleichbleibender Atmung sichtbar war. Zwar begannen einige *Sphagnum*-Arten sich im Unterwuchs anzusiedeln, aber diese konnten das Absterben der *Calluna* nicht kurzfristig kompensieren.

Auf den Flächen, auf denen die Renaturierung 15 Jahre zurücklag und sich ein *Sphagnum*-Rasen etabliert hatte, zusammen mit ein paar vereinzelten Exemplaren von *Calluna* (M5) und *Pinus x rotundata* Link (M6), hat sich eine neutrale THG Bilanz eingestellt mit ausgeglichenen R_{eco} und GPP Bilanzen bei leichten CH_4 Emissionen (12 bis 35 g C_{eq} m^{-2} a^{-1}). Allerdings können diese Sites in Jahren mit stark schwankenden Wasserständen (wie 2008) zeitweise Quellen für THG sein (182 bis 264 g C_{eq} m^{-2} a^{-1}), hauptsächlich angetrieben durch die Atmung und die Inaktivität der Sphagnen bei Trockenheit, insbesondere an der Oberfläche.

In Hinblick auf den Klimawandel und einen möglichen Rückgang der Niederschläge in einigen Regionen Europas, in denen immer noch Moore vorkommen können, rechnen wir damit, dass speziell Trockenheit im Sommer zum irreversiblen Absterben der Sphagnen und anderer ombrotropher Arten führen kann, die auf eine stetige Wasserzufuhr angewiesen sind. Moore dieser Regionen werden ihre Eigenschaft als Klimakühler verlieren. Jedoch lassen die Vorhersagen der Niederschlagsentwicklung für die Voralpenregion den Schluss zu, dass renaturierte Moore dieser Region, wie das Breitfilz, Senken für THG bleiben oder zumindest keine stetigen Quellen werden.

Ein Rückgang der THG Emissionen in ungleich größerer Höhe haben wir auf der Hochmoorwiese des Setzberger Feldes ermittelt, auf dem sechs verschiedene Varianten der Wiedervernässung und des Managements in Abhängigkeit vom Wasserstand verglichen worden sind. Je nach Lage der Sites über den Drainagen oder auf den Rücken ergaben sich signifikant unterschiedliche Einsparungspotentiale für die Treibhausgase. Allgemein war die Atmung (R_{eco}) auf den vernässten Sites auf die Hälfte reduziert, die Photosyntheserate (GPP) blieb jedoch vor und nach der Vernässung auf einem ähnlichen Niveau. Zusammen mit einer fast gänzlichen Beendigung der N_2O Emissionen nach der Wiedervernässung (zuvor: 64 bis 89 g C_{eq} m^{-2} a^{-1}; danach: 0 bis 23 g C_{eq} m^{-2} a^{-1}) war die Anhebung des Wasserstandes durch die Zerstörung der Drainagen vor allem auf diesen Sites hinsichtlich der THG Bilanzen am effektivsten. So betrug die Reduktion der THG zwischen 648 und 679 g C_{eq} m^{-2} a^{-1} und führte zu THG Bilanzen von -51 bis +88 g C_{eq} m^{-2} a^{-1}; die Beendigung der Bewirtschaftung auf Site M9 in Kombination mit der Etablierung einer lockerwüchsigen *Sphagnum fallax* H. Klinggr. Gesellschaft reduzierte die Emissionen abermals, wenn auch in geringem Umfang, und machte diese Fläche zu einer leichten Treibhausgassenke (-113 bis -59 g C_{eq} m^{-2} a^{-1}).

Auf den Rücken (M7 nach M12) nahmen die Emissionen zwischen 123 und 247 g C_{eq} m^{-2} a^{-1} ab auf noch positive Bilanzwerte von 112 bis 380 g C_{eq} m^{-2} a^{-1}. Im Gegensatz zur auf der Drainage gelegenen Site, war hier allerdings keine derartige Veränderung der Vegetation feststellbar. *Anthoxanthum odoratum* L. s. str. blieb das dominante Gras und *Climacium dendroides* (Hedw.) F. Weber. & Mohr das dominierende Moos, wie sie es schon bei den degradierten Sites M7 und M8 waren. Die Beendigung der Bewirtschaftung wie auf Site M11, die mit einem Wechsel der Vegetation hin zu einer *Sphagnum fallax* H. Klinggr. Gesellschaft wie auf Site M9 einherging, ließ die Emissionen um -328 bis -493 g C_{eq} m^{-2} a^{-1} zurückgehen. Somit stellte sich diese Site mit einem Wasserstand um -15 cm unter Flur als der effektivste Klimakühler mit Gesamt-Treibhausgasbilanzen zwischen -216 und -112 g C_{eq} m^{-2} a^{-1} dar.
Die Unterschiede in den Treibhausgasrückgängen nach den Vernässungsmaßnahmen zwischen den auf den Drainagen gelegenen Sites und denen auf den Rücken wurden durch unterschiedlich starke Reduktionen des aeroben Bodenporenraums hervorgerufen. Während der Wasserstand der Site auf der Drainage (M8) von -36 cm unter Flur auf -6 cm angehoben wurde, stieg der Wasserstand der auf einem Rücken gelegenen Site (M7) nur von -20 cm auf -15 cm. Folglich wurde auf den Sites der ehemaligen Drainagen der Mähwiese CH_4 in ähnlichem Umfang emittiert wie auf den Sites M3 und M4 auf den verschlossenen Gräben der Hochmoorweite (63 bis 92 g C_{eq} m^{-2} a^{-1}). Hingegen verblieben die CH_4 Emissionen der Sites auf den Rücken auf dem Niveau der Sites M5 und M6 auf den Rücken in der Hochmoorweite (5 bis 24 g C_{eq} m^{-2} a^{-1}), und dies auch nach Beendigung der Bewirtschaftung und einer Veränderung der Vegetation mit einer Zunahme insbesondere von Seggen.

Somit ergeben sich am Ende dieser Arbeit drei wesentliche Ergebnisse:

Der Grabenverschluss eines relativ ungestörten Hochmoores, das noch oder bereits wieder eine hochmoortypische Vegetation aufweist und die sich zudem selbst leicht ausbreitet führt nicht nur zu einem Rückgang der THG Emissionen dieses Hochmoores sondern kann dieses innerhalb eines relativ kurzen Zeitraums von 15 bis 20 Jahren wieder zu einer sicheren Senke für Treibhausgase machen, was in dessen Zukunft auch zu einem erneuten Torfwachstum führen kann.

Die Wiedervernässung von Hochmoorwiesen kann als erster Schritt hin zu einem naturnahen Hochmoor-Ökosystem verstanden werden, insbesondere auf lange Sicht und angesichts dessen, dass eine Bewirtschaftung im klassischen Sinn aufgrund der sehr feuchten bis nassen Bedingungen kaum mehr aufrecht erhalten werden kann. Hinzu kommen noch die Kosten für die Erhaltung des Drainagesystems, die nach einer Renaturierung entfallen.

Sofern aus irgendwelchen Gründen eine Nutzung beibehalten werden soll, führt eine Wiedervernässung der Flächen bei mittleren Jahreswasserständen von -10 bis -15 cm unter Flur zumindest zu einer Reduktion der Treibhausgase bis hin zu einer ausgeglichenen Bilanz, insbesondere wenn sich dort hochmoortypische Sphagnen-Gemeinschaften etablieren. Hier kann die Mahd in den ersten Jahren der Sphagnen-Präsenz sogar deren Ausbreitung in die Wiese bzw. das Grünland fördern.

Jedenfalls kann ein umfassender Klimaentlastungseffekt erst dann erreicht werden, wenn sich hochmoortypische Vegetation eingestellt hat, was wiederum dann zu erwarten ist, sobald keine Bewirtschaftung deren Wachstum und Expansion mehr einschränkt.