

BGD

12, 8467–8495, 2015

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Does *Juncus effusus* enhance methane emissions from grazed pastures on peat?

A. Henneberg¹, L. Elsgaard², B. K. Sorrell¹, H. Brix¹, and S. O. Petersen²

¹Department of Bioscience, Aarhus University, Ole Worms Allé 1, Building 1135, 8000 Aarhus C, Denmark

²Department of Agroecology, Aarhus University, Blichers allé 20, 8830 Tjele, Denmark

Received: 23 March 2015 – Accepted: 7 May 2015 – Published: 10 June 2015

Correspondence to: A. Henneberg (anders.henneberg@bios.au.dk)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Abstract

Methane (CH₄) emissions from drained organic soils are generally low, but internal gas transport in aerenchymatous plants may result in local emission hotspots. In a paired-sample field study at three different sites we measured fluxes of CH₄ with static chambers from adjacent sampling quadrats with and without *Juncus effusus* during four field campaigns. At all three sites, CH₄ was observed in the soil at all sampling depths (5–100 cm), and in most cases both above and below the groundwater table. During spring, local maxima suggested methanogenesis took place above the water table at all three sites. We found significant CH₄ emissions at all three sites, but emission controls were clearly different. Across the three sites, average emission rates (± 1 SE) for sampling quadrats with and without *J. effusus* were 1.47 ± 0.28 and 1.37 ± 0.33 mg CH₄ m⁻² h⁻¹ respectively, with no overall effect of *J. effusus* on CH₄ emissions, but a significant effect at one of the three sites. At this site, local CH₄ maxima were closer to the soil surface than at the other sites, and the upper soil layers were dryer. This could have affected both root CH₄ accessibility and CH₄ oxidation respectively, and together with limited gas diffusivity in the soil column, cause elevated CH₄ emissions from *J. effusus*. We conclude that aerenchymatous plants has the potential to act as point sources of CH₄ from drained peatlands, but more studies on the specific conditions under which there is an effect, are needed before the results can be used in modelling of CH₄ emissions.

1 Introduction

Undisturbed peatlands are significant sources of atmospheric methane with an estimated emission of around 30 Tg CH₄ yr⁻¹ (Frolking et al., 2011). Drainage for agriculture or forestry exposes the peat soil to oxygen and accelerates decomposition and carbon emissions of carbon dioxide rather than CH₄. Thus, CH₄ emissions are reduced partly because the activity of methanogens is attenuated in the upper oxic

BGD

12, 8467–8495, 2015

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[◀](#)

[▶](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

soil layer and partly because the oxic peat soils have a significant potential for microbial CH₄ oxidation (Kip et al., 2012; Segers, 1998; Ström et al., 2012). Also, methanogenesis may be attenuated as drainage increases the depth in the soil profile where the process takes place and the plant-derived carbon substrates for fermenters and methanogens at deeper peat depths may be more recalcitrant than near to the soil surface (Audet et al., 2013).

The strong influence of groundwater table on CH₄ emissions has been repeatedly demonstrated (e.g. Grünfeld and Brix, 1999; Moore and Roulet, 1993; Koebisch et al., 2013). A review by Couwenberg and Fritz (2012) concluded that when the water table is at 20 cm depth or below, CH₄ emissions are negligible. For water table depths closer to the surface, the abundance of aerenchymatous plants appeared to be a good indicator of CH₄ emissions (Couwenberg and Fritz, 2012) and other plant community indices may likewise have a predictive potential (Audet et al., 2013). Aerenchymatous plants provide a conduit to the atmosphere for gases dissolved in the soil water (including CH₄) thus bypassing the uppermost CH₄ oxidising soil layers (Schimel, 1995). Henneberg et al. (2012) demonstrated that the area of permeable root surface (especially lateral roots and root tips), and not above-ground plant biomass, was rate-limiting for CH₄ transport in soft rush (*Juncus effusus* L.) and probably most other wetland graminoids.

While the potential of vegetation indexes as indicators of CH₄ emissions has been pursued in wetland ecosystems, this has not to the same extent been considered for drained organic soils, where CH₄ emissions generally are low, negligible or even reversed to uptake of atmospheric CH₄ (Flessa et al., 1998; Schäfer et al., 2012). A recent study of greenhouse gas balances for eight organic soils (0.7–2.2 m peat depth) managed for agriculture confirmed the low or slightly negative flux of CH₄ from drained organic soils, with reported fluxes between -0.1 and $0.2 \text{ mgCH}_4 \text{ m}^{-2} \text{ h}^{-1}$ (Petersen et al., 2012). However, there were two exceptions with high emission rates at grassland sites with a history of cattle grazing. At these sites, some sampling quadrats (55 cm × 55 cm) with *J. effusus* emitted significant amounts of CH₄ throughout

the year, with emission rates of $1\text{--}5\text{ mgCH}_4\text{ m}^{-2}\text{ h}^{-1}$, despite low water table depths. Furthermore, the flux of CH_4 appeared to be correlated with the biomass of *J. effusus* (Petersen et al., 2012). It was proposed that compaction of the pasture by grazing cattle had created a diffusion barrier in the soil (hindering CH_4 transport), and that *J. effusus* could be an important point source of CH_4 on organic soils used for grazing due to the aerenchymatous CH_4 transport capacity.

The aim of this study was to assess the possible importance of *J. effusus* tussocks as point sources for CH_4 emissions to the atmosphere in peat soils drained for agriculture with otherwise low emission rates. We used a paired-sample approach to compare the CH_4 fluxes at micro-sites with and without *J. effusus* at three grasslands with a history of cattle grazing. We hypothesized that the emission rates of CH_4 would be significantly higher at sites with *J. effusus* compared to sites without *J. effusus* because of CH_4 transport through the aerenchyma of the plants.

2 Materials and methods

2.1 Site location and experimental design

Three different Danish fen peats at Mørke ($56^\circ22'57''\text{ N}$, $10^\circ24'23''\text{ E}$), Torsager ($56^\circ27'02''\text{ N}$, $9^\circ36'46''\text{ E}$) and Fussingø ($56^\circ28'52''\text{ N}$, $9^\circ49'37''\text{ E}$) with a history of grazing, and with tussocks of *J. effusus*, were selected for the study. The site at Mørke was also investigated by Petersen et al. (2012), where it was denoted *E-PG*. The Torsager site was located in a river valley with occasional flooding during winter, and this site had not been grazed for four years prior to the study. The areas selected for the gas flux measurements were fenced off to avoid disturbance from grazing cattle, and the sites were not fertilised during the 4 month monitoring period.

At each of the three sites, four plots in the pasture within a 25 m radius were selected, each with two side-by-side sampling quadrats ($55\text{ cm} \times 55\text{ cm}$) for gas flux measurements. One sampling quadrat (J) included a tussock of *J. effusus*, while

BGD

12, 8467–8495, 2015

Does *Juncus effusus* enhance CH_4 emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

the other quadrat (G) had grass without *J. effusus* (Fig. 1). A slit was made in the grass turf to facilitate installation of permanent frames made of 4 mm white PVC to a depth of 10 cm. These frames served as support for static chambers during gas flux measurements (Petersen et al., 2012). To minimise disturbances of soil gas profiles during sampling, boardwalks on poles were installed in front of each plot. Each grassland site was equipped with two 50 mm diameter polyethylene piezometers with a screen at 90–100 cm depth; the piezometers were positioned between two adjacent plots as indicated in Fig. 1. Recorded groundwater levels (GWL) in each piezometer were used as a reference for both neighbouring plots. Soil concentration profiles of CH₄ (see below) were determined near one of the piezometer positions at each site.

2.2 Field campaigns

Four sampling campaigns were conducted during the 2010 growth season, i.e., in late May, late June, early August and mid-September. Each sampling campaign included groundwater sampling, characterisation of *J. effusus* tussocks, CH₄ flux measurements, and determination of soil CH₄ concentration profiles.

Upon arrival at the site, GWL inside the piezometers were recorded. The piezometers were then emptied using a 12 V pump and left during gas flux measurements for fresh groundwater to enter. Around 100 mL water from the piezometers was then sampled for measurement of electrical conductivity (EC) and pH using a Cyberscan PC300 (Eutech Instruments Pte. Ltd.; Singapore). The Torsager site was flooded during the September sampling due to heavy rainfall. The standing water depth outside the piezometers was recorded, but as the floodwater had not penetrated the soil to the depth of the piezometer screen, the recorded water table did not represent the GWL in this case.

The diameter and circumference of each *J. effusus* tussock, and numbers of live and dead shoots were recorded on each of the four sampling days.

Methane flux measurements were conducted using static chambers (60 cm × 60 cm × 41 cm) constructed from white PVC as described by Petersen et al. (2012). To make a gas-tight seal during sampling, the chambers were held firmly against the permanent

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

frames by use of elastic straps. Gas samples (20 mL) were withdrawn via a butyl rubber septum at 15 min intervals (0, 15, 30, 45 and 60 min after deployment) using a syringe and needle, and transferred to 12 mL pre-evacuated Exetainer vials (Labco Ltd., High Wycombe, UK). Gas flux measurements were initiated between 10:00 and 12:30 LT. In parallel with gas sampling, soil temperatures at 5, 10 and 30 cm depth were measured at each plot using a high precision thermometer (GMH3710, Omega Newport, Deckenpfronn, Germany).

At Mørke we additionally determined CH₄ fluxes at the six sampling quadrats used in the long-term monitoring study reported by Petersen et al. (2012). These results were used for comparing with the original flux data from this site, and were not included in the statistical analyses presented here, which were based on the paired-sample statistical design.

Soil concentrations of CH₄ at 5, 10, 20, 50 and 100 cm depths were determined using an equilibrium sampler recently described by Petersen (2014). The soil gas diffusion probe (inner diameter, 12 mm, outer diameter, 16 mm) had a 10 mL reservoir (equilibrium cell) in contact with the surroundings via a 3 mm diameter opening covered by a silicone disk (12 mm × 0.5 mm) held in place by heat-shrinkable tubing. The reservoir was connected to the soil surface via 18G stainless steel tubes with Luer–Lock fittings, one of which extended to near the bottom of the reservoir. For sampling, the reservoir was flushed with 10 mL N₂ spiked with 50 μL L⁻¹ ethylene (C₂H₄), while the displaced and partly diluted gas sample was collected in a 10 mL glass syringe via a 3-way valve. From the glass syringe, the sample could be transferred to a 6 mL pre-evacuated Exetainer (Labco, High Wycombe, UK). Concentrations of CH₄ were corrected for dilution, which was typically in the order of 20 % as calculated on the basis of the C₂H₄ concentration. Following gas sampling, the equilibrium cell was flushed with > 100 mL N₂ to remove residual ethylene.

Gas samples were brought to the laboratory and analysed within two weeks using an Agilent 7890 gas chromatograph with a CTC CombiPal Autosampler (Agilent, Nærum, Denmark) configured as previously described (Petersen et al., 2012; Petersen, 2014).

The gas stream was lead to a flame ionization detector (FID) for CH₄ analysis. The carrier was N₂ at a flow rate of 45 mL min⁻¹. The FID was supplied with 45 mL min⁻¹ H₂, 450 mL min⁻¹ air and 20 mL min⁻¹ N₂. Temperatures of column and FID were 80 and 200 °C, respectively.

2.3 Soil characteristics

By the end of the monitoring period, 30 cm sections of soil were sampled to the lower boundary of the peat layer at each plot, or a maximum depth of 132 cm (0–30, 34–64, 68–98 and 102–132 cm), using a stainless steel corer (04.15 SA/SB liner sampler, Eijkelkamp, Giesbeek, the Netherlands). The soil samples were brought to the laboratory where they were homogenised. Approximately 10 g subsamples from each depth interval were then dried for 24 h at 105 °C to determine gravimetric soil moisture, and subsequently combusted at 450 °C for three hours to determine loss-on-ignition (LOI) as a measure of soil organic matter content. Also, 10 mL subsamples of peat were mixed with 20 mL of deionized water, stirred, and then left for 22 h before measuring pH and electrical conductivity (EC).

2.4 Data analysis

All calculations and statistical tests were performed using R (R Core Team, 2012). Soil characteristics at the three sites were compared with Tukey's HSD tests. Methane fluxes were calculated using the *HMR* package (Pedersen, 2012; Pedersen et al., 2010). Observed fluxes are reported, i.e. without filtering of values below the method detection limit, in accordance with the recommendations of Parkin and Venterea (2010). Among the 120 fluxes estimated in this study, 77 were best explained by the non-linear model of HMR, whereas linear regression (LR) was used in 33 cases. Ten cases were categorised as "no flux" by the HMR software, but visual inspection of the raw data identified outliers which were removed and the data sets were then successfully reanalysed with the four remaining observations.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

We used the package *lme4* (Bates et al., 2012) to construct a linear mixed effect model of the relationship between CH₄ flux as the dependent variable and vegetation type, with plot and sampling date as fixed effects (including also interactions). As random effects we used plot (nested within site) and the interaction between plot and site. To meet the requirements of variance homogeneity prior to data analysis, the flux estimates were log-transformed after adding a constant to the initial flux value to avoid negative values (i.e. $\log(x + 1)$). In preliminary runs, model effects with an F value < 1 were sequentially removed from the model. Visual inspection of residuals plotted against the fitted values and normal QQ plots did not show any sign of violation of model assumptions of normality and variance homogeneity. P values for the reduced mixed effect model were based on the Kenward–Roger approach (Kenward and Roger, 1997) using the package *pbkrtest* (Halekoh and Højsgaard, 2012), in which the model is tested against a model without the effect in question. Main effects were also tested against a model without interactions. In a separate analysis, site was left out as an effect, and the three sites were analysed separately.

Another linear mixed effects model was constructed to investigate relationships between CH₄ fluxes and the measured abiotic factors. The random effects were as above. To avoid problems with collinearity, covariates with the highest Variance Inflation Factor (VIF) were sequentially excluded from the model, using a threshold of 3 as suggested by Zuur et al. (2010). The following independent variables were included in the final model: soil temperature at 10 cm depth (Soil $T_{10\text{ cm}}$), groundwater level (GWL), groundwater pH (pH_{GW}), groundwater electrical conductivity (EC_{GW}), peat depth, soil pH at 34–64 cm depth ($\text{pH}_{34\text{ cm}}$), electrical conductivity at 0–30 cm depth ($\text{EC}_{\text{soil } 0\text{ cm}}$), and tussock diameter ($\text{Ø}_{\text{tussock}}$). Levels of significance for the model effects were again obtained using the Kenward–Roger approach for model comparison (Kenward and Roger, 1997).

3 Results

3.1 Soil characteristics

Peat depths at Torsager and Fussingø were generally at or below the maximum sampling depth of 132 cm, while at Mørke the organic layer was shallower with an average depth of 65 cm (Table 1). The sites also differed in average GWL which was closest to the soil surface at Mørke (i.e., at 37 cm below soil surface). The GWL in Mørke and Fussingø were relatively stable during the campaigns, ranging from 26 to 59 cm depth and 41 to 64 cm depth respectively. At Torsager the GWL increased gradually during the campaigns from a GWL at 120 cm depth during the first campaign to a water Table 10 cm above the soil surface during the flood in the last campaign.

Soil analyses showed differences in soil moisture, LOI, pH and EC_{soil} between depth intervals, and between the three sites (Table 2). Despite the higher GWL at Mørke, the soil layers generally contained less water (Table 2). Mørke had the most variable soil characteristics, and was more acidic at lower depths, with pH values as low as 3.5 in one plot (data not shown), compared to the other sites (Table 2).

3.2 Tussocks

The characteristics of the *J. effusus* tussocks varied between sites. Generally, the tussocks at Torsager were well-defined with thick shoots and the greatest circumference (Fig. 2). The tussocks at Mørke were relatively dense, but still allowed sporadic colonisation by other plant species (mostly pasture grasses). At Fussingø, tussocks were more diffuse, with slender shoots and less defined tussocks, which allowed for colonisation by other plant species (*Lotus pedunculatus*, *Rumex acetosa*, *Taraxacum* sp., *Cirsium arvense* and pasture grasses). The tussocks at Fussingø had the smallest number of shoots, and a lower proportion of dead shoots than at the other sites (Fig. 2).

BGD

12, 8467–8495, 2015

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

3.3 Soil CH₄ concentration profiles

Methane was present in the soil profile at all depths between 5 and 100 cm, and in most cases with significant concentrations both above and below the groundwater table (Fig. 3). Air- and water-filled porosities at the sampling depths are not known, and absolute concentrations of CH₄ could therefore not be calculated; instead equivalent gas phase concentrations are presented.

Methane concentrations varied dramatically between sites, and over time. Concentrations were in the order of 30-fold lower at Mørke than at Torsager and Fussingø, possibly because the peat layer at Mørke was more shallow and/or degraded. Interestingly there was evidence for methanogenesis above the water table at all three sites at the first sampling campaign, with local maxima at 10, 50 and 20 cm depth at Mørke, Torsager and Fussingø respectively. Methane production was also evident below the GWL at all three sites, with the highest activity in spring and early summer.

The CH₄ concentration profiles at all sites indicated that most of the CH₄ accumulating in the soil was oxidised before reaching the soil surface. Still, CH₄ concentrations at 5 cm soil depth were above atmospheric level, especially in spring and early summer, but declined steadily during the monitoring period at all sites; at Mørke from 25 to 2.6 ppmvCH₄, at Torsager from 9.1 to 2.1 ppmvCH₄ (no data available for the last sampling campaign due to flooding), and at Fussingø from 23 to 5.1 ppmvCH₄.

3.4 Methane emissions

Among the three grassland sites, CH₄ emissions were lowest at Mørke with an average (± 1 SE) CH₄ flux of $0.51 \pm 0.94 \text{ mgCH}_4 \text{ m}^{-2} \text{ h}^{-1}$, while the average flux at Fussingø was $1.19 \pm 0.64 \text{ mgCH}_4 \text{ m}^{-2} \text{ h}^{-1}$, and the highest CH₄ fluxes were seen at Torsager with an average flux of $2.55 \pm 3.20 \text{ mgCH}_4 \text{ m}^{-2} \text{ h}^{-1}$. This high average was, however, partly a result of the very high fluxes observed during the final campaign

BGD

12, 8467–8495, 2015

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

($7.3 \pm 2.9 \text{ mgCH}_4 \text{ m}^{-2} \text{ h}^{-1}$), which coincided with flooding of the river valley where the site was located.

Across all sites and sampling campaigns, the average emission rate for sampling quadrats with *J. effusus* was $1.47 \pm 0.28 \text{ mgCH}_4 \text{ m}^{-2} \text{ h}^{-1}$, and without *J. effusus* was $1.37 \pm 0.33 \text{ mgCH}_4 \text{ m}^{-2} \text{ h}^{-1}$. The CH_4 emission patterns were analysed with a mixed effects model (Table 3). Methane emissions varied significantly during the measurement period, but temporal dynamics differed between sites ($P < 0.001$), possibly due to the high CH_4 emission rates at the flooded Torsager site in September. Methane emission levels differed significantly between sites, but the linear mixed model showed no effect of vegetation type across the three sites ($P = 0.531$), although some individual plots did show consistently higher CH_4 emissions from sampling quadrats with *J. effusus* (Fig. 4). This may account for the significant interaction between site and vegetation type ($P = 0.022$).

Analysing the three sites separately, there was a significant effect of *J. effusus* on CH_4 emissions at Mørke ($P < 0.001$), but not at Torsager or Fussingø (Table 4). Also, CH_4 emissions at Mørke were constant during the measurement period ($P = 0.283$) despite the ten-fold decline in CH_4 concentration at 5 cm soil depth, whereas CH_4 emission rates increased significantly at Torsager ($P < 0.001$) and Fussingø ($P = 0.002$) over the season.

The six sampling quadrats used in a previous monitoring study at Mørke between September 2008 and October 2009 (Petersen et al., 2012) were re-visited in the present study conducted during 2010. The previously observed pattern was confirmed, where a single sampling quadrat with a *J. effusus* tussock was a constant and significant source of CH_4 while all other sampling quadrats showed no flux (Fig. 5).

3.5 Effects of abiotic factors

The relationships between CH_4 emission and several abiotic factors measured during the field campaigns were examined using a linear mixed model. The explanatory

BGD

12, 8467–8495, 2015

Does *Juncus effusus* enhance CH_4 emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



variables remaining after model reduction are shown in Table 5. GWL and peat depth in particular significantly influenced CH₄ emission from the sites, whereas soil temperature, EC and the measured tussock characteristics did not have a significant effect on CH₄ emissions. The average soil temperature in 10 cm depth (Soil $T_{10\text{cm}}$) was 12.9 ± 0.3 °C, and the low variation could be a reason for the limited explanatory power (Table 5).

4 Discussion

In this study we hypothesised that local hotspots of CH₄ emissions from pastures drained for agriculture could develop in the presence of *J. effusus*, a wetland plant that can transport gases effectively via its aerenchyma (Henneberg et al., 2012). In wetlands, reports on the importance of aerenchymatous plants for CH₄ emissions differ. Most authors have found that emissions from such vegetation are enhanced (Chanton and Dacey, 1991; Greenup et al., 2000; Koelbener et al., 2010; Noyce et al., 2014; Schimel, 1995), but reduced emissions can also occur (Bhullar et al., 2013; Fritz et al., 2011; Grünfeld and Brix, 1999). However, these studies were conducted in permanently flooded wetlands or mesocosms with a high water table. We specifically addressed plant mediated gas transport in drained peatlands which have so far received little attention.

We used a paired-sample approach at three sites to investigate relationships between *J. effusus* and CH₄ emissions from grasslands on organic soil used for grazing. The hypothesis that tussocks of *J. effusus* would always enhance CH₄ emissions from otherwise low-emitting areas was not confirmed. There was substantial variation in CH₄ emission levels between the three sites, between plots and sampling quadrats with and without *J. effusus*, and across the monitoring period. Only at Mørke, a location previously investigated by Petersen et al. (2012), did we find a statistically significant effect of vegetation type, and then only in one of four plots (Fig. 4a). In comparison to Mørke, the other two sites had significant emissions of CH₄ in all plots,

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

and differences between sampling quadrats with and without *J. effusus*, though not always with higher emissions in the sampling quadrat with *J. effusus*. Thus, CH₄ emission potentials in grazed grasslands are spatially heterogeneous, and as shown previously (Hendriks et al., 2010), the role of aerenchymatous plants in enhancing CH₄ emissions to the atmosphere may depend on micro-site conditions.

Methane emissions, which ranged from around zero to more than 10 mgCH₄m⁻²h⁻¹, depended significantly on groundwater level (Table 5). As would be expected, the highest emission rates were observed at Torsager after flooding, with rates equivalent to those reported from permanently flooded peatlands (Kim et al., 1999; Turetsky et al., 2014). Several authors have suggested that CH₄ emissions are insignificant when the GWL is below a certain threshold of 20 to 30 cm below the soil surface (Audet et al., 2013; Koebisch et al., 2013; Shannon and White, 1994). This threshold could not be confirmed in this study, where emissions of 1–3 mgCH₄m⁻²h⁻¹ were observed with the GWL at 40–50 cm depth. Also, it was found that CH₄ could be produced above the water table. Schäfer et al. (2012) likewise found significant CH₄ production potentials both above and below the water table at the Mørke site of the present study, and at a drained bog site used for grazing. The presence of methanogens in these soil layers was later confirmed by molecular characterisation of prevailing archaea (Görres et al., 2013). In our study, CH₄ accumulation in the soil profile above the water table was even higher at the other sites than at Mørke, and at all sites local maxima in CH₄ concentration were observed above the water table. Hence, there was strong evidence for methanogenesis above the water table at all three sites. In addition to groundwater level, peat depth had a significant effect on CH₄ emissions, which is probably due to a deeper organic layer supporting a higher CH₄ production. Our results do not indicate an effect of soil temperature on CH₄ emissions, as opposed to several other studies (e.g. Moore and Dalva, 1993). First, the variation of soil temperatures presented here is low, and second, the possible effect of temperature on CH₄ production may have been obliterated by the potential for CH₄ oxidation in the upper soil layers.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Gas diffusivity is critical for CH₄ accumulation, partly by controlling the proportion of anaerobic soil volume with a potential for methanogenesis, and partly by controlling the supply of O₂ for CH₄ oxidation (Moore and Dalva, 1993; Smith et al., 2003). Capillary forces have been shown to largely saturate peat well above the water table (Grünfeld and Brix, 1999). According to Schäfer et al. (2012), the peat at Mørke was degraded to H8–H10 on the Von Post scale. In comparison, the peat at Fussingø and Torsager sites were categorized as H8 and H6, respectively. Schwärzel et al. (2002) concluded that, due to shrinkage and mineralisation processes, degraded peat soils will maintain a high volumetric water content during periods of drying, and a decline in the proportion of macropores > 100 μm, which could have contributed to their ability to generate CH₄. The CH₄ accumulation we observed in the unsaturated zone during spring and early summer (Fig. 3), followed by depletion during summer and early autumn, could then be due to increasing CH₄ oxidation activity, or declining methanogenic activity over the season (Schäfer et al., 2012).

The positive effect of *J. effusus* on CH₄ emissions in Mørke cannot be fully explained from the results presented here, but contributing factors could include poor exchange of gases between soil and atmosphere, and a potential for methanogenesis above the water table. This could lead to accumulation of CH₄ in the *J. effusus* rhizosphere, which may extend to more than 60 cm depth (Justin and Armstrong, 1987). At Mørke there was a local maximum of soil CH₄ at 10 cm depth in May and June. This maximum was closer to the soil surface than the maxima observed at the two other sites, and well within reach of the roots of *J. effusus*. In the study of Schäfer et al. (2012), the CH₄ accumulation was lower in plots with *J. effusus* tussocks than in plots without *J. effusus*, which is consistent with plant-mediated transport of CH₄ (Chanton et al., 1989; Sorrell and Boon, 1994). We hypothesise two different scenarios causing the positive effect of *J. effusus* on CH₄ emissions at Mørke. First, it could be an effect of the low resistance pathway of the aerenchyma of *J. effusus* short-circuiting gas release through an otherwise compact soil with a very high resistance to gas diffusion. Second, the peat layer at Mørke was shallower, and the upper soil layers dryer, compared to

the Fussingø and Torsager sites. These factors may have contributed to lower CH₄ production and higher potential for CH₄ oxidation in the upper soil layers at Mørke. If the CH₄ oxidation potential in the upper soil layers exceeds the amount of CH₄ diffusing through the soil column, all CH₄ can be oxidized before reaching the atmosphere, and CH₄ is only emitted from *J. effusus*. The fact that *J. effusus* proved to be a significant point source of CH₄ from the sampling point from Petersen et al. (2012) revisited in this study (Fig. 5), indicated that the positive effect of *J. effusus* on CH₄ emissions in Mørke is temporally consistent.

5 Conclusions

The importance of *J. effusus* and other similar wetland plants for enhancing CH₄ emissions from drained peatlands is likely to vary considerably between and within sites, depending on factors such as water table depth and the balance between CH₄ production and oxidation processes, along with the access of roots to rhizosphere CH₄. The present and previous (Petersen et al., 2012) results from Mørke represented one scenario where significant CH₄ production combined with root access to CH₄ allowed tussocks of *J. effusus* to sustain consistent elevated CH₄ emissions during at least two separate growing seasons, though only in some micro-sites. The absence of an effect of *J. effusus* at the other two grassland sites suggests that whether or not such plants are present is of less importance under other conditions, such as when there are high rates of CH₄ production and the aerenchymatous pathway does not offer a significant short-circuit compared to direct release from the soil. Since the positive effect of *J. effusus* on CH₄ emissions is not consistent at all sites, and the relationship is not fully resolved, the results from this study cannot be implemented in CH₄ emission models at this point. The results highlight the need for more studies on the effect of aerenchymatous plants on CH₄ emissions from organic soils with a low water table, and on the necessary and sufficient conditions contributing to scenarios where the aerenchymatous pathway plays a significant role.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Acknowledgements. The authors thank Jørgen Nielsen for assistance during the field campaigns, Kristian M. Kristensen for valuable statistical advice and Mogens H. Greve for classification of soil samples. The studies were partly funded by the Department of Agroecology and the Graduate School of Science and Technology, Aarhus University.

References

- Audet, J., Johansen, J. R., Andersen, P. M., Baattrup-Pedersen, A., Brask-Jensen, K. M., Elsgaard, L., Kjaergaard, C., Larsen, S. E., and Hoffmann, C. C.: Methane emissions in Danish riparian wetlands: ecosystem comparison and pursuit of vegetation indexes as predictive tools, *Ecol. Indic.*, 34, 548–559, 2013.
- Bates, D., Maechler, M., and Bolker, B.: lme4: Linear Mixed-Effects Models Using Eigen and S4 Classes, R Package Version 0.999999-0, available at: <http://CRAN.R-project.org/package=lme4>, last access: 7 February 2013, 2012.
- Bhullar, G., Iravani, M., Edwards, P., and Olde Venterink, H.: Methane transport and emissions from soil as affected by water table and vascular plants, *BMC Ecology*, 13, doi:10.1186/1472-6785-13-32, 2013.
- Chanton, J. P. and Dacey, J. W. H.: Effects of vegetation on methane flux, reservoirs, and carbon isotopic composition, in: *Trace Gas Emissions by Plants*, edited by: Sharkey, T. D., Academic Press Limited, London, 65–92, 1991.
- Chanton, J. P., Martens, C. S., and Kelley, C. A.: Gas transport from methane-saturated, tidal freshwater and wetland sediments, *Limnol. Oceanogr.*, 34, 807–819, 1989.
- Couwenberg, J. and Fritz, C.: Towards developing IPCC methane “emission factors” for peatlands (organic soils), *Mires and Peat*, 10, 3, 1–17, 2012.
- Flessa, H., Wild, U., Klemisch, M., and Pfadenhauer, J.: Nitrous oxide and methane fluxes from organic soils under agriculture, *Eur. J. Soil Sci.*, 49, 327–335, 1998.
- Fritz, C., Pancotto, V. A., Elzenga, J. T. M., Visser, E. J. W., Grootjans, A. P., Pol, A., Iturraspe, R., Roelofs, J. G. M., and Smolders, A. J. P.: Zero methane emission bogs: extreme rhizosphere oxygenation by cushion plants in Patagonia, *New Phytol.*, 190, 398–408, 2011.
- Frolking, S., Talbot, J., Jones, M. C., Treat, C. C., Kauffman, J. B., Tuittila, E.-S., and Roulet, N.: Peatlands in the Earth’s 21st century climate system, *Environ. Rev.*, 19, 371–396, 2011.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



- Görres, C.-M., Conrad, R., and Petersen, S. O.: Effect of soil properties and hydrology on *Archaeal* community composition in three temperate grasslands on peat, *FEMS Microbiol. Ecol.*, 85, 227–240, 2013.
- Greenup, A. L., Bradford, M. A., McNamara, N. P., Ineson, P., and Lee, J. A.: The role of *Eriophorum vaginatum* in CH₄ flux from an ombrotrophic peatland, *Plant Soil*, 227, 265–272, 2000.
- Grünfeld, S. and Brix, H.: Methanogenesis and methane emissions: effects of water table, substrate type and presence of *Phragmites australis*, *Aquat. Bot.*, 64, 63–75, 1999.
- Halekoh, U. and Højsgaard, S.: pbkrtest: Parametric Bootstrap and Kenward Roger Based Methods for Mixed Model Comparison, R Package Version 0.3-4, available at: <http://CRAN.R-project.org/package=pbkrtest>, last access: 7 February 2013, 2012.
- Hendriks, D. M. D., van Huissteden, J., and Dolman, A. J.: Multi-technique assessment of spatial and temporal variability of methane fluxes in a peat meadow, *Agr. Forest Meteorol.*, 150, 757–774, 2010.
- Henneberg, A., Sorrell, B. K., and Brix, H.: Internal methane transport through *Juncus effusus*: experimental manipulation of morphological barriers to test above- and below-ground diffusion limitation, *New Phytol.*, 196, 799–806, 2012.
- Justin, S. H. F. W. and Armstrong, W.: The anatomical characteristics of roots and plant response to soil flooding, *New Phytol.*, 106, 465–495, 1987.
- Kenward, M. G. and Roger, J. H.: Small sample inference for fixed effects from restricted maximum likelihood, *Biometrics*, 53, 983–997, 1997.
- Kim, J., Verma, S. B., and Billesbach, D. P.: Seasonal variation in methane emission from a temperate *Phragmites*-dominated marsh: effect of growth stage and plant-mediated transport, *Glob. Change Biol.*, 5, 433–440, 1999.
- Kip, N., Fritz, C., Langelaan, E. S., Pan, Y., Bodrossy, L., Pancotto, V., Jetten, M. S. M., Smolders, A. J. P., and Op den Camp, H. J. M.: Methanotrophic activity and diversity in different *Sphagnum magellanicum* dominated habitats in the southernmost peat bogs of Patagonia, *Biogeosciences*, 9, 47–55, doi:10.5194/bg-9-47-2012, 2012.
- Koebisch, F., Glatzel, S., and Jurasinski, G.: Vegetation controls methane emissions in a coastal brackish fen, *Wetl. Ecol. Manag.*, 21, 323–337, 2013.
- Koelbener, A., Ström, L., Edwards, P., and Olde Venterink, H.: Plant species from mesotrophic wetlands cause relatively high methane emissions from peat soil, *Plant Soil*, 326, 147–158, 2010.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

- Moore, T. R. and Dalva, M.: The influence of temperature and water table position on carbon dioxide and methane emissions from laboratory columns of peatland soils, *J. Soil Sci.*, 44, 651–664, 1993.
- Moore, T. R. and Roulet, N. T.: Methane flux: water table relations in northern wetlands, *Geophys. Res. Lett.*, 20, 587–590, 1993.
- Noyce, G. L., Varner, R. K., Bubier, J. L., and Frolking, S.: Effect of *Carex rostrata* on seasonal and interannual variability in peatland methane emissions, *J. Geophys. Res.-Biogeo.*, 119, 24–34, 2014.
- Parkin, T. B. and Venterea, R. T.: USDA-ARS GRACEnet project protocols, chapt. 3. Chamber-based trace gas flux measurements, in: *Sampling Protocols*, edited by: Follett, R. F., United States Department of Agriculture, Beltsville, MD, 1–39, 2010.
- Pedersen, A. R.: HMR: Flux Estimation with Static Chamber Data, R package version 0.3.1, available at: <http://CRAN.R-project.org/package=HMR>, last access: 21 March 2013, 2012.
- Pedersen, A. R., Petersen, S. O., and Schelde, K.: A comprehensive approach to soil-atmosphere trace-gas flux estimation with static chambers, *Eur. J. Soil Sci.*, 61, 888–902, 2010.
- Petersen, S. O.: Diffusion probe for gas sampling in undisturbed soil, *Eur. J. Soil Sci.*, 65, 663–671, 2014.
- Petersen, S. O., Hoffmann, C. C., Schäfer, C.-M., Blicher-Mathiesen, G., Elsgaard, L., Kristensen, K., Larsen, S. E., Torp, S. B., and Greve, M. H.: Annual emissions of CH₄ and N₂O, and ecosystem respiration, from eight organic soils in Western Denmark managed by agriculture, *Biogeosciences*, 9, 403–422, doi:10.5194/bg-9-403-2012, 2012.
- R Core Team: R: a Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, available at: <http://www.R-project.org/>, last access: 22 January 2013, 2012.
- Schäfer, C. M., Elsgaard, L., Hoffmann, C. C., and Petersen, S. O.: Seasonal methane dynamics in three temperate grasslands on peat, *Plant Soil*, 357, 339–353, 2012.
- Schimel, J. P.: Plant transport and methane production as controls on methane flux from arctic wet meadow tundra, *Biogeochemistry*, 28, 183–200, 1995.
- Schwärzel, K., Renger, M., Sauerbrey, R., and Wessolek, G.: Soil physical characteristics of peat soils, *J. Plant Nutr. Soil Sc.*, 165, 479–486, 2002.
- Segers, R.: Methane production and methane consumption: a review of processes underlying wetland methane fluxes, *Biogeochemistry*, 41, 23–51, 1998.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

- Shannon, R. D. and White, J. R.: A three-year study of controls on methane emissions from two Michigan peatlands, *Biogeochemistry*, 27, 35–60, 1994.
- Smith, K. A., Ball, T., Conen, F., Dobbie, K. E., Massheder, J., and Rey, A.: Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes, *Eur. J. Soil Sci.*, 54, 779–791, 2003.
- Sorrell, B. K. and Boon, P. I.: Convective gas flow in *Eleocharis sphacelata* R. Br.: methane transport and release from wetlands, *Aquat. Bot.*, 47, 197–212, 1994.
- Ström, L., Tagesson, T., Mastepanov, M., and Christensen, T. R.: Presence of *Eriophorum scheuchzeri* enhances substrate availability and methane emission in an Arctic wetland, *Soil Biol. Biochem.*, 45, 61–70, 2012.
- Turetsky, M. R., Kotowska, A., Bubier, J., Dise, N. B., Crill, P., Hornibrook, E. R. C., Minkinen, K., Moore, T. R., Myers-Smith, I. H., Nykänen, H., Olefeldt, D., Rinne, J., Saarnio, S., Shurpali, N., Tuittila, E.-S., Waddington, J. M., White, J. R., Wickland, K. P., and Wilmking, M.: A synthesis of methane emissions from 71 northern, temperate, and subtropical wetlands, *Glob. Change Biol.*, 20, 2183–2197, 2014.
- Zuur, A. F., Ieno, E. N., and Elphick, C. S.: A protocol for data exploration to avoid common statistical problems, *Methods in Ecology and Evolution*, 1, 3–14, 2010.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

Table 1. Peat depth, groundwater level and number of shoots in tussocks of *J. effusus* at the three study sites. Data are mean \pm standard error ($n = 4$, $n = 8$ and $n = 16$ respectively) representing spatial variability for peat depth and temporal variability within sites for groundwater level and tussocks of *J. effusus*.

Site	Peat depth (cm)	Groundwater level depth (cm)	<i>J. effusus</i> (shoots tussock ⁻¹)
Mørke	65 \pm 7.7	37 \pm 3.8	281 \pm 26
Torsager	> 132 ^a	67 \pm 18	387 \pm 28
Fussingø	> 127 ^b	52 \pm 3.2	171 \pm 8

^a Peat depth in all plots in Torsager exceeded the measurement depth of 132 cm.

^b Peat depth in two out of four plots in Fussingø exceeded the measurement depth of 132 cm.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table 2. Average (\pm standard error, $n = 4$) gravimetric soil moisture, loss-on-ignition (LOI), pH and soil electrical conductivity (EC_{soil}) measured at the four plots at the three sites.

Depth (cm)	Mørke	Torsager	Fussingø
Soil moisture (%)			
0–30	53.8 \pm 6.2 a	76.9 \pm 2.0 c	70.0 \pm 3.3 b
34–64	75.0 \pm 4.8 a	83.6 \pm 1.5 b	82.9 \pm 1.4 b
68–98	48.9 \pm 14.9 a	83.7 \pm 1.6 b	86.1 \pm 0.8 b
102–132	27.1 \pm 1.8 a	84.1 \pm 1.0 b	88.8 \pm 0.6 b
LOI (%)			
0–30	39.6 \pm 11.9 a	60.4 \pm 5.8 b	64.7 \pm 7.7 b
34–64	63.8 \pm 13.6 a	71.4 \pm 2.3 ab	80.1 \pm 5.0 b
68–98	25.4 \pm 12.3 a	65.5 \pm 1.4 b	79.9 \pm 0.9 c
102–132	3.3 \pm 0.6 a	64.3 \pm 1.1 b	77.7 \pm 3.3 c
pH			
0–30	5.68 \pm 0.37 b	5.33 \pm 0.06 a	5.70 \pm 0.03 b
34–64	5.40 \pm 0.39 a	5.60 \pm 0.06 a	5.57 \pm 0.08 a
68–98	4.80 \pm 0.45 a	5.79 \pm 0.10 b	6.14 \pm 0.10 c
102–132	5.07 \pm 0.11 a	5.80 \pm 0.05 b	6.44 \pm 0.11 c
EC_{soil} (mScm ⁻¹)			
0–30	0.46 \pm 0.07 b	0.41 \pm 0.04 ab	0.38 \pm 0.03 a
34–64	0.70 \pm 0.20 a	0.61 \pm 0.09 a	0.96 \pm 0.18 b
68–98	0.60 \pm 0.13 a	0.62 \pm 0.10 a	0.94 \pm 0.12 b
102–132	0.63 \pm 0.18 a	0.59 \pm 0.09 a	0.93 \pm 0.12 b

Letters indicate significant ($P < 0.05$) difference within rows.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Table 3. Effects of site, vegetation (with or without *Juncus effusus*), sampling date on methane (CH₄) emission rates were evaluated using a linear mixed model. See text for a description of the model.

Effect	df, num	df, denom	F value	P
Site	2	8.4	6.48	0.022*
Vegetation	1	3.2	0.51	0.531
Sampling date	3	77	45.8	< 0.001***
Site × Vegetation	2	69	4.06	0.022*
Site × Sampling date	6	69	20.3	< 0.001***

* $P < 0.05$; *** $P < 0.001$.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

Table 4. Effects of vegetation (with or without *Juncus effusus*) and sampling date on methane (CH₄) emission rates were evaluated using a linear mixed model for each of the three sites separately.

	Effect	df, num	df, denom	F value	P
Mørke	Vegetation	1	24	14.1	< 0.001***
	Sampling date	3	24	1.18	0.283
	Vegetation × Sampling date	3	21	0.05	0.985
Torsager	Vegetation	1	24	0.28	0.592
	Sampling date	3	24	44.8	< 0.001***
	Vegetation × Sampling date	3	21	0.40	0.753
Fussingø	Vegetation	1	24	1.47	0.209
	Sampling date	3	24	5.86	0.002***
	Vegetation × Sampling date	3	21	0.09	0.963

*** $P < 0.001$.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table 5. Significant effects of the relationship between methane (CH₄) emission rate and the measured factors that remained in the model after exclusion of model effects based on variance inflation factors (VIF).

Effects	Significance
Soil $T_{10\text{ cm}}$	ns
GWL	***
pH _{ground water}	ns
EC _{ground water}	ns
Peat depth	***
pH _{34 cm}	**
EC _{soil 0 cm}	ns
$\emptyset_{\text{tussock}}$	ns

Soil $T_{10\text{ cm}}$ – soil temperature at 10 cm depth.

GWL – groundwater level.

EC_{ground water} – groundwater electrical conductivity.

pH_{34 cm} – pH at 34–64 cm depth.

EC_{soil 0 cm} – electrical conductivity of the soil at 0–34 cm depth.

$\emptyset_{\text{tussock}}$ – diameter of the *Juncus effusus* tussocks.

** $P < 0.01$; *** $P < 0.001$.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

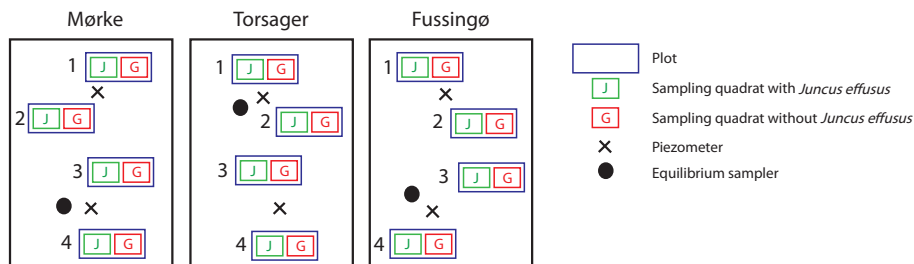


Figure 1. Experimental design. The three grassland sites each had four plots (1–4) consisting of two sampling quadrats for gas flux measurement with either grass alone (G) or grass with a tussock of *Juncus effusus* (J). Between each pair of plots, a piezometer was installed (x). Soil concentration profiles of methane (CH₄) were determined at 5 depths (from 5 to 100 cm) using equilibrium samplers (●) installed next to one of the piezometers.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

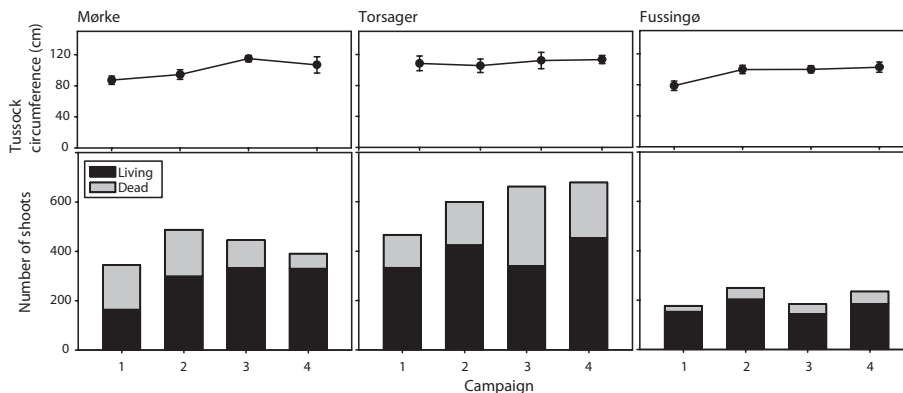


Figure 2. Mean circumference (\pm standard error, $n = 4$) and number of living and dead shoots ($n = 4$) of the tussocks in *Juncus effusus* sampling quadrats at the three sites, at the four sampling campaigns.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

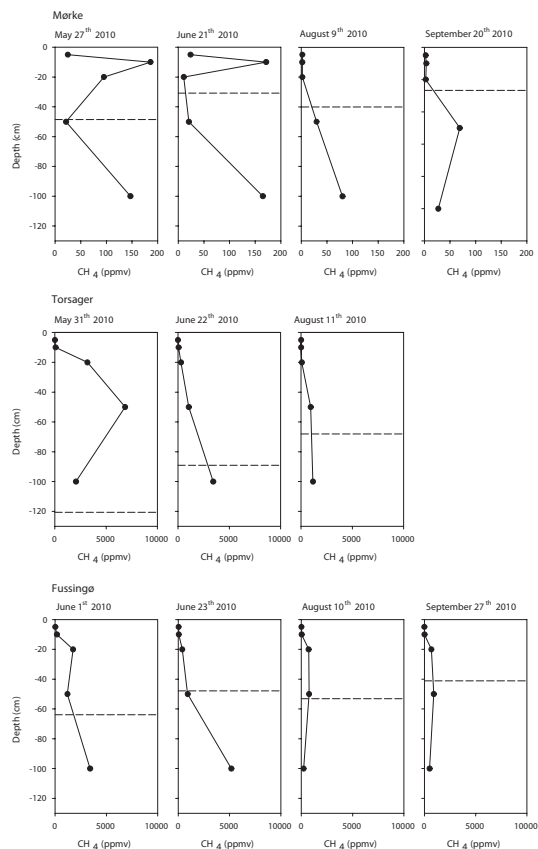


Figure 3. Soil methane (CH₄) concentration profiles for the three different sites at the four sampling dates. The dashed line represents the groundwater level. For Torsager measurements were not taken on the last sampling day due to excessive surface flooding. Note the different x axis scale for Mørke.

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)
[◀](#)
[▶](#)
[◀](#)
[▶](#)
[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

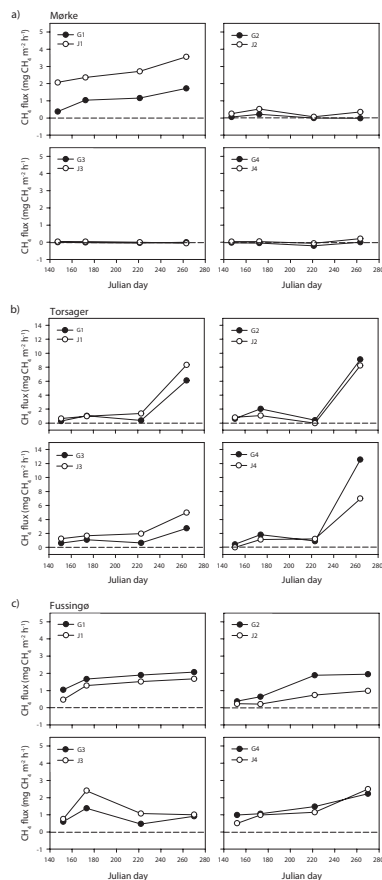


Figure 4. Methane (CH₄) fluxes at sampling quadrats with (-○-) and without (-●-) *Juncus effusus* at the three different sites during the course of the field campaigns. Note the different y axis scale in **(b)** Torsager.

Does *Juncus effusus* enhance CH₄ emissions from grazed pastures on peat?

A. Henneberg et al.

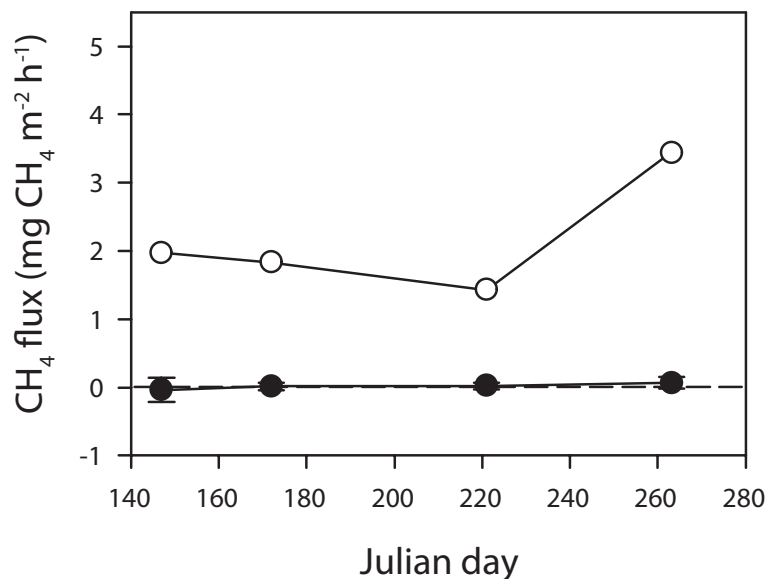


Figure 5. Methane (CH₄) emissions for the reference plots at Mørke with (-○-) *Juncus effusus* ($n = 1$) and without (-●-) *Juncus effusus* (mean ± standard error, $n = 5$) during the course of the field campaigns. These are the original sampling quadrats from Petersen et al. (2012).

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)