

1 **Authors' response: Interactive comment on "CH₄ and N₂O dynamics**
2 **in the boreal forest–mire ecotone" by B. Ľupek et al., BGD, 11, 8049–**
3 **8084, 2014, boris.tupek@helsinki.fi, 2 October 2014**
4

5 **Please, find our response *in italic font* and proceeded by # symbol.**
6 **Suggested text for the manuscript uses same font as our BGD paper.**
7 **We thank Referees for the valuable comments on the manuscript.**

8 **Anonymous Referee #1**

9 Received and published: 26 June 2014

10 Review of Tupek et al, 2014, BGD, 11, 8049–8084 CH₄ and N₂O dynamics in the
11 boreal forest–mire ecotone

12 General comments: This paper examines the production of CH₄ and N₂O through a
13 transitional landscape region commonly found in boreal environments. The paper uses
14 the closed chamber method for 2-3 years over nine locations on an ecotone gradient.
15 The paper finds minimal spatial patterns in N₂O due to the generally low fluxes while
16 CH₄ fluxes tended to follow a soil-wetness gradient. The authors did not detect any
17 evidence for "hot moment" fluxes of either gas and also found relatively stable fluxes
18 from year-to-year despite different wetness conditions in these years. I found the paper
19 well put-together and interesting in its presentation of the data. The paper helps to fill
20 a gap in current knowledge of these common transitional landscapes. It cites many interesting
21 papers and helps to contextualize its results through a comparison to these
22 other studies. I find the paper worth publishing in Biogeosciences after some revisions
23 and additions to the content as detailed below.

24 **# *Thank you!***

25 Suggestions: The paper would benefit from a stronger description of site differences,
26 including pH and CN ratios for the different landscape units. It seems that the pH is
27 not measured with each flux estimate, which is a pity in such a study. Especially with
28 a discussion of microbial communities and the lag-time in response to changing water
29 tables, pH can be a particularly useful indicator of CH₄ production potential. If you have
30 such data for the sites (it is unlikely to change so greatly through the year) it would be
31 nice to see it. Likewise some information about the site CN ratios would be useful for
32 understanding both CH₄ and N₂O fluxes.

33 **# *We agree with the Referee that results on pH and C/N ratios would help***
34 ***the reader to understand individual site potential CH₄ and N₂O fluxes. We***
35 ***analysed our remaining data and suggest extending the manuscript for pH of***
36 ***soil water solution and soil properties (bulk density and C/N ratios):***

37 *2 Material and methods*

38 *2.1 Study site characteristics*

39 *Page 8054, after Line 3*

40 **We measured pH during the 2005 summer campaign from soil water data collected on all sites**
41 **by suction-cup lysimeters. Three lysimeters were installed at 10 cm and one at depth of 30 cm**
42 **below the soil surface in each site. A detailed description of the lysimeters and sampling**
43 **procedure can be found in Starr (1985). The pH was measured on the day of water sampling in**
44 **the laboratory by a pH meter equipped with a glass electrode. The mean acidity level of the**

1 sites of forest-mire ecotone was gradually increasing from pH 5.6 in uplands (CT) to 4.4 in
 2 transitions (KR), whereas the mires were less acidic than the transitions with pHs of 5.1 and
 3 4.8 (VSR1 and VSR2 respectively) (Table 1). Collected soil water from a depth of 30 cm
 4 generally showed a higher pH than soil water pH from a depth of 10 cm. Three soil cores for
 5 each plot were taken in July 2006 from the top soil (0-10 cm) in upland forests and from the
 6 two profile depths (0-10 cm, 10-30 cm) in forest mire transitions and in peatlands. The volume
 7 of samples was measured before the oven drying at 70 °C to determine the bulk density. The
 8 bulk density of the upper organic layer ranged from 0.24 gcm⁻³ (KR) to 0.48 gcm⁻³ (MT) and was
 9 approximately half of the bulk density of the organic layer from depths of 10-30 cm (mean of
 10 transitions and mires 0.77 gcm⁻³) (Table 1). The C/N ratio was determined once for each plot
 11 from the soil organic matter analysed by dry combustion with Leco CNS-1000 (Leco Corp., USA).
 12 The C/N ratio was wider in the 0-10 cm profile (mean 37) than in the 10-30 cm profile (mean
 13 27). The highest N content and lowest C/N ratio along the ecotone was found in forest-mire
 14 transitions OMT+ and KgK (Table 1).

15 **Table 1. Site soil water solution pH and soil properties.**

	CT		VT		MT		OMT		OMT+		KgK		KR		VSR1		VSR2	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
pH 10 cm	5.57	0.36	5.14	0.42	5.24	0.08	4.68	0.39	4.58	0.30	4.46	0.14	4.37	0.22	5.06	0.39	4.80	0.44
pH 30 cm	6.20	0.06	6.18	0.02	5.91	0.13	5.30	0.11	5.53	0.04	4.91	0.10	4.55	0.08	5.32	0.15	4.79	0.19
Bulk density 0-10 cm	0.37	0.09	0.28	0.04	0.48	0.03	0.27	0.09	0.31	0.13	0.33	0.05	0.24	0.02	0.40	0.12	0.40	0.12
Bulk density 10-30 cm									0.92	0.07	0.31	0.12	0.85	0.03	0.90	0.07	0.90	0.07
Tot C (%) 0-10 cm	43.17		24.22		49.63		47.09		45.36		48.68		50.30		45.76		48.20	
Tot C (%) 10-30 cm									21.76		53.31		48.33		47.70		49.97	
Tot N (%) 0-10 cm	1.02		0.61		1.18		1.59		2.19		1.47		1.12		1.29		0.96	
Tot N (%) 10-30 cm									0.96		1.95		1.45		1.87		1.81	
C/N 0-10 cm	42.32		39.70		42.06		29.62		20.71		33.12		44.91		35.47		50.21	
C/N 10-30 cm									22.67		27.34		33.33		25.51		27.61	

16

17 *2 Material and methods*

18 *2.4 Statistical analysis*

19 *Page 8058, after Line 6*

20 **To examine correlations between CH₄ and N₂O fluxes and pH, and soil properties we preformed**
 21 **the Pearson's correlation tests.**

22 *3 Results*

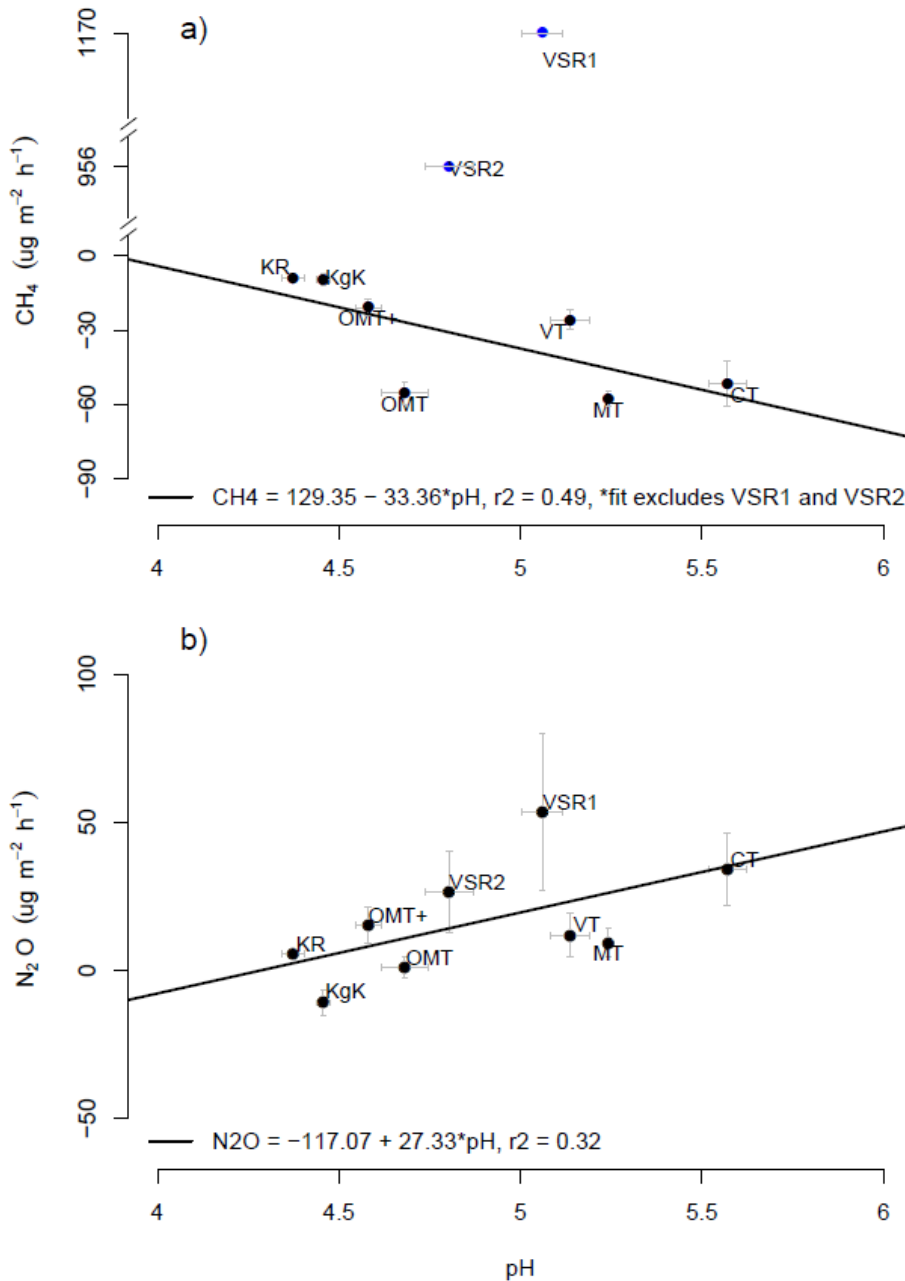
23 *Page 8063, after Line 2*

24

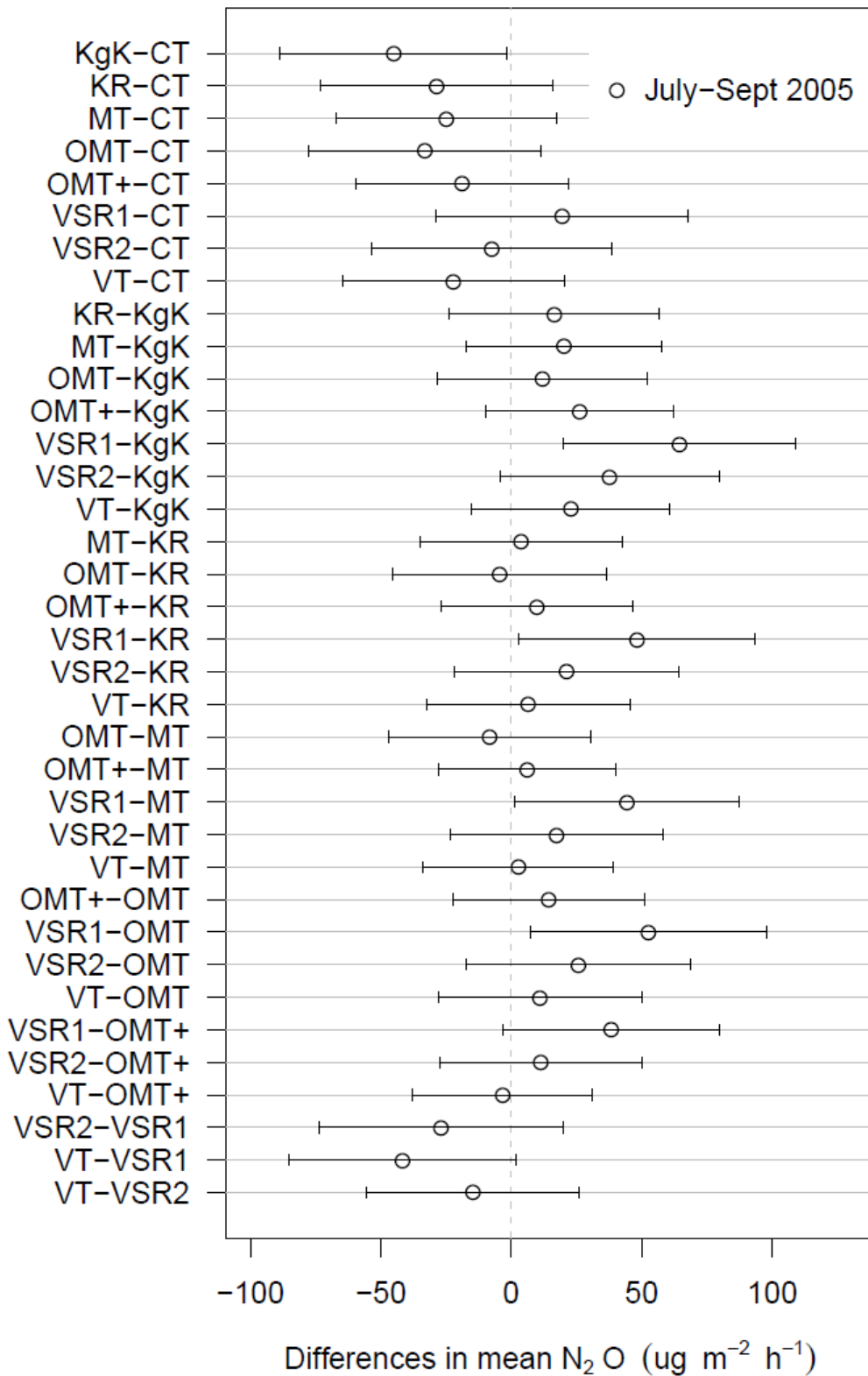
25 **3.6 Effects of pH and soil properties on CH₄ and N₂O flux**

26 **The site specific momentary CH₄ and N₂O fluxes did not show significant correlation with**
 27 **varying soil water pH (except for one correlation coefficient $r = -0.45$, $p = 0.02$ on MT for N₂O**
 28 **and pH at 10 cm). No correlation was found between CH₄ momentary data on the ecotone level.**
 29 **Although, for the CH₄ data including that for a group of upland forest and forest-mire**
 30 **transitions (excluding mires) Pearson correlation between momentary CH₄ fluxes and soil**
 31 **water pH was significant ($r = -0.32$, $p < 0.001$). Mean CH₄ fluxes ($\mu\text{g m}^{-2} \text{h}^{-1}$) of summer 2005 of**
 32 **upland forests and forest-mire transition were negatively correlated with mean pH (CH₄ =**

1 129.35 - 33.36*pH, $r^2 = 0.49$, Fig. 8a). The ecotone N_2O fluxes ($\mu\text{g m}^{-2} \text{h}^{-1}$) of the summer 2005
 2 pH campaign were significantly correlated with pH ($r = 0.174$, $p = 0.004$). The mean N_2O fluxes
 3 ($\mu\text{g m}^{-2} \text{h}^{-1}$) of sites increased with mean pH ($N_2O = -117.07 + 27.33*pH$, $r^2 = 0.32$, Fig. 8b).
 4 However, the post-hoc Tukey differences of mean N_2O fluxes from the forest floor for the pair-
 5 wise comparisons of forest/mire types were not significant for 31 pairs and mean N_2O flux
 6 differences were significant only for 5 pairs (KgK-CT, VSR1-KgK, VSR1-KR, VSR1-MT, VSR1-
 7 OMT, Figure 9). We did not find significant correlation between site specific mean CH_4 and N_2O
 8 flux and bulk density and/or C/N ratio.



9
 10 **Figure 8. Scatterplot between site specific mean pH and mean flux ($\mu\text{g m}^{-2} \text{g}^{-1}$) of a) CH_4 or b) N_2O**
 11 **of summer with intermediate moisture over the period of soil water sampling campaign (July-**
 12 **September 2005). The error bars show standard error. The CH_4 error bars for VSR1 and VSR2**
 13 **are not shown.**



1

2 **Figure 9. The post-hoc Tukey differences (error bars for 95% confidence intervals) of mean**
 3 **N_2O ($\mu g m^{-2} h^{-1}$) fluxes from forest floor for the pair-wise comparisons of forest/mire types**
 4 **(uplands - CT, VT, MT, OMT; transitions - OMT+, KgK, KR; and mires - VSR1, VSR2) over the**
 5 **period of soil water sampling campaign (July-September 2005).**

6

1 *4 Discussion*

2 *4.1 CH₄ dynamics*

3 *added text on Page 8064, after Line 2 and before Line 3*

4 **Temporally water saturated soil layers of pristine forest-mire transitions had low CH₄**
5 **production partly due to highly acidic pH levels imposing physiological restrictions on soil**
6 **microbial communities. Methanogenic activity in water saturated organic soils can be reduced**
7 **by high acidity (e.g. Ye et al. 2012). Small momentary CH₄ emissions (Supplement Fig. 3a)**
8 **observed in forest-mire transitions also indicated potential for occasionally higher production**
9 **than consumption/oxidation. Beside microsite differences in soil saturation and microbial**
10 **populations also plant communities (Fig. 1c) could play an important role in explaining**
11 **enhanced emissions (e.g. Saarnio et al., 1997, Riutta et al., 2007). For example, sedges through**
12 **aerenchymatic transport interplay with microbes by providing recently photosynthesized**
13 **carbon downwards and transporting CH₄ from microbial populations upwards (Alm et al.,**
14 **1997).**

15 *4.2 N₂O dynamics*

16 *added text on Page 8066, after Line 19 and before Line 20*

17
18 **Soil incubation studies under various moisture and temperature regimes (Pihlatie et al., 2004,**
19 **Szukics et al., 2010) imply that our higher forest floor N₂O emissions during the typical 2005**
20 **summer than during the dry 2006 summer (Supplement Fig. 3b) were probably induced by**
21 **stimulated N turnover through the soil wetting and drying cycle at a favorable temperature.**
22 **During conditions with intermediate moisture (July-September 2005) we observed also mean**
23 **N₂O flux of dry pine forest significantly larger than that of the paludified spruce forest (larger**
24 **CT than KgK), whereas mean N₂O flux of the water saturated mire was larger than four sites**
25 **(VSR1-KgK, VSR1-KR, VSR1-MT, VSR1-OMT) (Fig. 8, Fig. 9). Therefore during fluctuating soil**
26 **moisture, we could expect increased N₂O fluxes for the normally xeric (CT) and water saturated**
27 **(VSR1) site due to stimulated nitrification (CT in the rewetting phase, and VSR1 in the drying**
28 **phase). During July-September in 2005, CT and VSR1 sites were also least acid along the**
29 **ecotone which could favor nitrification and consequently N₂O emissions through denitrification**
30 **(Regina et al., 1996, Ste-Marie and Pare', 1999, Paavolainen et al., 2000). These studies**
31 **reported that increasing pH by rewetting could initiate nitrification. In contrast to the less acid**
32 **CT and VSR1, highly acid forest-mire transitions with the widest ranges of water level**
33 **fluctuations along the forest-mire ecotone ranked into a group of sites with lower N₂O fluxes.**
34 **Highly acid conditions prevent the development of nitrifiers, substrate affinity and**
35 **nitrification, even if ammonium is available (Ste-Marie and Pare', 1999, Paavolainen et al.,**
36 **2000). The fact that the net nitrification of acid sensitive nitrifiers positively increases with**
37 **forest floor pH, whereas acidification reduces it, suggests that the nitrifiers in our sites were**
38 **acid sensitive and not acid tolerant. The lack of nitrate renders any denitrification potential to**
39 **be negligible. Although, if nitrate had been present the low pH would enhance N₂O emissions**
40 **due to inhibiting di-nitrogenoxide reductase and increasing N₂O/N₂ ratio of denitrification (e.g.**
41 **Weslien et al., 2009).**

42 *Page 8066, Lines 20, 21, 22 were reformulated*

43 **In pristine peatlands nitrification positively depends on pH and negatively on water level**
44 **(Regina et al., 1996) for the supply of nitrate for denitrification, as the main source of N₂O**

1 emissions (Regina et al., 1996; Nykänen et al., 1995; Wray et al., 2007). Thus, during drying-
2 rewetting periods as in July-September 2005 our sites could initiate short-term significant
3 differences, but for the whole measurement period the lack of a statistically significant
4 difference in N₂O fluxes was probably due to its low nitrification potential. Generally the low pH
5 and the high C/N ratios of our forest floors suggest conditions of low nitrification potential.

6 *References*

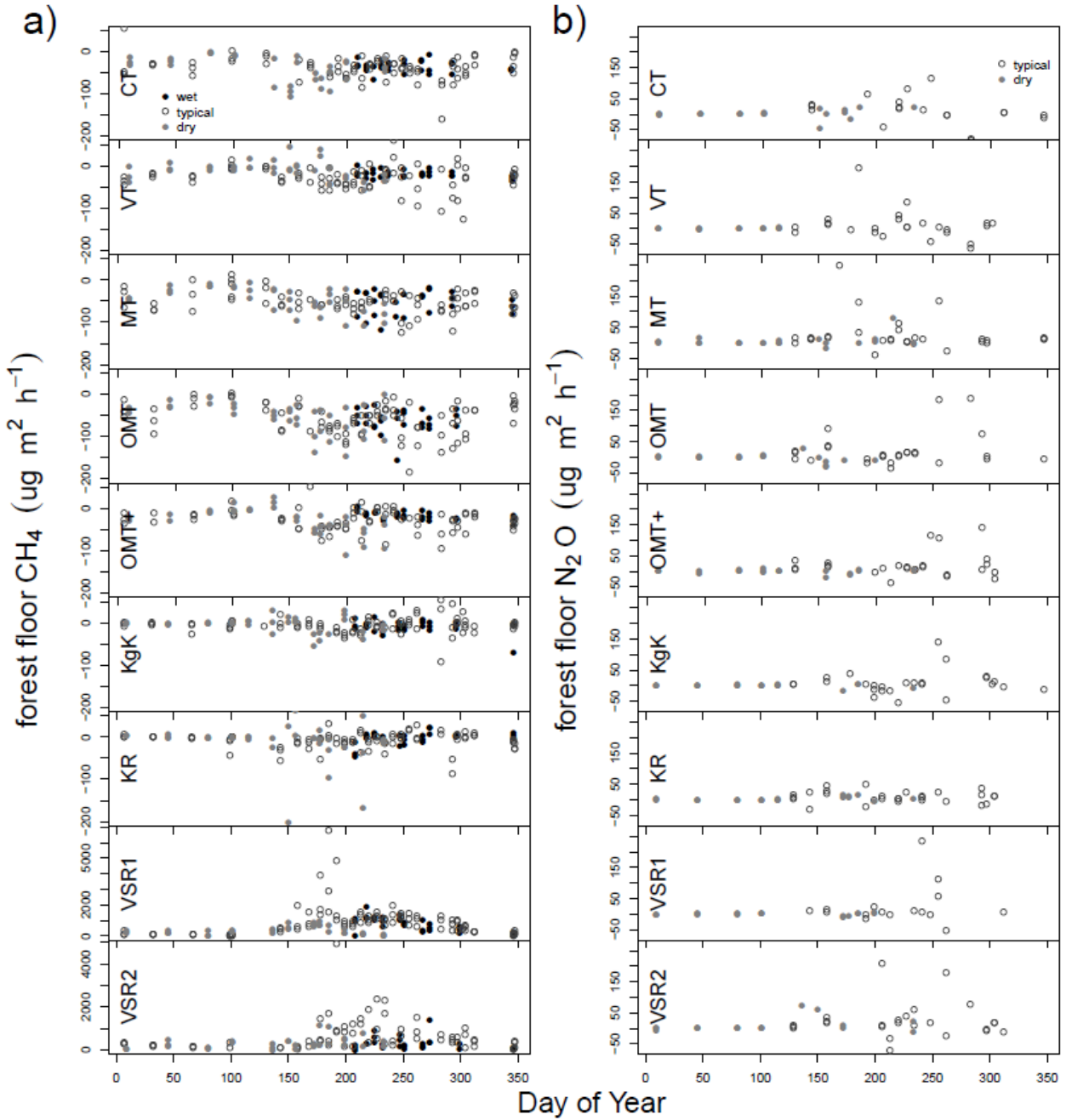
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27 pathways in peatlands across an ombrotrophic-minerotrophic gradient. *Soil Biol. Biochem.*, 54,
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29 *Acknowledgements, Page 8068, Line 24*

30 **We also thank Jukka Laine, Jukka Alm, Mike Starr and Frank Berninger for valuable**
31 **discussions; Mike Starr for providing suction cup lysimeters;**

32 The paper would benefit from a more complete time series of the fluxes for each site –
33 something like Figure 2 for each gas flux (or another style of presenting this information
34 – even the daily values). Otherwise it is hard to visualize how the time series may look,
35 how seasonal and interannual shifts may or may not occur, etc., from only the fluxvariable
36 relationships in Figs 4 and 7 and the overviews in Figs 3 and 5. This new figure
37 could indeed replace or supplement figures 3 and 5. Alternatively such a presentation
38 could be given as a supplemental on-line figure. **# In order to visualise the seasonal**
39 **and inter-annual shifts in CH₄ and N₂O fluxes we provide the time series of**
40 **daily momentary values (Supplement Fig. 3).**

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Supplement Figure 3. The momentary forest floor gas fluxes ($\mu\text{g m}^{-2} \text{ h}^{-1}$) of a) CH₄ and b) N₂O in forest/mire types (uplands CT, VT, MT, OMT, transitions OMT+, KgK, KR, and mires VSR1, VSR2) as measured during the years with exceptional moisture (wet, typical, and dry). The top-down arrangement of sites mimics the locations on the slope (see Fig. 1).

Minor suggestions

Page 8050, Line 4 omit "the" ;Page 8050, Line 20 "upscaling" Not "up scaling"

Page 8051, line 25 change richer to rich

Page 8052, line 24 promotes to promote

Page 8052, line 28 saturate to saturated

comments above were followed as suggested

1 Page 8055, line 9: Model number? (and/or supply more details about column and mesh
2 materials, gas flow rates and column temperature to allow for a reproducible study)
3 **# gas chromatograph (Hewlett-Packard, USA) model number HP-5890A was**
4 **added into the sentence**

5 Page 8055, line 18: add “the” before “gas chromatograph”
6 Page 8056, line 21: remove the comma and “which” and replace with “that”
7 Page 8057, line 8: replace “case” with “observation”
8 Page 8058, line 5: replace “the” with “a”
9 Page 8059, line 18: add “the” before “forest floor”
10 Page 8061, line 9: change “like” to “as”
11 - Lines 10-11: “was for uplands. . .” change to “was relatively low for uplands (10%) and
12 transitions (15%) and slightly higher for mires (22%).”
13 - Line 15: “fluxes” to “flux”
14 **# comments above were followed as suggested**

15
16 - Line 23: it would be nice to add the uncertainty range on the 18 cm estimate, as
17 this parameter value is the type of result of particular interest to upscaling and larger,
18 regional modeling studies (also the 14 oC result found in line 26)
19 **# we added uncertainty ranges and reformulated these sentences**
20 **... sigmoidal response with lower CH₄ fluxes towards the extreme ends. The optimum water**
21 **level for CH₄ effluxes was at 18 cm (se 2.2) below the surface with 16.6 cm tolerance which is A**
22 **deviation of water level up to 60% of CH₄ flux maximum (Figure 4, p < 0.001, WT_{opt} and WT_{tol} in**
23 **Table 3). Optimum near surface peat temperature for the CH₄ emissions was found at 13.9 °C**
24 **(se 1.4) with 6.4 °C tolerance (Figure 4, p < 0.001, T_{opt} and T_{tol} in Table 3).**

25
26 Page 8062, line 10: change “momentarily” to “momentary”
27 - Line 12: move “lower” to immediately after “were”
28 Page 8063, line 11 add “m” after 450
29 - Line 13 change “whereas” to “Alternatively”
30 - Line 14 awkward start to the sentence – I suggest “we have complemented the few
31 studies. . .” and “. . .have lowered the likelihood. . .”
32 **# comments above were followed as suggested**

33
34 Page 8065 the first paragraph needs more context and sign-posting to clarify that it
35 introduces the following two paragraphs. Please improve the transitions & outlining on
36 this page (perhaps “first, . . . “ and “second. . .” and more in this first paragraph).
37 **#we reformulated the paragraph**
38 **In our upland forests the role of soil physiochemical and microbiological drivers may have**
39 **contributed to the fact that the temperature and moisture significantly explained just 10% of**
40 **the variation. Although our mean CH₄ data did not show significant correlations with bulk**
41 **density, the porous organic horizon is known to enable larger diffusion and CH₄ oxidation**
42 **(Nakamo et al. 2004, Ullah and Moore 2011).**

43 - Line 21 do you mean “flark” instead of “flurk”?
44 **# yes, it should be “flark”**
45 Page 8066, Line 1: omit “with”
46 - Line 9, change “sometime” to “sometimes”, line 10 difference to differences.
47 Page 806, Line 2, remove parentheses from degrees-C

1 - Line 6, change “fast” to “quickly”
2 - Line 17, are you referring to a formal categorization system or emission-factor
3 methodology? If not I suggest “considered”.
4 **# comments above were followed as suggested**
5
6 Page 8078, Fig 1: In caption B can you add the site numbers after xeric, etc., to indicate
7 which categories belong with which sites?
8 **# site numbers were added into the figure caption**

9
10 Page 8080, Fig 3: It seems to me better to remove the VSR1 and mires data-axis
11 labels from the inset boxes since they are not presented (but seem to have some flux
12 observations within the range shown on these plots).
13 **# mires data-axis was removed from the inset box**

14 **Anonymous Referee #2**

15 Received and published: 30 June 2014

16 This manuscript presents CH₄ and N₂O fluxes measured along a forest-mire ecotone
17 using the closed chamber technique. The manuscript closes an important knowledge
18 gap as many studies on CH₄ and N₂O fluxes have been conducted at typical forest
19 sites and also in peatlands but I am solely aware of two published studies on CH₄
20 and N₂O fluxes from a forest-mire transition zone. These two published studies were
21 conducted in Canada. So this study would be the first from the European continent.
22 It has been suggested before that such transition zones might be a hot spot of CH₄
23 emissions. This study could show at different meteorological conditions that this hypothesis is
24 quite unlikely. The topic of the manuscript is well within the scope of the
25 journal and is particularly suitable for the special issue: “Towards a full GHG balance
26 of the biosphere”. The paper meets a basic scientific quality, it is well structured. The
27 applied closed chamber method is for sure the right one to achieve the goals of the
28 study, results are presented in a clear way and discussion is comprehensive. I highly
29 recommend that manuscript to be published in Biogeosciences Discussions.

30 **# Thank you!**

31 Minor suggestions:

32 Page 8059, Line 24

33 Unfortunately, neither Fig. 2 nor Fig 3 shows the correlation between CH₄ flux and ground
34 water level, please include a new figure to show that correlation.

35 **# In response to similar requests of you and Referee#1 and in order to help**
36 **visualize the relation between temperature, moisture and water table level**
37 **dynamics (Fig. 2), and forest floor CH₄ and N₂O fluxes (Fig. 3), we agree**
38 **with adding Supplement Fig. 3 with the momentary CH₄ and N₂O flux**
39 **measurements (page 7 of this document).**

40
41 Page 8061, Line 7

42 Just to clarify: which parameter shows the mean level of CH₄ fluxes in Table 1?

43 **The mean level of CH₄ fluxes of upland and transitional forests differed (Table 2, parameter**
44 **“group bi”), ...**

45
46 Page 8065, Line 21

47 change flurk to flark **# changed to “flark”**

48 Page 8068, Line 2 Why do you put _C in parenthesis? **# parenthesis were deleted**

1 Figure 3: please explain in the labelling of the figure what does 3a) and 3b) show
2 Figure 6: reference for that figure is missing in the text
3 **# The Fig.6 reference can be found on page 8062, line 14 and line 20.**

4
5 General comment to figures: it might be better to use consistent
6 designation for parts of one figure, either a), b) or right panel, left panel# **to ensure**
7 **consistency we changed designations for Fig. 6 and Fig. 7 to a) and b).**

8 **Anonymous Referee #3**

9 Received and published: 29 June 2014

10 General comments: The manuscript studies the question if CH₄ and N₂O dynamics in
11 transition zones between boreal forest and peatland are similar or different from those,
12 considering that vegetation and hydrology change spatially and temporally between
13 years. While carbon and nitrogen cycling in both boreal forests and peatlands are well
14 studied, the transition zone has been less investigated. This can be an important factor
15 for up-scaling to regional scales.

16 The authors report results from static chamber measurements along a 450m transect
17 for the climatically different years 2004, 2005 and 2006. Statistical analyses (ANOVA,
18 Tukey tests) are used to test differences between locations and years. Environmental
19 controls are analyzed by fitting linear regression models to the flux data. Generally,
20 substantial CH₄ fluxes only occur in the peatlands, while in forest soil and transition
21 zones mostly CH₄ oxidation (neg. CH₄ fluxes) occurs. N₂O emissions are small along
22 the entire transect. The authors conclude that these transition areas are likely no hot
23 spots for CH₄ and N₂O emissions.

24 The paper is well written and fits into the scope of 'Biogeosciences'.

25 **# Thank you!**

26 Minor comments: It looks like that the three forest-mire transition types (at least KgK
27 and KR) are more similar in their CH₄ emissions to the upland forest than to the mires
28 (N₂O emissions are similarly low), even though soil organic matter content and soil
29 moisture are higher than in the mineral forest soils.

30 The authors discuss that during the few occasions when the water table rises in the transition
31 zones, a 'slow' response of the microbial communities prevent higher methane fluxes. I
32 suggest to add vegetation characteristics in this discussion: e.g. sedges can both enhance
33 methane production by supplying 'fresh' carbon substrate to methanogens as well as provide
34 transport to the atmosphere via their aerenchyma.

35 **# In response to your comment on vegetation characteristics we suggest**
36 **adding additional information on CH₄ flux of transitions.**

37 *4 Discussion*

38 *4.1 CH₄ dynamics, Page 8064 before Line 3*

39

40 **Small momentary CH₄ emissions (Supplement Fig. 3a) observed in forest-mire transitions also**
41 **indicated potential for occasionally higher production than consumption/oxidation. Beside**
42 **microsite differences in soil saturation and microbial populations also plant communities (Fig.**
43 **1c) could play an important role in explaining enhanced emissions (e.g. Saarnio et al., 1997,**
44 **Riutta et al., 2007). For example, sedges through aerenchymatic transport interplay with**
45 **microbes by providing recently photosynthesized carbon downwards and transporting CH₄**
46 **from microbial populations upwards (Alm et al., 1997).**