

Interactive comment on “Partitioning of soil CO₂ efflux in un-manipulated and experimentally flooded plots of a temperate fen” by S. Wunderlich and W. Borken

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First, we like to thank the two reviewers for their constructive reviews.

Response to Referee 1 General comments The drought treatment in 2008 delayed the recovery of the redox potential during the first year of flooding in 2009. For example, methane production in the flooded plots reached the level of the control plots not before July/August 2009 (Estop-Aragones et al., unpublished data). In the growing season of 2010, no delay in methane production was observed between in the flooded plots. In terms of soil CO₂ effluxes, we assume that the preceding drought treatment (2008) had no measurable effect in the flooded plots in 2009. The explanation for this assumption

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is that the drought treatment itself had no effect on soil CO₂ effluxes (Muhr et al. 2011, see discussion). Thus, the redox potential in the flooded plots was still in transition in 2009, but it had no effect on soil CO₂ effluxes.

Specific comments P5291, L16: Following sentences have been modified or added: ‘A peat body with a thickness of 40-100 cm and an average C stock of 49 kg m⁻² has accumulated since the last deglaciation.’ The peat formation was likely disturbed by natural events and by human activity in the past.

P5291, L20; P5292, L15; P5299, L4: The information on P5299, L4 was incorrect. The amount of irrigation water varied between 1400 and 2000 mm per day. Values have been corrected in the text.

We agree that such an irrigation scenario is not typical for fen restoration. However, the slope of the fen regularly causes natural surface runoff during heavy rain events or snowmelt. Soil CO₂ effluxes were barely affected by surface runoff in the flooded plots. Surface runoff was interrupted in the permanently installed collars (used for CO₂ measurements) as the collars were about 40 cm above the peat surface. We used this collar size in order to integrate the hollow-hummock micro-topography. Thus, the conditions within the collars were similar to flooded fens with standing water. We can therefore exclude that permanent inputs of DOC, nutrients and O₂ as well as an export of DIC by surface runoff affected the soil CO₂ efflux. Whether irrigation water increased the soil CO₂ efflux outside the collars remains unclear. The residence time of irrigation water on the flooded plots was short and the exchange between irrigation water and peat water was restricted as indicated by the redox potential below the peat surface.

Following paragraph was added in the discussion: ‘The large amount of added irrigation water as well as the unevenly water level along the slope likely influenced the spatial pattern of C turnover in the flooded plots. Permanent input of oxygen by irrigation water could have promoted both autotrophic and heterotrophic respiration in the top cm of the peat surface. Moreover, DOC input by irrigation water represented an ad-

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ditional and continuous C source for heterotrophic respiration. However, the conditions within the collars, installed for CO₂ measurements, were different due to minor water exchange and thus small inputs of oxygen and DOC. Hence, the conditions within the collars correspond to conditions in flooded fens with standing water.'

P5298, L10: The effect of lowered soil temperature (1°C) on soil CO₂ efflux in the flooded plots has been discussed. Because of standing water within the collars we exclude a temperature effect on soil CO₂ efflux in the flooded plots.'

P5300, L15: The heterogeneity of heterotrophic ¹⁴CO₂ (66 – 103‰ corresponds to a difference in the mean age of about seven years which is not unusual for heterotrophic respiration of soil samples. Given the depth of the cores (25 cm), peat layers of varying thickness and age from past decades contributed to the heterogeneity of the ¹⁴CO₂ signature. Standard errors of partitioned CO₂ fluxes (Fig. 5a) were calculated after Phillips and Gregg (2001) where the variation of all ¹⁴C signatures and soil CO₂ efflux was considered. We are not aware that there is a statistical procedure to test for differences of partitioned fluxes between two treatments. Thus, we cannot provide p-values for differences of partitioned fluxes between the control and flooded plots.

P5301, L26: The term 'long-term effect' has been substituted by 'prolonged effect'
P5303, L25: We agree that flooding can have deviating effects on the C budget. We added following sentence: 'In view of differences in vegetation, peat decomposability and water table history, it is comprehensible that the C cycle of fen ecosystems respond inconsistent to flooding.'

Response to Referee 2

Response to comment 1) see response to comments of Referee 1

Response to comment 2) The amount of daily irrigation (50-70 m³ per plot) was needed because of the slope (20-30 cm within the plots) and consequently of the runoff in the fen. To raise the water table, sheet piles were installed in the flooded plots (Fig. 1) so

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that the water table was unevenly distributed in the plots. The collars were installed in the middle of the plots, and the exchange of water between within the collars and runoff water was minor. Despite the large input of DOC and nutrients by irrigation water, it seems that most of the solutes were not retarded or taken up by plants and microorganisms, but passed the flooded plots with surface runoff. Low concentrations of nitrate and sulfate (electron acceptors) in the top 10 cm of the peat suggest that there was little exchange of irrigation water with pore water.

Response to comment 3) regarding the heterogeneity of ¹⁴C data (see also response to reviewer 1). Mean age of respired CO₂ could be estimated using the ¹⁴CO₂ signature of the atmosphere. However, such mean age estimates are somewhat misleading because CO₂ originated from various sources of different age. Thus, often the terms 'young C' or 'old C' are used rather than a defined age. Commonly, radiocarbon age is used for age determination of solid organic matter or pure organic substances.

Response to comment 4) regarding information on roots. We provided information on root biomass pattern in Material and Methods (see below) and extended the discussion on root biomass as follows: 'At our site, two-third of root biomass existed in the top 15 cm of the peat body (Otieno et al., 2012). The production of grass roots below this depth is apparently small.'

Abstract L15 and L16: Variation (\pm) of rhizosphere respiration was added as suggested.

Introduction P5289, L6: The following sentence has been added: 'According to Turunen et al. (2002), the variation in peat accumulation partly results of the ecosystem type where bogs have higher average accumulation rates than fens.' Certainly, the range of peat accumulation is much wider, but here we refer to mean accumulation rates as summarized by the reviews. P5289, L10 – the word 'exponentially' has been added. P5289, L15 – The sentence has been revised: 'Descending or ascending water table may turn peatlands into net C sources or even stronger net C sinks (Bridgham

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et al., 2008).’ P5289, L21, The sentence has been rephrased: ‘On average, CO₂ efflux increased by 9.5 g C m⁻² y⁻¹ per 1 cm lowering of the water table and effective drainage by ditching almost doubled the CO₂ efflux in various boreal mires (Silvola et al., 1996).’ The average increase of 9.5 g C m⁻² y⁻¹ per 1 cm lowering of the water table refers to a linear regression between water table lowering and CO₂ efflux of different mires. Seasonal fluctuations in water table were different at the sites, so that we cannot provide a specific depth.

P5289, L25 – sentence has been changed as suggested.

P5290, L11 – Following sentence has been added: ‘In particular, the abundance and species composition of vascular plants affect the gas fluxes as the aerenchyma acts a gas conduit between subsurface peat and atmosphere (Ström et al., 2005).’

5290, L24 – Done.

Material and methods:

Chapter 2.3: collar issues Following sentence was added: ‘The size of collars allowed the integration of both hollows and hummocks in the collars, and thus the natural microtopography of this fen. As insertion of collars may affect soil CO₂ efflux and the partitioning of soil CO₂ efflux due to partial abscission of roots (Heinemeyer et al., 2010) we perforated collars at 2-4 cm peat depth which allowed ingrowth of roots. The top peat layer of 0-5 cm depth contains about 30% of the total root biomass (Otieno et al., 2012). The increase in CO₂ concentration was mostly monitored over 10 min because of the height of the collars. On warm days with high soil CO₂ efflux, CO₂ concentration was monitored between 5 and 10 min, so that the absolute increase in CO₂ concentration was usually less than 50 ppmv. The increase in CO₂ concentration was mostly strict linear over the entire monitoring time, indicating that soil CO₂ effluxes were not over- or underestimated due to the monitoring time. When r² of linear regression was < 0.97 we used the increase in CO₂ concentration during the first 3-4 min of incubation.

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Chapter 2.4, P5294, L18: Done.

Chapter 2.5, We made good experience with argon filled vials during all seasons. The vials fit to an autosampler which was connected to the GC.

Chapter 2.6, Due to the slope of the fen and the direction of runoff (see Fig. 1) there was no influence of flooding detectable in the C1 plot.

P5298, L1-2: We have no information concerning the sources of respired CO₂ during the 1-week interruption in the flooded plots. It seems that there was only a limited pool of easily decomposable C available as the CO₂ efflux in the control plots reached a similar level during that week. We do not think that the interpretation is tricky, but it illustrates how fast the fen responded to changing water table near the peat surface.

Results Chapter 3.1, We did not measure the temperature of irrigation water, but it was likely colder than pore water.

L10-15: We do not agree that the paragraph should be shortened because the interannual difference in temperature is relevant for the difference in CO₂ efflux in 2009 and 2010.

L23: ‘increase’ has been replaced by ‘recovery’

Chapter 3.2, ‘significantly’ has been added as suggested.

L17: We modified the sentence as: ‘The influence of flooding on soil CO₂ efflux was not statistically significant in 2010 (Table 1).’ The p-values (Table 1) have been verified. The effect of flooding on soil CO₂ efflux was not statistically different in 2010 because of the skew distribution of soil CO₂ efflux.

L21: ‘slightly’ has been added as suggested. Chapter 3.3 We would prefer no discussion on GPP as a driver of the seasonal variation of rhizosphere respiration as we have not measured PAR/GPP in this study.

5301: the last sentence has been removed as suggested.

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Chapter 3.4, P5302, L17-20: It is rather a methodological explanation of negative CO₂ net turnover rates than a discussion of results. Thus, we would prefer to make no changes.

Discussion A new paragraph was added in the discussion on the irrigation and specific conditions in the collars. We assume that temperature, DOC input as well as CO₂ outgassing from the flood water had no or minor effects on soil CO₂ effluxes in the flooded plots.

P5304, L-13-15 take out pers. comm. sentence. – We made no changes as no reason was stated by the reviewer.

L21 The complete paragraph has been revised: 'Unlike soil CO₂ effluxes, the CO₂ profiles of the peat body were permanently influenced by overflowing water. Nonetheless, flooding effectively reduced the biological CO₂ production at least at 10 cm depth and below as the CO₂ concentration did not build up in pore water. There are some hints that O₂ penetration was low in the top peat layer of the flooded plots. The strong decline of electron acceptors like sulfate and nitrate as well as methane production at 5 cm soil depth suggest minor mixing of pore water and overflowing irrigation water (Estop-Aragonés, pers. comm.). Despite apparently minor O₂ penetration, we assume that irrigation water continued heterotrophic and rhizosphere respiration to some extent in the top peat layer compared to flooded fens with standing water.'

4.2 In the Discussion, we used mean values from several sampling dates. \pm for % values could be misleading because it is not clear whether it relates to the temporal or spatial variation of heterotrophic or rhizosphere respiration.

P5305, L25: Following sentences were added: 'Moreover, we cannot exclude that rhizosphere respiration was still reduced in the control plots three years after collar insertion. The total disturbance of the root system through collar insertion, however, was constrained by the relatively large area of collars (0.18 m²) and by the fact that grass-dominated hummocks were entirely included in the collars. Roots in the hummocks

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with a height of up 30 cm above the hollows were barely affected by collar insertion.'

Conclusion: Changes have been made as suggested.

Table 1: The amount of irrigated water was not continuously measured in the flooded plots. The range has been given in the text. P-values have been verified. Co-variance was not calculated as C plots were not influenced by flooding.

Fig. 5: Error bars of partitioned CO₂ fluxes are given in Fig. 5a. The percentage variations of partitioned CO₂ fluxes on specific sampling dates have been added in the text. Error bars of percentage contributions of the two components would overlap in Fig. 5b, so that the presentation would be confusing with error bars.

Fig.6: The flooded periods have been indicated in both figures.

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