Author responses to comments of Referees #1 and #2 (Biogeosciences Discuss., 12, 17393–17452, 2015)

We are grateful for the valuable and detailed comments of both referees that helped us to substantially improve the manuscript and make it much clearer. We changed the manuscript as proposed in our “bgd-12-17393-2015-final_author_comments”. In some cases, however, we made additional changes that were not indicated in our final author comments but will improve the manuscript accordingly to the comments of both referees. The most important of the additional changes are indicated on pages 1-3. From pages 4-45 you will find the text of our bgd-12-17393-2015-final_author_comments as uploaded to Copernicus on 14th February. After page 45 the text of the manuscript is given in track change mode.

First referee

4. *„The overall feeling of presented paper is embarrassed without clearly formulated “home message”. This is probably due to missing hypotheses in the Introduction sections. Filling of knowledge gaps is not scientific aim. “*

We aimed at understanding what GHG fluxes can be expected after inundation and recolonization of formerly cutover temperate fens. As these systems have not been studied before, it was difficult to estimate the results in front. However, about some things we were sure when we started the GHG monitoring. And these we used to formulate the hypotheses: “We hypothesize that

(i) all sites are net CO_2 sinks: peat loss by oxidation has stopped after rewetting. The net CO_2 sink increases with nutrient status, the productivity of the vegetation and peaks under shallow inundation,
(ii) methane emissions increase with the productivity of the vegetation and peak under shallow inundation.
(iii) the net GHG balance is near neutral when water levels are close to surface because CH_4 emissions are balanced by the net CO_2 sink. The net GHG balance turns into a source when sites are continuously flooded because the global warming by CH_4 emissions exceeds the net CO_2 sink.”

We answered on hypotheses in the Discussion section. This implied changes at many parts of the Discussion, Conclusions and Abstract and helped to make the “home message” more clear.

We decided against our previous decision to move Fig.2 into the annex, because the diurnal chamber inter-comparison was important to correctly develop the annual methane models.

Second referee

The following comments of referee #2 are on the presentation of small scale and inter-annual variability of GHG emissions

Page 17426 Lines 5-9: *„ But when you treat CH4 as a GHG and consider GWP the picture changes, doesn't it? Also it should be given in percentage of annual site emissions to be comparable. “*

Page 17426 Lines 11-12: *„ As the last comment already suggests, taking the absolute values has only little meaning. Given that we typically measure CO2 in ppm and CH4 in pub I would state that CH4 exchange rates showed much higher variability in space and time (which is about the state of the art). The same holds for the annual comparison because it is not known whether the years were strongly different or not in comparison to an ? unfortunately imaginary ? long-term time series of annual emissions.“*

Page 17442: *„ See comment in text. I am skeptical about reporting this in absolute terms..“*

We agree with your view that our limited data neither allows to characterize inter-annual variability of GHG emissions (as we only measured fluxes for two years) nor to assess their small scale variability (because we have only three plots per site type). Consequently we removed the objective “to estimate the inter-annual and spatial variability of GHG emissions” from the introduction.

Still we think that NEE and CH_4 fluxes per plot and year, as shown in Figure 5, give an idea about which sites are more stable with respect to CO2 and CH4 emissions and which less. We reworked the table on variability of net CO_2 and CH_4 emissions (now Table 3). We removed information of inter-annual variability from Table 3, because inter-annual differences can be found in the preceding table (now Table 2) on annual fluxes. The new Table 3 presents absolute and relative small scale spatial variability of net CO_2 and CH_4 emissions:

Table 3. Small scale spatial variability of net CO_2 and CH_4 emissions

	Absolute small scale spatial variability (g C m^{-2} yr^{-1})[a]		Relative small scale spatial variability (%)[b]	
	NEE	CH_4 emissions	NEE	CH_4 emissions
BA *Eriophorum–Carex*	16 ± 13	0.5 ± 0.2	89 ± 105	4 ± 2
BA *Carex–Equisetum*	9 ± 5	1.4 ± 0.7	19 ± 12	10 ± 5
BA *Phragmites–Carex*	125 ± 140	6.4 ± 2.7	25 ± 25	17 ± 7
GK *Typha–Hydrocharis*	121 ± 66	3.2 ± 3.2	97 ± 63	5 ± 5
GK *Carex–Lysimachia*	95 ± 73	10.9 ± 8.3	47 ± 33	13 ± 10
GK *Phragmites–Lemna*	187 ± 153	24.2 ± 10.0	20 ± 11	25 ± 10

Given are means ± standard deviations, n = 6.

[a] absolute differences between annual plot emissions and annual site emissions.

[b] absolute differences between annual plot emissions and annual site emissions in percentages of absolute values of annual site emissions.

Author responses to comments of Referee #1 (Biogeosciences Discuss., 12, 17393–17452, 2015)

We are grateful for the valuable comments provided by referee #1. They helped us to improve the introduction of our research questions and to reduce or simplify tables.

1. *„I think that would be interesting use approach of ecophases (Mitsch, 2009). “*

The concept of ecophases characterizes the aquatic environment of a site at any moment (Hejný and Segal, 1998). It allows to describe ecoperiods what are sequences of different ecophases and by this to illustrate certain trends in the environment (cf. Krovolá et al., 2013). In our study, however, there were no shifts of the studied sites from one ecophase to another because water level, probably because water levels have been monitored only for two years and were quite stable within and between both years. The sites BA *Eriophorum–Carex* and BA *Carex–Equisetum* always belonged to the limosal and the sites GK *Phragmites–Lemna* and BA *Phragmites–Carex* to the littoral ecophase. The floating mats of *Carex–Lysimachia* and GK *Typha–Hydrocharis* could be also assigned to the littoral ecophase because the relative small water depths above surface just resulted from swimming on a larger water column. So, as there are no trends between ecophases, there is no realy need to use the concept of ecophases. Moreover, we are concerned that the application of the concept of ecophases in our study would make it more complicate. We found for example, that shallow flooding is a better measure to arrive at stable and low GHG emissions than deep flooding. However, with “shallow flooding” we do not only mean the limosal sites BA *Eriophorum–Carex* and BA *Carex–Equisetum* but also the littoral site BA *Phragmites–Carex*. The other littoral sites are not stable and most of them are strong GHG sources. We could argue that the definition of limosal by WL of 20 cm below to 10 cm above ground should be seen flexible and could also include BA *Phragmites–Carex* with average water levels of 15 cm above and maximum up to 20 cm above surface. However, this could lead to misunderstanding. As the water level dynamic is clearly presented by figures and tables, we do not see the advantage to classify the sites accordingly to ecophases.

Hejný, S. and Sega,l S., 1998: General ecology of wetlands. *In:* Westlake D.F., Květ J. and Szczepański A. (eds.), The Production Ecology of Wetlands, Cambridge University Press, Cambridge, 367–404.

Krolová M., Čižková H., Hejzlar J. And Poláková S. 2013. Response of littoral macrophytes to water level fluctuations in a storage reservoir. KNOWL MANAG AQUAT EC 408, 07. doi: 10.1051/kmae/2013042

2. *„As the result are presented modeled data only. Directly measured data are not presented and reader cannot compare actually measured data with modeled (theoretical) data. By my opinion, actually measured data have a higher value than modelled and estimated data. “*

For methane emissions we presented both, measured and modelled data. This was not possible for CO_2 exchange, because the timelines show daily averages but CO2 fluxes change strongly during a day. Showing modelled versus measured CO_2 fluxes would have required an additional figure. But instead we had compared modelled and measured data by leave-one-out cross-validation (see methods): "Stepwise one measurement campaign was left out after the other and the modelled R_{eco} and NEE fluxes obtained for the left out campaigns based on the remaining campaigns were compared with the measured fluxes. Model performance was assessed by the Nash–Sutcliffe efficiency (NSE, Moriasi et al., 2007)." The result are given in the results section for the CO_2 models: "Model performance tested for the H-approach was good for both years and all site types and plots. Cross-validation resulted in a median NSE of 0.78 (range from 0.38 to 0.90) for the R_{eco} models and of 0.76 (0.21 to 0.91) for the NEE models." and for the methane models: "The Lloyd–Taylor methane models performed well for all sites except for the second year of BA *Phragmites–Carex* and GK *Phragmites–Lemna*. NSE for all but the *Phragmites australis* sites ranged between 0.38 and 0.85 (median 0.58). Models of the *Phragmites australis* sites were acceptable in the first year (median NSE 0.37, range 0.05 to 0.82) but performed poor in the second year (median 0.01, range -0.25 to 0.24). Models of GK *Phragmites–Lemna* III and BA *Phragmites–Carex* III did not explain the high emissions in August 2011 (Figs. 3h and 4h). Both and the model of BA *Phragmites–Lemna* I overestimated emissions in spring and early summer 2012. Annual emissions calculated alternatively for the mentioned plots and second year by linear interpolation were 25, 28, and 118 g CH_4−C m^{-2} yr^{-1}, compared to 30, 32, and 139 g CH_4−C m^{-2} yr^{-1} derived by the temperature driven Lloyd–Taylor methane model, and lie within the 90% confidence intervals of the latter (Table A2 in the Annex). The Lloyd–Taylor models were therefore accepted despite of negative NSE."

3. *„Maybe it would be preferable omit the N2O fluxes. In the case of the N2O, authors argue that the role of N2O exchange was negligible for the GHG-balances of all sites). “*
The GHG balance of peatlands consists of CO_2, CH_4 and N_2O. We could skip the N_2O data and cite other studies from rewetted peatlands. But there are still not so much studies of GHG emissions from rewetted peatlands and only few have monitored all three GHGs. Moreover, there is no study of annual GHG emissions from rewetted peatlands in Belarus. Therefore we decided not to rely on other studies but monitor N2O fluxes ourselves. This was no additional work because our gas chromatograph analysed CH4 and N2O concentrations from the same air sample. Now we see from our results that N_2O emissions were indeed negligible. And with respect to the few studies on N_2O emissions from rewetted peatlands we think that it is useful to present these results.

4. *„The overall feeling of presented paper is embarrassed without clearly formulated “home message”. This is probably due to missing hypotheses in the Introduction sections. Filling of knowledge gaps is not scientific aim. “*
In the introduction we showed that shallow inundated cutover fens may become CO2 sinks and CH4 sources but that the combined GHG balance is unclear. The main interest of our study was to find out what GHG emissions can be expected when such fens are rewetted. There was no reason to assume that they would remain important GHG sources or even become small GHG sinks. The literature on comparable sites is rare and not equivocal. Therefore we decided to formulate our main questions instead of hypotheses. This was different in our former paper on the impact of shading by chambers on methane fluxes from *Phragmites australis* (Minke et al., 2014). In the mentioned study most of the literature indicated that there should be a significant impact and we consequently hypothesized to find significant lower methane emissions with opaque as compared to transparent chambers. Formulating clear hypothesis was not possible in our present study but in our opinion it is also the task of scientists to ask questions and try to answer them, even if they can not expect a distinct answer in front.
We changed the last paragraph of the introduction as follows:
“Whereas earlier studies indicate that the radiative forcing of such methane emissions may be compensated for by the simultaneous very strong net CO_2 uptake (Brix et al., 2001; Whiting and Chanton, 2001), recent observations described *Typha* dominated wetlands as often only weak CO_2 sinks (Rocha and Goulden, 2008; Chu et al., 2015; Strachan et al., 2015; but cf. Knox et al., 2015).

Given the not univocal results regarding the potential of plants to compensate for methane emissions by correspondingly high CO_2 uptake, it is unclear how the GHG emissions from cutover temperate fens develop after inundation and establishment of wetland plants. Therefore we measured the CO_2, CH_4, and N_2O emissions from representative vegetation types along water level gradients in two rewetted cutover fens with different nutrient conditions in Belarus. Our objectives were: (i) to assess GHG emissions from rewetted temperate cutover fens recolonized by wetland plants (ii) to analyse the effect of water level, vegetation and nutrient conditions on GHG exchange."

Minke, M., Augustin, J., Hagemann, U., and Joosten, H.: Similar methane fluxes measured by transparent and opaque chambers point at belowground connectivity of *Phragmites australis* beyond the chamber footprint, Aquat. Bot., 113, 63–71, 2014.

Page 17397 Lines 1-2: *„The claim that the plants are strong sources of methane is not true. The role and effect of plants in this case is enhancing of greenhouse gasses emissions from soil profile and its partial biochemical interactions. Please change the sentence : : :" of plants in shallow water of Typha and Phragmites australis, i.e. of species that are potentially strong sources of methane..."*

We changed the sentence: "Such fens differ from those in the above cited studies in particular by the massive establishment in shallow water of *Typha* and *Phragmites australis*, i.e. of species that are potentially strong pathways of methane (Kim et al., 1998; Brix et al., 2001; Whiting and Chanton, 2001; Kankaala et al., 2004; Hendriks et al., 2007; Chu et al., 2015; Knox et al., 2015; Strachan et al., 2015)."

Page 17397 Lines 4-5: *„ The radiative forcing in term of the IPCC (IPCC 2007) and I think that for processing studies of different ecosystems is more suitable use amount of Carbon (C) in different form such as C-CO2 and C-CH4. Biochemical processes used and transform (sequestered) a carbon and important role of wetlands is long-term store of this C in soil. "*

We agree that for process studies the element base is more suitable. However, the role of peatlands is important to both, the carbon balance and the climate impact. Therefore we present both, the exchange of CO_2 and CH_4 and the resulting carbon balance on an element base (cf. Table 3) but also the GHG balance (cf. Table 5). Rewetting of peatlands aims at both, restoring the carbon balance and reducing the GHG emissions. We were confident that reed beds of *Phragmites australis*, *Typha latifolia* and *Carex* are net carbon sinks. But we were concerned that these reed beds could be strong GHG sources because of the high GWP of methane. Therefore we addressed the GHG aspect in the mentioned sentence.

Page 17398: *„ A map to shown the site location at both the local and regional scale would be helpful. “*
We agree and prepare it.

Page 17401 Lines 19-22: *„I recommend shortening this paragraph “*
The results of the diurnal studies of methane emissions and the impact of shading for all sites were important for the construction of annual methane models because they showed were we needed to correct for the shading impact and how safe the annual estimates are. Therefore we would like not to skip this paragraph.

Page 17401 Line 25: *„ Meteorological parameters for the flux models were recorded in two climate stations at distance 5.6 km and 6.3 km. I think that climate stations are too far from places where chambers measurements were made. “*
Climate stations were indeed quite far. However, we did not only construct transfer functions using the correlation between site temperatures measured during GHG campaigns and data from the climate stations, but also calculated the error of the transfer functions and included it into the emission estimates. Correlations were very close for air temperature (R2 between 0.95 and 0.97) and also strong for soil temperature (R2 between 0.93 and 0.96). This gave us confidence that the constructed temperature timelines for the sites were reliable what was confirmed by the good results of the cross-validation.

Page 17402 Line 15: *„ It is true that in the eddy covariance community a positive sign refers to a flux from the ecosystem to the atmosphere and a negative sign to an ecosystem sink. But it is depending of our consensus; I think that organic production based on consumption of CO2 from the atmosphere cannot be negative. Production is positive fundamental process of the organic mass formation.“*
We think that using a positive or negative sign is both okay, as long as this is clearly explained. In our study we decided for the atmosphere perspective because, as stated above, we were in the first line interested in the GHG balance of the rewetted peatlands.

We oriented on the IPCC 2014 as well as on numerous studies on GHG emissions from peatlands cited in our manuscript.

IPCC 2014, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland

Page 17403: *„ Where measured soil temperatures for modeling? Soil temperatures from too far climate stations cannot be used for flux models..“*
We did not use soil temperatures from climate station for the flux models, but constructed transfer functions based on temperatures measured at the sites during GHG campaigns and temperatures from climate station (see comment above). This is described in the methods Page 17402 Lines 2-4: “Regression between site and climate station temperature data was subsequently applied to derive continuous half-hourly time series for each site.”

Page 17405 Line 15: *„Why add the annual random error of the approach one to the uncertainties of annual emission.“*
We decided to use two approaches because we wanted to be more confident about the result. Hoffmann et al. (2015) found that identical CO_2 modelling approaches can lead to very different estimates when seemingly small aspects are dealt with differently. Both approaches, that of Leiber-Sauheitl et al. (2014) and Hoffmann et al. (2015) are very sound and reasonable, but, however, differ in some aspects, like estimation of measured fluxes, importance of significance of fits, and equation used to estimate GPP parameters. It is not possible to clearly decide on what way is more appropriate. Therefore we used both approaches and, surprisingly, arrived at similar estimates. But we did not skip one approach because we can not clearly say what is more realistic. Instead we assumed the mean of both as flux estimate and the difference between both approaches to represent one part of the uncertainty. The other part of the uncertainty, the random error, we estimated for the approach of Hoffmann et al. (2015) by bootstrapping. The random error accounts for the error of the temperature transfer function and the error of fitting the R_{eco} and GPP parameters. To arrive at more realistic error estimates we accounted for the random error and for the difference between both

approaches and defined the confidence intervals as the difference between the annual sums of both approaches plus two times the annual random error.

Hoffmann, M., Jurisch, N., Albiac, B. E., Hagemann, U., Drösler, M., Sommer, M., and Augustin, J.: Automated modeling of ecosystem CO2 fluxes based on periodic closed chamber measurements: a standardized conceptual and practical approach, Agr. Forest Meteorol., 200, 30–45, 2015.

Leiber-Sauheitl, K., Fuß, R., Voigt, C., and Freibauer, A.: High CO_2 fluxes from grassland on histic Gleysol along soil carbon and drainage gradients, Biogeosciences, 11, 749–761, doi:10.5194/bg-11-749-2014, 2014.

Page 17409: *„This section is long. I recommend shortening this section and data presented in a table.“*

We agree and strongly reduced the first paragraph (Lines 3-19): “Mean annual temperature at Barcianicha during the first measurement year was 6.5 °C which corresponds to the long term mean (6.4 °C, 1979–2008). The second year was slightly warmer (6.9 °C). Annual precipitation in the first year was higher compared to the long-term mean (740 vs. 665 mm), and in the second year lower (633 mm). Giel’cykaŭ Kašyl’ was generally warmer and drier as compared to Barcianicha (long-term mean 7.3 °C and 594 mm, respectively, 1979–2008). Also here the first year was wetter (804 mm) and the second year drier (500 mm) while annual temperatures of the first year agreed to the long term mean but were higher (7.9°C) in the second year.”

Page 17410: *„ Differences in production of the Phragmites australis it may be caused by different density of stand. What is density of the reed stand?“*

The density of *Phragmites australis* was less at Giel’cykaŭ Kašyl’ but biomass larger as compared to Barcianicha. Number of green shoots of *Phragmites australis* at Barcianicha was 204 per m² in 2011 and 123 per m² in 2012. At Giel’cykaŭ Kašyl’ there were 48 green shoots in 2011 and 82 in 2012. This is because *Phragmites* culms at Giel’cykaŭ Kašyl’ were much higher and thicker than at Barcianicha. This is obviously due to different nutrient availability. We did not add information on shoot density because there is already very much information and the site description in the method section states that *Phragmites* culms at Barcianicha were up to two metres high and at Giel'cykaŭ Kašyl' three metres.

Page 17440: *„ I recommended add the Table 2 in the appendix as a detail information of plant species cover..“*
We agree and move it to the annex.

Page 17448 Fig. 2: *„Results of comparison of the different chamber types would be used in different paper which will be focused in this topic. In presented paper this point is not important detail of methods. What is main result of paper?“*
The results of the diurnal studies of methane emissions were important for the construction of annual methane models. We learned from the diurnal studies that we had to correct the growing season methane flux estimates of GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* by a factor of 1.2. Also we learned that we did not need to correct fluxes from the other sites. The annual methane models rely on the results of the diurnal studies. The figures of the *Phragmites australis* sites have been published by some of us before (Minke et al. 2014). We could skip them and cite the other publication. However, we would still need to discuss them because the mentioned publication did not discuss the implications of the findings for annual methane models. Therefore we prefer to keep also the figures of the *Phragmites australis* sites, and we are convinced that the presentation of the diurnal methane flux dynamic for all six sites in one figure supports the reader in following our argumentation regarding the construction of annual methane models. We suggest to move Fig.2 into the annex. This would help readers to concentrate on the main topic but allow them to check for details of the methane model.

Pages 17449 - 17450 Fig. 2: *„ Figures 3 and 4 could be merged into a single image with left and right panel of graphs. “*
We agree and combine them.

Page 17439 to 17446 Table 1 to 7: *„ Too many tables. I recommended simplified Table 1 (Site characteristics). Water level fluctuations are presented in Figure 3 and 4. Characteristics of individual plots on the site can be probably merged (averaged). “*
We agree and simplified Table 1, and moved Fig. 2 and Table 2 into the annex.
Please see below the simplified Table

Table 1. Site characteristics.

Site	Annual median water level (cm above surface)		Above Ground biomass[a] (g C m^{-2})	Surface peat				Profile description, top down[d]
	1st year	2nd year		pH[b]	C[c] (%)	N[c] (%)	C/N ratio	
BA *Eriophorum–Carex*	-3±2	-3±2	117±34	6.2±0.2	42.2±1.7	2.3±0.1	18.5±0.2	0–9 radicel peat (H6), 9–14 silty gyttja, 14–43 radicel peat (H4, H3), 43–119 brown moss peat (H3, H4), below: middle sand
BA *Carex–Equisetum*	8±1	8±1	55±22	6.1±0.0	43.0±0.2	2.6±0.2	16.8±1.1	0–15 radicel peat (H6), 15–30 radicel brown moss peat (H3), 30–34 *Alnus* peat (H4), 34–85 brown moss peat (H3), 85–95 clayey gyttja & coarse sand, below: fine sand
BA *Phragmites–Carex*	14±2	14±2	296±79	6.1±0.1	43.8±0.3	2.7±0.2	16.8±1.1	0–13 lost, 13–40 radicel peat (H5/H4), 40–67 brown moss peat (H3, H4), below: gravel
GK *Typha–Hydrocharis*	11±2	2±3	259±103	5.6±0.1	41.4±3.2	2.8±0.2	14.8±0.3	0–20 lost, 20–30 radicel peat (H5), 30–55 very highly decomposed peat with radicels (H8), 55–90 radicel peat with *Phragmites* (H5, H3), 90–103 brownmoss–radicel peat (H3),
GK *Carex–Lysimachia*	10±3	4±3	299±73	6.3±0.4	43.3±2.5	2.6±0.4	16.7±2.3	103–113 woody radicel peat with *Phragmites* (H4), 113–140 radicel peat with *Phragmites* and brown mosses (H4), 140–150 organogyttja, below: sand
GK *Phragmites–Lemna*	104±6	74±6	586±121	5.7±0.1	37.1±4.1	2.4±0.2	15.2±0.5	0–10 very highly decomposed peat with radicels (H8), 10–100 radicel peat with *Phragmites* (H4, H5), 100–170 radicel peat (H5), 170–185 organogyttja, below: sand

Given are means±standard deviations, *n* = 3 plots

[a] harvest at Barcianicha (first three sites) 2012-10-29, and at Giel'čykaŭ Kašyl' (last three sites) 2012-09-11, [b] pH (KCL) mean of three samples, [c] total carbon and nitrogen content, one sample, [d] von Post peat decomposition scale: H3 very slightly, H4 slightly, H5 moderately, H6 moderately highly, H8 very highly decomposed peat

Author response to comments of Referee #2 (Biogeosciences Discuss., 12, 17393–17452, 2015)

We are very thankful for the very valuable, detailed and constructive comments of anonymous referee #2. They helped us to considerably improve the manuscript.

General comments

1. We kept using both approaches to estimate annual CO_2 fluxes. Accordingly to Hoffmann et al. (2015) even changes in only one aspect of identical approaches can lead to strongly different results. As both approaches that we used differ in several aspects but both solutions are reasonable, we were not able to identify the “better” approach. Therefore we regarded the results of both as equally justified and considered the difference between both results as a better measure of uncertainty as compared to the random error of only one approach alone.

Hoffmann, M., Jurisch, N., Albiac, B. E., Hagemann, U., Drösler, M., Sommer, M., and Augustin, J.: Automated modeling of ecosystem CO2 fluxes based on periodic closed chamber measurements: a standardized conceptual and practical approach, Agr. Forest Meteorol., 200, 30–45, 2015.

2. Regarding the englisch language quality, we received from the BG editorial support that the paper will be send out to our in-house copy editors when it has been accepted for the final publication. The editors will typeset it and send it to the copy editors before sending it to me for proofreading.

Specific comments

Page 17395 Lines 1-2: *„Please give a half sentence reasoning, why. The informations on colonizing species goes into a separate sentence“*

We changed the sentence into: “Rewetting of temperate continental cutover fen peatlands usually causes inundation of areas that suffered intensive height losses while less deeply extracted parts remain at or above the water level. The flooded areas are – dependent on water depth – colonized by helophytes such as *Eriophorum angustifolium*, *Carex* spp., *Typha latifolia* or *Phragmites australis*.”

Page 17395 Line 6: *„Merely describes? Or rather analyses? To keep active voice, try: "Here, we analyze" instead.“*

We replaced “This paper describes“ by „Here, we analyze“.

Page 17395 Line 9: *„Greenhouse gas“*

We completed “Greenhouse“ into “Greenhouse gas“.

Page 17395 Line 10: *„What the heck are few-weekly intervals? I'd like more explicit information. For instance you could state, that measurement were run with intervals from one week to XX days. If few-weekly is retained it has to be written with normal dash and without spaces, an em-dash has a different meaning.“*

We replaced “in weekly to few – weekly intervals“ into “every two to four weeks”

Page 17395 Line 10: *„I am no native speaker either, but shouldn't it be simplified to "over two years"?.“*

We replaced “over a two years period“ by “for two years”.

Page 17395 Lines 15-16: *„Also netto? I think "sequestering" is reserved to the net amount of C that is stored. Maybe you'd better go for "took up" in this case?“*

Yes, netto. Both *Phragmites australis* sites were strong net CO_2 and Carbon (accounting for fluxes of NEE and CH_4) sinks. But as “sequestration” is reserved to C we replaced it by “took up”.

Page 17395 Lines 18-20: *„Could be simplified to: "Shallow, stable flooding seems better to arrive at low GHG emissions than deep flooding. The risk of high GHG emissions after rewetting is larger for eutrophic than for mesotrophic peatlands [and maybe you add an half sentence of reasoning here]". “*

We agree and modified as suggested: “Shallow, stable flooding seems better to arrive at low GHG emissions than deep flooding. The risk of high GHG emissions after rewetting is larger for eutrophic than for mesotrophic peatlands because of a strong link between site productivity and methane emissions.”

Page 17396 Lines 9-10: *„ within a few years“*

We added the missing “a”: “within a few years“.

Page 17396 Lines 16-17: *„In this order? I would prefer, that you use the sorting that is suggested by the literature, which means, that water level has to go first and ? most likely ? vegetation has to come last.“*

We reordered the factors accordingly: “water level, nutrient conditions and vegetation“.

Page 17396 Lines 28-29: *„I think, this is the point here....“*

Yes.

Page 17397 Line 2: *„sources? or rather pathways?“*

We changed “sources” into “pathways”.

Page 17397 Line 9: *„the more abundant species in European wetlands in general!“*

Yes, but to improve this section accordingly to suggestions of the first referee we skipped this sentence. Now it is: “Whereas earlier studies indicate that the radiative forcing of such methane emissions may be compensated for by the simultaneous very strong net CO_2 uptake (Brix et al., 2001; Whiting and Chanton, 2001), recent observations described *Typha* dominated wetlands as often only weak CO_2 sinks (Rocha and Goulden, 2008; Chu et al., 2015; Strachan et al., 2015; but cf. Knox et al., 2015).

Given the not univocal results regarding the potential of plants to compensate for methane emissions by correspondingly high CO_2 uptake, it is unclear how the GHG emissions from cutover temperate fens develop after inundation and establishment of wetland plants. Therefore we measured the CO_2, CH_4, and N_2O emissions from representative vegetation types along water level gradients in two rewetted cutover fens with different nutrient conditions in Belarus. Our objectives were: (i) to assess GHG emissions from rewetted temperate cutover fens recolonized by wetland plants (ii) to analyse the effect of water level, vegetation and nutrient conditions on GHG exchange.”

Page 17397 Lines 10-12: *„Really? This is crazy.“*

We did not find any publication additional to Brix et al. (2001). However, we skipped the whole sentence, see above.

Page 17397 Lines 15-16: *„Temperate but strongly continental. “*

Yes, we state this in the site descriptions: “Greenhouse gas fluxes were measured at two sites in Belarus with a temperate continental climate with fully humid conditions and warm summers (Dfb after Köppen, 1936; cf. Kottek et al., 2006).

Page 17398 Line 6: *„ or peat?“*

The reference says “земляные перемычки“, what is „earth dams“. They are made from the subsoil.

Page 17398 Line 6: *„Check phrase“*

We replaced “over” by “on”: “water level was raised on 60 % of the area”

Page 17398 Line 11: *„reed beds?“*

Yes, we added “beds”: “Vast reed beds …”

Page 17399 Line 2: *„ how close in meter?“*

We added this information: ”…, both three metres from each other.”

Page 17399 Lines 7-8: *„degree of decomposition was assessed visually? “*

Yes, the degree of decomposition was assessed visually in the field accordingly to the ten-stage scale (H1 to H10) of Von Post (AG Boden, 2005). In the Von Post method peat is taken in the hand and three aspects are analysed:

1. quality of plant structures visible in the peat
2. peat is pressed by the fingers and the flowing water is characterized with respect to colour and amount of peat substrate what is mushy enough to come out with the water through the fingers
3. the structure of the peat left in the hand after the water has been pressed out

Page 17399 Lines 22-23: *„ Why not equipping each site with a diver? “*

We agree that with one diver per site the estimation of the water level dynamics would have been easier. However, we were able to purchase only about 50 divers and needed them to study the linkage between vegetation and water level in pristine, drained, and rewetted fens and bogs all over Belarus. There were some hundred study sites and therefore we tried to use always one diver for several sites. The three sites studied at Giel’cykaŭ Kašyl are within one water body and close to each other and therefore one diver in between them was regarded to be sufficient. To develop the necessary transfer functions we established additional manual water level tubes at each of the sites. The same was true for the sites at Barcianicha.

Page 17399 Line 28: *„ Check phrase “*
We rephrased: “Because of strong peat oscillation this approach did not work for GK *Typha–Hydrocharis* and GK *Carex–Lysimachia*.”

Page 17400 Lines 1-3: *„ How exactly can this lead to water levels? “*
We concretize: “Photographic documentation (monthly during vegetation season, one time per winter, WL estimation error < 5 cm) was used here instead to reconstruct relative water levels for linear regression with Diver records.”
WL estimation on photos was supported by soil collars and their parts with known size, like width of battens and their distance to the collar’s top. Based on this we estimated the WL from photos with an error of less then 5 cm.

Page 17400 Lines 6-8: *„ How did you decide on row direction and distance within row? Why no other alignment was chosen? “*
We added one more sentence: “The row was East West oriented and the north side was the working side to minimize artificial shading during measurements.”
Distance of 40 cm was optimal for moving the chambers from plot to plot while the gas analyzer, connected by a five metre tube, was situated during the day at one point.

Page 17400 Lines 13-16: *„Please separate into to sentences and check phrasing. “*
We modified the sentence: “CO_2 exchange was measured with transparent chambers made of plexiglas (88% light transmission, ice packs for cooling, Drösler, 2005) and opaque chambers made of grey ABS plastic covered with a white film. Both were equipped with fans for air mixing and had an inner size 72.5 cm × 72.5 cm × 51.2 cm.”

Page 17400 Line 16: *„ of what size? “*
We added the size: “Opaque and transparent extensions of same area and 31.2 or 51.2 cm height with open tops…”

Page 17400 Lines 21-22: *„ Why so slow? “*
One value per five seconds was sufficient for flux calculation and allowed to use the data logger for somewhat more than one day before the memory was full.

Page 17400 Lines 25-26: *„ Why not recorded together with the air temperature and the “*
This would have been better, but our budget did not allow to purchase soil temperature probes for all sites. Next to this we were afraid to leave expensive equipment in the field. Therefore we used regression of manually recorded site soil temperatures with automatically recorded meteorological stations soil temperatures to reconstruct continuous site soil temperatures. The related error was accounted for by the error calculation.

Page 17400 Lines 27-28: *„ I'd prefer a sentence that specifies under which conditions measurements were conducted. In the current phrasing it could be misunderstood as referring to only one day.. “*
We clarified: “For CO_2 measurements bright or hardly cloudy days were selected to capture the complete PAR range from zero to solar noon. During each measurement campaign eight to ten transparent chamber measurements of two to three minutes were carried out on each plot from dawn until late afternoon.”

Page 17401 Lines 5-7: *„ This is quite a large interval. Do you have an explanation? “*
Three to four weeks is a typical interval between CO_2 exchange measurement campaigns by chambers (cf. Beetz et al., 2012; Beyer et al., 2015; Eickenscheidt et al., 2015). Indeed the gaps are large but it was not possible to conduct CO_2 measurement campaigns in smaller intervals because of site number and limitations in work capacity, equipment and sunny days. As described in the methods the relationships established separately for each of two measurement campaigns between GPP and PAR, and between R_{eco} and temperature were used to model CO_2 exchange between both campaigns, assuming that the relationships change gradually. This assumption was supported by the fact that biomass was not harvested and the water table was rather stable. Leave-one-out cross-validation resulted for all plots and years and positive NSE’s indicating that the model filled the gaps sufficiently reliable (see results).

Beetz, S., Liebersbach, H., Glatzel, S., Jurasinski, G., Buczko, U., and Höper, H.: Effects of land use intensity on the full greenhouse gas balance in an Atlantic peat bog, Biogeosciences, 10, 1067–1082, doi:10.5194/bg-10-1067-2013, 2013.

Beyer, C. and Höper, H.: Greenhouse gas exchange of rewetted bog peat extraction sites and a *Sphagnum* cultivation site in northwest Germany, Biogeosciences, 12, 2101–2117, doi:10.5194/bg-12-2101-2015, 2015.

Eickenscheidt, T., Heinichen, J., and Drösler, M.: The greenhouse gas balance of a drained fen peatland is mainly controlled by land-use rather than soil organic carbon content, Biogeosciences, 12, 5161–5184, doi:10.5194/bg-12-5161-2015, 2015.

Page 17401 Lines 10-11: *„ Any specific reason why? “*
Yes, we needed to transport the chambers a lot and for this it was advantageous to stack them into each other.

Page 17401 Line 13: *„ Do you know how well this thing measures? I.e., how precise and accurate the measurements were? “*
To ensure accuracy the GC was calibrated every day using three point calibrations for CH_4, N_2O and CO_2. Additionally always after 12 samples calibration gases were analysed and later used to correct for the drift. Precision of the GC was tested by repeated measurements of calibration gases and subsequent calculation of range limits (minimal detectable concentration changes) using the function flux.calib of the R package “flux 0.2–1” (Jurasinski et al., 2012). Range limits till end of 2011 were for CH_4 150 ppb and for N_2O 12 ppb. End of 2011 we adjusted an additional equalization valve what decreased the range limits, being then for CH_4 14 ppb and N_2O 9 ppb. Precision was accounted for during flux calculation, i.e. fluxes were assumed zero when concentration changes were below the range limits.

Jurasinski, G., Koebsch, F., and Hagemann, U.: Flux: Flux Rate Calculation from Dynamic Closed Chamber Measurements, R Package Version 0.2-1, Rostock, 2012.

Page 17401 Line 9: *„I guess "uncertainties" “*
Yes, we corrected it.

Page 17402 Line 24: *„measurement “*
We corrected it.

Page 17402 Line 16: *„Why the em-dash? Would be better without. “*
We removed the em-dash.

Page 17402 Line 17: *„as well as “*
We replaced “and” by “as well as“.

Page 17402 Line 21: *„We don't calculate, we estimate fluxes! “*
We replaced “calculation” by “estimation“.

Page 17403 Lines 5-6: *„In APPROACH ONE a moving window of variable time is applied to adjust.. And why you set this in all capital letters? Maybe you find a less offensive terminology for the two approaches? And would you please tell readers why you used two approaches? “*
We improved our explanation why we used two approaches: “Modeling NEE using the approach of Hoffmann et al. (2015) resulted in surprisingly high annual net CO_2 uptake rates of the *Phragmites australis* sites. To check for possible impacts of the calculation routine on the result we used alternatively the approach of Leiber-Sauheitl et al. (2014) and arrived at slightly smaller CO_2 sinks. Both approaches are reasonable, build on the same assumptions but differ with respect to flux estimation, reference temperature, GPP model and importance of the significance of the model fits, as described in the following paragraphs.
To avoid that modelled CO_2 exchange rates would be biased by specific features of only one of the approaches, both approaches were used to model annual CO_2 exchange rates and their means were taken as final estimates. Time series of daily CO_2 exchange rates, however, were drawn solely using results of the H-approach because both approaches show very similar shapes.”

We replaced “APPROACH ONE” by “H-approach” and “APPROACH TWO” by “LS-approach”, for Hoffmann-approach and Leiber-Sauheitl-approach, respectively.
The corrected sentence is: “In the H-approach a moving window of variable time was applied to adjust the starting point and length of the regression sequence accordingly to the regression quality.”
We replaced “APPROACH ONE” by “H-approach” and “APPROACH TWO” by “LS-approach” throughout the manuscript.

Page 17403 Line 7: *„check according to previous comment “*

We made a second sentence: “The optimal flux length was selected in a second step, based on the minimum Akaike Information Criterion (AIC) of the flux fit to the R_{eco} or the GPP functions.“.

Page 17403 Line 9: *„Same here like above “*

We reworded accordingly: “In the Leiber-Sauheitl (LS)–approach a moving window of constant length (one minute for all, but two minutes for opaque flux measurements at *Phragmites australis* plots because of large chamber volumes and slow concentration changes) was used to select the regression sequence with maximum R^2 and minimum variance.”

Page 17403 Line 16: *„In my opinion an approach is not able to fit something but you, the researchers used the approach to fit something. As suggested above, this should reflect in your language. Please, check the text for formulations like this. “*

We reworded accordingly: “In both approaches for each plot and campaign the Lloyd and Taylor (1994) equation (Eq. 1) was fitted to the regression of R_{eco} flux data on site temperatures.”

We corrected similar formulations throughout the text.

Page 17404 Line 16: *„ What do you mean by that? “*

We added an explanatory sentence: “Assuming declining GPP fluxes when PAR drops from 500 to 0 µmol m^{-2} s^{-1} α was set -0.01 and GP_{max} estimated as the mean campaign GPP flux.”

Page 17404 Lines 24-26: *„Focus or use solely? If the latter you can skip all the approach one/approach two stuff above and just focus on the one you finally used. I would prefer this for averaging the values resulting from these two approaches as you state in the next sentence.“*

Both approaches are well-founded and there is no reason to say that the one is more correct than the other. We do not know what result is closer to the reality because we did not apply an alternative and independent method to estimate the annual CO_2 balances. Both approaches build on the same general model assumption what is a gradually changing relationship between R_{eco} and temperature and between GPP and

PAR from one measurement campaigns to the next. Because of differences in flux estimation, selection of reference temperature, handling of significance and the different GPP formulas both approaches arrive at different though surprisingly similar results. By taking the average of the results of both approaches we account for the impacts of these computing differences and arrive – within the above described general model – at more robust results with larger and more realistic error bars as if we would use only one approach. Therefore we do not want to skip one of the approaches. Of course, there are more approaches described in the literature and it would improve the robustness of our results if we would have used them, too, but this was beyond the capacity of this paper and should first be analyzed in a more methodological study. Regarding the figures illustrating CO_2 time series we used for simplicity only the H-approach because the results of both approaches show very similar shapes.

We changed the sentence into: "Time series of daily CO_2 exchange rates, however, were drawn solely using results of the H-approach because both approaches show very similar shapes." and moved it into the section that introduced why two approaches have been applied.

Page 17405 Line 3: *„measurement "*

We replaced "measuring" by "measurement"

Page 17405 Line 4: *„models were obtained "*

We clarified the sentence: "Stepwise one measurement campaign was left out after the other and the modelled R_{eco} and NEE fluxes obtained for the left out campaigns based on the remaining campaigns were compared with the measured fluxes."

Page 17405 Lines 9-12: *„Please rephrase. "*

We rephrased the sentence "Campaign specific confidence intervals (p = 0.01) were determined for the temperature models, as well as for the R_{eco} and GPP parameter pairs by bootstrapping. Subsequently 100 samples were taken randomly from the confidence intervals and used to compute R_{eco}, GPP, and NEE models."

Page 17405 Lines 15-17: *„Why? "*

We clarified this in the section on Uncertainty, accuracy, and variability: "The random error of the CO_2 models calculated with the H-approach represents the uncertainty of the measuring campaigns, but not of the interpolation. As indicated by the differences between both approaches the uncertainty of the annual balances is larger. To arrive at more realistic error estimates we accounted for the random error and for the difference between both approaches and defined the confidence intervals as the difference between the annual sums of both approaches plus two times the annual random error calculated for the H-approach."

Page 17405 Line 18: *„harmonize plural or singular. "*
We corrected the sentence: "Inter-annual variability of annual NEE fluxes was calculated as the absolute differences between annual plot emissions and two-year plot means."

Page 17405 Line 24: *„estimated "*
We corrected the sentence: "Methane fluxes were estimated with the R package "flux 0.2–1" (Jurasinski et al., 2012) using linear regression."

Pages 17405-17406 Lines 25 and 1-2: *„First, you state that fluxes with NRMSE >= 0.2 are eliminated and then you state that fluxes were accepted if eliminiert und dann NRMSE < 0.4. How does this fit together? "*
We clarified this: "For normalized root mean square error (NRMSE) < 0.2 the flux with the largest number of concentration measurements was preferred. If NRMSE ≥ 0.2 a set of fluxes was estimated using the maximum number up to at least three concentration measurements. Subsequently the flux with the lowest NRMSE was selected. Fluxes were accepted if NRMSE < 0.4, $R^2 \geq 0.8$ and $n \geq 3$. This was the case in 639 out of 686 methane flux measurements, with 477 accepted fluxes based on $n \geq 4$."

Page 17406 Lines 25 and 7-8: *„Why with single drivers only? Isn't this often a multivariate phenomenon? And did you also test for some vegetation parameters? Such, like LAI, bear often quite strong explanatory power. Especially since you measured on Spots with Typha/Carex/Phragmites which are rather larger emergent macrophytes where LAI or other growth parameters typically perform quite well. "*
We are aware of the combined effects that factors have on methane emissions. Originally we applied multiple regression analysis to develop methane models (using ln(CH_4flux + 1), as Tuittila et al., 2000). This resulted in different factor combinations not only for different vegetation types, but also for different plots within the same vegetation types and for different years of the same plots. The narrow restriction of the models was

most likely due to the limited data pool (on average 18 methane flux values per plot and year) and because of this the models seemed pretty random.

We agree that plant parameters would have been helpful in the development of methane models, especially for plants that active ventilate when green. Unfortunately we did not have the possibility to monitor independent vegetation parameters like LAI. Therefore we included GPP, NEE and R_{eco} in the multiple regression analysis. While NEE was never significant and GPP only sometimes, R_{eco} was often significant. However, R_{eco} was seldom together with temperature in one model, but usually both parameters replaced each other. This was because of the strong correlation between temperature and R_{eco} and can be explained by the fact that R_{eco} was modelled using temperature as the driver. The differences among multiple regression models among plots and years of the same vegetation type and the strong dependence of R_{eco} from temperature were the main arguments why we decided against multiple regression analysis and looked instead for the most important, single parameter explaining methane fluxes.

Page 17406 Lines 25 and 8-9: *„What does it mean, "selected"? From which choice?“*

We completed the sentence accordingly: “Second, published nonlinear regression models were fitted to the relation between methane emissions and the driver and the optimal model was selected based on the AIC.”

Page 17407 Lines 17 and 19: *„I hope that you chose both the station data and the site temperature data points 1000 times with the same index. Did you? Otherwise this is flawed.“*

Yes, we did. Station and site temperature points were combined in one data frame accordingly to date and time and then sampled simultaneously by row indices with replacement.

We clarify the sentence: “First, the linear regression between soil temperatures at site and climate station was performed 1000 times with bootstrapped re-sampling of the site and station temperature data points with the same indices.”

Page 17407 Line 20: *„Which mean and sd do you mean here?“*

We mean the methane flux and its standard deviation.

We correct the sentence: “Second, a set of 1000 normally distributed flux values was generated for every flux measurement based on the flux estimate and its standard deviation.”

Page 17407 Lines 20-23: *„Now I am lost. What happens with bootstrapped residuals in the third step? I understand that you have 1000 models for each measurement day and from the whole of your models 1000 are selected in the next step. This seem to not provide a good coverage of the measuring frequency because it is quite unlikely that all models of one measurement day are skipped, isn't it? Anyway, you have to try to get this whole paragraph straight. In its current form is hard to follow.“*

To make the description clearer we added some numbers and separated the third point in two points: “Third, each of the 1000 soil temperature data sets was paired with one of the 1000 flux data sets and 1000 Lloyd and Taylor fits (Eq. 1) were performed.

Fourth, from each of the Lloyd and Taylor fits bootstrap parameter samples were created using bootstrap of the residuals (Efron, 1979; Leiber-Sauheitl et al., 2014). Bootstrap sample size was again 1000. More than 99% of the bootstrap fits were successful what resulted in more than 990000 parameter pairs per plot and year.

Finally, 1000 Lloyd and Taylor fits were randomly sampled from the parameter pairs, combined with the 1000 soil temperature data sets and used to calculate 1000 methane models per plot and year. For each time point and the annual sums 95% and 5% quantiles were calculated to construct confidence intervals of the time series and balances.”

Page 17407 Line 26: *„measurement“*

We corrected this: “As the CH_4 model fits build on all data of a year, the 90% confidence intervals do to some extent also account for the interpolation between measurement days.”

Page 17408 Lines 3-13: *„This should go into the methane section which should be renamed methane and nitrous oxide because these small bits of information do not justify sections and paragraphs “*

We agree and included the text into the methane section.

Page 17409 Lines 3-19: *„Do you really think, readers need these details? I'd suggest to strive for half the length of the current version and for increased readability by concentrating on the real key issues.“*

We shortened the paragraph: “Mean annual temperature at Barcianicha during the first measurement year was 6.5 °C which corresponds to the long term mean (6.4 °C, 1979–2008). The second year was slightly warmer (6.9 °C). Annual precipitation in the first year was higher compared to the long-term mean (740 vs. 665 mm), and in the second year lower (633 mm). Giel’cykaŭ Kašyl’ was generally warmer and drier as compared to Barcianicha (long-term mean 7.3 °C and 594 mm, respectively, 1979–2008). Also here the first year was wetter (804 mm) and the second year drier (500 mm) while annual temperatures of the first year agreed to the long term mean but were higher (7.9°C) in the second year.”

Page 17409 Line 27: *„In this formulation readers have to calculate for themselves what water levels prevailed in the second year. Better you keep your reference and change to: "and dropped to about 70cm above surface (you could then skip the "above surface" at the first occurrence)“*

We changed the sentence accordingly: “Water tables at GK *Phragmites–Lemna* (Giel’cyka˘u Kašyl’) were about one metre in the first year, and dropped to 70 cm above surface in the second year (Table 1).”

Page 17410 Lines 7-23: *„Since these parts refer to things that are more stable in time than weather and climatic conditions, these paragraphs should be moved up before the climate/weather results“*

We moved the paragraph to the beginning of the results.

Pages 17411 (from Line 5)-17413 (to Line 15): *„ With three replicates this can be pure chance” … “Rather start the paragraph with this very fundamental finding and then go into some detail afterwards but try to cut down text by half. All these numbers within the text are really hard to read. And it should be "sites".” … “No uncertainties?” … “Please, try to reformulate the whole section in this style: Less numbers and detail, more focus on generalities and important points. There can be some few numbers. But these should refer to really important issues like astonishingly high emissions or surprisingly low ones or the like. If you want them numbers readable, put them in a table.” … “Rather start with the point here: "The largest annual GPP rates” ... This should follow* *directly after the largest annual GPP rates because they obviously belong together. Rephrase accordingly."… „This paragraph was really an example of extended unreadability. Please revise, following my suggestions above."*

We revised the whole paragraph:

"**3.2 Carbon dioxide emissions**

Model performance tested for the H-approach was good for both years and all site types and plots. Cross-validation resulted in a median NSE of 0.78 (range from 0.38 to 0.90) for the R_{eco} models and of 0.76 (0.21 to 0.91) for the NEE models.

All sites of Barcianicha were net CO_2 sinks in the first year. NEE was −528 (90% confidence interval -933, -194) g CO_2−C m^{-2} yr^{-1} for BA *Phragmites–Carex*, -86 (-130, -38) g CO_2−C m^{-2} yr^{-1} for BA *Eriophorum–Carex* and −88 (-114, -68) g CO_2−C m^{-2} yr^{-1} for *Carex–Equisetum* (Fig. 5; Table 3). In the second year, resulting from increased R_{eco} and decreased GPP, the net CO_2 uptake decreased. NEE of BA *Phragmites–Carex* dropped to −329 (-431, -220) g CO_2−C m^{-2} yr^{-1}, BA *Eriophorum–Carex* became CO_2 neutral and BA *Carex–Equisetum* lost some 24 (-6, 55) g CO_2−C m^{-2} yr^{-1}. Both, sinks and sources were larger at the Giel'cykaŭ Kašyl' sites. NEE of GK *Phragmites–Lemna* was −611 (−819, −450) g CO_2−C m^{-2} yr^{-1} in the first and, despite of increasing R_{eco} fluxes, −1175 (−1567, −690) g CO_2−C m^{-2} yr^{-1} in the second year. The high values were attributed to extremely high annual GPP reaching in the second year −2267 (−2733, −1843) g CO_2−C m^{-2} yr^{-1} and therefore twice of R_{eco} (Fig. 5; Tab. 3). At the other Giel'cykaŭ Kašyl' sites R_{eco} and GPP also increased from the first to the second year, but differences between both fluxes were small. GK *Typha–Hydrocharis* consequently varied between a source of 151 (41, 300) g CO_2−C m^{-2} yr^{-1} in the first and a sink of −113 (−418, 66) g CO_2−C m^{-2} yr^{-1} in the second year. GK *Carex–Lysimachia* was a net CO_2 source in both years, releasing 166 (66, 252) g CO_2−C m^{-2} yr^{-1} in the first and 216 (48, 470) g CO_2−C m^{-2} yr^{-1} in the second year.

Inter-annual variability of NEE fluxes was low for BA *Eriophorum–Carex* (39±12 g CO_2−C m^{-2} yr^{-1}, mean ± SD; Table 4) and BA *Carex–Equisetum* (56±8 g CO_2−C m^{-2} yr^{-1}), larger for BA *Phragmites–Carex,* GK *Carex–Lysimachia* and GK *Typha–Hydrocharis*, and maximum (282±177 g CO_2−C m^{-2} yr^{-1}) for GK *Phragmites–Lemna*. With respect to small-scale variability of NEE the order of sites was similar (Table 4)."

Page 17413 Line 18: *„inside what?"*

It should be “inside of chamber”. We changed it accordingly, see next point, please.

Page 17413 Lines 20-22: *„Cooling tends to have a very strong effect on relative humidity and I don't know a real smart solution for that. The problem is, that changes in relative humidity may strongly affect stomatal conductance inducing bias to the measurements. Thus, it is less important how opaque differ from transparent chambers than how relative humidity develops during chamber placement.. I'd prefer some information on that here. “*

We added information on the increase of relative humidity and temperature during chamber placement in Table S1 of the supplement. To make the table easier accessible for the reader we then moved it into the annex (A1). The modified first sentence is: “Opaque and transparent slightly differently affected air temperature and relative humidity of the headspace. Despite of cooling temperature increased stronger in transparent (up to 3 ± 0.5 °C, mean ± SE; Table A1 in the Annex) as compared to opaque chambers (up 1.4 ± 0.2 °C). Relative humidity, in contrast, increased less in transparent (up to 18.1 ± 3.7 %) than in opaque chambers (up to 14.8 ± 2.3 %), but only at few measurement days the differences were significant (Table A1 in the Annex).”

Please see the updated Table A1:

Annex 1

Mean ± Std. Error of daytime (PAR > 2 µmol m^{-2} s^{-1}) CH_4 flux rates, PAR, T_{in}, and RH_{in} by plot and chamber type (DF = opaque mixed chamber, TF = transparent mixed chamber, D = not mixed opaque chamber). Values with same letter superscript do not differ significantly at $P < 0.05$ (Mann-Whitney or Kruskal-Wallis test; *post-hoc* non-parametric Nemenyi test), data of *BA Phragmites-Carex II* and *GK Phragmites-Lemna II* from Minke et al. (2014).

Site, plot and date	Chamber type	N	PAR (µmol m^{-2} s^{-1})	T_{in} (°C)	dT_{in} (°C)	RH_{in} (%)	dRH_{in} (%)	CH_4 flux (mg CH_4-C m^{-2} h^{-1})	Methane factor
BA Eriophorum-Carex I	DF	8	685^{a} ± 208	16.6^{a} ± 1.1	1.0^{a} ± 0.2	90.2^{a} ± 2.6	7.5^{a} ± 1.7	2.30^{a} ± 0.10	TF/DF = 1.09
2012-07-18	TF	7	1145^{a} ± 224	17.1^{a} ± 1.5	3.0^{b} ± 0.5	78.6^{a} ± 4.1	3.8^{a} ± 0.8	2.49^{a} ± 0.05	
BA Carex-Equisetum III	DF	7	937^{a} ± 401	17.4^{a} ± 1.4	1.5^{a} ± 0.4	90.1^{a} ± 2.1	5.8^{a} ± 1.7	2.30^{a} ± 0.08	TF/DF = 0.99
2012-07-18	TF	6	851^{a} ± 164	17.8^{a} ± 1.5	1.5^{a} ± 0.3	80.2^{b} ± 3.0	4.2^{a} ± 1.3	2.28^{a} ± 0.08	
BA Carex-Equisetum III	D	14	482^{a} ± 85	15.4^{a} ± 0.7	0.7^{ab}± 0.1	79.4^{ab} ± 2.6	9.1^{a} ± 1.0	0.76^{a} ± 0.03	TF/D = 1.07
2012-09-16	DF	14	535^{a} ± 95	15.6^{a} ± 0.7	0.5^{a} ± 0.1	86.2^{a} ± 1.5	7.5^{ab} ± 0.8	0.80^{a} ± 0.04	TF/DF = 1.02
	TF	13	584^{a} ± 95	15.3^{a} ± 0.6	1.3^{b}± 0.2	75.4^{b} ± 2.3	4.4^{b} ± 0.6	0.81^{a} ± 0.02	
GK Typha-Hydrocharis I	DF	9	869^{a} ± 157	24.3^{a} ± 1.2	1.0^{a} ± 0.2	94.4^{a} ± 1.7	18.1^{a} ± 3.7	16.61^{a} ± 0.43	TF/DF = 1.18
2012-07-12	TF	9	868^{a} ± 149	24.9^{a} ± 0.9	1.4^{a} ± 0.3	88.6^{a} ± 2.7	14.8^{a} ± 2.3	19.52^{b} ± 1.20	
GK Typha-Hydrocharis I	DF	11	821^{a} ± 136	19.9^{a} ± 1.2	0.8^{a} ± 0.2	85.3^{a} ± 3.0	15.5^{a} ± 2.8	14.04^{a} ± 0.24	TF/DF = 1.20
2012-07-13	TF	10	1097^{a} ± 146	20.7^{a} ± 1.4	1.7^{b} ± 0.3	80.3^{a} ± 3.7	11.8^{a} ± 2.1	18.00^{b} ± 0.20	
GK Carex-Lysimachia I	DF	9	923^{a} ± 115	24.2^{a} ± 1.1	1.0^{a} ± 0.2	84.9^{a} ± 3.0	9.2^{a} ± 1.5	14.28^{a} ± 0.22	TF/DF = 1.10
2012-07-12	TF	9	749^{a} ± 111	24.8^{a} ± 1.1	1.5^{a} ± 0.3	82.3^{a} ± 2.9	7.0^{a} ± 1.4	15.76^{b} ± 0.38	
GK Carex-Lysimachia I	DF	11	1207^{a} ± 188	20.1^{a} ± 1.3	1.4^{a} ± 0.2	83.4^{a} ± 3.3	12.7^{a} ± 2.1	14.62^{a} ± 0.33	TF/DF = 1.08
2012-07-13	TF	10	1121^{a} ± 177	21.1^{a} ± 1.5	3.0^{b} ± 0.5	78.8^{a} ± 4.3	7.5^{a} ± 1.2	15.81^{b} ± 0.23	
BA Phragmites-Carex II	D	16	830^{a} ± 130	19.4^{a} ± 1.1	0.6^{a} ± 0.2	81.0^{a} ± 3.2	11.8^{ab} ± 1.8	9.86^{a} ± 1.40	TF/D = 1.01
2012-08-08	DF	16	857^{a} ± 133	19.7^{a} ± 1.1	0.9^{a} ± 0.2	81.9^{a} ± 3.3	13.4^{a} ± 2.2	10.17^{a} ± 1.50	TF/DF = 0.98
	TF	16	735^{a} ± 121	19.2^{a} ± 1.2	0.8^{a} ± 0.1	76.5^{a} ± 3.7	6.0^{b} ± 1.0	9.95^{a} ± 1.51	
GK Phragmites-Lemna II	D	14	707^{a} ± 130	20.6^{a} ± 1.2	0.7^{ab} ± 0.2	70.4^{a} ± 3.2	6.0^{a} ± 1.5	13.70^{a} ± 1.68	TF/D = 1.27
2011-09-21	DF	13	819^{a} ± 125	21.7^{a} ± 1.3	1.0^{a} ± 0.2	71.1^{a} ± 3.1	13.8^{b} ± 1.8	17.42^{a} ± 2.39	TF/DF = 1.00
	TF	12	893^{a} ± 125	23.1^{a} ± 1.0	1.8^{b} ± 0.2	66.5^{a} ±2.5	6.6^{a} ± 1.0	17.46^{a} ± 2.08	

Page 17414 Lines 1-2: *„ I Don't use abbreviations here. You can save much more text when cleaning up above.“*

We removed the abbreviations D, DF and TF from the text.

Page 17414 Lines 4-5: *„ I don't believe this figure. It is quite unlikely. Do you have any explanation for such a perfect match? “*

You are right; the statement is not precise (cf. Table A1 in the Annex).

We corrected the sentence: “For all other sites the ratio of transparent to opaque chamber with fan ranged between 0.98 and 1.02.”.

There are different possible explanations for the fact that the ratio between both chamber types was close to one for both *Phragmites australis* sites and BA *Carex–Equisetum*. *Carex rostrata* is a passive conduit for methane and chamber closure was to short to change the transport rates. *Phragmites australis* is an active conduit and even short term shading can affect transport rates (see effect of short term shading by clouds in Minke et al. 2014). Here other processes may have sustained similar methane fluxes in both chamber types, for example continuation of gas transport by shoots outside the chamber that are connected with shoots inside the chamber by rhizomes. However, the effect of transparency was significant at least for *Typha latifolia* and this could indeed be the result of slightly stronger increase of relative humidity in opaque compared to transparent chambers what could affect stomatal conductance or just decrease the water concentration gradient between air inside and outside of the plant and therefore reduce inflow of air into the plant and consequently the gas transport.

Pages 17414 Line 16 - 17416 Line 12: *„ Rephrase. Make two sentences.” … „Rather express in terms of model quality and not in terms of NSE value, like "Most models of BA P-C and GK P-L showed rather poor fits (NSE ranging from XX to XX)." The parentheses is not obligatory. Would also be fine without” … „ Check phrasing” … „ Rather: "Small scale spatial variability of methane emissions at BA..."” … „Like before I suggest to skip many of the numbers and to focus on important points like this one. This could well introduce the whole methane section. After all, the whole results section has to become much shorter and should focus in text on the remarkable things. As said before, present numbers in tables and information in text.“*

We revised the whole paragraph:

“3.3.2 Annual methane emissions

The Lloyd–Taylor methane models performed well for all sites except for the second year of BA *Phragmites–Carex* and GK *Phragmites–Lemna*. NSE for all but the *Phragmites australis* sites ranged between 0.38 and 0.85 (median 0.58). Models of the *Phragmites australis* sites were acceptable in the first year (median NSE 0.37, range 0.05 to 0.82) but performed poor in the second year (median 0.01, range -0.25 to 0.24). Models of GK *Phragmites–Lemna* III and BA *Phragmites–Carex* III did not explain the high emissions in August 2011 (Figs. 3h and 4h). Both and the model of BA *Phragmites–Lemna* I overestimated emissions in spring and early summer 2012. Annual emissions calculated alternatively for the mentioned plots and second year by linear interpolation were 25, 28, and 118 g CH_4−C m^{-2} yr^{-1}, compared to 30, 32, and 139 g CH_4−C m^{-2} yr^{-1} derived by the temperature driven Lloyd–Taylor methane model, and lie within the 90% confidence intervals of the latter (Table A2 in the Annex). The Lloyd–Taylor models were therefore accepted despite of negative NSE.

GK *Phragmites–Lemna* had the highest methane emissions of all sites, estimated to 100 (90% confidence interval 48, 147) and 101 (61, 177) g CH_4−C m^{-2} yr^{-1} in the first and second year, respectively (Table 3). GK *Carex–Lysimachia* released less methane and GK *Typha–Hydrocharis* was with 60 (47, 77) and 68 (52, 92) g CH_4−C m^{-2} yr^{-1} the smallest source among the studied sites at Giel’cykaŭ Kašyl’, but still larger than the Barcianicha sites. BA *Phragmites–Carex* emitted 42 (28, 58) in the first and 36 (22, 52) g CH_4−C m^{-2} yr^{-1} in the second year. BA *Carex–Equisetum* was a much smaller methane source, but the absolute lowest annual methane emissions were estimated for BA *Eriophorum–Carex* being 10 (9, 13) in the first and 11 (10, 14) g CH_4−C m^{-2} yr^{-1} in the second year (Table 3). Inter-annual and small scale variability of methane emissions tended to increase with absolute methane emissions (Fig. 5; Table 4).”

Page 17416 Lines 23-24: *„ This confines the analysis..“*

Yes, and therefore we mentioned the number of plots and years.

Page 17416 Lines 25-26: *„ Start with the strongest and work your way down to the least.“*

We changed the sentence accordingly: “Median annual water level was very strongly with correlated GPP, weaker with NEE and CH_4 emissions, but not with R_{eco}, (Fig. 6).”

Page 17417 Line 11: *„ This is not really surprising..“*

You are right, but we wanted to mention this because the correlations were different when all sites were included (biomass not correlated with NEE but strongly with CH_4).

Page 17417 Lines 19-21: *„See! Remember my statement above about the inclusion of plant biomass parameters like LAI? I guess, this would have been beneficial..“*

Yes, we agree and we regret that we did not have the possibility to monitor LAI. However, it is nice that we still found the biomass relation for annual methane emissions.

Page 17418 Line 4: *„That is inexact since the GWP of the combined exchange of CO2 and CH4 is on the positive site. “*

We agree that the GWP of the combined exchange of CO2 and CH4 for the Barcianicha sites is (with one exception) positive (Table 5). And this means that the sites are GHG sources. Why do you regard our formulation “In both years the Barcianicha sites were very small GHG sources” to be inexact?

Page 17418 Line 4: *„was a small GHG sink“*

We added the missing “was”: “… and in the first year BA *Phragmites–Carex* was a small GHG sink, …”

Page 17418 Line 15: *„ This should come later. First present the balances, then write about their robustness. “*

We agree and changed the two sections to each other.

Page 17418 Lines 17-20: *„Interesting and understandable but I would not start the discussion with something this specific. Best would be starting with the general level of GHG exchange on the sites in comparison to the literature. “*

We agree, please see our answer above.

Page 17418 Lines 22-24: *„ This is published elsewhere already by some of you. Therefore, you might use it as an argument when discussing your results or limitations further down but it should not come at the beginning of the discussion. “*

Yes, we agree, please see our two answers above.

Page 17419 Lines 2-4: *„ I don't understand why you argue about diurnal variability here. Just before it was about chambers and in the next sentence you address day-to-day and seasonal variability. However, the next paragraph addresses diurnal variability. Maybe skip this sentence here or move it to the next paragraph?“*
We agree and deleted this sentence.

Page 17419 Lines 10-12: *„But this is just for a specific time period and, thus, cannot be assumed for the whole measurement period“*
We, and this is a problem. We only know that the dynamic is most pronounced during sunny days in the vegetation season, when *Phragmites australis* is green and relative air humidity drops strongly. Outside the growing season no pronounced diurnal emission dynamic is reported for *Phragmites australis*. As we have sampled the dynamic only for very few days of the growing season we do not know if it would be stronger at other days of the vegetation season. However, we can be sure that daylight emissions are higher than night-time emissions, and that measurements around midday will mostly results in larger flux estimates as compared to morning or evening measurements. Consequently, as we usually sampled between about 10:00 and 16:00 we should have most often caught values that were around or above the 24-hour average. Building the temperature model on such flux estimates should result in annual fluxes that do not underestimate but rather overestimate the actual flux. However, we do not have any mean to calculate if we really overestimated the annual fluxes and by how much.
We changed the sentence as follows: “However, a single measurement at any time during daylight does not represent the daily emission average. For the monitored days (Fig. 2) most measurements between 9.00 and 18.00 h resulted in equal or higher estimates as compared to the 24 hour mean. This indicates that also at other days during the growing period daylight measurements will have rather tended to result in flux estimates at or above the daily mean than below it.”

Page 17419 Lines 19-20: *„ If you can quantify this, you could also correct for the bias, couldn't you? “*
We can not correct for the bias, because we do neither know how far our single methane measurements during daylight were from the daily mean, nor how the diurnal emission amplitudes of the other days were. We have only good reasons, as given above, to assume that our measurements were mostly at or above the daily average

and consequently the annual flux estimates should be at or above the real emissions, too.

Page 17420 Lines 2-4: *„ This sounds a bit like you decided on a gut feeling.“*

Yes, you are right. As you mentioned above, we have only very few diurnal emission data. The ratio 1.2 was the highest observed for GK *Typha–Hydrocharis* and measured at the plot with the highest cover of *Typha latifolia*. We do not know the ratio for other days (it could be lower, but also higher than our observation). However, this ratio was calculated only from measurements taken from sunrise to sunset. At night time there will have been no differences between transparent and opaque and therefore the 24 hour ratio will have been lower. By correcting the emissions with the highest observed ratio of 1.2 we can therefore be quite sure to avoid underestimation of annual methane emissions. Maybe we overestimate the emissions. However, as we can not estimate the overestimation we can not subtract it. In peatland rewetting projects it is better to overestimate the project emissions than to underestimate them, because the project proponent needs to be sure that the estimated GHG emissions reductions compared to the baseline are realistic (a conservative approach, cf. Couwenberg et al., 2011).

Page 17420 Line 4: *„We do not calculate annual emissions, we estimate them.“*

We replaced “measured” by “estimated”: “Estimated annual emissions will consequently be at the high end of real emissions from the site.”

Page 17420 Lines 6-7: *„Check phrasing.“*

We modified the sentence: “*Typha latifolia* was not present at GK *Carex–Lysimachia* I during monitoring of diurnal methane emission dynamics at this plot in summer 2012.”

Page 17420 Lines 16-18: *„If you don't correct for shading you would get better fittings? First, how do you know? Second, why then not skip correction?.“*

Model fit quality would be similar because the correction factor was applied to all measured fluxes during the growing season. As there was a significant impact of shading we had to correct for shading because our routine measurements were conducted with opaque chambers. Without correction we would underestimate annual fluxes. The point is that we found a correction factor of 1.1 and the studied plot had no *Typha latifolia* while the other plots of the site GK *Carex–Lysimachia* had some *Typha latifolia*. This plant is known to actively circulate air and this process can be reduced by shading. Therefore we applied the factor of GK *Typha–Hydrocharis* of 1.2 to be sure not to underestimate annual fluxes. Consequently our estimates are rather close to or slightly above the real methane fluxes what is better than underestimation (see above).

Page 17420 Lines 19-21: *„ And so what?“*

We completed the sentence: “The lack of any shading impact on methane emissions from BA *Eriophorum–Carex* and BA *Carex–Equisetum* corresponds to the findings of Joabsson et al. (1999) and Whiting and Chanton (1992) for *Eriophorum angustifolium* and *Carex rostrata*, what supports our decision not to apply any correction factor to the estimated methane fluxes.”

Page 17420 Line 22: *„ Should come first since it did so also in the MM section. And by the way, the section starts with methodological considerations. I think in a kind of standard GHG paper the core results (balance, fluxes) should be discussed first (Either per GHG or together in a section), then you go into detail (then best per GHG) on methodological discussions.“*

We moved it in front of the methodological considerations on methane and both (Robustness of annual GHG balances) behind the presentation and comparison of annual emissions with data from the literature, as you suggested.

Page 17420 Lines 23-27: *„I'm really not sure about these two approaches. Given the length of the MS and the small differences between them, why you just decide for one of the two and use this without making such a fuss about the other one? This could help straighten the text. What is the benefit of reporting on the two approaches?.“*

The benefit of reporting on both approaches is to become more confident in the results. Even obviously small differences in some aspects of in general similar CO2 model approaches can result in large differences of estimated fluxes. For a 14 month integration period Hoffmann et al. (2015) tested the impact of i) linear interpolation of parameters instead of weighted flux interpolation and ii) varying degree of data aggregation during the modelling process. They found for their data that each of both aspects alone changed the integrated NEE by about 100 g CO_2-C m^{-2}. Given that H-approach and the LS-approach differ from each other in more than two aspects it is quite surprising that the results were still quite similar. However, as the decision regarding a number of aspects that differ between both approaches (especially the estimation of measured fluxes, application of Michaelis-Menten vs. Falge2000, and the dealing with not significant fits) is not so clear, it would be arbitrary to skip one of the approaches. Aiming at robust estimates we regard it advantageous to integrate the results of both approaches and to reduce the dependency of the values from a single approach.

Page 17421 Lines 1-4: *„You don't need two approaches to state this since it is well established.“*

The robustness of general model assumptions against differences in flux estimation and model parameterization is not well established and, as stated above, differences in some aspects of the calculation routine can have strong impacts on the model results (cf. Hoffmann et al., 2015). In our study the outcomes of the models were indeed similar, but this was not clear before and does not does allow for the conclusions, that both approaches will generally result in similar models. We would very much like to keep both approaches because this gives additional confidence in the flux estimates.

Page 17421 Lines 7-8: *„Check phrasing.“*

We corrected the sentence: “Net CO_2 uptake at GK *Phragmites–Lemna* was similar to the estimates of Brix et al. (2001; Table 7) in the first year but two times higher in the second year.”

Page 17421 Lines 10-12: *„ For which units and temporal periods?.“*

We formulated the sentence more precisely: “Based on dry weight of green above ground biomass assessed at the end of the growing seasons 2011 and 2012 and on published ratios between above ground and below ground biomass production we estimated the net annual primary production (NPP, g C m^{-2} yr^{-1}) of the *Phragmites australis* sites during both GHG measurement periods (Table 6).”

Page 17421 Line 12: *„estimated“*

We replaced “calculated” by “estimated”: “Using NPP, NEE, and GPP we estimated heterotrophic and autotrophic respiration (R_h and R_a, Table 6) and evaluated their meaningfulness.”

Page 17421 Lines 15-19: *„Way too long and hard to follow. Please make 2 or 3 sentences and rephrase “*

We rephrased as follows: “The ratios of heterotrophic respiration to methane emissions (CO_2-C / CH_4-C) were 2.2 and 2.3 in the first an second year, respectively for BA *Phragmites–Carex* and closer, 1.0 and 1.1 for GK *Phragmites–Lemna*. Similar ratios were found in incubation experiments for organic bottom sediments and the upper peat layer of a flooded former fen grassland (Hahn-Schöfl et al., 2011).”

Page 17421 Line 23: *„ See! You use it here correctly yourself. We should strive to be very clear on that in all instances. “*
We checked and corrected this throughout the text.

Page 17422 Lines 1-2: *„A comparison to a single other study is, in my opinion, not a good basis to build a discussion upon. If you have three studies with similar results and yours differs then this could be a basis. Otherwise it seems a bit erratic because readers don't know why you chose this one and not any other one. “* and
Page 17422 Lines 7-11: *„But why your site was how your site was? That would be the interesting point and not why they were different. And again, single site comparisons are somewhat arbitrary and do not offer much news. Try to generalize.“*
We revised the first paragraph accordingly to both of your suggestion:
“Annual methane emissions from BA *Eriophorum–Carex* and BA *Carex–Equisetum* were of the same magnitude as from similar vegetation types in two rewetted cutover Atlantic bogs (Wilson et al., 2009, 2013). Net uptake and net release of CO_2, however, was smaller for BA *Eriophorum–Carex* and BA *Carex–Equisetum* as compared to the mentioned Irish sites (Wilson et al., 2008, 2013; Table 7), perhaps partly resulting from the more continental climate.”

Page 17423 Line 3: *„ All the time you use the scientific names and now you don't. Would be better to use the scientific names here as well. “*
We replaced the English by scientific names: “Annual methane and CO_2 fluxes from floating *Carex – Typha* mats are not reported in the literature.”

Page 17423 Line 5: *„Should be "pristine, water saturated sedge fen" “*
We added the missing comma: “Methane emissions from GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* were higher compared to a pristine, water saturated sedge fen….”

Page 17423 Line 17: *„Better use the term "source" anywhere here. I had to read three times until I understand that this is about being a source for CO2.. “*

We skipped the first and rephrased the second sentence: “~~Both sites, however, were CO_2 and carbon sources.~~ However, a wet sedge fen in the southern Rocky Mountains (Wickland et al., 2001) and a water saturated *Typha angustifolia* marsh (Chu et al., 2015) were found to be CO_2 sources (Table 7).

Page 17423 Line 23: *„ leaves “*

We replaced “leafs” by “leaves”.

Page 17424 Lines 10-12: *„What about the error terms? You should always add them because ? I think ? we would then easily see that the lower ones of these values are kind of meaning less because in the uncertainty range they could also be carbon sources.“*

We added the error terms: “BA *Eriophorum–Carex*, BA *Carex–Equisetum*, BA *Phragmites–Carex* and GK *Phragmites–Lemna* had on average low GHG emissions (2.3 (90% confidence interval -1.0, 5.6), 4.2 (2.1, 6.8), −1.7 (-15.0, 10.2), and 4.2 (-26.8, 37.7) t CO_2 eq ha^{-1} yr^{-1}, respectively), and were mostly carbon sinks (−36 (-112, 28), −17 (-89, 63), −390 (-861, -164), and −795 (-1437, -363) g C m^{-2} yr^{-1}), confirming that important aims of peatland rewetting, i.e. restoration of the carbon sink function and reduction of GHG emissions have been largely achieved. Net carbon losses from GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* of the terrestrialization zone (83 (-332, 352) and 276 (140, 539) g C m^{-2} yr^{-1}, respectively), in contrast, were similar as from peat extraction sites (280 g C m^{-2} yr^{-1} – Drösler et al., 2014) and GHG emissions (25.1 (9.5, 37.9) and 39.1 (26.6, 58.0) t CO_2 eq ha^{-1} yr^{-1}) were even comparable to deep-drained temperate fen grassland (26 t CO_2 eq ha^{-1} yr^{-1} – Drösler et al., 2014; 65 t CO_2 eq ha^{-1} yr^{-1} – Eickenscheidt et al., 2015).”

Page 17424 Lines 23-24: *„ levels, also for next occurrence “*

We replaced “level” by “levels” in both occurrences.

Page 17424 Line 26: *„ rather "depth" “*

We replaced “thickness” by “depth”.

Page 17425 Line 17: *„ see above “*

We replaced “thickness” by “depth”.

Page 17425 Lines 10-11: *„ Formulation too absolute. Rather "At the study sites water level may have influence methane emissions rather via the plant species distribution than directly" Or so..“*

We adopted your suggestion: “At the study sites water level will have influenced methane emissions of the studied sites rather by plant species distribution then directly.”

Page 17425 Line 12: *„ Nitrous oxide emission were negligible for all sites. which likely resulted from....“*

We adopted your suggestion: “Nitrous oxide emissions were negligible for all sites, which likely resulted from permanent water saturatation and agrees with other studies from rewetted fens (Hendriks et al., 2007; Couwenberg et al., 2011; Wilson et al., 2013).”

Page 17425 Line 16: *„ How did you analyze these. Through indicator values?.“*

We first derived indicator values for species of our sites that were listed in the vegetation form concept (Koska et al., 2001) and then defined the nutrient conditions according to the range where the species overlapped. *Eriophorum angustifolium* for example occurs under oligotrophic and mesotrophic conditions, *Carex rostrata* under oligotrophic, mesotrophic and eutrophic conditions, and *Equisetum fluviatile* under mesotrophic, eutrophic and polytrophic conditions. Together they indicate for BA *Eriophorum-Carex* mesotrophic conditions.

We added this information as a third sentence to the methods section (page 17399, from Line 18): “Nutrient conditions of the sites were estimated using plant species groups as indicator (Koska et al. 2001).”

Koska, I., Succow, M., Clausnitzer, U., Timmermann, T., and Roth, S.: Vegetationskundliche Kennzeichnung von Mooren (topische Betrachtung), in: Landschaftsökologische Moorkunde, edited by: Succow, M. and Joosten, H., Schweizerbart, Stuttgart, 112–184, 2001.

Page 17425 Lines 26-28: *„ No question but also not surprising..“*

Yes, but as our data clearly shoes it, we decided to state it.

Page 17426 Line 4: *„ What else should be the strongest control if water levels are at or above ground? “*

Some things are trivial but still worth to be stated.

Page 17426 Lines 5-9: *„ But when you treat CH4 as a GHG and consider GWP the picture changes, doesn't it? Also it should be given in percentage of annual site emissions to be comparable. “*

Yes, if accounted for the GWP there is no difference (small scale variability of NEE = 3.4±4.0 t CO_2-eq ha^{-1} yr^{-1} and of CH_4 = 2.9±3.6 t CO_2-eq ha^{-1} yr^{-1}).

Page 17426 Lines 11-12: *„ As the last comment already suggests, taking the absolute values has only little meaning. Given that we typically measure CO2 in ppm and CH4 in pub I would state that CH4 exchange rates showed much higher variability in space and time (which is about the state of the art). The same holds for the annual comparison because it is not known whether the years were strongly different or not in comparison to an ? unfortunately imaginary ? long-term time series of annual emissions.“*

We agree that our sample number is to small (three plots, two years) for a real analysis of small scale and inter-annual flux variability. We also see the point that it is somewhat arbitrary to decide on reporting the variability on the element base or as GWP. We went for the element base because this is common in the literature (Helfter et al. 2015, Roulet et al., 2007). The latter reference found that NEE is the largest and most variable component of the C balance. We would avoid the decision between element base and GWP, if we would report variability as percentages of the annual flux. However, by this we would have lower variability for stronger sinks or sources and higher for sites with fluxes around zero. Inter-annual variability of NEE would be 221% for BA *Eriophorum-Carex* and 35% for GK *Phragmites-Lemna*. The reader could get the impression that NEE of the latter was more stable than NEE of BA *Eriophorum-Carex*. But this is wrong when absolute figures are considered (cf. Fig. 5). Absolute figures are more important to evaluate the stability of a peatland and the risk of high emissions after rewetting. Our aim was not a thorough analysis of small scale and inter-annual variability of emissions but to find out how strongly emissions differed between plots and years. Interestingly, while the small scale variability of GHG emissions is, as you expected, indeed not different between NEE (3.4±4.0 t CO_2-eq ha^{-1} yr^{-1}) and methane emissions (2.9±3.6 t CO_2-eq ha^{-1} yr^{-1}), the inter-annual variability is larger for NEE (4.2±4.3 t CO_2-eq ha^{-1} yr^{-1}) as compared to methane emissions (1.4±1.6 t CO_2-eq ha^{-1} yr^{-1}).

However, the paragraph on small scale and inter-annual variability is not essential for the manuscript. We therefore suggest the following solution: we keep on stating the variability on the element base in Table 4 (as the element base is often used and can be easily translated into GWP) but skip the paragraph were small scale and inter-annual variability are discussed, Page 17426 Lines 11-14: ~~“Small scale variability, calculated as absolute difference between annual plot emissions and annual site emissions was larger for NEE (92±108 g CO_2−C m^{-2} yr^{-1}) than for methane emissions (8±10 g CH_4−C m^{-2} yr^{-1}). Also inter-annual variability, calculated plot-wise as the absolute difference of annual emissions from the two years mean, was larger for NEE (116±119 g CO_2−C m^{-2} yr^{-1}) as compared to methane emissions (4±4 g CH_4−C m^{-2} yr^{-1}). Both can be explained by the fact that CO_2-fluxes are more directly linked to plant productivity than methane fluxes (Hyvönen et al., 1998; Bonneville et al., 2008; Schneider et al., 2012).”~~

Page 17426 Line 27: *„ Check phrasing, I think there is an "a" missing.“*
We added the “a”: “Plant litter was more abundant at Giel’cykaŭ Kašyl’, certainly because of higher plant productivity, but also because of a longer period since rewetting.”

Page 17427 Lines 10-17: *„ Would be nice in the discussion but seem a bit local for the conclusion in which we should strive to generalize our findings beyond the specific study site or study period..“*
The paragraph summarizes the most important outcomes of the discussion and serves as introduction for the conclusion. Section three of the discussion elaborates one point after the other but we regard it supportive for the reader to mention these outcomes at once combined. Why not doing it in the beginning of the conclusion?

Page 17427 Lines 19-20: *„ Check phrasing..“*
We rephrased the sentence: “This implies that the formulation of robust emission factors for high-productive vegetation types and mire ecosystems requires more long-term and spatially resolved GHG emission studies than for low-productive.”

Page 17427 Lines 26-27: *„Yes, this is a conclusion sentence!!..“*
Thank you.

Page 17440: *„Looks like you were quite a disturbance.“*

Not really, because the species coverages changed in both direction. *Phragmites australis*, for example, grew better at GK *Phragmites–Lemna* in the second year.

Page 17441: *„Although I understand that you want to present all numbers correctly and confidence intervals do not spread evenly around the mean I think the representation is hard to read. What about reporting like 339_364_396 (Reco of BA E-C year 1) or similar to that (e.g. just with spaces between the numbers..“*
We propose to replce “to” by “,”.
Table 3 would then become:

Table 3. Annual fluxes of CO_2, CH_4, and Carbon (C balance = NEE + CH_4 emissions) with 90% confidence intervals.

Site	Year	R_{eco} (g CO_2–C m^{-2} yr^{-1})	GPP (g CO_2–C m^{-2} yr^{-1})	NEE (g CO_2–C m^{-2} yr^{-1})	CH_4 emissions (g CH_4–C m^{-2} yr^{-1})	C balance (g C m^{-2} yr^{-1})
BA *Eriophorum–Carex*	1	364 (339, 396)	-449 (-512, -407)	-86 (-130, -38)	10 (9, 13)	-75 (-114, -30)
	2	406 (368, 458)	-413 (-449, -376)	-7 (-49, 21)	11 (10, 14)	4 (-35, 30)
BA *Carex–Equisetum*	1	232 (196, 262)	-320 (-361, -279)	-88 (-114, -68)	17 (13, 22)	-71 (-92, -56)
	2	327 (282, 371)	-302 (-334, -281)	24 (-6, 55)	13 (9, 16)	37 (8, 66)
BA *Phragmites–Carex*	1	614 (478, 737)	-1141 (-1595, -888)	-528 (-933, -194)	42 (28, 58)	-486 (-873, -156)
	2	706 (568, 842)	-1035 (-1134, -949)	-329 (-431, -220)	36 (22, 52)	-293 (-377, -205)
GK *Typha–Hydrocharis*	1	921 (841, 982)	-771 (-842, -665)	151 (41, 300)	60 (47, 77)	210 (111, 360)
	2	973 (818, 1156)	-1086 (-1476, -862)	-113 (-418, 66)	68 (52, 92)	-45 (-343, 142)
GK *Carex–Lysimachia*	1	1105 (1007, 1207)	-940 (-1081, -774)	166 (66, 252)	86 (63, 121)	252 (145, 356)
	2	1270 (1221, 1362)	-1054 (-1243, -789)	216 (48, 470)	85 (59, 142)	301 (137, 552)
GK *Phragmites–Lemna*	1	936 (733, 1200)	-1547 (-1726, -1386)	-611 (-819, -450)	100 (48, 147)	-516 (-747, -349)
	2	1092 (937, 1210)	-2267 (-2733, -1843)	-1175 (-1567, -690)	101 (61, 177)	-1074 (-1453, -565)

Uncertainties on the site level include the uncertainties of the plot models and the spatial heterogeneity. They were calculated by pooling the plot specific annual models derived by error calculation. Different CO_2 balances of the H-approach and the LS-approach were accounted for by adding the differences randomly to 50% of the respective annual values derived by error calculation with the H-approach. To derive uncertainties of C balances the annual models of NEE and CH_4 derived by plot–wise error calculation were summarized and combined site–wise.

Page 17442: *„ See comment in text. I am skeptical about reporting this in absolute terms..“*

We prefer to keep to the difference on the element base because these can easilily be translated into GWP (see our response above). Reporting variability in percentages of the annual emissions would lead to seemingly strong variability for sites with fluxes around zero and small for sites with large fluxes. However, we aimed at estimating how stable the rewetted sites with respect to emissions are (please see also our response above).

Page 17451: *„ Should be capital letters, like in the figure. And I really don't understand the many bars. Do you give all replicates separately? I strongly advice to put them together per site! There are examples of efficiently bringing the terms together to show them in balance bar plots in the literature..“*

Yes, it must be capital letters.

We present all replicates separately because we aimed at visualizing the differences of GHG emissions among them. This is not often done in the literature. However, it is quite instructive, because it gives an idea of the spatial and inter-annual variability of site emissions. Of course, the small number of years and plots does not allow for conclusive analysis (see our response above), but still we can conclude that emissions from some vegetation types are more stable than from other. We give confidence intervals for all replicates to show the uncertainty and allow to roughly estimate if GHG emission differences between plots are significant. We bring combine the plot emissions and present site emissions later, in Tables 3 and 5. We understand your concern in overestimation the importance of differences among plotsa and propose to skip Table S2 where the emissions of all plots are listed. Still we would like to present them in Figure 5, just to give an impression of the variability.

Page 17452: *„ No, these are scatter plots in which we might see correlations...“*

We modified the figure subtitle accordingly: “Scatter plots of annual NEE, R_{eco}, GPP, CH_4 emissions, median annual water levels (both years for all plots, n = 36), and above ground biomass carbon (second year for all plots, *n* = 18). Spearman’s ρ significant at ‘ $P \leq 0.05$; * $P \leq 0.01$; ** $P \leq 0.001$; *** $P \leq 0.0001$. Spearman’s ρ in brackets without GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* (*n* = 30 for correlations among water levels and fluxes; *n* = 15 for correlations among biomass and fluxes). Small symbols indicate first year, large symbols second year.”

Water level, vegetation composition and plant productivity explain greenhouse gas fluxes in temperate cutover fens after inundation

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M. Minke[1/5], J. Augustin[2], A. Burlo[3], T. Yarmashuk[4], H. Chuvashova[3], A. Thiele[5/6], A. Freibauer[1], V. Tikhonov[3], M. Hoffmann[7]

[1]Thünen Institute of Climate–Smart Agriculture, Braunschweig, Germany

[2]Institute for Landscape Biogeochemistry, ZALF e.V., Müncheberg, Germany

[3]Scientific and Practical Centre of the National Academy of Sciences of Belarus for Biological Resources, Minsk, Belarus,

[4]Institute for Nature Management of the National Academy of Sciences of Belarus, Minsk, Belarus

[5]Institute of Botany and Landscape Ecology, University Greifswald, Germany

[6]Michael Succow Foundation, Greifswald, Germany

[7]Institute of Soil Landscape Research, ZALF e.V., Müncheberg, Germany

Abstract

Peat extraction leaves a land surface with a strong relief of deep cutover areas and higher ridges. Rewetting ~~of temperate continental cutover fen peatlands usually causes inundation generally implies the creation of flooded areas, that suffered intensive height losses~~ inundates the deep parts while less deeply extracted zones remain at or above the water level. ~~T~~In temperate fens the flooded areas ~~which~~ are ~~– dependent on water depth –~~ colonized by helophytes such as *Eriophorum angustifolium*, *Carex* spp., *Typha latifolia* or *Phragmites australis* dependent on water depth. Reeds of *Typha* and *Phragmites* are reported ~~to be~~as large sources of methane, but data on net CO_2 uptake are contradictory for *Typha* and rare for *Phragmites*. Here, we analyze ~~This paper describes~~ the effect of vegetation, water level and nutrient conditions on greenhouse gas (GHG) emissions for representative vegetation types along water level gradients at two rewetted cutover fens (mesotrophic and eutrophic) in Belarus. Greenhouse gas emissions were measured campaign-wise with manual chambers ~~in weekly to few – weekly~~every two to four weeks ~~intervals over a~~for two years ~~period~~ and interpolated by modelling.

All sites had negligible nitrous oxide exchange rates. Most sites were carbon sinks and small GHG sources. Methane emissions ~~were~~ generally ~~associated~~ increased with net ecosystem CO_2 uptake. Mesotrophic small sedge reeds with water table around the land surface were small ~~net~~ GHG ~~emittor~~source~~s~~s in the range of 2.3 to 4.2 t CO_2 eq ha^{-1} yr^{-1}. Eutrophic tall sedge - *Typha latifolia* reeds on newly formed floating mats were substantial net GHG emitte~~o~~rs in the range of 25.1 to 39.1 t CO_2 eq ha^{-1} yr. They represent transient vegetation stages. *Phragmites* reeds ranged between -1.7 to 4.2 t CO_2 eq ha^{-1} yr^{-1} with an overall mean GHG emission of 1.3 t CO_2 eq ha^{-1} yr^{-1}. The annual CO_2 balance was best explained by vegetation biomass, which includes the role of vegetation composition and species. Methane emissions were obviously driven by biological activity of vegetation and soil organisms.

~~Small sedges were minor methane emitters and net CO_2 sinks, while *Phragmites australis* sites released large amounts of methane and sequestered took up very much CO_2. Variability of both fluxes increased with site productivity. Floating mats composed of *Carex* tussocks and *Typha latifolia* were a source for both methane and CO_2. We conclude that s~~Shallow flooding of cutover temperate fens is a suitable measure to arrive at low GHG emissions. *Phragmites australis* establishment should be promoted in deeper flooded areas and will lead to ~~comparably~~ moderate, but variable GHG emissions or even occasional sinks. The risk of ~~high~~large GHG emissions is higher for eutrophic than mesotrophic peatlands. Nevertheless, flooding of eutrophic temperate fens still represents a safe GHG mitigation option ~~for temperate fens~~ because even the hotspot of our study, the floating ~~eutrophic~~ tall sedge – *Typha latifolia* reeds~~terrestrialization zone~~, did not exceed the typical range of GHG emissions from drained fen grasslands and the spatially dominant *Phragmites australis* reed emitted by far less GHG than drained fens.

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~~hallow, stable flooding is a better measure to arrive atwas associated with lower GHG emissions than deep flooding, and that the risk of high GHG emissions consequent on rewetting is larger for eutrophic than for mesotrophic peatlands.~~

1 Introduction

Cutover peatlands represent about ten percent of all drained peatlands outside the tropics with the main share in the Nordic countries and Eastern Europe (Joosten and Clarke, 2002). Since the 1990s restoration of cutaway peatlands was conducted especially in Canada, Finland, Sweden and Ireland. Similar projects in Eastern Europe started later, but already cover vast areas. ~~42 ~~42,000 ha of degraded peatlands were restored in Belarus since 2007 and about ~~80 ~~80,000 ha since 2010 in the European part of Russia, aiming to decrease GHG emissions from microbial peat oxidation and peat fire incidents (Tanneberger and Wichtmann, 2011; Wetlands International, 2015).

A large proportion of the peatlands that have been rewetted or are available for rewetting in Russia and Belarus are abandoned cutover fens (Minayeva et al., 2009; Tanovitskaya and Kozulin, 2011). Rewetting of such sites creates a mosaic of wet and flooded zones and elevated drier parts, and results in rapid vegetation changes (Kozulin et al., 2010; Thiele et al., 2011). At sites with the water level close to surface species like *Eriophorum angustifolium*, *Carex vesicaria* and *Lythrum salicaria* establish within a few years, or, under more nutrient rich conditions, *Calamagrostis canescens*, *Lysimachia thyrsiflora*, *Carex elata* and *Salix*. At flooded areas with standing water depths of more than 20 cm mainly *Phragmites australis* emerges, whereas water levels above 30 cm in the medium term only result in the establishment of submerse and floating plants (Kozulin et al., 2010; Thiele et al., 2011).

Studies from rewetted cutover boreal peatlands and temperate bogs show that methane and carbon dioxide emissions are strongly related to ~~vegetation,~~ water level, ~~and nutrient conditions~~ vegetation, and meteorological conditions (Tuittila et al., 1999, 2000; Drösler, 2005; Yli-Petäys et al., 2007; Soini et al., 2010; Samaritani et al., 2011; Strack and Zuback, 2013; Wilson et al., 2013; Beyer et al., 2015). ~~Interannual variability of meteorological conditions, water levels and plant productivity can substantially affect annual GHG emissions from pristine and restored peatlands (Wilson et al., 2013; Günther et al., 2014; Helfter et al., 2015).~~ For rewetting it is frequently recommended to raise the water level throughout the year to close to the surface and to avoid inundation in order to promote the establishment of peat forming vegetation and to prevent high methane emissions (Drösler et al., 2008; Couwenberg et al., 2008, 2011; Joosten et al., 2012). Such conditions have been proven optimal for bog restoration (Beyer et al., 2015), but their feasibility for fens has been questioned (Koebsch et al., 2013; Zak et al., 2015). In practice, fens are often rewetted by shallow flooding.

So far, complete GHG balances are not available for rewetted temperate cutover fens. Such fens differ from those in the above cited studies in particular by the massive establishment ~~in shallow water~~ of *Typha* and *Phragmites australis* in shallow water, i.e. of species that are potentially strong ~~sources~~ pathways of methane (Kim et al., 1998; Brix et al., 2001; Whiting and Chanton, 2001; Kankaala et al., 2004; Hendriks et al., 2007; Chu et al., 2015; Knox et al., 2015; Strachan et al., 2015). Whereas earlier studies indicate that the radiative forcing of such methane emissions may be compensated for by the simultaneous very strong net CO_2 uptake (Brix et al., 2001; Whiting and Chanton, 2001), recent observations described *Typha* dominated wetlands as often only weak CO_2 sinks (Rocha and Goulden, 2008; Chu et al., 2015; Strachan et al., 2015; but cf. Knox et al., 2015). Moreover, submerse and floating plants that are ~~supp~~promoted~~orted~~ by deep flooding have much higher methane production potential ~~compared to~~than emergent species (Kankaala et al., 2003; Zak et al., 2015). ~~*Phragmites australis*, the more abundant species in European rewetted cutover fens is according to Brix et al. (2001) a potentially stronger net CO_2 sink, but no annual CO_2 exchange rates have yet been published from permanently inundated *Phragmites australis* wetland sites.~~

This study aims to ~~assess~~quantify GHG emissions from inundated temperate cutover fens recolonized by wetland plants. W~~To fill this knowledge gap w~~e measured for two years the CO_2, CH_4, and N_2O emissions from *Phragmites australis* communities and other representative vegetation types along water level gradients in ~~two~~ a mesotrophic and a eutrophic rewetted cutover fen~~s~~ ~~with different nutrient conditions~~ in Belarus. We hypothesize that

(i) ~~(i)~~ all sites are net CO_2 sinks: peat loss by oxidation has stopped after rewetting. The net CO_2 sink increases with nutrient status, the productivity of the vegetation and peaks under shallow inundation,~~.~~

;

~~(i)~~ ~~(ii)~~ methane emissions increase with the productivity of the vegetation and peak under shallow inundation~~inundation depth~~.

(ii)

(iii) ~~and (iii)~~ the ~~climate effect~~net GHG balance is near neutral ~~only~~ when water levels are close to surface because CH_4 emissions are balanced by the net CO_2 sink. ~~But~~The net GHG balance turns into a source ~~becomes increasingly negative~~when sites are ~~inundated~~continuously flooded because the global warming by CH_4 emissions exceeds the net CO_2 sink.

~~Our objectives were: (i) to assess GHG emissions from rewetted temperate cutover fens recolonized by wetland plants (ii) to analyse the effect of water level, vegetation and nutrient conditions on GHG exchange, and (iii) to estimate the inter-annual and spatial variability of GHG emissions.~~

2 Materials and methods

2.1 Study sites

Greenhouse gas fluxes were measured at two sites in Belarus (Fig. 1) with a temperate continental climate with fully humid conditions and warm summers (Dfb after Köppen, 1936; cf. Kottek et al., 2006). Both sites have been subject to peat extraction, but differ with respect to time since rewetting, water depth, peat characteristics and nutrient status, vegetation, and regional climate.

“Barcianicha” (54.10° N; 26.29° E) is located in central Belarus on an alluvial plain between the rivers Al’šanka and Zahodniaia (“Western”) Biarėzina and predominantly fed by groundwater discharge (Maksimenkov et al., 2006). In 1990 about 190 ha of Barcianicha were drained and from 1992 to 1995 peat was extracted by milling over an area of 150 ha to a remaining peat depth of about 80 cm. After abandonment ditches were closed with earth dams and water level was raised ~~over~~ on 60% of the area, allowing wetland species like *Phragmites australis*, *Carex rostrata* and *Eriophorum angustifolium* to establish (Maksimenkov et al., 2006). ~~despite~~ Strong water level amplitudes between summer and winter ~~(Maksimenkov et al., 2006).~~ were stabilized ~~I~~in 2007 by weirs and overflow dams ~~were built, which stabilized water levels~~. In 2010 most of the area had water levels at or slightly above the surface throughout the year. ~~Vast~~ Tall reeds, dominated by *Phragmites australis* of up to two metres height, covered the area. Three GHG monitoring sites were installed along a water level gradient, including the small sedge reeds~~an~~ *Eriophorum angustifolium*–*Carex rostrata* ~~site~~ (further indicated as BA *Eriophorum*–*Carex*)~~,~~ and *Carex rostrata*–*Equisetum fluviatile* ~~site~~ (BA *Carex*–*Equisetum*) at 15 m ~~further~~ distance, and a *Phragmites australis*–*Carex rostrata* ~~site~~ reed (BA *Phragmites*–*Carex*) ~~after~~ at another 30 m distance (Table A1~~2~~).

The second peatland, “Giel’cykaŭ Kašyl” (52.38° N; 25.21° E), forms part of the “Bierastaviec” fen and is situated on the left bank of Jasiel’da river. It belongs to the Ramsar site “Sporaŭski zakaznik” and was drained in 1975 (Kadastrovyj spravochnik, 1979). ~~After peat extraction m~~More than one metre of peat remained after peat extraction and grassland was established. But as the area proved to be unsuited for hay production, the pumping station was turned off in 1985.~~ and t~~The area was flooded by the Jasiel'da, which is connected with Giel'cykaŭ Kašyl' by a 300 m long channel. During the vegetation period the area receives additional water ~~that is ~~pumped out of an adjacent drained fen. *Phragmites australis* of three metres height dominates the area, which is flooded up to one metre above the surface. A 30–80 m wide swampy ~~terrestrialization ~~zone along the edges is formed by *Typha latifolia*, *T. angustifolia*, and tussocks of *Carex elata* and *C. vesicaria* floating on up to one metre of water. GHG monitoring was performed in the ~~terrestrialization ~~floating tall sedge reeds~~zone~~ at two sites: a *Carex elata*–*Lysimachia thyrsiflora* site (GK *Carex*–*Lysimachia*), and a *Typha latifolia*–*Hydrocharis morsus*–*ranae* site (GK *Typha*–*Hydrocharis*; Table A~~2~~1), ~~both ~~at three metres distance from~~close to~~ each other. The third *Phragmites australis*–*Lemna trisulca* site (GK *Phragmites*–*Lemna*) was situated 20 m from the first two sites in the deeper inundated main area, separated from the ~~terrestrialization ~~swampy zone by a flooded ditch.

2.2 Site characteristics

Each site was split into three plots. Peat depth, stratigraphy and degree of decomposition after Von Post (AG Boden, 2005) were ~~assessed visually~~determined for each site using a chamber corer (50 cm long, 5 cm diameter). One mixed surface peat sample (0–5 cm) from each plot was analysed for total carbon (C) and total N (Vario EL III, Germany), and three samples per plot for pH (Hanna Combo HI 98130, calibrated with 7.01 and 4.01 buffer solution, stored in KCl solution, HANNA instruments, USA). After the study, above ground biomass was harvested from all plots (Barcianicha, 29 October 2012; Giel'cykaŭ Kašyl', 11 September 2012), oven dried at 60 °C till weight constancy, and three mixed samples per plot were analysed for total C and N.

Vegetation cover of the 70 cm × 70 cm plots was assessed in coverage classes after Peet et al. (1998). Nomenclature for vascular plants and mosses follows Rothmaler (2002), and Abramov and Volkova (1998), respectively. ~~N~~The nutrient ~~conditions~~status of the sites w~~ere~~as estimated ~~using~~by plant species groups as indicator (Koska et al. 2001).

Water levels were measured continuously (daily averages stored) with Mini Diver data loggers (Eigenbrodt, Germany), installed in perforated tubes (inner diameter 46 mm). One Diver was situated next to BA *Carex*–*Equisetum* in Barcianicha, and another in the middle between the floating tall sedge – *Typha latifolia* ~~terrestrialization zone~~ sites and GK *Phragmites–Lemna* in Giel'cykaŭ Kašyl'. Manual water level measurements were conducted at each site in every second to third week. ~~To derive mean d~~Daily water levels relative to ground surface were calculated for every plot ~~we firsweret calculated~~ by linear regression between the continuous automatic water level time series ~~for every site by linear regression between automatically~~ and manually measured water levels ~~and than corrected for the distances between surface of plots and top of water level tubes~~. Because of strong peat oscillation t~~T~~his approach did not work for the floating sites GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* ~~because of strong peat oscillation~~. Photographic documentation (monthly during vegetation season, one time per winter, WL estimation error < 5 cm) was used here instead to reconstruct relative water levels for linear regression with Diver records.

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2.3 Measurement of greenhouse gas exchange

In order to account for typical small-scale differences between vegetation types we applied a manual chamber approach to measure greenhouse gas exchange. Each of the six GHG measurement sites was equipped with three plastic collars of 70 cm × 70 cm, established in a row about 40 cm apart from each other. Each collar represents one plot. The row was East - West oriented and the ~~n~~North side was the working side to minimize artificial shading during measurements. Collars were inserted 15 cm deep into the peat at Barcianicha. At Giel'cykaŭ Kašyl' because of the high water level, collars were fixed on tubes orthogonally inserted into the peat and anchored in the underlying sand. Measurements were conducted from pre-installed boardwalks from August 2010 to August 2012.

CO_2 exchange was measured with ~~air mixed (fan)~~ transparent chambers ~~(TF)~~ made of plexiglas (~~inner size 72.5 cm × 72.5 cm × 51.2 cm,~~ 88% light transmission, ice packs for cooling, Drösler, 2005) and ~~same sized, air mixed~~ opaque chambers ~~with fan (DF)~~ made of grey ABS plastic covered with a white film. Both were equipped with fans for air mixing and had an inner size 72.5 cm × 72.5 cm × 51.2 cm. Opaque and transparent extensions of same area and 31.2 or 51.2 cm height with open tops were used to enlarge the chambers to accommodate for tall plants. Chambers and extensions were sealed airtight by closed cell rubber tubes attached to the bottom rims (Drösler, 2005). Carbon dioxide concentrations were measured continuously by circulating air in a closed loop between the chamber and an infrared gas analyser (LI-820, LI-COR

Biosciences, USA) and recorded every five seconds by a data logger (CR200 or CR1000, Campbell Scientific, USA). Simultaneously, air temperature inside and outside the chamber, and PAR were recorded automatically (~~“~~“109~~”~~” temperature probes protected by radiation sheets, SKP215, Campbell Scientific, USA), while soil temperatures were measured manually in 2, 5, and 10 cm depth once per chamber measurement with Pro-DigiTemp insertion thermometers (Carl Roth, Germany). For CO_2 measurements~~During a measuring campaign (a bright or hardly cloudy day~~ bright or hardly cloudy days were selected to capture the complete PAR range from zero to solar noon. During the one-day measurement campaign~~)~~s eight to ten transparent chamber measurements of two to three minutes were carried out on each plot from dawn until late afternoon. Measurements were equally distributed over the daily range of PAR to determine light response of gross primary production (GPP). A similar number of opaque chamber measurements of 3–5 min were performed over the same period to capture the temperature response of ecosystem respiration (R_{eco}). Measurement campaigns were repeated every third to fourth week to account for seasonal changes in water table depth and plant development.

CH_4 and N_2O fluxes were measured once every second to third week during the snow free period and monthly during winter using non-air mixed opaque chambers~~ (D)~~, of the same material as the other opaque chambers~~DF~~, but shaped as a truncated pyramid (inner size at bottom 72.5 cm × 72.5 cm, inner size at top 62.5 cm × 62.5 cm, height 51.2 cm). Four to five air samples were taken from the chamber headspace during a 15–20 min enclosure and subsequently analysed in the laboratory with a gas chromatograph (Chromatec-Cristal 5000.2, Chromatec, Russia), using an electron capture detector (ECD) for analysing N_2O and a flame ionization detector (FID) for CH_4, and an auto-sampler (Loftfield, Germany). ~~Air and soil temperatures were measured with Pro-DigiTemp insertion thermometers.~~ From August 2010 to August 2012 a total of 36 CH_4 and N_2O as well as 26 CO_2-measuring campaigns were carried out at every site.

Diurnal CH_4 emission dynamics and the effect of chamber transparency and headspace mixing were additionally studied at one plot per site by frequent CH_4 measurements for one to two summer days, using alternately two (opaque and transparent, both with fan~~DF and TF~~) or three (opaque and transparent with and opaque without fan~~D, DF, and TF~~) chamber types (for details cf. Minke et al., 2014).

Parameters for the development of flux models were recorded on site during GHG-measurement~~ing~~ campaigns, and monitored continuously by nearby climate stations

(BA: Višnieva, 5.6 km NW of Barcianicha, and GK: Z'dzitava, 6.3 km NE of Giel'cykaŭ Kašyl'). At the stations soil temperatures in 2 and 5 cm depth, and air temperature 20 cm above surface were measured with ~~“~~“109~~”~~” temperature probes (Campbell Scientific, USA). Photosynthetically active radiation (PAR) was monitored using a SKP215 Quantum Sensor, precipitation with 52202 Raingauge Heated European, atmospheric pressure with CS100 Setra Barometric Sensor, and all data were recorded half-hourly with CR200 data loggers (all devices from Campbell Scientific, USA). Regression between site and climate station temperature data was subsequently applied to derive continuous half-hourly time series for each site. Due to technical problems with the rain gauges precipitation data were received from Gidrometcentr, Belarus, from the weather stations in Valožyn (15 km E of Barcianicha) and Pružany (54 km WNW of Giel'cykaŭ Kašyl'). Data from both weather stations of Gidrometcentr were also used to calculate 30 year (1979–2008) monthly averages of air temperature and precipitation.

2.4 Calculation of flux rates, annual emission models and uncertainties~~y~~

2.4.1 Carbon dioxide

The net ecosystem exchange (NEE, the CO_2 flux between the ecosystem and the atmosphere) is the balance between CO_2 inputs to the ecosystem by gross primary production (GPP) and CO_2 losses by ecosystem respiration (R_{eco}; Alm et al., 1997; Chapin et al., 2002). A positive sign refers to a flux from the ecosystem to the atmosphere, a negative sign to an ecosystem sink (cf. Falge et al., 2001). Annual NEE rates were modelled for each plot separately based on the plot ~~-~~and campaign specific relationships between R_{eco} and temperature, ~~and~~ as well as between GPP and PAR. Modeling NEE using the approach of Hoffmann et al. (2015) resulted in surprisingly high annual net CO_2 uptake rates of the *Phragmites australis* sites. To ~~account~~ check for possible impacts of the calculation routine ~~and underlying assumptions~~ on the result we used alternatively the approach of Leiber-Sauheitl et al. (2014) and arrived at slightly smaller CO_2 sinks. ~~the R script Version 1.4 of Hoffmann et al. (2015) (““APPROACH ONE””) and the R script of Leiber-Sauheitl et al. (2014) (““APPROACH TWO””).~~ Both approaches are reasonable, build on the same assumptions ~~base on Drösler (2005),~~ but differ with respect to flux ~~calculation~~estimation, reference temperature, GPP model and importance of the significance of the model fits, as described in the following paragraphs. To avoid that modelled CO_2 exchange rates would be biased by specific features of only one of the approaches, both approaches were used to model annual CO_2 exchange rates and their means were taken as final estimates. However, for simplicity we only present modelled CO_2 time series derived by the Hoffmann (H)-approach.

Calculation of measured CO_2 flux rates

Measured CO_2 flux rates were calculated in both approaches ~~by~~ as linear ~~regression~~CO_2 concentration change in the chamber over time. Measurements were discarded if PAR ~~differed~~ fluctuated by > ± 10% (transparent chambers) and chamber temperature > ± 0.75 K (transparent and opaque chambers) from the mean of the selected flux calculation interval. In the H-approach a moving window of variable time was applied~~APPROACH ONE applied a moving window of variable time~~ to adjust the starting point and length of the regression sequence according~~ly~~ to the regression quality. ~~and selected~~ T~~t~~he optimal flux length was selected in a second step, based on the minimum Akaike Information Criterion (AIC) of the flux~~its~~ fit to the R_{eco} ~~and~~ or the GPP functions~~, respectively~~. In the Leiber-Sauheitl (LS)~~-~~approach ~~APPROACH TWO used~~ a moving window of constant length (one minute for all~~, but~~ except for two minutes for opaque flux measurements at *Phragmites australis* plots because of large chamber volumes and slow concentration changes) was used to select the regression sequence with maximum R^2 and minimum variance. If maximum R^2 resulted in different fluxes than minimum variance (46% of all flux measurements) the mean of both was used as flux estimate.

Modelling of half-hourly CO_2 exchange rates

In ~~B~~both approaches ~~for each plot and campaign~~ the Lloyd and Taylor (1994) equation (Eq. 1) was fitted to ~~the regression of~~ R_{eco} flux data ~~onto~~against site temperatures~~-~~ for each plot and campaign~~-for each plot and campaign by the Lloyd and Taylor (1994) equation (Eq. 1)~~.

$$R_{eco} = R_{ref} \times \exp\left[E_0 \times \left(\frac{1}{T_{ref} - T_0} - \frac{1}{T - T_0} \right) \right] \quad (1)$$

R_{eco} = ecosystem respiration (mg CO_2−C m^{-2} h^{-1}), R_{ref} = R_{eco} at reference temperature (mg CO_2−C m^{-2} h^{-1}), E_0 = activation energy like parameter (K), T_{ref} = reference temperature (283.15 K), T_0 = temperature constant for the start of biological processes:

(227.13 K), *T* = soil or air temperature during measurement of best fit with the dataset (K).

~~APPROACH ONE~~In the H-approach ~~fitted~~ Eq. (1) was fitted to ~~calculated~~ R_{eco} flux rates separately for air temperature and soil temperatures and ~~selected~~ the final R_{eco} parameter pairs were selected out of all significant ($p \leq 0.1$) sets based on the lowest AIC. If parameterization was not significant or failed, or if the daily temperature amplitude was below 3 K, the average CO_2 flux of the measurement campaign was used. ~~APPROACH TWO~~In the LS-approach ~~calculated~~ one R_{eco} fit per plot and campaign was calculated ~~for the regression of R_{eco} fluxes on in~~against ~~relation to~~ air temperatures~~, because only one flux was estimated per measurement~~. If parameterization was impossible or the temperature ~~ranged~~ amplitude was below 2 K, the mean campaign R_{eco} flux was used.

In a second step GPP fluxes were determined by subtracting modelled R_{eco} fluxes from timely corresponding, measured NEE flux rates. ~~APPROACH ONE~~In the H-approach ~~fitted~~ a rectangular hyperbola equation (Michaelis-Menten, 1913; Eq. 2) was fitted to the relation between PAR and GPP flux rates to calibrate GPP parameter sets of *α* (initial slope of the curve; light use efficiency) and GP_{max} (rate of carbon fixation for infinite PAR).

$$GPP = \frac{\alpha \times PAR \times GP_{\max}}{\alpha \times PAR + GP_{\max}} \qquad (2)$$

GPP parameter pairs with lowest AIC were selected from each campaign out of all significant regression parameters ($p \leq 0.1$). If the parameter estimation failed, a non rectangular hyperbolic equation was fitted to the data (Gilmanov et al., 2007). If this failed, too, an average parameter approach was used. Assuming declining GPP fluxes when PAR drops from 500 to 0 µmol m^{-2} s^{-1} *α* was set -0.01 and GP_{max} estimated as the mean campaign GPP flux. ~~APPROACH TWO~~In the LS-approach ~~applied~~ the modified Michaelis-Menten model of Falge et al. (2001; Eq. 3) was applied and ~~calculated~~ GP2000 was calculated instead of GP_{max}, i.e. the rate of carbon fixation at PAR of 2000 µmol m^{-2} s^{-1}. Campaigns for which no GPP fit was found were skipped.

$$GPP = \frac{\alpha \times PAR \times GP2000}{GP2000 + \alpha \times PAR - \frac{GP2000}{2000} \times PAR} \qquad (3)$$

Based on the GPP parameter pairs and continuously monitored PAR data, GPP was modelled ~~by~~ in both approaches for each plot at a temporal resolution of 30 min. NEE was subsequently calculated as the difference between GPP and R_{eco}.

~~As both approaches used very similar functions and produced similar results we focus on APPROACH ONE for the presentation and discussion of the modelled CO$_2$ time series. Annual budgets are presented as the mean of both approaches.~~

Uncertainty, accuracy, and variability

Model performance for the interpolation between the measurement campaigns was estimated for the ~~APPROACH ONE~~H-approach by leave-one-out cross-validation. Stepwise one ~~measuring~~ measurement campaign was left out after the other and the modelled R_{eco} and NEE fluxes ~~obtained~~were compared with the measured fluxes in ~~for~~ the left out campaigns~~based on the remaining campaigns were comparedmodel calculated with the remaining campaigns, comparing the modelled R_{eco} and NEE fluxes with the measured ones at the left out campaign~~fluxes. Model performance was assessed by the Nash–Sutcliffe efficiency (NSE, Moriasi et al., 2007).

The random error of the annual CO$_2$ balances was calculated for the ~~APPROACH ONE~~H-approach using the R-script Version 1.1 of Hoffmann et al. (2015). ~~From every~~ C~~c~~ampaign specific confidence intervals (*p* = 0.01) were determined~~created by bootstrapping~~ for the temperature models, as well as for the R_{eco} and GPP parameter pairs by bootstrapping. ~~,~~Subsequently 100 samples were ~~randomly~~ taken randomly from the confidence intervals and used to compute R_{eco}, GPP, and NEE models. The random error of the CO$_2$ models calculated with the H-approach represents the model uncertainty ~~of~~at the days of the measur~~ing~~ement campaigns, but not of the interpolation. As indicated by the differences between ~~both~~the H and LS approaches the uncertainty of the annual balances is larger. To arrive at more realistic error estimates we accounted for the random error and for the difference between both approaches and defined the confidence intervals as the difference between the annual sums of both approaches plus two times the annual random error calculated for the H-approach.~~The calculated 90% confidence intervals of annual R_{eco}, GPP and NEE fluxes represent the uncertainty of the measuring campaigns, but not of the interpolation.~~

~~Uncertainties of annual emissions were estimated as 50% of the difference between annual sums of both approaches plus the annual random error calculated for APPROACH ONE~~.

~~Inter-annual variability of annual NEE fluxes was calculated as the absolute differences between annual plot emissions and two years plot mean. Small scale spatial variability~~

~~was calculated as the absolute differences between annual plot emissions and annual site emissions.~~

2.4.2 Methane and nitrous oxide

Calculation of ~~methane~~ fluxes

Methane fluxes were ~~calculated~~ estimated with the R package “flux 0.2–1” (Jurasinski et al., 2012) using linear regression. For normalized root mean square error (NRMSE) < 0.2 the flux with the largest number of concentration measurements was preferred. If NRMSE ≥ 0.2 a set of fluxes was estimated using the maximum number up to at least three concentration measurements. Subsequently the flux with the lowest NRMSE was selected.~~Outliers were eliminated for normalized root mean square error (NRMSE) ≥ 0.2, what was the case in 168 out of a total of 645 methane flux measurements from all campaigns~~. Fluxes were accepted if NRMSE < 0.4, R^2 ≥ 0.8 and n ≥ 3. This was the case in 639 out of 686 methane flux measurements, with 477 accepted fluxes based on $n \geq 4$.

Nitrous oxide flux rates and their standard deviations were calculated with linear regression using the same air samples as accepted for CH_4 flux calculation.

Modelling of ~~methane~~ emissions

Methane fluxes correlated with some environmental factors. This allowed to develop a ~~A~~ univariate nonlinear regression model for ~~calculation of~~ daily methane fluxes ~~was developed in two steps~~. The relatively small number of observations did not allow any multivariate approaches. First, the relation between environmental factors (air temperature, soil temperature, water level, air pressure, PAR, GPP, R_{eco}, NEE) and measured CH_4 fluxes was tested for each plot using non-parametric Spearman’s correlation to identify the strongest driving parameter. Second, several published~~a~~ nonlinear regression models (Eqs. 1, 4, 5) were fitted ~~was selected that best reflects~~to the relation between methane emissions and the driver and the optimal model was selected based on the AIC.

The strongest Spearman’s ρ correlations were found between methane fluxes and instantaneous on site soil temperature (median ρ for two years and all 18 plots = 0.85, n = 36), followed by half-hourly and daily R_{eco} (both 0.83), half-hourly GPP (−0.80; both modelled with ~~APPROACH ONE~~the H-approach), and on site air temperature (0.75).

Mean daily site specific soil temperatures, calculated by linear regression between site measurements and climate station data, also correlated well with methane fluxes (median ρ per plot and year = 0.85) and had a strong covariance with other factors. Water level did not correlate significantly with methane emissions at any plot, possibly because it was always close to or above the surface. Therefore mean daily soil temperature was chosen as the single driving factor for modelling methane emission.

The temperature dependency of methane production and emission was previously described by the Arrhenius function or its logarithmic form (Conrad et al., 1987; Schütz et al., 1990; Daulat and Clymo, 1998; Kim et al., 1998)

$$F = A \times e^{\frac{-E}{R \times T}} \quad (4)$$

F = flux rate of CH_4 (mg CH_4 −C m^{-2} h^{-1}), A = Arrhenius parameter (mg CH_4 −C m^{-2} h^{-1}), E = apparent activation energy (J mol^{-1}), R = gas constant (8.314 J mol^{-1} K^{-1}), T = soil temperature (K).

Also an exponential function or its logarithmic form has been widely applied to calculate methane emission in relation to temperature (Dise and Gorham, 1993; Saarnio et al., 1997; Kettunen et al., 2000; Tuittila et al., 2000; Laine et al., 2007; Rinne et al., 2007; Wilson et al., 2009):

$$F = a \times e^{b \times T} \quad (5)$$

F = flux rate of CH_4 (mg CH_4 −C m^{-2} h^{-1}), a = flux rate at T = 0 °C (mg CH_4 −C m^{-2} h^{-1}), b = coefficient (°C^{-1}), T = soil temperature (°C).

The third tested function ~~we tested~~ was the Lloyd and Taylor (1994) equation ~~developed by Lloyd and Taylor (1994)~~ for soil respiration (Eq. 1, Sect. 2.4.1).

We used the AIC to select from Eqs. (1), (4), and (5) the one that best fitted to our data set. The differences were small but the AIC of the Lloyd and Taylor ~~function~~ equation (Eq. 1) was the smallest for 33 out of 36 fits (fits for 2 years and 18 plots) and was therefore chosen to model methane emissions for all plots and years.

As N_2O fluxes did not correlate with recorded environmental factors annual emissions were estimated by linear interpolation ~~was used to calculate annual emission estimates~~between measurements.

Uncertainty, accuracy, and variability

Model performance was tested by leave-one-out cross-validation.

Errors of modelled annual methane emissions were calculated using Monte Carlo simulation in four steps. We included ~~First,~~ the uncertainty of the temperature transfer from the climate station to the site, the uncertainty of the measured flux rates, ~~the uncertainty of the RECO fits~~ and the parameter uncertainty of the Lloyd and Taylor ~~equation~~fits. ~~the linear regression between soil temperatures at site and climate station was performed~~Temperature uncertainty was quantified by 1000 times ~~with~~ repeated bootstrapped re-sampling of site and station ~~temperature~~ temperatures ~~data points~~with the same indices. Second, a set of 1000 normally distributed flux values was generated for every flux measurement based on the calculated CH_4 flux ~~estimate~~rates ~~mean~~ and ~~its~~their standard deviation. Third, each of the 1000 soil temperature data set was paired with one of the 1000 flux data sets and ~~the residuals of the resulting~~ 1000 Lloyd and Taylor fits (Eq. 1) were ~~bootstrapped 1000 times~~performed. Fourth, from each of the Lloyd and Taylor fits 1000 bootstrap parameter samples were created using bootstrap of the residuals (Efron, 1979; Leiber-Sauheitl et al., 2014). ~~Bootstrap sample size was again 1000.~~ More than 99% of the bootstrap fits were successful what resulted in more than 990000 parameter pairs per plot and year. Finally, 1000 Lloyd and Taylor fits were randomly sampled from the parameter pairs~~selected~~, ~~paired~~ combined with the 1000 soil temperature data set and used to calculate 1000 methane models per plot and year~~were calculated~~. For each time point and the annual sums 95% and 5% quantiles were calculated to construct confidence intervals of the time series and annual gas balances. As the CH_4 model fits ~~build on~~ ~~includes all data of a year~~include the temperature and methane flux uncertainties~~y~~ over the entire year, the 90% confidence intervals do~~es~~ to some extent also account for the interpolation between ~~measuring~~ measurement days.

~~Inter-annual and small scale spatial variability of annual methane emissions was calculated in the same way as of NEE (2.4.1).~~Uncertainties of annual N_2O fluxes were calculated solely based on estimates and standard deviations of the measured fluxes. 1000 normally distributed values of each flux were generated and linearly interpolated. This resulted in 1000 annual emission estimates per plot and year, but the calculated 90% confidence intervals represent only the uncertainties of the measured fluxes.

~~2.4.3 Nitrous oxide~~

~~Flux rates~~

~~Nitrous oxide flux rates and their standard deviations were calculated with linear regression using the same air samples as accepted for CH_4 flux calculation.~~

~~Annual emissions~~

~~Measured N_2O fluxes were linearly interpolated for annual emission estimates.~~

~~Uncertainty~~

~~Based on flux mean and standard deviation 1000 normally distributed values of each flux were generated and linearly interpolated. The 90% confidence intervals calculated from the resulting 1000 annual emission estimates represent the uncertainty of the measured fluxes.~~

2.5 Statistical analyses

Correlations between annual balances of CH_4 and CO_2 with site factors were tested using the non-parametric Spearman's ρ.
Differences of daytime methane fluxes among chamber types were analysed using either the Mann–Whitney test or the Kruskal–Wallis test with the post-hoc nonparametric Tukey-type multiple comparison procedure developed by Nemenyi (Zar, 1999).

3 Results

3.1 Site conditions

Most of the residual peat at both peatlands was very slightly to moderately decomposed radicel peat (Table 1). Surface peat was eutrophic and acid at both study sites, but less decomposed at Barcianicha as compared to Giel'cykaŭ Kašyl' (Table 1) .Barcianicha had ~~about 40 cm below surface~~ 27 to 76 cm thick layers of brown moss peat about 40 cm below surface, while for Giel'cykaŭ Kašyl' notable amounts of *Phragmites* macrofossils were found in the upper 100 to 140 cm of the profile.~~Surface peat was~~

~~eutrophic and acid at both study sites, but less decomposed at Barcianicha as compared to Giel’cykaŭ Kašyl’ (Table 1).~~

Vegetation was homogeneous within sites types at Barcianicha and ~~did~~varied ~~only slightly~~little ~~vary~~ between years (Table A1). ~~BA *Eriophorum–Carex* was dominated by *Eriophorum angustifolium*, BA *Carex–Equisetum* by *Carex rostrata* and BA *Phragmites–Carex* by *Phragmites australis*. Nutrient conditions as indicated by v~~Vegetation ~~were~~ indicated mesotrophic conditions at Barcianicha (Koska et al., 2001). At Giel’cykaŭ Kašyl’ ~~Differences in~~ species cover was homogeneous among plots and years ~~were also small~~ for GK *Phragmites–Lemna* ~~at Giel’cykaŭ Kašyl’~~ (Table A1). The floating sites GK *Carex–Lysimachia* and GK *Typha–Hydrocharis* constituted a strongly interweaved fine mosaic of sedge tussocks and cattail and shared many species. Vegetation indicated eutrophic conditions for Giel’cykaŭ Kašyl’ (Koska et al., 2001).

Mean annual temperature at Barcianicha ~~during the first measurement year~~ was 6.5 °C in the first and 6.9 °C in the second measurement year, ~~which corresponds~~close to the long term mean (6.4 °C, 1979–2008). ~~The second year was slightly warmer (6.9 °C).~~ Annual precipitation in the first year (740 mm)~~,~~ ~~due to heavy summer rains (Fig. 2a)~~ was higher ~~compared to~~than the long-term mean (~~740 vs.~~ 665 mm) due to heavy summer rains (Fig. 2a), ~~and~~but lower (633 mm) in the second~~ year lower (633 mm)~~.

Giel’cykaŭ Kašyl’ (Fig. 2b) was generally warmer and drier ~~as compared to~~than Barcianicha (long-term mean 7.3 °C and 594 mm, respectively, 1979–2008). Also here the first year was wetter (804 mm) and the second year drier (500 mm) ~~while~~and annual temperatures ~~of the first year agreed~~ were close to the long term mean ~~but were higher~~ (7.3 °C in the first year; ~~(~~7.9 °C~~)~~ in the second year).~~(15 August 2010–14 August 2011) was 6.5 °C which corresponds to the long term mean (6.4 °C, 1979–2008). The second year (15 August 2011–14 August 2012) was slightly warmer (6.9 °C). Annual precipitation in the first year was, due to heavy summer rains (Fig. 1a), higher compared to the long-term mean (740 vs. 665 mm), and in the second year lower (633 mm). Mean daily air temperatures were above 5 °C for 209 days and below 0 °C for 97 days during the first year, but only for 195 and 73 days, respectively, during the second year.~~

~~At Giel’cykaŭ Kašyl’ long-term mean annual temperatures were generally higher and precipitation lower (7.3 °C and 594, respectively, 1979–2008) compared to Barcianicha. The deviations of both years from the long-term mean, however, were in the same direction: the first year annual temperature was the same and precipitation larger (804 mm) as compared to the long-term mean, while the second year was warmer 15 (7.9 °C) and drier (500 mm). Heavy rains occurred in September and November 2010 and~~

~~August 2011, while September and October 2011 and July 2012 almost suffered from water deficits (Fig. 1b). The warm period (> 5 °C) at Giel'cykaŭ Kašyl' was longer in both years (222 and 210 days) as compared to Barcianicha and the frost period shorter (90 and 66 days)~~.

Annual water levels relative to the surface at Barcianicha ~~were highest~~decreased in the order~~ at~~ BA *Phragmites–Carex* (14 ± 2~~3 to 16~~ cm above surface), ~~slightly lower at~~ BA *Carex–Equisetum* and ~~just below surface at~~ BA *Eriophorum–Carex* (at surface; Table 1). Differences among plots within sites were small (Figs. 4c, 4d, and 4e). Annual values for both years were the same (Table 1). Summer and winter median water levels were very similar, despite ~~of~~ temporal fluctuations of up to 18 cm~~ (Fig. 3, Table 1)~~.

Water tables at GK *Phragmites–Lemna* (Giel'cykaˇu Kašyl') were about one metre ~~above surface~~ in the first year, and dropped to about 70~~by 30~~ cm above surface in the second year (Table 1). At the close by floating tall sedge – *Typha latifolia* reed sites ~~GK *Typha–Hydrocharis* and GK *Carex–Lysimachia*~~ water levels were only ~~up~~ about 10 ~~to 13~~ cm above the surface and the drop from the first to the second year was small, both because of the oscillating peat surface. Summer water levels were lower than winter levels, but never dropped significantly below surface (Table 1, Figs. 4n and 4o).

~~Differences of a~~Annual water levels varied more among plots ~~within sites at Giel'cykaŭ Kašyl' were larger as compared to~~than at Barcianicha, with a maximum of 11 cm at GK *Phragmites–Lemna* (Fig. 4p).

~~Most of the residual peat at both peatlands was very slightly to moderately decomposed radicel peat (Table 1). Barcianicha had about 40 cm below surface 27 to 76 cm thick layers of brown moss peat, while for Giel'cykaŭ Kašyl' notable amounts of *Phragmites* macrofossils were found in the upper 100 to 140 cm of the profile. Surface peat was eutrophic and acid at both study sites, but less decomposed at Barcianicha as compared to Giel'cykaŭ Kašyl' (Table 1).~~

~~Vegetation was homogeneous within sites types at Barcianicha and did only slightly vary between years (Table 2). BA *Eriophorum–Carex* was dominated by *Eriophorum angustifolium*, BA *Carex–Equisetum* by *Carex rostrata* and BA *Phragmites–Carex* by *Phragmites australis*. Nutrient conditions as indicated by vegetation were mesotrophic at Barcianicha (Koska et al., 2001).~~

~~Differences in species cover among plots and years were also small for GK *Phragmites–Lemna* at Giel'cykaŭ Kašyl' (Table 2). The sites GK *Carex–Lysimachia* and GK *Typha–Hydrocharis* constituted a strongly interweaved fine mosaic of sedge~~

~~tussocks and cattail and shared many species. Vegetation indicated eutrophic conditions for Giel’cykaŭ Kašyl’ (Koska et al., 2001).~~

Above ground biomass harvested in autumn 2012 at Barcianicha (Table 1) was largest for BA *Phragmites–Carex* (296 ± 79~~221–379~~ g C m^{-2}), lower for BA *Eriophorum–Carex* (117 ± 34~~97–156~~ g C m^{-2}) and smallest for BA *Carex–Equisetum* (55 ± 22~~31–73~~ g C m^{-2}). Biomass harvests of GK *Typha-Hydrocharis* and GK *Carex-Lysimachia* were similar to BA *Phragmites–Carex*, but that of GK *Phragmites–Lemna* were two times larger (586 ± 121~~502–725~~ g C m^{-2}, Table 1). ~~Higher~~ The doubled biomass production of *Phragmites australis* at Giel’cykaŭ Kašyl’ compared to Barcianicha ~~is another indicator of different nutrient status in both peatlands~~supports the nutrient rich conditions, probably resulting from different water supply (river and grassland drainage water for GK, groundwater for BA) and different land use history (after peat extraction temporary grassland before rewetting of GK, rewetting directly after peat extraction of BA).

3.2 Carbon dioxide emissions

Model performance tested for the H-approach was good for both years and all site types and plots. Cross-validation resulted in a median NSE of 0.78 (range from 0.38 to 0.90) for the R_{eco} models and of 0.76 (0.21 to 0.91) for the NEE models.“”

All sites of Barcianicha were net CO$_2$ sinks in the first year. NEE was −528 (90% confidence interval -933, -194) g CO$_2$−C m^{-2} yr^{-1} for BA *Phragmites–Carex*, -86 (-130, -38) g CO$_2$−C m^{-2} yr^{-1} for BA *Eriophorum–Carex* and −88 (-114, -68) g CO$_2$−C m^{-2} yr^{-1} for *Carex–Equisetum* (Fig. 5, Table 2). In the second year, resulting from increased R_{eco} and decreased GPP, the net CO$_2$ uptake decreased. NEE of BA *Phragmites–Carex* dropped to −329 (-431, -220) g CO$_2$−C m^{-2} yr^{-1}, BA *Eriophorum–Carex* became CO$_2$ neutral and BA *Carex–Equisetum* ~~lost some~~turned into a small source of 24 (-6, 55) g CO$_2$−C m^{-2} yr^{-1}.~~Within-site variation ranged from x to y% of annual NEE (Table 3).~~

Both, sinks and sources were larger at the Giel’cykaŭ Kašyl’ sites. NEE of GK *Phragmites–Lemna* was −611 (−819, −450) g CO$_2$−C m^{-2} yr^{-1} in the first and, despite of increasing R_{eco} fluxes, −1175 (−1567, −690) g CO$_2$−C m^{-2} yr^{-1} in the second year. The high values were attributed to extremely high annual GPP reaching ~~in the second year~~ −2267 (−2733, −1843) g CO$_2$−C m^{-2} yr^{-1} in the second year, equivalent to ~~and therefore~~ twice ~~of~~the R_{eco} fluxes (Fig. 5, Tab. 3). At the other Giel’cykaŭ Kašyl’ sites R_{eco} and GPP also increased from the first to the second year, but R_{eco} and GPP largely balanced each other~~differences between both fluxes were small~~. GK *Typha–Hydrocharis*

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consequently varied between a source of 151 (41, 300) g CO_2–C m^{-2} yr^{-1} in the first and a sink of −113 (−418, 66) g CO_2–C m^{-2} yr^{-1} in the second year. GK *Carex–Lysimachia* was a net CO_2 source in both years, releasing 166 (66, 252) g CO_2–C m^{-2} yr^{-1} in the first and 216 (48, 470) g CO_2–C m^{-2} yr^{-1} in the second year.

On average the net CO_2 sink at Barcianicha decreased in the second year by 130 g CO_2–C m^{-2} yr^{-1} or 56% but increased at Giel'cykaŭ Kašyl' by 259 g CO_2–C m^{-2} yr^{-1} or 263% compared to the first year.

Small scale spatial variability of annual NEE fluxes was largest for GK *Phragmites–Lemna* (187 ± 153 g CO_2-C m^{-2} yr^{-1}, mean ± standard deviation of the absolute differences between annual plot emissions and annual site emissions, *n*=6; Table 3; Fig. 5). Absolute within site spatial variability of NEE exchange rates was lower for BA *Phragmites–Carex*, GK *Carex–Lysimachia* and GK *Typha–Hydrocharis* and small for BA *Eriophorum–Carex* and BA *Carex–Equisetum* (16 ± 13 and 9 ± 5 g CO_2-C m^{-2} yr^{-1}; Table 3, Fig. 5). The order of sites changes, when within site variability of NEE is related to annual site NEE fluxes. Relative variability was the same for BA *Carex–Equisetum* and GK *Phragmites–Lemna* (19 ± 12% and 20 ± 11%, respectively, Table 3). This is related to the importance of the annual flux magnitude as illustrated by BA *Eriophorum–Carex* in the second year that resulted from an annual site NEE of -7 g CO_2-C m^{-2} yr^{-1} and an absolute within site spatial variability of 11 g CO_2-C m^{-2} yr^{-1} in a relative variability of 152%.

~~Model performance tested for APPROACH ONE was good for both years and all site types and plots. Cross-validation resulted in a median NSE of 0.78 (range from 0.38 to 0.90) for the R_{eco} models and of 0.76 (0.21 to 0.91) for the NEE models.~~

~~Annual R_{eco} fluxes varied significantly among the sites studied at Barcianicha. Sitewise averaged R_{eco} for the first and second year were 614 and 706 g CO_2–C m^{-2} yr^{-1} from BA *Phragmites–Carex*, 364 and 406 g CO_2–C m^{-2} yr^{-1} from BA *Eriophorum–Carex*, 232 and 327 g CO_2–C m^{-2} yr^{-1} from BA *Carex–Equisetum* (Table 3). At Barcianicha R_{eco} increased from the first to the second year for all sites, but most significantly for BA *Carex–Equisetum* as indicated by lacking overlap of confidence intervals between years. Within site variability was small for BA *Eriophorum–Carex* and BA *Carex–Equisetum*, and more pronounced for BA *Phragmites–Carex* (Fig. 5, Table S2 in the Supplement). Also the timelines were nearly identical among plots of BA *Eriophorum–Carex* and BA *Carex–Equisetum* while daily R_{eco} emissions from BA *Phragmites–Carex* during the summers were lower from plot one than from the other plots (Fig. 3). With respect to annual GPP fluxes the sites of Barcianicha followed the same order as for~~

~~R_{eco}, but the annual GPP sink was smaller in the second as compared to the first year (Table 3). GPP fluxes from BA *Phragmites–Carex* were −1141 and −1035 g CO_2–C m^{-2} yr^{-1} in the first and second year, respectively, but only −449 and −413 g CO_2–C m^{-2} yr^{-1} from BA *Eriophorum–Carex*, and −320 and −302 g CO_2–C m^{-2} yr^{-1} from BA *Carex–Equisetum*. Daily and annual variability of GPP among plots within sites was more pronounced than of *R*eco (Figs. 3 and 5). All site of Barcianicha were net CO_2 sinks in the first year (Fig. 5). NEE fluxes from BA *Phragmites–Carex* were −528 g CO_2–C m^{-2} yr^{-1} and lower from BA *Eriophorum–Carex* and BA *Carex–Equisetum* (−86 and −88 g CO_2–C m^{-2} yr^{-1}, respectively; Table 3). In the second year, resulting from increased R_{eco} and decreased GPP, NEE was lower from BA *Phragmites–Carex* (−329 g CO_2–C m^{-2} yr^{-1}) and BA *Eriophorum–Carex* (−7 g CO_2–C m^{-2} yr^{-1}) and BA *Carex–Equisetum* became a small net CO_2 source (24 g CO_2–C m^{-2} yr^{-1}; Table 3). Inter-annual variability of NEE fluxes was 110±113 g CO_2–C m^{-2} yr^{-1} for BA *Phragmites–Carex*, 39±12 g CO_2–C m^{-2} yr^{-1} for BA *Eriophorum–Carex* and 56±8 g CO_2–C m^{-2} yr^{-1} for BA *Carex–Equisetum* (Table 4, Fig. 5). Small scale variability of NEE was similar to inter-annual variability for BA *Phragmites–Carex* (125±140 g CO_2–C m^{-2} yr^{-1}) but smaller for BA *Eriophorum–Carex* and BA *Carex–Equisetum* (16±13 and 9±5 g CO_2–C m^{-2} yr^{-1}, respectively).~~

~~Annual R_{eco} fluxes from Giel'cykaŭ Kašyl' sites were higher than from Barcianicha. They were largest in both years from GK *Carex–Lysimachia* (1105 and 1270 g CO_2–C m^{-2} yr^{-1}), followed by GK *Phragmites–Lemna* (936 and 1092 g CO_2–C m^{-2} yr^{-1}) 15 and GK *Typha–Hydrocharis* (921 and 973 g CO_2–C m^{-2} yr^{-1}; Table 3). Differences between sites were less clear than in Barcianicha and confidence intervals of GK *Phragmites–Lemna* overlapped with both other sites. Annual R_{eco} fluxes from GK *Carex–Lysimachia* significantly increased from the first to the second year. The increase was similarly strong though not significant for GK *Phragmites–Lemna* but small for GK *Typha–Hydrocharis*. There was considerable variability of daily and annual R_{eco} emissions among plots within all sites of Giel'cykaŭ Kašyl' (Figs. 4 and 5, Table S2 in the Supplement). Annual GPP fluxes at Giel'cykaŭ Kašyl' were generally higher than at Barcianicha but the order of sites with respect to GPP fluxes did not follow that of R_{eco} (Table 3). GK *Phragmites–Lemna* had with −1547 g CO_2–C m^{-2} yr^{-1} in the first and −2267 g CO_2–C m^{-2} yr^{-1} in the second year the largest annual GPP rates. GPP fluxes of GK *Carex–Lysimachia* and GK *Typha–Hydrocharis* were lower, but also increased from the first to the second year (from −940 to −1054 and from −771 to −1086 g CO_2–C m^{-2} yr^{-1} for GK *Carex–Lysimachia* and GK *Typha–Hydrocharis*, respectively). As for~~

~~Barcianicha, daily and annual within sites variability of GPP was stronger than of R_{eco} (Figs. 4 and 5). The largest net CO_2 sink among all studied sites was GK *Phragmites–Lemna* (Table 3). NEE of this site was −611 g CO_2–C m^{-2} yr^{-1} in the first and −1175 g CO_2–C m^{-2} yr^{-1} in the second year. GK *Typha–Hydrocharis* varied between net source of 151 g CO_2–C m^{-2} yr^{-1} in the first year and sink of −113 g CO_2–C m^{-2} yr^{-1} in the second year. GK *Carex–Lysimachia* was a net CO_2 emitter in both years (166 and 216 g CO_2–C m^{-2} yr^{-1}). NEE varied considerably between the three plots of each site at Giel'cykaŭ Kašyl' (Fig. 5, Table S2) and confidence intervals on the site level were accordingly wide (Table 3). Small scale spatial NEE variability of GK *Phragmites–Lemna* was 187±153 g CO_2–C m^{-2} yr^{-1} (Table 4). It was also high for GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* (121±66 and 95±73 g CO_2–C m^{-2} yr^{-1}), despite of much smaller NEE. Inter-annual NEE variability of GK *Phragmites–Lemna* was higher than spatial variability (282±177 g CO_2–C m^{-2} yr^{-1}). It was similar to spatial NEE variability for GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* (132±64 and 74±56 g CO_2–C m^{-2} yr^{-1}).~~

3.3 Methane emissions

3.3.1 Diurnal variability of methane emissions and impact of chamber types

Opaque and transparent chambers slightly differe~~ntly~~d ~~affected~~in the development of air temperature and relative humidity of the headspace during the measurements. Despite ~~of~~ cooling temperature ~~increased stronger~~rose more in transparent (up to 3 ± 0.5 °C, mean ± standard error; Table A2) ~~as compared to~~than in opaque chambers (up to 1.4 ± 0.2 °C). ~~R~~Due to cooling, however, relative humidity ~~, in contrast,~~ increased less in transparent (up to 18.1 ± 3.7%) than in opaque chambers (up to 14.8 ± 2.3%)~~,~~. ~~but only at few measurement days the d~~Differences were significant at few measurement days only (Table A2).~~Environmental conditions (inside air temperature and relative humidity, outside PAR) during the measurement campaigns of the diurnal methane patterns were comparable among chamber types, with the exception of BA *Carex–Equisetum* III where relative air humidity (RH) was significantly higher in opaque chambers with fan (DF) than in transparent with fan (TF) (Table S1 in the Supplement)~~.

~~A p~~Pronounced diurnal methane emission dynamics ~~was~~ were observed for BA *Phragmites–Carex* and GK *Phragmites–Lemna*, much stronger than for any other site (Fig. ~~2~~3). Significantly different methane emissions between opaque and transparent chambers, however, were only found for GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* (Table ~~S~~A2~~1 in the Supplement~~). Measurements with transparent~~TF~~ chambers resulted here in ~~1.2 and 1.1 times~~20% and 10% higher emission estimates ~~as compared to~~than with opaque chambers with fan~~DF~~. Also for BA *Eriophorum–Carex* I measurements with transparent chambers~~TF~~ ~~gave higher results~~produced 9% higher flux rates than opaque chambers~~fanDF (factor 1.09)~~, but the difference was not significant (Fig. ~~2~~3, Table A2). ~~For~~ At all other sites the ~~ratio~~ flux rates measured with~~of~~ transparent ~~to~~and opaque chambers with fan ~~ranged between 0.98 and 1.02TF/DF was~~agreed within 2%.~~ equal one. Methane emissions measured by opaque chambers without head space mixing~~fan ~~(D) were slightly but not significantly below that of~~ opaque ~~DF chambers with fan (Table AS12 in the Supplement).~~ The chamber intercomparison suggests a potential reduction of convective gas transport in *Typha latifolia* by shading with the regularly applied opaque chambers without fan.

~~The findings of the chamber intercomparison were used to correct~~Consequently, the measured growing season fluxes from GK *Typha–Hydrocharis* and GK *Carex–Lysimachia*. ~~which~~ were corrected upwards by 20% as *Typha latifolia* was present at all plots except for GK *Carex-Lysimachia* I~~x~~ in 2012 where the diurnal chamber intercomparison took ~~were multiplied by the transparent to opaque chamber with~~ fan~~TF/DF ratio of 1.2 to account for potential reduction of convective gas transport in *Typha latifolia* by shading with the regularly applied opaque chambers without fan. The factor 1.2 was applied for GK *Carex–Lysimachia* instead of 1.1, because *Typha latifolia* was present in all plots of that site, with the exception of plot I in 2012, where the diurnal chamber intercomparison took~~ place (Table A2~~2~~). Fluxes from the other sites were not corrected because chamber effects were not significant.

3.3.2 Annual methane emissions

The Lloyd–Taylor methane models performed well for all sites except for the second year of BA *Phragmites–Carex* and GK *Phragmites–Lemna*. NSE for all but the *Phragmites australis* sites ranged between 0.38 and 0.85 (median 0.58). Models of the *Phragmites australis* sites were acceptable in the first year (median NSE 0.37, range 0.05 to 0.82) but performed ~~poor~~worse in the second year (median 0.01, range -0.25 to 0.24) where models did not adequately capture the seasonal course of methane emissions at three out of nine *Phragmites* plots. Models of GK *Phragmites–Lemna* III and BA *Phragmites–Carex* III did not explain the high emissions in August 2011 (Figs.

4h and 4s). Both and the model of BA *Phragmites–Lemna* I overestimated emissions in spring and early summer 2012. Annual emissions were calculated alternatively by linear interpolation for the second year of BA *Phragmites–Lemna* I and III and GK *Phragmites–Lemna* III~~by linear interpolation~~. The resulting flux rates of ~~-~~25, 28, and 118 g CH_4–C m^{-2} yr^{-1}~~, compared to 30, 32, and 139 g CH_4–C m^{-2} yr^{-1}~~ lie within the 90% confidence intervals of ~~derived by the~~ the temperature driven Lloyd–Taylor methane model~~, and lie within the 90% confidence intervals of the latter~~ (30, 32, and 139 g CH_4–C m^{-2} yr^{-1}; Table A3). The Lloyd–Taylor models were therefore accepted despite of negative NSE.

GK *Phragmites–Lemna* had the highest methane emissions of all sites, estimated to 100 (90% confidence interval 48, 147) and 101 (61, 177) g CH_4–C m^{-2} yr^{-1} in the first and second year, respectively (Table 2). GK *Carex–Lysimachia* released less methane. ~~and~~ GK *Typha–Hydrocharis* was ~~with 60 (47, 77) and 68 (52, 92) g CH_4–C m^{-2} yr^{-1}~~ the smallest source among the studied sites at Giel'cykaŭ Kašyl' with 60 (47, 77) and 68 (52, 92) g CH_4–C m^{-2} yr^{-1}, but still larger than the Barcianicha sites.

BA *Phragmites–Carex* emitted 42 (28, 58) in the first and 36 (22, 52) g CH_4–C m^{-2} yr^{-1} in the second year. BA *Carex–Equisetum* was a much smaller methane source, but the absolute lowest annual methane emissions were ~~estimated for~~found at BA *Eriophorum–Carex* being 10 (9, 13) in the first and 11 (10, 14) g CH_4–C m^{-2} yr^{-1} in the second year (Table 2).

Methane emissions of all sites hardly differed between years (Table 2). They decreased in the second year at Barcianicha by on average 3 g CH_4–C m^{-2} yr^{-1} or 14% but increased at Giel'cykaŭ Kašyl' by 4 g CH_4–C m^{-2} yr^{-1} or 5% compared to the first year.

Absolute and relative small scale variability of methane emissions tended to increase with annual methane emission height (Fig. 5, Table 3).

~~The Lloyd–Taylor models generally reflected the temperature control of methane fluxes, were robust towards single events of extremely high or low fluxes, and allowed for comprehensive error calculation. Model performance was better in the first (median NSE= 0.55, range from 0.05 to 0.85) than in the second year (median NSE= 0.42, −0.25 to 0.76). Best first year models (NSE= 0.77 to 0.85) were that of GK *Carex–Lysimachia* I, *Phragmites–Lemna* I, and of all plots of BA *Carex–Equisetum*. Best models of the second year (NSE= 0.58 to 0.76) were of BA *Carex–Equisetum* III, GK *Carex–Lysimachia* II, and of all plots of BA *Eriophorum–Carex*. Low NSE values were found for most models of BA *Phragmites–Carex* and GK *Phragmites–Lemna*. Negative NSEs indicated poor performance of the second year methane models of BA *Phragmites–*~~

~~*Carex* I and III, and GK *Phragmites–Lemna* III. The second year model of GK *Phragmites–Lemna* III and BA *Phragmites–Carex* III did not explain the very high emissions in August 2011 (Figs. 3h and 4h). Both, and the second year model of BA *Phragmites–Lemna* I, overestimated emissions in spring and early summer 2012. Annual emissions calculated alternatively for the mentioned plots and second year by linear interpolation were 25, 28, and 118 g CH_4–C m^{-2} yr^{-1}, compared to 30, 32, and 139 g CH_4–C m^{-2} yr^{-1} derived by the temperature driven Lloyd–Taylor methane model, and lie within the 90% confidence intervals of the latter (Table S2 in the Supplement). The Lloyd–Taylor models were therefore accepted for the described plots despite of negative NSE.~~

~~Annual methane emissions at Barcianicha from BA *Phragmites–Carex* were for the first and second year 42 and 36 g CH_4–C m^{-2} yr^{-1} (Table 3). Emissions were lower from BA *Carex-Equisetum* (17 and 13 g CH_4–C m^{-2} yr^{-1}) and BA *Eriophorum–Carex* (10 and 11 g CH_4–C m^{-2} yr^{-1}). Wide confidence intervals on the plot level and considerable small scale variability of methane emissions from BA *Phragmites–Carex* resulted in large uncertainties on the site level (Fig. 5, Table 3). Small scale spatial methane emission variability of BA *Phragmites–Carex* was 6.4±2.7 g CH_4–C m^{-2} yr^{-1} (Table 4). For BA *Carex–Equisetum* it was 1.4±0.7 g CH_4–C m^{-2} yr^{-1} and for BA *Eriophorum–Carex* only 0.5±0.2 g CH_4–C m^{-2} yr^{-1}. Inter-annual variability of methane emissions from BA *Phragmites–Carex* was 3.0±3.6 g CH_4–C m^{-2} yr^{-1}, from BA *Carex–Equisetum* 2.3±0.5 g CH_4–C m^{-2} yr^{-1}, and from BA *Eriophorum–Carex* 0.5±0.0 g CH_4–C m^{-2} yr^{-1} (Table 4). Maximum methane emissions at Barcianicha occurred from June to August at BA *Eriophorum–Carex* and BA *Carex–Equisetum* but at BA *Phragmites–Carex* only in July and August (Fig. 3). Local emission peaks were measured at BA *Phragmites–Carex* end of April–begin of May.~~

~~Methane emissions from Giel’cykaŭ Kašyl’ were higher than from Barcianicha. GK *Phragmites–Lemna* had in both years the highest methane emissions of all sites (100 and 101 g CH_4–C m^{-2} yr^{-1} in the first and second year, respectively). Emissions from GK *Carex–Lysimachia* were 86 and 85 g CH_4–C m^{-2} yr^{-1}, and from GK *Typha–Hydrocharis* 60 and 68 g CH_4–C m^{-2} yr^{-1} (Table 3). Largest methane emissions from all Giel’cykaŭ Kašyl’ sites occurred during the summer months (Fig. 4). Summer emissions from GK *Phragmites–Lemna* were much higher in 2011 as compared to 2010 and 2012. Methane emission from Giel’cykaŭ Kašyl’ sites considerably varied among plots and between years (Fig. 5, Table 4). Inter-annual variability of methane emissions was 11.6±2.8 g CH_4–C m^{-2} yr^{-1} for GK *Phragmites–Lemna*, 4.2±2.9 g CH_4–C m^{-2} yr^{-1}~~

~~for GK *Typha–Hydrocharis*, and 1.2±0.9 g CH_4–C m^{-2} yr^{-1} for GK *Carex–Lysimachia*. Small scale variability was higher for GK *Phragmites–Lemna* and GK *Carex–Lysimachia* (24.2±10.0 and 10.9±8.3 g CH_4–C m^{-2} yr^{-1}, respectively), but for GK *Typha–Hydrocharis* similar to inter-annual variability (3.2±3.2 g CH_4–C m^{-2} yr^{-1}). Large spatial variability is also reflected by the confidence intervals on the site level, which are wider for GK *Carex–Lysimachia* and GK *Phragmites–Lemna* as compared to GK *Typha–Hydrocharis* (Table 3).~~

3.4 Nitrous oxide emissions

Emissions of N_2O from all plots were around zero (Fig. 5e and f). Maximum plot emissions were around 0.5 g N_2O−N m^{-2} yr^{-1}, but were usually compensated for by similar large uptakes in a neighbour plot or the other year. The overlap of the 90% confidence of all sites, plots and years indicates that N_2O emissions were not significantly different among them.

3.5 Correlations between annual GHG emissions and site parameters

GHG emissions were only weakly related to surface ~~P~~peat characteristics. Spearman's *ρ* of the ~~were similar among all plots (Table 1) and there was only a weak correlation~~ correlation between annual methane emissions and C/N ratio was −0.50* and ~~, as well as~~ between annual net CO_2 exchange and pH ~~(Spearman's *ρ* = −0.50* and~~ 0.40' (~~, respectively,~~ ' $P \leq 0.05$; * $P \leq 0.01$, $n = 36$; i.e. correlation of peat characteristics of 18 plots ~~were correlated~~ with annual fluxes of these plots of two GHG measuring years). Median annual water level was not correlated with R_{eco}, but with NEE and CH_4 emissions and most~~very~~ strongly with GPP~~, and weaker with NEE and CH_4 emissions~~ (Fig. 6). Correlations of water levels with R_{eco}, GPP, NEE and CH_4, were highly significant when the floating sites GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* were excluded from the analysis (Fig. 6, *ρ* in brackets). Correlations of water level with NEE and CH_4 ~~and~~ were also strong for Barcianicha alone (*ρ* = −0.60**, 0.85***, respectively, ** $P \leq 0.001$; *** $P \leq 0.0001$, $n = 18$).

Total above ground biomass carbon harvested after the second measuring year strongly correlated with the second year annual balances of CH_4, R_{eco} and GPP, but not with NEE (Fig. 6). Without the floating tall sedge – *Typha latifolia* sites ~~GK *Typha–Hydrocharis* and GK *Carex–Lysimachia*~~ correlations between biomass and balances of

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R_{eco} and GPP were stronger and the correlation between biomass and NEE became highly significant. When only Barcianicha was analysed, correlation between biomass and methane emissions where not significant, but correlations between biomass and R_{eco}, GPP, and NEE were strong ($\rho = 0.98^{***}$, -0.98^{***}, -0.95^{**}, respectively, $n = 9$). Annual CH_4 emissions did not correlate with annual NEE, but strongly with R_{eco} and GPP (Fig. 6). Excluding GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* resulted in highly significant correlation between methane and NEE (Fig. 6, $\rho = -0.83$, $P < 0.0001$, $n = 30$). For Barcianicha alone correlation between NEE and CH_4 emissions was also significant ($\rho = -0.67$, $P = 0.0028$, $n = 18$).

As expected, within-site variation of R_{eco} and absolute GPP generally scaled with biomass. (Fig. 6). Methane emissions increased among plots of BA *Phragmites–Carex* with increasing absolute GPP and R_{eco} and all three fluxes were positively correlated ~~to~~ with above ground biomass. A positive correlation between biomass and methane also occurred ~~on the small scale also~~ for GK *Carex–Lysimachia*, while at GK *Phragmites–Lemna* methane emissions tended to decrease with increasing net CO_2 uptake (Fig. 6).

3.6 Carbon and GHG-balances of sites

Both *Phragmites* sites were surprisingly strong carbon sinks (Table 2) but also methane sources and had only low net GHG emissions with an overall mean of 1.3 t CO_2 eq ha^{-1} yr. The two years average GHG balances of the shallowly flooded, mesotrophic site BA *Phragmites–Carex* and the deeply inundated, eutrophic site GK *Phragmites–Lemna* were −1.7 (90% confidence interval -15.0, 10.2) and 4.2 (-26.8, 37.7) t CO_2 eq ha^{-1} yr^{-1}, respectively. The mesotrophic small sedge reeds BA *Eriophorum–Carex* and BA *Carex–Equisetum* with water tables around the land surface were weak carbon sinks and methane sources (Table 2). Both sites were small net GHG emitters of 2.3 (-1.0, 5.6) and 4.2 (2.1, 6.8) t CO_2 eq ha^{-1} yr^{-1}, respectively. The eutrophic, floating tall sedge – *Typha latifolia* reeds were, despite of shallow relative water depths, strong methane sources and in most years also net CO_2 emitters. GK *Typha–Hydrocharis* was a substantial GHG source of 25.1 (9.5, 37.9) t CO_2 eq ha^{-1} yr^{-1} and GK *Carex–Lysimachia* even emitted 39.1 (26.6, 58.0) t CO_2 eq ha^{-1} yr^{-1}.

~~without *Phragmites* were relative weak sinks or sources of carbon while the *Phragmites* sites were surprisingly strong carbon sinks. GK *Phragmites–Lemna* and BA *Phragmites–Carex* were strong, and BA *Eriophorum–Carex* and BA *Carex–Equisetum* weak carbon~~

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~~sinks, while GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* released high amounts of carbon (Table 3).~~

~~Net uptake of carbon dioxideCO_2 and emissions of methane by Barcianicha sites nearly compensated each other with respect to their global warming potential for a time horizon of 100 years (Myhre et al., 2013; Table 5). In both years the Barcianicha sites were very small GHG sources and in the first year BA *Phragmites–Carex* a small GHG sink, but the uncertainties of the GHG balances of the latter site were large. The Giel'cykaŭ Kašyl' Compensation for the warming effect of high sites were generally net GHG emitters as methane emissions exceeded the net CO_2 sink except for was achieved at Giel'cykaŭ Kašyl' only in the second year by GK *Phragmites–Lemna* in the second year thanks with anto extremely high NEE. The site was a moderate GHG source in the first year when methane emissions were similar to the second year but NEE two times smaller. GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* were strong methane sources, too. At the same time they were mostly small CO_2 sources, and as a result, significant GHG emitters. However, confidence intervals of GHG emissions from the Giel'cykaŭ Kašyl' sites were very large.~~ The role of N_2O exchange was negligible for the GHG-balances of all sites.

~~BA *Phragmites–Carex* and GK *Phragmites–Lemna* were strong carbon sinks (Table 2) but also methane sources and and had only low GHG emissions of on average −1.7 (90% confidence interval -15.0, 10.2) and 4.2 (-26.8, 37.7) t CO_2 eq ha^{-1} yr^{-1}, respectively. However, because of large differences among plots and between years the uncertainties were higher as compared to the not inundated site BA *Eriophorum–Carex* and the very shallowly (8±1 cm) flooded BA *Carex–Equisetum* (2.3 (-1.0, 5.6) and 4.2 (2.1, 6.8) t CO_2 eq ha^{-1} yr^{-1}, respectively). GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* were, despite of similar shallow water depths, strong methane and CO_2 sources (Tables 2, 4). Average GHG emissions from GK *Typha–Hydrocharis* were 25.1 (9.5, 37.9) t CO_2 eq ha^{-1} yr^{-1} and from GK *Carex–Lysimachia* even 39.1 (26.6, 58.0) t CO_2 eq ha^{-1} yr^{-1}.~~

~~In summary, the mesotrophic tall sedge/Eriophorum reeds with water table around the land surface were small net GHG emittors in the range of 0 to 5 t CO2 eq ha-1 yr. The eutrophic tall sedge/Typha reeds on newly formed floating mats were substantial net GHG emittors in the range of 22 to 40 t CO2 eq ha-1 yr. *Phragmites* reeds ranged between -5 to 14 t CO2 eq ha-1 yr with an overall mean GHG emission of 1 t CO_2 eq ha^{-1} yr.~~

4 Discussion

~~4.1 Robustness of annual GHG balances~~

~~4.1.1 Methane~~

~~The pronounced diurnal methane emission dynamics from BA *Phragmites–Carex* and GK *Phragmites–Lemna* with fivefold flux increases from morning to midday result from active air transport in *Phragmites australis* aerenchyma in the growing season related to sun light (Armstrong and Armstrong, 1991; Brix et al., 1992; Armstrong et al., 1996). In contrast to other studies (Van der Nat and Middelburg, 2000; Günther et al., 2013) we did not find a significant impact of chamber transparency on measured methane emission rates, maybe because enclosed plants were connected by rhizomes with culms outside the chamber. Such connection is supposed to allow for pressure propagation and continuation of unrestrained convective gas flow (Juutinen et al., 2004; Minke et al., 2014). Consequently the application of opaque chambers has not biased annual emission estimates from the *Phragmites australis* sites. But frequency of measurements and the selected annual model based on daily soil temperature as driver did not account for diurnal flux variability. Day-to-day variability and seasonal variation of average daily emissions from *Phragmites australis* stands are strongly controlled by sediment temperature (Kim et al., 1998; Kankaala et al., 2004), which supports our decision to use soil temperature for modelling methane emission. However, a single measurement at any time during daylight does not represent the daily emission average and would for the monitored days (Fig. 2) mostly have resulted in equal or higher estimates as compared to the 24 hour mean (daily average calculated from transparent chamber measurements were 6.75 mg CH_4–Cm^{-2} h^{-1} from BA *Phragmites–Carex* II, and 9.54 mg CH_4–Cm^{-2} h^{-1} from GK *Phragmites–Lemna* II). So, possibly the high emission events in summer 2011 not explained by the models of BA *Phragmites–Carex* III and GK *Phragmites–Lemna* III were daily maxima and the models were still at or just below the daily averages. Fluxes in spring and early summer 2012 were most likely overestimated by the models of BA *Phragmites–Carex* I and III, because they were measured predominantly at midday and early afternoon of clear or only partly clouded days and can therefore be expected to exceed the daily average. The same holds for~~

~~summer fluxes in 2012 at GK *Phragmites–Lemna* III. In summary, our approach tended to overestimate the real emissions at the *Phragmites australis* sites.~~

~~The less pronounced diurnal methane emission dynamics of GK *Typha–Hydrocharis* with only a short term peak in the mid-morning (first day) and the reduction of emissions when chambers were shaded agree with other studies of *Typha latifolia* (Chanton et al., 1993; Whiting and Chanton, 1996). Similar to *Phragmites australis*, green parts of *Typha latifolia* pressurize during daylight which drives convective gas transport and accelerates methane efflux (Brix et al., 1992; Whiting and Chanton, 1996). Although no transient emission peak was observed at the second day, the ratio of transparent/opaque chamber was the same for both days (Table S1). Other researchers calculated similar transparent/opaque ratios for *Typha latifolia* (1.1 – Whiting and Chanton, 1996; 1.3 – Günther et al., 2013). However, we do not know the variability of the ratio under different weather conditions. Therefore we used the correction factor 1.2 for total daily methane emissions during the growing season, despite the irrelevance of chamber transparency at night time. Calculated annual emissions will consequently be at the high end of real emissions from the site.~~

~~*Typha latifolia* did not grow on the diurnal monitored plot I of GK *Carex–Lysimachia* in summer 2012. Instead *Carex elata* dominated. Gas transport in sedges is driven only by diffusion (Armstrong, 1979; King et al., 1998). Existing studies led to different outcomes regarding the effect of shading by chambers. Shading reduced methane emissions from *Carex aquatilis* (Morrissey et al., 1993) and *Carex allivescers* (Hirota et al., 2004), but not from *Carex limosa* and *C. rostrata* (Whiting and Chanton, 1992) and *C. acutiformis* (Günther et al., 2013). We do not know the reason for the small but significant shading impact on methane fluxes from plot I of GK *Carex–Lysimachia*. However, *Typha latifolia* was, except for this plot in summer 2012, always present at all plots of GK *Carex–Lysimachia* (Table 2). Correction of daily fluxes from GK *Carex–Lysimachia* using the factor 1.2 from GK *Typha–Hydrocharis* accounted for this. Again, the calculated annual CH_4 emissions will represent the high end of real emissions from the site.~~

~~The lack of any shading impact on methane emissions from BA *Eriophorum–Carex* and BA *Carex–Equisetum* corresponds to the findings of Joabsson et al. (1999) and Whiting and Chanton (1992) for *Eriophorum angustifolium* and *Carex rostrata*.~~

~~**4.1.2 Carbon dioxide**~~

~~The two approaches used to model CO_2 exchange rates resulted in very similar annual balances. Plot-wise annual R_{eco} calculated with APPROACH ONE was on average 5% 25 (±5%, *n* = 36) below APPROACH TWO, while the GPP sink was higher by 1% (±3%, *n* = 36). Resulting annual net CO_2 uptake was consequently on average stronger for APPROACH ONE than for APPROACH TWO. The mean difference of NEE between both approaches was 43±41 g CO_2–C m^{-2} yr^{-1} (*n* = 36), but 77±40 g CO_2–C m^{-2} yr^{-1}, when calculated only for *Phragmites australis* plots (*n* = 12). This indicates that measured fluxes and general modelling assumptions, i.e. the temperature relation of R_{eco} and PAR relation of GPP were robust towards differences in flux calculation and model parameterization. Also the good results of the cross validations of the models of APPROACH ONE at all sites indicate a high reliability of the results.~~

~~The net annual CO_2 sink of the *Phragmites australis* sites was large, especially at GK *Phragmites–Lemna*. The first year NEE of this site equalled the estimate of Brix et al. (2001; Table 7) but the second year uptake was two times higher. To test for plausibility we roughly estimated the carbon flux partitioning in the ecosystem from independent data. We estimated the net primary production (NPP) based on measured green above ground biomass and published ratios between above ground and below ground biomass production (Table 6). Using NPP, NEE, and GPP we calculated heterotrophic and autotrophic respiration (R_h and R_a, Table 6) and evaluated their meaningfulness. As expected because of inundation, heterotrophic respiration was low, ranging between 77 and 114 g CO_2–C m^{-2} yr^{-1}. The ratio of heterotrophic respiration to methane emissions (CO_2-C / CH_4-C) was for BA *Phragmites–Carex* 2.2 and 2.3 and for GK *Phragmites–Lemna* 1.0 and 1.1, what is similar to ratios found in incubation experiments for the upper peat layer (1.6) and organic bottom sediments (0.7) of a flooded former fen grassland (Hahn-Schöfl et al., 2011). Calculated autotrophic respiration was half of GPP, but differed considerably between years (43 to 61%). This may result to a large extent from the uncertainty of the estimates (especially of NPP), as the efficiency of converting GPP to NPP is generally assumed to be relatively constant (cf. Chapin et al., 2002). In summary, our very rough estimation resulted for the *Phragmites australis* sites in reasonable annual rates of heterotrophic respiration and shares between NPP and Ra.~~

4.1~~2~~ Annual CO_2 and methane balances ~~of similar sites~~

Contrary to our hypothesis (i) only three sites were stable net CO_2 sinks, two sites switched between sink and source and one site was a net CO_2 source in both years. Surprisingly, both eutrophic tall sedge -~~/~~ *Typha latifolia* reeds on newly formed floating mats were net CO_2 sources over the two year period although the mats suggest a net carbon accumulation since rewetting.

For all site years with a net CO_2 sink we can argue in line with hypothesis (i) that peat loss by oxidation has stopped after rewetting. We suggest that also in site years with a net CO_2 source the CO_2 loss originated from decaying plant material rather than from peat. All source sites were fully water-saturated throughout the year and had substantial methane emissions, indicating fully anaerobic conditions. We suggest that the CO_2 originated from accumulated plant litter or from high stress related plant respiration as the sites where CO_2 sources occurred were characterized by transitional vegetation stages (see below).

The CO_2 and methane balances of the mesotrophic small sedge reeds at Barcianicha ~~this study generally~~ agree with the literature ~~for the mesotrophic tall sedge/*Eriophorum* reeds~~. ~~The e~~Eutrophic tall sedge - ~~/~~*Typha latofilia* reeds on newly formed floating mats have not been studied before but results generally agree with literature from eutrophic mineral reed ecosystems. The *Phragmites* reeds also agree with literature with regard to the methane emissions, but have an exceptionally strong CO_2 sink. In the following details are discussed for the three site groups.

Annual methane emissions from BA *Eriophorum–Carex* and BA *Carex–Equisetum* were ~~higher and NEE was lower as compared to a shallowly inundated cutover Atlantic blanket bog colonized by *Eriophorum angustifolium* (CH_4 = 5.3 g CH_4–C m^{-2} yr^{-1}, NEE= –348 g CO_2–Cm^{-2} yr^{-1}; Table 7; Wilson et al., 2013). This could be due to climate differences, or caused by different soil properties, as the Atlantic bog peat was oligotrophic and very acid. Methane emissions from a *Eriophorum angustifolium–Carex rostrata* site in another rewetted cutover Irish bog were lower and dropped from 3.2 g CH_4–C m^{-2} yr^{-1}, in a wet year (WL ~ 5 cm above surface) to 2.4 g CH_4–C m^{-2} yr^{-1} in a drier year (WL ~ 6 cm below surface) (Wilson et al., 2009). This site, however, was a CO_2 source (163 and 408 g CO_2–Cm^{-2} yr^{-1} in the wet and drier year, respectively, Wilson et al., 2007) probably due to additional CO_2 production when water from the calcareous subsoil came into contact with the slightly acidic residual peat (cf. Harpenslager et al., 2015)~~ of the same magnitude as from similar small sedge reeds in two rewetted cutover Atlantic bogs (Wilson et al., 2009, 2013). Net uptake and net release of CO_2, however, was smaller for BA *Eriophorum–Carex* and BA *Carex–*

Equisetum as compared to the mentioned Irish sites (Wilson et al., 2007, 2013; Table 6), perhaps partly resulting from ~~the more continental climate~~lower productivity.

Methane emissions from BA *Phragmites*–*Carex* compared well to the shallow water inner reed zone (33 g CH_4–C m^{-2} yr^{-1}) and that from GK *Phragmites-Lemna* to the deep water outer reed zone (122 g CH_4–C m^{-2} yr^{-1}) of lake Lake Vesijärvi in Southern Finland (Table ~~7~~6; Kankaala et al., 2004). Methane emissions from a *Phragmites australis* dominated, shallowly inundated marsh in north-central Nebraska, USA (60 g CH_4–C m^{-2} yr^{-1}; Kim et al., 1998) as well as from wet *Phragmites australis* stands in a rewetted Dutch fen (88 g CH_4–C m^{-2} yr^{-1}; Hendriks et al., 2007) were ~~with 60, respectively 88 g CH_4–C m^{-2} yr^{-1}~~ between both *Phragmites* ~~*australis* sites~~reeds of the present study. Annual NEE fluxes of both *Phragmites australis* sites were more than ten times higher than at a freshwater tidal reed wetland in NE China, though above ground biomass was comparable (Zhou et al., 2009). The differences result from smaller ratios of R_{eco} to GPP in the present (0.58 ± 0.09, $n = 4$) compared to the tidal reed study (0.95) and can be explained by permanent inundation of BA *Phragmites*–*Carex* and GK *Phragmites*–*Lemna*, and consequently low heterotrophic respiration~~ (see Sect. 4.1.2)~~, while the soil of the tidal reed wetland was periodically aerated. The importance of water level was also evident for a *Phragmites australis* site in a rewetted former grassland fen in NE Germany that sequestrated 83 g CO_2–Cm^{-2} yr^{-1} and emitted 11 g CH_4–C m^{-2} yr^{-1} in an exceptionally wet year (WL at surface) but released 68 g CO_2–Cm^{-2} yr^{-1} and only 1 g CH_4–C m^{-2} yr^{-1} in a typical year (WL below surface; Günther et al., 2014).

Annual methane and CO_2 fluxes from floating tall sedge – ~~*cattail*~~ *Typha latifolia* ~~mats~~ reeds are not reported in the literature. Methane emissions from GK *Typha*–*Hydrocharis* and GK *Carex*–*Lysimachia* were higher compared to a pristine, water saturated sedge fen (dominated by *Carex aquatilis*) in the southern Rocky Mountains (30 to 34 g CH_4–C m^{-2} yr^{-1}; Table ~~7~~6; Wickland et al., 2001) or to *Carex acutiformis and Typha latifolia* sites during the wet year in the above mentioned rewetted fen grassland (47 and 10 g CH_4–C m^{-2} yr^{-1}, respectively; Günther et al., 2014). They were comparable to temperate *Typha latifolia* (82 g CH_4–C m^{-2} yr^{-1}; Whiting and Chanton, 2001) and *T. angustifolia* marshes (51 g CH_4–C m^{-2} yr^{-1}, Chu et al., 2015; 127 g CH_4–C m^{-2} yr^{-1}, Strachan et al., 2015). The constantly high water levels made us expect a net CO_2 uptake at GK *Typha*–*Hydrocharis* and GK *Carex*–*Lysimachia*, as was found for *Typha latifolia* and *T. angustifolia* marshes (Whiting and Chanton, 2001; Strachan et al., 2015), for a water saturated temperate sedge fen in the Czech Republic (Dušek et al., 2012), and in the wet year for *Carex acutiformis and Typha latifolia* (Günther et al., 2014).

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However, in contrast to our first hypothesis the sites GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* were net CO_2 sources. Similar, ~~Both sites, however, were CO_2 and carbon sources.~~ a wet sedge fen in the southern Rocky Mountains (Wickland et al., 2001) and a water saturated *Typha angustifolia* marsh (Chu et al., 2015) were found to be CO_2 sources (Table 6)~~Net CO_2 emissions, though smaller as compared to our study, were also observed from a wet sedge fen in the southern Rocky Mountains (77 to 84 g CO_2–Cm^{-2} yr^{-1}; Wickland et al., 2001), and in two of three years from a water saturated *Typha angustifolia* marsh (Chu et al., 2015)~~. Chu et al. (2015) explain their findings by abnormal climatic conditions. ~~However~~As~~,~~ climatic conditions during the first year of the present study were similar to the long term average, ~~and~~ other factors, like reduced GPP because of shading from old standing leave~~f~~s (Rocha et al., 2008) may have been important, as there was much dry biomass present. Also the high water levels and their strong fluctuations may have imposed stress on the vegetation (Dušek et al., 2012), as indicated by changes in the cover of the dominant species between years (Table A~~2~~1) and the early aging of the sedges. High R_{eco} fluxes from the floating tall sedge – *Typha latifolia* reeds ~~both sites~~ could be the result of increased ~~high~~ maintenance respiration because of environmental stress (Chapin et al., 2002) combined with high ~~increased~~ heterotrophic respiration from decomposing dead plant material which formed the main part of the sedge tussocks (estimated from photographic documentation). This indicates that the plant communities were not well adapted to the present conditions and ~~may~~ represent a transient development stage.

4.2 Robustness of annual GHG balances

4.2.1 Methane

Overall, our measurement design and data treatment produces annual methane balances at the high end of the expected real fluxes.

The pronounced diurnal methane emission dynamics from BA *Phragmites–Carex* and GK *Phragmites–Lemna* with fivefold flux increases from morning to midday result from active air transport in *Phragmites australis* aerenchyma in the growing season ~~related to~~driven by sun light (Armstrong and Armstrong, 1991; Brix et al., 1992; Armstrong et al., 1996). In contrast to other studies (Van der Nat and Middelburg, 2000; Günther et al., 2013) we did not find a significant impact of chamber transparency on measured methane emission rates, maybe because enclosed plants were connected by rhizomes with culms outside the chamber. Such connection ~~is supposed~~seems to allow for pressure propagation and continuation of unrestrained convective gas flow (Juutinen et al., 2004; Minke et al., 2014). Consequently the application of opaque chambers has not biased annual emission estimates from the *Phragmites australis* sites.

Day-to-day variability and seasonal variation of average daily emissions from *Phragmites australis* stands are controlled by sediment temperature (Kim et al., 1998; Kankaala et al., 2004), which supports our decision to use soil temperature for modelling methane emissions. However, a single measurement at any time during daylight does not represent the daily emission average. For the monitored days (Fig. 3) most measurements between 9.00 and 18.00 h resulted in equal or higher estimates as compared to the 24 hour mean. ~~This indicates that also at other days~~Our daylight measurements during the growing period ~~daylight measurements will have rather tended to result in flux estimates at or above the daily mean than below it~~slightly overestimate the daily methane flux rates. ~~So, possibly the high emission events in summer 2011 not explained by the models of BA *Phragmites–Carex* III and GK *Phragmites–Lemna* III (Figs. 4h and 4s) were daily maxima and the models were still at or just below the daily averages. Fluxes in spring and early summer 2012 were most likely overestimated by the models of BA *Phragmites–Carex* I and III, because they were measured predominantly at midday and early afternoon of clear or only partly clouded days and can therefore be expected to exceed the daily average. The same holds for summer fluxes in 2012 at GK *Phragmites–Lemna* III.~~ In summary, our approach tended to overestimate the real emissions at the *Phragmites australis* sites.

GK *Typha–Hydrocharis* ~~The~~showed less pronounced diurnal methane emission dynamics ~~GK *Typha–Hydrocharis*~~ (Fig. 3). ~~with only a short term peak in the mid-morning (first day) and t~~Unlike *Phragmites*, *Typha latifolia* reacted on shading. The reduction of emissions ~~when~~by opaque chambers ~~were shaded~~ agrees with other studies of *Typha latifolia* (Chanton et al., 1993; Whiting and Chanton, 1996). Similar to *Phragmites australis*, green parts of *Typha latifolia* pressurize during daylight which drives convective gas transport and accelerates methane efflux (Brix et al., 1992; Whiting and Chanton, 1996). ~~Although no transient emission peak was observed at the second day, the ratio of transparent/opaque chamber was the same for both days (Table A2).~~ Obviously, *Typha latifolia* plants are less connected than *Phragmites* and cannot compensate for small scale shading during chamber deployment. ~~Other researchers calculated similar~~Our transparent/opaque ratios of measured methane flux rates of 1.2 agrees with previous studies for *Typha latifolia* (1.1 – Whiting and Chanton,

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1996; 1.3 – Günther et al., 2013). However, we do not know the variability of the ratio under different weather conditions. ~~Therefore w~~We ~~us~~applied the correction factor 1.2 for total daily methane emissions during the growing season, ~~despite the irrelevance of~~although chamber transparency ~~at night time~~only matters during daylight. Estimated annual emissions will consequently be at the high end of real emissions from the site.

~~*Typha latifolia* was not present at GK *Carex–Lysimachia* I during monitoring of diurnal methane emission dynamics at this plot in summer 2012. Instead *Carex elata* dominated.~~ Methane measurements were significantly affected by shading at the floating *Carex elata* plot, but not at the small sedge plots dominated by~~,~~ *Carex rostrata* and *Eriophorum angustifolium*~~ dominated sites were not affected by shading~~. Gas transport in sedges is driven only by diffusion (Armstrong, 1979; King et al., 1998). Existing studies ~~led to different outcomes~~were ambiguous regarding the effect of shading by chambers. Shading reduced methane emissions from *Carex aquatilis* (Morrissey et al., 1993) and *Carex allivescers* (Hirota et al., 2004), but not from *Carex limosa* and *Carex~~.~~ rostrata* (Whiting and Chanton, 1992), ~~and~~ *Carex~~C.~~ acutiformis* (Günther et al., 2013) and *Eriophorum angustifolium* (Joabsson et al., 1999, Whiting and Chanton, 1992)~~. We do not know the reason for the small but significant shading impact on methane fluxes from plot I of GK *Carex–Lysimachia*. However, *Typha latifolia* was, except for this plot in summer 2012, always present at all plots of GK *Carex–Lysimachia* (Table A1). Correction of daily fluxes from GK *Carex–Lysimachia* using the factor 1.2 from GK *Typha–Hydrocharis* accounted for this. Again, the calculated annual CH_4 emissions will represent the high end of real emissions from the site.~~

~~The lack of any shading impact on methane emissions from BA *Eriophorum–Carex* and BA *Carex–Equisetum* corresponds to the findings of Joabsson et al. (1999) and Whiting and Chanton (1992) for *Eriophorum angustifolium* and *Carex rostrata*, what supports our decision not to apply any correction factor to the estimated methane fluxes.~~

4.2.2 Carbon dioxide

The two approaches used to model CO_2 exchange rates resulted in very similar annual balances. Plot-wise annual R_{eco} calculated with the H-approach was on average 5 ± 5% ~~25~~ (mean ± standard deviation, *n* = 36) below the LS-approach, while ~~the~~ GPP sink was 1 ~~% (~~± 3%~~,~~ (~~-~~*n* = 36) higher~~by 1% (±3%, *n* = 36)~~. Resulting annual net CO_2 uptake was consequently on average stronger for the H-approach than for the LS-approach. The mean difference of NEE between both approaches was 43 ± 41 g CO_2–Cm^{-2} yr^{-1} (*n* =

36)~~ n = 12)(n = 12)~~. This indicates that measured fluxes and general modelling assumptions, i.e. the temperature relation of R_{eco} and PAR relation of GPP were robust towards differences in flux calculation and model parameterization. Also the good results of the cross validations of the models of the H-approach at all sites indicate a high ~~reliability~~rob~~s~~ustness of the results.

The net annual CO_2 sink of the *Phragmites australis* sites was surprisingly large, especially at GK *Phragmites–Lemna*. The first year NEE of this site ~~equalled~~agreed with the estimate of Brix et al. (2001; Table 6) but the second year uptake was ~~two times higher~~twice as high. To test for plausibility we roughly estimated the carbon flux partitioning in the ecosystem from independent data. Based on dry weight of green above ground biomass assessed at the end of the growing seasons 2011 and 2012 and on published ratios between above ground and below ground biomass production we estimated the net annual primary production (NPP, g C m^{-2} yr^{-1}) of the *Phragmites australis* sites during both GHG measurement periods (Table 5). Using NPP, NEE, and GPP we estimated heterotrophic and autotrophic respiration (R_h and R_a, Table 5) and evaluated their meaningfulness. As expected because of inundation, heterotrophic respiration was low, ranging between 77 and 114 g CO_2−Cm^{-2} yr^{-1}. The ratios of heterotrophic respiration to methane emissions (CO_2-C / CH_4-C) were 2.2 and 2.3 in the first an second year, respectively for BA *Phragmites–Carex* and closer, 1.0 and 1.1 for GK *Phragmites–Lemna*. Similar ratios were found in incubation experiments for organic bottom sediments and the upper peat layer of a flooded former fen grassland (Hahn-Schöfl et al., 2011). Calculated autotrophic respiration was half of GPP, but differed considerably between years (43 to 61%). This ~~may result to a large extent from~~range is plausible given the uncertainty of the underlying estimates (especially of NPP), as the efficiency of converting GPP to NPP is generally assumed to be relatively constant (cf. Chapin et al., 2002). In summary, ~~our very rough estimation resulted for the *Phragmites australis* sites in reasonable annual rates of heterotrophic respiration and shares between NPP and *R*a~~the carbon partitioning test was plausible and supports the exceptional net CO_2 uptake in the *Phragmites* sites. Such uptake may be explained by strong rhizome formation in a relatively young reed ecosystem but may not represent a long-term equilibrium.

4.3 Controls of annual GHG emissions

Reality proved more complex than our hypotheses. We studied transient vegetation development stages after fen rewetting, which may not necessarily be generalized to equilibrium stages. The findings related to the hypotheses are as follows:

(i) The annual CO_2 balance was best explained by vegetation biomass, which includes the role of vegetation composition and species. *Phragmites* reeds were by far the most productive ecosystems at both studied peatlands. The nutrient status affected productivity, but species effects dominated the CO_2 balance. Inundation depth had no systematic effect on the annual CO_2 balance.

(ii) Methane emissions were site specific. They increased with productivity and correlated strongly with $R_{\cancel{ECO}eco}$ fluxes. Methane was obviously most driven by biological activity of vegetation and soil organisms. Continuously inundated sites tended to have higher methane emissions than sites where water levels remained near the land surface.

Under mesotrophic conditions rewetting leads to stable small net GHG sources or even sinks because methane emissions are largely balanced by the net CO_2 sink. Under eutrophic conditions, rewetted fens remain net GHG sources in most cases. Vegetation types can be sinks or sources of CO_2 and emit substantial amounts of methane so that rewetting effects on the GHG balance remain difficult to predict.

(iii)

(iv) We reject, however, that the CO_2 sink and methane emissions peak under shallow inundation. In contrast, the various vegetation types with shallow water ~~in the terrestrialization zone~~ showed strongly diverging CO_2, methane and GHG balances in a small water level range.

~~In a meta-analysis Bain et al. (2014) found that methane emissions from boreal and temperate, undrained and rewetted peatlands tend to increase but the CO_2 sink to decrease along a water table gradient from 30 cm below to 20 cm above surface. A positive relation between inundation depth and methane emissions was also found in the present study, what confirms our second hypothesis. But in contrast to Blain et al. (2014), the CO_2 sink strength also increased with higher water tables, with the exception of GK *Typha–Hydrocharis* and GK *Carex–Lysimachia*. As a result and in contrast to our third hypothesis, inundation was not always associated with a increasingly negative climate effect. In both peatlands the *Phragmites australis* communities grew at higher inundation depths and were larger CH_4 sources but also stronger CO_2 sinks as compared to the sedge communities in the shallower areas. As a consequence BA *Phragmites–Carex* and GK *Phragmites–Lemna* were very strong~~

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~~carbon sinks (Table 2) and had only low GHG emissions of on average −1.7 (90% confidence interval -15.0, 10.2) and 4.2 (-26.8, 37.7) t CO_2 eq ha^{-1} yr^{-1}, respectively. However, because of large differences among plots and between years the uncertainties were higher as compared to the not inundated site BA *Eriophorum–Carex* and the very shallowly (8±1 cm) flooded BA *Carex–Equisetum* (2.3 (-1.0, 5.6) and 4.2 (2.1, 6.8) t CO_2 eq ha^{-1} yr^{-1}, respectively). GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* were, despite of similar shallow water depths, strong methane and CO_2 sources (Tables 2, 4). Average~~The high GHG emissions from the floating tall sedge – *Typha latifolia* reeds ~~even 39.1 (26.6, 58.0) t CO_2 eq ha^{-1} yr^{-1} what is~~are comparable to deep-drained temperate fen grassland (26 t CO_2 eq ha^{-1} yr^{-1} – Drösler et al., 2014; 65 t CO_2 eq ha^{-1} yr^{-1} – Eickenscheidt et al., 2015). In contrast to the other sites of the present study, important ~~aims~~targets of peatland rewetting, i.e. restoration of the carbon sink function and reduction of GHG emissions have not been achieved for GK *Typha–Hydrocharis* and GK *Carex–Lysimachia*.

~~The average GHG emissions from all studied sites were with 12.2 t CO_2 eq ha^{-1} yr^{-1} similar to GHG emissions from rewetted rich temperate fens (10 t CO_2 eq ha^{-1} yr^{-1}) as given by Blain et al. (2014). However, GHG emissions and carbon balances differed considerably among the studied sites. BA *Eriophorum–Carex*, BA *Carex–Equisetum*, BA *Phragmites–Carex* and GK *Phragmites–Lemna* had on average low GHG emissions (2.3, 4.2, −1.7, and 4.2 t CO_2 eq ha^{-1} yr^{-1}, respectively), and were weak to strong carbon sinks (−36, −17, −390, and −795 g C m^{-2} yr^{-1}), confirming that important aims of peatland rewetting, i.e. restoration of the carbon sink function and reduction of GHG emissions have been largely achieved. Net carbon losses from GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* of the terrestrialization zone (83 and 276 g C m^{-2} yr^{-1}, respectively), in contrast, were similar as from peat extraction sites (280 g C m^{-2} yr^{-1} – Drösler et al., 2014) and GHG emissions (25.1 and 39.1 t CO_2 eq ha^{-1} yr^{-1}) were even comparable to deep-drained temperate fen grassland (26 t CO_2 eq ha^{-1} yr^{-1} – Drösler et al., 2014; 65 t CO_2 eq ha^{-1} yr^{-1} – Eickenscheidt et al., 2015).~~ In the following we discuss the background for the revision of the hypotheses, ~~To understand~~ reasons for the~~se~~ differences among sites ~~we now look on~~and ~~discuss~~ the ~~potential~~ individual drivers ~~for~~ of ~~individual~~ the GHG fluxes.

4.3.1 Water table

In a meta-analysis Blain et al. (2014) found that methane emissions from boreal and temperate, undrained and rewetted peatlands tend to increase but the CO_2 sink to decrease along a water level gradient from 30 cm below to 20 cm above surface. The water level in our study ranged from 3 cm below to 104 cm above surface with most sites within 10 cm water table range. The diverse vegetation types with roughly similar water table had widely diverging CO_2, methane and GHG balances that we cannot confirm any trend.

~~Significant correlation between annual water level and methane emissions, as well as between water level and CO_2 fluxes (Fig. 6) indicate that emission differences among sites may be caused by water level differences.~~ In drained peatlands water table ~~depth~~ position defines the ~~thickness~~ depth of the aerobic zone and consequently the rate of peat oxidation (Blain et al., 2014, Couwenberg et al., 2011). The~~As discussed above (4.2) all~~ sites of the present study, however, were permanently water saturated and ~~heterotrophic respiration was consequently low. W~~water levels ~~link to~~affect CO_2 fluxes ~~differences among sites~~ most likely ~~more~~ indirectly~~, by influencing other variables that control CO_2 fluxes~~ via other controlling factors, for example vegetation composition. Methane emissions under flooded conditions are hardly ~~are~~ affected by water table position ~~-~~(Blain et al., 2014)~~as it defines the thickness depth of the oxidation zone at the soil surface or – under flooded conditions – in the water column (Couwenberg and Fritz, 2012)~~. ~~However, w~~When aerenchymous plants are abundant, as in the present study, they dominate the gas exchange and methane bypasses the oxygenated water column (Whiting and Chanton, 1992; Chanton and Whiting, 1995~~; Couwenberg and Fritz, 2012~~). ~~A~~l~~i~~n analogy to CO_2, ~~t the study sites~~ water level ~~will have influenced~~has affected methane emissions of the studied sites mainly ~~rather~~indirectly by ~~plant species distribution then directlyS~~vegetation composition and the type and abundance of aerenchymous plants~~o, water level influenced methane emissions of the studied sites also mainly by influencing plant species distribution~~.

~~Nitrous~~ Near-zero nitrous oxide emissions ~~were f~~at ~~or~~ all sites ~~about zero, what is the result of permanent water saturatation and~~ agree~~s~~ with other studies from rewetted fens with permanent water saturation (Hendriks et al., 2007; ~~Couwenberg et al., 2011;~~ Wilson et al., 2013).

4.3.2 Nutrient conditions

The different –nutrient status of the studied peatlands cannot be explained by surface peat properties, which were both eutrophic, but ~~Nutrient conditions as indicated by vegetation composition were dominantly controlled~~ by water supply (river and grassland drainage water for Giel’cykaŭ Kašyl’, groundwater
for Barcianicha).~~;~~ ~~while surface peat (eutrophic at both sites) was less important.~~ ~~CO_2 fluxes and methane emissions were higher from the eutrophic Giel’cykaŭ Kašyl’ as compared to the mesotrophic Barcianicha.~~ ~~The very high R_{eco} fluxes from GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* could be partly the result of increased microbial activity due to nutrient rich conditions. Still, most of the influence of nutrient conditions on GHG exchange rates will have been~~ ~~As for water level, nutrient conditions affected GHG emissions via their influence on vegetation.~~ Eutrophic conditions supported the establishment of more productive plant species at Giel’cykaŭ Kašyl’ compared to the mesotrophic Barcianicha~~. Also the~~, higher productivity of *Phragmites australis* and higher microbial activity indicated by higher R~~$_{ECO}$~~$_{eco}$ and methane fluxes ~~differed strongly between both peatlands~~. This is in line with Blain et al. (2014) who found that methane and CO_2 emissions are higher from rich temperate rewetted fens as compared to poor fens and bogs. Our results indicate that rich temperate rewetted fens may be further subdivided into mesotrophic and eutrophic to account for significantly different methane emissions.

4.3.3 Vegetation and plant productivity

~~In both peatlands the *Phragmites australis* communities grew at higher water tables and were larger CO_2 sinks and CH_4 sources as compared to the sedge communities in the shallower areas.~~ Plant productivity was the main control of CO_2 fluxes, as indicated by the strong correlation between biomass and NEE for all sites except GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* (Fig. 6). ~~Small scale variability, calculated as absolute difference between annual plot emissions and annual site emissions was larger for NEE (92±108 g CO_2–C m^{-2} yr^{-1}) than for methane emissions (8±10 g CH_4–C m^{-2} yr^{-1}). Also inter-annual variability, calculated plot-wise as the absolute difference of annual emissions from the two years mean, was larger for NEE (116±119 g CO_2–C m^{-2} yr^{-1}) as compared to methane emissions (4±4 g CH_4–C m^{-2} yr^{-1}). Both can be explained by the fact that CO_2-fluxes are more directly linked to plant productivity than methane fluxes (Hyvönen et al., 1998; Bonneville et al., 2008; Schneider et al., 2012).~~

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However, also differences of methane emissions within sites~~interannual and small scale variability of methane emissions~~ increased with above ground biomass and GPP (Fig. 6), and ~~was~~ were larger in Giel’cykaŭ Kašyl’ compared to Barcianicha, and in both peatlands for the *Phragmites australis* sites (Table 3). This is most likely due to control of vegetation and plant productivity on methane emissions, as indicated by the highly significant correlation between ~~methane emissions and net CO_2 uptake (Fig. 6, when analysed without the terrestrialization zone) and between~~ methane emissions and biomass, and can be explained by supply of organic material and by plant mediated gas exchange (Whiting and Chanton, 1993; Chanton et al., 1995; Bellisario et al., 1999; Whalen, 2005).

Fresh organic substrates were rather limited at Barcianicha, as indicated by~~where~~ the thin layer of litter and many bare peat patches~~ indicated the lack of plant litter substrate for methane generation~~. More emissions can be expected when more litter accumulates (Waddington and Day, 2007). Plant litter was more abundant at Giel’cykaŭ Kašyl’, certainly because of higher plant productivity, but also because of a longer period since rewetting and deeper inundation. This may explain why ~~the~~ a strong correlation between NEE and methane emissions was found at Barcianicha, but not at Giel’cykaŭ Kašyl’. Methane production ~~was obviously less depending~~ did not only depend ~~on~~ on actual primary production, especially in the floating tall sedge – *Typha latifolia* reeds ~~the terrestrialization zone~~ of Giel’cykaŭ Kašyl’. Methane emissions from GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* were high and, similar to the large R_{eco} fluxes, at least partly fuelled by old litter~~, because both sites were no net CO_2 sinks~~. Also allochthonous carbon can not be excluded as a substrate for methane production at Giel’cykaŭ Kašyl’ (Chu et al., 2015), for example from floating plants like *Lemna trisulca* that form detritus with a much higher methane production potential compared to *Phragmites australis* litter (Kankaala et al., 2003).

The zone of floating mats will most likely continue for many years to emit large amounts of methane and only a shift towards *Phragmites australis* dominated plant communities with larger CO_2 sink potentials seems to allow for reduction of GHG emissions. Such a shift may not be unlikely, because *Phragmites australis* is growing on most of the area of Giel’cykaŭ Kašyl’ and has been abundant at GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* in former times, as indicated by macrofossils in the peat profile (Table 1).

5 Conclusions

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The eutrophic peatland Giel’cykaŭ Kašyl’ with deep standing water had a large carbon sink potential, but also a high risk of local net CO_2 losses. The site varied spatially and temporally between being a small net GHG sink and a large GHG source because of high methane emissions. The mesotrophic peatland Barcianicha with shallow, constant water levels, in contrast, constituted a smaller but more stable carbon sink and only a small GHG source. Both net CO_2 uptake and methane emissions were strongly linked to vegetation and plant productivity, which in turn were related to water level and nutrient conditions. Emission variability increased with productivity of sites. This implies that the formulation of robust emission factors ~~requires more long-term and spatially resolved GHG emission studies in case of high-productive than for low-productive vegetation types and mire ecosystems~~for high-productive vegetation types and mire ecosystems requires more long-term and spatially resolved GHG emission studies than for low-productive ones.

Unexpectedly high carbon losses and GHG emissions from the floating tall sedge – *Typha latifolia* reeds ~~terrestrialization zone~~ of Giel’cykaŭ Kašyl’ were most likely caused by vegetation suffering from high and strongly fluctuating water levels. The exact sources of these high emissions, as well as the duration and successional pathway of the supposed transitional phase require further ~~study~~investigation.

Our study indicates that permanent, shallow inundation of cutover temperate fens is a ~~more~~ suitable measure to arrive at low GHG emissions. ~~than deep flooding, as the latter may create unfavourable conditions for plant growth and carbon sequestration, and the site may remain a strong net GHG source because of high methane emissions. If shallow flooding cannot be practically realized, deep flooding seems to be a reasonable alternative, at least when~~ *Phragmites australis* ~~can be established~~establishment should be promoted in deeper flooded areas and will lead to comparably moderate, but variable GHG emissions or even occasional sinks. ~~The~~ The study supports previous findings for ~~drained~~rewetted peatlands that the risk of high GHG emissions is higher for eutrophic ~~as compared to~~than mesotrophic peatlands. In spite of the possible high emissions in some vegetation types or years, flooding of eutrophic fens still ~~has to be preferred over keeping~~represents a safe GHG mitigation option for temperate fens ~~grasslands deeply drained, because the GHG emissions from the latter are similar to those from~~because even the hotspot of our study, the eutrophic floating mats~~terrestrialization zone~~, ~~but~~ did not exceed ~~those~~ typical ~~from~~ GHG emissions from drained fen grasslands and the spatially dominant flooded *Phragmites australis* reed emitted by far less GHG than drained fens.

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Table 1. Site characteristics.

Site	Annual, summer, winter median water level[a] (cm above surface)		Above Ground biomass[b] (g C m^{-2})	Surface peat				Profile description, top d
	1st year	2nd year		pH[c]	C[d] (%)	N[d] (%)	C/N ratio	
BA *Eriophorum–Carex*	-3, -4, -3 ± 1	-3, -4, -1 ± 1	117 ± 34	6.2 ± 0.2	42.2 ± 1.7	2.3 ± 0.1	18.5 ± 0.2	0–9 radicel peat (H6), 9–14 silty gyttja, 14 H3), 43–119 brown moss peat (H3, H4), b
BA *Carex–Equisetum*	8, 7, 8 ± 1	8, 7, 10 ± 1	55 ± 22	6.1 ± 0.0	43.0 ± 0.2	2.6 ± 0.2	16.8 ± 1.1	0–15 radicel peat (H6), 15–30 radicel bro 30–34 *Alnus* peat (H4), 34–85 brown mos clayey gyttja & coarse sand, below: fine sand
BA *Phragmites–Carex*	14, 14, 14 ± 1	14, 14, 16 ± 1	296 ± 79	6.1 ± 0.1	43.8 ± 0.3	2.7 ± 0.2	16.8 ± 1.1	0–13 lost, 13–40 radicel peat (H5/H4), 40 (H3, H4), below: gravel
GK *Typha–Hydrocharis*	10, 5, 13 ± 3	2, 0, 2 ± 3	259 ± 103	5.6 ± 0.1	41.4 ± 3.2	2.8 ± 0.2	14.8 ± 0.3	0–20 lost, 20–30 radicel peat (H5), 30–55 decomposed peat with radicels (H8), 55–90 radicel peat with *Phragmites* (H5, H3), 90–103 brownmoss–radicel peat (H3), 103–113 woody radicel peat with *Phragmites* (H4), 113–140 radicel peat with *Phragmites* and brown mosses (H4), 140–150 organogyttja, below: sand
GK *Carex–Lysimachia*	10, 7, 12 ± 3	4, 2, 4 ± 3	299 ± 73	6.3 ± 0.4	43.3 ± 2.5	2.6 ± 0.4	16.7 ± 2.3	
GK *Phragmites–Lemna*	104, 86, 114 ± 6	74, 65, 75 ± 6	586 ± 121	5.7 ± 0.1	37.1 ± 4.1	2.4 ± 0.2	15.2 ± 0.5	0–10 very highly decomposed peat with r radicel peat with *Phragmites* (H4, H5), 100–170 radicel peat (H5), 170–185 organogyttja, below: sand

Given are means ± standard deviations, *n* = 3 plots

[a] Summer = June-August, winter = December-Februar, [b] harvest at Barcianicha 2012-10-29, and at Giel'čykaŭ Kašyl' 2012-09-11, [c] pH (KCL) mean of three samples, [d] total carbon and nitrogen content, one sample, [e] von Post peat decomposition scale: H3 very slightly, H4 slightly, H5 moderately, H6 moderately highly, H8 very highly decomposed peat

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~~**Table 2.** Plant species cover of GHG measuring plots in summer 2010 and 2012.~~

	~~**BA**~~						~~**BA**~~						~~**BA**~~					
	~~***Eriophorum–Carex***~~						~~***Carex–Equisetum***~~						~~***Phragmites–Carex***~~					
	~~2010~~			~~2012~~			~~2010~~			~~2012~~			~~2010~~			~~2012~~		
~~**species**~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~
~~*Eriophorum angustifolium*~~	~~6~~	~~6~~	~~7~~	~~6~~	~~6~~	~~6~~												
~~*Marchantia polymorpha*~~	~~3~~	~~2~~	~~2~~						~~2~~									
~~*Dicranella cerviculata*~~	~~3~~	~~2~~	~~2~~	~~3~~	~~4~~	~~4~~		~~6~~	~~2~~									
~~*Juncus* cf. *compressus*~~		~~1~~		~~3~~	~~2~~	~~2~~	~~2~~	~~2~~		~~2~~	~~2~~	~~2~~						
~~*Utricularia intermedia*~~											~~2~~	~~2~~	~~7~~	~~6~~	~~7~~			
~~*Chara* spec.~~										~~2~~		~~3~~				~~1~~		
~~green algae~~												~~4~~				~~2~~		
~~*Phragmites australis*~~											~~1~~		~~7~~	~~8~~	~~6~~	~~8~~	~~8~~	~~8~~
~~*Dicranella heteromalla*~~													~~2~~	~~2~~	~~2~~			
~~*Carex rostrata*~~	~~2~~	~~2~~	~~3~~	~~2~~	~~2~~	~~2~~	~~7~~	~~7~~	~~6~~	~~7~~	~~6~~	~~6~~	~~3~~	~~3~~	~~3~~	~~3~~	~~3~~	~~3~~
~~*Equisetum fluviatile*~~	~~2~~			~~2~~	~~2~~		~~2~~	~~2~~	~~2~~	~~2~~	~~2~~	~~2~~	~~1~~	~~1~~	~~1~~	~~1~~		~~1~~
~~*Salix cinerea*~~	~~1~~	~~1~~		~~1~~			~~1~~	~~1~~	~~1~~	~~1~~			~~1~~		~~4~~	~~1~~		
~~*Drepanocladus aduncus*~~			~~2~~										~~5~~			~~2~~		~~4~~

	~~**GK**~~						~~**GK**~~						~~**GK**~~					
	~~***Carex–Lysimachia***~~						~~***Typha–Hydrocharis***~~						~~***Phragmites–Lemna***~~					
	~~2010~~			~~2012~~			~~2010~~			~~2012~~			~~2010~~			~~2012~~		
~~**species**~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~	~~I~~	~~II~~	~~III~~
~~*Thelypteris palustris*~~	~~4~~					~~6~~												
~~*Calamagrostis neglecta*~~	~~4~~					~~2~~												
~~*Carex elata*~~	~~2~~	~~5~~	~~6~~	~~8~~	~~5~~	~~2~~			~~7~~			~~8~~						
~~*Carex vesicaria*~~	~~7~~	~~2~~		~~3~~	~~6~~	~~2~~	~~2~~	~~3~~		~~5~~	~~5~~							
~~*Typha latifolia*~~	~~6~~	~~7~~	~~6~~		~~4~~	~~4~~	~~6~~	~~7~~	~~3~~	~~6~~	~~3~~	~~4~~						
~~*Galium palustre*~~	~~2~~	~~2~~	~~2~~	~~2~~	~~2~~	~~2~~				~~2~~	~~2~~	~~2~~						
~~*Cardamine amara*~~	~~2~~	~~2~~	~~1~~	~~2~~	~~2~~				~~1~~	~~2~~	~~1~~	~~2~~						
~~*Lycopus europeus*~~		~~2~~		~~2~~	~~2~~	~~2~~			~~1~~		~~1~~	~~1~~						
~~*Lysimachia thyrsiflora*~~	~~1~~	~~2~~	~~2~~	~~3~~	~~2~~	~~2~~				~~2~~	~~4~~	~~2~~						
~~*Lemna trisulca*~~							~~2~~				~~2~~			~~1~~		~~2~~	~~2~~	~~2~~
~~*Phragmites australis*~~													~~7~~	~~7~~	~~8~~	~~9~~	~~7~~	~~8~~
~~*Stratiotes aloides*~~													~~1~~	~~6~~			~~5~~	~~2~~
~~*Drepanocladus aduncus*~~	~~2~~	~~5~~	~~2~~	~~6~~	~~8~~	~~3~~	~~3~~	~~2~~	~~2~~	~~8~~	~~3~~	~~7~~	~~2~~			~~2~~		~~2~~
~~*Hydrocharis morsus–ranae*~~				~~2~~	~~3~~	~~2~~	~~3~~	~~3~~	~~2~~	~~4~~	~~6~~	~~3~~	~~3~~	~~5~~	~~4~~	~~5~~	~~8~~	~~6~~

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~~*Lemna minor*~~	~~2~~	~~2~~		~~2~~	~~1~~			~~2~~	~~2~~	~~2~~		~~1~~	~~1~~			~~2~~

~~Vegetation types of sites studied in Barcianicha: *Eriophorum angustifolium–Carex rostrata*–reed (BA *Eriophorum–Carex*), *Carex rostrata–Equisetum fluviatile*–reed (BA *Carex–Equisetum*), *Phragmites australis–Carex rostrata*–reed (BA *Phragmites–Carex*), and Giel'čykaŭ Kašyl': *Carex elata–Lysimachia thyrsiflora*–reed (GK *Carex–Lysimachia*), *Typha latifolia–Hydrocharis morsus–ranae*–reed (GK *Typha–Hydrocharis*), *Phragmites australis–Lemna trisulca*–reed (GK *Phragmites–Lemna*). Plant cover scale according to Peet et al. (1998): Class 1 = very few individuals, 2 = cover of 0–1%, 3 = 1–2%, 4 = 2–5%, 5 = 5–10%, 6 = 10–25%, 7 = 25–50%, 8 = 50–75%, 9 = 75–95%, 10 >=95%. Species not exceeding cover class 2 are only shown if they meet class 2 in more than two relevés.~~

Table ~~3~~2. Annual fluxes of CO_2, CH_4, and Carbon (C balance = NEE + CH_4 emissions) with 90% confidence intervals.

Site	Year	R_{eco} (g CO_2–C m^{-2} yr^{-1})	GPP (g CO_2–C m^{-2} yr^{-1})	NEE (g CO_2–C m^{-2} yr^{-1})	CH_4 emissions (g CH_4–C m^{-2} yr^{-1})	C balance (g C m^{-2} yr^{-1})
BA *Eriophorum–Carex*	1	364 (339 to 396)	-449 (-512 to -407)	-86 (-130 to -38)	10 (9 to 13)	-75 (-114 to -30)
	2	406 (368 to 458)	-413 (-449 to -376)	-7 (-49 to 21)	11 (10 to 14)	4 (-35 to 30)
BA *Carex–Equisetum*	1	232 (196 to 262)	-320 (-361 to -279)	-88 (-114 to -68)	17 (13 to 22)	-71 (-92 to -56)
	2	327 (282 to 371)	-302 (-334 to -281)	24 (-6 to 55)	13 (9 to 16)	37 (8 to 66)
BA *Phragmites–Carex*	1	614 (478 to 737)	-1141 (-1595 to -888)	-528 (-933 to -194)	42 (28 to 58)	-486 (-873 to -156)
	2	706 (568 to 842)	-1035 (-1134 to -949)	-329 (-431 to -220)	36 (22 to 52)	-293 (-377 to -205)
GK *Typha–Hydrocharis*	1	921 (841 to 982)	-771 (-842 to -665)	151 (41 to 300)	60 (47 to 77)	210 (111 to 360)
	2	973 (818 to 1156)	-1086 (-1476 to -862)	-113 (-418 to 66)	68 (52 to 92)	-45 (-343 to 142)
GK *Carex–Lysimachia*	1	1105 (1007 to 1207)	-940 (-1081 to -774)	166 (66 to 252)	86 (63 to 121)	252 (145 to 356)
	2	1270 (1221 to 1362)	-1054 (-1243 to -789)	216 (48 to 470)	85 (59 to 142)	301 (137 to 552)
GK *Phragmites–Lemna*	1	936 (733 to 1200)	-1547 (-1726 to -1386)	-611 (-819 to -450)	100 (48 to 147)	-516 (-747 to -349)
	2	1092 (937 to 1210)	-2267 (-2733 to -1843)	-1175 (-1567 to -690)	101 (61 to 177)	-1074 (-1453 to -565)

Uncertainties on the site level include the uncertainties of the plot models and the spatial heterogeneity. They were calculated by pooling the plot specific annual models derived by error calculation. Different CO_2 balances of the ~~APPROACH ONE~~H-Approach and the ~~APPROACH TWO~~LS-Approach were accounted for by adding the differences randomly to 50% of the respective annual values derived by error calculation with the ~~APPROACH ONE~~H-Approach. To derive uncertainties of C balances the annual models of NEE and CH_4 derived by plot–wise error calculation were summarized and combined site–wise.

Table ~~4~~3. Small scale spatial variability of net CO_2 and CH_4 emissions

	Absolute small scale spatial variability (g C m^{-2} yr^{-1})[a]		Relative small scale spatial variability (%)[b]	
	NEE	CH_4 emissions	NEE	CH_4 emissions
BA *Eriophorum–Carex*	16 ± 13	0.5 ± 0.2	89 ± 105	4 ± 2
BA *Carex–Equisetum*	9 ± 5	1.4 ± 0.7	19 ± 12	10 ± 5
BA *Phragmites–Carex*	125 ± 140	6.4 ± 2.7	25 ± 25	17 ± 7
GK *Typha–Hydrocharis*	121 ± 66	3.2 ± 3.2	97 ± 63	5 ± 5
GK *Carex–Lysimachia*	95 ± 73	10.9 ± 8.3	47 ± 33	13 ± 10
GK *Phragmites–Lemna*	187 ± 153	24.2 ± 10.0	20 ± 11	25 ± 10

Given are means ± standard deviations, *n* = 6.

[a] absolute differences between annual plot emissions and annual site emissions.

[b] absolute differences between annual plot emissions and annual site emissions in percentages of absolute values of annual site emissions.

~~Inter–annual and small scale spatial variability of net~~ ~~CO_2~~ ~~and methane emissions.~~

~~Site~~	~~Inter–annual variability~~[a]		~~Small scale spatial variability~~[b]	
	~~NEE (g CO_2–C m^{-2} yr^{-1})~~	~~CH_4 emissions (g CH_4–C m^{-2} yr^{-1})~~	~~NEE (g CO_2–C m^{-2} yr^{-1})~~	~~CH_4 emissions (g CH_4–C m^{-2} yr^{-1})~~
~~BA *Eriophorum–Carex*~~	~~39±12~~	~~0.5±0.0~~	~~16±13~~	~~0.5±0.2~~
~~BA *Carex–Equisetum*~~	~~56±8~~	~~2.3±0.5~~	~~9±5~~	~~1.4±0.7~~
~~BA *Phragmites–Carex*~~	~~110±113~~	~~3.0±3.6~~	~~125±140~~	~~6.4±2.7~~
~~GK *Typha–Hydrocharis*~~	~~132±64~~	~~4.2±2.9~~	~~121±66~~	~~3.2±3.2~~
~~GK *Carex–Lysimachia*~~	~~74±56~~	~~1.2±0.9~~	~~95±73~~	~~10.9±8.3~~
~~GK *Phragmites–Lemna*~~	~~282±177~~	~~11.6±2.8~~	~~187±153~~	~~24.2±10.0~~

~~Given are means ± standard deviations, *n* = 6~~

[a] ~~Inter–annual variability, calculated as the mean of the absolute differences between annual plot emissions and two years plot mean~~

[b] ~~Small scale spatial variability, calculated as the mean of the absolute differences between annual plot emissions and annual site emissions~~

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Table ~~5~~4. GHG balances based on the global warming potentials of CO_2, CH_4 and N_2O for a time horizon of 100 yr (GWP_{100} of CO_2=1, of CH_4=28 and of N_2O=265 CO_2–equivalents, Myhre et al., 2013) with 90% confidence intervals.

Site	Year	CO_2 balance ($t\ CO_2\ eq\ ha^{-1}\ yr^{-1}$)	CH_4 balance ($t\ CO_2\ eq\ ha^{-1}\ yr^{-1}$)	N_2O balance ($t\ CO_2\ eq\ ha^{-1}\ yr^{-1}$)	GHG balance ($t\ CO_2\ eq\ ha^{-1}\ yr^{-1}$)
BA *Eriophorum–Carex*	1	-3.1 (-4.8 to -1.4)	3.8 (2.9 to 5.0)	-0.1 (-0.8 to 0.8)	0.5 (-1.4 to 3.1)
	2	-0.3 (-1.8 to 0.8)	4.2 (3.6 to 5.1)	0.2 (-0.2 to 0.8)	4.1 (2.3 to 6.0)
BA *Carex–Equisetum*	1	-3.2 (-3.2 to -2.5)	6.4 (5.0 to 8.0)	-0.1 (-0.7 to 0.5)	3.1 (1.9 to 5.0)
	2	0.9 (-0.2 to 2.1)	4.7 (3.2 to 6.1)	-0.3 (-0.9 to 0.2)	5.3 (3.3 to 7.3)
BA *Phragmites–Carex*	1	-19.4 (-34.2 to -7.1)	15.6 (10.4 to 21.6)	-0.3 (-2.9 to 3.0)	-4.1 (-16.9 to 11.9)
	2	-12.1 (-15.8 to -8.1)	13.3 (8.4 to 19.4)	-0.6 (-3.6 to 2.0)	0.7 (-6.5 to 6.6)
GK *Typha–Hydrocharis*	1	5.5 (1.5 to 11.0)	22.3 (17.4 to 28.6)	0.6 (-1.7 to 2.7)	28.5 (21.5 to 38.9)
	2	-4.2 (-15.3 to 2.4)	25.5 (19.3 to 34.4)	0.4 (-0.7 to 1.5)	21.7 (7.6 to 36.1)
GK *Carex–Lysimachia*	1	6.1 (2.4 to 9.2)	32.3 (23.6 to 45.5)	-0.1 (-2.1 to 1.8)	38.2 (27.8 to 53.7)
	2	7.9 (1.8 to 17.2)	31.6 (22.2 to 53.1)	0.4 (-0.8 to 1.9)	39.9 (25.8 to 60.7)
GK *Phragmites–Lemna*	1	-22.4 (-30.0 to -16.5)	35.7 (18.0 to 54.7)	0.6 (-2.4 to 3.8)	13.9 (-10.6 to 36.0)
	2	-43.1 (-57.5 to -25.3)	37.7 (22.9 to 66.2)	0.0 (-3.5 to 3.4)	-5.4 (-29.2 to 40.0)

Confidence intervals include the uncertainties of the plot models and the spatial heterogeneity. To derive uncertainties of GHG balances the annual models of CO_2 (NEE), CH_4 and N_2O derived by plot–wise error calculation were summarized and combined site–wise.

Table ~~6~~5. Estimation of net primary production (NPP), heterotrophic (R_h) and autotrophic respiration (R_a) from the *Phragmites australis* sites.

site	year	GPP (g CO_2–C m^{-2} yr^{-1})	NEE (g CO_2–C m^{-2} yr^{-1})	AGB, green (g C m^{-2})[a]	Assumed ratio BG NPP/ AG NPP[b]	NPP (g C m^{-2} yr^{-1})[c]	R_h (g CO_2–C m^{-2} yr^{-1})[d]	R_a (g CO_2–C m^{-2} yr^{-1})[e]	R_a/[GPP]
BA *Phragmites–Carex*	1	-1141	-528	260	1.4	624	96	517	0.45
	2	-1035	-329	169	1.4	406	77	629	0.61
GK *Phragmites–Lemna*	1	-1547	-611	322	1.2	707	96	840	0.54
	2	-2267	-1175	586	1.2	1289	114	978	0.43

[a] Green above ground biomass (AGB) present at end of the first measuring year was estimated for each GHG–plot from biomass harvest at three to four sample plots (40 cm × 40 cm) close to collars accordingly to the share of green vs. dead culms. At the end of the second year green AGB of the plots was calculated from the plot harvest (Table 1) accordingly to the share of green vs. dead culms.

[b] Green AGB was assumed to equal above ground net primary production (AG NPP), although this may underestimate NPP by about 10% (Westlake, 1982). Reported below ground net primary production (BG NPP) to AG NPP ratios range from 0.34 – 2.58 (Westlake, 1982; Scarton et al., 1999; Soetaert et al., 2004; Asaeda et al., 2006). We used the estimate of 1.4 from reeds in North Jutland (Schierup, 1978; cited in Westlake, 1982) for BA *Phragmites–Carex* and a lower ratio (1.2) for GK *Phragmites–Lemna*, because below ground biomass allocation of *Phragmites australis* was found to be proportionally less in deep (70 or 75 cm), compared to shallow (20 or 5 cm) water (Vretare et al., 2001).

[c] net primary production (NPP) = AG NPP plus BG NPP

[d] heterotrophic respiration (R_h) = NPP minus [NEE]

[e] autotrophic respiration (R_a) = [GPP] minus NPP

Table 6~~7~~. Net annual CO_2 and CH_4 emissions from temperate wetlands with vegetation comparable to Barcianicha' and Giel'čykaŭ Kašyl'.

Location, climate[a]	Site description, method[b]	Dominant plant species	Study years	water level[c] (cm above surface)	NEE[d] (g CO_2–C m^{-2} yr^{-1})	CH_4 emissions[d] (g CH_4–C m^{-2} yr^{-1})	Reference
Oweninny bog, Ireland, 54.12°N 9.58°W (Cfb)	cutover blanket bog with oligotrophic, acid peat, rewetted 2003 (ch)	*Eriophorum angustifolium*	2009 to 11	7±1	-348 ± 222	5.3 ± 0.1	Wilson et al., 2013
Turraun, Ireland, 53.28°N 7.75°W (Cfb)	cutover bog with slightly acidic peat and calcareous subsoil, rewetted 1991 (ch)	*E. angustifolium – Carex rostrata*	2002 to 03	5, -6.3	163, 408	3.2, 2.4	Wilson et al., 2007, 2009~~8~~
		Typha latifolia	2002 to 03	7, 0.3	266, 451	29.1, 21.6	
Trebel valley mire complex, NE Germany, 54.10°N 12.73°E (Cfb)	former fen grassland, rewetted 1997 (ch)	*Phragmites australis*	2011/12 to 2012/13	-9, -19	-83, 68	11, 1	Günther et al., 2014
		T. latifolia		6, -4	-43, 94	10, 3	
		C. acutiformis		5, -3	-3, 81	47, 3	
Mokre´ Louky, Czech Republic, 49.02°N 14.77°E (Cfb)	eutrophicated sedge fen (ec)	*C. acuta*	2006 to 08	-20 to 10	-199±66		Dušek et al. 2012
Vejlerne Nature Reserve, Denmark, 56.93°N 9.05°E (Cfb)	brackish wetland (ch, 10 occasions, two years)	*P. australis*		summer – to winter +	-552	48	Brix et al., 2001
Horstermeer, Netherlands, 52.14°N 5.04°E (Cfb)	land along the ditches of a former fen grassland, rewetted about 1995 (ch)	*P. australis – T. latifolia*	2006	-2 to 5		87.6	Hendriks et al., 2007
Newport News Swamp, Virginia, USA, 37°N 76.5°W (Cfb)	freshwater marsh, 20 cm organic layer (ch)	*T. latifolia*	1992/93	5 to 20	-896	8	Chanton, 2001
Florida, USA, 30.5°N 84.25°W (Cfa)	lake shore (ch)	*T. latifolia*	1992 to 93	5 to 20	-978, -1139	51.6, 72.0	
San Joaquin Freshwater Marsh, California, USA, 33.66°N 117.85°W (Csb)	freshwater marsh (ec)	*T. latifolia*	1999 to 03	summer – to winter +	136±363		Rocha and Goulden, 2008
Sacramento–San Joaquin Delta, California, USA, 1st site: 38.05°N 121.77°W, 2nd site: 38.11°N 121.65°W (Csa)	former fen pasture, rewetted 2010 (ec)	*T. spp., Schoenoplectus acutus*	2012/13	107	-368	53	Knox et al., 2015
	former agricultural fen, rewetted 1997 (ec)			26	-397	38.7	
Mer Bleue, Ontario, Canada, 45.4°N 75.5°W (Dfb)	freshwater marsh (ec – NEE, ch – CH_4)	*T. angustifolia*	2005 to 09	at surface	−224 ± 54	127 ± 19	Strachan et al., 2015
Ballards Marsh, Nebraska, USA, 42.87°N 100.55°W (Dfa)	freshwater marsh, 10 to 30 cm litter (ec)	*P. australis*	1994	40 to 60		60	Kim et al., 1998
Winous Point, Lake Erie, Ohio, USA, 41.47°N 83°W (Dfa)	freshwater marsh, 20 cm organic layer (ec)	*T. angustifolia – Nymphaea odorata*	2011 to 13	20 to 60	65±92	50.8 ± 6.9	Chu et al., 2015
Lake Vesijärvi, S Finland, 61.08°N 25.50°E (Dfc)	inundated peatland on the shore of an eutrophic lake (ch)	*P. australis*	1997 to 99	10 to 20		33 ± 13.5	Kankaala et al., 2004
		P. australis	1997 to 99	30 to 70		122.3 ± 56.5	
Loch Vale watershed, Colorado, USA, 40.29°N 105.66°W (Dfc)	pristine sedge fen (ch)	*C. aquatilis*	1996 to 98	water saturated	81±4	31.2 ± 2.1	Wickland et al., 2001
Panjin Wetland, Liaoning Province, NE China, 41.13°N	freshwater tidal wetland with silty clay (ec)	*P. australis*	2005	vol. SWC 3% to 46%	-65		Zhou et al., 2009

Formatiert: Englisch (Großbritannien)

121.90°E (Dwa)

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[a] climate type after Köppen and Geiger (Kottek et al., 2006): Cfb – Warm temperate, fully humid, warm summer; Cfa – Warm temperate, fully humid, hot summer; Csb – Warm temperate with dry and warm summer; Csa – Warm temperate with dry and hot summer; Dfb – Snow climate, fully humid, warm summer; Dfa – Snow climate, fully humid, hot summer; Dfc – Snow climate, fully humid, cool summer and cold winter; Dwa – Snow climate with dry winter and hot summer

[b] ch – chamber method, ec – eddy covariance method

[c] annual water level (listed for one or two years, but given as mean ± standard deviation when three or more years) or water level range (water level of dry to water level of wet season)

[d] annual NEE and methane emissions, listed for one or two years, but given as mean ± standard deviation when three or more years

Table A1. Plant species cover of GHG measuring plots in summer 2010 and 2012.

	BA						**BA**						**BA**					
	Eriophorum–Carex						***Carex–Equisetum***						***Phragmites–Carex***					
	2010			2012			2010			2012			2010			2012		
species	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Eriophorum angustifolium	6	6	7	6	6	6												
Marchantia polymorpha	3	2	2						2									
Dicranella cerviculata	3	2	2	3	4	4		6	2									
Juncus cf. *compressus*		1		3	2	2	2	2		2	2	2						
Utricularia intermedia											2	2	7	6	7			
Chara spec.										2		3				1		
green algae												4				2		
Phragmites australis											1		7	8	6	8	8	8
Dicranella heteromalla													2	2	2			
Carex rostrata	2	2	3	2	2	2	7	7	6	7	6	6	3	3	3	3	3	3
Equisetum fluviatile	2			2	2		2	2	2	2	2	2	1	1	1	1		1
Salix cinerea	1	1		1			1	1	1	1			1		4	1		
Drepanocladus aduncus			2										5			2		4
	GK						**GK**						**GK**					
	Carex–Lysimachia						***Typha–Hydrocharis***						***Phragmites–Lemna***					
	2010			2012			2010			2012			2010			2012		
species	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Thelypteris palustris	4					6												
Calamagrostis neglecta	4					2												
Carex elata	2	5	6	8	5	2			7			8						
Carex vesicaria	7	2		3	6	2	2	3		5	5							
Typha latifolia	6	7	6		4	4	6	7	3	6	3	4						
Galium palustre	2	2	2	2	2	2				2	2	2						
Cardamine amara	2	2	1	2	2				1	2	1	2						
Lycopus europeus		2		2	2	2			1		1	1						
Lysimachia thyrsiflora	1	2	2	3	2	2				2	4	2						
Lemna trisulca							2				2			1		2	2	2
Phragmites australis													7	7	8	9	7	8
Stratiotes aloides													1	6			5	2
Drepanocladus aduncus	2	5	2	6	8	3	3	2	2	8	3	7	2			2		2
Hydrocharis morsus–ranae				2	3	2	3	3	2	4	6	3	3	5	4	5	8	6
Lemna minor					2	2	2	1		2	2	2	1	1		2		

Vegetation types of sites studied in Barcianicha: *Eriophorum angustifolium–Carex rostrata*–reed (BA *Eriophorum–Carex*), *Carex rostrata–Equisetum fluviatile*–reed (BA *Carex–Equisetum*), *Phragmites australis–Carex rostrata*–reed (BA *Phragmites–Carex*), and Giel'čykaŭ Kašyl': *Carex elata–Lysimachia thyrsiflora*–reed (GK *Carex–Lysimachia*), *Typha latifolia–Hydrocharis morsus–ranae*–reed (GK *Typha–Hydrocharis*), *Phragmites australis–Lemna trisulca*–reed (GK *Phragmites–Lemna*). Plant cover scale according to Peet et al. (1998): Class 1 = very few individuals, 2 = cover of 0–1%, 3 = 1–2%, 4 = 2–5%, 5 = 5–10%, 6 = 10–25%, 7 = 25–50%, 8 = 50–75%, 9 = 75–95%, 10 >=95%. Species not exceeding cover class 2 are only shown if they meet class 2 in more than two relevés.

Table A2.

Mean ± Std. Error of daytime (PAR > 2 µmol m^{-2} s^{-1}) CH_4 flux rates, PAR, T_{in}, and RH_{in} by plot and chamber type (DF = opaque mixed chamber, TF = transparent mixed chamber, D = not mixed opaque chamber). Values with same letter superscript do not differ significantly at $P < 0.05$ (Mann-Whitney or Kruskal-Wallis test; *post-hoc* non-parametric Nemenyi test), data of *BA Phragmites-Carex II* and *GK Phragmites-Lemna II* from Minke et al. (2014).

Site, plot and date	Chamber type	N	PAR (µmol m^{-2} s^{-1})	T_{in} (°C)	dT_{in} (°C)	RH_{in} (%)	dRH_{in} (%)	CH_4 flux (mg CH_4-C m^{-2} h^{-1})	Methane factor
BA Eriophorum-Carex I	DF	8	685^{a} ± 208	16.6^{a} ± 1.1	1.0^{a} ± 0.2	90.2^{a} ± 2.6	7.5^{a} ± 1.7	2.30^{a} ± 0.10	TF/DF = 1.09
2012-07-18	TF	7	1145^{a} ± 224	17.1^{a} ± 1.5	3.0^{b} ± 0.5	78.6^{a} ± 4.1	3.8^{a} ± 0.8	2.49^{a} ± 0.05	
BA Carex-Equisetum III	DF	7	937^{a} ± 401	17.4^{a} ± 1.4	1.5^{a} ± 0.4	90.1^{a} ± 2.1	5.8^{a} ± 1.7	2.30^{a} ± 0.08	TF/DF = 0.99
2012-07-18	TF	6	851^{a} ± 164	17.8^{a} ± 1.5	1.5^{a} ± 0.3	80.2^{b} ± 3.0	4.2^{a} ± 1.3	2.28^{a} ± 0.08	
BA Carex-Equisetum III	D	14	482^{a} ± 85	15.4^{a} ± 0.7	0.7^{ab}± 0.1	79.4^{ab} ± 2.6	9.1^{a} ± 1.0	0.76^{a} ± 0.03	TF/D = 1.07
2012-09-16	DF	14	535^{a} ± 95	15.6^{a} ± 0.7	0.5^{a} ± 0.1	86.2^{a} ± 1.5	7.5^{ab} ± 0.8	0.80^{a} ± 0.04	TF/DF = 1.02
	TF	13	584^{a} ± 95	15.3^{a} ± 0.6	1.3^{b}± 0.2	75.4^{b} ± 2.3	4.4^{b} ± 0.6	0.81^{a} ± 0.02	
GK Typha-Hydrocharis I	DF	9	869^{a} ± 157	24.3^{a} ± 1.2	1.0^{a} ± 0.2	94.4^{a} ± 1.7	18.1^{a} ± 3.7	16.61^{a} ± 0.43	TF/DF = 1.18
2012-07-12	TF	9	868^{a} ± 149	24.9^{a} ± 0.9	1.4^{a} ± 0.3	88.6^{a} ± 2.7	14.8^{a} ± 2.3	19.52^{b} ± 1.20	
GK Typha-Hydrocharis I	DF	11	821^{a} ± 136	19.9^{a} ± 1.2	0.8^{a} ± 0.2	85.3^{a} ± 3.0	15.5^{a} ± 2.8	14.04^{a} ± 0.24	TF/DF = 1.20
2012-07-13	TF	10	1097^{a} ± 146	20.7^{a} ± 1.4	1.7^{b} ± 0.3	80.3^{a} ± 3.7	11.8^{a} ± 2.1	18.00^{b} ± 0.20	
GK Carex-Lysimachia I	DF	9	923^{a} ± 115	24.2^{a} ± 1.1	1.0^{a} ± 0.2	84.9^{a} ± 3.0	9.2^{a} ± 1.5	14.28^{a} ± 0.22	TF/DF = 1.10
2012-07-12	TF	9	749^{a} ± 111	24.8^{a} ± 1.1	1.5^{a} ± 0.3	82.3^{a} ± 2.9	7.0^{a} ± 1.4	15.76^{b} ± 0.38	
GK Carex-Lysimachia I	DF	11	1207^{a} ± 188	20.1^{a} ± 1.3	1.4^{a} ± 0.2	83.4^{a} ± 3.3	12.7^{a} ± 2.1	14.62^{a} ± 0.33	TF/DF = 1.08
2012-07-13	TF	10	1121^{a} ± 177	21.1^{a} ± 1.5	3.0^{b} ± 0.5	78.8^{a} ± 4.3	7.5^{a} ± 1.2	15.81^{b} ± 0.23	
BA Phragmites-Carex II	D	16	830^{a} ± 130	19.4^{a} ± 1.1	0.6^{a} ± 0.2	81.0^{a} ± 3.2	11.8^{ab} ± 1.8	9.86^{a} ± 1.40	TF/D = 1.01
2012-08-08	DF	16	857^{a} ± 133	19.7^{a} ± 1.1	0.9^{a} ± 0.2	81.9^{a} ± 3.3	13.4^{a} ± 2.2	10.17^{a} ± 1.50	TF/DF = 0.98
	TF	16	735^{a} ± 121	19.2^{a} ± 1.2	0.8^{a} ± 0.1	76.5^{a} ± 3.7	6.0^{b} ± 1.0	9.95^{a} ± 1.51	
GK Phragmites-Lemna II	D	14	707^{a} ± 130	20.6^{a} ± 1.2	0.7^{ab} ± 0.2	70.4^{a} ± 3.2	6.0^{a} ± 1.5	13.70^{a} ± 1.68	TF/D = 1.27
2011-09-21	DF	13	819^{a} ± 125	21.7^{a} ± 1.3	1.0^{a} ± 0.2	71.1^{a} ± 3.1	13.8^{b} ± 1.8	17.42^{a} ± 2.39	TF/DF = 1.00
	TF	12	893^{a} ± 125	23.1^{a} ± 1.0	1.8^{b} ± 0.2	66.5^{a} ±2.5	6.6^{a} ± 1.0	17.46^{a} ± 2.08	

Table A3. Annual fluxes of CO_2, CH_4, and N_2O with confidence intervals

site	year	plot	R_{eco} (g CO_2-C m^{-2} yr^{-1})	GPP (g CO_2-C m^{-2} yr^{-1})	NEE (g CO_2-C m^{-2} yr^{-1})	CH_4 emissions (g CH_4-C m^{-2} yr^{-1})	N_2O emissions (mg N_2O -N m^{-2} yr^{-1})
BA *Eriophorum-Carex*	1th	I	378 (359 to 398)	-496 (-514 to -478)	-118 (-132 to -104)	11 (9 to 14)	-80 (-189 to 21)
		II	358 (338 to 378)	-441 (-449 to -433)	-83 (-102 to -63)	10 (8 to 12)	-89 (-213 to 49)
		III	355 (338 to 372)	-411 (-415 to -406)	-56 (-75 to -37)	10 (8 to 13)	79 (-65 to 245)
	2nd	I	436 (413 to 459)	-444 (-451 to -437)	-8 (-35 to 19)	12 (10 to 14)	32 (-67 to 130)
		II	391 (367 to 414)	-413 (-421 to -406)	-23 (-51 to 6)	11 (9 to 12)	39 (-38 to 115)
		III	390 (379 to 401)	-381 (-387 to -375)	9 (-5 to 23)	11 (10 to 14)	95 (-75 to 284)
BA *Carex-Equisetum*	1th	I	210 (195 to 226)	-287 (-296 to -278)	-77 (-87 to -66)	15 (13 to 18)	-40 (-148 to 71)
		II	245 (227 to 263)	-350 (-362 to -338)	-105 (-115 to -95)	19 (16 to 23)	-21 (-132 to 85)
		III	241 (226 to 255)	-322 (-334 to -310)	-82 (-88 to -76)	17 (14 to 21)	-23 (-203 to 168)
	2nd	I	303 (280 to 326)	-286 (-292 to -280)	17 (-9 to 43)	10 (8 to 13)	-28 (-110 to 56)
		II	353 (334 to 372)	-331 (-335 to -327)	22 (2 to 43)	14 (13 to 19)	-84 (-150 to -12)
		III	323 (300 to 347)	-290 (-295 to -284)	34 (10 to 57)	14 (12 to 16)	-113 (-296 to 79)
BA *Phragmites-Carex*	1th	I	498 (473 to 522)	-967 (-999 to -935)	-469 (-517 to -421)	32 (26 to 39)	-515 (-833 to -226)
		II	693 (646 to 741)	-1555 (-1600 to -1509)	-861 (-942 to -780)	46 (34 to 57)	356 (-246 to -982)
		III	650 (594 to 705)	-902 (-921 to -884)	-253 (-318 to -188)	48 (36 to 61)	-75 (-487 to 335)
	2nd	I	615 (562 to 669)	-963 (-980 to -947)	-348 (-410 to -285)	30 (21 to 35)	-63 (-977 to 849)
		II	769 (691 to 848)	-1122 (-1136 to -1108)	-353 (-437 to -269)	45 (36 to 57)	-466 (-943 to 849)
		III	732 (680 to 785)	-1018 (-1052 to -984)	-286 (-360 to -212)	32 (24 to 42)	87 (-174 to 374)
GK *Typha-Hydrocharis*	1th	I	877 (836 to 918)	-801 (-813 to -790)	76 (36 to 116)	59 (49 to 73)	95 (-673 to 886)
		II	923 (912 to 934)	-831 (-844 to -817)	92 (74 to 111)	59 (47 to 73)	130 (-279 to 533)
		III	963 (942 to 984)	-680 (-697 to -663)	284 (263 to 304)	61 (44 to 83)	220 (-52 to 515)
	2nd	I	1104 (1046 to 1161)	-1446 (-1480 to -1412)	-342 (-424 to -261)	63 (51 to 75)	151 (-124 to 449)
		II	827 (816 to 838)	-870 (-881 to -859)	-43 (-60 to -27)	65 (50 to 82)	74 (-223 to 372)
		III	988 (972 to 1005)	-943 (-967 to -919)	46 (20 to 72)	77 (59 to 103)	76 (-111 to 257)
GK *Carex-Lysimachia*	1th	I	1124 (1090 to 1158)	-962 (-989 to -934)	162 (135 to 189)	86 (74 to 100)	-137 (-677 to 419)
		II	1167 (1124 to 1211)	-1065 (-1084 to -1047)	102 (60 to 144)	72 (59 to 86)	162 (-160 to 505)
		III	1024 (1005 to 1044)	-792 (-814 to -770)	233 (206 to 259)	101 (75 to 140)	-91 (-358 to 160)
	2nd	I	1246 (1224 to 1268)	-811 (-837 to -785)	435 (395 to 475)	84 (65 to 121)	100 (-140 to 346)
		II	1331 (1296 to 1367)	-1205 (-1248 to -1162)	126 (56 to 196)	67 (56 to 82)	-56 (-220 to 88)
		III	1233 (1219 to 1246)	-1146 (-1188 to -1104)	87 (42 to 132)	102 (76 to 162)	229 (-128 to 599)
GK *Phragmites-Lemna*	1th	I	921 (892 to 949)	-1446 (-1511 to -1380)	-525 (-607 to -443)	113 (88 to 139)	58 (-524 to 684)
		II	767 (729 to 804)	-1516 (-1568 to -1465)	-750 (-827 to -673)	61 (43 to 83)	-101 (-783 to 548)
		III	1121 (1037 to 1206)	-1680 (-1737 to -1623)	-559 (-623 to -495)	112 (73 to 164)	468 (-256 to 1176)
	2nd	I	1170 (1122 to 1219)	-2678 (-2745 to -2611)	-1507 (-1584 to -1431)	87 (65 to 113)	99 (-652 to 872)
		II	970 (929 to 1012)	-2235 (-2362 to -2108)	-1265 (-1381 to -1149)	77 (57 to 110)	-437 (-1017 to 140)
		III	1135 (1062 to 1208)	-1887 (-1939 to -1836)	-752 (-825 to -679)	139 (86 to 202)	330 (-253 to 937)

Uncertainties of CO_2 balances on the plot level were calculated as 50% of the difference between the H-Approach and the LS-Approach plus the 90% CI's of the H-Approach. Plot level uncertainties for CH_4 represent the 90% confidence intervals (CI's) of the models, but for N_2O only the 90% CI's of the measured N_2O fluxes.

Figure 1. Location of the study sites

Figure 2~~1~~. Cumulative monthly precipitation (bars) and average monthly air temperatures (dots) for Barcianicha (A) and Giel'čykaŭ Kašyl' (B). Actual temperatures (black) were measured in (A) Višnieva, 5.6 km NW of Barcianicha, and (B) Z'dzitava, 6.3 km NE of Giel'čykaŭ Kašyl'. Actual precipitation data (black) and 30 year averages (1979–2008) of temperatures and precipitation (grey) are from meteorological stations of ~~"~~“Gidrometcentr~~"~~” in (A) Valožyn, 15 km E of Barcianicha, and (B) Pružany, 54 km WNW of Giel'čykaŭ Kašyl'.

Figure 3~~2~~. Diurnal variation of methane emissions, measured with different chamber types, and outside PAR, at BA *Eriophorum*–*Carex* (plot I, 18 July 2012), BA *Carex*–*Equisetum* (plot III, 16 September 2012), BA *Phragmites*–*Carex* (plot II, 8 August 2012), GK *Typha*–*Hydrocharis* and GK *Carex*–*Lysimachia* (both plot I, 12 Jul 2012 and 13 July 2012), and GK *Phragmites*–*Lemna* (plot II, 21 September 2011). Data of BA *Phragmites*–*Carex* and GK *Phragmites*–*Lemna* are from Minke et al. (2014).

Figure 4~~3~~. Mean daily air temperature (a~~A~~) and mean daily PAR (b~~B~~) at Višnieva (a, b) and Z'dzitava (l, m), ~~and~~ mean daily water table positions~~ (C, D, E)~~, mean daily measured (points) and modeled (lines) CH_4 fluxes~~ (F, G, H)~~, and mean daily modeled (~~APPROACH ONE~~H-approach) GPP, and R_{eco} (I, J, K) of Barcianicha (c to k) and Giel'čykaŭ Kašyl' sites (n to v).

~~**Figure 4.** Mean daily air temperature (A) and mean daily PAR (B) at Z'dzitava, and mean daily water table position (C, D, E), mean daily measured (points, for F and G multiplied with 1.2) and modeled (lines) CH_4 fluxes (F, G, H), and mean daily modeled (APPROACH ONE) GPP and R_{eco} (I, J, K) of Giel'čykaŭ Kašyl' sites.~~

Figure 5. Annual CO_2 (NEE, R_{eco}, GPP), CH_4 and N_2O fluxes at Barcianicha (a~~A~~, ~~C~~c, ~~E~~e) and Giel'čykaŭ Kašyl' (b~~B~~, ~~D~~d, ~~F~~f). Uncertainties for CO_2 fluxes are 50% of the difference between both modelling approaches plus the 90 % confidence intervals of the ~~APPROACH ONE~~H-approach. Uncertainties for CH_4 represent 90 % confidence

intervals of the models, but for N_2O only 90 % CI of the measured N_2O fluxes. Light grey = 1st year, darker grey = 2nd year. Plots are ordered I, II, III.

Figure 6. ~~Correlations~~ Scatter plots of~~among~~ annual NEE, R_{eco}, GPP, CH_4 emissions, median annual water levels (both years for all plots, n = 36), and above ground biomass carbon (second year for all plots, *n* = 18). Spearman's *ρ* significant at ' *P* ≤ 0.05; * *P* ≤ 0.01; ** *P* ≤ 0.001; *** *P* ≤ 0.0001. Spearman's *ρ* in brackets without GK *Typha–Hydrocharis* and GK *Carex–Lysimachia* (*n* = 30 for correlations among water levels and fluxes; *n* = 15 for correlations among biomass and fluxes). Small symbols indicate first year, large symbols second year.