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Biogeosciences Discussions

Interactive comment on "Microbial activity, methane production, and carbon storage in Early Holocene North Sea peats" *by* Tanya J. R. Lippmann et al.

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We thank the reviewer #2 for their considered and constructive comments on this manuscript. We provide a response to each comment below.

Reviewer 2: Anonymous Referee #2 Received and published: 19 February 2021

Reviewer 2 Note from reviewer: I do not have expertise in the experimental elements of this manuscript, thus my critique of microbial activity, gene sequencing and methane pro- duction is limited. General comments This manuscript documents a significant carbon store in the North Sea during the last glacial-interglacial transition, with exper-

iments to understand the precise microbial activity and methane production/potential. The authors use gene-based sequencing to understand the microbial community structure and to explore the role and potential of peat microbial communities in carbon (methane) cycling. A key contribution of this work is quantifying these peats via observations/measurements and incubation experiments to determine the carbon storage potential with implications for better understanding the role of peat deposits in the global carbon budget. This manuscript is well written and contributes important knowledge for better understating the role of buried peats in the carbon cycle. Two overall suggestions (1) keep discussion and result separate. For example, "capped by either shallow marine clay or sands" should perhaps move the 'shallow marine' interpretation to the discussion section. There are countless other examples of discussion embedded into the results section, for example starting at L477-L484. This would help with the organization of the manuscript. Also (2) perhaps place more emphasis on the global implications of this work for the carbon budget ie. How much does this change our estimates of carbon stores? What are the potentials for this carbon to be released in the future? Are there any other regions where a similar peat has been deposited?

R: When writing the manuscript, we found that limited interpretation of the results was required when explaining analyses that compare different experimental techniques (e.g. Fig. S4). We have revised the results section to keep this to a minimum.

L358: In the geological literature, it is common practice that lithographic descriptions include the sediment origin. Therefore, it is our opinion that "capped by either shallow marine clay or sands" is an observation, not an interpretation. We will modify L358 to reflect that this description is observational: "The localized nature of this landscape is apparent in the lithographic differences observed between and within sites (Fig 2). Peat deposits lie upon Pleistocene sands, capped by marine clays, at all sites. At some sites the overlying clay layer is stratified by marine sands (i.e. Dorthea Shallow SW, Dorthea SSW, Dorthea NW, Fredricksborg NE, Fig. 2) ."

We will move L170-L174, " Peat was recovered at all sites, except Easting Down, Stor-

mvogel, and Darci's site." to L357 of the results section.

We will move L361-364, "The basal-peat developed due to rising groundwater as a result of the postglacial sea-level rise and was quickly capped by rapidly deposited clays and subsequent sand deposits in most instances or directly capped by sand in others." to create a new paragraph at L605 the discussion. We would like to add the following sentence to this paragraph, "We hypothesise that rapid flooding of the peatland led to the generation of large volumes of methane. In instances where this methane has neither escaped (by ebullition) or been consumed (by methanogens), it remains trapped by the porosity of the peat. Future studies may consider isotopic analysis as an indicator of origin."

Move: L390-L393, "The highest concentration of CH4 was observed at the Vittorio site, at the latitude of Vlieland. The Vittorio site had the second thickest peat layer in this study, but the thickness of the peat layer does not appear to play a determining role in CH4 concentrations, as both thick and thin peat layers harboured both high and low CH4 concentrations." to L631 of the discussion.

Move L409-L12, "The period of active peat formation depended on the ability of peat formation to keep up with the rising groundwater table and on hydrological conditions; e.g., peat formation commenced earlier in areas with a less permeable substrate than in areas with a sandy substrate" to L701 of the discussion.

Move L477-483, "It is striking that the same three-step bryophyte dominated sequence of Sphagnum-Tomentypnum nitens-Warnstorfia/Drepanocladus occurs in both geographically as well as temporally different sites. However, in contrast to the sequence of the Max Gundelach site, where Sphagnum magellanicum is present only at the start of the sequence, Sphagnum papillosum is present throughout the peat deposits at the Fredricksborg NE site. In general, plant remains are better preserved in the layers dominated by Sphagnum spp. than in those dominated by brown mosses." to L691 the discussion.

To quantify this carbon budget in relation to other carbon stock, we will add the following to L625, "The 741 Tg C stored in these submerged peats is equivalent to 70% of the C stored in Dutch peatlands today (1,030 Tg-C), and equivalent to 2.4% of the C stored in globally, the largest peatland C storage facility, the Congo Basin complex (30,600 Tg-C, Dargie et al., 2017)." We will add the following sentence to explain the mechanisms that could release this carbon into the atmosphere, "This carbon store has the potential to be released into the overlying water column in the occurrence of a marine seep, that could be either naturally initiated or an outcome of fossil fuel extraction (see Schneider von Deimling et al. 2015)."

We will quantify the CH4 budget in relation to global CH4. We will add the following to L632, "If released in one go, the 0.411 Tg-CH4, stored in these submerge peats is equivalent to approximately one quarter of the annual biogenic oceanic CH4 emissions (2 Tg yr-1), and one month of the CH4 emissions from all oceanic sources that were reported in 2000-2009. If released in one go, this amount is equivalent to approximately one month of the global atmospheric CH4 growth reported for the years, 2000-2009 (5.8Tg yr-1) or 1.5 weeks of the global atmospheric CH4 growth that occurred in 2017 (16.8 Tg yr-1)."

Reviewer 2 Specific comments Reviewer 2 L70 – "ice sheets reaching as far south as the Doggerbank area were subjected to strong glacio-isostatic adjustment" – ice sheets were subject to GIA? Or the earth was subject to GIA? please clarify.

R: Thank you for picking this up. We will edit the sentence to, "During the Last Glacial Maximum, the basin floor of the study area was subjected to strong glacio-isostatic adjustments (Vink et al., 2007)."

Reviewer 2 L95 – "task of measuring CH4 stores remains challenging" – why is this the case?

R: We will add the following sentence to L95. "Despite extensive efforts to map basal-peats at the global scale in recent decades (Treat et al., 2019; Xu et al., 95 2018), most

basal-peats are submerged beneath ocean sediments which are hard to reach, meaning accessing and measuring CH4 stores remains challenging (Dean et al., 2018)."

Reviewer 2 L145 – why were these sites chosen for microbial sequencing? This is unclear. Do they provide good spatial coverage that is representative of the region?

R: We chose to divide the experiments over the different sites in order to obtain the maximum amount of information possible, while taking the experimental constraints into consideration. Due to limitations in the available sample amounts we were not able to carry out both the incubation studies and the amplicon sequencing on the cores of the first sampling expedition. We will clarify in L394-396: "Unfortunately, the cores from the first sampling expedition did not provide enough material to perform both sequencing and the incubation experiments. Therefore, four sites (Fig. 2a-d) representing both high and low CH4 concentrations were chosen from the 2017 cruise (southern North Sea) for 16S rRNA gene-based sequencing to unravel the microbial community structure. Subsequent to the 2018 cruise (mid-Northern North Sea), a second cluster of four sites (Fig. 2e-f) were chosen to investigate the role and potential of in situ microbial communities in CH4 cycling."

Reviewer 2 L213 – same as above. why were these particular sites chosen for microbial sequencing? This is unclear.

R: As above.

Reviewer 2 L325-327 – this mixture of high/low sampling resolution and high/low taxonomic resolution is interesting. Perhaps an extra line on why this technique was chosen?

R: We propose to replace L325-L327 with the following text: "The Max Gundelach site, was analysed with low sample resolution but high taxonomic resolution, showing the main peat components as well as an overview of the less abundant taxa. As the less abundant taxa were, in this research, not highly relevant we analysed the Fred-

ericksborg NE site with high sample resolution but low taxonomic resolution, showing only the main peat components. The sites can be compared based on the main peat components."

Reviewer 2 L391 – " the thickness of the peat layer does not appear to play a determining role in CH4 concentrations, as both thick and thin peat layers harboured both high and low CH4 concentrations" – this is an interesting finding of this work, with implications for carbon modelling of paleo-peatlands. Is it possible to show this graphically? A quick plot showing thickness vs. CH4 concentration?

R: We will adjust Figure 3, the methane depth profiles, to include the peat thickness and will adjust the figure caption as follows: "Depth profiles of methane concentrations at all sites in μmol L-1. The yellow line indicates the average methane concentration across all measurements. The green line indicates the average methane concentrations of seawater, measured in the same area (Borges et al., 2016). The pink shaded regions are indicative of peat. Note the varying y axes."

Reviewer 2 L420 – The header suggests that this section will contain information on plant macrofossil communities, but there is no such information here.

R: Section 3.4 includes the following subsections, consistent with the Biogeosciences guidelines: '3.4.1 Local vegetation succession in the southern North Sea', '3.4.2 Local vegetation succession in the mid North Sea at Doggerbank', '3.4.3 Local vegetation succession is analogous across sites'.

Reviewer 2 L489 – given the high spatial vari- ability in peat thickness, I would expect to see (large?) errors on this estimate. What uncertainties were incorporated into this calculation and how do they impact the result- ing error?

R: We will include the following after L185 of the methods, "The minimum and maximum peat layer thickness' were used to calculate the lower, and upper estimates of total peat volume, and total CH4 minimum and maximum error using the following formula: Total

CH4 = V * CH4 Where V is peat volume (m-3), CH4 concentration (μmol L-1) was calculated using measured sediment porosity, and the mean CH4 concentration was calculated using all samples."

Reviewer 2 L614 – what is meant by "from a similar period"? is this referring strictly to the time interval, or the sequence of events (SL rise) that would cause these peats to be buried?

R: We will clarify this sentence: "These findings may indicate that other basal-peats that formed during the LGM, have the potential to function as CH4 storage facilities and address an important gap in the inventory of global marine carbon, CO2, and CH4 budgets."

Fig. 1 – Does the 3rd panel "North Sea basin" refer to present-day condi- tions? It might be worth clarifying. Fig. 1 caption – "The distribution of tsites within this sampling area" – sites?

R: We would like to change the 3rd panel of Fig 1 to "North Sea basin (present day conditions, human-induced climate warming, rising sea levels)". Fig 1 caption should indeed be, "sites" and not "tsites". Thank you for picking this up.

We have used a new citation that we will include in the reference list: Dargie, G., Lewis, S., Lawson, I. et al. Age, extent and carbon storage of the central Congo Basin peatland complex. Nature 542, 86–90 (2017). https://doi.org/10.1038/nature21048

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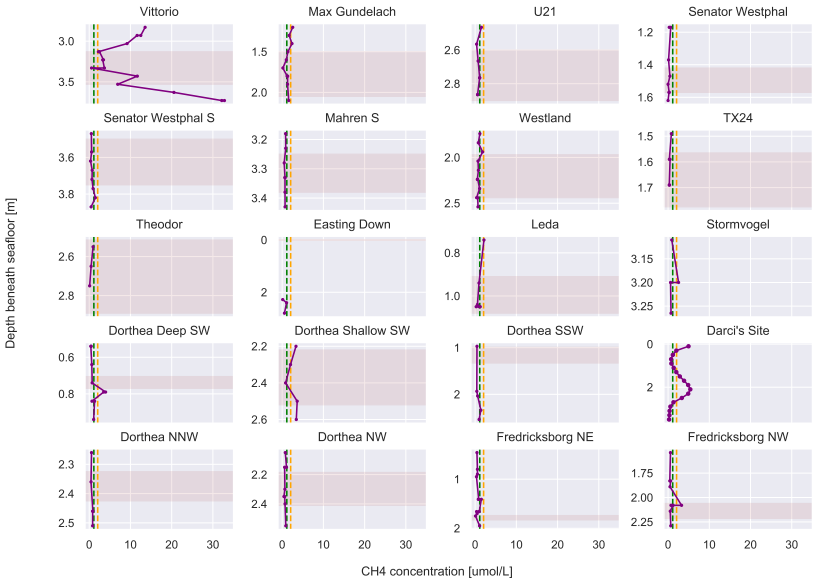

Fig. 1.