Reviewer #1

Muller et al., explores the carbon storage and accumulation in the Helgoland mud area and show high carbon accumulation especially in areas under the direct influence pf the Elbe. The rates of carbon accumulation in these muds is equivalent to those in the Skagerrak and Norwegian Trough two of the key depositional environment in the North Sea. This work highlights that the carbon storage and accumulation potentially of Helgoland mud area have been overlooked and shows the muddy depositional area need to be investigated more closely.

This manuscript will be of interest to a broad audience and after some minor revisions will be ready for publication.

Author's response: We would like to thank the reviewer for the thoughtful and constructive feedback on our manuscript.

Line 83 - As part of the BMBF-funded collaborative project APOC (Anthropogenic impacts on particulate organic carbon cycling in the North Sea), this is an acknowledgment and not required in the main text.

Author's response: The statement regarding the project funding was suppressed in the main text and is in the acknowledgement. The project name remains in the main text because it is referred to later in the text.

Line 86 -Should be in the methods. If you mention a detailed literature review, it is now expected that you provide search terms etc. in the supp mat. Since section 4.1. of the results is focused on this data compilation more details are required even with the data archived in Pangea.

Author's response: Line 86 was moved to the materials and methods section (lines 143-145, lines correspond to the manuscript version without track changes). Additional information on the literature review is now given in the supplementary material.

Line 94 - (3) estimate the carbon budget of this significant depocentre in the German Bight of the North Sea. I agree that the first two objectives have been archived but the third on is a push, to make this stronger focus on objective 1 and 2.

Author's response: Thank you for this comment. We reformulated the aim accordingly (line 94-95) and renamed the respective chapter in the discussion: 5.4 Annual organic carbon accumulation in the Helgoland Mud Area.

Line 115 - Although the swept area ratio is low in the HMA the intensity outside is high. Though I suspect impossible to fully quantify how much sediment is resuspended and deposited in the HMA from these activities. Might be useful to mention this process at this point.

Author's response: Indeed, a quantification of the impact of bottom trawling and respective resuspension and transport on the deposition of sediment in the HMA is not possible in the framework of this study. However, the overall contribution of bottom trawling on SPM load, transport and deposition is added in lines 126-128.

Line 135 - multiple corer (MUC) should this be multi-corer?

Author's response: "multiple corer" (MUC) was changed to "multi-corer" in line 148.

Line 147 - Samples were taken at 1-cm-intervals in the top 10 cm and every second centimetre below. Can you clarify if this is the porewater sampling or the intervals the cores were sliced at. I assume it is the porewater if so add a sentence describing the sediment sampling.

Author's response: The intervals are similar for pore-water and solid-phase sampling and clarified in line 159.

Line 187 - Could more details be added to the grain size prep, sample mass, wet or dry, etc.

Author's response: We kept the description of the employed methods brief in the manuscript for better overall readability. The description of chemical sample treatment is found in the following line, which we perceived as the most essential bit of information. All samples were measured in water in the instrument's wet cell and no dispersing agents were used. The sample mass varied and was chosen to fit the technical requirements (the instrument uses a relative scale to represent sample concentration/laser attenuation). For coarser samples, we used an approx. volume of up to 10 ml freeze-dried and unprocessed sample. For finer samples, a much smaller volume was used.

Line 189 - Sediment samples were freeze-dried and both, moisture and porosity, were calculated by the mass loss, assuming a sediment grain density (quartz) of 2.65 g cm-3 (e.g., Anderson and Schreiber, 1965). Was the grain size analysis preparation carried out on dry sample. If so move this be moved earlier in the paragraph.

Author's response: The sentence was moved to lines 168-169.

Line 225 - Why was the CRS model chosen over the others, please provide clarification.

Author's response: The CRS model was chosen since the CFCS is more affected by sediment redistribution due to e.g. bioturbation or physical mixing. Arias-Ortiz et al. (2018) showed that the calculated sedimentation rate using the constant flux, constant sedimentation (CFCS) model deviated by 20 to 95% in a sediment mixing scenario, while the CRS model - using the inventory to calculate the rates - deviated by only 2 to 5%. The statement was added to the materials and methods section in lines 213-216.

Results - The results section provide a good overview of the data and the figures are of high quality and communicate the work well.

Author's response: Thank you very much for the comment.

Figure 8 - The IDW should be introduced in the statistical section of the methods.

Author's response: IDW was added to the statistical section in line 266-267.

Line 527 - Section heading?

Author's response: Line 547 is now numbered as Section 5.2.1.

Figure 12 - were the burial efficiencies calculate in the same manner as this study are they comparable?

Author's response: Please find a detailed description regarding this topic in the reply to reviewer #2 (General comment section).

Section 5.4 - A new paper by Diesing et al, 2024 will be useful in further highlighting the importance of the HMA in comparison to the wider north west European shelf. https://www.nature.com/articles/s43247-024-01502-8

Author's response: Thank you very much for this suggestion. A comparison was added in lines 675-677.

Line 644 - total organic carbon (TOC), why is this being defined in the conclusion, has it not be used before?

Author's response: The abbreviation TOC is now used in line 682.

Reviewer #2

Review of the manuscript egusphere-2024-1632

Muller et al. aim to estimate the capacity of the Helgoland Mud Area (HMA) to store and recycle organic carbon and the factors controlling the efficiency of this preservation. The study site is particularly interesting to achieve this objective because the different zones of the area are subject to different forcing (e.g., trawling, river inputs, origin of organic matter). The authors finally showed the importance of such systems for organic carbon sequestration by estimating the relative contribution of the HMA to organic carbon burial at the scale of the North Sea.

The manuscript presents an interesting data set to improve the understanding and the budget of organic carbon burial on continental shelves. Overall, it is well written but sometimes confusing. It lacks of organization and some figures are not relevant. Although the data set is interesting, the work has too many deficiencies and inaccuracies to be suitable for publication in Biogeosciences. Moreover, it lacks of comparisons with similar environments to be of an international interest.

Author's response: We would like to thank the reviewer for the detailed and insightful comments, which helped to improve the manuscript. We have revised the introduction and the discussion (see lines 640-653 and 675-677, lines correspond to the manuscript version without track changes) to better highlight the implications of our study and its broad international relevance. However, we do not agree with the statement that our paper/study is mainly of a regional interest. As described in our manuscript, to our knowledge, there is no study available so far that has performed a detailed assessment of the factors that control the burial/preservation of organic matter (OM) in fine-grained sediments of the North Sea. We have therefore used the Helgoland Mud Area, which is characterized by a broad range of natural depositional conditions (water depth, sedimentation rates, origin/reactivity of organic matter, etc.) - as a test field or natural laboratory, respectively, to determine the key factors that control OM burial in the North Sea. Only in this way we were able to determine the key factors in the required – and at the same time unprecedented - high spatial resolution – including the extremely time-consuming radiometric analyses (^{210}Pb, ^{226}Ra, ^{137}Cs). In this respect, the results obtained in the framework of this study present key findings for the whole North Sea as well as for shelf seas in general/globally– as these represent the most important seafloor areas for the longterm burial of organic carbon and, thus, key natural sinks for CO_2. Moreover, the North Sea is a crucial area in Europe due to its important role in economy (e.g., offshore energy, fishing activities, navigation) and ecology. Our results are not only important for better a understanding of carbon fluxes and burial in the North Sea, with important implications for estimations of European blue carbon wealth, but also provide key process-understanding that can be applied to all mud belts on continental shelves worldwide.

We thank the reviewer for the suggestion to extend the comparison with similar environments, in order to discuss and complement the global comparison. We included and discuss more studies in similar environments (lines 640-653 and 675-677) in addition to the global comparison and Figure 12.

General comments

Reviewer: The paper is mainly of a regional interest and I think that an entire section of the discussion would have be devoted to a comparison with other environments. In the Figure 12, the burial efficiencies calculated in the HMA are compared with those measured in other marine environments. This comparison is interesting but too general. Indeed, the burial of organic carbon on continental shelves has been studied for some decades and several studies have quantified it in environments that are morphologically similar to the HMA. A comparison with such systems would have been relevant to complement the global comparison presented in the Figure 12.

Author's response: Thank you for this suggestion. Indeed, extending the comparison to similar environments helped to highlight the global relevance of this study. We included more studies in similar environments (lines 640-653 and 675-677) in addition to Figure 12.

Reviewer: Another major concern is related to the estimates of organic carbon accumulation rates and burial efficiencies. Firstly, TOC accumulation rates are estimated from a mean TOC value for each site. However, such estimates are usually made using either surface organic carbon contents to calculate a part of organic carbon inputs to the sediments or organic carbon contents measured at the core bottom to estimate organic carbon burial rates.

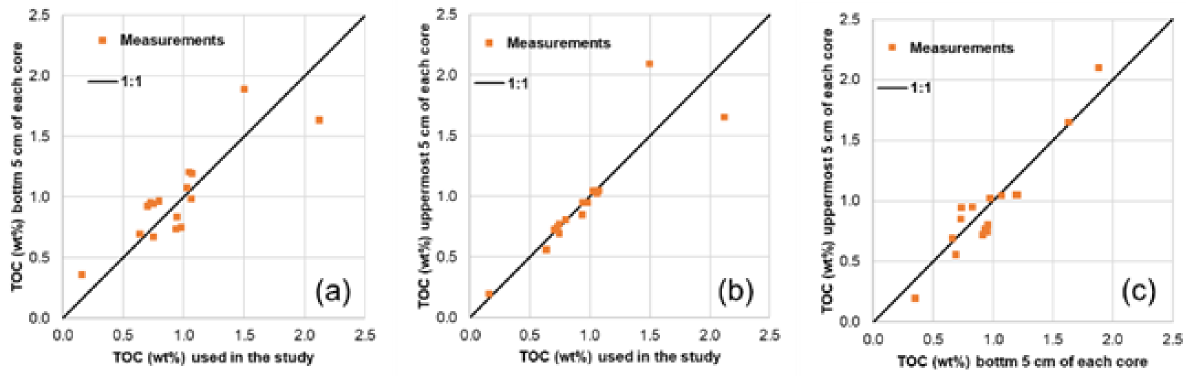

Figure 1: TOC contents (orange squares) of (a) the interval used in the study and the bottom 5 cm of the core, (b) the interval used in the study and the uppermost 5 cm of the core and (c) the bottom 5 cm of the core and the uppermost 5 cm of the core. The black line is the 1:1 relation.

Author's response: We can demonstrate that the TOC contents show no or only little variation over depth and remain almost constant, (Fig. 1a-c). Within the natural variability, we see no clear/systematic deviation from the 1:1 line. Therefore, we consider the values presented in the manuscript and the following calculations using these values to be sound.

Reviewer: Secondly, the organic carbon inputs, used to estimate organic carbon burial efficiencies, are calculated as the sum of aerobic respiration and organic carbon burial rates. For this calculation, it is not clearly indicated which values of TOC are used (i.e., the bottom value, an average of values below the oxygen penetration depth, an average of the last points of the profiles). In addition, such calculations are typically made by summing organic carbon burial rates, calculated from bottom TOC contents, and total organic carbon remineralization rates. However, aerobic respiration rates do not represent the total benthic remineralization. The data show that aerobic respiration is limited to the first 1-2cm of sediment. However, the degradation of organic matter continues below this surface layer as indicated by the profiles of DIC shown in the Figure 3. In addition, since the relative importance of the different pathways of organic matter remineralization is not presented, there are no data to justify that aerobic respiration is the main pathway for organic matter remineralization in these sediments. Accordingly, the values of organic carbon burial efficiencies and the subsequent interpretations are not reliable.

Author’s response: As outlined in the Materials and Methods chapter we calculated the organic carbon burial efficiency as described by Burdige (2007) and van de Velde et al. (2023): we assume aerobic respiration to be responsible for most of the total organic carbon remineralisation since no further decrease in TOC over depth can be seen in our data (see Fig. 1). This is an approach similar to the one in Mouret et al. (2010), Sobek et al. (2011) and Oguri et al. (2022). It is correct, that we did not consider anaerobic remineralisation independently. However, previous studies have demonstrated that in depositional settings characterised by oxic bottom-water conditions, aerobic respiration is the dominant pathway of organic matter degradation. Moreover, diffusive oxygen uptake was shown to indirectly also include anaerobic degradation pathways because part of the oxygen is consumed by oxidation of reduced reaction products liberated into pore water as a consequence of anaerobic mineralization pathways (e.g., Wenzhöfer and Glud, 2004; Glud, 2008 and references therein). As reviewed by Glud (2008), this allows to use oxygen consumption rates as a reasonable estimate for organic carbon mineralisation. We have quantified the possible offset by the fraction of anaerobic remineralisation and considered it justified to use our present data for comparison of OC BE within the HMA and with literature data, in particular as there is no standard approach (for various approaches see Henrichs and Reeburgh, 1987; Aller, 1998; Ogrinc et al., 2003; Sobek et al., 2011; Sampere et al., 2011; Baloza et al., 2022). In our opinion, the application of a full diagenetic model to address anaerobic remineralisation processes exceeds the scope of this study and is subject of a follow-up manuscript currently in preparation.

Reviewer: Finally, the efficiency of TOC preservation is partly discussed by comparing the mean TOC contents of different stations. As it is indicated that the area is fueled with particles of different origins, this approach is not reliable.

Author’s response: It is correct that (1) we compare the TOC contents and therefore the preservation of OC in the study area and (2) that different sources deliver OC to different areas within the HMA. However, this is exactly what we discuss: the difference in origin, and hence reactivity, is - besides the oxygen exposure time/sedimentation rate - a key factor for the preservation and burial (efficiency) of OC on shelf sediments.

Reviewer: For example, the influence of bottom trawling on organic carbon preservation is estimated by comparing TOC contents at three stations (W, Cdeep, NW). However, the three sites have different grain-size and the site with the lowest TOC contents is the one where the sediments are coarser (D50~58µm versus 26-30µm for the others). Therefore, it is likely that the difference in TOC contents is due to the difference in grain size rather than to an influence of bottom trawling on organic matter remineralization.

Author’s response: Thank you for this comment. We would like to point out that the comparison of the 3 stations in light of bottom trawling is a side aspect in the discussion where we merely provide evidence for an impact in context of the current literature. Regarding the reviewer’s argument, we agree that the grain sizes indeed differ between the sites (coarser at the frequently trawled site, finer at the other two). However, we think this is no reason not to evaluate the impact of bottom trawling on the preservation of OC at these sites. Bottom trawling not only enhances the oxygen exposure time and hence aerobic remineralisation but also causes resuspension of the sediments, preferentially affecting fine particles as shown by e.g. O’Neill and Summerbell (2011). Thus, bottom trawling reduces the resilience of the sediment to resuspension (Bruns et al., 2023). Recurrent bottom trawling at the same site and natural events will then lead to increased sediment remobilization (Bruns et al., 2023) and result in coarser residual sediments (Mengual et al., 2016). We added this aspect in this section accordingly, to make this point clear (lines 569-572).

Specific comments

Title: I suggest to replace “test field” by “case study” or to modified the title such as: “Depositional controls and budget of organic carbon burial in fine grained sediments of the the Helgoland Mud Area (North Sea)”

Author’s response: The title has been changed from “Depositional controls and budget of organic carbon burial in fine-grained sediments of the North Sea – the Helgoland Mud Area as a test field” to “Depositional controls and budget of organic carbon burial in fine-grained sediments of the North Sea – the Helgoland Mud Area as a natural laboratory” to reflect the intention of this study to use the most important depocentre in the German Bight as a representative natural laboratory to assess of the factors controlling the organic carbon burial in fine-grained coastal and shelf sea sediments.

l. 20 – « lowest TOC contents ». Precise the range of values between brackets.

Author’s response: The TOC content ranges from 0.7 – 1.0 wt% in the shallow eastern HMA and has been added in line 21.

l. 55 – 57 – The authors only mentioned the free-energy yield of aerobic respiration to justify that it is a key process for organic carbon preservation. However, some labile compounds are as efficiently degraded in oxic as in anoxic conditions. The sentence should be modified to precise that the effect of oxygen exposure time is mainly relevant for refractory organic compounds.

Author’s response: An addition to the statement has been made in line 59.

l. 58: The bottom trawling should be mentioned as a process that could enhance the exposure time of organic matter to dissolved oxygen.

Author’s response: Bottom trawling has been added as a process enhancing oxygen exposure time in lines 61-64.

l. 62 - 65: The sentence from “Natural sediment” to “prolonged aerobic respiration” develops the same idea that the sentence at the beginning of the paragraph. The paragraph should be revised to avoid repetitions.

Author’s response: Thank you for this comment. The paragraph was revised accordingly.

l. 75 – 77 : The sentence “In these cohesive sediments diffusion is the dominant transport process and oxygen only penetrates a few millimetres into the sediments, leading to the establishment of anoxic conditions at shallow sediment depth that enhance the build-up of OM” develops an idea with no links with the previous and following sentences and so confuses the paragraph. I recommend to suppress this sentence to clarify the text.

Author’s response: Thank you for this comment. The statement regarding the build-up of OM in fine-grained sediments has been revised and contextualised to clarify the text (lines 76-79).

l.79: “these seafloor habitats characterized by high organic carbon burial efficiencies”. Precise the typical range of burial efficiencies observed in these environments to justify this affirmation.

Author's response: The statement was reformulated in the text (lines 80-83).

l.100: Precise the tidal range and the mean significant wave height to justify that the area is subject to a high hydrodynamics.

Author's response: The tidal range and significant wave heights have been added in the text. Lines 101-104 read now: The southern North Sea is characterised by high tidal and wave energy regimes with a tidal range of ~ 1.5 to 3 m and significant wave height during storm events up to 5 m in the German Bight (Hagen et al., 2021). Seafloor processes are mostly characterised by local transport and resuspension of material in sand-rich sedimentary environments (Figge, 1981; de Haas et al., 1996; Zeiler et al., 2000; de Haas et al., 2002).

On the Figure 1a, the blue point representing the dumping site is not well visible because the bathymetry is also represented in blue.

Author's response: The colour of the dot representing the dumping site in Fig. 1 was changed to orange for better visibility.

In the introduction, it is indicated that sedimentation rates have already been estimated in the studied area. The range of mean sedimentation rates previously estimated has to be presented in the section "Study area".

Author's response: The range of previously estimated sedimentation rates and the respective methods have been added to the section "Study area" (lines 117-124).

l. 113: Precise the discharge of the Elbe and Weser rivers to give an idea of their potential importance on sediment inputs.

Author's response: The discharge was of the Elbe and Weser rivers was added in lines 115-116.

l. 123-124: The reason of the deposition of fine sediments in the study area is discussed with no clear conclusions. These sentences should be revised based on recent literature. For example, Walsh and Nittrouer (2009) have detailed several types of fine-grained depositional environments influenced by rivers and presented systems with the same morphology of the HMA.

Author's response: Due to the complex hydrodynamic situation in the German Bight, the HMA cannot be classified according to the classic estuarine and shelf deposition presented by e.g., Walsh and Nittrouer (2009). However, this is an ongoing research topic within the project APOC. The statement has been reformulated (lines 134-135).

l.134-135: Precise what are the different depositional environments studied, at least in brackets.

Author's response: The different depositional environments have been added in brackets in lines 146-147.

It is not necessary to precise the place where the analyses were performed. This makes the text heavy. The description of the methods is enough.

Author's response: These parts of the text have been suppressed in the method section.

There is no indication that oxygen concentrations were monitored during the measurements of oxygen profiles. Was the bottom water saturation at 100%? If not, the oxygen saturation in the overlying water of the core has to be controlled/monitored to ensure that *in situ* conditions are reproduced.

Author's response: Indeed, bottom water oxygen concentrations were close to saturation (CTD data, not shown) and bottom water oxygen contents averaged at 94,8 % at the sediment-water interface, with two outliner measurements at 65 % and 79 % at sites S and E, respectively. Bottom water oxygen saturation has been added to the text (lines 377-379).

l. 184: Please add a symbol on the Figure 1a to highlight the stations selected for grain size analyses. However, it is quite difficult to visualize the transects.

Author's response: As requested, a table showing for which sites grain size analyses (a.o.) were carried out has been added at the beginning of the results section. Furthermore, the sites for which grain size measurements were performed are shown in Figure 8b. In order to maintain clarity of Fig. 1a, no additional information was added to Fig. 1.

It is indicated that the samples for particulate analyses were freeze-dried (l. 189, l. 200) but they were stored at 4°C and not frozen (l. 152-153).

Author's response: Sediment sample aliquots were frozen before freeze-drying. This was added in line 168.

Precise the reproducibility of radionuclides measurements between the gamma and the alpha detector.

Author's response: The reproducibility of the radionuclide measurements between gamma and alpha spectrometry was evaluated for four samples from all three cores analysed by alpha spectrometry. All cross-measurements agree within 1 sigma uncertainty (Fig. 2). An addition has been made to the text in lines 208-210.

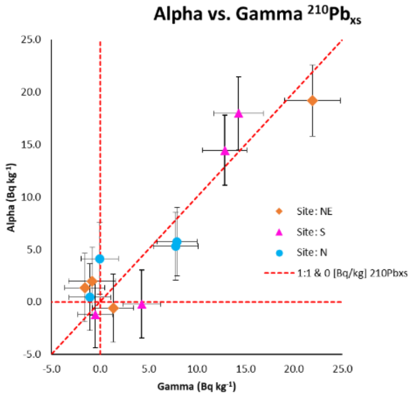

Figure 2: Reproducibility measurements between alpha and gamma spectrometry. The red dashed lines are the 1:1 relation and 0 Bq kg^{-1}.

l. 230-234: The reproducibility of TOC measurements has to be precise.

Author's response: The reproducibility of the TOC measurements was added to the manuscript: Based on replicate analyses of two different standards, the precision (relative standard deviation in percentage) was 1.23 % for the standard of 0.99 wt% (n=15), and 1.34 % for the standard 5.00 wt% (n=7) (lines 224-225).

l. 250-253: This has already been indicated in the introduction. As the sentences do not bring additional information, they can be suppressed.

Author's response: We decided to keep this paragraph in the results since this section provides the results of the literature survey in more detail (in which time frame, number of studies/cores). As Reviewer #1 suggested, line 86 has been moved to the materials and methods section (lines 143-145) and more details were added to the supplementary material.

I recommend placing the Figure 2 in supplementary material. Moreover, a table synthetizing the parameters measured at each station would be useful because all the parameters were not measured at all sites.

Author's response: Figure 2 was moved to the supplementary material. Table 2 shows now the overview of all parameters determined at each site.

The Results section is confusing partly because of the order in which the data are described. I recommend starting with a description of the physical properties of the sediments, then the age models, then the TOC contents and finally the origin of organic matter and aerobic remineralization.

Author's response: The Results sections have been reorganised accordingly. The Materials and Methods sections have also been reorganised to ensure consistency.

Rather than presenting oxygen profiles in supplementary materials, it would be more relevant to make a synthetic figure with the profiles and to include it in the results section.

Author's response: A synthetic figure (Fig. 7) of the oxygen profiles has been added to the results section.

Table 2: Explicit the unit of porosity because porosity usually has no unity.

Author's response: Porosity has no unit, it is given as rel. = relative. It has been changed to (-) (Table 3).

Figure 5: Explain more clearly the reasons why there are subsurface Pb_{xs} maximums on several cores.

Author's response: Please, see the detailed comment below in which we also discuss this topic.

The profiles of $^{210}Pb_{xs}$ are sometimes noisy or present several maximums (e.g., N, W, Cdeep, SC, SE). Some anomalies may be related to grain size changes. Accordingly, the profiles of grain-size should be presented next to the $^{210}Pb_{xs}$ profiles or, if they are not available, the profiles of porosity. Due to these anomalies that are not explained in the manuscript, it would be better to estimate a sedimentation rate from a linear regression of the $^{210}Pb_{xs}$ profiles and to adjust the model thanks to Cs data rather than estimating sedimentation rates according to ages as it is done in the Figure 6. Indeed, these sedimentation rates likely integrate the noise of the profiles and do not represent realistic variations of the sedimentation. If the sedimentation is fairly constant, the linear regression give robust sedimentation rates that could be extrapolated on the entire core.

Author's response: Thank you for this comment, it shows that our careful assessment of different age models was not completely clear in the text. As requested, the porosity and grain size profiles are now shown next to the radionuclides (Fig. 2).
To the pattern of $^{210}Pb_{xs}$ and subsurface maxima: It is true, that the profiles are somehow noisy and show subsurface maxima. The small-scale maxima (e.g., site W at 19.5 and 25.5 cm) could be the result of storm events as described by van der Zee et al. (2003) using ^{210}Pb data and an X-radiograph. The upper subsurface maxima - close to the sediment surface - is most likely a sediment-mixing signal. Arias-Ortiz et al. (2018) describe such $^{210}Pb_{xs}$ profiles in detail. The profiles can be altered by sediment mixing ("backwards bend" at the top of the sediments, similar activity over a mixing interval or a linear rather than exponential pattern), or be a result of rapid MAR (mass accumulation rate) changes (added in line 213-216 and line 397-399). Since various studies indicate sediment mixing in the German Bight/HMA (Hintzen et al., 2012; Oehler et al., 2015; Wrede et al., 2017; Thünen Institute, 2018) we attribute these changes to sediment mixing rather than rapid changes in MAR.
To the calculation of the sedimentation rate: The underlying truth/assumption of any age model is to assign a certain age to a certain depth in the sediment and applies to both the CRS and the CFCS. The calculations performed here follow the compilation of formulas presented by Sanchez-Cabeza and Ruiz-Fernández (2012). For the CRS in short: an age is assigned to every layer and the cumulated mass is calculated, delivering a respective MAR. Using the MAR and porosity the sedimentation rate is calculated (for more details see Sanchez-Cabeza and Ruiz-Fernández, 2012).
To the suggestion to use a linear regression model: The linear regression model assumes constant flux and constant sedimentation (CFCS). Arias-Ortiz et al. (2018) quantified the impact on age models/sedimentation rates of different processes altering $^{210}Pb_{xs}$ profiles. They showed that the calculated sedimentation rate using the CFCS model deviates by 20 to 95 % in a sediment mixing scenario, while the CRS (constant rate of supply, used in this study) using the inventory to calculate the rates deviated only by 2 - 5 %. This was added to the text in lines 213-216. Since we assume mixing to be a relevant process in the HMA, we chose the CRS model and used the ^{137}Cs as an independent time marker, rather than fixing our model to the ^{137}Cs activity. In our case, at site W (affected by mixing), the CFCS model deviates by ~15 % from the CRS model.
To the integration of the "noisy" signal: We quantified the impact for site W with the two subsurface maxima at 19.5 and 25.5 cm. If we use an interpolation excluding those higher activities the sedimentation rate using the CRS age model changes by only 3 % (or 0.1 mm yr^{-1}) and can thereby be neglected. This has been added in lines 310-312.

l. 382-384: Describe the typical shape of the profiles affected by mixing.

Author's response: Examples of $^{210}Pb_{xs}$ profiles affected by sediment mixing are now given in lines 407-409.

l. 394-395: It is indicated that no prediction on changes on sedimentation rates can be made with the method used. However, it is what it is represented in the Figure 6. According to the discussion, I recommend to remove the Figure 6. The values of interest are already presented in the Table 3.

Author's response: It is true that it is not possible to describe changes in sedimentation rates without over-interpreting the system. Nevertheless, Fig. 3 provides a substantial contribution to this insight, as the characteristic changes in sedimentation rate at the top of the core further indicate sediment mixing. Therefore, Fig. 3 is crucial for interpretation/the argument, whether changes in sedimentation rates, or rather sediment mixing is present.

l. 365-403: These paragraphs would be move in the material and methods or results sections. Indeed, while they could clarify the section 4.5 they confuse the discussion.

Author's response: Thank you for this comment. We clarified the section by transferring additional information to the materials and methods section and streamlining this part of the discussion. Section 5.1 is now more focussed on the discussion of our data and general statements are suppressed. However, the interpretation of sedimentation rate changes can only be performed once the data are created. We think that the discussion of whether sedimentation rates change over time or sediments are mixed is a crucial point of the discussion/interpretation of our data.

The interpolation of the Figure 8b is too extensive toward the north and the south where there are no data point.

Author's response: Thank you for this comment. The interpolation was reduced in the north and south (Fig. 8b).

l. 478: It is mentioned the potential occurrence of an advective transport at some stations. However, it is inconsistent with the use of a diffusive model to estimated fluxes of dissolved oxygen at the sediment-water interface from oxygen profiles. In such a case, permeability measurements have to be presented to justify the use of this method to estimate oxygen fluxes

Author's response: Thank you for this comment. We corrected the statement regarding the pore-water mixing processes (lines 496-497). The largest D_{50} grain size is ~ 60 µm (Site E). Using the empirical relation of permeability and median grain size for North Sea sediments presented by Neumann et al. (2017a) permeabilities of our sediments are below 10^{-14} m^2, which are classified as impermeable sediment (Neumann et al., 2017b; Ahmerkamp et al., 2017). Therefore, the diffusive model used to estimate the oxygen fluxes is valid.

On the Figure 9, the significant correlation between MAR and TOC seems mainly related to one extreme point (I supposed the station SC). Is the correlation still significant without this extreme point? Moreover, the linear relationship between the parameters was tested using a Pearson correlation without indicating if the data follow a normal distribution. This has to be indicated prior performing a parametric analysis. Otherwise, the correlation has to be tested with a non-parametric analysis like a Spearman correlation.

Author's response: The relation of MAR and TOC (Fig. 9) is neither in the Figure (orange) nor in the text stated to be significant (cor = 0.37, p = 0.26, Fig. 9a, line 503).
However, for all correlations/regressions, the normal distribution of residuals was tested using the Kolmogorov-Smirnov test, showing that all residuals of the linear regressions follow a

normal distribution. To clarify this, the Materials and Methods section was edited (lines 261-262).

l. 529: The title of the section has no number.

Author's response: The section number was added in line 546.

l. 550: The section is numbered 5.2.1 but there is no section 5.2.2.

Author's response: According to the suggestion above, section "5.2.1" was changed to "5.2.2" (line 574).

l. 521-564: Variations in TOC contents may also be related to grain size changes. It would be relevant to discuss this point in this paragraph, which is rather speculative.

Author's response: A detailed comment regarding this topic is given in the general comment section above. A statement regarding the differences in grain sizes has been added in lines 569-572.

Technical corrections

l. 147: Replace "second centimeter" by "two centimeters"'

Author's response: "second centimetre" was changed to "two centimetres" in line 159.

l. 189: Use "water content"' rather than "moisture"

Author's response: "Moisture" was changed to "water content" in line 168.

References:

Ahmerkamp, S., Winter, C., Krämer, K., de Beer, D., Janssen, F., Friedrich, J., Kuypers, M. M. M., and Holtappels, M.: Regulation of benthic oxygen fluxes in permeable sediments of the coastal ocean, Limnol. Oceanogr., 62, 1935–1954, https://doi.org/10.1002/lno.10544, 2017.

Aller, R. C.: Mobile deltaic and continental shelf muds as suboxic, fluidized bed reactors, Mar. Chem., 61, 143–155, https://doi.org/10.1016/S0304-4203(98)00024-3, 1998.

Arias-Ortiz, A., Masqué, P., Garcia-Orellana, J., Serrano, O., Mazarrasa, I., Marbà, N., Lovelock, C. E., Lavery, P. S., and Duarte, C. M.: Reviews and syntheses: 210Pb-derived sediment and carbon accumulation rates in vegetated coastal ecosystems – setting the record straight, Biogeosciences, 15, 6791–6818, https://doi.org/10.5194/bg-15-6791-2018, 2018.

Baloza, M., Henkel, S., Geibert, W., Kasten, S., and Holtappels, M.: Benthic carbon remineralization and iron cycling in relation to sea ice cover along the eastern continental shelf of the Antarctic Peninsula, J. Geophys. Res. Ocean., 127, https://doi.org/10.1029/2021JC018401, 2022.

Bruns, I., Bartholomä, A., Menjua, F., and Kopf, A.: Physical impact of bottom trawling on seafloor sediments in the German North Sea, Front. Earth Sci., 11, 1–13, https://doi.org/10.3389/feart.2023.1233163, 2023.

Burdige, D. J.: Preservation of organic matter in marine sediments: controls, mechanisms, and an imbalance in sediment organic carbon budgets?, Chem. Rev., 107, 467–485, https://doi.org/10.1021/cr050347q, 2007.

Glud, R. N.: Oxygen dynamics of marine sediments, Mar. Biol. Res., 4, 243–289, https://doi.org/10.1080/17451000801888726, 2008.

Henrichs, S. M. and Reeburgh, W. S.: Anaerobic mineralization of marine sediment organic matter: Rates and the role of anaerobic processes in the oceanic carbon economy, Geomicrobiol. J., 5, 191–237, https://doi.org/10.1080/01490458709385971, 1987.

Hintzen, N. T., Bastardie, F., Beare, D., Piet, G. J., Ulrich, C., Deporte, N., Egekvist, J., and Degel, H.: VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data, Fish. Res., 115–116, 31–43, https://doi.org/10.1016/j.fishres.2011.11.007, 2012.

Mengual, B., Cayocca, F., Le Hir, P., Draye, R., Laffargue, P., Vincent, B., and Garlan, T.: Influence of bottom trawling on sediment resuspension in the ‘Grande-Vasière’ area (Bay of Biscay, France), Ocean Dyn., 66, 1181–1207, https://doi.org/10.1007/s10236-016-0974-7, 2016.

Mouret, A., Anschutz, P., Deflandre, B., Chaillou, G., Hyacinthe, C., Deborde, J., Etcheber, H., Jouanneau, J.-M., Grémare, A., and Lecroart, P.: Oxygen and organic carbon fluxes in sediments of the Bay of Biscay, Deep Sea Res. Part I Oceanogr. Res. Pap., 57, 528–540, https://doi.org/10.1016/j.dsr.2009.12.009, 2010.

Neumann, A., Möbius, J., Hass, H. C., Puls, W., and Friedrich, J.: Empirical model to estimate permeability of surface sediments in the German Bight (North Sea), J. Sea Res., 127, 36–45, https://doi.org/10.1016/j.seares.2016.12.002, 2017a.

Neumann, A., van Beusekom, J. E. E., Holtappels, M., and Emeis, K.-C.: Nitrate consumption in sediments of the German Bight (North Sea), J. Sea Res., 127, 26–35, https://doi.org/10.1016/j.seares.2017.06.012, 2017b.

O’Neill, F. G. and Summerbell, K.: The mobilisation of sediment by demersal otter trawls, Mar. Pollut. Bull., 62, 1088–1097, https://doi.org/10.1016/j.marpolbul.2011.01.038, 2011.

Oehler, T., Martinez, R., Schückel, U., Winter, C., Kröncke, I., and Schlüter, M.: Seasonal and spatial variations of benthic oxygen and nitrogen fluxes in the Helgoland Mud Area (southern North Sea), Cont. Shelf Res., 106, 118–129, https://doi.org/10.1016/j.csr.2015.06.009, 2015.

Ogrinc, N., Faganeli, J., and Pezdic, J.: Determination of organic carbon remineralization in near-shore marine sediments (Gulf of Trieste, Northern Adriatic) using stable carbon isotopes, Org. Geochem., 34, 681–692, https://doi.org/10.1016/S0146-6380(03)00023-8, 2003.

Oguri, K., Masqué, P., Zabel, M., Stewart, H. A., MacKinnon, G., Rowden, A. A., Berg, P., Wenzhöfer, F., and Glud, R. N.: Sediment Accumulation and Carbon Burial in Four Hadal Trench Systems, J. Geophys. Res. Biogeosciences, 127, https://doi.org/10.1029/2022JG006814, 2022.

Sampere, T. P., Bianchi, T. S., Allison, M. A., and McKee, B. A.: Burial and degradation of organic carbon in Louisiana shelf/slope sediments, Estuar. Coast. Shelf Sci., 95, 232–244, https://doi.org/10.1016/j.ecss.2011.09.003, 2011.

Sanchez-Cabeza, J. A. and Ruiz-Fernández, A. C.: 210Pb sediment radiochronology: an integrated formulation and classification of dating models, Geochim. Cosmochim. Acta, 82, 183–200, https://doi.org/10.1016/j.gca.2010.12.024, 2012.

Sobek, S., Zurbrügg, R., and Ostrovsky, I.: The burial efficiency of organic carbon in the sediments of Lake Kinneret, Aquat. Sci., 73, 355–364, https://doi.org/10.1007/s00027-011-0183-x, 2011.

Thünen Institute: Fine-scale footprint of bottom trawling in the German EEZ of the North Sea (2012-2016), https://hub.hereon.de/server/rest/services/NOAH_geoDB/TI_SARnested/MapServer, 2018.

van de Velde, S. J., Hylén, A., Eriksson, M., James, R. K., Kononets, M. Y., Robertson, E. K., and Hall, P. O. J.: Exceptionally high respiration rates in the reactive surface layer of sediments underlying oxygen-deficient bottom waters, Proc. R. Soc. A Math. Phys. Eng. Sci., 479, https://doi.org/10.1098/rspa.2023.0189, 2023.

Walsh, J. P. and Nittrouer, C. A.: Understanding fine-grained river-sediment dispersal on continental margins, Mar. Geol., 263, 34–45, https://doi.org/10.1016/j.margeo.2009.03.016, 2009.

Wenzhöfer, F. and Glud, R. N.: Small-scale spatial and temporal variability in coastal benthic O2 dynamics : Effects of fauna activity, 49, 1471–1481, https://doi.org/https://doi.org/10.4319/lo.2004.49.5.1471, 2004.

Wrede, A., Dannheim, J., Gutow, L., and Brey, T.: Who really matters: influence of German Bight key bioturbators on biogeochemical cycling and sediment turnover, J. Exp. Mar. Bio. Ecol., 488, 92–101, https://doi.org/10.1016/j.jembe.2017.01.001, 2017.

van der Zee, C., van Raaphorst, W., Helder, W., and de Heij, H.: Manganese diagenesis in temporal and permanent depositional areas of the North Sea, Cont. Shelf Res., 23, 625–646, https://doi.org/10.1016/S0278-4343(03)00024-4, 2003.