Reply to RC2

Reviewer 2 attests that "this study provides novelty with its spatial approach to mapping OCAR (with associated uncertainty) and is a welcome contribution to net sediment accumulation and depocentre research."

General comments:

Comment: […] the title of the manuscript could be updated to include OCAR for clarity.

Reply: Agreed.

Action: New title reads:

Organic carbon densities and accumulation rates in surface sediments of the North Sea and Skagerrak

Comment: The break-down of regions into different 'carbon-processing zones' is a novel concept in mapping, however more thought is required in the discussion as to the physical and biogeochemical processes that transport and cycle carbon on the shelf – and acknowledging the differences between OC accumulation and OC burial (e.g. Zonneveld et al., 2009).

Reply: Following comments from reviewer 1 (RC1), we have already made changes to section 6.2. These relate to the role of bioturbation in OC cycling and the transport of OC to the burial zone. We agree that it is important to stress the difference between OC accumulation and burial and concede that this was not clear enough in the original manuscript. We therefore have added a short paragraph to the introduction that explains the difference between the two. We also rename the burial zone to accumulation zone.

Action: We have inserted a paragraph to the introduction that outlines the differences between OC accumulation and burial:

It is important to stress the difference between OC burial and OC accumulation here. Burial is the deposition of OC below the zone of active degradation (Keil, 2015)*. OC degradation in surficial seafloor sediments happens via various processes including aerobic respiration, denitrification, manganese reduction, iron reduction, sulfate reduction and methanogenesis* (Berner, 1980)*. Burial thus is the removal of OC from the active carbon cycle and the burial rate can be expressed as the product of sediment accumulation and OC content at the depth below which no further degradation of OC occurs* (Middelburg, 2019)*. It is, however, difficult to determine that depth. Various depth horizons have been used, e.g. the lower boundary of the sulfate reduction zone* (Jørgensen et al., 1990)*, 15 cm* (Hartnett et al., 1998) *and 10 cm* (Bakker and Helder, 1993)*. OC accumulation rates, on the other hand, can be calculated for any specific depth interval of the sediment column. Due to the difficulties of determining the relevant depth to estimate burial rates and the scarcity of burial rate data, we decided to estimate OC accumulation rates instead.*

Furthermore, we rename the burial zone to accumulation zone and add the following sentence:

This zone might be termed burial zone according to Huettel and Rusch (2000). *However, for consistency with our analysis we term this zone accumulation zone.*

Comment: An additional table of the outputs used to make final OC stock estimates would be useful (for those who can't/don't use R).

Reply: We are not entirely sure what the reviewer is referring to. The calculation of OC stocks is given in section 4.2, equation 6. This is a simple multiplication of the sum of all OC density pixels with the reference depth (0.1 m) and the size of one pixel (250,000 m^2). We cannot see the need for a table.

Action: No action taken.

Comment: I question the usefulness of comparing these OC stocks to other stocks; for instance, coastal ecosystems have different mechanisms for sequestering carbon and are spatially limited. Soils are more comparable by area, however presumably there are much more data available due to ease of sampling and therefore lower uncertainties?

Reply: Despite the mentioned differences, we believe that the presented comparisons are useful. We see them as an integral part of our study as they put the shelf sediment OC stocks into context. Soil OC stocks have long been recognised for their carbon storage ecosystem function and so have more recently Blue Carbon ecosystems. The comparisons highlight the importance of shelf sediment OC stocks.

Action: We have added a sentence that explains why the comparisons were made:

To gauge the importance of North Sea shelf sediments as an OC store, we compare them with coastal habitats and terrestrial soils in the following:

Comment: Uncertainty estimates in this paper for the sedimentation and OCAR are quite high (same order of magnitude) generally, and I wondered why they were highest in areas with a higher density of data points? (This could be a misunderstanding on my part of the model, but detail would promote clarity!)

Reply: Uncertainties are shown as absolute values, i.e. they have the same unit as the predicted variable. A very different picture emerges when uncertainties are shown as relative values (% of predicted value). This information is currently only displayed in the supplements S1 and S3. If it is deemed important to move the figures into the main document, this could be done.

Action: Currently none.

Comment: I think this paper needs to acknowledge the differences between accumulation rates and burial rates – for instance in section 6.3, it is stated that “zones of OC burial” have been identified, however there was no investigation into how the OC density varied with depth to comment on how effective this site is for burial, and this is an important distinction to make.

Reply: We agree, and as stated before we are now explaining the difference between OC accumulation and burial. Furthermore, we have renamed the burial zone to accumulation zone and any further reference to burial, other than in a general way (e.g. in the introduction), has been removed.

Action: See above.

Comment: Data for the model are limited, with few to no datapoints over large areas of the North Sea and large assumptions are made. Further details would be welcomed relating to data selection, model outputs, interpretation of RSME and variance in the results, and some assumptions could be strengthen by links to the literature (e.g. OC change with depth; oxygen penetration as a function of mud). There is noticeably little discussion of the effect of sediment type on OC which has been shown to be a significant predictor of OC.

Reply: This appears to be a general comment, with more detail given in the specific comments below.

Action: Detailed below in responses to specific comments.

Specific comments:

#Introduction

It sets the scene well but more clarity needs to be give as to how this study is novel compared to other predictive spatial models for OC stocks (e.g. is it due to a new framework, a different location being studies, or is it about calculating accumulation rates?). The link between OC and sediment type isn't clear, although a focus is made of cohesive sediments. Can the authors expand on what these are and why are the more relevant to OC? Some more detail could be included about the benefits of random forest modelling as a rationale for why this method 'appears' to have been chosen in recent modelling studies. The text from lines 48 – 57 could be strengthened. Why should marine carbon stocks be accounted for and what kinds of damage are possible as a result of disturbance.

Reply: We would argue that the main purpose of the introduction is to set the scene. Aspects about the novelty of the study should be pointed out in the discussion, and apparently this was at least partly successful as the reviewer states that the "break-down of regions into different 'carbon-processing zones' is a novel concept". We did not intend to focus on cohesive sediments specifically or sediment type in general. We would argue that links between sediment type or grain-size and OC content are well-known and would not require specific mention. The section in question was rather intended to briefly summarise the knowledge on demersal fishing impacts on OC in sediments. We do not mention random forest in the introduction, rather, more generically, we refer to machine learning approaches. We have slightly updated the sentence in question to point out advantages of machine learning over geostatistics. As per specific comments below, the text from lines 48 – 57 was strengthened. We added detail on the relevance of stocks and accumulation rates.

Action: Sentence on machine learning and geostatistics slightly altered:

Recent studies appear to prefer machine-learning over geostatistical approaches (Seiter et al., 2004) *due to their performance, flexibility, and generality* (Hengl et al., 2018).

Action: Information on relevance of OC stocks and accumulation rates in the context of management added:

Well-constrained estimates of OC stocks and accumulation rates are also required from a marine management point of view. *OC stocks are a measure of vulnerability potential, while accumulation rates are a measure of the mitigation potential* (Jennerjahn, 2020). The potential of so-called Blue Carbon ecosystems (mangroves, salt marshes, seagrass meadows and potentially macroalgae) to sequester and store OC is an important ecosystem service that has been highlighted in recent years (Duarte et al., 2005; Mcleod et al., 2011; Nellemann et al., 2009). More recently, it has been shown that fjord (Smeaton et al., 2016, 2017) and continental shelf sediments (Diesing et al., 2017) harbour considerable amounts of OC. In the United Kingdom, the shelf sediment stock (205 Tg) accounts for 93% of OC stored in coastal and marine habitats (Luisetti et al., 2019) and outweighs combined seagrass and saltmarsh stocks (13.4 Tg) by a factor of »15. In Namibia, the marine sediment OC stock is estimated to be larger than the soil OC stock (Avelar et al., 2017). Determining national carbon stocks is essential to understand the potential vulnerability of those stocks to human activities~~for climate change mitigation actions~~; however, national assessments for greenhouse gas reporting do not account for marine stocks such as organic carbon stored in shelf sediments (Avelar et al., 2017). In Norway, the government has underlined the significance of OC uptake by marine vegetation but OC accumulation~~burial~~ in marine sediments is currently not considered (Anon, 2013). […]

#Line 27 – Can the authors suggest what other differences might account for large differences in global stock estimates?

Reply: We believe that the estimates of Atwood et al. (2020) are far too high due to the assumptions that have been made in that study. Specifically, they standardised to a depth of 1 m by taking the average OC stock per centimetre and multiplying it by 100, i.e., they did not account for reductions in OC with increasing depth. Other assumptions might also be questionable, e.g., the application of a pedotransfer function that shows very high scatter in the data range typical for OC content of marine sediments. However, we felt it would be distracting to discuss these issues in the introduction. It would also be difficult to sum the above up in a simple, short sentence; hence we decided to not address this in the discussion.

Action: No action taken.

#Line 39 – Misleading - suggests the authors will look at burial rates as well as accumulation.

Reply: Agreed.

Action: We have now inserted a paragraph detailing the differences between the two and mention that our study only deals with OC accumulation.

#Line 44 – Suggest the authors make reference to these fjord studies coming from the UK (other fjordic studies are available if the authors wanted a more global perspective in this argument). Is this study trying to improve the North Sea estimates specifically or estimates generally? (Line 41).

Reply: The main statement of the sentence in question is that beyond Blue Carbon ecosystems, fjordic and open marine sediments harbour large amounts of OC. We refer to some foundational studies which attempted to estimate such OC stocks. We are unsure whether the reviewer thinks we should have referenced additional studies from the UK?

Action: No action taken.

#Line 47 – The inclusion of Namibia is unexpected in this comparison. What is the relevance?

Reply: Generally, it is assumed that terrestrial soil OC stocks are larger than marine counterparts. In Namibia, this appears not to be the case, presumably due to upwelling offshore (high OC) and desert environments onshore (low OC). The sentence was included to highlight this specific situation.

However, we would be willing to delete the sentence if the reviewer thinks it is confusing. The other reviewers seem to not think that way.

Action: Sentence will be deleted if required.

#Line 53 – Suggest removing 'projects' (replace with strategy?) – I don't think stocks themselves can be used to mitigate against GG emissions.

Reply: Agreed.

Action: Replace projects with strategies.

#Line 55 – Can the authors provide some detail about the kinds of damage attributed to carbon release?

Reply: Agreed.

Action: The types of damages have been specified in brackets for coastal (areal loss of seagrass habitats, sediment OC loss from saltmarshes) and shelf sea sediment (resuspension by bottom contact fishing).

#Line 59 – To strengthen the idea of using MPAs, can the authors provide some detail as to how MPAs have been used to protect BC carbon storage?

Reply: Agreed.

Action: We have added "by slowing, halting, or reversing the trend of degradation and loss of e.g. seagrass and mangrove ecosystems. In Indonesia, MPAs reduced mangrove loss by about 140 km^2 and avoided emissions of 13 Tg CO_2 equivalent between 2000 and 2010 (Miteva et al., 2015)."

#Line 74 – A note to reflect on the likelihood of MPAs (especially on this scale) being developed to protect the seabed against demersal fishing – this isn't a straight-forward decision.

Reply: We agree, this will be a contentious issue, but big challenges require bold solutions. However, this is beyond the topic of the paper.

Action: No action taken.

#Line 79 – It is not clear how linking to an area most heavily impacted by human activities is ideal for understanding accumulation rates – the study isn't necessarily looking at the effects of human activities on accumulation rates.

Reply: Maybe not, but this study aims at estimating OC stocks and accumulation rates in a marine environment that is impacted by human activities, hence the discussion of potential impacts of bottom contact fishing on OC stored in surficial seafloor sediments.

Action: We have changed the sentence which now reads: “This makes the area ideal for our study, which has the objectives to estimate OC stocks and accumulation rates of surface sediments in a regional sea that is impacted by human activities.”

#Data

Generally, some more detail is requested for the final datasets used (there are large areas of the North sea with no data – do they not exist?), some of the assumptions made on sedimentation rates and the criteria used to assign accumulative areas. Are figures or supplementary datasets available for the oxygen penetration depth and oxygen exposure time? I’m not clear from the text what form these data take – continuous raster layers? Oxygen exposure time is calculated using the sedimentation rate which is modelled within this study – so the uncertainties will be carried across presumably. Are the Haas data reliable? Some more detail on why certain values were changed and the criteria used to make these decisions would be useful.

Reply: Additional information on the datasets, assumptions on sedimentation rates and criteria used to assign accumulative areas is given, see replies to specific comments below. Figures showing all predictor variables are now provided as well. We also provide additional detail on the deselection of four sedimentation rate values (see below).

#Line 108 – Can the authors elaborate on what pseudo-observations are and if they are comparable?

Reply: Agreed.

Action: Section 3.1.1 was amended to give a more detailed explanation on pseudo-observations:

Pseudo-observations are ‘virtual’ samples that are placed in undersampled areas and for which the value of the response variable can be assumed with high certainty. Hengl et al. (2017) cite 0 % soil OC in the top 2 m of active sand dunes as an example. The placement of pseudo-observations was restricted to areas of erosion and non-deposition (based on the sedimentary environment layer, as described in chapter 3.2)*, for which* a sedimentation rate of 0 cm yr^{-1} could be assumed. *The pseudo-observations were placed randomly to avoid human bias.*

#Line 111 – What was it about the 210-Pb profiles that made the authors reject some data?

Reply: Sentence was changed to give additional information.

Action: The following information was added:

…due to low ^{210}Pb activities and indistinct decreases with depth.

#Line 116 – Suggest making a reference to Supp Data Table and provide some more detail in the text for these data. Where have the OC measurements come from? How many etc.

Reply: Agreed.

Action: The first part of section 3.1.2 was rewritten:

Previous studies have predicted OC concentrations and sediment porosity separately to calculate OC stocks (Diesing et al., 2017; Lee et al., 2019; Wilson et al., 2018). Here, we first calculate OC density from concurrent measurements of OC concentrations and sediment dry bulk densities or porosities. This has two advantages: First, there is no need to transform the response variable as would be necessary in the case of OC concentrations reported as weight-% or fractions. Second, only one model instead of two needs to be fitted. *This is advantageous as fitting two models would likely increase the uncertainty of the predictions. Initially, a wide range of data sources were accessed. Ultimately, 373 samples fulfilled the criterion of providing OC content and dry bulk density/porosity measured on the same sample. These samples were collected and measured by the Geological Survey of Norway, the Centre for Environment, Fisheries and Aquaculture Science, Bakker and Helder* (1993) *and de Haas et al.* (de Haas et al., 1997)*. The full dataset used for subsequent modelling is shown in Figure 2 and provided as Supplementary Data Table 2.*

#Line 124 – Refer to Supp Data Table for reference.

Reply: We now refer to the Supplementary Data Table a few lines before, so maybe this is no longer necessary.

Action: No action taken.

#Line 143 – Suggest including a figure to show the Folk classes of the area and the 'cleaned' boundaries.

Reply: Agreed.

Action: We provide an additional figure as supplementary material.

#Line 145 – What criteria were used to decide whether an area was potentially accumulative or not?

Reply: The sentence was rewritten to provide more clarity.

Action: The sentence now reads:

These potential accumulation areas were critically reviewed in the light of measured sedimentation rates and geological interpretation of sediment cores (de Haas et al., 1997 and references therein).

#Line 147 – Can the authors describe generally what the relationship between measured oxygen depth and mud content is expected to be? Does oxygen penetrate more or less in mud? What is the relationship to cohesive sediments?

Reply: According to the equations provided in Table 1, oxygen penetration depth decreases with increasing mud content up to 8 weight-%. Further increases in mud content do not affect the oxygen penetration depth.

Action: We now provide maps of all predictors including oxygen penetration depth, as requested by reviewer 1. This might help get a better understanding of how oxygen penetration depth varies spatially.

#Method

The use of the QRF Random Forest model is well justified, and the methods are clear / concise. Some detail on what the different types of error / variance generated mean would be useful and how this differs from the coefficient of determination.

Reply: There was an error in the formula for calculating the explained variance. This effectively means that r^2 and variance explained are essentially the same.

#Line 198 – Would be useful to provide a conversion factor to OC stocks from other studies referenced in this study e.g. Tg - Mt / Tmol and that use different units. This would make inter-study comparisons easier / more transparent.

Reply: Agreed.

Action: We now provide additional information regarding the conversion of Tg to Mt and Tmol:

OC stocks and uncertainties are reported in Tg. One Tg equals 1 Mt or 0.083 Tmol C.

#Line 204 - Somewhere it should be noted that there is a difference between carbon accumulation rates and burial rates (i.e. just because carbon is accumulating, doesn't automatically mean it is being buried in the same amounts).

Reply: See reply to general comments. We now provide a paragraph in the introduction that explains differences between OC accumulation and burial. We also state that we estimate OC accumulation.

Action: No further action deemed necessary here.

#Line 221 - Specifically what were these variables that accounted for 95.5% of the variance?

Reply: Principal components might have contributions from all variables. The loadings are now provided as part of Supplement S4 – Regionalisation. However, we do not show this information in the main document. It would be difficult to express the contributions verbally in a simple manner, and this might distract from the main points. The main message of the sentence in question is that a very large part of the variance of the initial variables can be expressed with four principal components, and it is these which are subsequently used for clustering (regionalisation). We also provide boxplots of the six variables along with the spatial representation of the regions, which allow to infer typical characteristics of the three regions.

Action: Updated Supplement S4 with loadings.

#Results

Concise reporting – although it is not entirely clear how to interpret / use the RMSE and Explained Variance values. A table showing how the final results have been derived would be useful – can the model output results at specific stages? A breakdown of the average sedimentation / OC density and

OCAR results by the three regions would be useful. It is not clear to me why there is higher uncertainty in higher sedimentation rates which is also where there is a higher density of data points. The results section might not be the correct section to answer this but do the authors have any insights into why there is a much higher proportion of OC accumulating (87%) in the Norwegian Trough than the proportion stored here (25.9%) – Is there high turnover here? The discussion mentions several characteristics of this area which enhance preservation of OC.

Reply: We still struggle to understand "how a table showing how the final results have been derived would be useful". What exactly is meant with final results? If it is the OC stock, then calculations were made as outlined in equation 6 based on the predicted pixel values, the size of a pixel and the reference depth. We also provide information on OC density and accumulation rates per region in Figure 6. Regarding higher uncertainty in areas of higher sedimentation rates despite more data points: Figure 3 shows absolute uncertainty (same unit as predicted variable). Absolute uncertainties would be expected to increase with increases in predicted values. However, the relative uncertainty (% of predicted value) gives a very different picture. This information is currently only displayed in the supplement S1. If it is deemed important to move the figures into the main document, this could be done. Regarding higher proportions of OC accumulating then being stored in the Norwegian Trough: This might be due to the somewhat arbitrary reference depth of 10 cm that was chosen. If we would be able to choose a reference age (with variable depth across the basin), this would probably account for the differences mentioned. Unfortunately, this is (currently) not possible.

#Discussion

#Relevance – This section can be strengthened. Perhaps the section needs to be re-titled to "Context". There are many assumptions made (for instance how OC changes with depth), which increase the uncertainty in the scaled-up estimates (making it less useful for improved carbon stock accounts). The discussion on reporting uncertainties could reflect on how to improve uncertainties. The authors argue that their uncertainty estimates are robust because they are based on soil OC mapping studies which, will be different to the marine realm because sampling is easier and there are different predictor variables influencing OC distributions presumably. The comparison of shelf sediment stocks to coastal "blue carbon" doesn't acknowledge the differences between the ecosystems e.g. that coastal habitats are spatially limited to the intertidal zone, have a much smaller areal coverage and has a different mechanism in terms of carbon sequestration. The argument for the Norwegian Trough as a unique and highly effective zone of carbon accumulation (if this is what the authors are trying to argue) needs to be re-worked for emphasis – it gets lost by the introduction of Scottish and Irish fjords.

Reply: 'Context' might be an equally appropriate title of the section, but we called it 'Relevance' because it was intended to outline the relevance of North Sea OC stocks and accumulation in a wider context. Globally, soils are named as an important OC store, so we wanted to compare our results with those stocks. Likewise, Blue Carbon ecosystems and fjords have been named as important places of OC accumulation and we make comparisons in that direction. Several reviewers commented on the upscaling of the OC stocks of Lee et al. (2019) from 5 cm to 10 cm depth. Apparently, this section missed clarity, so we removed it, as LaRowe et al. (2020) provide the estimate we require (i.e., top 10 cm of global shelf sediments). We briefly discuss in the beginning of section 6.4 that the most likely source for high uncertainties are the available samples due to biases regarding the coverage of the temporal, geographical and predictor variable space. We then go on to explain that the provided uncertainty maps could be used to guide additional sampling with the aim to reduce uncertainty. We did not argue that our uncertainty estimates are robust because they are based on soil OC mapping studies. Rather, we argue that they are robust because they consider two sources of uncertainty: uncertainty in the model and in variations of available data. To do so, we adapted a methodology that was developed for soil OC mapping. We now briefly acknowledge that Blue Carbon ecosystems differ in terms of areal coverage and carbon sequestration. The argument for the Norwegian Trough as an effective zone of OC accumulation has been emphasised.

Action: The first paragraph of section 6.1 reads now:

The surface sediments of the North Sea and Skagerrak store 230.5 ± 134.5 Tg of OC. This compares with 9.6 to 25.0 Pg C stored globally in bioturbated Holocene shelf sediments (0 – 10 cm) as estimated by LaRowe et al. (2020)*. Hence, sediments in the North Sea and Skagerrak store approximately 0.9 – 2.4 % of the global stock in an area that accounts for ≈1.7 % of the global shelf.*

#Line 260 - A figure would be useful to put the 'global continental shelf' in the context of the global seafloor (and then the two regional seas into context as well).

Reply: This sentence has been removed, hence no longer relevant.

Action: None.

#Line 264 – The assumption is very vague - are there any studies that provide an estimate of how OC stock changes with depth to get a narrower estimate?

Reply: This sentence has been removed, hence no longer relevant.

Action: None.

#Line 270 - Where does 58% OC stock uncertainty come from? Line 233? (Explained variance?)

Reply: Uncertainty divided by estimate times 100.

Action: The text was updated:

*When comparing uncertainties in OC stock estimates with other reported values of spatial predictions at a regional to global scale, we find that our value of 58 % (100 * 134.5 Tg / 230.5 Tg) is similar to that reported by Lee et al.* (2019) *amounting to 49 %, while other studies did not report any estimates of uncertainty* (Diesing et al., 2017; LaRowe et al., 2020)*.*

#Line 272 – The comparison to lower uncertainty values from local studies could be further developed.

Reply: Agreed.

Action: Sentences added:

An intrinsic assumption of modelling approaches such as the one presented here is that the measured response variable is representative at the scale of the pixel size of predictor variables. The likelihood for this being true increases when the pixel size approaches the size of the seabed area that was *sampled with a grab or corer. Higher resolution predictor variables, as frequently used in local studies, might therefore have lower uncertainties associated with the predictions.*

#Line 274 - Is this a good comparison? Does soil OM have similar predictor variables (e.g. current speed?) Soils are presumably easier to sample as well and therefore have a better spatial range of samples. Some further development of the argument would be helpful.

Reply: Terrestrial counterparts of marine sciences are generally years if not decades ahead regarding methodology. We think it is therefore prudent to transfer developed methodologies from the terrestrial to the marine realm. The mentioned methodology for soil OC mapping is sufficiently generic that we cannot see how a transfer of such knowledge would be detrimental. However, our wording might be confusing, and we therefore rephrased the sentence.

Action: The sentence now reads:

We believe that our approach to uncertainty assessment is very robust as it estimates uncertainty in the model and in variations of available data.

#Line 282 - Coastal habitats are limited spatially by depth and limited to coastlines - generally intertidal zone which is not considered the continental shelf. Can the authors provide an area estimate for these coastal habitats to provide context for the OC-stock values reported? How do the OC densities compare when normalised to area?

Reply: Agreed.

Action: We provide additional information on coastal habitats:

Coastal vegetated habitats (saltmarsh, seagrass, kelp and tidal flat) are known to bury large amounts of carbon despite occupying only 0.2 % of the global ocean surface (Duarte et al., 2005, 2013). Coastal habitats ~~(saltmarsh, seagrass, kelp and tidal flat)~~ on the northwest European continental shelf store between 8.3 and 40.8 Tg C in the upper 10 cm in an area of 20,900 – 35,000 km^2 (Legge et al., 2020), equating to OC densities between 24 and 195 kg m^{-3}. This indicates that shelf sediment stocks (230.5 Tg) are approximately an order of magnitude larger despite lower OC densities of 1.1 to 13.6 kg m^{-3}~~, even without accounting for the smaller area of the North Sea and Skagerrak~~.

#Line 293 - The word project is ambiguous and implies that sediments can be managed to increase sequestration of CO2. The link between greenhouse gases and OC found in sediments is not made. What are the implications for accounting for these stocks? National inventory numbers would increase - but how can this be useful of greenhouse gas reporting?

Reply: After re-reading the paragraph, we felt that the whole sentence might be slightly misplaced. We therefore decided to discuss such issues in section 6.3 (Implications for management).

Action: A new paragraph has been added to section 6.3 after the first paragraph:

Marine sediment OC stocks are presently not considered in the context of national carbon inventories for greenhouse gas reporting. The question has been raised whether those stocks should be considered as part of national carbon accounting (Avelar et al., 2017). *It is becoming clearer that marine sediments store sizeable amounts of OC* (Diesing et al., 2017; Lee et al., 2019; Luisetti et al., 2019)*, which might be vulnerable to human activities such as demersal fishing. Likewise, there exist hot spots of OC accumulation* (Bianchi et al., 2018) *like the Norwegian Trough, as demonstrated here. A further exploration as to how management of marine sediment OC could contribute towards national greenhouse gas emission reduction targets might therefore be prudent; however, this requires new accounting guidance and governance frameworks* (Luisetti et al., 2020)*. The assessment of the OC stock size should be coupled with an assessment of the anthropogenic impacts on that stock* (Avelar et al., 2017)*. When assessed in the context of naturally occurring disturbance (e.g., by currents and waves), this will contribute towards a more complete picture of the vulnerability of marine sediment OC stocks to remineralisation and potential release of CO_2 to the atmosphere* (Atwood et al., 2020)*. We provide spatially explicit information on stock sizes and the uncertainty in the estimates, which could be utilised in such vulnerability assessments.*

#Lines 300 – 304 - Suggest rearranging - I think the authors are trying to say that the Norwegian trough could be an OC accumulation zone unique even to fjord environments because it is apparently not heterogeneous?

Reply: Agreed.

Action: We have rearranged the paragraph, which now reads:

The accumulation of OC is effectively limited to the Norwegian Trough, with the highest rates found in the Skagerrak. Predicted OCARs vary between approximately 4 and 66 g m^{-2} yr^{-1} in the Norwegian Trough, with a mean OCAR of 19.4 g m^{-2} yr^{-1}. Reported OCARs measured in fjord sediments in Norway and Sweden bordering on the North Sea and Skagerrak range from 12 to 54 g m^{-2} yr^{-1} (Huguet et al., 2007; Müller, 2001; Nordberg et al., 2001, 2009; Skei, 1983; Smittenberg et al., 2004, 2005; Velinsky and Fogel, 1999)*, indicating that OCARs in the Norwegian Trough are of a comparable magnitude. However, fjords in Scotland and Ireland have been shown to be heterogeneous in sediment distribution and OC concentrations* (Smeaton and Austin, 2019)*, and hence also OC accumulation. Judging from published sediment maps* (e.g. Elvenes et al., 2019)*, the same applies to fjords in Norway. Conversely, the Norwegian Trough is characterised by fine-grained sediments* (Mitchell et al., 2019) *and OC accumulation occurs throughout the geomorphological structure. Additionally, the area of the Norwegian Trough is much larger than even the largest fjords in Norway, highlighting its relevance as the most important place of OC accumulation in the North Sea and Skagerrak.*

#Line 303 – Reference / figure to back-up that the Norwegian trough has homogenous sediment?

Reply: Agreed.

Action: Reference added (see above).

#Zones of OC processing at the seafloor – The first paragraph is too reflective and needs a few more references for statements. It isn't clear how initial studies of OC cycling on the shelf led to the notion of rapidly accumulating coastal sediments? The authors provide a useful summary of environmental seafloor processes to explain oxygen dynamics.

Reply: We are not sure what the reviewer means with "too reflective". Is this comment referring to the first two sentences, which summarise our results regarding the regionalisation? We would deem this rather an appropriate way of introducing the discussion on the zones of OC processing. Initial process studies focussed on accumulation areas and this might have led to the notion of rapidly accumulating coastal sediments. References were given for this.

Action: No action taken.

Lines 339-342 are unclear that the characteristics listed are for sediment properties that influence OC cycling. Needs a little re-working.

Reply: We would have thought that the reasoning provided is clear, as we state frequently cited factors that increase the potential for OC preservation. However, as reviewer 3 also requests rewording to promote clarity, we provide additional detail.

Action: The sentences were changed:

This lack of advective oxidation (Huettel et al., 2014; Huettel and Rusch, 2000) *translates into slower OC degradation. Fine-grained sediments provide mineral protection* (Hedges and Keil, 1995; Hemingway et al., 2019; Keil and Hedges, 1993; Mayer, 1994)*, which also promotes OC preservation. Short oxygen exposure times* (Hartnett et al., 1998) *due to shallow oxygen penetration depths and relatively high sedimentation rates limit the time for aerobic mineralisation. Collectively, this leads to high OC densities and accumulation rates.*

#Implications for management – This section is currently too vague. Although the implications of refining zones due to OC processing is an interesting concept and potentially a useful way of simplifying areas for management, the scales discussed for MPAs are probably too large to be effective or manageable. Natural disturbance hasn't been acknowledged.

Reply: This section has been strengthened by the inclusion of two paragraphs on OC stocks in the context of greenhouse gas emissions accounting (see above) and the reactivity of OC (following a comment from reviewer 1). We do not discuss any scales for MPAs in our text. Rather, we provide information on OC accumulation rates. Based on these data and in conjunction with other pieces of evidence, it might be possible to identify sites for MPAs. A brief mention of natural disturbance has now been made in the newly added text.

#Line 351 – "Potential zones of OC burial" - there was no investigation into how the OC density varied with depth to comment on how effective this site is for burial – this should be removed.

Reply: As stated earlier, we have tightened the terminology and are now referring to zones of OC accumulation.

Action: No further action.

#Suggestions for Future Research – More detail is required around further data collection – the goal of data collection needs to be elaborated and more thought into specifically what data would be useful / beneficial to collect to answer questions relating to carbon stocks. The sampling design examples are very technical - who might undertake this enormous task? Some detail about existing data stores would be useful for reader understanding that national and pan-European datacentres do exist. I think some further discussion on the ideas behind 'source of OC' – and why this might be relevant to further study in terms of thinking about climate mitigation – is needed. The authors presume this is common knowledge.

Reply: We provide more information on parameters to be measured now. However, this section was not meant to be an exhaustive discussion on which parameters would be useful to answer specific research question. It was rather meant to stimulate debate. We would consider our suggestions regarding sampling design as specific, which might in fact be useful. We also mention that such methods help minimising the sampling effort. We now refer to existing databases. We explain in the text that the source of OC (terrestrial or marine) is relevant for carbon offsetting schemes, as such schemes would not allocate offset-credits for allochthonous (i.e., terrestrial) OC due to the risk of duplicating carbon sequestration gains that have already been accounted for in adjacent ecosystems.

#Line 375 – Further discussion about what new samples are being recommended for collection. To collect what specifically? grain size? Carbon measurements? to what depth? In-situ oxygen / current data / sedimentations rates?? What are the questions / gaps to inform what data are required?

Reply: Additional information is given.

Action: Sentence now reads:

Consequently, there is a need for the collection and analysis of new samples on OC content, dry bulk density, sedimentation rates and ancillary parameters (e.g., grain size).

#Line 378 – Could you elaborate on how economic benefits can be achieved?

Reply: Agreed.

Action: Sentence added:

Jin et al. (2020) *developed an analytical model of the economic effects of global carbon emissions including uncertainty about biological carbon pump sequestration and estimated that the benefit to narrow the range of uncertainty about ocean carbon sequestration is on the order of $ 0.5 trillion.*

#Line 380 – What type of baseline dataset?

Reply: There is additional information given at the end of section 6.3.

Action: Additional text:

However, such analyses must consider that the OC stocks, as mapped in this study, likely have been affected already by decades of demersal fishing. Our maps therefore do not represent a baseline in a sense of an undisturbed state.

#Line 388 – Agreed - however there are national sampling programmes that have standardised protocols – do these need to be advertised' to the research community / or informed by the research community?

Reply: We agree that a standardisation of methods has been done in the past, otherwise this study would not have been possible. However, such standardisations were probably not being made with OC budgeting in mind. For example, OC contents have been measured at sediment slices of various sizes, while in terrestrial soil mapping standard depths are used (Hengl et al., 2014).

Action: None.

#Line 391 – Such facilities do exist – e.g. ICES.

Reply: Yes, but ICES is collecting data on a wide range of parameters. We were thinking of a repository which is more specific to sediment carbon. It appears that such a database has just been made public.

Action: Sentence altered:

Although facilities to store and retrieve quality-controlled seafloor data centrally exist (e.g., EMODnet, ICES), it would still be advantageous to establish global data archives that are more specific to marine sedimentary carbon such as MOSAIC (van der Voort et al., 2020).

#Line 396 – How likely is there to be terrigenous OM in shelf sediments? Any studies that have looked at this?

Reply: There is limited information in the PhD thesis of de Haas (1997). However, the paragraph was meant to indicate that more data are required.

Action: None.

Technical Corrections

Comments are provided with specific line references for consideration:

#Line 7 – Suggest re-wording; Sediments don't protect the seabed from disturbance, Sediments can store carbon, provided left undisturbed (from anthropogenic activity).

Action: Text changed to "e.g., by storing organic carbon if left undisturbed from anthropogenic activity."

#Line 10 – Inclusion of 'us' between 'allows to'.

Action: Agreed.

#Line 16 – Suggest updating 'on par' with 'comparable'.

Action: Agreed.

#Line 30 – Suggest replacing 'were' with 'have been'.

Action: Agreed.

#Line 31 - Suggest replacing ‘did not include’ with ‘have not included’.

Action: Agreed.

#Line 33 – Reference for importance of continental margins in OC cycling – and important in what way?

Action: This was detailed in the previous paragraph. No action.

#Line 37 – Use of the word ‘appear’ without suggesting why this might be. What are the advantages of machine learning over geostatistical approach?

Action: Text updated:

…*due to their performance, flexibility, and generality* (Hengl et al., 2018)

#Line 41 – Suggest replacing ‘point of view’ with ‘perspective’.

Action: Agreed.

#Line 42 – Reference for the inclusion of ‘potentially macroalgae’ in the BC definition.

Action: Reference (Krause-Jensen and Duarte, 2016) included.

#Line 63 – Add ‘The’.

Action: Agreed.

#Line 64 – Suggestion for consideration. Is ‘fertilization’ the right term? to fertilise means to stimulate productivity - this would reduce OC presumably. Is enrichment a better term?

Action: This is the word used in the cited reference. No action.

#Line 66 – Suggest including ‘sediment’ between ‘deeper layers’.

Action: Agreed.

#Line 69 – Change ‘expectable’ to ‘expected’.

Action: Agreed.

#Line 78 – suggest replacing ‘it is one of the regional seas’ with ‘they are the’ for comprehension.

Action: Agreed.

Regional setting – Figure 1 - Request to add the labels for the two regional seas on figure 1 location map.

Action: Agreed.

#Line 89 – Suggest re-wording ‘generally deepening from south to north’. Specific depths?

Reply: Is this necessary information that couldn’t be gleaned from Figure 1?

Action: None.

#Lines 117, 118, 120 – Use of the word concentration is incorrect. Update to content (mass per unit mass) – See Flemming & Delafontaine, 2000.

Action: Agreed.

#Line 133 – suggest adding ‘relevance to OC’.

Action: Agreed.

#Line 139 – Suggest addition of appropriate reference to reinforce-up this statement.

Reply: This would appear to us as common knowledge

Action: None.

#Line 155 – Suggest replacing ‘target’ with ‘response’ to keep the terms consistent.

Action: Agreed.

#Line 158 – Inclusion of the word ‘us’.

Action: Agreed.

#Line 183 -Would be useful to include a sentence describing what the RMSE explains (and the difference between this and the MSE in the context of the model performance)

Action: Sentence modified:

RMSE *measures how far apart on average predicted values are from observed values. It* might range from 0 to infinity, with an ideal value of 0.

#Line 273 - Suggest replacing ‘how’ with ‘in which’.

Action: Agreed.

#Line 283 - 284 – Sentence doesn’t make sense compare to preceding sentence.

Action: No longer relevant due to changes made to paragraph.

#Line 285 – Does ‘collectively’ mean ‘global’?

Action: Changed to globally.

#Line 315 – References to initial process studies?

Action: References added:

(e.g. Balzer, 1984; Jørgensen, 1977; Martens and Val Klump, 1984)

#Line 316 – How did one lead to the other?

Reply: What is meant with ‘one’ and the ‘other’? We are simply naming sediment characteristics in cohesive, diffusion-dominated sediments.

Action: None.

#Line 339 – 341 – Sentence isn’t well constructed or complete.

Action: Sentence has been changed (see above).

#Line 342 – Suggest inclusion of ‘a’ burial zone.

Action: Agreed.

#Line 350 – Suggest replacing ‘on par’ with ‘comparable’.

Action: Agreed.

#Line 351 – Suggest replacing ‘act differently’ with ‘have different roles’? (’act’ suggests it is a conscious action - not a by-product of location and physical environment

Action: Agreed.

#Line 354 – I don't understand the point about 'total annual rate in the North Sea'.

Action: Replaced with 'the annual rate of OC accumulation by coastal vegetated habitats (Legge et al., 2020).

#Line 370 – Suggest adding 'However' at start of sentence.

Action: Agreed.

#Line 382 - Relative importance on what? I assume OC but this isn't explicit.

Action: Added "OC distribution".

#Line 405 – Suggest replacing 'on par' with comparable.

Action: Agreed.

Literature

Anon: Integrated Management of the Marine Environment of the North Sea and Skagerrak (Management Plan). Meld. St. 37 (2012–2013) Report to the Storting (white paper). [online] Available from: https://www.regjeringen.no/contentassets/f9eb7ce889be4f47b5a2df5863b1be3d/en-gb/pdfs/stm201220130037000engpdfs.pdf, 2013.

Atwood, T. B., Witt, A., Mayorga, J., Hammill, E. and Sala, E.: Global Patterns in Marine Sediment Carbon Stocks, Front. Mar. Sci., 7, 165, doi:10.3389/fmars.2020.00165, 2020.

Avelar, S., van der Voort, T. S. and Eglinton, T. I.: Relevance of carbon stocks of marine sediments for national greenhouse gas inventories of maritime nations, Carbon Balance Manag., 12(1), 10, doi:10.1186/s13021-017-0077-x, 2017.

Bakker, J. F. and Helder, W.: Skagerrak (northeastern North Sea) oxygen microprofiles and porewater chemistry in sediments, Mar. Geol., 111(3), 299–321, doi:https://doi.org/10.1016/0025-3227(93)90137-K, 1993.

Balzer, W.: Organic matter degradation and biogenic element cycling in a nearshore sediment (Kiel Bight)1, Limnol. Oceanogr., 29(6), 1231–1246, doi:https://doi.org/10.4319/lo.1984.29.6.1231, 1984.

Berner, R. A.: Early diagenesis: A theoretical approach, Princeton University Press., 1980.

Bianchi, T. S., Cui, X., Blair, N. E., Burdige, D. J., Eglinton, T. I. and Galy, V.: Centers of organic carbon burial and oxidation at the land-ocean interface, Org. Geochem., 115, 138–155, doi:https://doi.org/10.1016/j.orggeochem.2017.09.008, 2018.

Diesing, M., Kröger, S., Parker, R., Jenkins, C., Mason, C. and Weston, K.: Predicting the standing stock of organic carbon in surface sediments of the North–West European continental shelf, Biogeochemistry, 135(1–2), 183–200, doi:10.1007/s10533-017-0310-4, 2017.

Duarte, C. M., Middelburg, J. J. and Caraco, N.: Major role of marine vegetation on the oceanic carbon cycle, Biogeosciences, 2(1), 1–8, doi:10.5194/bg-2-1-2005, 2005.

Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I. and Marbà, N.: The role of coastal plant communities for climate change mitigation and adaptation, Nat. Clim. Chang., 3(11), 961–968, doi:10.1038/nclimate1970, 2013.

Elvenes, S., Bøe, R., Lepland, A. and Dolan, M.: Seabed sediments of Søre Sunnmøre, Norway, J. Maps, 15(2), 686–696, doi:10.1080/17445647.2019.1659865, 2019.

de Haas, H., Boer, W. and van Weering, T. C. E.: Recent sedimentation and organic carbon burial in a shelf sea: the North Sea, Mar. Geol., 144, 131–146, doi:10.1016/S0025-3227(97)00082-0, 1997.

Hartnett, H. E., Keil, R. G., Hedges, J. I. and Devol, A. H.: Influence of oxygen exposure time on organic carbon preservation in continental margin sediments, Nature, 391, 572 [online] Available from: http://dx.doi.org/10.1038/35351, 1998.

Hedges, J. I. and Keil, R. G.: Sedimentary organic matter preservation: an assessment and speculative synthesis, Mar. Chem., 49(2–3), 81–115, doi:10.1016/0304-4203(95)00008-F, 1995.

Hemingway, J. D., Rothman, D. H., Grant, K. E., Rosengard, S. Z., Eglinton, T. I., Derry, L. A. and Galy, V. V: Mineral protection regulates long-term global preservation of natural organic carbon, Nature, 570(7760), 228–231, doi:10.1038/s41586-019-1280-6, 2019.

Hengl, T., de Jesus, J. M., MacMillan, R. A., Batjes, N. H., Heuvelink, G. B. M., Ribeiro, E., Samuel-Rosa, A., Kempen, B., Leenaars, J. G. B., Walsh, M. G. and Gonzalez, M. R.: SoilGrids1km — Global Soil Information Based on Automated Mapping, PLoS One, 9(8), e105992 [online] Available from: https://doi.org/10.1371/journal.pone.0105992, 2014.

Hengl, T., Nussbaum, M., Wright, M. N., Heuvelink, G. B. M. and Gräler, B.: Random forest as a generic framework for predictive modeling of spatial and spatio-temporal variables, PeerJ, 6, e5518, doi:10.7717/peerj.5518, 2018.

Huettel, M. and Rusch, A.: Transport and degradation of phytoplankton in permeable sediment, Limnol. Oceanogr., 45(3), 534–549, doi:10.4319/lo.2000.45.3.0534, 2000.

Huettel, M., Berg, P. and Kostka, J. E.: Benthic Exchange and Biogeochemical Cycling in Permeable Sediments, Ann. Rev. Mar. Sci., 6(1), 23–51, doi:10.1146/annurev-marine-051413-012706, 2014.

Huguet, C., Smittenberg, R. H., Boer, W., Sinninghe Damsté, J. S. and Schouten, S.: Twentieth century proxy records of temperature and soil organic matter input in the Drammensfjord, southern Norway, Org. Geochem., 38(11), 1838–1849, doi:https://doi.org/10.1016/j.orggeochem.2007.06.015, 2007.

Jennerjahn, T. C.: Relevance and magnitude of “Blue Carbon” storage in mangrove sediments: Carbon accumulation rates vs. stocks, sources vs. sinks, Estuar. Coast. Shelf Sci., 247, 107027, doi:https://doi.org/10.1016/j.ecss.2020.107027, 2020.

Jin, D., Hoagland, P. and Buesseler, K. O.: The value of scientific research on the ocean’s biological carbon pump, Sci. Total Environ., 749, 141357, doi:https://doi.org/10.1016/j.scitotenv.2020.141357, 2020.

Jørgensen, B., Bang, M. and Blackburn, T.: Anaerobic mineralization in marine sediments from the Baltic Sea-North Sea transition, Mar. Ecol. Prog. Ser., 59, 39–54, doi:10.3354/meps059039, 1990.

Jørgensen, B. B.: The sulfur cycle of a coastal marine sediment (Limfjorden, Denmark)1, Limnol. Oceanogr., 22(5), 814–832, doi:https://doi.org/10.4319/lo.1977.22.5.0814, 1977.

Keil, R.: Hoard of fjord carbon, Nat. Geosci., 8, 426 [online] Available from:

http://dx.doi.org/10.1038/ngeo2433, 2015.

Keil, R. G. and Hedges, J. I.: Sorption of organic matter to mineral surfaces and the preservation of organic matter in coastal marine sediments, Chem. Geol., 107(3–4), 385–388, doi:10.1016/0009-2541(93)90215-5, 1993.

Krause-Jensen, D. and Duarte, C. M.: Substantial role of macroalgae in marine carbon sequestration, Nat. Geosci, 9(10), 737–742 [online] Available from: http://dx.doi.org/10.1038/ngeo2790, 2016.

LaRowe, D. E., Arndt, S., Bradley, J. A., Burwicz, E., Dale, A. W. and Amend, J. P.: Organic carbon and microbial activity in marine sediments on a global scale throughout the Quaternary, Geochim. Cosmochim. Acta, 286, 227–247, doi:https://doi.org/10.1016/j.gca.2020.07.017, 2020.

Lee, T. R., Wood, W. T. and Phrampus, B. J.: A Machine Learning (kNN) Approach to Predicting Global Seafloor Total Organic Carbon, Global Biogeochem. Cycles, 33(1), 37–46, doi:10.1029/2018GB005992, 2019.

Legge, O., Johnson, M., Hicks, N., Jickells, T., Diesing, M., Aldridge, J., Andrews, J., Artioli, Y., Bakker, D. C. E., Burrows, M. T., Carr, N., Cripps, G., Felgate, S. L., Fernand, L., Greenwood, N., Hartman, S., Kröger, S., Lessin, G., Mahaffey, C., Mayor, D. J., Parker, R., Queirós, A. M., Shutler, J. D., Silva, T., Stahl, H., Tinker, J., Underwood, G. J. C., Van Der Molen, J., Wakelin, S., Weston, K. and Williamson, P.: Carbon on the Northwest European Shelf: Contemporary Budget and Future Influences, Front. Mar. Sci., 7, 143, doi:10.3389/fmars.2020.00143, 2020.

Luisetti, T., Turner, R. K., Andrews, J. E., Jickells, T. D., Kröger, S., Diesing, M., Paltriguera, L., Johnson, M. T., Parker, E. R., Bakker, D. C. E. and Weston, K.: Quantifying and valuing carbon flows and stores in coastal and shelf ecosystems in the UK, Ecosyst. Serv., 35, 67–76, doi:10.1016/J.ECOSER.2018.10.013, 2019.

Luisetti, T., Ferrini, S., Grilli, G., Jickells, T. D., Kennedy, H., Kröger, S., Lorenzoni, I., Milligan, B., van der Molen, J., Parker, R., Pryce, T., Turner, R. K. and Tyllianakis, E.: Climate action requires new accounting guidance and governance frameworks to manage carbon in shelf seas, Nat. Commun., 11(1), 4599, doi:10.1038/s41467-020-18242-w, 2020.

Martens, C. S. and Val Klump, J.: Biogeochemical cycling in an organic-rich coastal marine basin 4. An organic carbon budget for sediments dominated by sulfate reduction and methanogenesis, Geochim. Cosmochim. Acta, 48(10), 1987–2004, doi:https://doi.org/10.1016/0016-7037(84)90380-6, 1984.

Mayer, L. M.: Surface area control of organic carbon accumulation in continental shelf sediments, Geochim. Cosmochim. Acta, 58(4), 1271–1284, doi:10.1016/0016-7037(94)90381-6, 1994.

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H. and Silliman, B. R.: A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2, Front. Ecol. Environ., 9(10), 552–560, doi:10.1890/110004, 2011.

Middelburg, J. J.: Carbon Processing at the Seafloor, in Marine Carbon Biogeochemistry : A Primer for Earth System Scientists, pp. 57–75, Springer International Publishing, Cham., 2019.

Mitchell, P. J., Aldridge, J. and Diesing, M.: Legacy data: How decades of seabed sampling can produce robust predictions and versatile products, Geosci., 9(4), 182, doi:10.3390/geosciences9040182, 2019.

Miteva, D. A., Murray, B. C. and Pattanayak, S. K.: Do protected areas reduce blue carbon emissions? A quasi-experimental evaluation of mangroves in Indonesia, Ecol. Econ., 119, 127–135, doi:https://doi.org/10.1016/j.ecolecon.2015.08.005, 2015.

Müller, A.: Geochemical expressions of anoxic conditions in Nordåsvannet, a land-locked fjord in western Norway, Appl. Geochemistry, 16(3), 363–374, doi:https://doi.org/10.1016/S0883-2927(00)00024-X, 2001.

Nellemann, C., Corcoran, E., Duarte, C. M., Valdés, L., De Young, C., Fonseca, L. and Grimsditch, G.: Blue Carbon: The Role of Healthy Oceans in Binding Carbon: A Rapid Response Assessment. [online] Available from: http://www.grida.no/files/publications/blue-carbon/BlueCarbon_screen.pdf, 2009.

Nordberg, K., Filipsson, H. L., Gustafsson, M., Harland, R. and Roos, P.: Climate, hydrographic variations and marine benthic hypoxia in Koljö Fjord, Sweden, J. Sea Res., 46(3), 187–200, doi:https://doi.org/10.1016/S1385-1101(01)00084-3, 2001.

Nordberg, K., Filipsson, H. L., Linné, P. and Gustafsson, M.: Stable oxygen and carbon isotope information on the establishment of a new, opportunistic foraminiferal fauna in a Swedish Skagerrak fjord basin, in 1979/1980, Mar. Micropaleontol., 73(1), 117–128, doi:https://doi.org/10.1016/j.marmicro.2009.07.006, 2009.

Seiter, K., Hensen, C., Schröter, J. and Zabel, M.: Organic carbon content in surface sediments—defining regional provinces, Deep Sea Res. Part I Oceanogr. Res. Pap., 51(12), 2001–2026, doi:10.1016/j.dsr.2004.06.014, 2004.

Skei, J.: Geochemical and sedimentological considerations of a permanently anoxic fjord — Framvaren, south Norway, Sediment. Geol., 36(2), 131–145, doi:https://doi.org/10.1016/0037-0738(83)90006-4, 1983.

Smeaton, C. and Austin, W. E. N.: Where's the Carbon: Exploring the Spatial Heterogeneity of Sedimentary Carbon in Mid-Latitude Fjords, Front. Earth Sci., 7, 269, doi:10.3389/feart.2019.00269, 2019.

Smeaton, C., Austin, W. E. N., Davies, A. L., Baltzer, A., Abell, R. E. and Howe, J. A.: Substantial stores of sedimentary carbon held in mid-latitude fjords, Biogeosciences, 13(20), 5771–5787, doi:10.5194/bg-13-5771-2016, 2016.

Smeaton, C., Austin, W. E. N., Davies, A. L., Baltzer, A., Howe, J. A. and Baxter, J. M.: Scotland's forgotten carbon: a national assessment of mid-latitude fjord sedimentary carbon stocks, Biogeosciences, 14(24), 5663–5674, doi:10.5194/bg-14-5663-2017, 2017.

Smittenberg, R. H., Pancost, R. D., Hopmans, E. C., Paetzel, M. and Sinninghe Damsté, J. S.: A 400-year record of environmental change in an euxinic fjord as revealed by the sedimentary biomarker record, Palaeogeogr. Palaeoclimatol. Palaeoecol., 202(3), 331–351, doi:https://doi.org/10.1016/S0031-0182(03)00642-4, 2004.

Smittenberg, R. H., Baas, M., Green, M. J., Hopmans, E. C., Schouten, S. and Sinninghe Damsté, J. S.: Pre- and post-industrial environmental changes as revealed by the biogeochemical sedimentary record of Drammensfjord, Norway, Mar. Geol., 214(1), 177–200, doi:https://doi.org/10.1016/j.margeo.2004.10.029, 2005.

Velinsky, D. J. and Fogel, M. L.: Cycling of dissolved and particulate nitrogen and carbon in the Framvaren Fjord, Norway: stable isotopic variations, Mar. Chem., 67(3), 161–180, doi:https://doi.org/10.1016/S0304-4203(99)00057-2, 1999.

van der Voort, T. S., Blattmann, T. M., Usman, M., Montluçon, D., Loeffler, T., Tavagna, M. L., Gruber, N. and Eglinton, T. I.: MOSAIC (Modern Ocean Sediment Archive and Inventory of Carbon): A (radio)carbon-centric database for seafloor surficial sediments, Earth Syst. Sci. Data Discuss., 2020, 1–27, doi:10.5194/essd-2020-199, 2020.

Wilson, R. J., Speirs, D. C., Sabatino, A. and Heath, M. R.: A synthetic map of the north-west European

Shelf sedimentary environment for applications in marine science, Earth Syst. Sci. Data, 10(1), 109–130, doi:10.5194/essd-10-109-2018, 2018.