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Interactive comment on "Organic carbon in surface sediments of the North Sea and Skagerrak" *by* Markus Diesing et al.

Anonymous Referee #2

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1. General Comments The authors of the manuscript "Organic carbon in surface sediments of the North Sea and Skagerrak" have presented a spatial modelling framework to predict and map the spatial distribution of surficial organic carbon (OC) densities and organic carbon accumulation rates (OCAR) in two regional seas in the North East Atlantic. The results are aligned with previous studies looking at (spatial distributions of) OC in the North Sea (de Haas et al., 1997 & 2002; Legge et al., 2020, Smeaton et al., 2020). However, 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. On this point the title of the manuscript could be updated to include OCAR for clarity. An interesting element to this study is the identification of the Norwegian Trough as being a highly effective accumulator and store for OC (al-

though the authors themselves note on line 94 that this has been previously observed in a study over 20 years ago), and the authors suggest, as effective as the nearby fjordic environments, which is an unusual finding for continental shelf sediments. 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). The provision of the R Markdown files is welcome and useful for traceability of results as is the provision of the raw data used in the models. 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). The paper is well-written and concise but some more references to the supplementary data and figures would be useful as well as to support some statements (Detail provided below). There are some elements of this manuscript that could be improved, and I have provided detailed comments and suggestions in 'Specific Comments' and 'Technical Corrections' below. They relate primarily to: providing more detail about the data and how they have been selected/processed; how the final results have been calculated (a table would be useful to break down the component outputs from the model); further development of some of the processes mentioned (C-cycling, transport, C-accounting) and core arguments and in the discussion to realise the impact of these findings and; re-wording some paragraphs to help with comprehension and clarity. The aims of the paper are important and relevant, although 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? 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!) 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. 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.

2. Specific Comments I have provided comments that address individual scientific question or issues below. The comments are broken down by section, and line numbers are given to address specific issues. #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. #Line 27 – Can the authors suggest what other differences might account for large differences in global stock estimates? #Line 39 – Misleading - suggests the authors will look at burial rates as well as 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) #Line 47 – The inclusion of Namibia is unexpected in this comparison. What is the

relevance? #Line 53 – Suggest removing 'projects' (replace with strategy?) – I don't think stocks themselves can be used to mitigate against GG emissions. #Line 55 – Can the authors provide some detail about the kinds of damage attributed to carbon release? #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? #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. #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. #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. #Line 108 – Can the authors elaborate on what pseudo-observations are and if they are comparable? #Line 111 – What was it about the 210-Pb profiles that made the authors reject some data? #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. #Line 124 – Refer to Supp Data Table for reference. #Line 143 – Suggest including a figure to show the Folk classes of the area and the 'cleaned' boundaries. #Line 145 – What criteria were used to decide whether an area was potentially accumulative or not? #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? #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. #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. #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) #Line 221 - Specifically what were these variables that accounted for 95.5% of the variance? #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. #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. #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. Lines 339-342 are unclear that the characteristics listed are for sediment properties that influence OC cycling. Needs a little re-working. #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.. #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. #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). #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? #Line 270 - Where does 58% OC stock uncertainty come from? Line 233? (Explained variance?) #Line 272 – The comparison to lower uncertainty values from

local studies could be further developed. #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. #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? #Line 293 - The word project is ambiguous and implies that sediments can be managed to increase sequestration of CO_2. 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? #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? #Line 303 – Reference / figure to back-up that the Norwegian trough has homogenous sediment? #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. #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? #Line 378 – Could you elaborate on how economic benefits can be achieved? #Line 380 – What type of baseline dataset? #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? #Line 391 – Such facilities do exist – e.g. ICES. #Line 396 - How likely is there to be terrigenous OM in shelf sediments? Any studies that have looked at this?

3. Technical Corrections Comments are provided with specific line references for con-

sideration: #Line 7 – Suggest re-wording; Sediments don't protect the seabed from disturbance, Sediments can store carbon, provided left undisturbed (from anthropogenic activity). #Line 10 – Inclusion of 'us' between 'allows to'. #Line 16 – Suggest updating 'on par' with 'comparable'. #Line 30 – Suggest replacing 'were' with 'have been'. #Line 31 - Suggest replacing 'did not include' with 'have not included'. #Line 33 – Reference for importance of continental margins in OC cycling – and important in what way? #Line 37 – Use of the word 'appear' without suggesting why this might be. What are the advantages of machine learning over geostatistical approach? #Line 41 – Suggest replacing 'point of view' with 'perspective'. #Line 42 – Reference for the inclusion of 'potentially macroalgae' in the BC definition. #Line 63 – Add 'The'. #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? #Line 66 – Suggest including 'sediment' between 'deeper layers'. #Line 69 – Change 'expectable' to 'expected'. #Line 78 – suggest replacing 'it is one of the regional seas' with 'they are the' for comprehension. Regional setting – Figure 1 - Request to add the labels for the two regional seas on figure 1 location map. #Line 99 – Suggest re-wording 'generally deepening from south to north'. Specific depths? #Lines 117, 118, 120 – Use of the word concentration is incorrect. Update to content (mass per unit mass) – See Flemming & Delafontaine, 2000. #Line 133 – suggest adding 'relevance to OC'. #Line 139 – Suggest addition of appropriate reference to reinforce-up this statement. #Line 155 – Suggest replacing 'target' with 'response' to keep the terms consistent. #Line 158 – Inclusion of the word 'us'. #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) #Line 273 - Suggest replacing 'how' with 'in which'. #Line 283 - 284 – Sentence doesn't make sense compare to preceding sentence. #Line 285 – Does 'collectively' mean 'global'? #Line 315 – References to initial process studies? #Line 316 – How did one lead to the other? #Line 339 – 341 – Sentence isn't well constructed or complete. #Line 342 – Suggest inclusion of 'a' burial zone. #Line 350 – Suggest replacing 'on par' with 'comparable'. #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 #Line 354 – I don't understand the point about 'total annual rate in the North Sea'. #Line 370 – Suggest adding 'However' at start of sentence. #Line 382 - Relative importance on what? I assume OC but this isn't explicit. #Line 405 – Suggest replacing 'on par' with comparable.

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