Response to Reviewer #1

Review of manuscript bg-2020-17: "Persistent effects of sand extraction on habitats and associated benthic communities in the German Bight"

General comments:

This paper intends to investigate the effects of historic and recent intensive dredging on habitats and benthic fauna in the German Bight in a dredging area near Sylt. This is a follow-up paper of Mielck et al 2018 where the focus was on morphological changes due to sand extraction for beach nourishment. This definitely is of scientific value and interest in the field of effect studies and increasing demand of sand for both industrial purposes and coastal protection. However, I had to find out myself that this was a 'follow-up' study and really needed to read the Mielck paper to get better insights in this study and understand the situation of the area. At least, this could have been better referred to.

Furthermore, the way it is written and presented now, especially the discussion adds little value compared to the previous study. Although, in itself, it really is a different study and could add interesting new scientific insights. But therefore, this manuscript has to be thoroughly reworked with focus on the new aspects i.e. defining the different habitats related to the dredging history of the sites and characterizing the benthic communities related to these habitats. The introduction should therefore at least make a clear referral to the previous study and the conclusions of that one. Moreover the manuscript should better introduce the available knowledge on the topic of impact of sand extraction on benthic habitats since too few references have been cited, while already quite some literature is available and this would situate the study in a broader perspective.Objectives should also be better delineated to make clear what the main aim of this exact study was. This could also help maybe to explain the unconventional way of benthic sampling i.e. very small sample volume used for species identification compared to volume used for sediment analyses. Results are too vague and too descriptive. Extra multivariate analyses should be done to characterize communities. Maybe acoustic data together with sediment data could be used in a PCA and these PCA results (=axis scores) can in their turn be used in the faunal analyses so that acoustic data are really used to determine benthic communities? This study would really benefit from a better combination of both datasets, since this is its strength. While in the current version of the manuscript, these two datasets are treated as separate entities. Discussion is too superficial and adds very few new insights compared to the previous paper as well as said above. Plus it thus not really discuss the results of this study. I also do not agree with the conclusion made. The historic dredging actually caused a loss of habitat in my opinion. You even get a change in EUNIS habitat, so regeneration to the original habitat, without human intervention, will not be possible in that sense you cannot speak about regeneration/recovery. This could be discussed in the light of the MSFD, D6 seafloor integrity C1 habitat loss. See also specific comments for some extra input in the discussion that could lift it up to an interesting contribution for the scientific community. Also here, quite some literature is already available to put your results in a wider perspective but only very few references have been used. Looking into the existing body of literature and putting your results in this wider perspective would give more body to the discussion. To conclude, the manuscript cannot be

published in the current version, thorough revision is needed of all sections and some new analyses need to be done to make this a valuable contribution.

Dear Reviewer #1,

Thank you for your revision and the numerous helpful comments and suggestions for improvement. Indeed, this manuscript is something like a follow-up to one of our previous study (Mielck et al. 2018). The focus of that study was set on morphological changes due to marine aggregate extraction in the same study area using bathymetric data between 1993 and 2017. For the new study presented here, we collected new data and intended to focus on the impact of sand extraction on the habitats and the associated benthic communities. You are right that the conclusion of the previous work needs to be better communicated in the introduction or at least in the section "Study area". We will certainly address this weakness.

Many thanks also for the provided literature and the hint to the ICES WGEXT reports, which are very helpful to improve our introduction with more facts and recent information about this topic, which is also useful for deeper discussion and a meaningful conclusion.

We think that a better delineation of the aims of this study towards a combination of the used data sets (benthos analysis and hydroacoustic data) is a very good way to improve the whole study. We already started some statistical analysis (e.g. SIMPER) and think that this will add more insights into the habitat characteristics.

A recovery towards the pre-dredging conditions is of course not possible since the coarse Pleistocene sediment cannot be replaced without a new ice-age. When sand mining started in 1984, the coastal authorities and also some scientist assumed, the so-called "Wanderfeinsand" (migrating fine sand, Tabat, 1979; Köster 1979), which is ubiquitous in the German Bight, will refill the pits relatively quick. This did not happened until now because of to weak sedimentation rates. However, a recovery to a fine sand habitat might be possible (maybe in decades or centuries). When the pits are flattened enough also current velocity will increase again. This would prevent an accumulation of muddy material.

The word "regeneration" will adequately been substituted with "recovery" and "re-establishment" throughout the whole manuscript.

Specific comments in chronological order:

Introduction

L30-31: 'current' with references from 2010 is somewhat outdated in my opinion. I would suggest to check ICES WGEXT reports where recent figures are yearly reported for NE Atlantic countries. Latest report has figures from 2018 even making a distinction between extraction for coastal protection and for industrial purposes, see https://www.ices.dk/community/groups/Pages/WGEXT.aspx

Thank you for the information about the latest data.

While between 1998 and 2002 approximately 53 million m^3 was extracted, a total of 73.2 million m^3 was extracted from the northern European Continental Shelf in 2018 (ICES, 2016, ICES, 2019).

L30-42: very few references while quite some papers have been published on these topics so would be good to support these lines with extra references. Just naming a few: Le Bot et al 2010, Foden et al 2009, Kubicki et al 2007, Van Lancker et al 2015, also in cooperative research report of ICES WG on extraction a lot of references are incorporated in chapter on ecological impact of sand extraction (http://ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/CRR330.pdf)

The quoted reference are very helpful and a good support. Additionally they are a good basis for further literature. Thank you.

L64-66: refine/rephrase your objectives – maybe better in the form of hypotheses, research questions?

As already mentioned above, we think, that the aims and objectives should be adjusted towards new statistical analysis. Maybe like this:

"The aim of this study was to further determine the impacts of extensive marine aggregate extraction on the regional macrozoobenthic communities. The main objectives were to (i) gain a deeper understanding of the correlation between the prevailing habitats and the recovery state of the associated benthic assemblages, to (ii) evaluate temporal recovery patterns along with short- and long-term changes in the community structures and to (iii) investigate the potential of a re-establishment of pre-dredging conditions regarding fine sand domains (Pleistocene material cannot be re-established). Therefore, dredging pits of different ages and, as a control, the sandy areas surrounding the extraction site were compared for sediment and benthic faunal composition. Using hydroacoustic gear and sediment grab samples, habitat maps were created combining sediment properties with information about abundance and diversity of the macrozoobenthos."

L70 and further: this part should be moved to acknowledgements

Indeed.

Study area

L74: make 'study area' a section under M&M

Good Idea.

L75 - Fig1: Please include location of reference area(s) plus add information (best in a more detailed zoom) on e.g. geological layers, bathymetry and past and 'recent' dredged areas on the map, so it is more in line with the information provided in study area paragraph

We already revised Fig. 1 and added bathymetric information as well as the alignment of the Saalian moraine, from which the sediment has been extracted. Additionally, we include the locations of differently-aged extraction areas and the reference area. The zoom-factor was also increased.

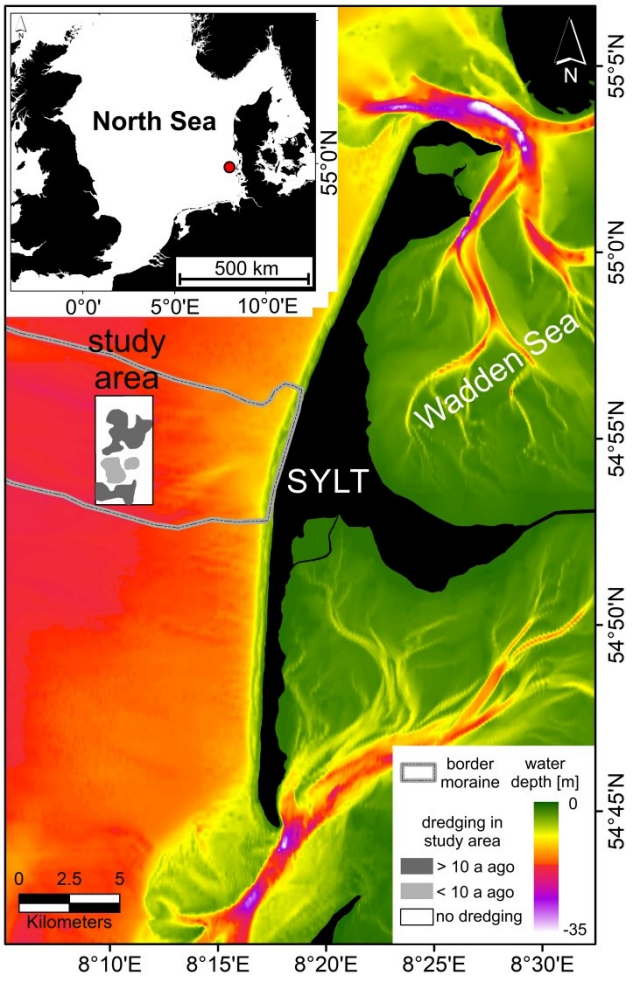

Figure 1: Study area "Westerland dredging area" located west of the Island of Sylt (SE North Sea). Bathymetric information were provided by the German Federal Maritime and Hydrographic Agency (BSH, 2018) and own measurements. Geological data were modified after Streif and Köster, 1978 (subaquatic border of the Saalian PISA-moraine).

L78: water depths between 14 and 30 m, is this natural depth range or does this include extraction pits already? Confusing, I would suggest to report 'natural' depth

The stated water depths include the extraction pits. The seafloor in the study area and also in the surroundings is very flat. The natural water depth ranges between 14 and 17.5 m in the research site.

L79: would be good to add cumulative amount of sand that has been extracted since 1984

Since 1984, more ~41 Mio m³ were extracted.

L82: what type of dredging is done? Static or trailer dredging?

Dredging was achieved using Trailing suction Hopper Dredgers.

L83: typo add IS derived

Ok. Thank you

L84: 'prevails' strange wording, better 'takes place'?

Yes, of course.

Material and methods

L94 'all-over' replace by 'over-all', 'high-resolute' replace by 'high resolution'

Indeed

L95-96: Please put transects and location of grab samples on a map.

Transects and positions of the grab samples are provided in the section 'results'. We can add this information to the manuscript at this section. (Captions of Fig. 2 and Fig. 4a can be modified to highlight this information.)

L95: These 55 transects were done for both multibeam and sidescan? Simultaneously or on different days? Please provide information on this in M&M section. Also not clear how long survey was, all in one week, several days throughout January? January can be quite heavy weather and shallow area so weather can have influence on measurements, certainly when spread over several days. Info needed.

During the survey, which took place between January 25th and January 27th at calm weather conditions, multibeam echosounder and sidescan sonars were used simultaneously on all transects. Ground truthing comprised 53 grab samples for grain-size analysis and macrobenthic fauna and were done on January 31th.

L111: please add what focus is of 330 kHZ and what of 1MHz sonar

Using different frequencies result in more detailed information about the seafloor environment. Sidescan mosaics recorded with a low frequency generally yield information about large-scale objects on the seafloor (e.g. facies changes, sandwaves, megaripples) while a high frequency give more information about small-scale structures (e.g. ripple marks, stones (Mielck et al. 2015)).

L126: very unconventional way of sampling benthos, very small samples for macrobenthos…I would expect the other way around big enough subsample for sediment and main sample for benthos? Why was this done this way? Clear justification is needed

Initially, this study was planned as a follow-up to investigate the further sedimentation characteristics of the dredging holes. When deep sediment dredging was first applied, the deeper water layer and sediment inside the dredging holes temporarily depleted in oxygen and became close to azoic (Armonies & Buschbaum 2008, unpublished report for the national authorities). This was thought to be due to the diameter/depth aspect favouring stagnant conditions in relatively small but deep holes. As a consequence, the national authorities decided that further dredging should use the same holes, i.e. increase their diameter instead of creating many small holes. The present study was an opportunity to check whether or not the larger diameter of the dredging holes would faciliate water circulation and thus enable permanent establishment of a macrozoobenthic community in the depths of the holes. Accordingly, the main questions to answer were

(1) is there life macrozoobenthos in the dredging holes?

(2) if yes, typical sediment-specific (i.e. mud-dwelling) fauna or just temporary opportunists washed into the holes from ambient sediments?

(3) is the benthic biomass inside the holes already comparable to ambient sediments, i.e. is the function as a potential feeding ground for higher trophic levels already restored?

To answer these simple questions, small sediment cores taken along with the sediment ground-truthing samples were considered adequate. A full description of the benthic communities in- and outside the dredging holes was not intended in this study. Only after the present results, it is clear that the current state of macrozoobenthic development warrants further studies with focus on the benthic communities, and therefore, with a sampling design adequate to reveal far more details of benthic community composition.

Armonies, W. , Buschbaum, C. (2008): Fachgutachten Makrozoobenthos im Rahmen der UVS für das Sandentnahmegebiet "Westerland III" westlich von Sylt. Im Auftrag des Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, pp. 1-94.

L129-130: class 0 control, is this really control, undisturbed conditions?? What about indirect/secondary impacts? Can you be certain that these are not at all affected by the dredging?

We know the seafloor west of Sylt very well. For example, in Mielck et al. 2015 we made a study in an area ca. 6 km northeast of the dredging area. Additionally, during the joint research project WIMO (2010-2015), we investigated several study areas more than 20 km south of it. The investigation shows that the seafloor conditions are very similar to the conditions in class "0" (patterns of fine and coarse sand -> so called sorted bedforms). During the dredging process in our study area, only small portions of very fine material are released to the water. This fraction was not detected in the grain-

size spectrum of our sediment samples in this area west of Sylt. It seems that the material is transported away by tidal currents in northern direction.

A direct impact due to dredging activities in class "0" can be excluded, since this is not permitted by the coastal authorities. In addition, the bathymetry does not show any signs of dredging.

Results

L140: replace 'excavation' by 'extraction' – try to be consistent throughout the manuscript

No problem.

L141: how do you know they are only partially refilled? What was depth after cessation of extraction? What is depth now? Please support your statements with numeric data.

We showed the refill process in a previous paper about the dredging area (Mielck et al. 2018: Morphological changes due to marine aggregate extraction for beach nourishment in the German Bight (SE North Sea)). Here, we also used data from 1993, that showed water depth of ~26 m in the northern pit. At this point of time, dredging activities were still conducted in this part of the study area. In 2008, water depths were at ~22 m and 10 years later, no measureable differences in water depth occurred. Moreover, we made investigations with a seismic device that revealed old slope failures in the subbottom, which are an indicator for a refill process.

Additionally, data from Zeiler et al. (2004) reveal that similar dredging depths (~ 33 m water depth) were also achieved in the year 1991. The dredging depth after cessation seemed to be generally at this level in order to limit the size of impact.

L141-145: in text, you mention letters a, b, c , d but these are not indicated on figure2. Please make sure that your figures and text match.

Yes, this can be done very easily.

– actually these are results from a previous study so delete here? Or clarify, since now it is confusing because you refer to/compare with earlier published study and description of these dredging pits is not the aim of this study.

You are right, that the refill process is a result from the previous study. However, we think that it is important to show at least a bathymetric map of the study area and to give a hint to the refill process. Hence, we can add a reference to Mielck et al. 2018 at this place.

Note: The bathymetry shown here was recorded in 2019 and was not published in Mielck et al. 2018.

L146-147: please define what is high, intermediate and low backscatter

The backscatter of the seafloor is illustrated in a grey-scale. When taking a look on Fig. 2 (right) you can see, that there are three different backscatter classes in the sonar-mosaic consisting of a range of

grey values(high, intermediate, low backscatter). They represent three domains: coarse sand, fine sand, and mud. Since the backscatter in the hydroacoustic is a complex process, it is not easy to define exact borders at the 8-bit color palette. There were many attempts in the past; however, the backscatter could be affected by very many parameters: e.g. the slope of the seafloor, the distance between the seafloor and the transducer, the slant range and angle of inclination, the gain-settings etc.

The post-processing software SonarWiz, which we used, has an option for automatic classification. However, there are always some artefacts in the resulting maps. Hence, we prefer to show the "raw" data in a sonar mosaic and do a supervised classification of the habitats with ARCGIS aided by our ground-truth data.

We can change this phrase in the manuscript, in order to clarify this aspect.

L156-157 – Fig4: would be good to have delineation of different dredging zones cf. old, new ones this would make interpretation of the maps more clear.

These delineations are already included in Figure 2 (left). Fig. 4 already yields many features and we think that it is not a good idea to add more lines to the figure. However, we can put a hint in the caption regarding the ages: e.g.: "For age of the dredging zones cf. Fig. 2 (left)."

L162: on which results this statement is based? Data in results are needed to support this? E.g. multivariate analyses or cluster analyses.

As already mentioned: We will provide additional SEMPER and ANOSIM statistics/results.

L166-170: unclear – is there a difference between undisturbed and control? First time mentioned in the paper. Please rephrase.

No, there is no difference and this will be rephrased.

L174-177: idem as comment above, please use multivariate analyses to back up these statements with SIMPER to demonstrate which species are making the difference between the groups

Yes, we will do it (see above).

Discussion

L190: okay, low sedimentation rates but how does the mud comes in? Do these pits not act as traps for mud?

Yes, this is correct. They act as sediment traps. The current velocity decreases inside the pits and muddy material, which is in suspension (most likely coming from rivers) accumulates in the pits. This is one result from the previous study (Mielck et al. 2018) and was also a finding from Zeiler et al., 2004, who measured current velocities inside the dredging pits. This information should be added to the manuscript.

"The current velocity strongly decrease inside the pits which allows the suspended mud to accumulate on the seafloor (Zeiler et al., 2004)."

L191-193: this is for the first time you mention the earlier study with which you compare the 2019 measurements – this causes the reader to be very confused all the way throughout the paper. Should be made clear from the beginning, even in introduction results of previous study should be situated.

To set it in a better context, this information can be added to the section 2.1 Study area. E.g.: "This study is a follow-up to the previous study Mielck et al. 2018, which focused on morphological changes due to marine aggregate extraction in this study area using bathymetric data between 1993 and 2017."

L212: is this a successional state? In my opinion, this is just an altered habitat which will never recover to the old state and reach a different equilibrium or has already reached it in the historic dredging pits. I would call this physical loss of benthic habitat (cf. MSFD descriptor 6 C1) due to dredging, even at the EUNIS level. For more background information see reports on this topic http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/Fisheries%20Resources%20Steering%20Group/2019/WKBEDPRES2/WKBEDPRES2_Report_2019.pdf + related info. Very weak discussion regarding the benthic results/benthic habitats. This is focus of the paper but it fails to add body to this topic while it actually should be the main part of the discussion. Combining the acoustic data with the biological data, is the interest of this paper.

As already mentioned above: Maybe a recovery to a common fine sand habitat is possible although the coarse sand is lost forever. When the pits are flattened enough also current velocity will increase again. This would prevent an accumulation of muddy material. We will check your provided information, which surly will be a good basis for further discussion.

L213-214: what are these habitat types? Where do you find which one? How related to dredging history? This is what should be discussed? Which habitat type, you found where and what are the indicator species for this type of habitat? As said above, this should be focus of discussion.

We will improve our discussion based on your suggestions.

L216: do you want restoration? Naturally, it will probably not be possible? So if you want restoration maybe mitigation through human intervention is needed? Or if not, leave it like it is, other suggestions?

See above. We will think about it and consider to mentioning this in the discussion.

What would be frequency needed for monitoring, yearly, every 5 years? Every 10

During our investigations in the past years, we did a semiannual monitoring program in this area. The dredging season is generally between May and September. Before they started the extraction in spring 2017, we started our monitoring program to evaluate the situation and what happened to the new dredging pits from the last season during winter storms. When the dredging season was finished in September, we did a second survey to detect the new dredging pits and so on the next years. Since the analysis of the benthic communities is relatively great effort, we would do this only every two years in the future.

We could at this Information to the manuscript:

"As a strategy to monitor the further development in the extraction sites, we suggest semiannual investigations of the different habitat types by hydroacoustic means combined with the analysis of the benthic communities every two years."

years? As you suggest, rate of infilling is very slow so why put money in a monitoring study where you already know the result? Wouldn't it be better to put the money in other research questions or mitigation measures or 'working with nature' designs? Or studies to prevent this happening again with the ongoing dredging? I am just putting forward some ideas, topics that could be included in the discussion and that would give it more scientific value. Now the discussion is too superficial, it could be lifted up by going more into depth in the main topics of your study.

A regular monitoring is very meaningful, as the dredging activities will take place each year. We believe, hence, that these activities should be monitored by collecting hydroacoustic and benthic data on the same temporal scale. It will further allow us to control for other potential external influences, such as storm events. However, we will come up with ideas, how the impact of dredging might be reduced.

When we started the monitoring program, it was the first time that sophisticated multibeam devices were used in this area. We already knew that the accumulation rate is very slow. However, we did not know that it is that slow. Additionally, we had no idea, what happened to the benthic communities after more than 30 years after the impact.

However, aspects like working with nature or mitigation measures are important and should be mentioned in the discussion as prospection for the future.