# Reviewer #1

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

The manuscript has improved a lot since the previous version. New analyses have been done and many parts have been rewritten or additions were made. I still believe this is a valuable addition to the literature on effects of sand extraction, certainly because it is such a valuable time series and a quite unusual way of dredging. However, I think there is still quite some room for improvement.

First, the authors keep to their idea that return to pre-dredging habitat is possible and that what is present now is a transient habitat, which is not the case. Although they have nuanced this statement compared to the previous version, by saying it might take centuries, I believe that this is a local permanent change of the habitat from sand to mud/fine sediment (=loss of habitat). Although, it is just on a small surface area, this needs to be recognized throughout the whole manuscript and especially in abstract and discussion (see specific comments).

We have now taken this into account in the manuscript in a few places. Regarding the newly created mud habitats, we share the opinion of the reviewer that a permanent habitat loss has taken place. However, we (and also Reviewer#2) see slight signs of regeneration especially in the shallower pits in the northeast. Here, the sediment patterns that originally characterized the study area have already re-established themselves. Detailed information is provided below.

What I am also still missing in discussion is the answer to the famous 'so what' question e.g. what are the implications for management of sand extraction in this area? What are implications of this changed habitat? What does it mean for future sand extraction? Also regarding monitoring strategy, discussion could be elaborated. The discussion needs this kind of paragraphs to get more body.

Discussion was extended and revised in many places. For more details see below.

Also the unconventional way of macrobenthos sampling should be recognized and discussed. Do you e.g. expect same results when conventional bigger samples would have been taken? This merits at least some discussion.

The effect of the small sample size has been included in the discussion, see for line 159:

"For faunal analyses this sample volume may be unusually small but we judged it sufficient to find out whether dredging had a strong effect."

Thirdly, ANOSIM was said to be done, but I cannot find these results. Some kind of visualization in MDS plot or so would also help to show/read this results better. I also believe, the results are still lacking the combination of sediment and faunal analysis. This can be easily done in Primer and would strengthen the faunal results.

With respect to macrobenthos, both reviewers seem to expect far more than intended in this study: we regard this a pilot study just aiming to find out whether or not the re-filling of the pits with a sediment type finer than ambient has significant effects on macrofaunal species composition, abundance, or biomass. These effects indeed have been proven during this study by significant changes in total abundance, species richness, abundance changes of the dominant species, and hence a change in the dominance spectra. A more detailed analysis of the recovery process and all the factors included was not intended in this study, and our sampling design is not adapted to such advanced analyses. Thus, some questions raised by the reviewers are really interesting and should be

studied in more detail, but this requires extra sampling with a far more sophisticated design. An attempt to answer these questions from the current data base may succeed in some cases – as we tried with our ANOSIM analysis; however, a critical review of these results left the suspicion that the current data might be strongly over-interpreted by ANOSIM. Consequently, we dropped the ANOSIM and concentrated on changes in abundance of dominant species that can be proven without reasonable doubt.

To allow publication, these different aspect should be tackled so reworking is needed. I leave it to the editor to decide whether this can be still be done in this journal.

**Some extra comments that I had whilst reading through the manuscript:**

Abstract:
L24-28: In my opinion, it should be recognized that there is habitat loss due to sand extraction. The habitat type has changed and will not recover without human intervention or a new ice age as matter of speaking. All evidence (morphological and faunal) is pointing in this direction. So, this should be stated this boldly in the abstract and not say that 'it will be a matter of centuries' and 'that it implies that coarse material is transported which actually will never be the case'… Just say it like it is without twists and turns. So rephrase this part of the abstract.

We rephrased this part of the abstract while considering the arguments of the reviewer:

Line 23: "Since re-establishment of disturbed benthic communities depends on previous re-establishment of habitat characteristics, the low sedimentation rates indicate that a return to a pre-dredging habitat type with its former benthic community and habitat characteristics is likely to be impossible. Since coarse sand is virtually immobile in this area, a regeneration towards natural conditions is unlikely without human interference (e.g. mitigation measures like depositing coarse material on the seafloor to restore the sessile epifauna) or without a new ice age which once formed this area.

**Introduction:**

L36: is this the figure of coastal protection? Or total extracted? Since you are talking just about coastal protection best to mention this total figure…

This is the total amount of aggregates which were extracted. In the most cases, it was for coastal protection. We added the word "especially" to the sentence because there was also sand mining for other purposes:

Line 34: "marine aggregates needed especially for coastal protection"

L46-47:' even develop in unexpected directions' replace by 'or new habitats are developed'

Replaced and rewritten in Line: 46:

"Whether or not the benthic communities are able to recover to their pre-dredging state, remain disturbed, or new habitats with altered benthic communities are developed, is crucial information for a holistic assessment of the impact of such a coastal defense measure."

L53: 'sensibility' should be 'sensitivity'

corrected

L64: aim 3 should be ‘investigate the potential of a re-establishment TO pre-dredging conditions’, all the other information is too much and contains already ‘results’

corrected

We rephrased the “aims” for more clarity:

Line 59: “The aim of this study was to further follow the re-filling process of the dredging pits and, as a new aspect, to find out whether and how extensive marine aggregate extraction affects regional macrozoobenthic communities. If local faunal composition was mainly ruled by larval supply, faunal composition inside the dredging pits may be similar to ambient sediments. Otherwise, if sediment composition was an important factor, faunal composition in the muddy sediments of dredging pits should considerably differ from composition in ambient sandy sediments.”

Topic was moved to the discussion. The following sentence has been deleted.
“regarding fine sand domains (coarse Pleistocene material cannot be re-established because of weak current velocities).”

**Material & methods**

L106: add ‘for this study’, hydroacoustic data and…

Changed:
Line 111: “For the study presented here, hydroacoustic data and sediment samples were taken…”

L112 and Fig 2: Position of VVgrabs should be put as dots on this map. Just refer to results is not sufficient. Putting them on this map helps to see the balance of your design.

Yes, that makes sense. We put the positions of the grab sample stations on Fig. 2 (both bathymetry and sidescan mosaic). We deliberately chose not to label the stations because otherwise too much of the mapping would be covered.

L127: should be habitat character**istics**

Corrected in line 131

L151: replace fresh by ‘wet’ weight, or even ‘blotted wet’ if you dipped the animals first

Replaced by “wet” in line 157

**Results:**

L187: was it not highly significant in the most recent pits? There are quite high mud concentration in the recent pits, it seems. L197: is this the same for the other sediment fraction as well? Or is it mainly mud that differs? Would be good to mention.

We included a new version for Fig.5 showing more details of the sediment composition and added the new information (Tab. 2) to the manuscript:

Line 202:
"After >10 years of recovery, the number of species returned to a level as high as for the control site ($p=0.10$), while it was significantly lower in the recently dredged sites when compared to the undisturbed (control) site ($p<0.01$; Fig. 5). These changes in macrozoobenthic species density and abundance were accompanied by significant changes in sediment composition. Recently dredged sites had a low sand and a high mud content and were very heterogeneous sorted; older pit sediments were intermediate between fresh pits and ambient sediment, with intermediate sorting but with a mud content still far above ambient sediment level and with a median grain size only slightly higher than in fresh pits (Fig. 5). The percentage mud content differed significantly between all combinations of disturbance classes ($p<0.05$) and therefore, may be best suited as a proxy for changes in sediment composition.

Paralleling these changes in sediment composition, the composition of the macrozoobenthic community strongly changed during the recovery phase. Six of the ten most abundant species showed significant abundance variations between site classes (Table 2). Compared to the ambient sediments, abundance of the polychaetes *Magelona johnstoni, Pisione remota, Aonides paucibranchiata, Polygordius appendiculatus,* and *Goniadella bobretzkii*, all sand dwelling species, sharply dropped in fresh (class 1) dredging holes and did not return to ambient levels in older pits (Table 2). The polychaete Nephtys cirrosa temporarily vanished from fresh dredging holes while mud-dwelling Notomastus latericeus temporarily showed up in the fresh pits. Older (class 2) dredging holes showed increases of abundance above ambient level in brittle stars *Ophiura ophiura* and its associate bivalve *Kurtiella bidentata*. Finally, the trumpet worm *Lagis koreni* became the numerical dominant species in older pits (Table 2). Most of these changes are likely to be caused by the changes in sediment composition: species that correlate significantly with increasing median grain size decreased in the pits while the muddy-sand species *Lagis koreni* increased (Table 2). Thus, faunal composition in older dredging holes is an assemblage of muddy-sand dwellers and strongly differs from the ambient assemblage of sand dwellers. A community composition equivalent to ambient conditions was not reached in any of the extraction pits."

L200-205: no ANOSIM results are mentioned. It would be good to first tell where significant differences in species composition are situated. Eg between all classes or just between dredged and non-dredged? Plus actually, visualization of these results in an MDS plot would be good. Plus by combining sediment data with faunal data e.g. by vector overlay in your MDS plot and thus finding correlations between the axes and the sediment variables this would strengthen your results further.

Has been changed; see our comment on macrobenthos above.

**Discussion**

L233-234: you should not speak about restoration. I really believe this is not possible in this case. These pits might be filled naturally but will be a different habitat than the pre-dredging one. This is a permanent change.

We removed "restoration" and revised this part of the manuscript.

Line 245:
“Based on such low rates of sedimentation, a complete backfill of the pits is likely to take centuries (Mielck et al., 2018). After refill, the previous accumulations of muddy material in deeper layers of the sediment will persist, potentially affecting the living conditions for deeper-dwelling fauna.

This natural backfill cannot restore full pre-dredging conditions, for two other reasons: The first are differences in sediment composition. While coarse-to-medium sand was removed during dredging, the backfill material is fine sand with a high mud content. This is due to the relative immobility of coarse sand (Tabat, 1979; Werner, 2004; Mielck et al., 2015).“

L249: you cannot call this a transient habitat type, this is the current habitat type which has changed permanently, it is habitat loss due to dredging that occurred in this area. This is for the moment, still not enough recognized throughout the discussion.

We revised this part of the discussion:

Line 281:
“It is replaced by a new habitat type…”

L257: it is indeed not a vast habitat loss but it is a local habitat loss. The habitat has permanently changed. As said before this should be recognized.

At this point we have once again referred to the habitat lost
Line 287:
“Currently, sand mining accompanied by local habitat loss is restricted to a relatively small part of the SE North Sea…”

L266-273: breaks flow of discussion why should this be mentioned? Delete? Better to focus on monitoring strategy instead, which comes suddenly out of the blue in the end. I also do not agree with semiannual surveys. This really is a waste of money for the old pits. Definitely since you have showed that backfill is so slowly. So there won’t be big changes expected. In active dredging pits, it is another story, there it could be valuable to measure more often since there changes are ongoing. So important to make distinction between areas in monitoring strategy.

We think, that the mentioning harmful chemicals which come along with the mud is an important aspect which should not be concealed (also in agreement with reviewer #2). We revised the discussion to avoid any “break flows”. More detailed information is given below.
Regarding the monitoring strategy, we agree with the reviewer that it is not necessary to monitor the old pits twice a year because no strong changes are expectable.
We add these sentences to the manuscript:

Line 297:
“As a strategy to monitor the further development in the extraction sites, we suggest investigations of the occurring habitat types by hydroacoustic means combined with the analysis of the benthic communities. For younger pits with fast rates of change, this should be done twice a year for habitat types and every two years for benthic fauna; for older pits with a slow rate of change, a habitat survey every two years and a faunal analysis once per decade may be sufficient, to save money, time and resources.“

L282: situation will never be original.

We rephrased the conclusion:

Line 314:
"This state may then remain for the next centuries, until the pits are largely backfilled and attain a surface sediment layer similar to original - at least regarding the morphology. But even then, living conditions may deviate from the former conditions, because the fine backfill sediments changed the habitat permanently."

However, in the Northeast, indications of regeneration become visible (in agreement with reviewer#2):

Line 318:
"However, at some positions, especially in the flat pits in the Northeast, slight regeneration towards pre-dredging conditions becomes visible. Here, patterns of sediment, which are coinciding with the seabed relief, recaptured the seafloor. This should be monitored in the future."

L284-285: working with nature should be mentioned already in discussion or at least mention something about mitigation measures. E.g. stones/rocks could be placed in pits to restore these sessile epifauna when backfill has stopped?

We mentioned these aspects in the discussion now. Additionally, discussion was extended.

Line 256:
"However, virtually no stones could be detected in the older dredging pits (Fig. 4 (c), (d)), as they were already buried by slope failures shortly after the dredging activity (Mielck et al. 2018). Thus, these patches of hard substrata and also the coarse sand areas are inevitably lost for the benthic epifauna. These habitats could only be restored by mitigation measures like depositing stones, gravel and coarse sand on the seafloor to allow for colonization of sessile epifauna."

Line 261:

"When planning the study, benthic fauna was included as an additional aspect in the pit recovery process because previous studies (Mielck et al. 2018) indicated that the sediments accumulating in the pits were finer than ambient sediments, and small subsamples for macrobenthos were deemed sufficient to check whether change in sediment composition had a strong effect on benthic macrofauna that would justify further studies. Significant differences of faunal composition between dredged sites and ambient sediments despite the small sample volumes indicates that changes are indeed strong, both on the community and on the species level. Larger samples might have proven this for even more species.

Species typical for coarse grained sand such as the polychaetes *Pisione remota*, and *Polygordius appendiculatus* could not re-establish in the fine sediments of the pits because they have an interstitial life-style equivalent to meiofaunal-sized organisms, i.e. they need a sediment type with pore sizes large enough for movement without displacing the sand grains. Based on the realized distribution across sediment types in the eastern North Sea, most benthic species seem to be restricted to a species-specific spectrum of sediment composition (Armonies, in prep.). However, since sediment composition correlates with many other factors such as hydrodynamic stress and sediment stability (Snelgrove and Butman, 1994), or oxygen supply and biogeochemistry (Giere 2008, Giere et al. 1988), the causes for these restrictions are not clear. Therefore, we can only state that the sediment types occupied in the dredging pits coincide with the sediment types occupied in the

surroundings (see supplementary material Table 2). In this sense, species composition of the benthic infauna changed according to sediment composition in the dredging holes."

Figures:

Fig2L528: add which are **'directly'** unaffected and replace 'dredged by 'dredging'

Added and changed

Fig 5: what do the letters a and b mean in the figure? Please add to the legend.

The figure has been extended and the legend revised.

## Reviewer #2

The authors have gone a good length to improve the manuscript following constructive and detailed comments provided by reviewers 1 and 2. Improvements include a more elaborate description of the context of this study including previous work done in the area, a better definition of research questions for this study, better explanation of the methods, and more elaborate discussion on the longer term expectations regarding recovery to the original state at the sand extraction pits.

However, whilst both reviewers recommended to elaborate on the benthic communities established in relation to the different habitats formed as a result of dredging, which is probably the most interesting aspect of this study, the authors to my opinion could have done much better than the minimalistic 16 lines of text in results section 3.2 dealing with benthos, and statistical analysis merely addressing differences in benthos between more recent and past disturbance versus undisturbed state. In the discussion the authors state that the species composition of the macrozoobenthic infauna changed according to sediment composition in the dredging pits, but this is not substantiated by any direct analysis of fauna versus sediment characteristics.

Section 3.2 was strongly extended regarding this aspect. Supplementary material Table 5 was enlarged by more statistics (more details are provided below).

An underlying problem in the analysis of habitats is that habitat mapping based on hydroacoustics (illustrated in Fig. 2 and 4) seems to distinguish a much greater habitat heterogeneity in the dredging pits, comprising patches of coarse sand, fine sand and mud, than the uniform mud drape which is described in the text. To me, this gives the impression that the hydroacoustics often fail to distinguish the mud drape, but rather record the acoustically more reflective sand present below the mud. This would need to be properly acknowledged.

Sidescan sonars are normally not able to penetrate the sediment more than 2 cm. In the pits, the hydroacoustic backscatter is not easy to interpret because the soundings are reflected by the slopes resulting in high backscatter while the slope on the other side give no reflection because they lie in acoustic shadow. That's the reason why we marked the pits as "dredging marks" in the sediment distribution map (Fig. 4) and do not interpret the backscatter responses from the pits regarding sediment type. In order to analyze the sediment distribution in the pits, the results of the granulometric analyze were used. We mentioned this briefly in the caption of figure 3:

Line 568: “(D) cone shaped funnels representing the dredging marks on the seafloor. Since higher backscatter values occur on the slopes of the funnels that are directed towards the sonar source differences in sediment distribution are not distinguishable using hydroacoustic.”

Regarding the hydroacoustically delineated habitats as shown in Fig. 4, no mention is made of seafloor relief in the study area except the dredging pits, even though a quick glance at the bathymetric and acoustic backscatter maps in Fig. 2 is sufficient to note a distinct coincidence of features of seabed relief and backscatter in the seabed areas surrounding the dredging pits. To me these features seem to represent low dunes composed of fine sand, lying on top of a coarse-grained Pleistocene sand which is outcropping in troughs in between the dunes. And the pattern of alternating dunes and troughs seems to extend also into the older dredging pits, especially in the northern part of the study area. This makes me wonder if the so-called “Wanderfeinsand” is actually moving across the shallower dredging pits, making habitats at these sites more dynamic than suggested by the authors.

We have now considered these aspects in the manuscript. Both the connection between bathymetry and sediment patterns and the slight signs of regeneration are now mentioned. More details below.

Regarding ground truthing of hydroacoustically delineated habitats, it does not help that the miniature pie charts presented in Fig. 4 are concealing the habitat present at the sampling location, and that some of the pies are overlapping.

We revised Figure 4. The pies are no more overlapping and the exact positions of the grabs are now not concealed by the pies as you suggest below.

In the attached document, I have included a large number of smaller mostly textual comments, and also some repeating of more general points of criticism raised above.

Line 25: replace “implies” by “requires”

Sentence was rewritten

Line 28: Working with nature implies making use of natural processes, but natural processes moving substantial amounts of sediment seem to be absent here.

“the term “Working with nature” was replaced by “mitigation measures”:

Line 26:

“Since coarse sand is virtually immobile in this area, a regeneration towards natural conditions is unlikely without human interference (e.g. mitigation measures like depositing coarse material on the seafloor to restore the sessile epifauna) or without a new ice age which once formed this area.”

Line 33: As a result, there is a world-wide high demand...

rewritten

Line 35: 2007 a or b?

It is “2007a”. corrected (also in the references)

Line 35: Danovaro

Name corrected

Line 36: continental shelf

Corrected

Line 36: from 53 annually to 73 annually?

No, it was altogether 53 million $m^3$ between 1998 and 2002. We added this to the manuscript:

Line 36:

"…the extracted volume rose from altogether 53 million $m^3$ between 1998 and 2002 to a total of 73.2 million $m^3$ in 2018."

Line 44: 2003

corrected

Line 46: 2007 a or b?

This is "b" – corrected (also in the references)

Line 58: 2005

corrected

Line 60: The statistical analysis addresses only relationship of fauna with disturbance class, not with different habitats or sediment characteristics determined in samples.

The chapter on animal-sediment relationships has been expanded in results, discussion, and supplementary material. See above (Reviewer #1) and below.

Line 65: hydroacoustics and sediment grab sampling

corrected

Line 68: Hydroacoustics have proven very effective for remote sensing seafloor classification

corrected

Line 72: In my understanding, the sonar transmits an acoustic pulse, the echo is the signal reflected from the seafloor.

That is true. We have corrected this in the manuscript:

Line 72:

"Sonar systems such as sidescan sonars allow to investigate the backscatter intensity by transmitting an acoustic pulse, which will be reflected by the seafloor and received by a transceiver."

Line 76: 2017

corrected

Line 76: Also sediment properties? What other purpose does groundtruthing as mentioned in previous sentence have?

Yes, indeed. We have deleted the superfluous sentence.

Line 78: Two things that require more thorough analysis: 1) relationship benthos with sediment type, 2) relationship sediment type with acoustic backscatter

1) has been changed, see above

2) Determining the relationship between sediment type and acoustic backscatter is not any easy task. Because of alternating gain-settings, slopes on the seafloor, range from the seafloor to the transducer etc. the backscatter intensities can strongly shift. In our case especially regarding the deep pits, this would statistically not be possible. For interpretation of sidescan sonar data, it is usual to do it in a "supervised way". Unsupervised methods often lead to a wrong classification of the seafloor (e.g. BSH, 2016: Anleitung zur Kartierung des Meeresbodens mittels hochauflösender Sonare in den deutschen Meeresge-bieten. BSH Nr. 7201).

We added this sentence to the manuscript:

Line141: The results of the grain-size analysis were used to relate the backscatter intensities to the prevailing sediment distribution.

Line 89: outcropping in the WDA

We added this to the manuscript in Line 90.

Line 90: No outcrops of boulder clay here? Or are glacial deposits actually pushed up fluvial sands and gravel originating from NW European rivers?

WDA is crossed by a Saalian moraine called PISA. The coarse sand and the stones are relicts of these moraine which was – of course – strongly eroded during sea level rise in the Holocene. Fine sand was transported through rivers and partially accumulated in this area. Boulder clay was not found here.

Line 91: From Fig. 1 it seems the moraine core strikes WNW. Or do the grey lines merely indicate the boundaries of where Pleistocene sediment is outcropping from below Holocene sand?

No, the grey lines show the position of the moraine core (after Köster 1979). Vast parts of this core are now covered with fine sand as you can see in Fig. 4. However, you are right. In our study area, the moraine strikes more in WNW direction. Further to the west, the direction changes to NNW. We changed this in the manuscript.

Line 92: "At the study area, this moraine core strikes in west-north-west direction…"

Line 92: Also fine grained sand! Please give more detail on dimension and orientation of these bedforms. Fig 2 seems to show low sand dunes with ~100 m wavelength and E-W strike, perpendicular to coastline of Sylt, which alternate in regular pattern with shallow troughs in which coarse sediment prevails. Fig. 3 shows very regular linear megaripples with ~1 m wavelength and N-S strike, parallel to coastline. Both types of bedforms would suggest active bedload sediment transport.

The origin and development of the sorted bedforms was subject of the investigation by Mielck et al. 2015. They can also be found further to the north were the study took place:

Mielck, F., Holler, P., Bürk, D., and Hass, H. C.: Interannual variability of sorted bedforms in the coastal German Bight (SE North Sea), Cont. Shelf Res., 111, 31–41, 2015.

We added some further information regarding size, wavelength and setup to the manuscript:

Line 93: "The surface of the seafloor in WDA is characterized by bands of coarse-grained rippled sand, so called sorted bedforms which are very common west off Sylt (Diesing et al., 2006; Mielck et al., 2018). Most of these bands have a wavelength of ~100 m and strike in east-west direction. The ripples within the coarse-grained areas do not strike in the same direction as they were most likely

formed during storm events (alignment perpendicular to storm direction). The sorted bedforms are often overlaid by a layer of migrating fine sand that leads to the consequence that their shape is frequently altered (Mielck et al. 2015)."

Line 92: Bedforms is not a term specifically reserved for bands of coarse-grained rippled sands, but for any sedimentary structure resulting from sediment transport.

That's true, however "sorted bedforms" is a fixed term in the coastal geology. Sometimes these structures are also called "rippled scour depressions", however, sorted bedforms is more common.

Line 96: No capitals

corrected

Line 98: This would be the best place to specify the dates of the recent and past dredging zones as given in Fig. 2.

Information was added to this place:
Line 103:
"The study area includes recent dredging zones (younger than 10 years), sand deposits exploited already more than 10 years ago, and…"

Line 99: The older pits are shallower than the more recent ones. Does this reflect a change in dredging practice, of were the older pits originally deeper than they are now? If so, how much deeper and what does this tell about backfill?

All these questions were already answered in Mielck et al. 2018. The dredging practice never changed. Originally, the old pits were as deep as the new ones. However, after a short time (~1 year), the pits flattened because of slope failures at the steep slopes. Later mud accumulated in the pits.

Line 100: I would expect that in the steep sides of the pits the same coarse Pleistocene sand is present as was extracted from the pits? Or do you mean fine sand that entered over the rim of the pit and temporarily accumulated on the sloping sides of the pit before moving further down?

We have expressed this somewhat misleadingly. Of course, there is coarse sand at the pits. However, during the flattening process, this sand slides to the bottom of the pits and fine sand, coming from the immediate vicinity (seafloor surface) covers the slopes and also the bottom of the pits.
For more clarity, we changed this part in the manuscript:

Line 105: "The Pleistocene coarse sands in the pits exposed during sand extraction were rapidly covered by a layer of fine sand due to slides at the steep slopes. The fine sand originates from the immediate seafloor surface around the pits."

Are Pleistocene sands not naturally outcropping off Sylt? Only after removal of Holocene top layer?

We meant, of course, the Pleistocene sand within the pits. Outcropping of Pleistocene material can often be found off Sylt (e.g. sorted bedforms). See above.

Line 100: were

corrected

Line 101: accumulated

corrected

Line 105: by

corrected

Line 106: collected

corrected

Line 106: Meaning new hydroacoustic data, in addition to data collected earlier between 1993 and 2017?

Yes. We changed this sentence for more clarity:

Line: 109: “For the study presented here, hydroacoustic data and sediment samples were taken using the research vessel *Alkor* in January 2019.”

Line 136: Please explain if delineation of habitats as shown in Fig. 4 was exclusively done on the basis of hydroacoustic data, after which ground truthing was used to link the different backscatter signatures to sediment type. Or if ground truthing data was also taken into account in delineation of the habitats.

While delineation of the habitats using ArcGIS, also the ground truthing data (i.e. mean grain sizes after Folk and Ward calculated with GRADISTAT) were used. We added these sentences to the manuscript:

Line 140: “The size of the stones was determined by measuring slant angle and length of the acoustic shadow using the software EdgeTech Discover. The results of the grain-size analysis were used to relate the backscatter intensities to the prevailing sediment distribution.”

Line 141: as

corrected

Line 141: and for macrobenthos analysis

Added to the manuscript
Line 146:
“For ground truthing of hydroacoustic data and for macrobenthos analysis, a total of 53 grab samples were taken…”

Line 149: Reviewer 1 asked for clarification of the small size of the benthos subsample, in comparison to available total sample. This is not really answered here.

Small sample size is explained in the methods section:
Line 155: “For faunal analyses this sample volume may be unusually small but we judged it sufficient to find out whether dredging had a strong effect.”

Line 151: wet

revised

Line 152: In view of the heterogeneity of the sediment in the study area, the relationship between fauna and sediment type seems also very relevant to investigate!

This part has been considerably expanded (see above and below).

Line 153: for

corrected

Line 154: for

corrected

Line 154: for

corrected

Line 160: analysis

corrected

Line 167: produced by

corrected

Line 169: Do you have data on the original depth of the older pits, and how much sediment has filled in since cessation of dredging?

This question was also already answered in Mielck et al. 2018. Originally, the old pits had a depth of ~ 30 m (below sea surface). Now, they have a water depth off approx. 25 m. However, in the beginning, the accumulation rates were much higher because of slope failures. Today, we assume sedimentation rates (with mud) between 2 and 18 mm. We added this information shortly to the manuscript:

Line 173: “Thus, even the oldest depressions have only partially refilled with sediment after 35 years (quick backfill of about 5 m and very low sedimentation rates after the first year; c.f. Zeiler et al. 2004; Mielck et al. 2018).”

Line 171: There is much overlap in content with lines 174-181. However, no mention whatsoever of seabed topographis features that are very distinctly coinciding with backscatter patterns: low dunes composed of fine sand extending in E-W direction, alternating with shallow troughs in which coarser or more acoustically reflective sediment is outcropping. These E-W oriented features are most clearly developed on the undisturned seabed surrounding the dredging pits, but seem to extend also into the older and shallower pits, especially in the north of the study area. This would suggest more mobility of the Wanderfeinsand than assumed in this manuscript.

We have included the connection between topography and backscatter in the manuscript and also mentioned the mobility of the fine sand dunes:

Line 177: “Ground truthing with grain-size analyses of the sediment (Fig. 4A and B) revealed that high backscatter domains represent rippled coarse sand zones (sorted bedforms). Intermediate backscatter stands for fine sand. Coarse and fine sand zones were often demarcated by sharp borders (Fig. 3A). These backscatter patterns distinctly coinciding with the topography (compare Fig. 2 left and right), while low dunes composed of relatively mobile fine sand (extending in east-west direction) alternating with shallow troughs where relative immobile coarser sediment is exposed. These seafloor features are most pronounced on the undisturbed seafloor around the dredging pits, but also appear to extend into the older and shallower pits especially in the North of the study area.”

Line 175: Outside the dredging pits, it seems that high-backscatter and intermediate backscatter domains alternate in a regular pattern, distinctly coinciding with alternating E-W oriented shallow troughs and low crests. This coincidence between backscatter and bathymetry should be mentioned. With the additional information that low-lying high-backscatter domains are characterised by coarse sand with stones, and the higher ground intermediate backscatter domains by fine sand, suggests the presence of low dunes or sheets of fine sand that migrate in along-shore direction over a surface covered with lag deposit of coarse sand with stones. Has this been discussed in the Mielck et al 2018 paper? This pattern of high-backscatter troughs and intermediate backscatter crests seems to extend also into the older dredging pits, in particular the northernmost one, which would suggest that large-scale bedforms may be migrating across these pits.

The topography was extensively discussed in Mielck et al 2018 and also the sediment distribution (18 grab samples were taken), however not the backscatter intensities from the different domains since there were no sidescan sonar mosaics available in this study. We have included the connection between topography and backscatter in this manuscript (see above line 177).

Line 175: high backscatter

changed

Line 175: Is high backscatter related to the coarse nature of the sediment, or also or even mostly to the fact that the sloping sides of the ripples are oriented towards the sonar source?

High backscatter is a combination of both coarse-grained sediment and the slopes. When the ripples are orientated perpendicular to the movement direction of the sonar source, they might not be visible in the sonograms, however, the backscatter will still be high. But this is only very rarely the case, as the ripples almost never run dead straight.

Line 177: The meaning of light/dark shades should better be explained in the figure caption.

The caption of figure 3 was revised:

Line 565: (A) rippled coarse sand (dark) and smooth fine sand (bright) demarcated by a sharp border. (B) cobbles and boulders. In the direction of the sonar source, these objects initially exhibit high backscatter followed by a bright acoustic shadow from which no backscatter can occur. (C) very smooth mud area with low backscatter surrounded by a domain of fine sand with intermediate backscatter. (D) cone shaped funnels representing the dredging marks on the seafloor. Higher backscatter values occur on the slopes of the funnels that are directed towards the sonar source.

Line 180: This is also particularly true for the conspicuous feature in the north of the study area near 54 deg 56 min N, which again coincides with a distinct step in bathymetry. Is this a man-made feature?

No, this is not a man-made feature. This is part of the moraine (see Fig. 1). At this position, coarse Pleistocene sediment is outcropping and not covered by the “Wanderfeinsand”.

Line 181: , in the sonograms represented as areas with uniform low backscatter,

The sentence was supplemented
Line 188:
“Extended areas of mud, in the sonograms represented as areas with uniform low backscatter, could only be…”

Line 182: funnels? cavities? depressions?

We changed it to „depressions“.

Line 184: I would rather call it a sediment distribution map and a bathymetric map.

changed

Line 185: This is not a very adequate description of what seems a distinct pattern.

We modified this sentence:
Line 193: “While undisturbed ambient sediments were mostly fine sands interspersed with strips of coarse sand.”

Line 186: In this phrasing, nothing reflects the patchy and to some extent patterned distribution of coarse and fine sands that is also seen in the pits, and very limited occurrence of mud. Are the hydroacoustics unfit to detect relatively thin drape of mud covering the bottom of the pits, and merely recording the underlying acoustically reflective sand units? If this is the case, this should be properly acknowledged!

Sidescan sonars are not able to penetrate the sediment more than 2 cm.

In the pits, the hydroacoustic backscatter is not easy to interpret because the soundings are reflected by the slopes resulting in high backscatter while the slope on the other side give no reflection because they lie in acoustic shadow. That’s the reason why we marked the pits as “dredging marks” in the sediment distribution map (Fig. 4) and do not interpret the backscatter responses from the pits regarding sediment type. In order to analyze the sediment distribution in the pits, the results of the granulometric analyze were used.

Line 186: If anything is clear from Fig. 5A, it is that mud content is significantly higher in the younger and deeper pits than in the older and shallower pits, which is opposed to the notion that the pits are gradually filling in with mud as time passes.

Right, we clarified that “pure” mud accumulation was temporary in young pits and turned to ‘muddy fine sand’ accumulations in older pits. Figure 5 was revised and Table 2 was added.

Line 189: Only 16 lines describing relationships between benthos and habitat/sediment type along with development of the dredging pits through time is a bit disappointing. Most of this merely addresses relationship between benthos and disturbance class, not habitat.

Section 3.2 was strongly extended regarding this aspect.

Supplementary material Table 5 was enlarged by statistics on the realized niches with respect to sediment composition of numerically dominant species in ambient sediments of the study area. These data show that the species identified as sand dwellers all attain highest abundances in sand and had rarely or never been recorded in mud. Conversely, *Lagis koreni* was scarcely found in sandy sediments but attained maximum abundances in mud; hence it was classified a mud-dweller.

Line 190: And what about sediment type?

has been rephrased (see section 3.2).

Line 215: coinciding with seabed relief features

Revised:
Line 231: "Before the dredging activity started in 1984, the study site was characterized by patterns of fine and coarse sand (sorted bedforms, coinciding with seabed relief features), which are very common in this area…"

Line 216: And seem to extend into the older and shallower dredging pits.

We also believe that slight tendencies towards regeneration can be seen in some places. For Reviewer#1 this is denied for the mud habitats. Here also no signs of regeneration are to be recognized and one can therefore speak of a habitat loss.

Revision in line 233:
"These pre-dredging conditions are still present between the dredged areas and east of them (Fig. 2, 3A, 4) and seem to extend into the older and shallower dredging pits especially in the Northeast."

Line 218: While dredging was ongoing the bottom of the pits was littered with stones that were too large to be sucked in by the dredger.

Revision:
Line 235: "The dredging pits, in contrast, have different surface layers. Directly after dredging, the surface is composed of coarse sand and stones, that were too large to be sucked in by the dredger."

Line 219: From backscatter maps it seems that the fine sand cover is patchy in the pits, revealing also the underlying coarser sand.

This process takes longer so that at the beginning stones and coarse sand can be observed on the seabed. After a few months, however, this is no longer the case, as the taken sediment samples also show.

We modified the sentence to be more precise:
Line 236: "Soon afterwards, this layer got more and more covered by fine sand probably deriving from the (formerly steep) rims of the pits."

Line 219: Or entering across the rims?

Maybe, when the slopes are flattened enough. However, this is not easy to prove with our data.

Line 220: allowed

Corrected

Line 221: But according to what is shown in Fig. 2 and 4, mud cover is far from uniform over the bottom of the pits, but restricted to a few small patches.

Since the sidescan sonar recordings in the fresh pits are too patchy for classification (see above) we marked these areas as “dredging marks” in Fig. 4. When you take a look on the sediment samples coming from this area (e.g. samples 28, 29, 31 and 33), you can see the high mud content within these pits. Maybe after a couple of years when the pits have flattened, the mud will also become visible in the sidescan sonar.

Line 239:
We added “after a couple of months” to this sentence in order to show that this process needs some time.

Line 224: This only shows fill up rate at later stage. Any data on initial fill up rate?

In the beginning, the fill-rates are relatively high due to slope failures. We mentioned this in line 173 and line 236. However, the backfill should not be in the focus of the manuscript because it was already discussed in Mielck et al. 2018.

Line 231: According to lines 89-90 the extracted sand is not just sand but coarse sand.

That’s true. It is coarse-to-medium sand. We changed this in line 250.
“While coarse-to-medium sand was removed during dredging…”

Line 233: If the coarse sand is a Pleistocene relict, and backfill is by fine sands which are mobile, then I don't see how coarse sands could become mixed in the backfill.

At request of reviewer #1, this part of the manuscript has already been revised.

Line 244:
“Based on such low rates of sedimentation, a complete backfill of the pits is likely to take centuries (Mielck et al., 2018). After refill, the previous accumulations of muddy material in deeper layers of the sediment will persist, potentially affecting the living conditions for deeper-dwelling fauna. This natural backfill cannot restore full pre-dredging conditions, for two other reasons: The first are differences in sediment composition. While coarse-to-medium sand was removed during dredging, the backfill material is fine sand with a high mud content. This is due to the relative immobility of coarse sand (Tabat, 1979; Werner, 2004; Mielck et al., 2015).”

Line 234: What previous accumulations of fine material?

See above

Line 240: year?

2019, revised

Line 243: This is not demonstrated by any direct statistical analysis, only inferred from differences in fauna from different disturbance classes.

Additional data are given in the supplementary material substantiating the classification of dominant species with sediment types. The discussion section was strongly extended.

Line 248: The replacement of sandy by muddy seabed does not necessarily mean loss of feeding ground. According to Fig. 5D, biomass hasn't changed significantly. Actually, the trapping of organic detritus in the pits could be expected to lead to higher benthic production. The increased water depth in the pits seems a more likely barrier to predation of benthos by diving birds.

The potential loss of feeding ground has been refined: it's a potential loss of feeding ground for depth-limited predators and/or for those feeding on sand ground only.
As regards the relation of organic matter supply and benthic production, we fear the relation is not as simple as expected by the reviewer; potential oxygen depletion with increasing organic matter content has to be taken into account, in particular in a low-circulation environment as are the pits.

Line 262: Not demonstrated in this study.

The correlation of sediment composition and faunal composition has been refined in both the results section and the discussion, and with references in supplementary materials.

Line 267: Indeed, by favouring deposition of organic detritus, boosting benthic productivity.

See above comment to line 248: right, organic matter deposition may boost benthic productivity – but only if organic matter was in short supply before AND if increased organic matter content does not result in oxygen deficiency.

Line 272: Even if Wanderfeinsand is supposedly practically immobile, and deposition rate of mud in the pits is far below detection of hydroacoustics?

Yes, that is right. We modified this part of the manuscript. The monitoring should be limited to the fresh dredging pits and the ongoing mining.

Line 297: "As a strategy to monitor the further development in the extraction sites, we suggest investigations of the occurring habitat types by hydroacoustic means combined with the analysis of the benthic communities. For younger pits with fast rates of change, this should be done twice a year for habitat types and every two years for benthic fauna; for older pits with a slow rate of change, a habitat survey every two years and a faunal analysis once per decade may be sufficient, to save money, time and resources."

Line 373: Not referred to in text.

deleted

Fig. 3: Refer to Fig. 2 for explanation of ship tracks and different shades of grey. And some more explanatory text would be welcome.

We added more explanatory text to the caption of Fig. 3. Line 565:

"Figure 3: Seafloor features detected within the two sidescan sonar mosaics: (A) rippled coarse sand (dark) and smooth fine sand (bright) demarcated by a sharp border. (B) cobbles and boulders. In the direction of the sonar source, these objects initially exhibit high backscatter followed by a bright acoustic shadow from which no backscatter can occur. (C) very smooth mud area with low

backscatter surrounded by a domain of fine sand with intermediate backscatter. (D) cone shaped funnels representing the dredging marks on the seafloor. Higher backscatter values occur on the slopes of the funnels that are directed towards the sonar source."

Figure 4: Unfortunately, the pie conceal the nature of the sediment patch from which the sample was taken: fine or coarse sediment or mud. Better shift the pie's a bit sideways with tieline connected to exact sampling point. Also the overlapping of the pie's for samples 49-54 is not really convenient.

We revised Figure 4 as you suggested. The pies are no more overlapping and the exact positions of the grabs are now not concealed by the pies. Tielines were also added.

Figure 5: Please explain meaning of a and b

Fig. 5 was replaced by a new version and the legend revised

Why on a log-10 scale? The range of values can be easily displayed on a non-log scale.

We revised Figure 5 and removed the log-10 scale (though this didn't change anything).