Ecological assessment of intense aggregate dredging activity on the Belgian part of the North Sea

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Abstract

Yearly around 3 million m³ of marine sand is extracted in the Belgian part of the North Sea (BPNS) both for construction purposes and coastal protection. Benthic monitoring is undertaken on a yearly basis to evaluate the potential effects of aggregate dredging on the soft sediment benthic ecosystem. During the past three years, monitoring effort has mainly been focused on the areas that are or have been most intensively dredged: Buiten Ratel (zone 2br), Thorntonbank (zone 1) and Oosthinder (zone 4c).

Closure of the most intensively dredged area of the Buiten Ratel in January 2015 (BRMC) did not alter sediment composition nor the macrobenthic community to pre-dredging conditions, two years after cessation of dredging**.** The increased percentages of shells (>1600 µm) and very fine sand (63-125 µm), as a result of the intensive dredging activity in previous years, persisted, whichsupports the survival of the heterogenic, dynamic community that was established during dredging. A peak of the early coloniser *Spiophanes bombyx* was observed, which is most probably related to the cessation of dredging.

The increased dredging on the western part of the Thorntonbank in the past years, created a local new 'biodiversity hot spot' on the Thorntonbank. The dredging induced mixed sediments with presence of mud/very fine sand, which attracts macrobenthic species that are typically correlated with fine sands in addition to the coarse sand *Ophelia* habitat species. This is a verly similar pattern as was observed on the 'extraction hot spot' of the Buiten Ratel (BRMC).

Surprisingly, peak extraction on the Oosthinder in 2014 did not invoke significant sediment changes. Also, the number of macrobenthic species, nor the density or benthic community structure did change (yet), although a very high amount of sand was extracted at this site. Most probably, the extraction period was too short to lead to similar changes as noted on the Buiten Ratel and Thorntonbank.

Introduction

Yearly around 3 million m³ of marine sand is extracted in the Belgian part of the North Sea (BPNS) both for construction purposes and coastal protection. Dredging for marine aggregates inevitably results in disturbance of the seabed and it's biological habitats. Dredging impact on the seabed is both direct e.g. through removal of sediments and indirect e.g. through deposition of sediment plumes (Tillin et al. 2011). Furthermore, many studies have shown that marine aggregate dredging has the potential to change the composition of seabed sediment habitats (Foden et al. 2009, Le Bot et al. 2010). Since marine macrobenthic communities are strongly related to sediment habitats (Degraer et al. 2008, Vanaverbeke et al. 2011), they are good indicators to measure potential changes in seabed habitats (Van Hoey et al. 2010). Hence, the focus for our study on the benthic habitat.

For many years, ILVO conducts benthic monitoring aimed at evaluating the potential effects of aggregate dredging on the soft sediment benthic ecosystem. Since 2010, sampling has intensified and the sampling strategy was adjusted by allocating more reference stations (De Backer et al. 2011). Aggregate dredging in the

BPNS is restricted to four dedicated zones as cited in RD 19 April 2014 and the Marine Spatial Plan RD 20 March 2014. Control on the dredging activities is done by means of an Electronic Monitoring System (EMS, the black-box) on board the extraction vessels. During the past years, biological monitoring effort has mainly been focused on the areas that are most intensively dredged according to EMS data.

EMS data showed that since 2009, extraction intensified on the central part of the Buiten Ratel sand bank (BRMC area). Between 2010 and 2014, the BRMC area was the 'hot spot' of extraction activities on the BPNS with yearly extracted volumes upto almost 1.9 million m³ (Degrendele et al. 2014). These high extraction volumes changed the sediment composition in the area to mixed sediments, as such creating a heterogenic habitat with a mixture of coarse and fine sand species (De Backer et al. 2014a, De Backer et al. 2014b). The 'hot spot of extraction' was found to be as well a 'hot spot of biodiversity' with high macrobenthic species numbers and densities. However, the high degree of extraction caused a 5 m deep depression in the area, and as a consequence the area was closed for extraction in January 2015 (Degrendele et al. 2014, Roche et al. 2017, this volume). Benthic monitoring inside the area continued after closure of the area in order to investigate whether the closure of the area had an immediate effect on the rich benthic habitat that was established during dredging.

Due to closure of the BRMC area, dredging activities gradually shifted from the central part of the Buiten Ratel towards the Thorntonbank (zone 1). EMS data showed a big increase from 2014 onwards, with 1.8 million m³ extracted in 2016. Dredging on the Thorntonbank is mainly concentrated on the western part (Vandenbranden et al. 2017, Roche et al., 2017, this volume). Upto 2013, the benthic ecosystem was not affected as there was only a low degree of dredging activity on the Thorntonbank (De Backer et al. 2014a). To find out whether the increased amount of dredging had an effect on the benthic ecosystem, we intensified the benthic monitoring on the Thorntonbank during the past years.

Furthermore, aggregate dredging for coastal protection increased steeply after the start of the Master Plan Coastal Safety, approved by the Flemish government in 2011 (Van Quickelborne 2014). For this plan, at least 20 million m³ of sand is needed to protect the Belgian coastline against extreme storm events at a 1:1000 years return period (Mertens et al. 2011). In order to be able to cope with these huge amounts of sand, a new concession zone on the Hinderbanken was agreed upon (zone 4). Since 2012, sand for some huge beach nourishment projects originates from zone 4, and more specifically zone 4c on the Oosthinder. The dredging activity in area 4c is mostly concentrated in relatively short time periods, since it is in function of beach nourishments. However, in these short time intervals, large volumes are extracted with a total of 2.5 million m³ extracted between January and June in 4c in 2014. This peak extraction was the biggest ever on the BPNS (Van Lancker et al. 2016), and thus it was important to evaluate the ecological benthic impact of such a short-term, but huge extraction event.

The benthic monitoring and subsequent data analyses for this report focussed on the following research questions:

1) What is the effect of the closure of the BRMC area (zone 2br) on the 'benthic biodiversity hotspot' that was created during intensive dredging?
2) How is the benthic ecosystem on the Thorntonbank (zone 1) affected by the increased dredging activity?
3) Did the short-term huge dredging activity in 2014 affect the benthic ecosystem of the Oosthinder (zone 4c)?

Material and methods

This study focusses on the three most used aggregate dredging areas in the period 2010-2016 on the Belgian part of the North Sea (BPNS): Buiten Ratel (zone 2 br), Thorntonbank (zone 1) and Oosthinder (zone 4c). For detailed info on extraction volumes and extraction history within these areas, we refer to Vandenbranden et al. (2017, this volume) and Roche et al. (2017, this volume).

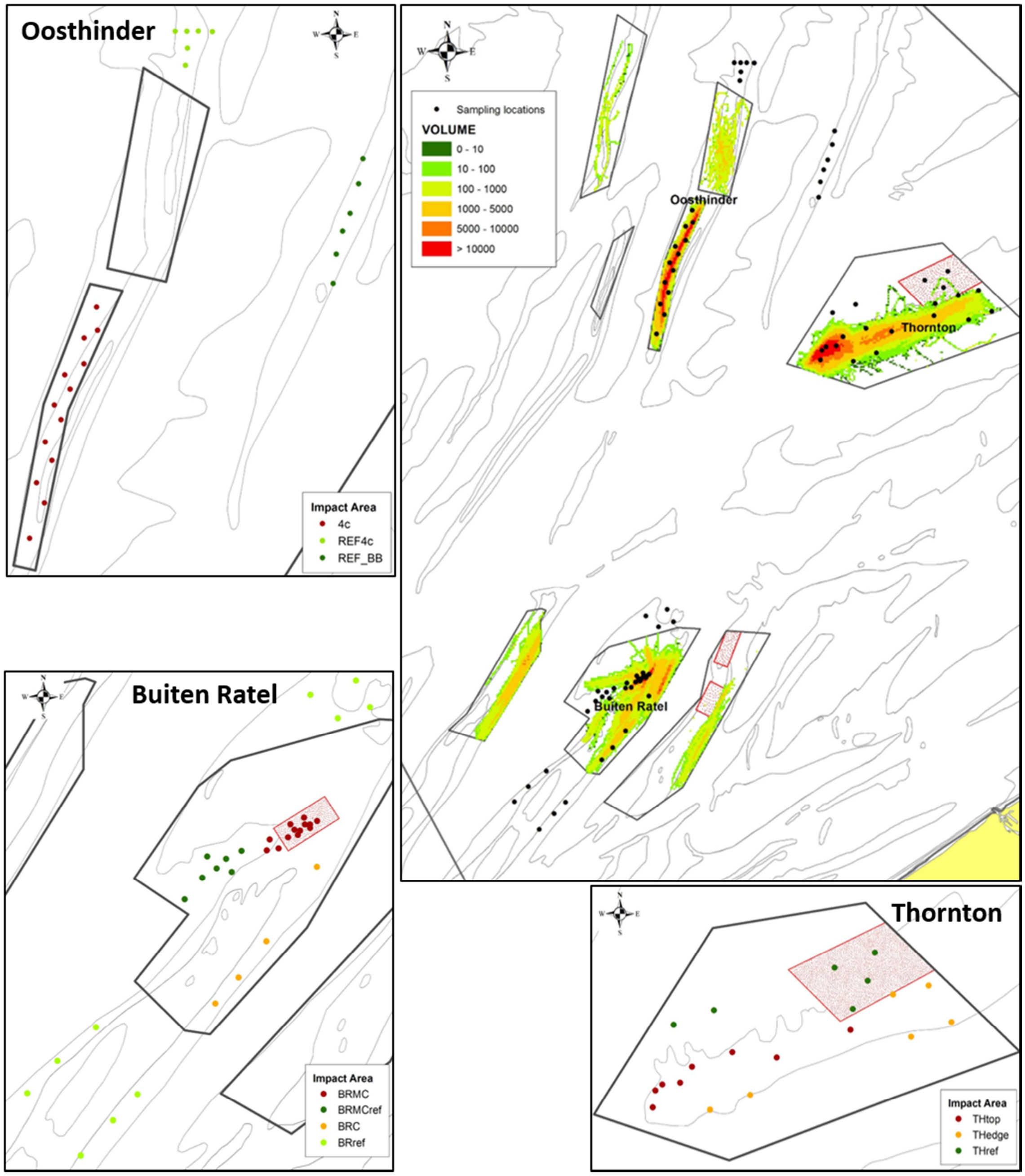

Figure 3: Map of aggregate concession areas on the BPNS with extracted volumes (m³/ha) based on black box data over the period 2013-2016 and biological sampling locations (top right). Detailed figures show impact and reference areas within each concession area.

Sampling and sample processing

The position of the sampling locations was chosen based on black-box data (a system that keeps track of extraction time and location of the extraction vessels). In all extraction areas, both impact and reference locations were allocated to allow for an ecological impact assessment (Figure 3). Within the different concession zones, samples were allocated within different impact areas based on dredging pressure (e.g. on the Buiten Ratel, BRMC samples with high dredging pressure and BRC samples with lower pressure), and within different reference areas based on the location of the reference samples (e.g. REF4c samples on Oosthinder sand bank and REF_BB samples on Bligh Bank). In Table 1 and Figure 3, an overview is given of the different impact areas per study site.

Sampling took place on board the RV Belgica, RV Simon Stevin and catamaran Last Freedom on a yearly basis between 2010 and 2016 in autumn (September/October) and at some occasions in spring (March) as well (see Table 1 for sampling times). Furthermore, at the Oosthinder, one extra sampling was done in July 2012 on board the RV Simon Stevin, one month after the first extraction phase had stopped and on the Thornthonbank, samples from autumn 2004 have been included in the analyses (Table 1).

Macrobenthos was sampled by means of a Van Veen grab (surface area 0.1 m²), one Van Veen per location at every sampling occasion. Real-time coordinates of each location were noted. The fauna was sieved alive over a 1-mm sieve, stained with eosin to facilitate further sorting, and preserved in an 8% formaldehyde–seawater solution. All individuals were identified to species level if possible, and counted. For biomass measurements, each species/taxon in every sample was blotted on absorbent paper before being weighed (wet weight) to the nearest 0.00001 g.

A small sediment core (3.6 cm ∅) was taken from each Van Veen sample for granulometric analysis. Grain size fractions up to 1600 µm were analysed using a Malvern Mastersizer 2000G hydro version 5.40 (Malvern, 1999), and determined as volume percentages according to the Wentworth scale. The fraction > 1600 µm was sieved first and as well calculated as volume percentage. The following classes were used: clay/silt (<63 µm), very fine sand (63-125 µm), fine sand (125-250 µm), medium sand (250-500 µm), coarse sand (500-1000 µm), very coarse sand (1000-1600 µm), shells/gravel (>1600 µm).

Data analyses

In total, 618 stations have been sampled in the period 2010-2016 (incl. 2004 for Thornton area) within the different concession areas. To determine dredging intensity at the biological sampling locations, real time coordinates of every sampling location were plotted in ArcMap 10. Around each location, a circular 50 m radius buffer was drawn. The shapefile with buffer locations and the 'black box' data were imported in R 3.0.2 (R Core Team 2013) to calculate the cumulative extracted volume within the buffer area (surface area 8000 m²) in the year prior to biological sampling. Thus, dredging intensity used throughout this manuscript refers to volumes per surface area of 8000 m² per year (the year prior to biological sampling), unless mentioned otherwise.

Species richness (S), density and biomass were calculated for every macrobenthos sample using PRIMER v6 (Clarke and Gorley 2006). Spearman rank correlations were done between univariate measures, dredging intensity and sediment parameters to identify which univariate measures or sediment parameters were possibly influenced by aggregate dredging.

First, we tested a three-factorial Permanova design with factors 'year', 'season' and 'impact' to test for differences between seasons. When 'season' was significant, further analyses were done on each season separately (only autumn data are presented in this case).

To test for dredging effects, we used a two-factorial permanova design with factors 'year' and 'impact' on an Euclidean distance resemblance matrix for univariate parameters (species number, density, biomass and sediment variables) and on a Bray-Curtis resemblance matrix for community structure. This was done for each concession zone separately. The primary aim was to analyse interaction effects between 'year' and 'impact', since these would reveal whether the changes that occurred could be attributed to changes in the dredging pressure i.e. cessation of dredging in BRMC area, increased dredging on Thorntonbank or peak dredging on the Oosthinder. When a significant effect for the 'impact x year' interaction term was found, pairwise tests were conducted to test for differences between impact areas within each year or between years within an impact area. SIMPER analyses were done to find the species responsible for the observed changes.

Table 1: Overview of impact areas (with codes used throughout the manuscript) per concession zone and indication of sampling time. Au= autumn, su= summer and spr= spring.

Concession zone	**Impact area**	**Description**	**2004**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Buiten Ratel	BRMC	Most impacted area on BPNS until 2014, closed since January 2016		spr&au	spr&au	au	au	spr&au	spr&au	au
	BRMCref	Area with similar sediments as BRMC but without dredging		au	spr&au	au	au	spr&au	spr&au	au
	BRC	Area located to the SW of BRMC on the flank of the BR with lower dredging pressure		spr&au	au	au	au	spr&au	spr&au	au
	Brref	Reference area located outside the concession area both to the north and the south		spr&au	au	au	au	spr&au	spr&au	au
Thorntonbank	THtop	Impact area with high dredging pressure located on top of the bank, increasingly used since 2013	au	au	au	au	au	au	/	au
	THedge	Impact area with very low dredging pressure located at the edges of the bank	au	au	au	au	au	au	/	au
	THref	Reference area within the concession zone but without dredging pressure	au	au	au	au	au	au	/	au
Oosthinder	4c	Impact area used mainly for dredging for coastal protection with high pressure in certain periods		spr&au	au	spr, su & au	au	spr&au	/	/
	REF4c	Reference area in the north of the Oosthinder outside the concession area		spr&au	au	spr, su & au	au	spr&au	/	/
	REF_BB	Reference area on the Bligh Bank		spr&au	au	spr & au	au	spr&au	/	/

Relationships between the multivariate data cloud and environmental variables (grain size fractions, median grain size and dredging intensity) were investigated through DISTLM (Distance-based linear models) analysis using the BEST procedure and AICc criterion. Before running the DISTLM analysis, environmental data were normalised and collinearity among variables was examined using Spearman rank correlation coefficients. If a linear dependency between variables was identified (r>0.8), only one of the variables was retained in the analysis.

All analyses were executed using Primer v6 with PERMANOVA add-on software (Clarke and Gorley 2006, Anderson et al. 2008).

Results and discussion

BUITEN RATEL

Dredging in sampling stations

Before closure of the BRMC area on the Buiten Ratel in January 2015, average dredging intensity ranged between 3260 m³ per year in 2010 and 5900 m³ per year in 2014 around the BRN stations (buffer area 8000 m²)(Figure 4). As such the area was disturbed by dredging activity on 40 to 70 days a year. After closure in January 2015, dredging activity ceased in the area of the BRNstations, hence the steep decrease in dredging intensity since end 2014 (Figure 4). Around the BRC stations on the Buiten Ratel, dredged volumes were much lower ranging between 64 m³ per year in 2015 and 785 m³ per year in 2014 (Figure 4), equivalent to a seabed disturbance on 1 to 13 days a year. In the BRC area, dredging decreased as well after the closure of BRMC, although the area is still open for extraction.

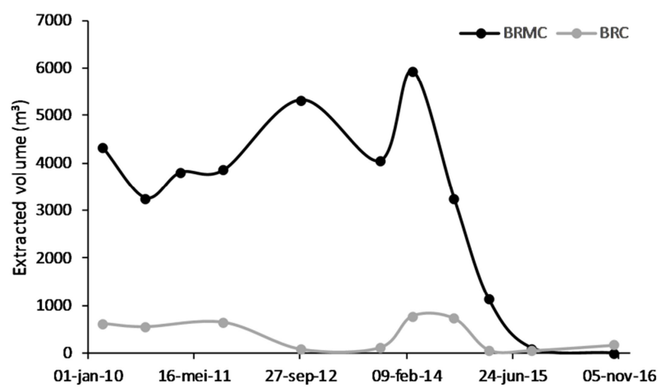

Figure 4: Average extraction volumes over time at the biological BRMC and BRC stations. Extraction volumes per year are based on EMS data, 365 days prior to the biological sampling date in a circular buffer area around the sampling location with a radius of 50 m (8000 m² surface area).

Sediment characteristics

Sediment composition was significantly different for the factor impact (p=0.0001), but it did not differ significantly over the years (p= 0.3), nor within the interaction term 'year x impact' (p=0.95). Especially, the very fine sediment fraction (63-125 µm) and the shell fraction (> 1600 µm) were significantly higher in the BRMC area compared to both reference areas (BRref and BRMCref) and the BRC area (pairwise tests, p<0.05) (Figure 5). Furthermore, both of these fractions were slightly positive correlated with dredging intensity, resp. r=0.29 and r=0.24. The higher percentage of both fine and coarse material were previously reported but sample number was too small at that time to allow for significant differences (De Backer et al. 2014a, De Backer et al. 2014b). The increased time series reconfirms, and strengthens the previous observations.

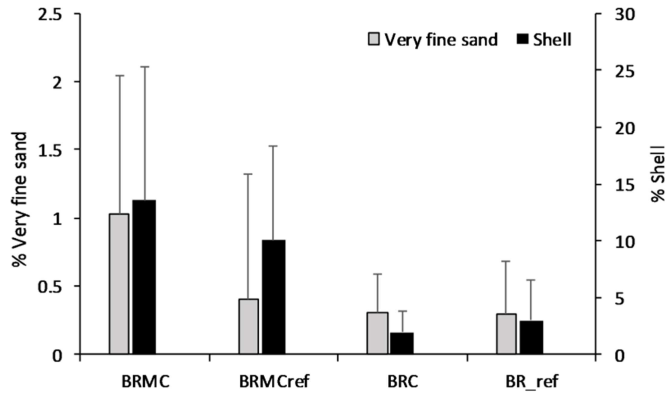

Figure 5: Average percentage very fine sand (63-125 µm, left) and shell (>1600 µm, right) for the different impact groups at the Buiten Ratel (average ± SD).

When zooming in on the BRMC area, sediment composition did not change significantly over the years (p=0.13). Also after the closure in January 2015, no changes have been observed. However, although not significant, we did observe a decreasing trend in median grain size of the sand fraction in the BRMCarea, especially during the years were aggregate dredging took place (Figure 6). This decreasing trend matches the decrease observed in back scatter values in the same area by COPCO (Roche et al. 2017, this volume).

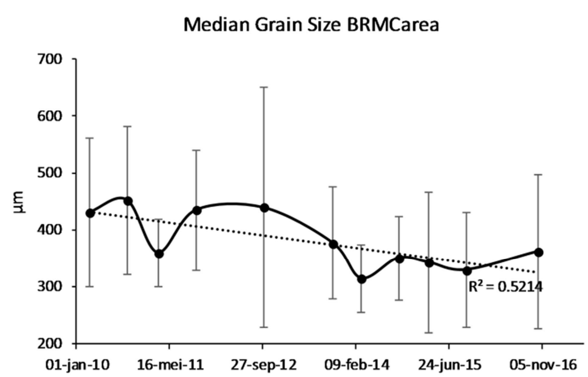

Figure 6:Time series of average median grain size of the sand fraction (± SD) within the BRMC area.

Ecological characteristics

As the ecological characteristics of both seasons differed significantly from each other in species numbers and densities, only autumn data are presented here, although overall spring patterns are very similar.

Species number S and density N differed significantly for factor 'impact' (both p=0.0001) and 'year' (resp. p=0.0019 and p=0.043), but not for the interaction 'impact x year'. Intensive dredging in the BRMC area positively affected both parameters S and N since pairwise tests showed that S and N were significantly higher in the BRMCarea compared to all other areas (Figure 7). The less intensively dredged area, BRC, did not differ significantly in S and N from the reference area BRref, indicating that dredging at intensities < 800 $m^3\ yr^{-1}$ did not affect the univariate parameters. For both parameters, interannual variation was observed with lowest S and N in 2011 for most areas (Figure 7). For biomass, only the factor 'impact' was significant with the highest densities in the reference area BRref, which is due to the higher presence of *Echinocardium cordatum* within these samples. Results for all three parameters are consistent with previous results reported in De Backer et al. (2014a).

Closure of the BRMC area in January 2015, did not cause changes in the observed univariate pattern for the years 2015 and 2016. Species number and density remained higher compared to the other areas after cessation of the dredging activity (Figure 7).

The multivariate species pattern was best explained by the environmental variables % medium sand, median grain size of the sand fraction, % shells, % very fine sand and dredging intensity, together explaining 25% of the observed variation (DISTLM, BEST-AICc). For multivariate species composition, a significant 'year x impact' effect was observed (p=0.0002). Within all years, BRMC differed significantly in species composition from the other areas BRMCref, BRC and BRref (pairwise tests within years p<0.05) (Figure 8). While BRC did not differ significantly in species composition from the reference area BRref in any year (pw test within years p>0.05) as shown by a high degree of overlap within the PCOplot (Figure 8). SIMPER analyses showed that BRC and BRref both belong to the *Nephtys cirrosa* community typical for medium sands (Van Hoey et al. 2004) characterised by *Nephtys cirrosa*, *Bathyporeia elegans* and *guilliamsoniana*, *Urothoe brevicornis, Spiophanes bombyx* and *Magelona johnstoni*. The BRMCref area is typical *Ophelia borealis* habitat characteristic for coarser sands (Van Hoey et al. 2004) with typical interstitial species. While BRMC is a mixture of species typical for *Ophelia borealis* and species characteristic for *Abra alba* such as *Kurtiella bidentata, Cirratulidae* sp.and *Lanice conchilega.* When looking between years within each zone (pairwise tests within 'year x impact' within impact), we found for BRC almost no significant differences between years, for BRMCref and BRC some years differed from each other, but many did not, while for BRMC most years differed significantly from each other. This large interannual variation within the BRMC area could be related to the higher degree of physical disturbance due to dredging within this area. The samples from the BRMC area taken after closure of the area clustered together with the samples of the area when dredging was still taking place, however they were dominated by *Spiophanes bombyx* and *Poecilochaetes serpens* (SIMPER), that is why they are on one side of the BRMC cluster in the PCOplot (Figure 8). For *P. serpens*, no ecological information is available, but *S. bombyx* is regarded as a typical 'r' selecting species with a short life span, high dispersal potential and high reproductive rate. It is often found at the early successional stages of variable, unstable habitats, and thus quickly may colonize an area following perturbation (Ager et al. 2005 and references therein).

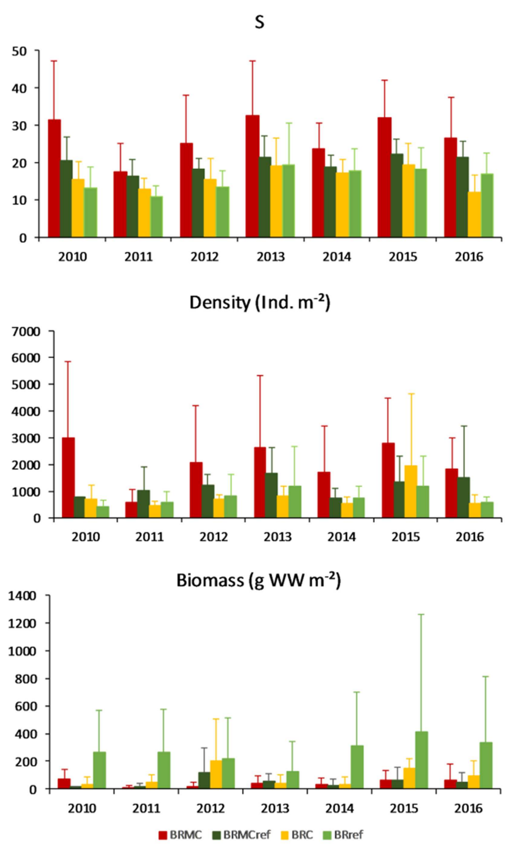

Figure 7: Univariate parameters species number, density and biomass for the different impact areas on the Buiten Ratel over time in autumn. Bars show averages ± SD.

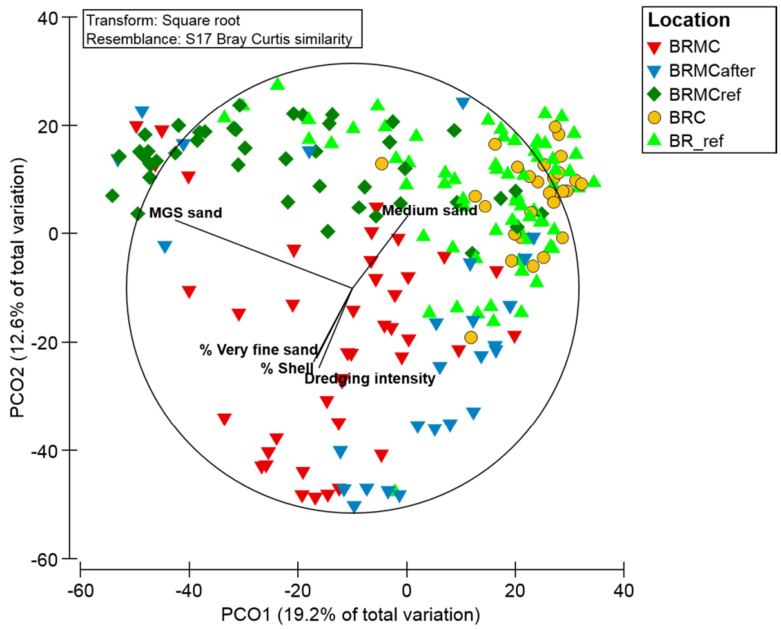

Figure 8: PCOplot based on species abundance data of the Buiten Ratel with indication of the different impact areas. Samples within the BRMC area, taken after closure of the area for dredging, have been assigned a different colour. Vector overlay shows environmental parameters correlating for at least r>0.3 with the observed multivariate pattern.

THORNTONBANK

Dredging in sampling stations

Average extraction volumes around the edge stations on the Thorntonbank (THedge) did not exceed 50 m³ per year (Figure 9), which means that there was only dredging activity on average on one day in the year previous to biological sampling. Around the top stations (THtop), however, average extraction volumes increased steeply since 2013 upto on average 2500 m³ per year (surface area 8000 m²) in 2016 (Figure 9). The stations were disturbed by dredging activity on average on 52 days per year.

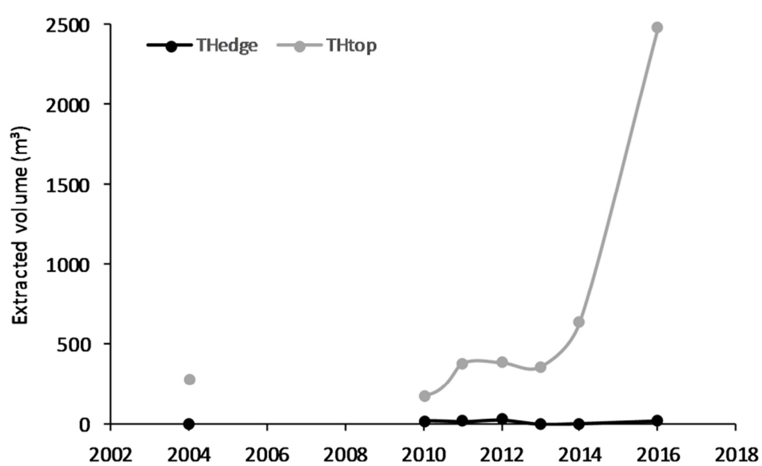

Figure 9: Average extraction volumes over time around top and edge biological sampling locations. Extraction volumes per year are based on EMS data, 365 days prior to the biological sampling date in a circular buffer area around the sampling location with a radius of 50 m (8000 m² surface area).

Sediment characteristics

Sediment composition on the Thorntonbank remained similar over the years (p=0.15), and it did also not change within one impact group over time (interaction 'year x impact', p=0.37). Significant differences were observed in sediment composition for the factor 'impact' (p=0.0091) due to slightly higher percentages of fine sand and lower percentages of coarse sand in the THedge stations (Figure 10). However, the median grain size of the sand fraction did not differ significantly over years (p=0.2), between impact groups (p=0.18) or within the interaction 'year x impact' (p=0.9). Median grain size of the sand fraction was on average around 360 - 390 µm and the dominant fraction was medium sand in all areas (Figure 10).

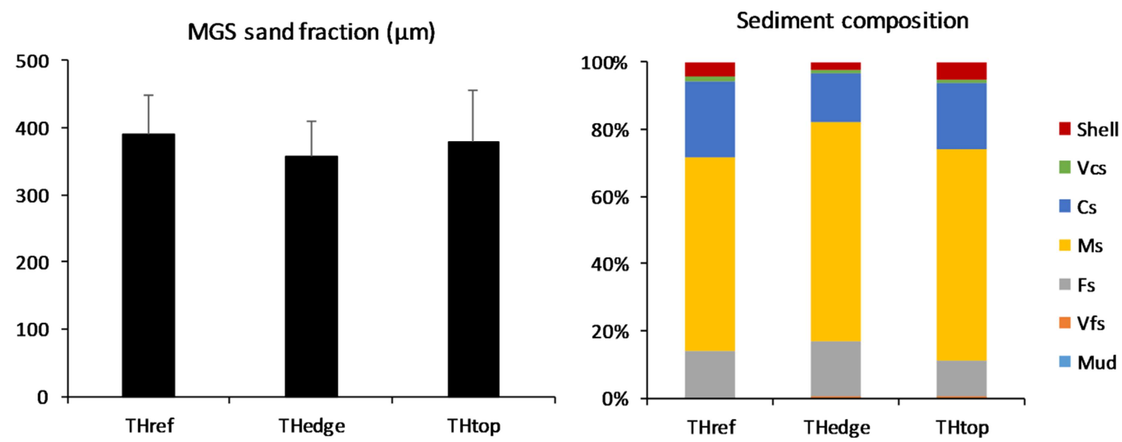

Figure 10: Average median grain size (MGS) of the sand fraction (±SD, left) and sediment composition (right) for the different impact groups on the Thorntonbank. Sediment fractions are largely according to the Wenthworth scale: mud (silt+clay < 63µm), vfs= very fine sand (63-125 µm), fs=fine sand (125-250 µm), ms=medium sand (250-500 µm), cs=coarse sand (500-1000 µm), vcs=very coarse sand (1000-1600 µm) and shell (>1600 µm).

The higher degree of aggregate dredging in THtop stations seems thus not to have changed sediments yet when taking into account all stations over the entire Thorntonbank area. However, when we zoom in on the most heavily dredged area for the year 2016, where dredging activity, based on EMS data, was high at some of the sampling locations, dredging did have a local effect on sediments. In stations TB42 and TB43 (both THtop stations), we observed mixed sediments with a higher percentage of shells (>10%) and as well presence of low percentages of mud and/or very fine sand, while these finest fractions were absent in the other stations (Figure 11). Medium and coarse sand fractions were lower in these high intensity stations (ca 5000 m^3 extracted in the year previous to biological sampling) compared to the nearby stations with somewhat lower dredging intensity (<3000 m^3) (Figure 11), probably because these fractions have been extracted. These findings match the backscatter results observed by COPCO, where an increase in BS is found in relation to increased dredging volumes, indicating the presence of coarser shell fragments due to screening and/or excavation of a coarser layer due to dredging (Roche et al. 2017, this volume). Furthermore, overall positive correlations were found between dredging intensity and mud (Spearman r= 0.4), very fine sand (Spearman r=0.3) and shells (Spearman r= 0.4).

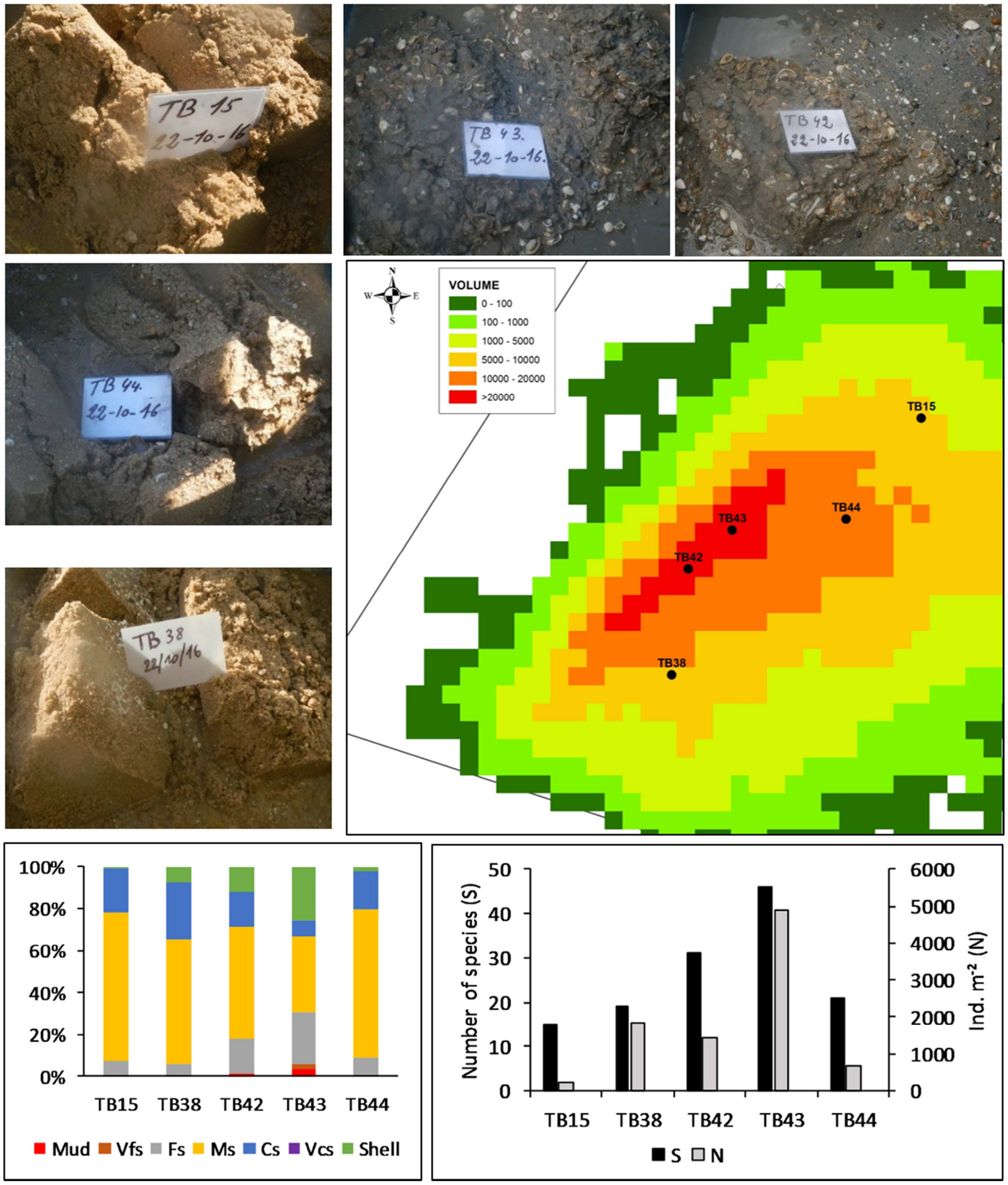

Figure 11: Detail of the high dredging intensity area on the Thorntonbank with cumulative EMS data of the period 2013-2016 in the background and location of the sampling stations. Left bar chart shows the sediment composition for each station, sediment pictures visualise the sediments sampled at each station and right bar charts shows number of species and density within the stations.

Ecological characteristics

Number of species, density and biomass were not significantly affected by the increased dredging at the top of the Thorntonbank when observing the wider area (year x impact resp. p=0.25, p=0.76 and p=0.86). Density and biomass were also not significantly different between years (resp. p= 0.07 and p= 0.29) or between impact zones (resp. p=0.16 and p=0.47). While number of species did not differ significantly between impact zones (p=0.23), but showed a significant interannual variation (p=0.0001) (Figure 12). Although not significant, biomass including *Echinocardium cordatum* was much lower in the most impacted area, while biomass without

E. cordatum was quite similar between the impact areas (Figure 12). This indicates again, just as in previous reportings (Newell et al. 1998, De Backer et al. 2014a), the sensitivity of this species for dredging activity.

When zooming in on the most disturbed area, just as for sediment composition, we see that on a small spatial scale, an increased species number and density were observed in the most heavily impacted stations (Figure 11). Especially the number of species is almost double as high as the normal observed average numbers that were around 15-20 species per sample. Furthermore, when looking at all samples correlations, between S and N and dredging intensity have been found that were positive resp. Spearman r=0.35 and r=0.4, indicating that dredging positively affected species number and density.

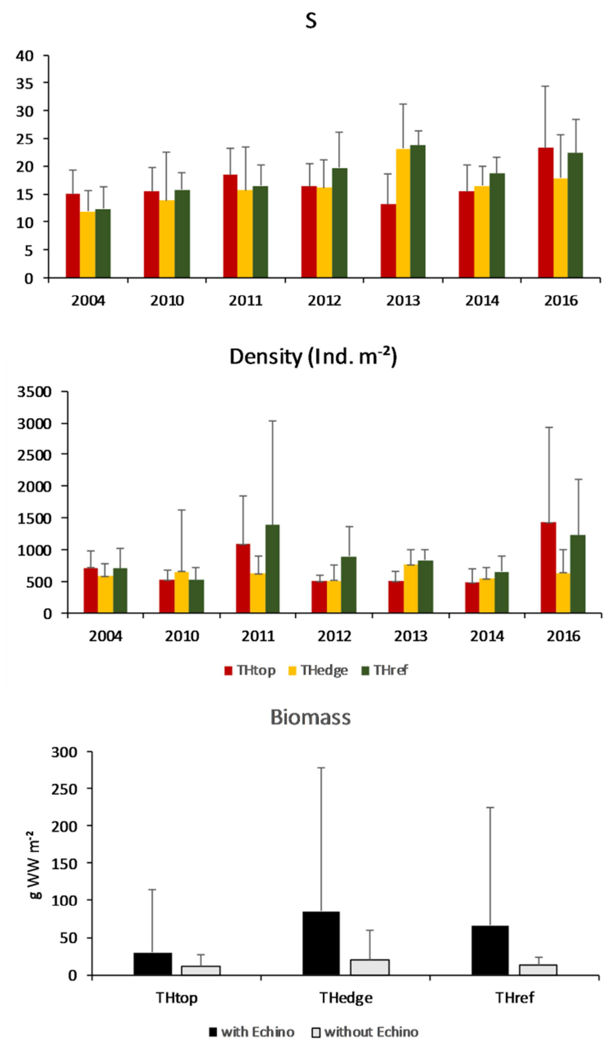

Figure 12: Univariate parameters species number and density for the different impact areas on the Thorntonbank over time. Biomass with and without Echinocardium cordatum is shown for the different impact areas. Bars show averages ± SD.

The multivariate species pattern is best explained by different sediment fractions (fine sand, medium sand, coarse sand and shell) and by dredging intensity, which together account for 22% of the observed variation (DISTLM – BEST-AICc). The increased dredging did not significantly alter the species composition in the wider THtop area (year x impact, p=0.55). Although factors 'year' and 'impact' were significant (both p=0.0001), most samples cluster together along PCO axes 1 and 2 (Figure 13), and SIMPER revealed that all impact areas are characterized by *Ophelia borealis* habitat as defined by Van Hoey et al. (2004). Differences between areas and years were mainly due to fluctuations in densities. One exception is some of the stations with higher dredging intensity, especially TB42 and 43 (ca 5000 m³ extracted in the year prior to biological sampling), which cluster a bit further apart along PCO axis 3 (Figure 13). The species composition in these 2 stations is quite different and changed towards species typical for *Abra alba* habitat like *Kurtiella bidentata, Abludomelita obtusata, Cirratulidae, Lanice conchilega, Anthozoa* and *Lagis koreni,* and additionally high densities of *Poecilochaetes serpens* were present. It is most probably the change in sediment (see previous paragraph) with the presence of mud and very fine sand that attracted these species, since all of these are characteristic for finer sediments and were normally not to be expected on the top of the Thorntonbank.

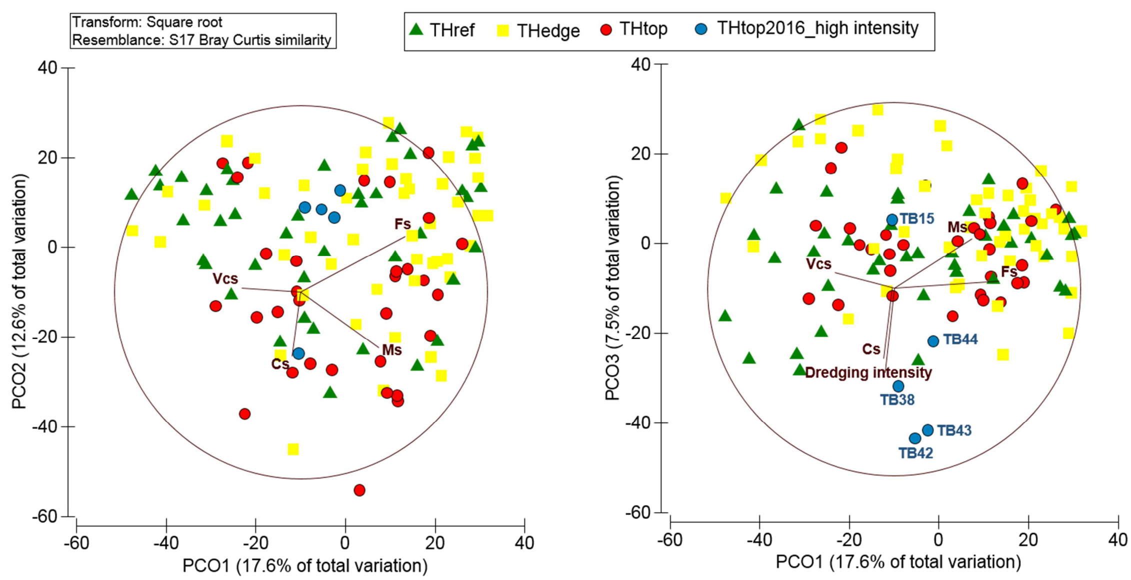

Figure 13: PCOplot showing first three axes based on species abundance data of the Thorntonbank with indication of the different impact areas. Samples within the THtop area with highest dredging intensities have been assigned a different colour. Vector overlay shows environmental parameters correlating for at least r>0.3 with the observed multivariate pattern. Fs=fine sand (125-250 µm), Ms=medium sand (250-500 µm), Cs=coarse sand (500-1000 µm), Vcs=very coarse sand (1000-1600 µm).

OOSTHINDER

Dredging in sampling stations

Aggregate dredging started in 2012 in zone 4c, and reached average extracted volumes of 700 m³ per year around the biological sampling locations (Figure 14), as such the seabed was disturbed on average on 5 days per year. In 2014, volumes increased steeply upto 4600 m³ per year around the biological sampling locations (surface area 8000 m²) (Figure 14). The seabed in the biological locations was on average disturbed on 35 days because of the dredging activity.

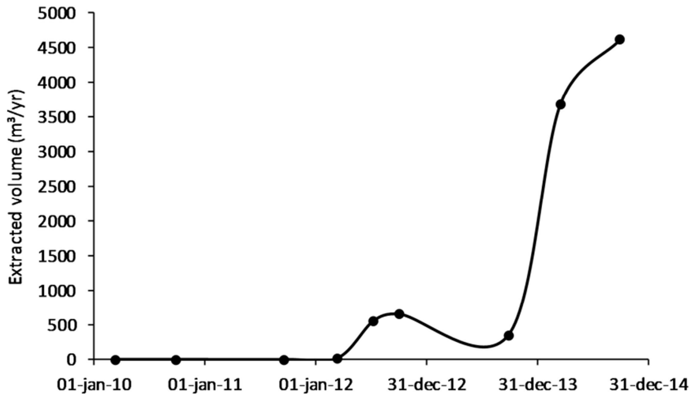

Figure 14: Average extraction volumes over time around the biological sampling locations within zone 4c. Extraction volumes per year are based on EMS data, 365 days prior to the biological sampling date in a circular buffer area around the sampling location with a radius of 50 m (8000 m² surface area).

Sediment characteristics

Sediment composition did not significantly change due to intensive dredging at the Oosthinder (year x impact, p=0.95). Medium sand was the dominant fraction in all zones over the years with on average 63% (± SD 10) in the impact area 4c, 71 %(± SD 9) in the reference area on the Oosthinder (REF4c) and 75% (± SD 7) in the reference on the Bligh Bank. However, significant differences in sediment composition were observed between impact groups (p=0.0001), and also between years (p=0.0021), but trends were similar in reference and impact areas. (REF_BB). In all areas, a slight fining of the sediment was observed over the years as can be seen from a decrease of the median grain size of the sand fraction (Figure 15), which is due to an increase of fine sand (125-250 µm), and a decrease of coarse sand in all areas (500 – 1000 µm). Although, this decrease cannot be directly related to dredging (interaction year x impact, p≥0.6 for all fractions), we found a positive correlation between extracted volume and fine sand (Spearman r= 0.5), and a slight negative correlation between extracted volume and median grain size (Spearman r= -0.3) and coarse sand (r=-0.25). Furthermore, Van Lancker et al. (2015) found a fining as well, together with more heterogeneous sediments in the dredging area, and the back scatter results on the HBMC area also show a downward shift in dB values related to extraction, again indicating fining of the sediment (Roche et al. 2017, this volume).

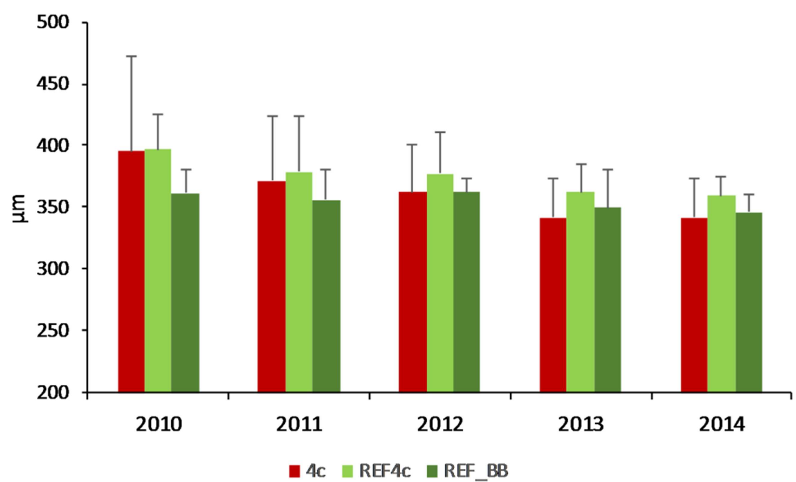

Figure 15: Average median grain size of the sand fraction over time for the different impact groups on the Oosthinder.

Ecological characteristics

Univariate parameters species number S, density N and biomass were significantly different between seasons, hence spring and autumn samples were analysed separately. Since patterns are similar between seasons, only autumn data are presented.

None of the univariate parameters was significantly affected by the dredging activity that started in 2012 in area 4c (year x impact, $p>0.05$). Even in 2014, just after the very intensive dredging for coastal protection, no deviations in univariate parameters were observed compared to the reference areas or to previous years (Figure 16). The only significant effect detected was a lower species number in the REF_BB area compared to 4c ($p=0.02$) and REF4c ($p=0.016$) throughout the entire sampling period (2010-2014) (Figure 16).

Also none of the univariate measures was correlated with dredging intensity indicating again that the dredging had no effect on the structural parameters of the benthic community.

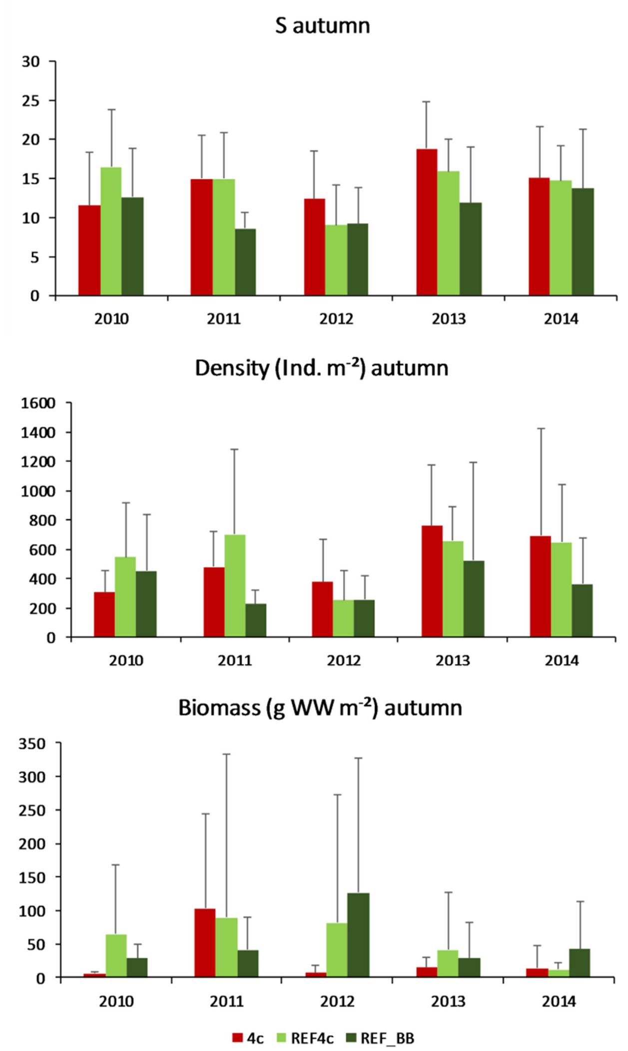

Figure 16: Univariate parameters species number, density and biomass for the different impact areas on the Oosthinder over time in autumn. Bars show averages ± SD.

DISTLM analysis selected different sediment fractions (fine sand, coarse sand and shell) together with dredging intensity as best explaining the observed variation in the multivariate species pattern, but only 17% could be explained (BEST – AICc). Although, the interaction term 'year x impact' was significant (p=0.0001), dredging activity seems not to have caused large changes within the species composition of the impacted area. The pattern shown in the PCOplot confirms this, since no specific separate cluster of 'after dredge samples' (4c_after) can be discerned (Figure 17). Samples of all areas belong to the *Ophelia borealis* habitat as defined by Van Hoey et al. (2004) characterised by interstitial species such as *Hesionura elongate* and *Microphthalmus* but also by *Ophelia borealis*, *Nephtys cirrosa* and *Gastrosaccus spinifer* (SIMPER). Area 4c differed significantly in all years from REF_BB, and except for 2010, also from REF4c (pairwise tests), so also before the start of dredging small differences were present mainly due to differences in densities of some species. Within the different areas, species composition showed as well differences between most years (pairwise tests), again owing mainly to density differences which might be related to the observed slight fining of the sediment.

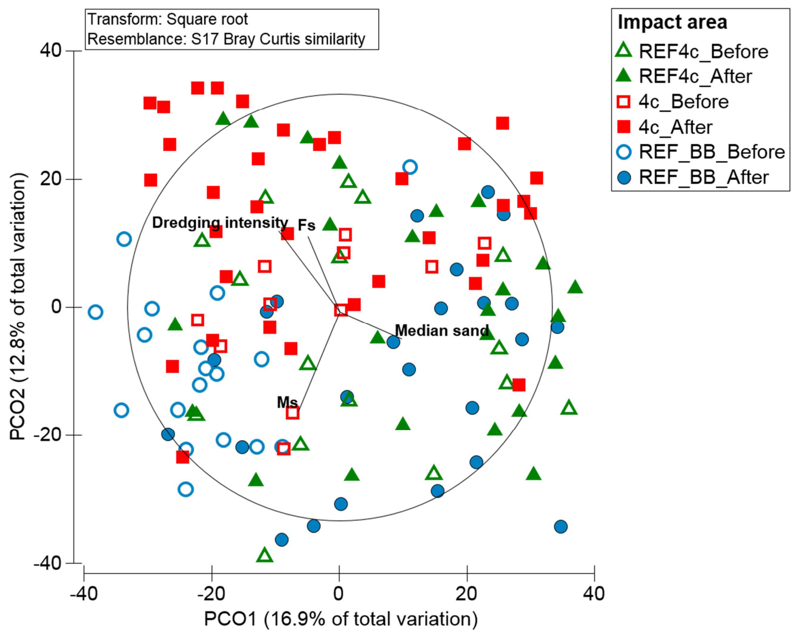

Figure 17: PCOplot based on species abundance data of the Oosthinder with indication of the different impact areas before and after start of dredging. For better visualization years have been grouped in before and after dredging period. Vector overlay shows environmental parameters correlating for at least r>0.3 with the observed multivariate pattern.

Conclusions

Benthic monitoring was focussed on three areas where intensive dredging is or has been taking place: Buiten Ratel (zone 2br), Thorntonbank (zone 1) and Oosthinder (zone 4c). The aim of this study was to evaluate the effect of the dredging activity in each of these areas on the benthic ecosystem. The main conclusions are formulated as answers to the three questions posed in the introduction:

1) What is the effect of the closure of the BRMC area (zone 2br) on the 'benthic biodiversity hotspot' that was created during intensive dredging before closure?

Results from previous reports and publications (De Backer et al. 2011, De Backer et al. 2014a, De Backer et al. 2014b) were confirmed. The intensive dredging (>10000 m³/ha/yr) that took place in the BRMC area before the closure resulted in a sediment change with on the one hand coarsening of the sediment due to more shells and gravel because of reject chute or excavation of coarser layers, and on the other hand increased input of fines due to overspill. This created a heterogenic habitat with increased macrobenthic species numbers and densities, being inhabited by a dynamic, transitional community characterised by a mixture of muddy sand and coarse sand species (De Backer et al. 2014b). **Sediment composition and macrobenthic community did not change 2 years after closure of the area for dredging in January 2015**. In 2015 and 2016, **increased percentages of shells (>1600 µm) and very fine sand (63 -125 µm) persisted** compared to nearby reference locations, **and supported the survival of the heterogenic, dynamic community** that was established during intensive dredging activities. However, the cessation of dredging seemed to have triggered two species *Spiophanes bombyx* and *Poecilochaetus serpens*, both species peaked in the BRMC area after closure of the area for dredging. *S. bombyx* is a species with a short life span, high dispersal potential and high reproductive rate, and it is known to quickly colonize variable, unstable habitats after perturbation (Ager et al. 2005 and references therein), which explains its dominant occurrence in the closed BRMC area. This species is an early colonizer, so it would be interesting to see which steps will follow in the colonization process since perturbation due to dredging has stopped. Nevertheless, for the moment, we can conclude that after two years without dredging, the 'biodiversity hot spot' remained. Over the coming years, the follow-up monitoring will proof how sediments and the benthic community will further evolve with increasing time after dredging.

2) How is the benthic ecosystem on the Thorntonbank (zone 1) affected by the increased dredging activity?

Upto 2013, no effect on the benthic ecosystem was measured on the Thorntonbank in relation to the medium dredging intensity (<5000 m³/ha/yr) on the benthic ecosystem was measured on the Thorntonbank (De Backer et al. 2014a). After 2013, dredging activity increased, and in 2016, 1.8 million m³ was extracted in zone 1, almost double compared to 2013. Especially in 2016, intensity was high around some of the biological sampling locations (5000-10000 m³/ha/yr). Although, the wider area on the Thorntonbank did not show an effect of the increased dredging on the benthic ecosystem, we did observe an effect at a small spatial scale in the most dredged area on the western part of the Thorntonbank. Quite similar as in the BRMC area, intensive dredging on a small area changed the sediments with an increase in coarse shell fragments (>1600 µm) and a mutual increase in mud/very fine sand (<125 µm). This change of sediments caused a shift in the benthic habitat from *Ophelia borealis* habitat to a mixture of *Ophelia* and *Abra alba* habitat, similar as in the BRMC area. For the first time, typical fine sand species like *Kurtiella bidentata, Cirratulidae* and *Lanice conchilega* were observed on the Thorntonbank. Densities and species numbers increased as well, fully consistent with the effects observed on the Buiten Ratel. This indicates that the **intensive dredging in a small spatial area on the Thorntonbank created a 'hot spot of biodiversity',** comparable to the one observed in BRMC area.

3) Did the short-term huge dredging activity in 2014 affect the benthic ecosystem of the Oosthinder (zone 4c)?

Extraction in zone 4c started in 2012 with an extracted volume of 750 000 m³ over a period of 4 months (March till June), in 2013 almost 1 million m³ was extracted, and in 2014 a peak extraction of 2.5 million m³ took place over a period of 6 months (January till June). Upto 2013, no changes in sediment or benthic habitat were detected (De Backer et al. 2014a). Two more sampling events were performed in 2014 (in March and October) to evaluate whether the peak extraction of 2014 had an impact on the benthic habitat. Although, a slight fining trend was observed in median grain size of the sand fraction, which is in line with the observations of Van Lancker et al. (2015, 2016), and with the shift in back scatter values measured by COPCO (Roche et al. 2017, this volume), **no significant changes in sediment composition** could be detected. **Also species numbers, density and community structure were not (yet) impacted by the peak extraction**. The species community encountered was, comparable to previous years, a typical *Ophelia borealis* community with many interstitial species. This result seems quite surprising, since really huge volumes of sand were extracted. Possible explanations for the lack of impact could be that the sediments remained similar with a high dominance of medium sand (>60 %) or that the area has always been exposed to high natural disturbance and large sediment movements, which makes the dominant benthic organisms resistant and resilient against disturbance by aggregate dredging (Cooper et al. 2011). A third explanation may be that extraction stopped in June, which is before the summer recruitment period, so new recruits were able to directly colonise the area. In any case, benthic monitoring of this area will be continued to follow-up on coming extraction events. We will focus on the size of species and on the ratio juveniles-to-adults, in order to see whether the latter recruitment hypothesis makes sense.

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Quality assurance

All analyses were performed in a NBN EN ISO/IEC 17025 regulated environment. ILVO (ANIMALAB) is certified for macrobenthos species identification with NBN EN ISO/IEC 17025 (BELAC T-315 certificate).

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