Synthesis of the monitoring of the aggregate extraction on the Belgian Continental Shelf from 2011 till 2014

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Introduction

This contribution presents a summary of the essential facts concerning the control and monitoring of the sand extraction in the Belgian part of the North Sea and the impact of this dredging on the seabed bathymetry, morphology and sedimentary nature, observed since the previous study day in October 2011. Due to the divers target audience of this report – dredging industry, marine scientists and engineers, marine environment managers, economists, etc. – the subject is described as factual and concise as possible. More in-depth information can be found in the other publications from the Continental Shelf Service and the listed references.

In the first part of the contribution an overview is given of the events from the last three years having an important impact on the monitoring program, be it legislative or technical, followed by a summary of the monitoring activities from the Continental Shelf Service from 2011 till present. The second part provides a summary of the statistics of the extraction and monitoring data acquired between 2011 and 2014. The results are combined with the previous data and the conclusions based on the analysis of the entire datasets are compared with earlier findings. This approach allows an extension of our spatial and temporal point of view and leads to more robust and pragmatic conclusions about the real impact of the sand extraction on the marine environment.

Overview of the period 2011-2014

Regulation related to monitoring

Two new regulations have an impact on the monitoring program from the Continental Shelf Service: the Royal Decrees of March 20th 2014 and April 19th 2014. These new legislations change the areas where aggregate extraction is allowed (figure 1). Control zone 2 is subdivided in three sectors corresponding with the three sandbanks in the zone: Kwintebank (2KB), Buiten Ratel (2BR) and Oostdyck (2OD). The areas in between the banks are now outside the control zone and thus closed for extraction. This large diminution in exploitable surface is the consequence of the delineation of the Habitat area, which encompasses the entire control zone 2. Sector 1b of control zone 1, corresponding with the western end of the Gootebank, is eliminated, limiting control zone 1 to the western end of the Thorntonbank (sector 1a). Furthermore, the extractable volume in control zone 2 is reduced by 17.000 m^3 each year (1% of the extractable volume in 2014), again a consequence of the Habitat area.

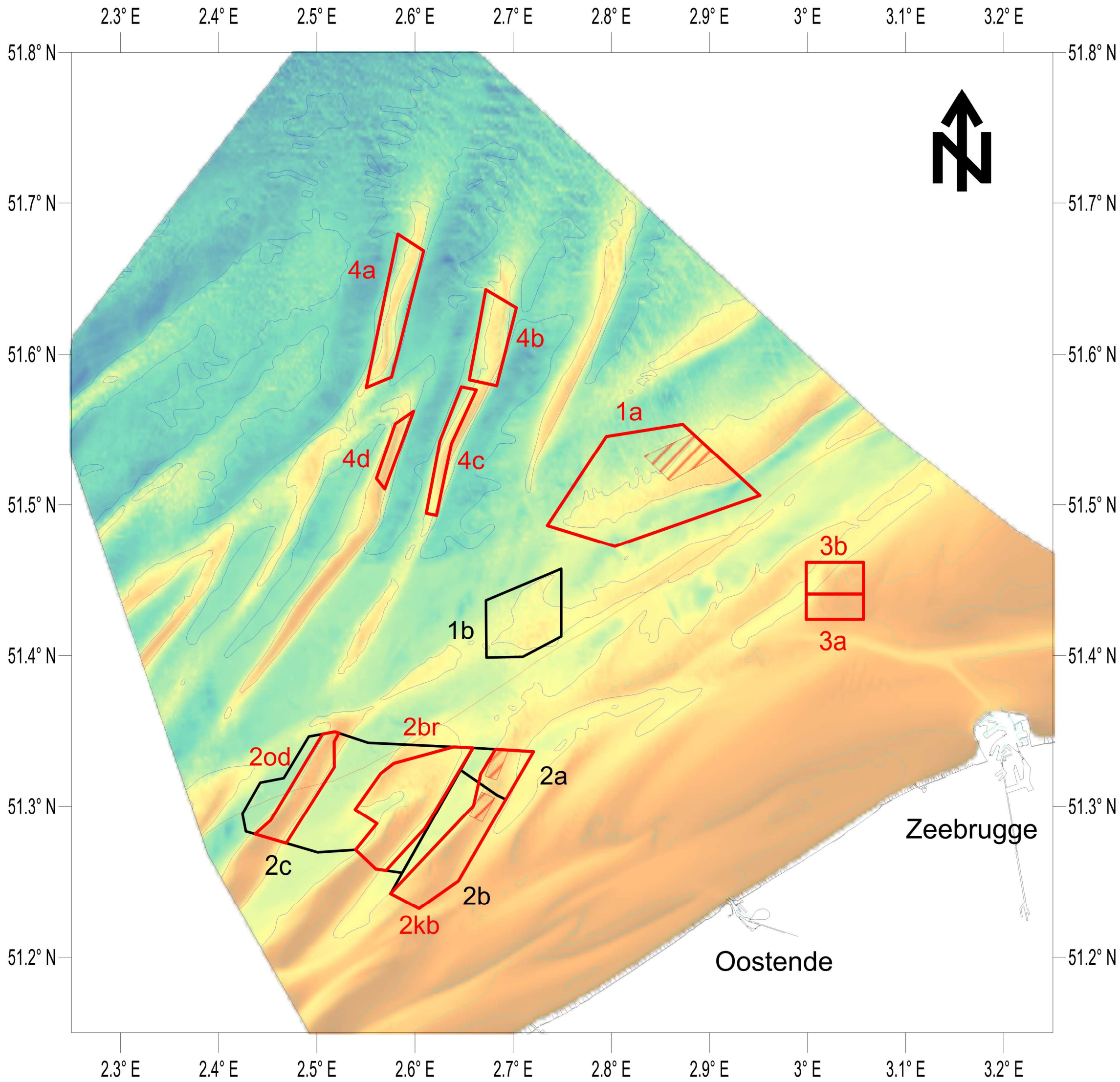

Figure 1: Overview of the current extraction control zones (in red) and former or altered control zones (in black). The hatched areas in red are closed sectors inside the larger control zones.

Technological development

Since 1996, Electronic Monitoring Systems (EMS) are used to control the extraction activities on the Belgian part of the North Sea. It is the responsibility of the Management Unit of the North Sea Mathematical Models (MUMM) to manage the EMS, currently installed aboard 15 dredging vessels and to process the data recorded, on behalf of the FPS Economy. On the basis of the recorded data, it is possible to verify whether the conditions of the concessions are respected. In 2013 the Electronic Monitoring System received an important upgrade (Van den Branden et al., this volume). The new system makes it possible to analyse the data more quickly and frequently, resulting in a closer control on the extraction activity itself.

The monitoring of the impact of the extraction is studied with the EM3002D multibeam echosounder (MBES) from the Continental Shelf Service, installed onboard the research vessel Belgica. In 2009 and 2010 accuracy measurements confirmed the high quality standard (IHO Special Order) of the bathymetric measurements with the EM3002D (Roche and Degrendele, 2011, Roche et al., 2011). To guaranty the stability of the bathymetric system, this evaluation is repeated as often as possible. In 2011, 2012 and 2014 additional measurements in the Vandammesluis (figure 2) were carried out, and the results were compared with previous surveys and the known depths inside the lock. Table 1 summarizes the results of the comparison between the surveys from 2011 till 2014 and the reference depth. Furthermore, longitudinal profiles in the lock are compared with the digitized plan (figure 3). Overall the results remain stable, with the exception of the most recent survey, which shows a shallower profile. An average difference of 8 cm with the reference is observed. This latest survey took place shortly after the installation of a new positioning system aboard RV Belgica and a subsequent new measurement of the geometry of the reference points on the ship. A new survey is planned at the end of 2014 to confirm or correct this result and if necessary to adjust the geometrical parameters in the calculation.

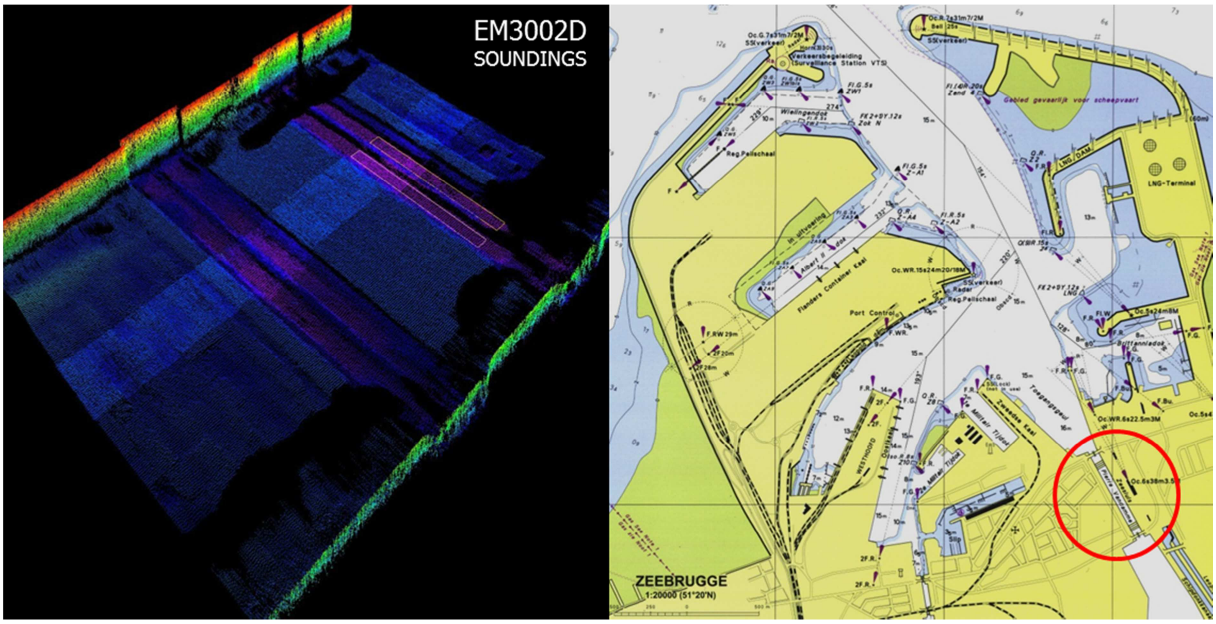

Figure 2: MBES recording of the Vandammesluis with the areas where soundings are compared – location of the Vandammesluis in Zeebrugge (encircled in red).

Belgica EM3002D 09/02/2011					Reference
area	n	mean TAW (m)	stdv (m)	diff (m)	TAW
detail 1	6050	16.54	0.10	-0.03	16.57
detail 2	6060	16.54	0.09	-0.03	16.57
detail 5	52520	15.12	0.05	0.01	15.11
Belgica EM3002D 18/09/2012					Reference
area	n	mean TAW (m)	stdv (m)	diff (m)	TAW
detail 1	6924	16.57	0.11	0.00	16.57
detail 2	6471	16.56	0.13	-0.01	16.57
detail 5	44947	15.13	0.09	0.02	15.11
Belgica EM3002D 28/02/2014					Reference
area	n	mean TAW (m)	stdv (m)	diff (m)	TAW
detail 1	1854	16.47	0.04	-0.10	16.57
detail 2	2343	16.47	0.05	-0.10	16.57
detail 5	25262	15.02	0.05	-0.09	15.11

Table 1: Comparison between the measured depths referenced to TAW in three areas in the lock and the known depths (number of points, mean, standard deviation and difference with the reference for each survey and area).

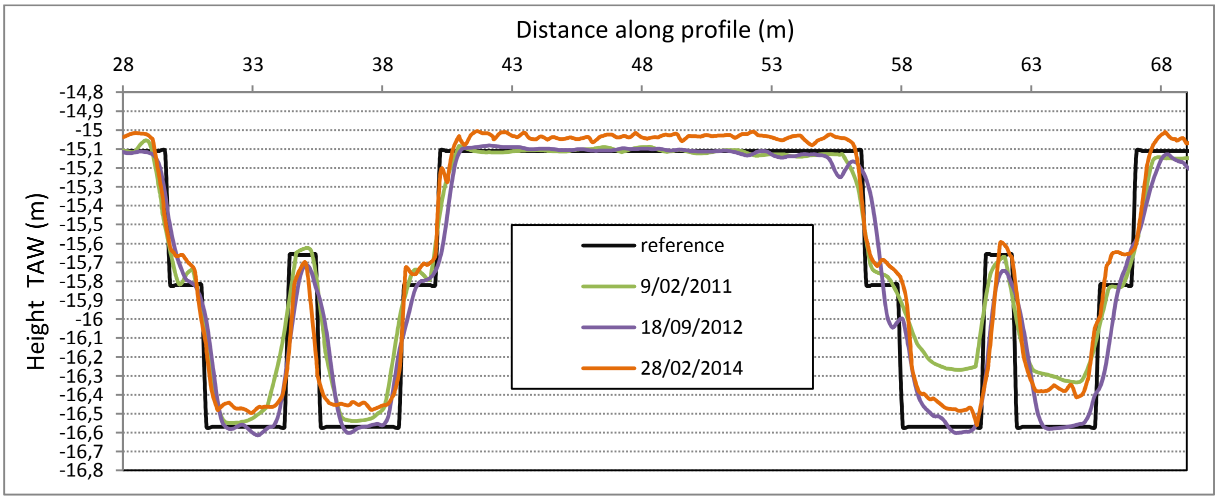

Figure 3: Profile of the quality measurements in 2011, 2012 and 2014 along the Vandammesluis, compared to the profile based on the official plans of the lock.

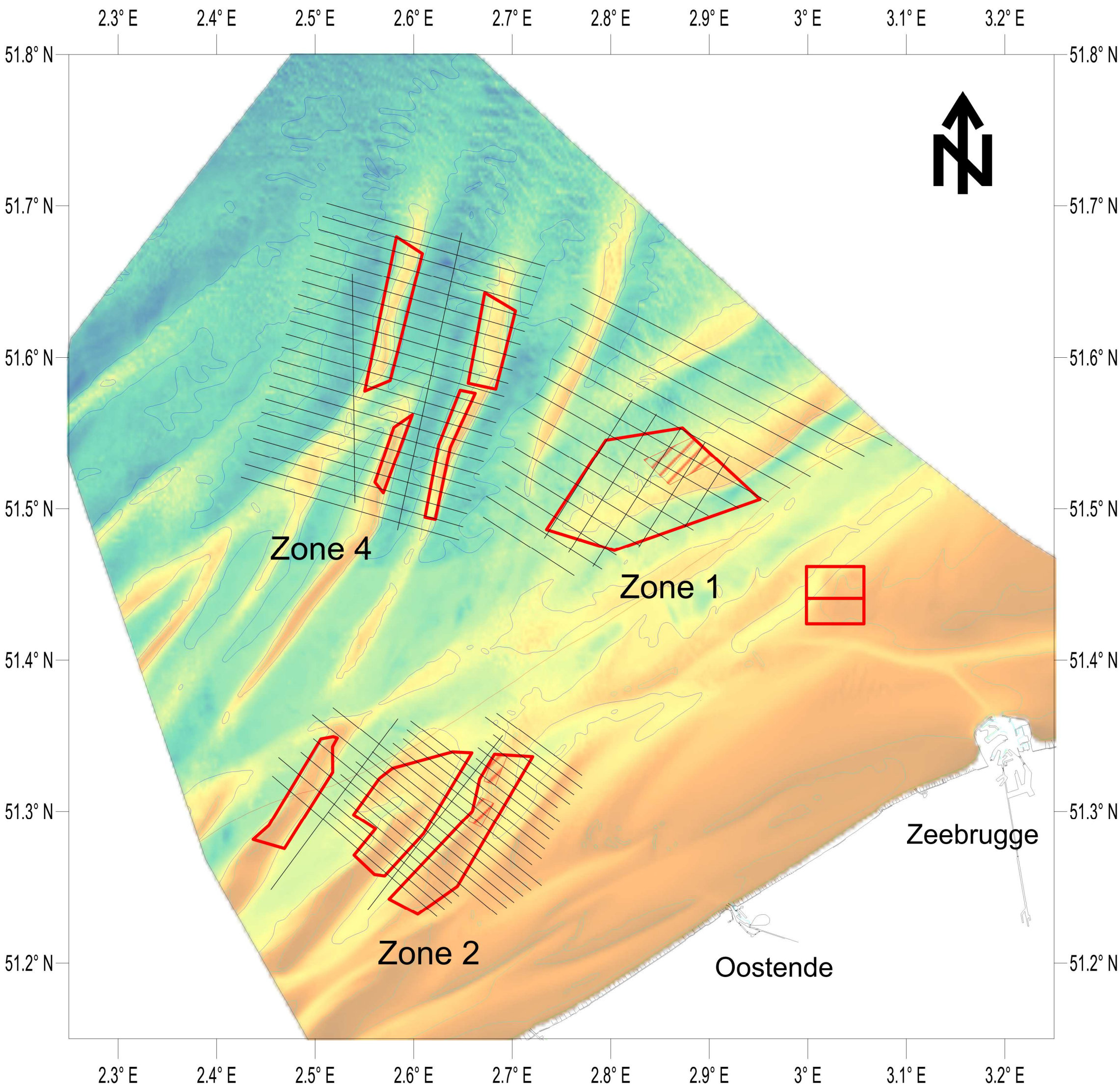

Figure 4: Location of the DECCA lines (in black) across the control zones (in red).

Monitoring activities

The impact of the extraction on the seafloor is studied on two different levels (Roche et al., 2011). Starting in 2007, MBES surveying has been performed along DECCA lines (figure 4) across the Flemish banks in zone 2 (Kwintebank, Buiten Ratel and Oostdyck) and across the Thorntonbank in zone 1. These extensive surveys are repeated yearly in order to evaluate the global evolution of the sandbanks. Since 2011, control zone 4 is studied in the same way. This time series makes it possible to study the differences in evolution between extracted and non-extracted areas and provides a global view on the impact of sand extraction on the seabed morphology and sediments.

Secondly, a number of smaller areas are surveyed more frequently. The delimitation of these monitoring areas is based on the monitoring of the extraction activities with the EMS: they coincide with the most extracted areas at a given time. These zones are studied in detail and provide a good idea of the local impact of the most intense extraction on the seafloor. Based on the recent cartography of the EMS data, a couple of new monitoring areas have been recently defined: HBMC in 2012 and TBMAB in 2013, corresponding with the shift of the most dense extraction activities to these areas. Figure 5 shows their location, together with the earlier defined and regularly surveyed monitoring areas. Note that the areas BRMB and ODMA are now partly outside the new limits of control zone 2, which will result in a new monitoring strategy for these areas.

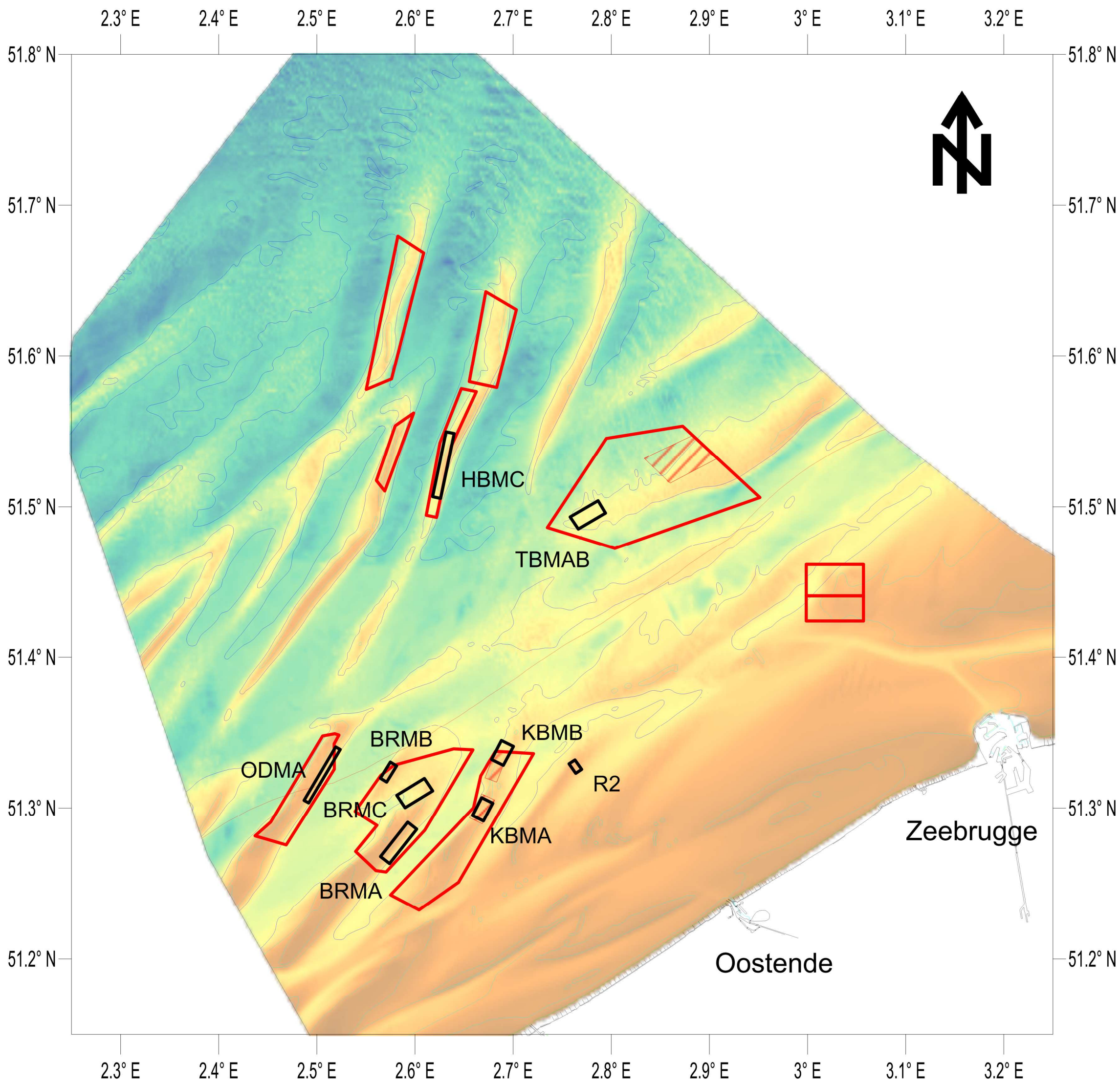

Figure 5: Location of the monitoring areas (in black), in and outside the control zones (in red).

As stated before, the DECCA lines are surveyed only once a year. A more frequent monitoring would be too time-consuming. The frequency of the surveys on the monitoring areas varies and depends on the extraction density. The areas with currently the most extraction and subsequently the highest expected impact on the seabed are monitored more frequent. As figure 6 illustrates, BRMC, which is the area with the most extraction in zone 2, was surveyed 10 times in a three year period, while the areas where the extraction limit of 5 m was exceeded and that have been closed previously (KBMA and KBMB) or that are outside the control zone (R2), were only surveyed half that much. The number of monitoring areas keeps increasing (TBMAB and HBMC) due to changes in extraction patterns and the start of extraction by the Flemish Government in zone 4 (see below).

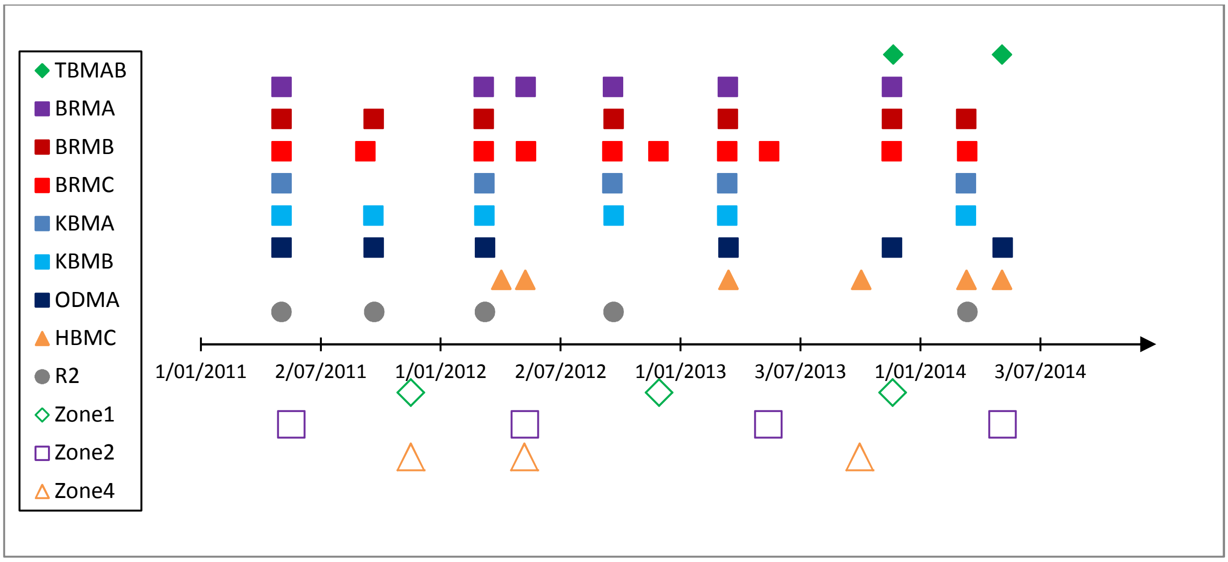

Figure 6: Time line showing the monitoring surveys since 2011. The monitoring areas are displayed above the timeline, the monitoring along DECCA lines beneath.

Monitoring results

Extraction from 2011 till 2014

The EMS is a fundamental tool for the control of the extraction as it allows to calculate for any surface and any time interval the extracted volume. Using the data collected with EMS, the density and geographical pattern of the extraction activities can be mapped and analyzed. Here, an overview of the evolution of the extraction during the period 2011 – 2013 is given. The EMS data for 2014 is not yet complete and will not be included and discussed in this report. The maps of the extracted volumes represent a 100x100 m grid covering the entire Belgian part of the North Sea. The total volume extracted in each grid cell is computed from the EMS data.

The grid of the cumulative volumes from 2003 to 2010 and the successive annual maps (figure 7 till 10) offer a clear view of the spatial evolution of the extraction. Inside zone 2 the extraction is still concentrated on the central part of the Buiten Ratel (monitoring area BRMC), while only small volumes are extracted on the Kwintebank and Oostdyck. The volume extracted on the Thorntonbank in zone 1 remains stable, making this at present, together with the Buiten Ratel and the Oosthinder, the most exploited area. A new monitoring area in zone 1, TBMAB was created and is now measured regularly to supervise the local impact. The extraction in zone 4 started in 2012 and focusses on the southern part of the Oosthinder, in sector 4c. Subsequently the monitoring zone HBMC was created in 2012 and is frequently surveyed to establish the impact from the intensive extraction activities. Another clear observation is the extraction in 2011 and 2013 in zone 3. Figure 11 shows a map of the total volumes from 2003 till the end of 2013, and shows the location of the three currently most supervised monitoring areas, mentioned above.

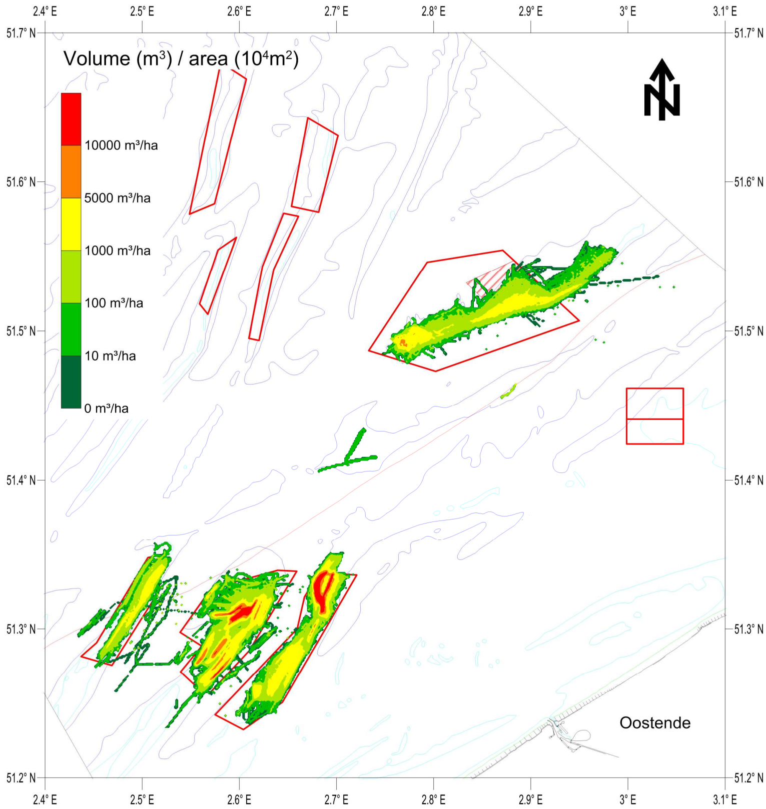

Figure 7: Extraction density in volume/area ($m^3/10^4m^2$ or m^3/ha) from 2003 till 2010.

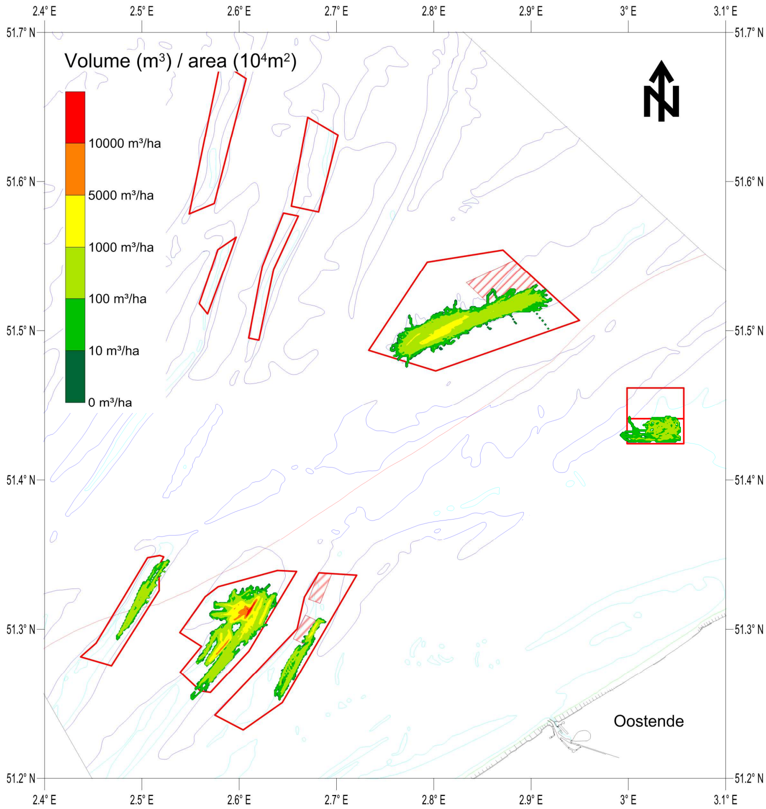

Figure 8: Extraction density in volume/area ($m^3/10^4m^2$ or m^3/ha) in 2011.

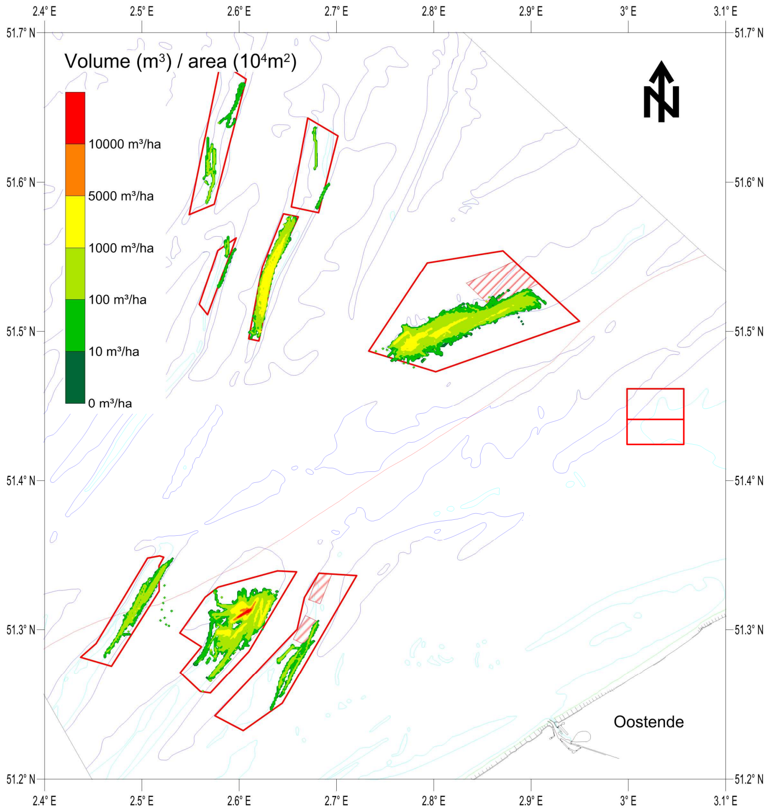

Figure 9: Extraction density in volume/area ($m^3/10^4m^2$ or m^3/ha) in 2012.

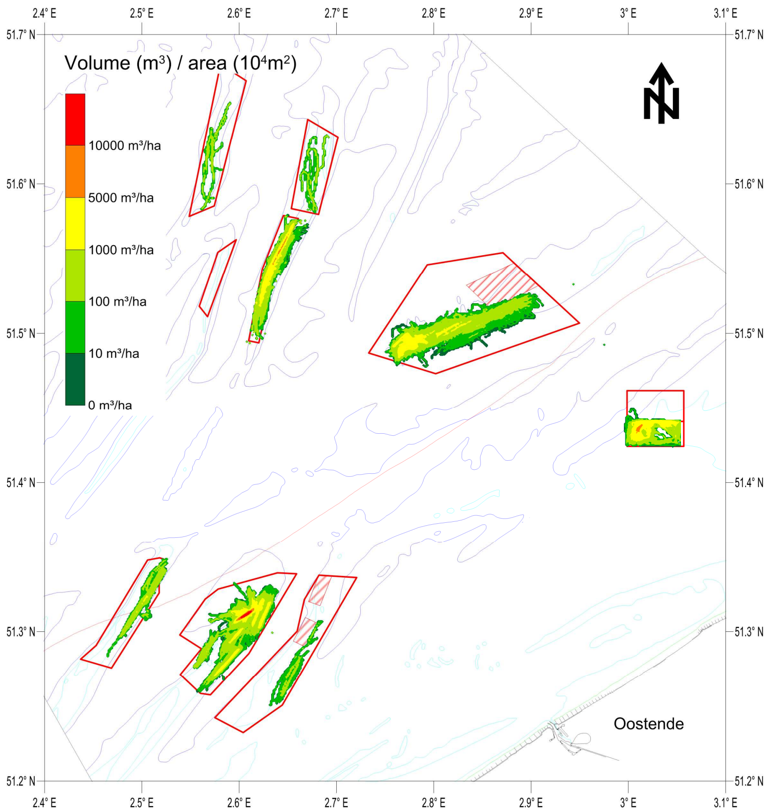

Figure 10: Extraction density in volume/area ($m^3/10^4m^2$ or m^3/ha) in 2013.

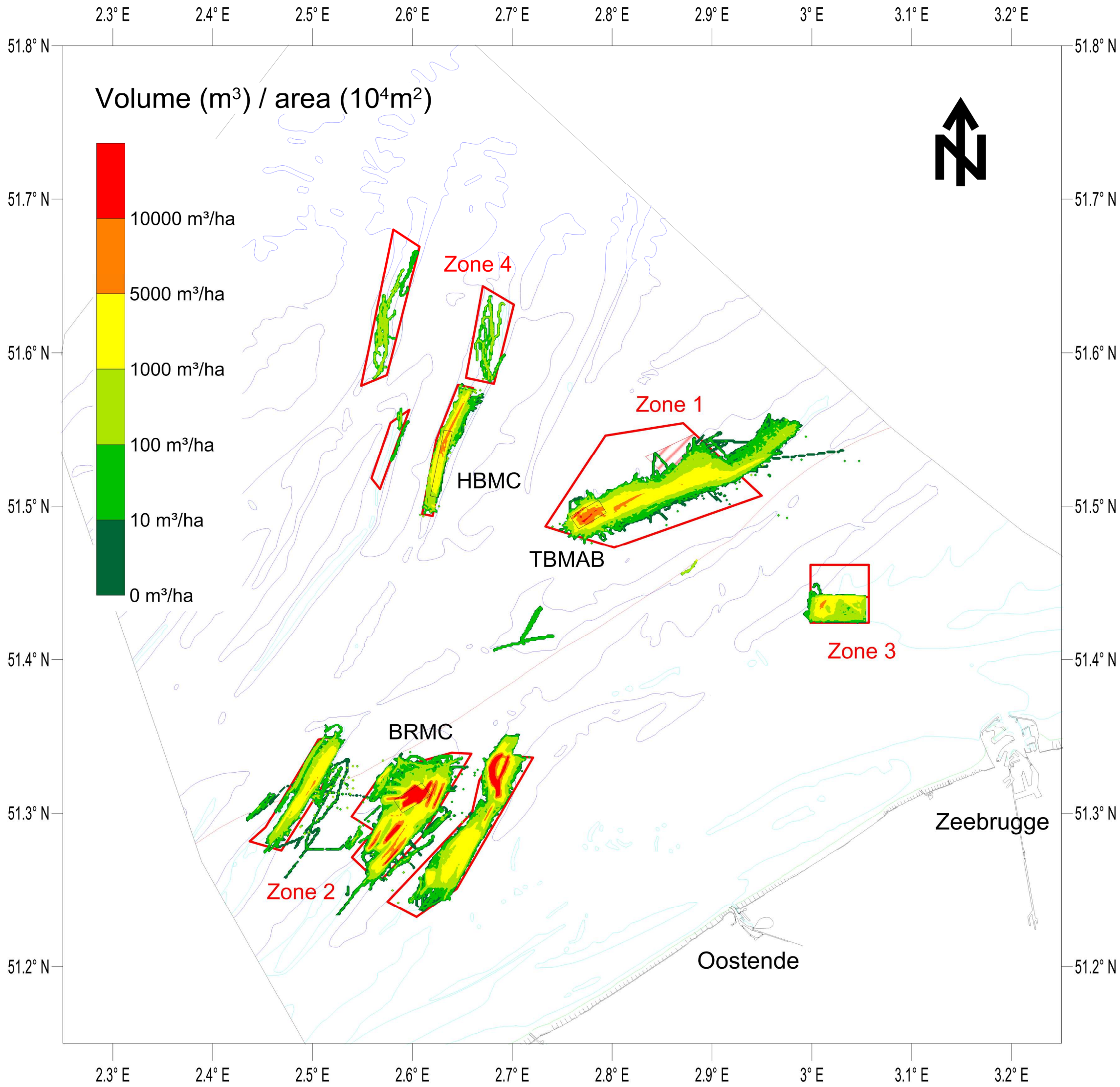

Figure 11: Extraction density in volume/area ($m^3/10^4m^2$ or m^3/ha) from 2003 till 2013 with the most extracted monitoring areas (in black) inside each control zone (in red).

Evolution and impact of the extraction

This report only focusses on the monitoring of the impact of the extraction on the bathymetry, morphology and available sediments, and the physical consequences of the extraction. The ecological impact is studied in depth by the Flemish Institute for Agricultural and Fisheries Research (ILVO) (De Backer et al., this volume). An integrated monitoring of sediment processes focused on zone 4c is organized by OD Nature (Van Lancker et al., this volume). The part of the monitoring program which studies the physical impact is mainly based on the acoustic cartography of the seabed. All data since 2009 were acquired with the EM3002D multibeam echosounder onboard RV Belgica. After the processing of the data (position, tide and draught correction and data cleaning) the soundings were modelled with a resolution, depending of the scale of the investigated area and the density of the available data. To be able to compare with data from before 2009, recorded with an EM1002 multibeam echosounder, these were converted towards the EM3002D reference level (Roche et al., 2011). In the analysis the resulting grids are compared and subtracted to evaluate the bathymetric evolution and the available sediment. A positive difference corresponds with accretion while a negative difference indicates erosion.

The results are discussed for each control zone separately, with the exception of zone 3, where no monitoring is performed up till now.

Control Zone 1

The extraction on the Thorntonbank remains fairly stable (figures 8-10). The cartography of the depth changes along the DECCA lines in 2011 (figure 12) shows no area with a distinct higher impact. It needs to be noted that the area with a higher total extracted volume on the western end of the Thorntonbank (visible on the background layer on figure 12) is not covered by the DECCA lines. The alteration of positive and negative values on the bank is mainly the effect of the shift of the sand dunes. In 2013 (figure 13) the situation looks different. The change is overall more negative and the extreme negative values on the bank correlate with the most extracted areas. Since the difference locally exceeds 2 m, a new monitoring was created (TBMAB) which covers the most affected part of the bank.

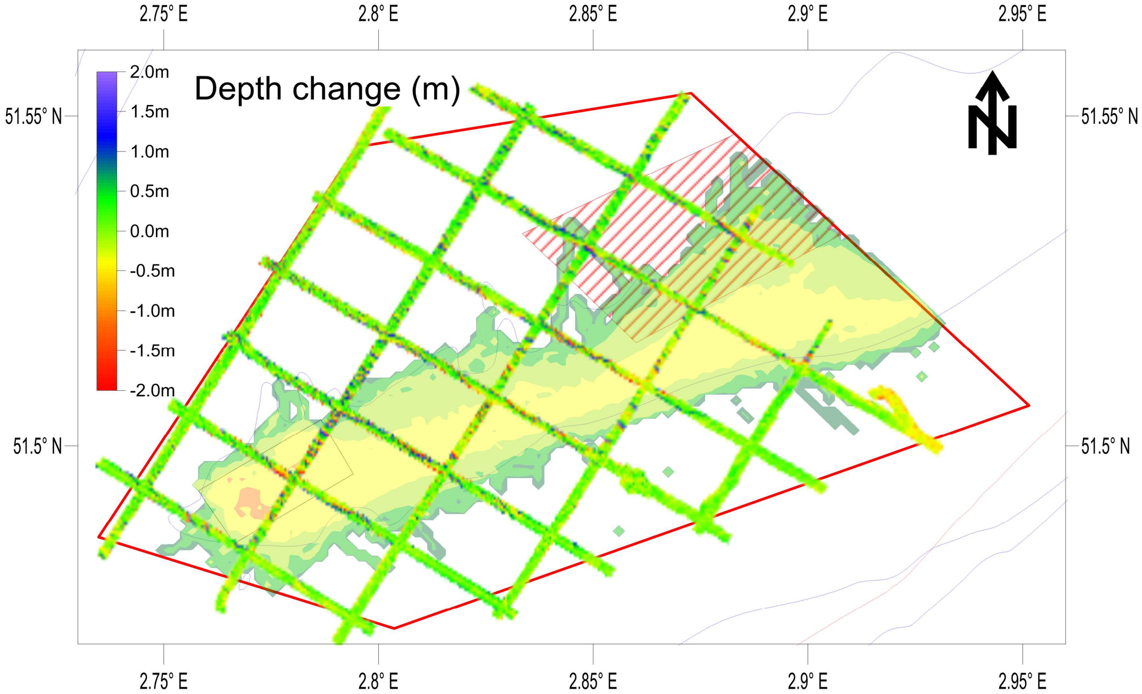

Figure 12: Depth change between the survey along DECCA lines from 17/11/2011 and the reference model. Positive values show an increase in sediment, negative values a decrease. A map showing the extraction density between the survey date and the reference model is used as background.

Both, the last bathymetric survey of TBMAB in 2013 (figure 14) and the difference map between this survey and the reference map for zone 1 from 2003 (figure 15), show a deepening along a corridor with a SW-NE direction. This is also visible on the area to the east of TBMAB, which was mapped during the same RV Belgica measurement campaign.

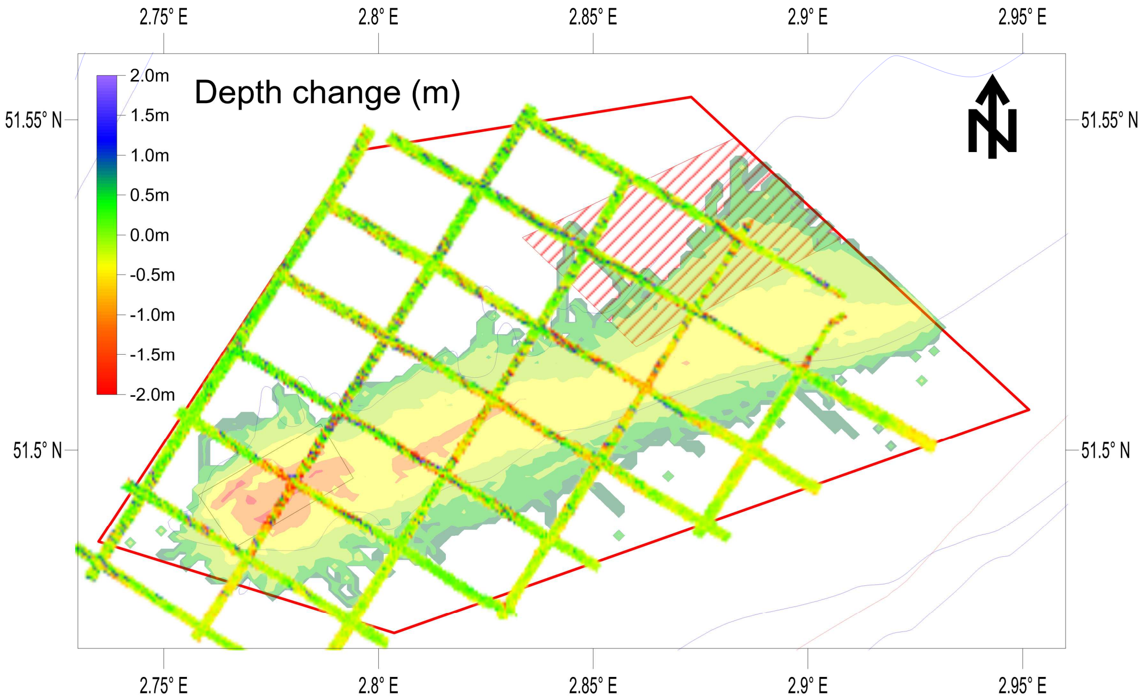

Figure 13: Depth change between the survey along DECCA-lines from 20/11/2013 and the reference model. Positive values show an increase in sediment, negative values a decrease. A map showing the extraction density between the survey date and the reference model is used as background.

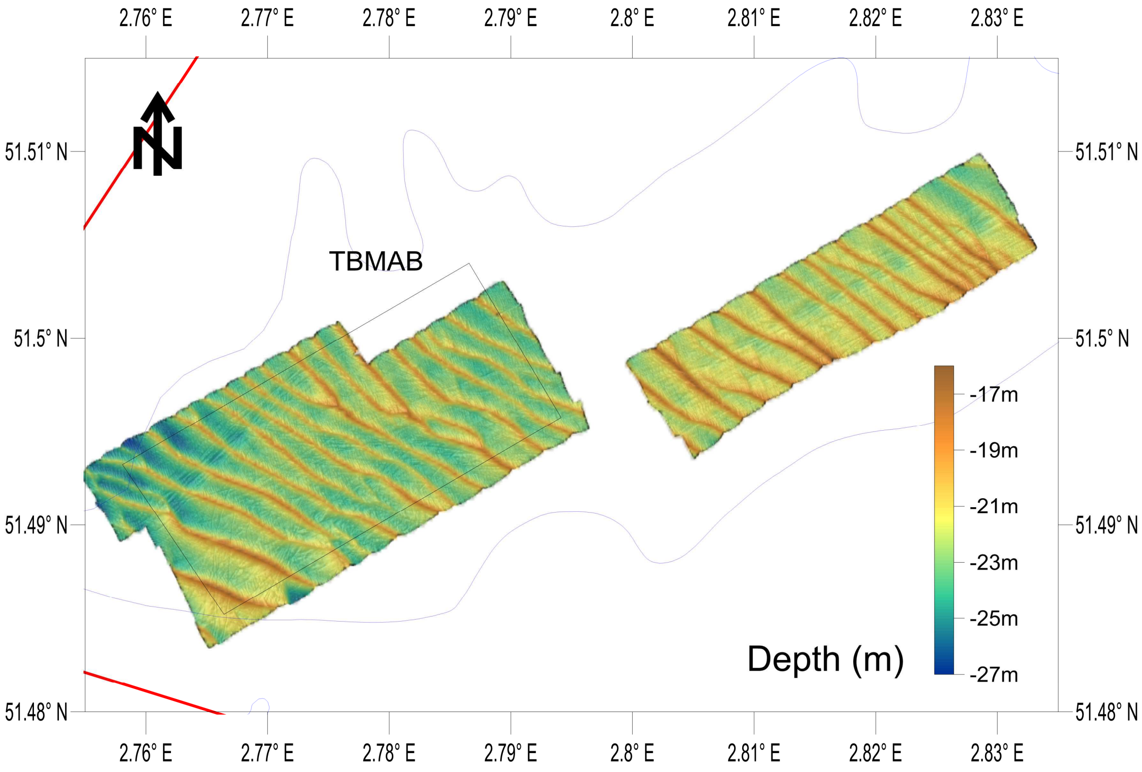

Figure 14: Bathymetry of monitoring area TBMAB, survey 20/11/2013. Depths are referenced to LAT.

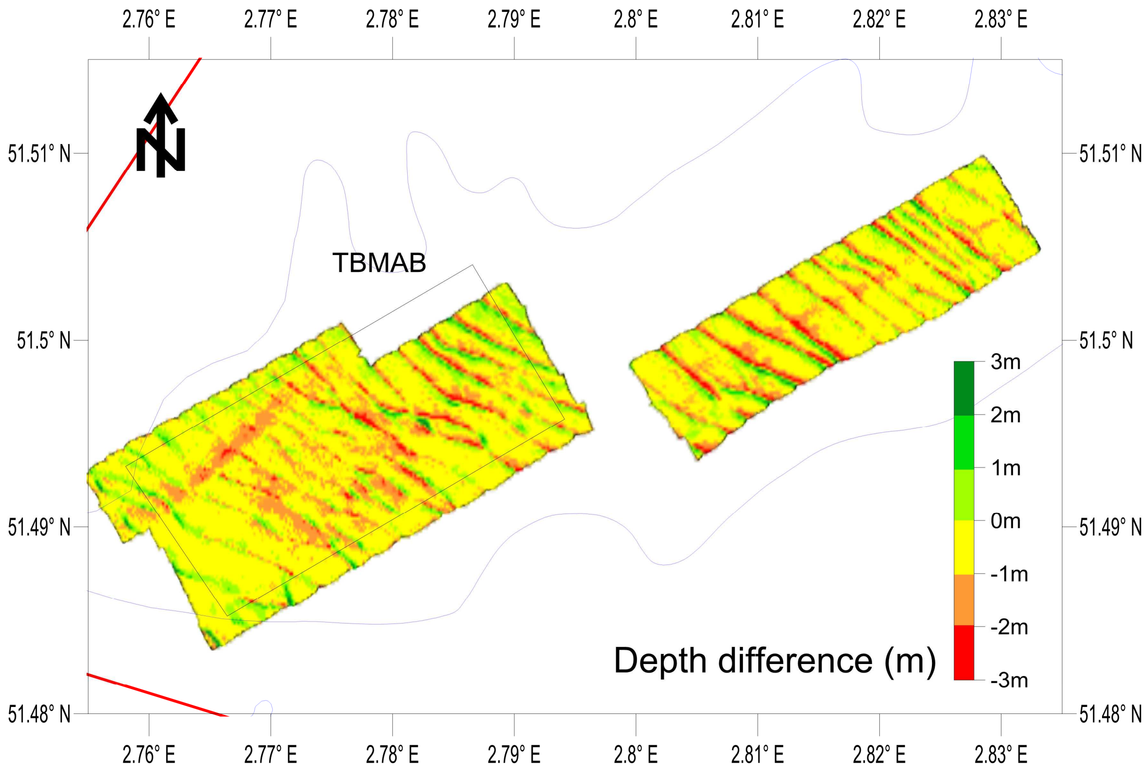

Figure 15: Depth difference between monitoring area TBMAB (survey of 20/11/2013) and the reference model for zone 1. Positive values show an increase in sediment, negative values a decrease.

Control Zone 2

The ongoing monitoring along DECCA lines in zone 2 confirms the results from earlier publications (Degrendele et al., 2010, Roche et al., 2011): The most pronounced differences between the DECCA lines and the 2003 reference model (figure 16) are observed on top of the sandbanks. These high differences are explained by the displacement of the very large dunes covering the sandbanks. The largest decreases of sediment on the Buiten Ratel, Oostdyck and Kwintebank still correspond with the areas with the highest volume of extracted sand. The unexpected negative results in the swale between the Buiten Ratel and Oostdyck fall inside the total combined uncertainty of the reference model and the recent survey (Roche et al., 2011). To avoid the uncertainty due to systematic biases of individual surveys, the quantitative comparison with EMS data, that will be discussed later on, is carried out combining all available data.

To evaluate the local impact six different monitoring areas are surveyed as much as possible (figure 17): the areas on the Kwintebank are formerly heavily extracted but now closed, BRMC is the most extracted since 2008, and the other are on less extracted parts of the Buiten Ratel and Oostdyck. The continuous and frequent measurements provide enough data to allow robust conclusions on the evolution.

The recent results for the “old” monitoring areas KBMA and KBMB (figure 18) seem to confirm the conclusions from the former monitoring reports and articles (Roche et al., 2009, Degrendele et al., 2010). After the closure for extraction the bathymetry and sediments of the areas remain stable, although a slightly negative trend since 2011 is visible. More specific surveys are planned to confirm this trend and verify its significance.

The extraction in ODMA, BRMA and BRMB (figures 19, 20 and 21) varies: from very sporadic in BRMB to recently very high in BRMA and a low constant value for ODMA. This is reflected in the volume decrease for the three zones (figure 22): a small decrease for BRMB and a parallel evolution for BRMA and ODMA.

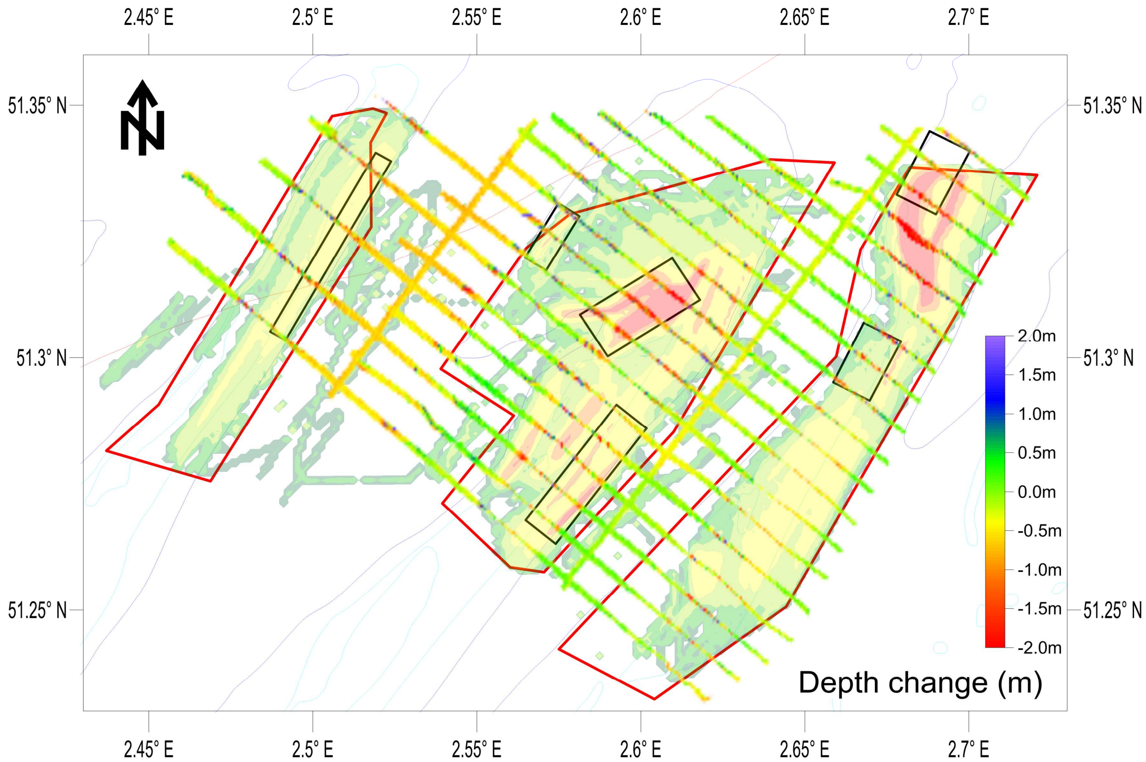

Figure 16: Depth change between the survey along DECCA-lines from 15/05/2013 and the reference model. Positive values show an increase in sediment, negative values a decrease. A map showing the extraction density between the survey date and the reference model is used as background.

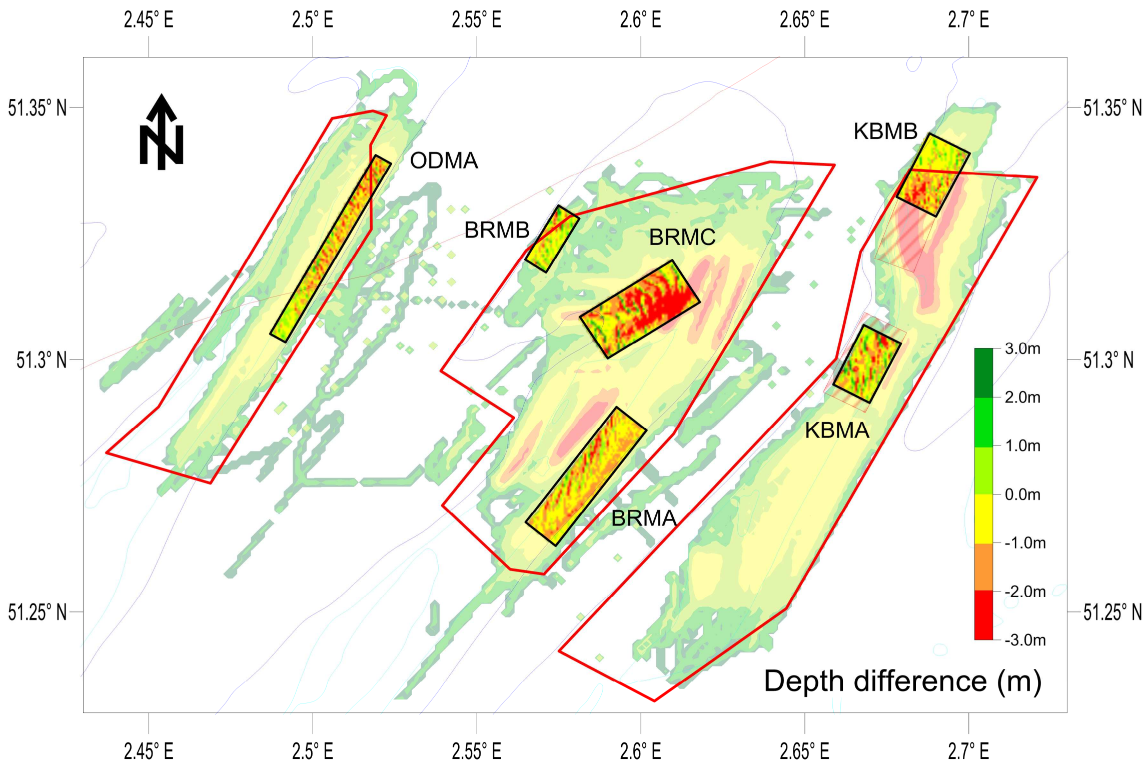

Figure 17: Depth difference between the most recent surveyed monitoring areas (2013 for BRMA, 2014 for BRMB, BRMC, ODMA, KBMA and KBMB) and the reference model for zone 2. Positive values show an increase in sediment, negative values a decrease. A map showing the extraction density between the survey date and the reference model is used as background.

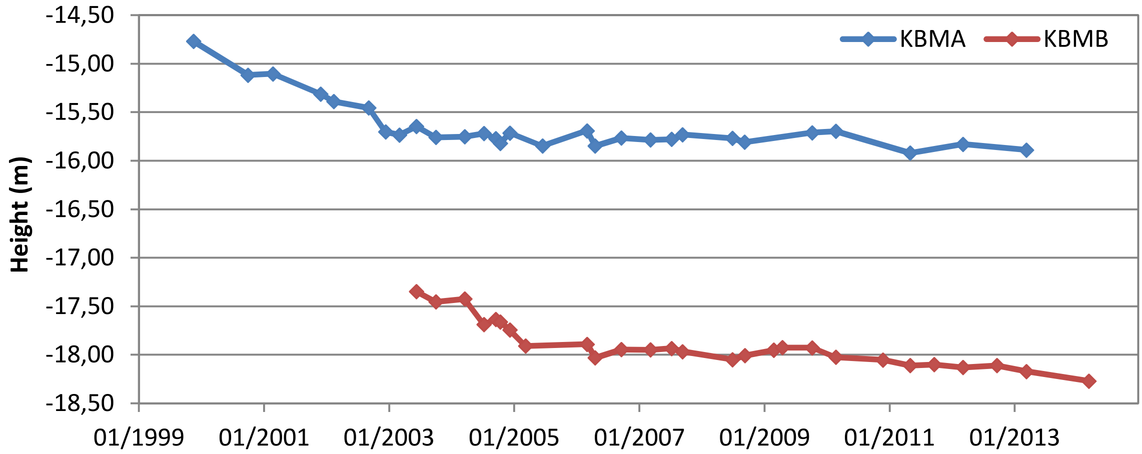

Figure 18: Evolution of the average height referenced to MLLWS of the two monitoring areas on the Kwintebank.

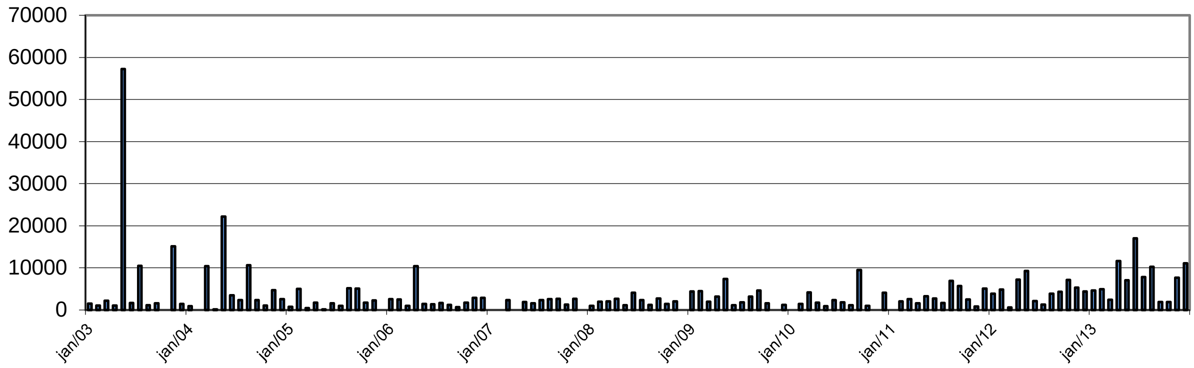

Figure 19: Evolution of the monthly extracted volume (in m^3) in the monitoring area ODMA.

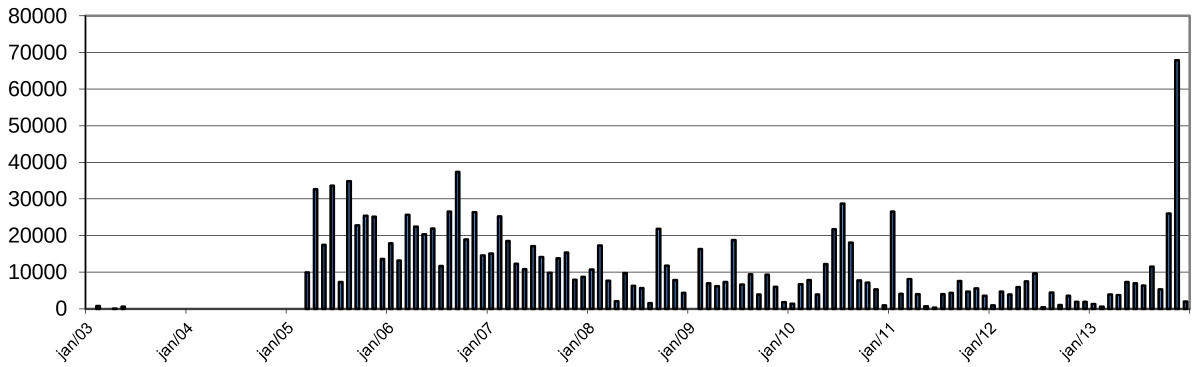

Figure 20: Evolution of the monthly extracted volume (in m^3) in the monitoring area BRMA.

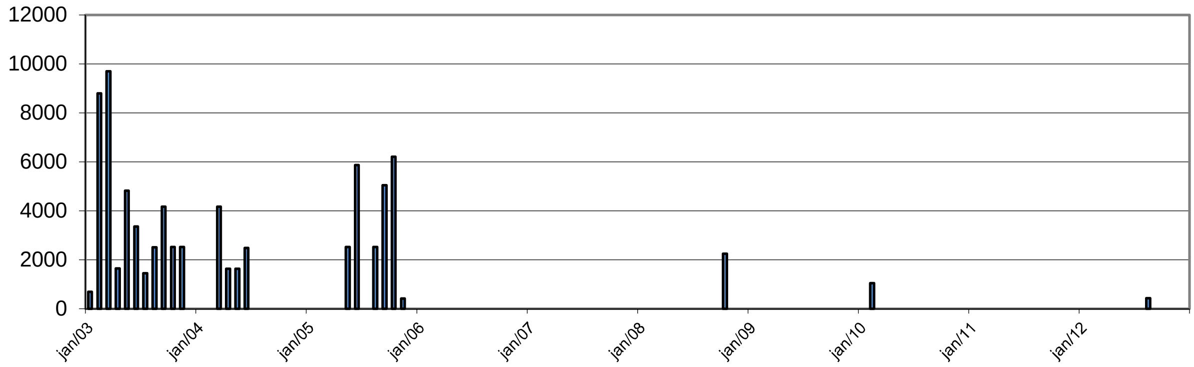

Figure 21: Evolution of the monthly extracted volume (in m^3) in the monitoring area BRMB.

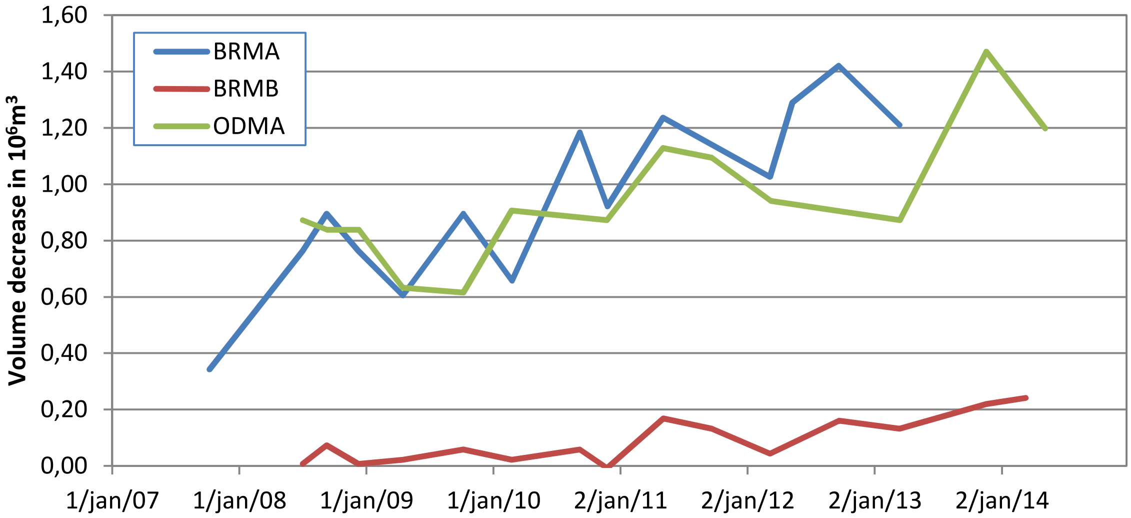

Figure 22: Evolution of the measured volume decrease (in $10^6 m^3$) inside the monitoring areas on the Buiten Ratel (BRMA and BRMB) and Oostdyck (ODMA).

Since 2008, after the closure of the northern depression on the Kwintebank, the central part of the Buiten Ratel (BRMC) has become the most densely extracted area on the Belgian part of the North Sea (figure 23). The impact is very clear: the initial situation in 2003 (figure 24) dominated by large sand dunes is transformed in a landscape marked by the furrows created by the dredging vessels (figure 25). The difference between both surfaces exceeds 5 meter in the centre of the area (figure 26). The extraction is legally limited to a maximum of 5 meter below the reference surface. A profile across BRMC confirms that this legal boundary has been exceeded (figure 27). The comparison between the volume decrease, calculated from the MBES measurements, and the extracted volume based on EMS demonstrates the relation between both (figure 28).

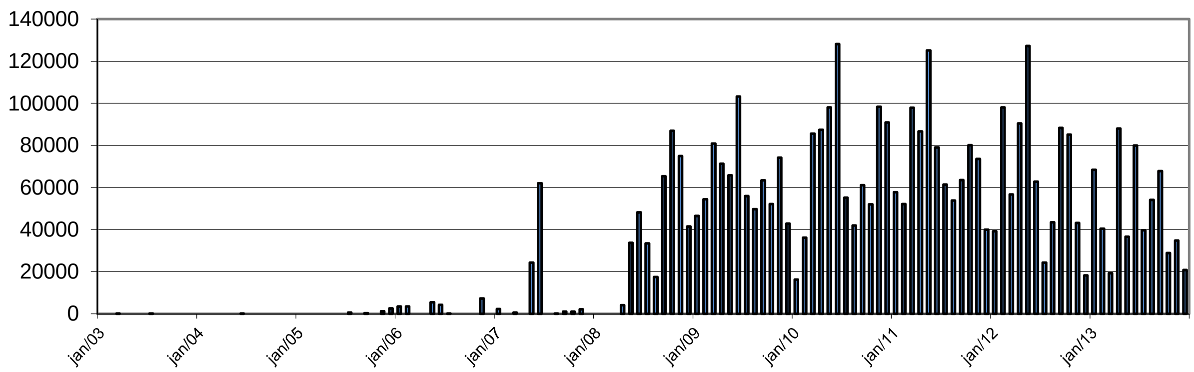

Figure 23: Evolution of the monthly extracted volume (in m^3) in the monitoring area BRMC.

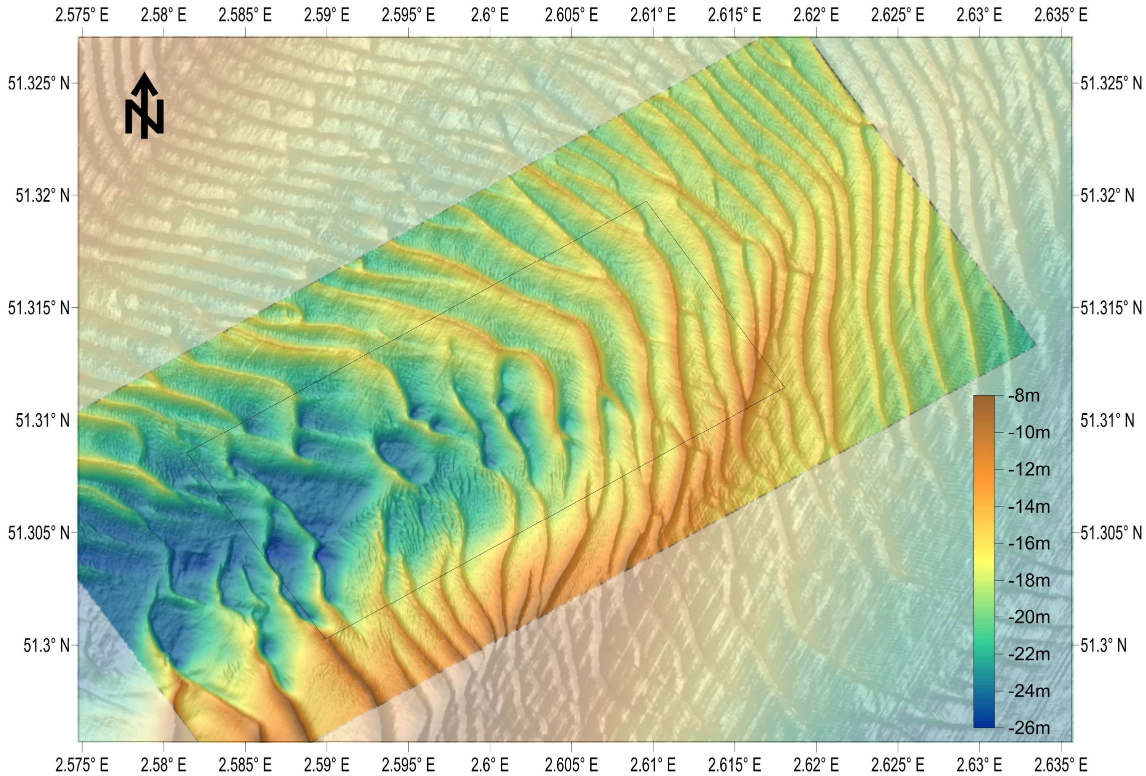

Figure 24: Bathymetry of monitoring area BRMC (limits in black) based on the reference model of zone 2 from 2002. Depths are referenced to MLLWS.

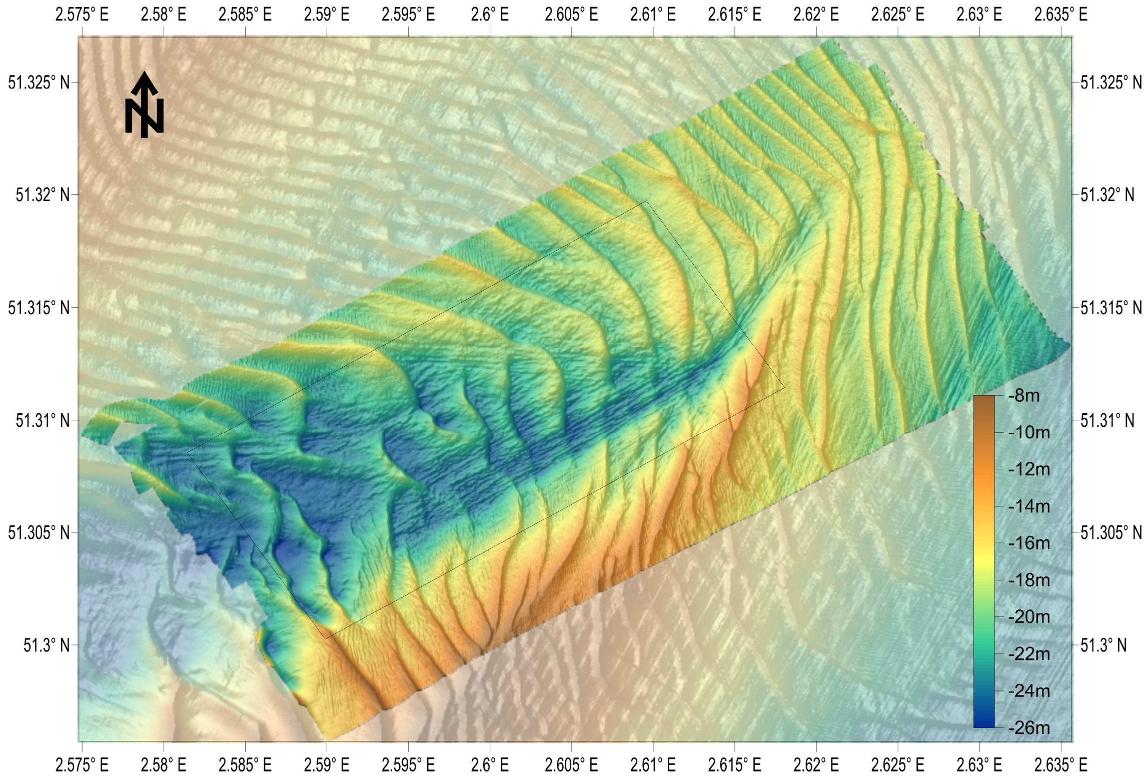

Figure 25: Bathymetry of monitoring area BRMC (limits in black), survey of 13/03/2014. Depths are referenced to MLLWS.

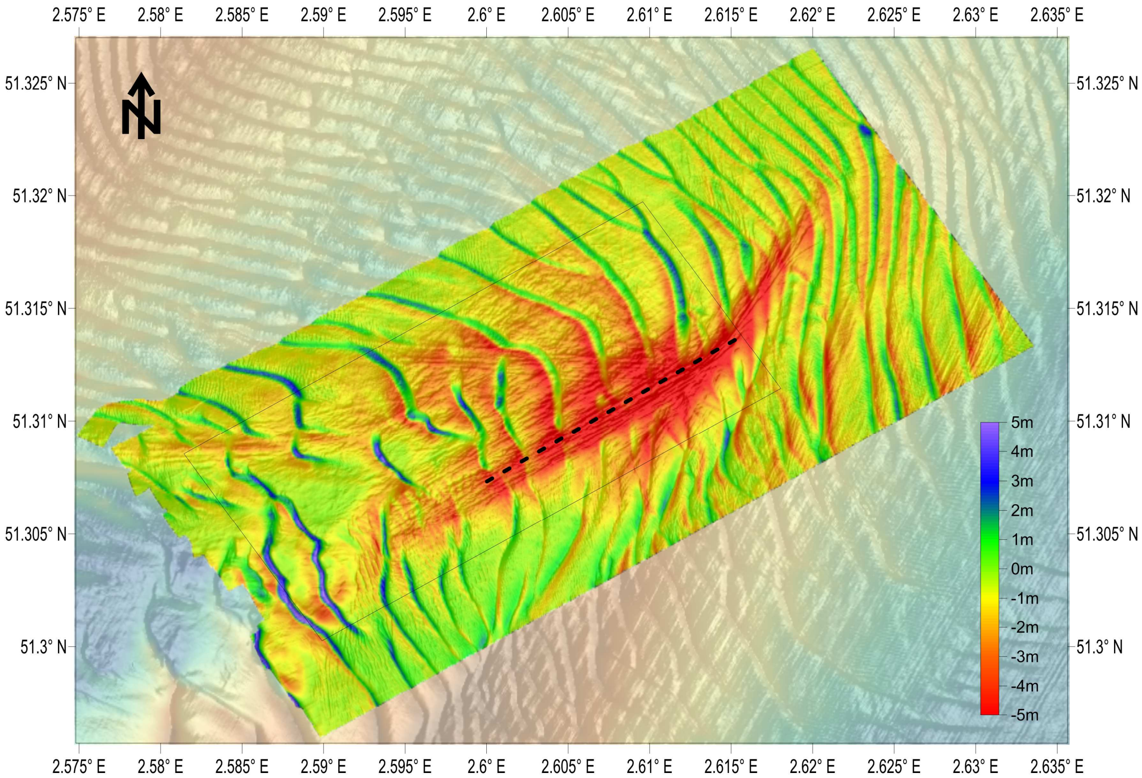

Figure 26: Depth difference between monitoring area BRMC (limits in black), survey of 13/03/2014, and the reference model for zone 2 from 2002. Positive values show an increase in sediment, negative values a decrease. The dashed line is the location of the profile from figure 27.

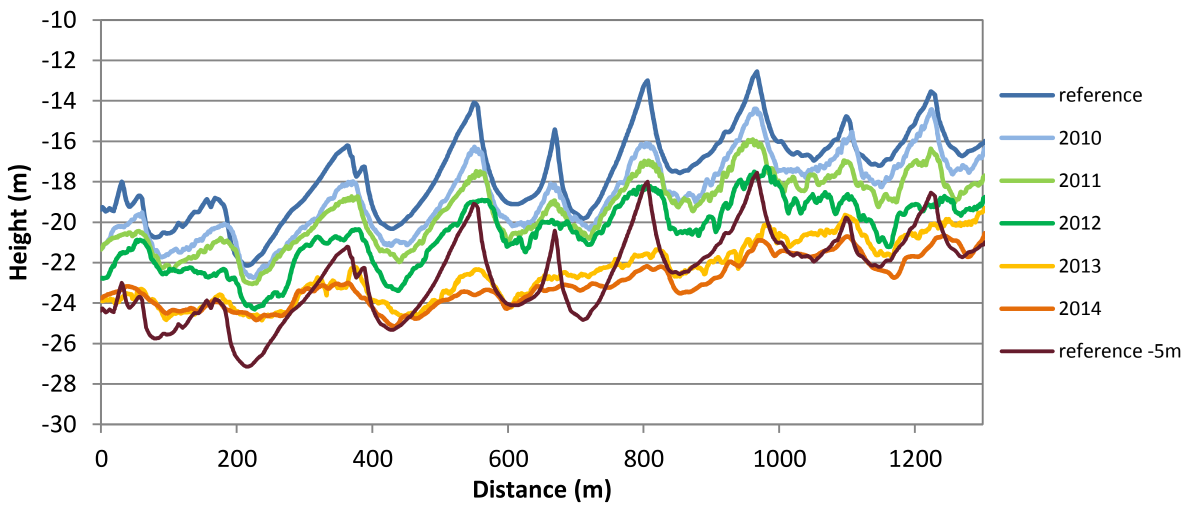

Figure 27: Bathymetric profile across the monitoring area BRMC (dashed line on figure 26). Depths are referenced to MLLWS.

As a result, the Continental Shelf Service advised for a closure in 2015 of an area which encompasses all locations where the limit of 5m is exceeded (figure 29). The coordinates of this area (table 2) and the motivation were published in a report (Degrendele et al., 2014). Based on this report, the consultative commission on the sand extraction at sea unanimously approved the proposal to close the central part of the Buiten Ratel.

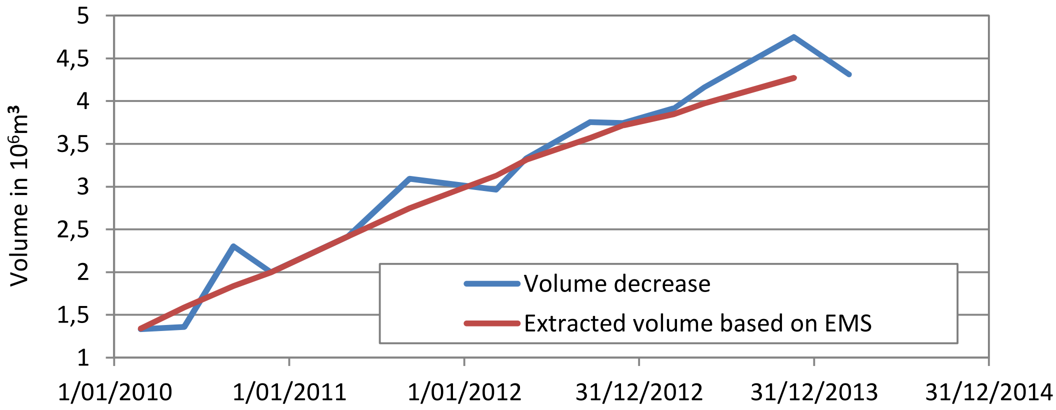

Figure 28: Comparison between the measured volume decrease (in 10^6 m^3) inside the monitoring area BRMC on the Buiten Ratel and the extracted volumes based on EMS calculated for the same surveys. A value of 0.96 is calculated for the Pearson correlation coefficient.

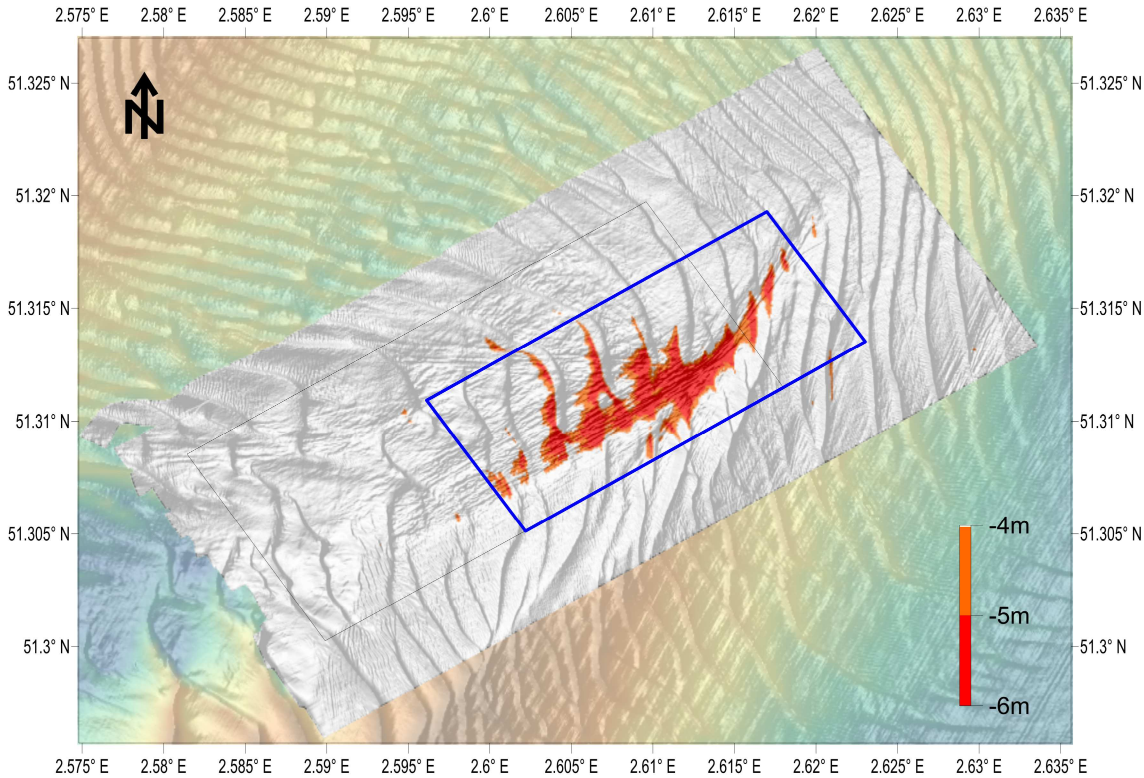

Figure 29: Decrease of depth between the monitoring area BRMC (limits in black), survey of 13/03/2014, and the reference model for zone 2 from 2002. The area that will be closed for extraction in 2015 is indicated in blue.

WGS84 UTM ZONE 31		LAT LONG			
Meter		Degrees		Degrees minutes	
X	Y	North	East	North	East
472269	5683832	51.30513	2.60219	51° 18.3075'	2° 36.1314'
471850	5684479	51.31093	2.59612	51° 18.6556'	2° 35.7674'
473308	5685401	51.31928	2.61699	51° 19.1570'	2° 37.0192'
473726	5684757	51.31351	2.62302	51° 18.8108'	2° 37.3811'

Table 2: Coordinates of the area on the Buiten Ratel that will be closed for extraction in 2015.

Control Zone 4

The extraction in zone 4 started in 2012, so the overall impact is still limited. The surveys along the DECCA lines across the banks in 2012 and 2013 (figure 30) do not show any significant impact. They only illustrate the very dynamic character of the many large sand dunes on the Hinderbanken (the alteration of blue and red on figure 30).

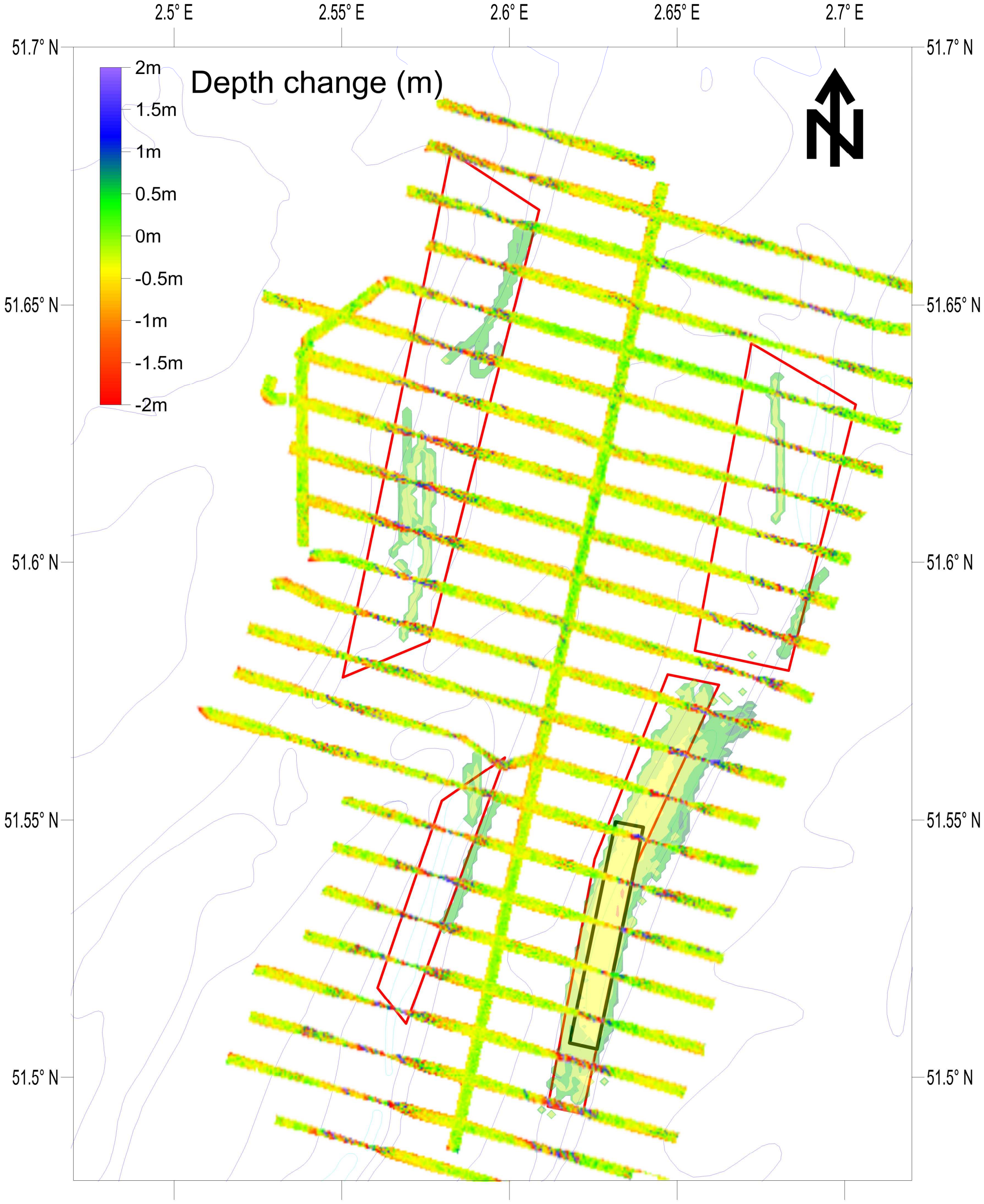

Figure 30: Depth change between the survey along DECCA lines from 15/05/2013 and the reference model. Positive values show an increase in sediment, negative values a decrease. A map showing the extraction density between the survey date and the reference model is used as background.

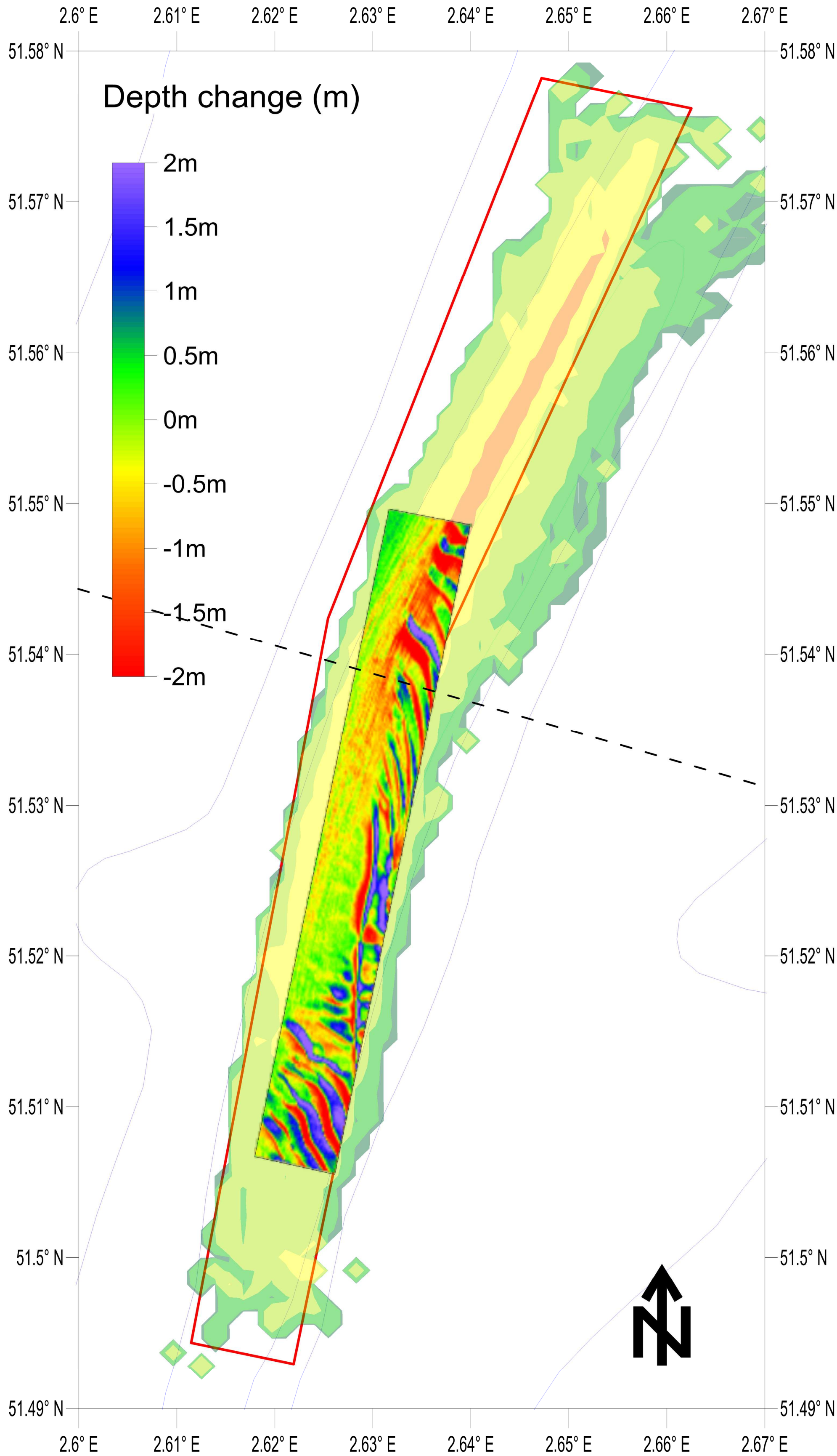

Figure 31: Depth difference between the survey HBMC from 12/03/2014 and the reference model for zone 2. Positive values show an increase in sediment, negative values a decrease. A map showing the extraction density between the survey date and the reference model is used as background.

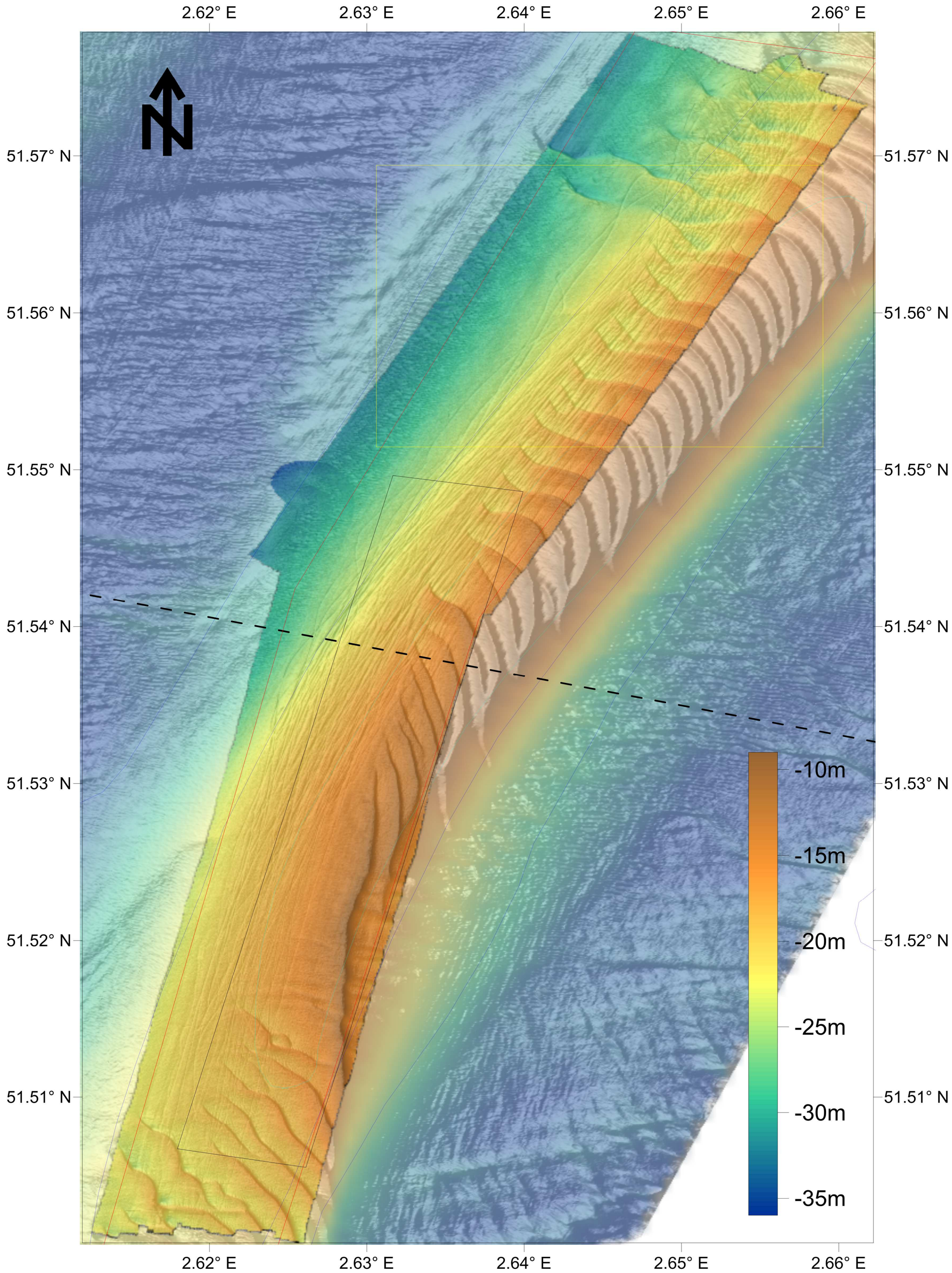

Figure 32: Bathymetry of monitoring area HBMC (limits in black), survey of 12/03/2014. Depths are referenced to LAT. The yellow rectangle is the location of the detailed image in figure 34, the dashed line is the location of the profile from figure 35.

In 2014 the impact is already more obvious. The extraction is concentrated on the central and northern part of sector 4c. Monitoring area HBMC covers only the central and southern part of this sector (figure 31) and thus the monitoring area is occasionally extended to the entire sector (this was the case for the survey on figure 32). The extraction is also very concentrated in time (figure 33). In short intervals, large volumes are excavated for the Master plan Coastal Safety. The bathymetry shows large furrows that are created by the large dredging vessels (figures 33 and 34). The evolution along a profile in sector 4c (figure 35), combining data from the DECCA line surveys and from the HBMC surveys, demonstrates two facts: first, the large sand dunes are very mobile (a shift of 25 m a year) and secondly, the clear impact on the topography from 2014 onwards.

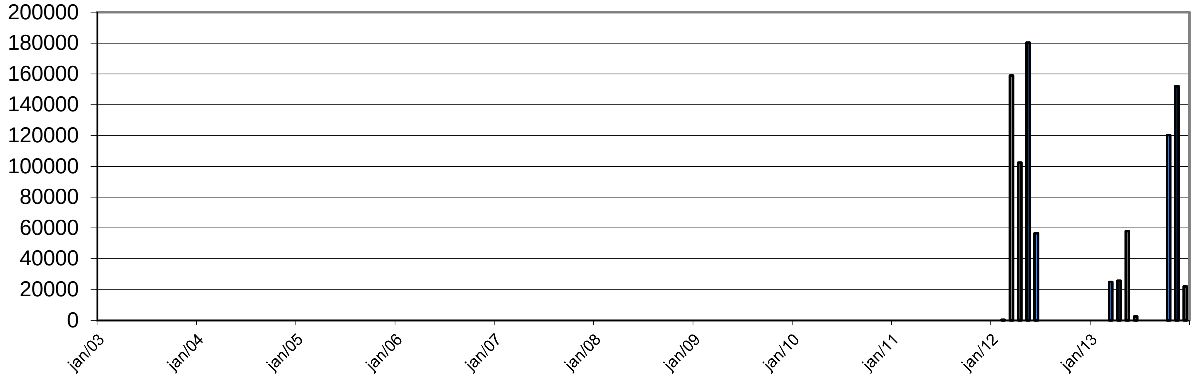

Figure 33: Evolution of the monthly extracted volume (in m^3) in the monitoring area HBMC.

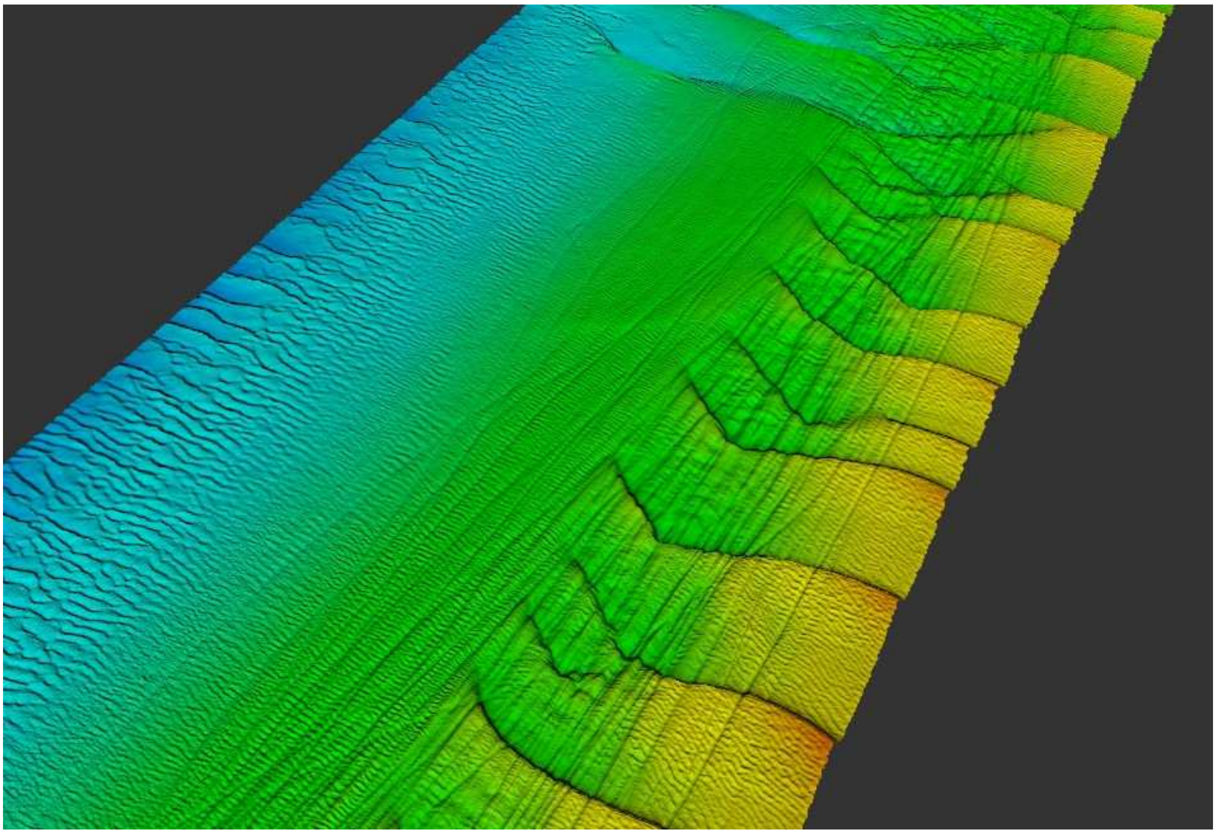

Figure 34: Detail of the northern part of sector 4c, survey of 12/03/2014 (location see figure 33).

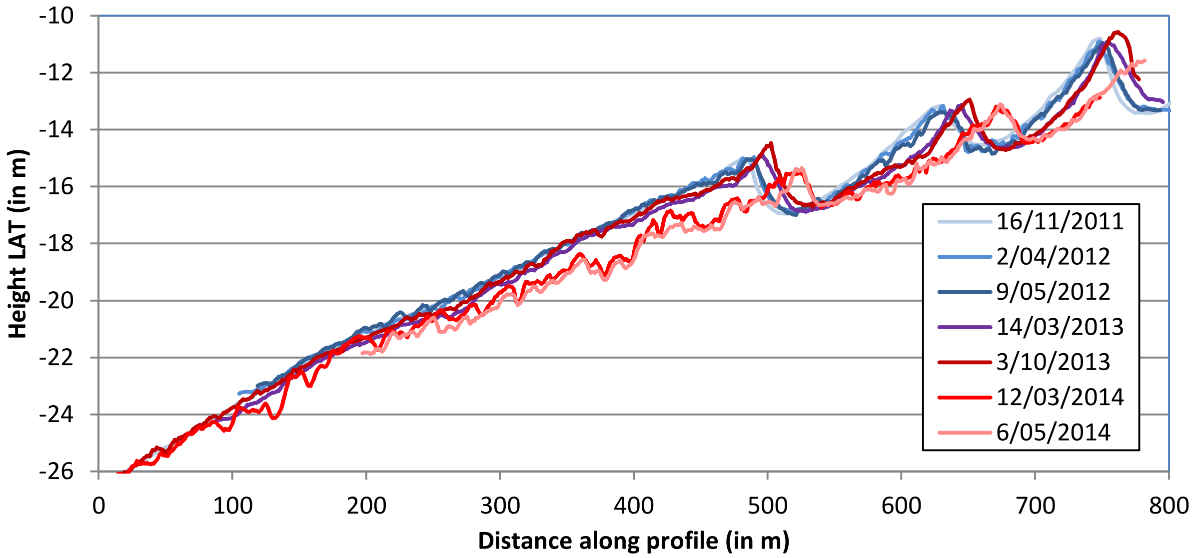

Figure 35: Bathymetric profile across the Oosthinder and the monitoring area HBMC (dashed line on figures 31 and 33). Depths are referenced to LAT.

Correlation MBES – EMS data

The predicted bathymetric differences caused by the extraction activities can be compared with the bathymetric differences measured with the EM3002D along the DECCA lines and in the monitoring areas relatively to the reference models of zones 1, 2 and 4 (figure 36). The methodology has been described previously (Roche et al. 2011 and Roche et al. 2013). A strong correlation is observed between the bathymetric differences measured with the MBES and the bathymetric differences caused by the extraction for both the DECCA data and the monitoring areas data. Globally, considering all the data together, the square of the linear correlation coefficient (Pearson R) between the bathymetric difference measured with the MBES and the bathymetric difference caused by the extraction is almost equal to 0.95. This correlation is statistically highly significant: most of the bathymetric variation observed on the extraction zones can be explained by the extraction itself. Surprisingly, a mean bathymetric variation of -0.3 m is observed in areas where the extracted volume is zero. Such a global decrease of the bathymetry is questionable and must be investigated in detail. It could be related to fluctuations in the accuracy of the reference models due to insufficient corrections of the draft of the ship. Furthermore, our current bathymetric measurements with the MBES EM3002D are themselves subject to errors included in the IHO S44 special order confidence interval which is +/- 0.3 m for 20 m water depth. This confidence interval puts our results into perspective.

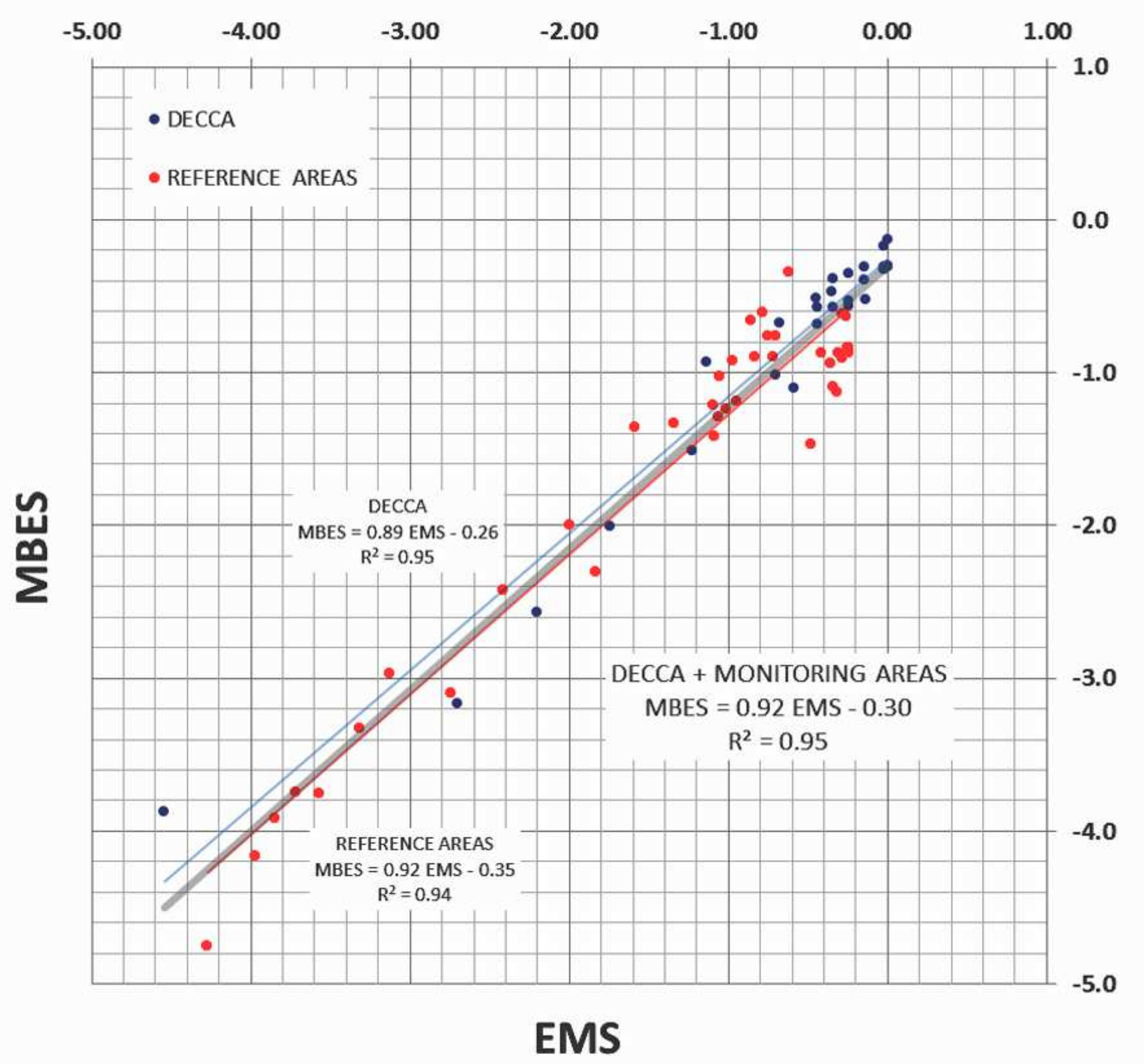

Figure 36: Plot of the bathymetric difference measured with the MBES data versus the bathymetric difference deduced from EMS data; linear regression line based on the DECCA data (blue dots and line) and reference area data (red dots and line) separately and together (grey line).

Conclusions

The main conclusion from the earlier reports and publications (Degrendele *et al.*, 2010, Roche et al., 2011 and Roche et al., 2013) is confirmed: the sand extracted on the Belgian part of the North Sea must be considered as a non-renewable resource whose extraction has a local and non-cumulative impact.

MBES technology remains the most appropriate tool to evaluate with great reliability the impact of the extraction on the seabed topography, morphology and sedimentary nature. But there are a couple of observations that need attention and further investigation: a recent small negative trend is observed in several time series, and although the values fall inside the confidence interval of the MBES data (Lurton et al., 2011 and Roche & Degrendele, 2011), a close follow up is needed. The impact of the accuracy of the reference models on the global trends needs further investigation. In this point of view the annual evaluation of the quality of the measurements on reference sites (the Vandammesluis and a stable area on sea) becomes an invaluable tool and requires more focus and time investment (Roche & Degrendele, 2011).

At this moment, the legal limit for the extraction is still 5 m below the reference surface defined by the Continental Shelf Service. On the central part of the Buiten Ratel this limit has recently been exceeded in a continuous area and subsequently this area will be closed for extraction in 2015 (Degrendele et al, 2014).

The upgrade of the EMS system will allow a faster follow up of the spatial and temporal variations of the extracted volumes. The fast depletion of the legally allowed volumes in certain areas makes a more adaptable monitoring necessary. Due to the closure of the central part of the Buiten Ratel in 2015, the extraction pattern will undoubtedly change.

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First of all, the excellent navigation by the crew of R/V Belgica during the campaigns was crucial for the monitoring program. The Operational Directorate Natural Environment (former Management Unit of the Mathematical Model of the North Sea and the Scheldt Estuary - BMM) provided the necessary ship time on board the R/V Belgica. The colleagues from ILVO and BMM are thanked for the collaboration in the establishment of a balanced and all-embracing monitoring program.

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