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Flemish government
COASTAL DIVISION

Synthesis report on the effects of dredged material dumping on the marine environment (licensing period 2012-2016)

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Colophon

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The photo on the front page is a Landsat-8 image from the Belgian nearshore area (16/03/2014), showing the turbid coastal waters with high sediment concentration (yellow-brown) and the dumping of dredged material from the harbour of Zeebrugge on the ZBO dumping site visible as a dark coloured surface plume at about 51°22.5 N 3°16 E (Vanhellemont and Ruddick, 2014).

Content

1. Introduction

Dumping at sea of dredged material is carried out in accordance with the federal law of 20th January 1999 and a permit is given in accordance with the procedure defined in the royal decree (RD) of 12th March 2000, and revised by the RD of 18th October 2013 by which the validity period for the permits has changed from 2 years till 5 years. Corresponding to article 10 of this procedure, every 5 years a "synthesis report" has to be established for the Minister who has the North Sea under his competences. After 2.5 years a "progress report" has to be written and sent to the Minister. The synthesis report needs to include recommendations which support the development of an enforced environmental management (see chapter 2). The current synthesis report covers the period 2012-2016.

Permits for dumping of dredged material at sea were given to the Maritime Access Division who is responsible for maintaining all maritime access channels to the coastal ports as well as to the Coastal Division of the Agency for Maritime Services and Coasts who is responsible for the maintenance of the coastal marinas. In the ministerial decree (MD) of 19 December 2013 (BS 16.01.2014) the validity of the MD for the dumping of dredged material at sea for both Flemish authorities (AMT and AMCS-CD) has been prolonged until 31 December 2016, in accordance with the royal decree (RD) of 18 October 2013. The permitted and the actual dumped quantities are presented in chapter 3.

The international framework for dumping at sea of dredged material is the (regional) OSPAR Convention (1992) and the (worldwide) London Convention (1972) and Protocol (1996). These conventions and their associated guidelines take into account the presence of any contaminants within the sediment and whether some alternative beneficial use is possible. In implementing these guidelines, e.g. action levels (sediment quality criteria) have to be defined, dumping sites have to be chosen and a permanent monitoring and research program has to be carried out (see chapters 4 to 7).

2. Recommendation to the Minister

2.1. Present state of the recomendations

2.1.1 Policy recommendations

Recommendation	Intermediate status (2014)	Current status (2016)
The legal aspects of the dredged material dumping from the ports of Nieuwpoort and Blankenberge through a fixed pipeline (point discharge) needs to be investigated.	The research is carried out.	
Within the EU MSFD - Good Environmental Status (GES) attention will be put on the developments of indicators focussing on the dumping of dredged material at sea.	The MSFD monitoring program is ready and was consultable until 15/06/2014. The reporting of the effects of dumping operations will be carried out conform MSFD guidelines.	The relevant indicators for dumping of dredged material are presented and discussed in chapter 7.
Existing monitoring and research programs will be changed in order to be conform the guidelines formulated by the MSFD.	The MSFD monitoring program is ready and was consultable until 15/06/2014. The reporting of the effects of dumping operations will be carried out conform MSFD guidelines.	The relevant indicators for dumping of dredged material are presented and discussed in chapter 7.

2.1.1 Policy supported research

Recommendation	Intermediate status (2014)	Current status (2016)
A field study will be carried out that will be used to validated previous research on the efficiency of a dumping site, with the aim to possibly define a new dumping site	The field study took place in October-November 2013. The framing measurements lasted for one year and have ended in April 2014. First results have been reported end of 2014.	The field study has been reported in 2015, see chapter 6.1.
During 4 RV Belgica campaigns per year in total 6 13 hour cycles are executed in order to collect vertical profiles and to calibrate the sensors used in the long-term deployments. The long-term measurements at MOW1 are continued. Data are analysed, interpreted and reported.	For each year (2012 and 2013) four measuring campaigns with in total 6 13 hour cycles have been executed. Long-term data and the 13h measurements have been reported for the period 2012-2013.	Long-term and 13h measurements have been reported for 2012-2015. In 2014 7 13 hours measurements have been carried out. Due to the not availability of the RV Belgica during part of 2015 and 2016, the number of 13 hours is limited to three (2015) and two (2016).
Execution of measurements and data analysis to support the field study	The field study took place in October-November 2013. The framing measurements lasted for one year and have ended in April 2014. First results have been reported end of 2014.	The field study has been reported in 2015, see chapter 6.1.
The geographical variability of the turbidity maximum zones will be studied using satellite images and weather conditions. The findings will allow identifying processes	MODIS satellite images together with 11 weather types and 2 climatological situations have been used, the results are reported in chapter 4.1	

that influences the SPM concentration. This is needed to e.g. understand long-term variations and climate induced changes and to identify the best dumping site in accordance with the weather pattern.		
The correlation between biomass and floc size (and thus settling velocity) is often referred to in scientific literature; however, up to now few quantitative data are available. The long-term time series collected at MOW1 will allow a systematic and quantitative analysis in combination with satellite and other in situ data.	A first phase of the research has been reported, see chapter 4.3.1. The presence of biomass results is large floc size of the SPM in summer than winter. As a consequence the settling and deposition of SPM and the erosion resistance increases.	The research has been carried out and has been reported, see chapter 4.3. Further data collection and specific research is planned in the future
The cohesive sediment transport model has been adapted and improved during the previous years and will be validated.	The ±1300 days of observation from MOW1 form the basis for the model improvement (flocculation model) and validation.	New bathymetry and a setup of the Belgian Coastal model using the COHERENS V2 software has been carried out in 2016.
The current ecological monitoring program is capable of detecting changes in the structural benthic habitat characteristics (density, biomass, diversity) induced by the dumping of dredged material. In the future we will investigate if changes occur in the functional benthic characteristics (feeding class, mobility class, reworking mode) as consequence of the dumping operations.	The functional characteristics (Biological traits) have been identified for a large number of benthic species and they can be applied in the analysis for the synthesis report 2016.	The impact evaluation on the functional status of the benthic habitat is still in progress, due to the lack of a specific MSFD indicator. Only exploratory analysis and updates on the definition of the functional characteristics of benthic species has been carried out. Because of the preliminary status it is not implemented in the current report.
Previous research has also shown that possibly a critical limit of dumping exists, where changes in habitat can lead to ecological changes. Can such a limit be marked out from an ecological perspective, taking into account the cumulative effects, the habitat type and sensitivity, and the impacted surface area?	These analysis need to be carried out conform the Belgian MSFD implementation (end 1st cycle is in 2018). Further guidelines are waited for in order to execute the analysis in more detail. A preparatory analysis will be carried out in the synthesis report 2016.	The relevant indicators for dumping of dredged material are presented and discussed in chapter 7. An exploratory analysis is carried out that gives a view of the relation between changes in the benthic indicator and the quantities dumped and this as a function of the habitat type (chapter 5.2).
On very short term no unambiguous effects of dumping on the mobile fauna (epifauna and demersal fish) seem to occur. As a function of habitat changes long term changes at some of the dumping sites (S1) is recommended to evaluate possible structural and functional changes in these fauna components on the long run.	Currently long term data are still collected, so that by the end of 2016 12 years of data will be available that allows investigating the possible effects on mobile fauna. Currently a study is carried out dealing with the long term variations in epifauna and demersal fish. This analysis is ongoing and will be reported in the synthesis	These results are integrated in the synthesis report (chapter 5.1), where the 12 year data of epifauna and demersal fish for the different dumping sites is analysed. The influence of dumping on this mobile fauna is limited, except for the epifauna at S1.

	report 2016.	
Research on chemicals on dumping sites will be extended with a general determination of the toxicity to evaluate the effect of chemical pollutants, and with a screening towards the so-called emerging contaminants.	The general toxicity is determined through the use of microtoxtests on mud samples from navigation channels. Results indicate that the samples are slightly acute toxic caused by non-bio-available components. A general screening, carried out in collaboration with VITO, suggested that a lot of emerging contaminants may be present on the dumping sites (see chapter 5.4). Based on these results it was decided to determine and assess a broad scope of contaminants in the coming years.	In a first step the presence of pesticides on the dumping sites was investigated. Not one of the more than 300 investigated pesticides had concentrations higher that the quantification limit. Further research will focus on other emerging contaminants.
Determination of the health index on fish allows estimating the general health status. This is complementary to the observations of external and visual fish diseases that are currently already carried out.	To determine the age estimates, verified through otoliths, was completed. Data analysis is ongoing.	This analysis has been carried out and reported, see chapter 5.6.

2.2. New recommendations (2017-2021)

1. Further to the research carried out during the period 2009-2016, the study of the practical implementation of a new dumping site west of Zeebrugge needs to be continued. The research should focus on possible alternatives, concerning the location as well as the exploitation scenarios, and the environmental impact of these possible alternatives should be investigated. The latter will serve as input for the EIA.

2. The remaining capacity of dumping site S1 is limited. In the near future possible alternatives for the dumping site need to be investigated. A new search area has to be defined, comparable as with the alternative dumping location of Zeebrugge West. This search area can be used as input for the modification of the MSP (2017-2018).

3. The research on dumping methods and sites for the dredging at Blankenberge and Nieuwpoort needs to be continued.

4. The monitoring and evaluation of indicators relevant for the dumping of dredged material for the MSFD - Good Environmental Status needs to be developed further.

5. Specific emphasis need to be given within the MSFD framework to “Marine Litter”. Further research to the definition of a baseline and of the origin of the litter is needed. If relevant then the research should be carried out in cooperation with other actors.

6. The researches on fish diseases will be continued at ILVO, but – due to the very limited relevance for the research on the effects of dumping of dredged material – the outcomes will not an-

ymore be reported in the framework of dredged material dumping and its effects on the marine environment.

7. The collection of necessary ecological, chemical, hydrodynamical and sedimentological data for the basic research on the effect of dumping of dredged material will be continued and if necessary optimised in function of police choices.

8. With the use of the Sediment Profile Imaging (SPI) technique, near bed ecological and sedimentological processes need to be better investigated.

9. A large scale sediment sampling campaign needs to be setup, inclusive the checking towards actualisation of the sampling locations.

10. Based on the analysis results of the large scale sampling campaign, investigations should be pursued to check if an actualisation of the SQC is needed.

11. The research on anti-fouling products, their use and dispersion, needs to be continued and where necessary extended.

3. Dredging and dumping

To conserve the maritime access channels to and to maintain the depth in the Belgian coastal harbours dredging is needed in order to guarantee safe maritime transport. This type of dredging is called maintenance dredging. Most of the dredged material is being dumped at sea except when the dredged material is contaminated (see chapter 6.2) or when the quality is suitable for beach nourishment. The last use is called beneficial use of dredged material (see chapter 3.2.3).

3.1 Dredging activities

Since 2008, dredging years are following calendar years and since 2006 a distinction is being made between permits for maintenance dredging (validity 2 years) and permits for capital dredging (these permits are granted for the period of working). The areas to be dredged are divided in accordance with the target depth which is defined in function of the expected vessel types and their maximum draught.

The use of certain dredging technique is dependent upon the site, the hydrodynamic and meteorological circumstances and the nature of the sediment to be dredged. Evaluation is being made on the basis of economical, ecological and technical criteria. In Belgium most commonly trailing suction hopper dredgers are used with a hopper capacity from 5000 to 10000 m³.

In the access channels and Flemish harbours, maintenance dredging is virtually continuous throughout the year. Maintenance dredging in fishing harbours and marinas is taking place before and just after the coastal tourist period. A major port - and its connected access channels - with a diversity of customers may need to carry out a capital project every few years to accommodate changes in the patterns of trade and growth in the size of the vessels to be accommodated.

During the execution of (maintenance) dredging works, marine litter is currently taken into account. The dredged litter is if possible removed from the hopper and stored in a container on board for further sorting and treatment.

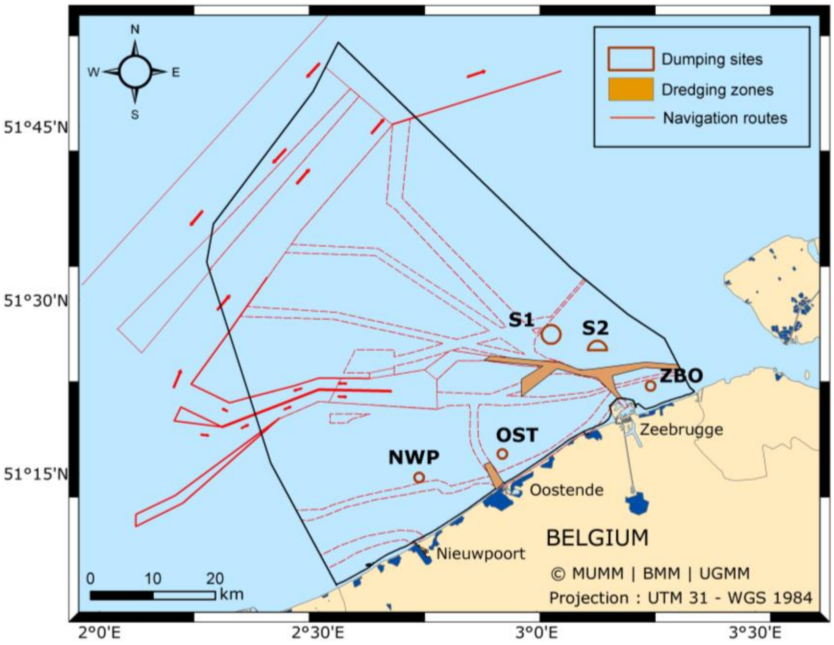


Figure 3.1: Dumping sites in the Belgian part of the North Sea.

3.2 Dumping activities

3.2.1 Quantities permitted

In the former licensing period 1 January 2010 – 31 December 2011 prolonged till 31 December 2016 (royal decree of 18.03.13), four permits for maintenance dredging were granted to the Maritime Access Division as well as three permits to the Agency for Maritime and Coastal Services. The maximum and average attributed quantities which may be dumped at sea per year and per dumping area are given in Tables 3.1 and 3.2. The location of the dumping sites is shown in Figure 3.1. It should be noted that the permit holder is requested to not exceed the average quantities.

Table 3.1: Permits for the Maritime Access Division (AMT).

Permit reference	**Dredging site**	**Type dredging**	**Dumping site**	**Yearly permitted quantities (TDM)**	
				average	**maximum**
M.B. ref. BS/2011/01	• Scheur West • Scheur Oost • Pas van het Zand, CDNB en Voorhaven Zeebrugge	maintenance	S1	2,300,000 2,300,000 6,400,000	2,800,000 2,800,000 7,150,000
		Total :		**11,000,000**	**12,750,000**
M.B. ref. BS/2011/02	• Scheur West • Scheur Oost • Pas van het Zand, CDNB en Voorhaven Zeebrugge	maintenance	S2	500,000 375,000 2,000,000	600,000 450,000 2,400,000
		Total :		**2,875,000**	**3,450,000**
M.B. ref. BS/2011/03	• Toegangsgeulen Oostende (Stroombankkil, ingangsgeul) • Haven Oostende	maintenance	OST	600,000 500,000	900,000 700,000
		Total :		**1,100,000**	**1,600,000**
M.B. ref. BS/2011/04	• CDNB Zeebrugge • Haven en Voorhaven Zeebrugge	maintenance	ZBO	3,900,000 2,100,000	5,500,000 3,150,000
		Total :		**6,000,000**	**8,650,000**
		GRAND TOTAL		**21,045,000**	**26,550,000**

Table 3.2: Permits for the Agency for Maritime and Coastal Services.

Permit reference	**Dredging site**	**Type dredging**	**Dumping site**	**Yearly permitted quantities (TDM)**	
				average	**maximum**
M.B. ref. BS/2011/05	• Jachthaven Oostende – RYCO • Jachthaven Oostende – Montgomery dok	maintenance	OST	50,000 50,000	75,000 75,000
		Total :		**100,000**	**150,000**
M.B. ref. BS/2011/06	• Vaargeul Blankenberge • Vlotdok Blankenberge • Spuikom Blankenberge	maintenance	ZBO	100,000 100,000 100,000	200,000 150,000 150,000
		Total :		**300,000**	**500,000**
M.B. ref. BS/2011/ Nieuwpoort	• Toegangsgeul Nieuwpoort • Vaar- en havengeul Nieuwpoort • Oude Vlotkom Nieuwpoort • Nieuwe jachthaven Nieuwpoort • Novus Portus Nieuwpoort	maintenance	NWP	70,000 200,000 100,000 200,000 200,000	100,000 300,000 200,000 300,000 300,000
		Total :		**770,000**	**1,200,000**
M.B. ref BS/2012/01	• Oude Vissershaven Zeebrugge	maintenance	ZBO	70.000	120.000
		GRAND TOTAL		**1,240,000**	**1,970,000**

3.2.2 Quantities dumped

Since 2007 dredging years are following calendar years. Table 3.3 gives an overview of the quantities dumped at sea since 1991 till March 2008 to keep historical data. It should also be noted that the amounts mentioned in the table are being used for the yearly OSPAR reporting of dumped dredged material, also for continuation in former reporting years. Table 3.4 gives the overview of the quantities of maintenance dredged material dumped yearly since 2007.

The maps in appendix 1 give a visual image of the maintenance dredging and dumping intensity during the period 2011 to 2015. The dredging intensities give an indication of the rate of sedimentation, while the dumping intensities show where most of the dredged material is being dumped over the surface of the dumping site. Both, dumping and dredging intensity maps are being used for validation of the mathematical models and for defining monitoring stations.

Table 3.3: Quantities of dredged material dumped since 1991.

Quantities dumped in wet tonnes(*)								
period	**S1**	**S2**	**ZBO**	**OST**	**NWP**	**R4 (**)**	**S3 (**)**	**Total**
April 1991 - March 1992	14,176,222	7,426,064	10,625,173	4,416,386				36,643,845
April 1992 - March 1993	13,590,355	5,681,086	10,901,837	3,346,165				33,519,443
April 1993 - March 1994	12,617,457	5,500,173	10,952,205	3,614,626				32,684,461
April 1994 - March 1995	15,705,346	2,724,157	8,592,891	3,286,965				30,309,359
April 1995 - March 1996	14,308,502	2,626,731	8,432,349	4,165,995				29,533,577
April 1996 - March 1997	14,496,128	1,653,382	7,609,627	2,763,054				26,522,191
Quantities dumped in tonnes dry matter (*)								
🟨 maintenance								
🟩 capital								
period	**S1**	**S2**	**ZBO**	**OST**	**NWP**	**R4**	**S3**	**Total**
April 1997 - March 1998	6,045,581	1,563,485	6,593,905	745,147				14,948,118
April 1998 - March 1999	7,455,619	482,108	2,976,919	467,107				11,381,753
April 1999 - March 2000	2,885,801	89,556	3,189,077	591,605				6,756,039
	6,187,601	41,583						6,229,184
April 2000 - March 2001	1,684,517	784,343	4,971,782	559,332		310,670	51,150	8,361,794
	3,873,444	614,657						4,488,101
April 2001 - March 2002	2,031,147	329,798	2,623,069	565,938				5,549,952
	2,527,392							2,527,392
April 2002 - March 2003	3,314,115	858,607	2,311,650	491,217	289,949			7,265,538
	2,413,760	208,885	1,369,939					3,992,584
April 2003 – March 2004	5,246306	716,427	3,126,392	646,276	142,420			9,877,821
	829,486	24,896	447,219					1,301,601
April 2004 – March 2005	1,826,561	1,826,033	3,003,397	464,307	71,928			7,192,226
April 2005 – March 2006	3,017,123	1,234,640	2,973,545	599,905				7,890,077
April 2006 – March 2007	3,791,724	505,644	2,394,828	819,665	178,269			7,690,130
	7,930,966	90,673	401,944					8,423,583
April 2007 – March 2008	5,769,680	1,266,266	2,361,012	428,839	201,581			10,027,378
	545,907	369,804		335,283				1,250,994

(*) Before April 1997, the manual "bucket" method was used to evaluate the quantity of dredged material on board a ship. Since April 1997, an automatic measurement device is used which allows directly evaluating the quantity of dry material on board ships. Comparison between both systems is not possible.
(**) Closed for dumping since end 2004

Table 3.4: Quantities of maintenance dredged material dumped at sea per calendar year (in TDM).

Year	S1	S2	ZBO	OST	NWP	Total
2007	5,592,676	1,389,364	2,219,780	460,167	118,100	**9,770,087**
2008	4,589,589	80,014	4,667,225	864,863	103,541	**10,305,232**
2009	6,144,522	1,591,871	3,776,038	241,544	156,456	**11,910,431**
2010	3,642,577	2,598,212	3,342,526	304,235	179,186	**10,066,736**
2011	5,290,142	2,946,850	2,062,762	562,690	64,234	**10,926,678**
2012	4,320,751	2,650,587	2,843,505	359,997	175,121	**10,349,961**
2013	5,988,596	1,969,370	3,021,397	654,488	211,722	**11,845,573**
2014	3,782,916	2,523,263	4,005,689	414,260	171,481	**10,897,609**
2015	5,538,995	3,022,536	3,945,216	504,944	162,128	**13,173,819**

3.2.3 Beneficial use

To keep the access channel to Blankenberge harbour open, maintenance dredging on a regular basis is needed. Wind and current patterns cause a rapid influx of sand from the nearby beaches and a sand plate is being built up. As a consequence of this, the chemical and morphological qualities of this sand are very good. Contamination is virtually non-existent. Within the environmental legislation of the Flemish Region, re-use of dredged material as soil is possible, providing a specific certificate is delivered. Table 3.5 gives an overview of the quantities of dredged material from the access channel to Blankenberge used beneficially to reinforce coastal defence on the nearby beaches.

Table 3.5: Beneficial use of dredged material.

Period	Beneficially used dredged material (m^3)
November 2007 – February 2008	69.526
May 2008 – June 2008	18.661
November 2008 – December 2008	30.884
April 2009	9.588
November 2009 – January 2010	21.354
October 2010 – October 2011	22828
2012	148.757
2013	96.924
2014	155.166
2015	67.848
Total	**144.013**

4. Physical aspects related to dredging and dumping operations

Dredging operations in coastal areas are essential in order to maintain channels and harbours navigable for large vessels. These deepened areas are not in equilibrium with the hydrodynamics and as a consequence sediments are quickly accumulating after removal. The amount of sediments to be dredged depends to a large part on the suspended particulate matter (SPM) concentration, the hydrodynamic conditions and the dumping operations itself. Depending on the location of the disposal site, significant amounts of the disposed matter may recirculate in suspension or as high concentrated benthic layers back to the dredging areas, increasing thus the volume to be dredged (Van den Eynde and Fettweis 2006).

Using SPM concentration measurements to differentiate between anthropogenic impact and natural variations requires the availability of long-term time series of in situ and remote sensing measurements as well as of validated numerical model results that encompass the temporal as well as the spatial scale. With increasing implementation of long-term monitoring stations an understanding of variations and short term impacts became possible (e.g. Badewien et al. 2009; Garel and Ferreira 2011; Fettweis et al. 2011; Henson 2014; Jalón-Rojas et al. 2015). SPM exists in form of aggregates of mineral and living and non-living organic particles with concentrations, compositions, sizes, and structural complexities. The processes that causes variations in SPM concentrations are physical and biological one that act on time scales from well below seconds (turbulence) over tides to months, even to larger scale climatic (e.g. NAO, climate change) or astronomical cycles (e.g. 18.6 year lunar cycle). Adding to this are random disturbances, either due to natural processes (e.g. storm, river flooding), or human activities such as dredging and dumping. As a consequence, SPM properties and concentrations fluctuate on a broad range of temporal and spatial scales with different magnitudes and exhibit substantial gradients with distance from the coast. The variations in SPM concentration have to been known in order to understand and predict how human activities alter the marine ecosystems, to implement cost-effective dredging and dumping operations and to develop environmental policies aiming at a more sustainable management of the marine environment.

This chapter describes the results of the monitoring efforts with regard to a better physical description of SPM concentration variability on different timescales. The regional setting of the area under investigation is described in chapter 4.1, and the implemented monitoring activities using benthic landers, shipborne measurements and remote sensing data are presented in chapter 4.2. Chapters 4.3 and 4.4 focus on the physics of SPM dynamics (flocculation, natural variability). The results from these chapters are used in chapter 4.5 to quantify the effects of natural forcings and in chapter 4.6 to quantify the impact of dumping of fine-grained material on the natural SPM dynamics. The field study of an alternative dumping location west of Zeebrugge, which is presented in chapter 6.1, is based on the methods and measuring data summarized in this chapter.

4.1. The Belgian nearshore area

The Belgian nearshore is characterized by semidiurnal tides, strong tidal currents, and a coastal turbidity maximum area with SPM concentrations between 0.02 and more than 0.15 g/L at the surface and between 0.1 and more than 4 g/L near the bed; lower values (<0.01 g/L) occur offshore (Baeye et al. 2011; Fettweis et al. 2012b). The measuring location MOW1 is situated at the marine limit of influence of the Westerscheldt estuary and the Rhine-Meuse delta (Lacroix et al. 2004; Arndt et al. 2011), and in the vicinity of major dredging and dumping sites. The strong tidal currents and the low freshwater discharges from rivers result in a well-mixed water column. South-westerly winds dominate the overall wind climate, followed by winds from the NE sector. Maximum wind speeds coincide with south-westerly winds; nevertheless, the highest waves are generated under north-westerly winds. The tidal current ellipses are elongated at the measuring location and vary on average between 0.2–0.8 m/s during spring tide and 0.2–0.5 m/s during neap tide at 2 m above the bed. The occurrence of fluffy layers on top of consolidated black and anoxic mud deposits of Holocene age have frequently been observed in Van Veen grab, box core samples and acoustic signals taken at this location (Fettweis et al. 2009; Baeye et al. 2012).

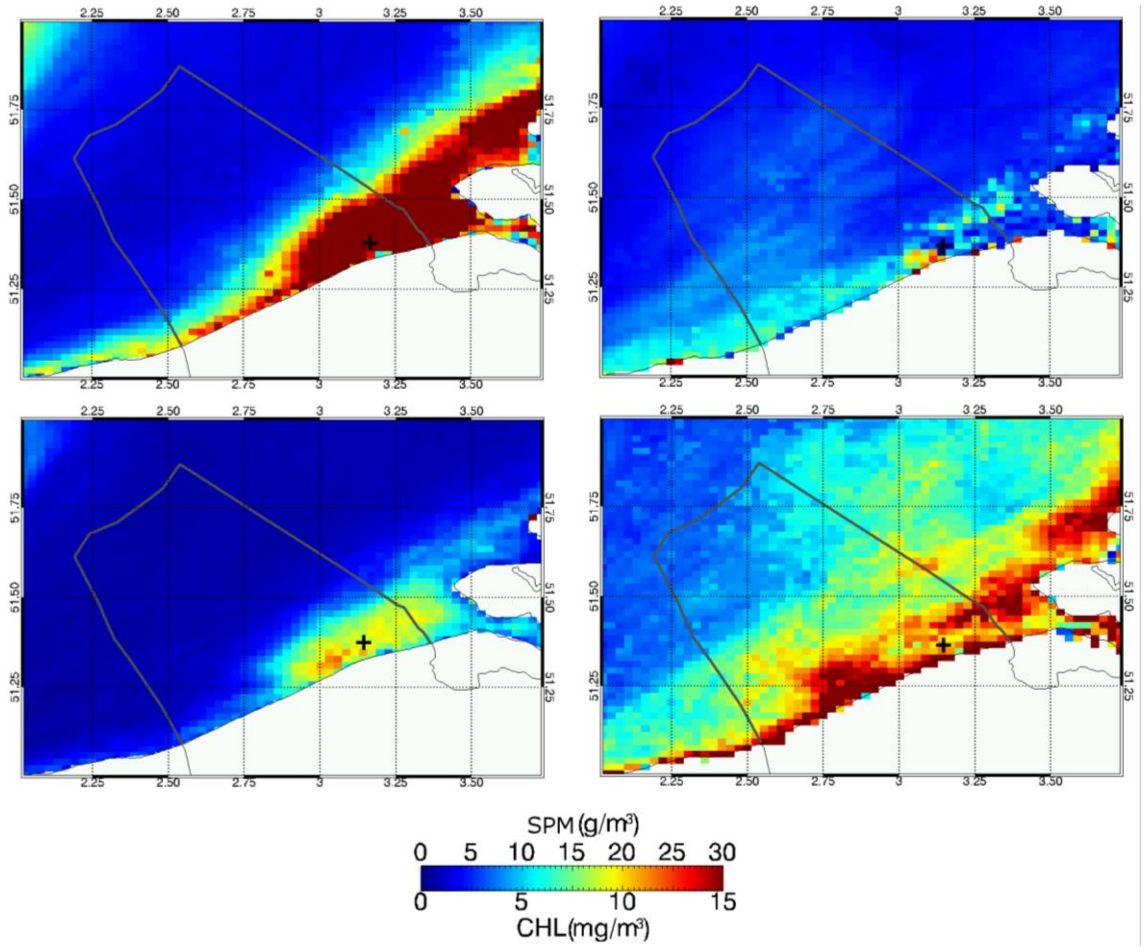


Figure 4.1: The mean surface SPM (left) and Chlorophyll concentration (right) during winter (above) and summer (below) in the Belgian coastal area (southern North Sea). Data are from MERIS satellite. The cross indicates the in situ measuring station MOW1 (from Fettweis et al. 2014).

4.2. Collection of long-term SPM concentration data

In the Belgian nearshore area, close to the port of Zeebrugge, continuous measurements of SPM dynamics are available at MOW1 located about 5 km offshore in the coastal turbidity maximum zone and at a water depth of about 10 m MLLWS, see Figure 4.1. These data together with satellite data have been used to assess the variability of the SPM concentration in the Belgian nearshore area in order to quantify the influence of dredging and disposal operations.

The monitoring station at MOW1 is similar to other observational platforms that have been installed worldwide to capture temporal and spatial variability of the SPM concentration over scales ranging from cm (turbulent regimes) to whole basins (seasonal regimes) using optical and acoustical sensors as well as sensors that give additional information on shape and size of the SPM (see e.g. Butman et al. 1979; Grabemann and Krause 1979; Guézennec et al. 1999; Krivtsov et al. 2008; Badewien et al. 2009, Cartwright et al. 2009; Palinkas et al., 2010; Garel and Ferreira 2011; Nauw et al. 2014; Anastasiou et al. 2015; Fettweis and Baeye 2015; Jalón-Rojas et al. 2015; van der Hout et al. 2015).

The spatial (and temporal) variability of SPM dynamics in the Belgian nearshore area has been investigated using satellite images (see e.g. Pleskachevsky et al. 2005; Fettweis et al. 2007; Eleveld et al. 2008; Pietrzak et al. 2011; Fettweis et al. 2012b; Rivier et al. 2012).

4.2.1 In situ data: Instrumentation and processing

Current velocity, salinity, temperature, SPM concentration and Particle Size Distribution (PSD) were collected with a tripod. The instrumentation suite consisted of a 5 MHz ADVOcean velocimeter, a 3 MHz SonTek Acoustic Doppler Profiler (ADP), two D&A optical backscatter point sensors (OBS3+), a Sea-bird SBE37 CT and a Sequoia Scientific Laser In Situ Scattering and Transmissometer 100-X (type-C). All data (except LISST) were stored in two SonTek Hydra data logging systems. The tripod was moored at the MOW1 location between 3 and 6 weeks and was then recovered and from December 2009 on replaced with a similar tripod system to ensure continuous time series. The OBSs were mounted at 0.2 and 2.3 m above the bed (mab) and the LISST at 2.3 mab. The ADP was downward looking and profiling the lowest 1.8 m of the water column. The ADP and OBS data are more or less equally distributed over the seasons, whereas LISST data are for 80% from winter season due to low bio fouling. The long deployments ensured sampling of conditions that include complete periods of neap and spring tides, seasons, as well as the occurrence of a variety of meteorological events.

Long-term data series of SPM concentration are typically measured indirectly with e.g. sensors that measure the backscatter intensity of light in volt or of sound in dB (Thorne and Hanes 2002; Downing 2006; Rai and Kumar 2015). Conversion of the sensor output to physical units (e.g. mass or volume concentration) results from a ladder of lab, field and data post-processing procedures. It requires direct measurements in the laboratory using calibration against standard turbidity solutions (Amco clear) and in the field using SPM mass concentrations determined through filtration of water samples. OBS readings were converted into SPM concentration by calibration against filtered water samples collected several tidal cycles every year using a robust linear regression model. The ADP profiler was attached at 2.3 mab and down-looking, measuring current and acoustic intensity profiles with a bin resolution of 0.25 m. The backscattered acoustic signal strength was used to estimate SPM concentrations following the approach of Thorne and Hanes (2002). The upper OBS-derived SPM concentration estimates was used to calibrate the ADP's first bin. The echo intensity of the backscattered acoustic signal gives an indication of SPM concentration variation if the particle size distribution and characteristics remain the same. This is often not the case in tidal environments where cohesive and non-cohesive sediments can both be in suspension during high flow velocities (Baeye et al. 2011; Fettweis et al. 2012a).

4.2.2 Remote sensing data and processing

The satellite-based imagery selected for this study was provided by the Medium Resolution Imaging Spectrometer (MERIS) and the Moderate Resolution Imaging Spectroradiometer (MODIS), both providing 1 to 2 daily images over the North Sea area. Oceanographic parameters related to ocean colour, such as the chlorophyll-a (Chl) and SPM concentration were derived from the water leaving reflectance in specific spectral bands. Chl concentration was estimated using the MERIS case 2 algorithm (see Doerffer and Schiller 2006). Remotely sensed SPM concentration is estimated from water leaving reflectance at 667 nm using the generic multi-sensor algorithm of Nechad et al. (2010).

4.3 Flocculation influences SPM concentration

4.3.1 Multimodality of SPM flocs size distribution

Cohesive sediments change size, density and thus settling velocity through flocculation (Eisma 1986). The relationship between floc diameter, SPM concentration and shear stress (Dyer 1989) shows that turbulent flow is needed to enhance particle aggregation and to increase the size and settling velocity of the flocs. At very low turbulences aggregation hardly occurs and at too high turbulences floc breakage is enhanced, resulting in a decrease in size and settling velocity of the flocs. The large flocs that occur during slack water will quickly settle, increase the near-bed SPM concentration and form lutoclines that separates the water column with generally lower SPM concentration from the fluffy layers (Mehta 1984; Winterwerp 2002; Becker et al. 2013). Flocculation of fine-grained sediments also develops a multimodal particle size distribution (PSD) consisting of a four-level ordered conceptual structure, namely, primary particles, flocculi, microflocs and macroflocs (Figure 4.2).

Primary particles consist of fine particles with a wide size range of 0.25 - 2.5 µm, including clay minerals, organic and calcareous particles, picophytoplankton and heterotrophic bacteria (Andrews et al., 2010). Flocculi consist of strongly bound clay minerals with a size range of 10 - 20 µm. Microflocs consist of flocculi and partly of primary particles with a size range of 50 - 200 µm. Macroflocs are built up with microflocs and partly with primary particles and flocculi, and have a size range of hundreds to

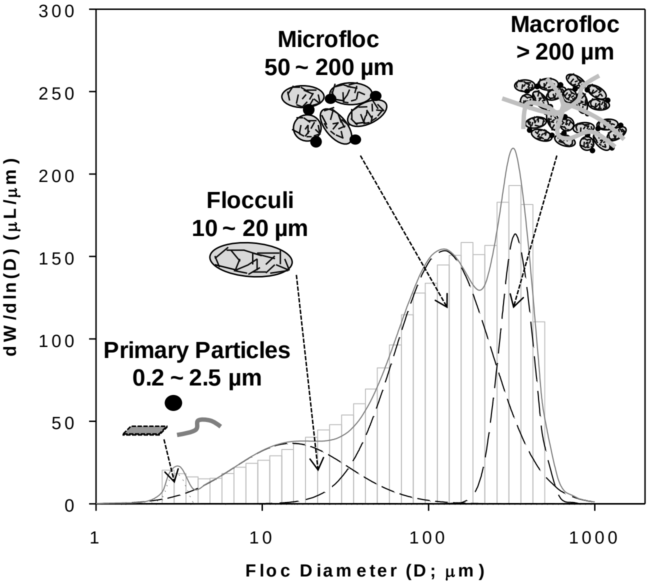


Figure 4.2: A multimodal PSD and schematic diagrams of the discrete aggregate groups of primary particles, flocculi, microflocs and macroflocs (from Lee et al. 2012).

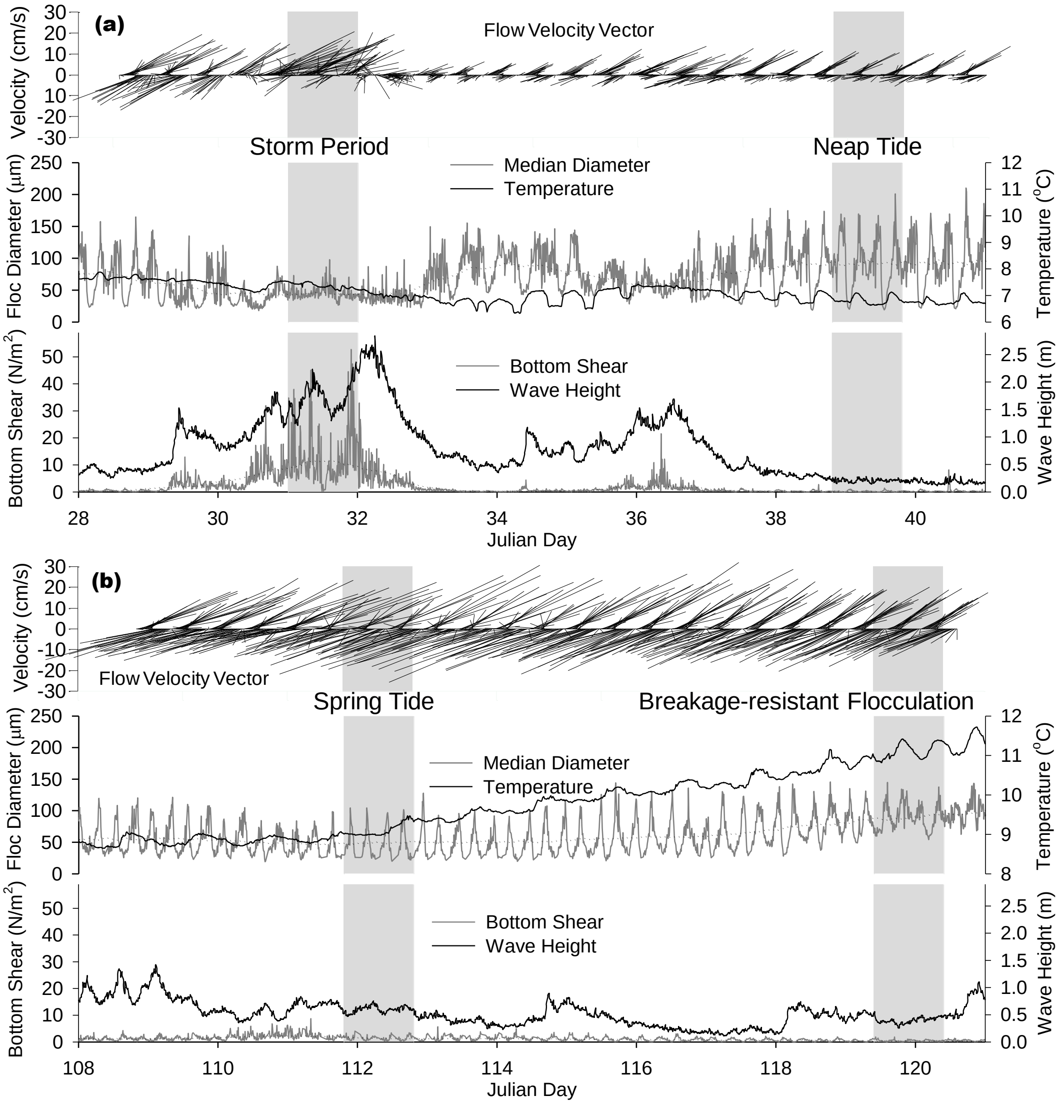


Figure 4.3: A time series of the flow velocity vector, median floc diameter (D_{50}), turbulent shear (τ) and temperature (^{o}C) collected in the Belgian nearshore area (Blankenberg site) during the (a) 28/01/2008 - 11/02/2008 and (b) 15/04/2008 – 05/06/2008. The dotted lines show the smoothed curves with the moving averages of seventy data points. The shaded area represents a tidal cycle with specific flow condition and flocculation behaviour (from Lee et al. 2012).

thousands of micrometres. In fact, primary particles, flocculi, microflocs, and macroflocs are highly interactive under flocculation and transport and alternately raise or sink their peaks in a multimodal PSD in a flow-varying tidal cycle of a coastal zone (Manning and Bass 2006; Mikkelsen et al. 2006). A time-varying multimodal PSD constitutes a scientific record of flocculation and transport of the constituent particles and aggregates in a coastal zone. Understanding the possible causes of a multimodal PSD, one can use a time series of multimodal PSDs to investigate the particle and aggregate dynamics in a coastal zone as shown in Figure 4.3, see Lee et al. (2012) for more detailed informations.

Curve-fitting software was used to decompose the multimodal PSD to the subordinate log-normal PSDs of primary particles, flocculi, microflocs and macroflocs. The new curve fitting analysis allowed us to decompose multimodal PSDs to the subordinate unimodal log-normal PSDs and to investigate a time series of the multimodal PSDs in a qualitative and quantitative way. Results from the curve fitting analysis for a time series of multimodal PSDs agree with the general flocculation theory in that shear-dependent flocculation was a main contributor to the changing multimodality of a PSD of suspended particulate matter in the Belgian nearshore area. The PSDs at low turbulent shear skewed toward large size with a large volume fraction of aggregates in an aggregation-dominant condition, whereas the PSDs at high turbulent shear skewed toward small size with a large volume fraction of building blocks in a breakage-dominant condition. The results further revealed an important finding that flocculation became breakage-resistant against turbulent shear in the spring season. Breakage-resistant flocculation, which concurred with a temperature and light rise, was presumably caused by biologically mediated flocculation associated with the spring phytoplankton bloom. In order to support these findings, the measurement data at MOW1 were systematically analysed (see § 4.3.2) and a biological flocculation model based on the bimodal model of Lee et al. (2011, 2014) is in development as well as the implementation of new measuring scheme to identify the concentration of transparent exopolymeric particles (TEP) in the Belgian nearshore area that are thought to be responsible for the increase of floc strength.

4.3.2 Seasonality of SPM concentration is caused by flocculation

The suspended particulate matter (SPM) concentration in the high turbidity zones of the southern North Sea is inversely correlated with chlorophyll (Chl) concentration. During winter SPM concentration is high and Chl concentration low and vice versa during summer. This seasonality has often been associated with the seasonal pattern in wind forcing. However, the decrease in SPM concentration corresponds well with the spring algal bloom (see Figure 4.1 and 4.5). Despite the improved understanding of flocculation dynamics and their interaction with turbulence and bio-mineralogical composition, our knowledge is still insufficient to describe the impact of high primary production in spring and summer on floc sizes that induce changes in settling, formation of high concentration mud suspensions and resuspension of fine-grained sediments, as is mentioned in Figure 4.3. SPM dynamics are controlled by flocculation, which influences the size and deposition rate of the SPM. Flocculation depends on the turbulent intensity (tides, wind, waves) and on the surface properties of the suspended particles, which are of electrochemical or microbial origin (Mietta et al. 2009). Microbial products, such as TEPs, are released by algae and bacteria and influence aggregation (Logan et al., 1995; Engel, 2000). Chl concentration, wind velocity and wave height all have a seasonal signal. Below we will briefly discuss to what extent the seasonality in SPM concentration as observed at MOW1 during 2011 is controlled by changes in flocculation due to physical and biological effects, see Fettweis et al. (2014) and Fettweis and Baeye (2015) for a more elaborated discussion.

Physical controls

The geometric mean SPM concentration at MOW1 increased from 357 mg/l (117 mg/l) during summer towards 431 mg/l (145 mg/l) during winter at 0.2 mab (2 mab). As tidal forcing is approximately equal during both seasons we will focus on meteorological conditions as a potential driving force of seasonality. The data indicate that the differences in wind direction and strength between the seasons are small. Similar results have been obtained for the waves (Fettweis et al. 2014). The influence of waves is significant: the geometric mean SPM concentration was 64 mg/l (145 mg/l) lower during calm conditions than during stormy periods in winter (summer). The effects of the storm extend a certain period after the storm. The duration of storm influence depends on wind direction, wind strength and wave height and can last up to a few days after the storm. The influence period is longer when waves are higher as more sediment have been resuspended or fluidized. Influence of storms is mainly detected in the near bed layer and decreases towards the surface. Storms with wave heights of more than 2 m affect the SPM concentration for a period of about 5 days after the storm. Storms with significant wave heights above 2 m occurred once during summer and nine times during winter. The total duration of these high wave events was 0.1 days (summer) and 4.3 days (winter). 2.8 days of winter storms occurred during LISST measurements. Higher SPM concentration due to these meteorological conditions influenced the signal over a period of about 14 days. This represents 10% of the measurements in winter. It does not, however, explain the 20% higher SPM mass concentration and the 50% higher SPM volume concentration near the bed or the 100% higher SPM mass concentration in the surface during winter.

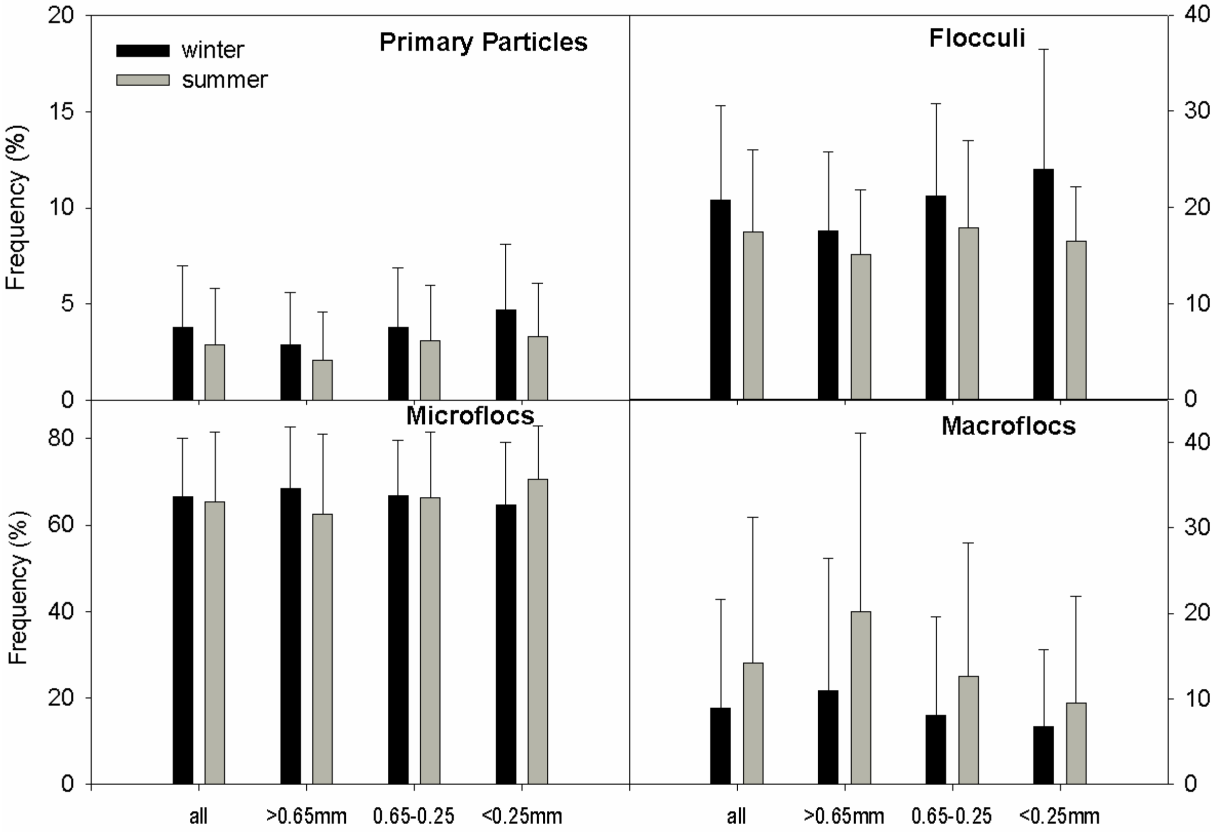


Figure 4.4: Frequency of primary particles, flocculi, microflocs and macroflocs for the summer and winter season and according to Kolmogorov scale (λ_k); λ_k<0.25 mm and λ_k>0.65 mm are the 15th and 85th percentiles at MOW1. The geometric mean size of the microflocs is 66 ± 24 µm (winter) and 73 ± 21 µm (summer), and for the macroflocs 222 ± 44 µm (winter) and 220 ± 44 µm (summer). Primary particles and flocculi have constant size of 3 µm and 15 µm respectively (from Fettweis et al. 2014).

Biological controls

Based on the decomposition of the measured PSD into four subordinate log-normal functions it was found, despite the seasonal signal in median floc size (D50-summer: 64 µm, D50-winter: 51 µm), that the sizes of macroflocs only show small variations during seasons (summer: 220 µm, winter: 222 µm). The frequency of macroflocs, however, has a seasonal signal. Macroflocs are more abundant in the SPM in summer than winter regardless of the turbulence intensity (Figure 4.4). The rate of breakup of large flocs and the equilibrium size of flocs in turbulent flow depend on their strength (Kranenburg 1999; Winterwerp 2002). Our observations of PSDs suggest that the maximum size is mainly controlled by the intensity of turbulence and the flocculation time. The tidal current ellipses are elongated at the measuring site and time available for floc formation is limited to the short periods of slack water (current velocity below 0.2 m/s at 1.8 m above the bed last on average 45 minutes at the measuring location), which are not sufficient for the flocs to attain their equilibrium size. If the abundance of macroflocs as a function of turbulence intensity is a proxy of floc strength then Figure 4.4

shows that flocs in summer are stronger than in winter. The stronger flocs resist shear-induced break-up and the higher proportion of large flocs results in a higher settling rate during summer and thus a lower SPM concentration. Only during storms (wave height > 2 m) in summer did a significant break-up of the larger flocs into smaller particles occur. The higher frequency of macroflocs in summer is compensated by lower frequencies of primary particles and flocculi. The size and frequency of the microfloc population in the PSDs has almost no seasonal signal (Figure 4.4).

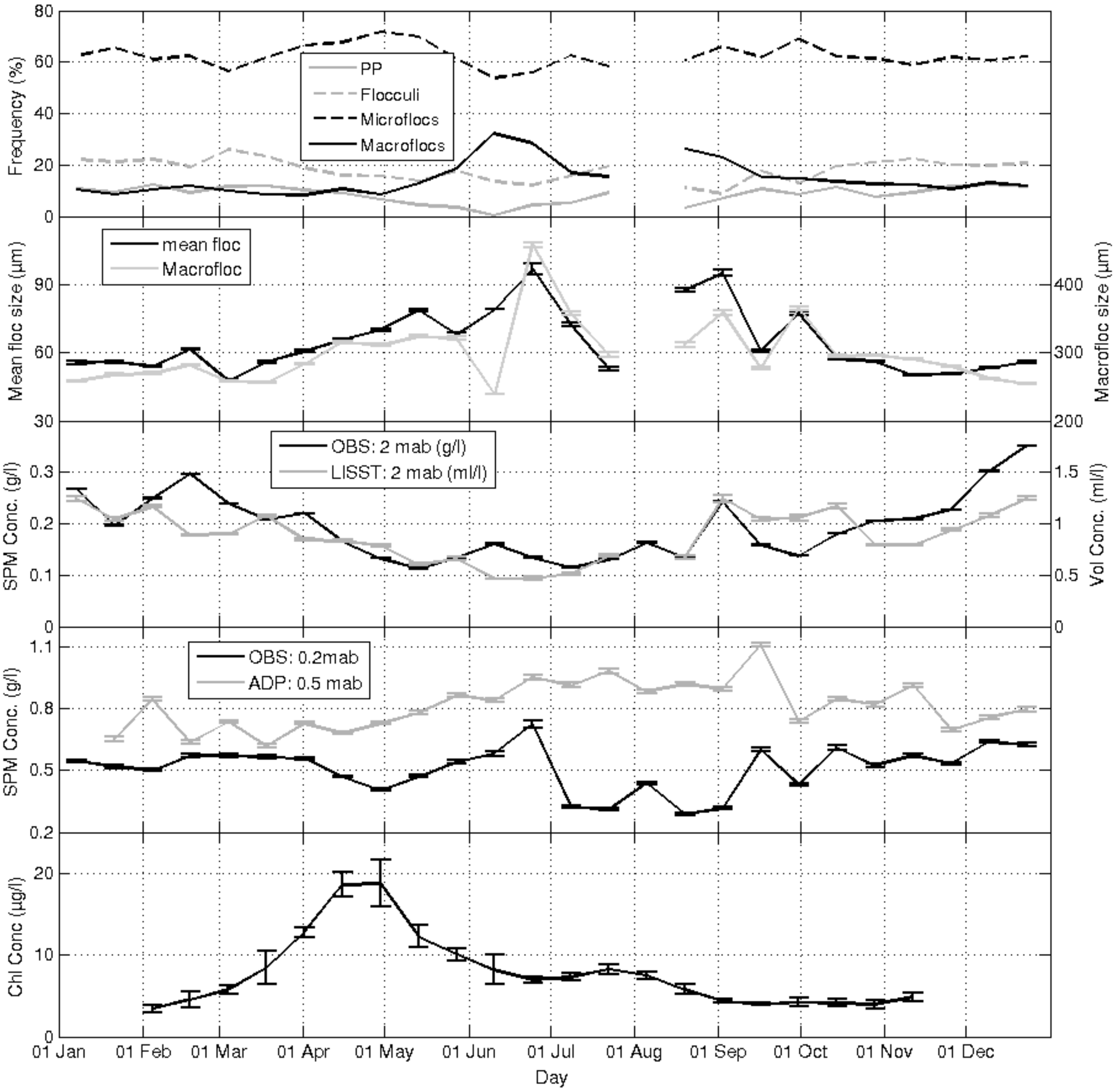


Figure 4.5: Two weekly averaged frequencies of primary particles, flocculi, microflocs and macroflocs; mean and macrofloc size; SPM mass (OBS) and volume (LISST) concentration at 2 mab; SPM mass (OBS and ADP) concentration near the bed; and surface chlorophyll concentration at MOW1. The Chl concentrations are from MERIS satellite and cover the period 2003-2011, the other data are from the period 2005-2013. The error bars are standard errors (from Fettweis and Baeye 2015).

Discussion

Floc size and settling velocities have been evaluated as a function of sea state characterized by the low pass filtered Kolmogorov length scale. The results show that the seasonality in floc size and settling velocity is only partially influenced by calm or stormy weather as the floc sizes remain higher in summer under various physical conditions. Erosion of larger particles from the sea bed during storms, is therefore of minor importance to explain the seasonality at 2 m above the sea bed. Bio-mediated flocculation is caused by the presence of Transparent Extracellular Polymers (TEPs) that are released by algae and bacteria (Logan et al. 1995; Engel 2000; Passow 2002).

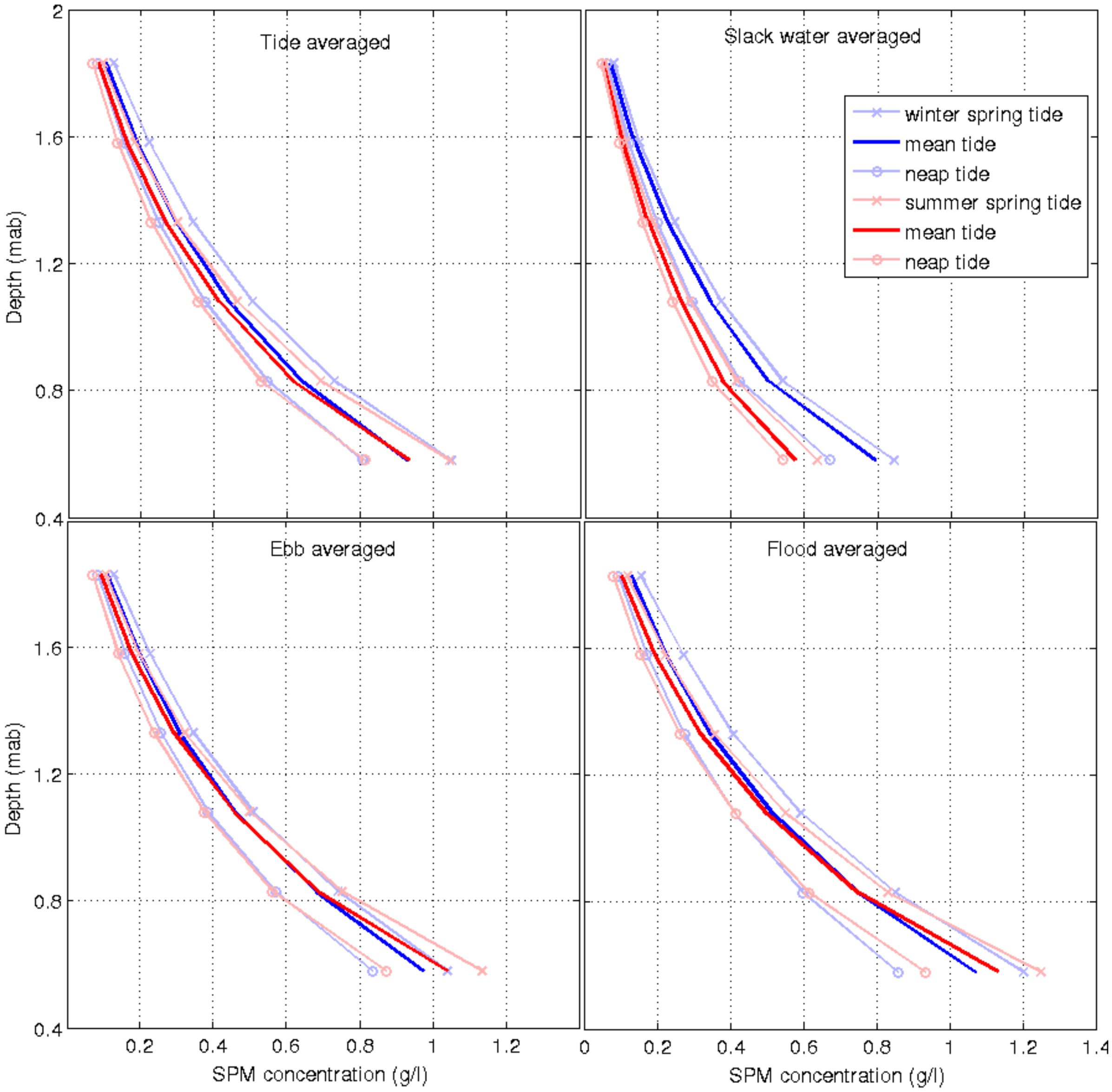


Figure 4.6: Ensemble averaged ADP backscatter derived SPM concentration profiles of the lowest 2 m of the water column at MOW1 averaged over a tidal cycle, slack water, ebb and flood in winter and summer and for different tidal ranges (from Fettweis and Baeye 2015).

The gluing capacity of these microbial exudates is known to enhance the building of organic-rich macroflocs (Chen et al. 2005; Droppo et al. 2005). The phytoplankton bloom starts in early spring with a diatom bloom and shifts towards a phaeocystis bloom in April and May at the measuring location (Lancelot et al., 1987). Floc sizes show a significant increase in spring, followed by a decrease in July and again an increase in August and September (Figure 4.5). The decrease in July is possibly linked with the decrease of diatoms and phaeocystis concentrations, and hence TEP concentration, due to a shortage in nutrients and an increase in predation pressure by heterotrophic plankton species (Rousseau et al. 2002). Highest floc sizes are observed end of June and end of August, thus after the spring and summer blooms. Although the summer bloom is less pronounced, it results in Chl, heterotrophic bacteria and zooplankton concentration levels (Lancelot et al. 2005) that are able to maintain high TEP concentration that generates these high floc sizes. These periods correspond with lower SPM concentrations in the water column, higher near bed SPM concentrations and higher frequencies of macroflocs. Our results suggest that floc size controls settling and deposition and thus sediment dynamics. This is also reflected in the near bed profiles of SPM concentration as derived from the ADP backscatter, see Figure 4.6. These profiles show the non-linear increase in SPM concentration towards the bed, but they also show that the SPM concentration at 1.8 mab is lower during summer whereas the seasonal differences are smaller at 0.5 mab or even reversed (summer is higher during ebb and flood). TEPs and other bio-stabilizators reduce erosion and resuspension of mud deposits (Droppo et al. 2001; Black et al. 2002; Gerbersdorf et al. 2008; Maerz and Wirtz 2009). Therefore, during summer a larger part of the cohesive sediments is kept in a high concentration mud suspension (HCMS), fluid mud or consolidated bed layer. The presence of HCMS or fluid mud results in a reduction of the bottom shear stress and thus a decrease of erosion. In winter the strength of the deposits decreases, due to lower TEP concentrations flocs are getting less strong and therefore are more easily resuspended, resulting in higher SPM concentrations. The occurrence of fluffy layers of 0.05-0.10 m thickness has frequently been observed in bed samples from the measuring location. This is also confirmed by the ADV altimetry signal, which recorded variation in bed level occurring during a tidal cycle up to 20 cm.

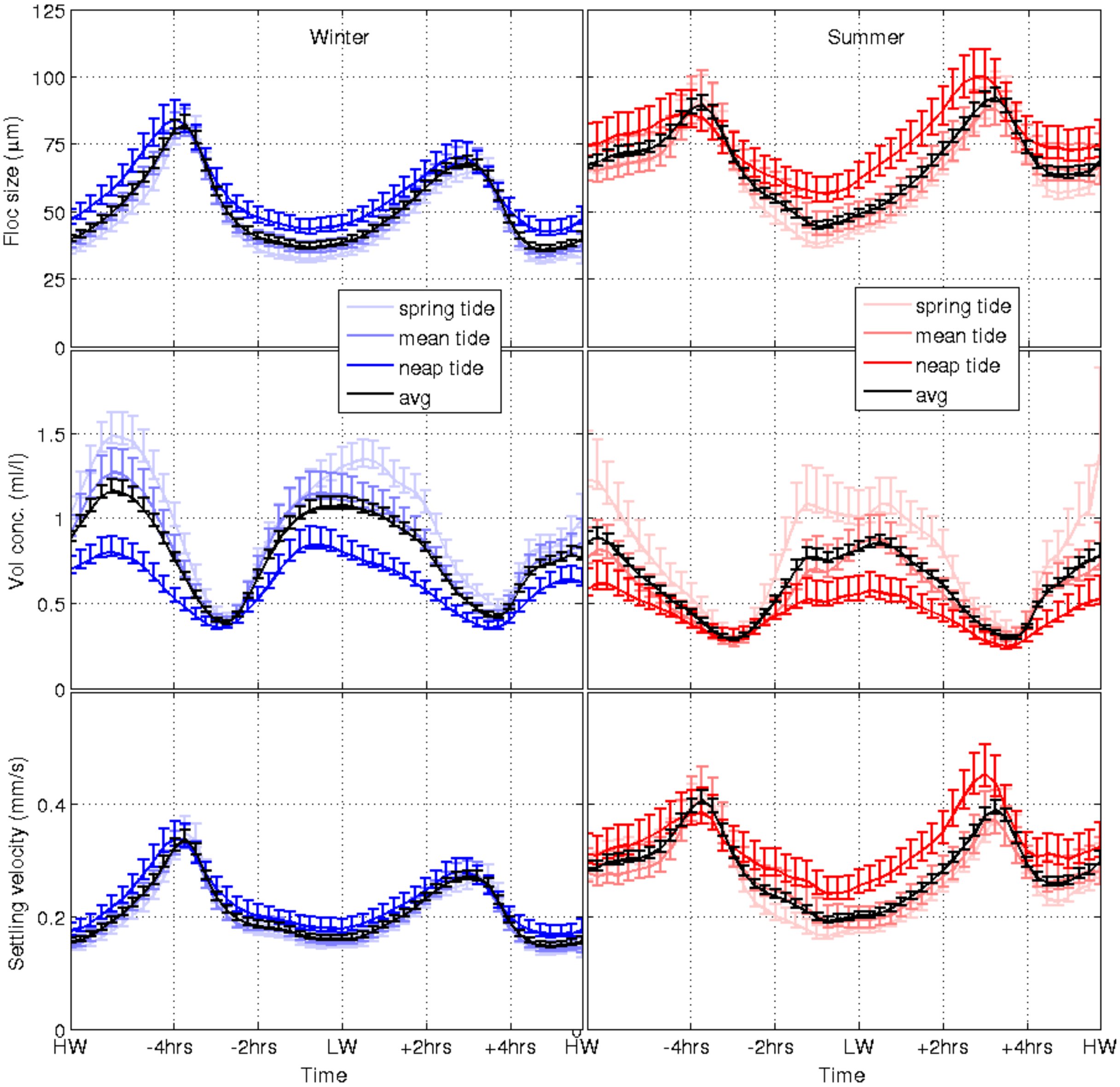


Figure 4.7: Ensemble averaged geometric mean floc size (µm), volume concentration (ml/l) and settling velocity (mm/s) at 2.0 mab during a tidal cycle in winter (left) and summer (right) (black line) and for different tidal ranges at MOW1. The error bars are standard errors (from Fettweis and Baeye 2015).

The geometric mean floc size, the SPM volume concentration and the settling velocity at 2 mab during winter and summer season and for different tidal ranges are shown in Figure 4.7. The figure shows that seasonal differences are more pronounced for floc size and settling velocity than SPM volume concentrations. The SPM volume concentration is generally higher in winter than in summer. This corresponds with the SPM mass concentration recorded at 1.8 mab by the ADP and at 2 mab by the OBS. The geometric mean floc size is on average higher in summer than winter. The largest floc sizes occur during slack water and the smallest during peak ebb and flood currents. The course of floc size during a tidal cycle in summer differs somewhat from its course in winter. E.g. the floc sizes during flood in summer are higher than during ebb, which is not the case in winter. Similarly, the floc sizes in winter during ebb-flood slack water (3 hours before HW) are smaller than the floc sizes during flood-ebb slack water (3 hours after HW); during summer the differences are less pronounced except for the smallest and largest tidal ranges. The settling velocities are between 0.18 and 0.35 mm/s in winter and 0.18 and 0.45 mm/s in summer. Note that the settling velocities in summer are larger during whole the tidal cycle. The difference in settling velocity between winter and summer is significant when no seasonal variation in fractal dimensions is assumed; summer settling velocities are then on average 35% higher than winter ones. In order to take into account effects of organic matter enrichment on the density of macroflocs in summer, the fractal dimension of the macroflocs was changed from 2.1 to 2.0. Although this corresponds to about 50% reduction in effective density of the macroflocs and 0.03 mm/s reduction of the summer mean settling velocity (0.28 to 0.25 mm/s), the mean settling velocities are still about 20% higher in summer.

The larger floc sizes in summer are caused by higher frequency of macroflocs and larger sizes of micro- and macroflocs in summer than in winter. The shift from microflocs to macroflocs during low turbulence periods in summer reflects physical changes in flocculation type, from turbulence mediated flocculation in winter towards an additional biological mediated flocculation in summer. The data indicate that larger flocs are formed during slack water in summer through aggregation of microflocs and that during periods with high turbulent shear the flocs break up in microflocs, flocculi and primary particles. In winter we observe that the floc population consists mainly of microflocs that have been formed through aggregation of flocculi and primary particles. When turbulent shear increases again then the microflocs disintegrate into their next smaller constituents. The link with biological activity is shown in Figure 4.5, where the over 14 days averaged frequencies of the four aggregate groups of the flocs, floc sizes, SPM volume and mass concentration, and surface Chl concentrations are shown for the period 2005-2013. The Chl concentration increases during spring algae bloom in April and during a second bloom in July.

The long-term data series of SPM concentration, floc size and settling velocity show a distinct seasonal signal. During summer the SPM concentration is higher in the near-bed, but lower higher up in the water column; during winter the opposite is found. The floc size and settling velocity have an opposite seasonality: smaller flocs and thus settling velocities occur in winter and larger flocs and settling velocities in summer. Physical drivers such as wave heights and alongshore residual transports, have a much weaker correlation with the observed seasonality. The seasonality in floc size and thus settling velocity is mainly the result of biological effects that enhances the size of the marine muddy flocs in summer. The results indicate that the SPM, or at least a significant part of it, stays in the area during summer and winter. In summer the SPM is more concentrated in the near bed layer, whereas in winter the SPM is better mixed throughout the water column. The lower SPM concentrations in the water column during summer are thus compensated by higher near bed SPM concentrations and possibly by a higher probability of occurrence of lutoclines.

4.4 Geographical variability of SPM concentration

Meteorological patterns, acting on regional and global scales, are responsible for wave induced resuspension and determine the advection of water masses. Changes in wind pattern and strength will therefore influence SPM concentration in a larger area. Climatological effects are linked to the frequency of occurrence of certain weather patterns, e.g. the North Atlantic Oscillation (NAO) is responsible for much of the observed weather and climate variability in the North Sea, especially during winter months (Hurrel 1995; Schwiers et al. 2006). The meteorology of the southern North Sea is characterized by the west to east passage of depressions, and by the development or weakening of high pressure systems. These fluctuations of the wind field occur at time scales of a few days to one week, whereas the climate variability acts on seasonal and longer time-scales. The winter NAO exhibits significant multi-decadal variability with positive values indicating anomalously strong westerly winds and wet conditions over north-western Europe; whereas negative values indicate weaker westerly flow, less precipitation and intrusion of colder arctic air (Hurrel 1995). The use of atmospheric circulation patterns to describe different situations has proven to be very useful in meteorological and climate change studies (Demuzere et al. 2009; Ullman and Monbaliu 2010). For the North Sea region, spatial and temporal changes of weather pattern strongly influence the climatic conditions and the hydrodynamic circulation patterns. The analysis is based on weather types to produce ensemble averages of SPM concentrations maps from satellite and in situ measurements as well as current velocity from numerical model results for typical meteorological and climatological conditions. In total 11 weather types have been used, consisting of 2 pure vorticity types (Anticyclonic, Cyclonic), 8 directional types (N, NE, E, SE, S, SW, W, NW) and an unclassified type (U). Furthermore, climatological impact has been investigated using the NAO indices in order to classify the winter SPM concentration maps, see Fettweis et al. (2012b) for more details.

4.4.1 Meteorological induced pattern of SPM concentration

The southern North Sea, with stronger tidal currents and shallower water, has higher SPM concentrations than the northern North Sea. The most important high turbidity areas are the Belgian Dutch Coastal zone; the Thames plume extending eastward into the East-Anglian plume; the Humber coast and the Wadden Sea, see Figure 4.8. The difference between the mean surface SPM concentration are shown for per weather type and the yearly average data is shown in Figures 4.9 (pure weather types) and 4.10 (directional weather types) together with the residual surface currents during the corresponding weather type. Differences in SPM concentration between the 11 weather types and the yearly average data occur on regional and local scale. They can be related to changes in advection and resuspension.

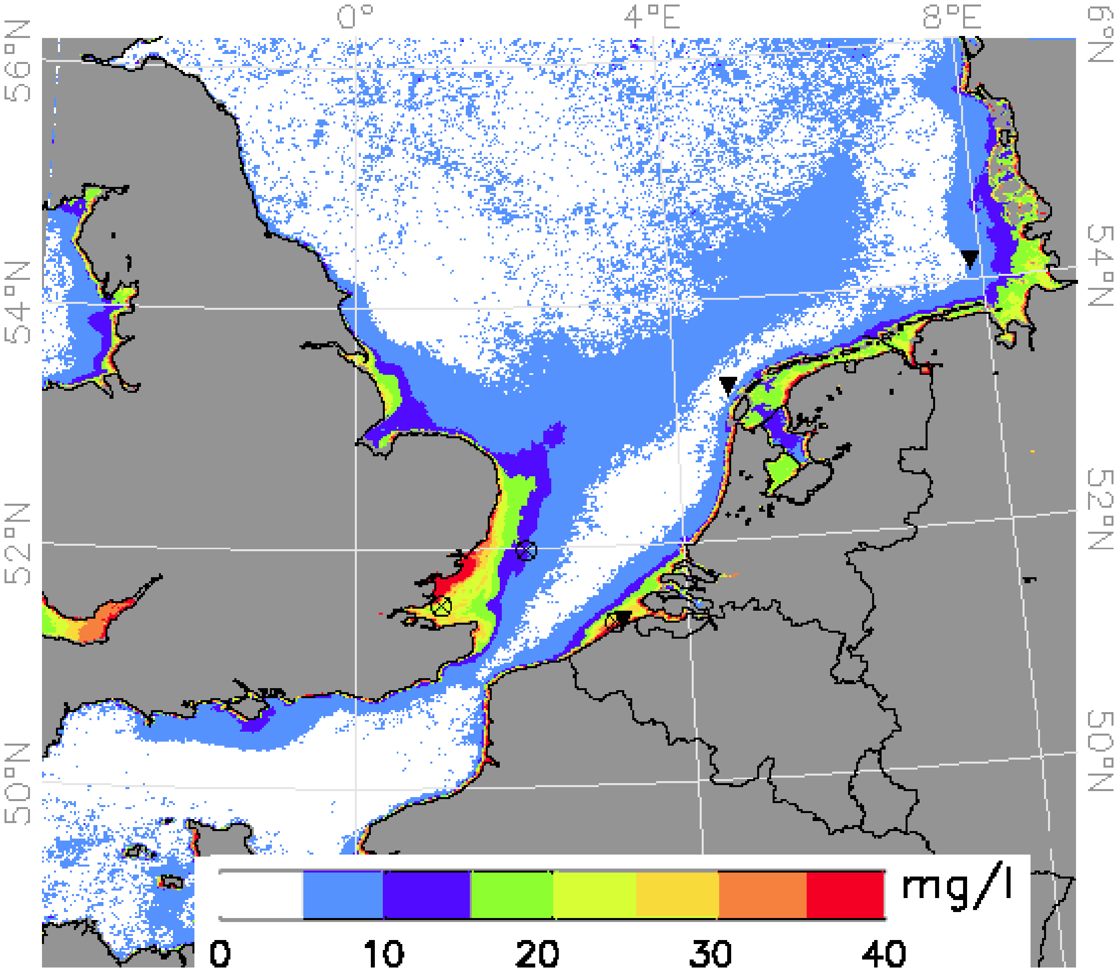


Figure 4.8: Mean SPM concentration (mg/l) for 2002-2009 derived from MODIS data. Triangles indicate wave rider buoys at Bol van Heist (51.38°N, 3.21°E), Eierlandse Gat (53.28°N, 4.66°E) and Helgoland (54.16°N, 7.87°E); the crosses show the in situ SPM concentration measurement stations Warp Anchorage (51.53°N, 1.03°E), West Gabbard (51.98°N, 2.08°E) and MOW1 (51.36°N, 3.11°E) (from Fettweis et al. 2012b).

Weather type U has generally a lower and weather type S a globally (slightly) higher surface SPM concentration compared with the average situation. This is mainly caused by seasonal effects, with U more frequent during the low surface SPM concentration spring-summer season and S more frequent during the high surface SPM concentration autumn-winter season. The low significant wave heights during both weather types indicate that the patterns are caused by mainly tidal forcing. Weather type A is the most frequently occurring; it is almost equally distributed throughout the year and reflects thus nearly the average situation. The other weather types all exhibit regional and local changes with no global trends that can be attributed to resuspension and advection processes. The SPM concentration maps confirm that changes in weather type affect the distribution of surface SPM concentration in the North Sea as they have an influence on hydrodynamics, and consequently on the transport and resuspension of cohesive sediments. Furthermore significant differences in behaviour exist between the high turbidity areas, which can be linked to advection and/or resuspension events. Resuspension depends on the water depth and the wave height. As the waves are higher along the Dutch coast and the German Bight than in the southern Bight and as water depth is similar (10-20m), resuspension will be more important in these areas than in the Southern Bight.

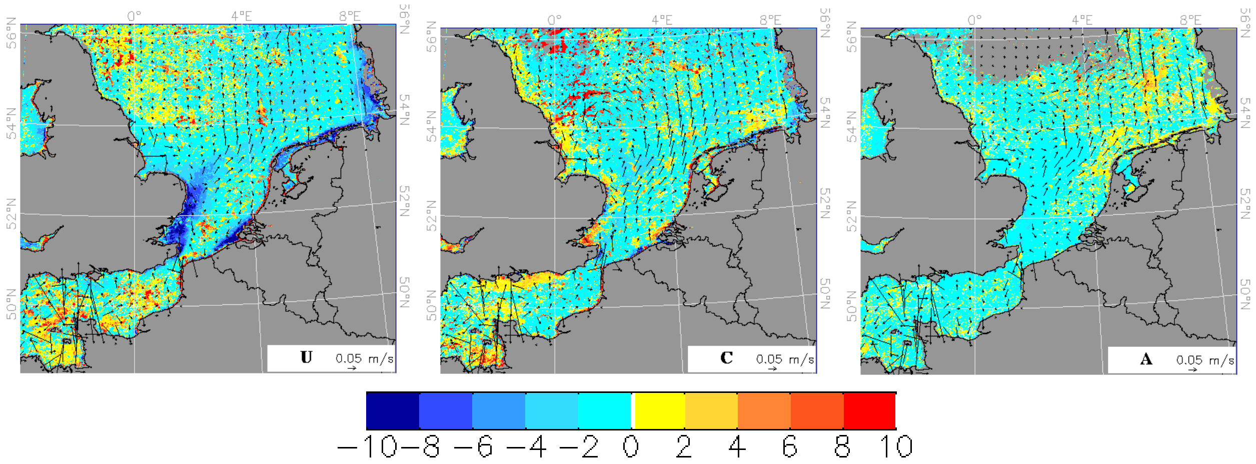


Figure 4.9: Difference between mean SPM concentration according to pure weather types (U, C, A) and yearly average data (negative values: lower than, positive values higher than yearly average values; the arrows are the residual current vectors) (from Fettweis et al. 2012b).

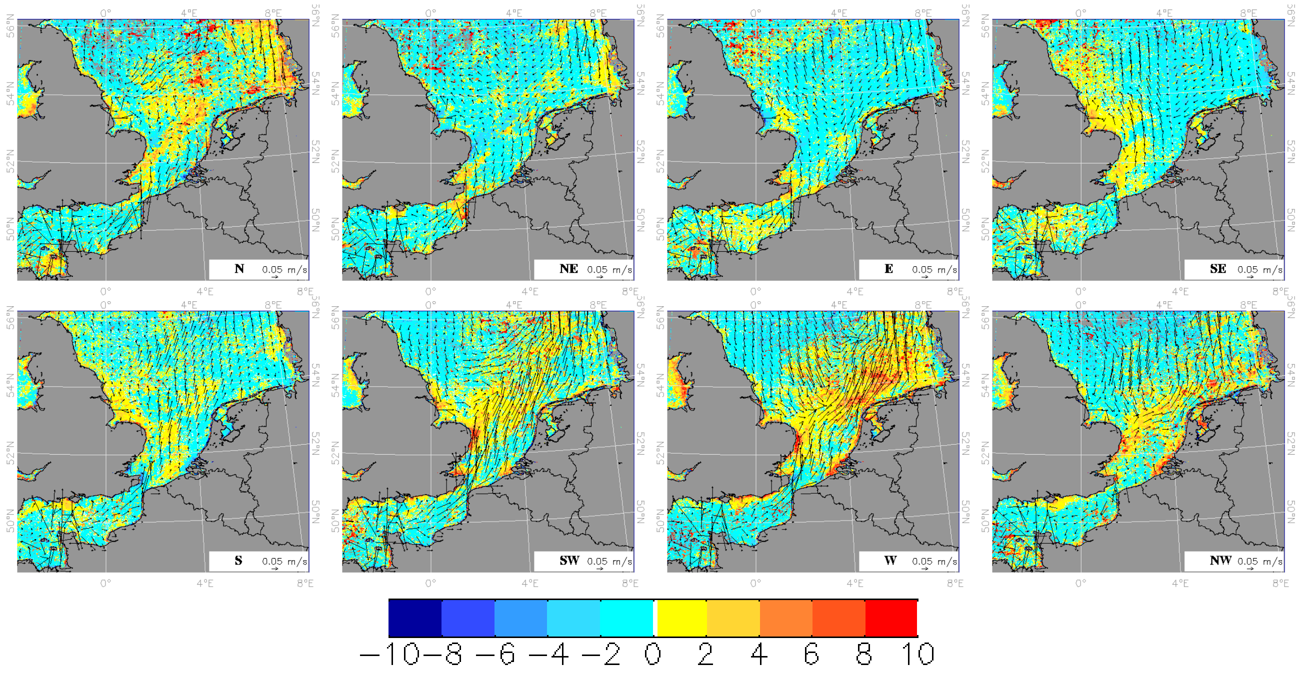


Figure 4.10: Difference between mean SPM concentration according to directional weather types (N, NE, E, SE, S, SW, W, NW) and yearly average data (negative values: lower than, positive values: higher than yearly average values; the arrows are the residual current vectors) (from Fettweis et al. 2012b).

The residual currents per weather type are an indication of the advection of SPM in the surface layer. We see that significant differences occur in magnitude and direction depending on weather type. The advection is generally southwest to westward during weather types N, NE and E. The opposite occurs for weather types C, E, S, SW, W and NW. Towards the coastline current ellipses are more elongated and residual flow is dominated by alongshore flow and the direction of the flow can locally be different from the general residual circulation.

The higher than average SPM concentrations observed in the East Anglian plume, Thames and/or the German Bight during weather types NE, N, NW, W and SW correlate well with the higher significant wave heights during these weather types and are thus the result of mainly local resuspension, as confirmed by Pleskachevsky et al. (2005) and Pietrzak et al. (2011). Locally differences can be seen during these weather types that are linked to a stronger influence of advection especially around Dover, along the Belgian-Dutch and North Frisian coast. The high turbidity around Dover and along the Belgian-Dutch coast for example, has shifted towards the northeast during weather types SW and W whereas during weather types NE and E the opposite occurs with generally higher concentrations towards the southwest. This has been correlated with the occurrence of an increased subtidal alongshore flow towards the northeast induced by the wind patterns (Baeye et al. 2011).

The shear stresses due to waves during the other directional weather types (E, SE, and S) are low and the changes in SPM concentration relative to the yearly average situation are thus not caused by significant resuspension events. Wave height is relatively high in the Southern Bight as compared to the German Bight for weather type NE; this together with the south-westward directed subtidal alongshore currents explains the enhanced SPM concentration in the Strait of Dover. We observe a general decrease in SPM concentration in the North Sea during weather types E and SE, except in the Strait of Dover. These two weather types have no typical seasonal signal, and as a consequence the pattern is explained by a low resuspension of fine-grained sediments in the North Sea, whereas the increase in the Strait of Dover area is caused by advection of SPM towards the English Channel.

4.4.2 Climate induced patterns of SPM concentration

The NAO exerts a dominant influence on the distribution of wintertime SPM concentration as shown in Figure 4.11. The difference between both situations shows that during winters with negative NAO index the SPM concentration is on average higher in the Strait of Dover and the Belgian-French and English coastal areas. During a winter with positive NAO index, higher SPM concentrations are found in the German Bight, the central North Sea and along the Dutch coast (except West Frisian coast). Positive NAO winters are associated with higher frequency of SW winds, generally higher waves and an enhanced north-eastward directed residual water transport. The observed differences between both winter situations are thus explained by a combination of transport of SPM out of the Southern Bight and local resuspension due to higher waves in the rest of the North Sea.

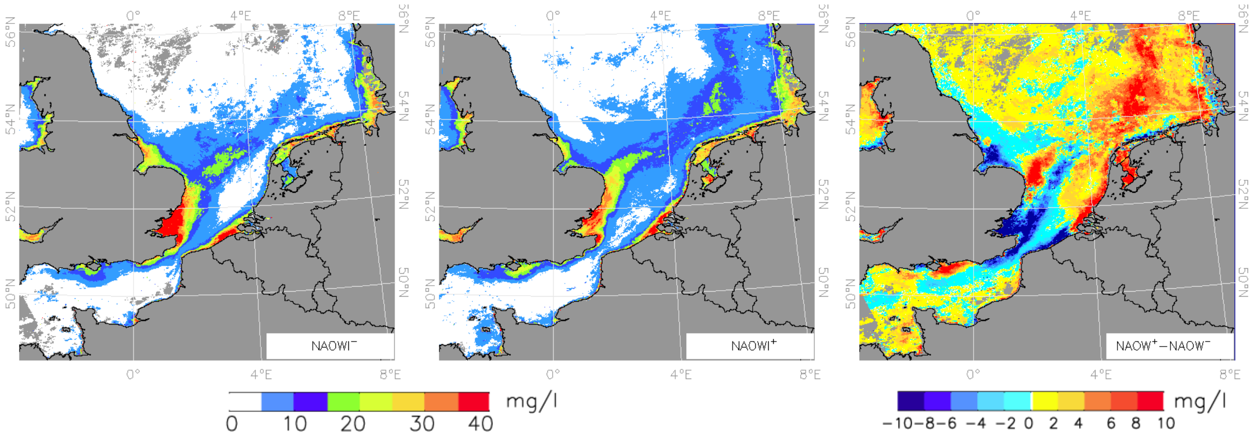


Figure 4.11: Mean SPM concentration according to NAO index. Winter 2006 with strong positive NAO index (left); winter 2007 with strong negative NAO index (middle) and the difference between NAOWI- and NAOWI+ SPM concentration maps (negative values: higher in NAOWI+; positive values: higher during NAOWI-) (from Fettweis et al. 2012b).

4.5 Time variability of SPM concentration

On short time scales, the predominant forces that cause variations in SPM concentrations are related to tides, waves and meteorological conditions. On longer time scales neap–spring cycles, climate and seasonal variations are significant. These forcing's have an influence on the horizontal and vertical distribution of the SPM in the water column (Mehta 1991; Wan et al. 2014). In order to investigate these time variations a classification of the data has been carried out. To every tidal cycle classification, parameters were assigned that take into account seasons, tidal range, alongshore current, and the significant wave height. Each tidal cycle starts at high water (HW). The tidal cycles of each class were then ensemble averaged. The tidal range was calculated from the harmonic tidal signal and then grouped according to the P66 (3.95 m) and P33 (3.31 m) percentiles into a spring tide (SP, >P66), mean tide (MT, P66-P33), and neap tide (NT, <P33). The influence of weather systems on SPM concentration was investigated by grouping the tidal cycles according to the residual alongshore flow and the significant wave height.

The SPM mass concentrations during winter and summer season, different tidal ranges, residual alongshore flow and wave condition is shown in Figures 4.12. The SPM concentration varies typically with ebb-flood and with tidal range. The ensemble averages indicate that the mean SPM concentration at 0.2 mab during summer (winter) is about 13% lower (higher) than the mean SPM concentration during the whole year. The seasonal difference is more pronounced at 2 mab where the difference with the mean during the whole year is ±25%. The tidal averaged SPM concentration at 0.2 and 2 mab during winter spring (neap) tide increases (decreases) by about 25% with respect to the tidal averaged SPM concentration during all tides in winter. During a NE-ward directed residual alongshore current (P10) in winter the tidal averaged SPM concentration decreases by 20% at 0.2 mab and 13% at 2 mab, with respect to the tidal averaged SPM concentration in winter. During SW-ward directed residual alongshore current (P90) the values are almost equal to the tidal averaged SPM concentration in winter. Low (high) wave conditions result in a decrease (increase) of the tidal averaged SPM concentration by 9% (16%) at 0.2 mab and by 8% (11%) at 2 mab. The results show that high waves and negative residual alongshore flow direction induce the highest variations near the bed (0.2 mab), whereas seasonal effects are more pronounced higher up in the water column. The effect of tidal range is similar near the bed and in the water column. The results indicate that SPM concentration is mainly tide dominated, but the occurrence of storms will impact the shallow regions through resuspension and by advection.

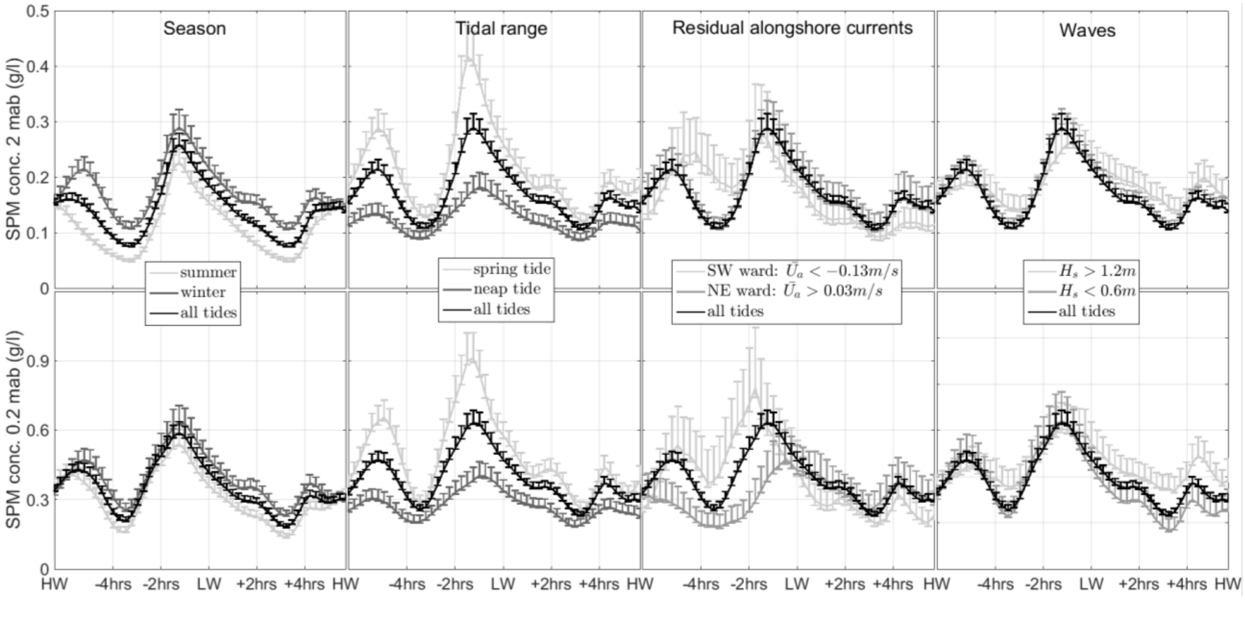


Figure 4.12: MOW1 (2005-2013), ensemble averaged OBS-derived SPM concentration at 2 and 0.2 mab during a tidal cycle as a function of season, tidal amplitude, direction of the residual alongshore current and significant wave heights. The data grouped according to tidal amplitude, residual alongshore current and significant wave heights are for winter period. The error bars are the standard errors. Slack water occurs around 4h before and 3 hours after LW (from Fettweis et al. 2016).

4.6 Effects of dumping of dredged material on SPM concentration

Water clarity or turbidity is a key parameter to understand the marine ecosystem and is mainly controlled by the SPM concentration. Environmental data on water clarity collected during the last century in the North Sea, indicate significant local and global environmental changes due to human activities and climate change (Fettweis et al. 2009; Capuzzo et al. 2015; van Maren et al. 2016). The conclusions from these studies are, however, hampered by the often very qualitative nature of the historical data and the very low time resolution of the measurements with regard to the high dynamic nature of the systems in which the data have been collected (Houziaux et al. 2011). How human activities have altered the environment prior to the late 20th century can therefore only be roughly estimated. In view of documenting current and future trends or changes, high quality measurements spanning long time, large geographical scales and high time resolutions, became a matter of growing importance in the last decades (Henson 2014; Witbaard et al. 2012), the time series we have collected at MOW1 site since 2005 fit very well in this objective.

Regarding the effects of the dumping of fine-grained sediments on shorter time scales, they are relatively well described with respect to environmental impacts (Smith and Rule 2001; Stronkhorst et al. 2003; Orpin et al. 2004; Simonini et al. 2005; Bolam et al. 2006; Dufour and Van Lancker 2008; Okada et al. 2009; Stockmann et al. 2009; Fettweis et al. 2011; Agunwamba et al. 2012; Bolam 2012; van Maren et al. 2015). Relatively less attention has been paid to the effect of the dumping of fine-grained material on the dredging works itself (e.g. Kapsimalis et al. 2013). Depending on the location of the dumping site, significant amounts of the dumped matter may recirculate in suspension or as high concentrated benthic layers back to the dredging areas, increasing thus the volume to be dredged and dumped. A smart relocation of the dumping site that does not induce recirculation is a straight forward way to decrease dredging volumes, costs and environmental impact. The field study (described in chapter 6.1) allowed quantifying the effect of disposal of fine-grained sediments from maintenance dredging works on the SPM concentration at two location outside (amongst which MOW1) and 4 locations inside the port of Zeebrugge. In the high-turbidity Belgian near shore area the natural forcing (tidal rand, random events, and seasons) are responsible for the major variability in the SPM concentration signal at MOW1. Dumping operations have a smaller but significant influence on the SPM concentration. The mean SPM concentration at MOW1 increases by about 10% higher when the dredged matter is disposed at the regular site ZBO; this represents a probability of 55% to have higher SPM concentration than using the alternative (ZBW).

4.7 Conclusions

Main conclusions, with relevance to sediment dynamics, influence of dredging and dumping operations and monitoring strategies are:

1) The use of in situ and remote sensing measurement data to detect changes in SPM concentration has enhanced system understanding of the present state. The in situ measurements based on optical and acoustical sensors have in addition helped in estimating the direction of changes induced by the dumping of fine-grained dredged material. In the high-turbidity Belgian near shore area natural forcings are responsible for the major variability in the SPM concentration signal, while disposal has only a smaller influence. The mean SPM concentrations at MOW1 is about 10% higher when the dredged matter is disposed at ZBO site; this represents a probability of 55% to have higher SPM concentration than using the alternative (ZBW). Nevertheless the smaller influence, a reduction in the SPM concentration by about 10% near the entrance to the port of Zeebrugge will reduce the sedimentation in the port by about the same percentage as most of the material that entered the harbour stays there.

2) Quantifying the variability of SPM concentration is crucial to elucidate the processes that have an influence (tides, tidal range, alongshore flow, waves, seasons); to understand the typical range of the variability, and to identify anomalous natural or human induced events. The use of optical or acoustical sensors to detect variations in SPM concentration has revealed the importance in understanding the present state and in estimating the direction of changes induced by the human activities, such as

dredging and dumping operations. The use of different sensors (optical, acoustical backscatter) has also revealed the big differences in outcome that are a consequence of the fact that measurements are inherently associated with uncertainties.

3) The annual cycle of SPM concentration is mainly caused by the seasonal biological cycle, rather than wind and waves. The data show that during the spring algae bloom floc sizes are getting larger as flocculation becomes breakage-resistant against turbulent shear, highlighting a transformation of mainly microflocs and flocculi in winter towards more muddy marine snow with larger amounts of macroflocs in spring and summer. The larger fraction of macroflocs reduces the SPM concentrations in the turbidity maximum area as they settle faster, as a consequence light condition in the surface layer increases and algae growth is enhanced. Whence, it is mainly the microbial activity in spring and summer and the formation of sticky exopolymeric substances that lead to a decrease in SPM concentration in the study area rather than the seasonal pattern in wind conditions. The high spring algae blooms are caused by an excess supply of nutrients from human activities, and affect flocculation dynamics. This suggests that the fine-grained sediment dynamics has probably been altered during the last decades and that a reduction in eutrophication will not only reduce the algae bloom, but possibly also changes the quantities to be dredged and dumped.

4) The long-term data series at MOW1 shows that during summer, the SPM concentration is higher in the near bed but lower higher up in the water column; during winter, the opposite is found. The results indicate that the SPM, or at least a significant part of it, stays in the area during summer and winter. In summer, the SPM is more concentrated in the near-bed layer, whereas in winter, the SPM is better mixed throughout the water column. The lower SPM concentrations in the water column during summer are thus compensated by higher near-bed SPM concentrations and possibly by a higher occurrence of HCMAS and fluid mud layers.

5. Biological and chemical aspects related to dredging and dumping operations

5.1 Epibenthos and fish fauna at the dumping sites

The aim of this chapter is to evaluate the influence of the dumping of dredged material on the epibenthic and demersal fish fauna in the Belgian coastal area. Species belonging to these animal groups are mobile, and living on or just beneath the sediment surface. This lifestyle makes them less sensitive to the pressure (burial) accompanied to the dumping of dredged material (Neal 2008). Changes in epibenthos and demersal fish are therefore expected to be more indirect, i.e. due to changes in the habitat characteristics (sediment type) or food availability. This type of effects has been investigated by means of a control-impact monitoring design at each dredge dumping site since 2005.

5.1.1 Material and Methods

Both ecosystem components were sampled with an 8-meter beam trawl, equipped with a fine-meshed shrimp net (stretched mesh width 22mm in the cod end) and a bolder chain. In 2004-2009, the beam was dragged during 30 minutes (average distance of 3500 m) at an average speed of 4 knots over the bottom. Since 2010, the sampling duration was reduced to 15 minutes (distance of 1750m), to allow a better sampling of the impact area itself (Van Hoey et al. 2012). The sampling design is a control-impact design, with one track in the impacted area (impact, I), one alongside the dumping site (nearby control, nC) and one at a long term monitoring stations (control, C), allowing three assessment categories (I versus C, I versus nC and I versus C+nC). At dumping site S1, the number of tracks in the impact area was doubled, with the aim to better investigated possible changes in the epibenthos and fish fauna in relation to the changes in bottom morphology (Van Hoey et al. 2012). Based on a multivariate community analysis (4th root transformed dataset, Bray-Curtis similarity) on the entire dataset (Appendix 2, Figure A2.1), each sample was linked to a specific habitat type (Table 5.1). That way, natural spatial habitat variation could be taken into account in the impact assessment. Sampling time, start and stop coordinates and sampling depth were recorded for each sample in order to enable a correct conversion towards sampled surface units (per 1000m^2). Sampling was executed over a period of 10 years (2005-2015) in post-winter (March) and post-summer (September-October) at the 5 dumping sites. Occasionally, sampling events failed due to a ruptured net, bad weather conditions or unavailability of a research vessel (post-summer 2015). Nevertheless, data from 340 sampling events were available for the analysis.

Per sampling event, the complete catch was sorted, identified, measured and counted (Van Hoey et al. 2012). This dataset was then reduced, removing taxa irrelevant for this analysis, i.e. Phyla Porifera, Cnidaria, Bryozoa and Nemertina, hard substrate fauna (e.g. mussels, oysters, barnacles, limpets) or records of unidentifiable individuals (catalogued at phylum level). A beam trawl catch generally contains different types of fauna. Therefore, taxa were allocated to 4 ecosystem components, i.e. ‘fish’ (bentho-pelagic fish [cod, whiting] and flatfish [sole, plaice]), a ‘pelagic fauna’ group (taxa living mostly in the water column, e.g. herring, sprat, mackerel, *Alosa spp*, and squids), an ‘epibenthos’ group (taxa living on the sediment surface, e.g. shrimps, starfish, brittle stars, sea snails and urchins) and a ‘macrofauna’ group (taxa living in the sediment, e.g. bivalves, anthozoans, *Callianassa, Echinocardium*).

For these four ecosystem component groups, the following characteristics were determined: number of taxa (species richness), Shannon Wiener diversity (h’ log2), density (ind./1000m^2) and biomass (gWet Weight/1000m^2; only for epibenthos and macrofauna). Changes in these characteristics were analysed for the fish and epibenthos groups only, since beam trawling is not the optimal monitoring technique for pelagic fauna and macrofauna. A graphical visualization was made for each characteristic, in order to distinguish patterns over time. If a similar pattern was visible, the dumping activity was expected to be minor compared to the natural variation over time. Additionally, an indicator assessment (BEQI, Benthic Ecosystem Quality Index, www.beqi.eu; Van Hoey et al. 2007; appendix 3 for details on procedure) was performed for two periods (2005 to 2009 [period 1], 2010 to 2015 [period 2]). The BEQI assessment is considered to be an objective tool to classify the comparability between two groups of samples. With this indicator, the difference in characteristics between the impact samples and control (nearby and long-term) samples for each dumping site was scored. Indicator scores below 0.6 (on a scale between 0 and 1) indicate a deviation of the characteristics in the impact area compared to the control.

Table 5.1: Overview of the impact stations, nearby control stations and overall monitoring stations per dumping site, for epibenthos and demersal fish.

	NWP	OST	ZBO	S1	S2
Habitat type	*Abra alba* habitat	*Macoma balthica* habitat	*Macoma balthica* habitat	*Abra alba* habitat	*Nephtys cirrosa* habitat
Impact sample	ft2251	ft1401	ft7001	Ft7801 ft7803 ft7804	ft7101
Nearby control sample	ft2252	ft1402	ft7002	ft7802	ft7102
Overall control sample	ft120 *ft230 (before 2010)*	ft140/ ft140bis *ftB10 (until 2010)*	ft140/ft140bis *ftB10 (until 2010)*	ft120 *ft230 (before 2010)*	ftB04 ftB03 *ftB07* *ft230 (after 2010)*

5.1.2 Results

Macoma balthica habitat: Dumping site OST and ZBO

At **dumping site OST**, species richness and epibenthos density showed a similar pattern over time for the three categories, with a few exceptions (Figure 5.1). Deviations for density were related to very high densities of *Crangon crangon* (up to 6500 ind./1000m²). In post-summer and post-winter of period 1, the densities in the impact area were generally lower than in the control, whereas in post-winter of period 2, it was the other way round. In several years, the species richness was slightly higher in the impact area, but it varied over time (especially in post-winter). The lower species richness in period 2 was related to the change in track length.

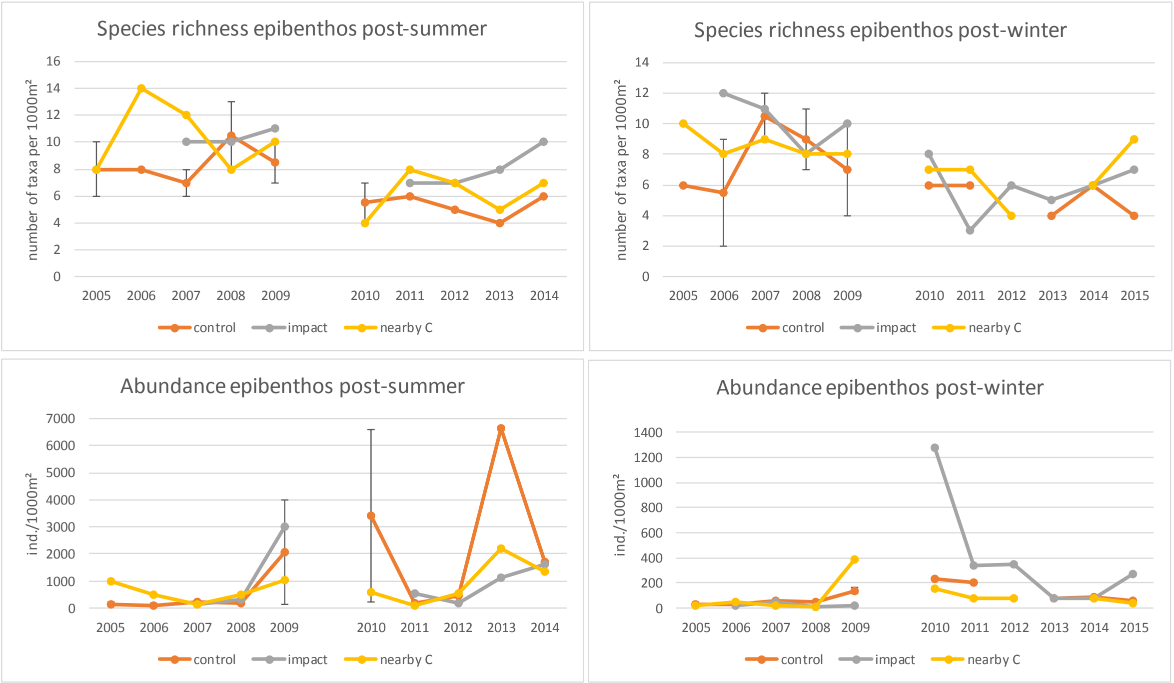


Figure 5.1: Average species richness (above) and abundance (below) for epibenthos in post-summer (left) and post-winter (right) per year at dumping site OST. One sampling event per year, except for the years 2005-2010 for the control category (two).

The parameters for fish showed similar values between the categories and a similar pattern over time (Figure 5.2). In the post-winter of period 2, however, density was slightly higher in the impact area. For fish, there was no obvious difference for the parameters between the two periods and sampling strategies. The species richness and density of fish and epibenthos were clearly higher in the post-summer period compared to post-winter.

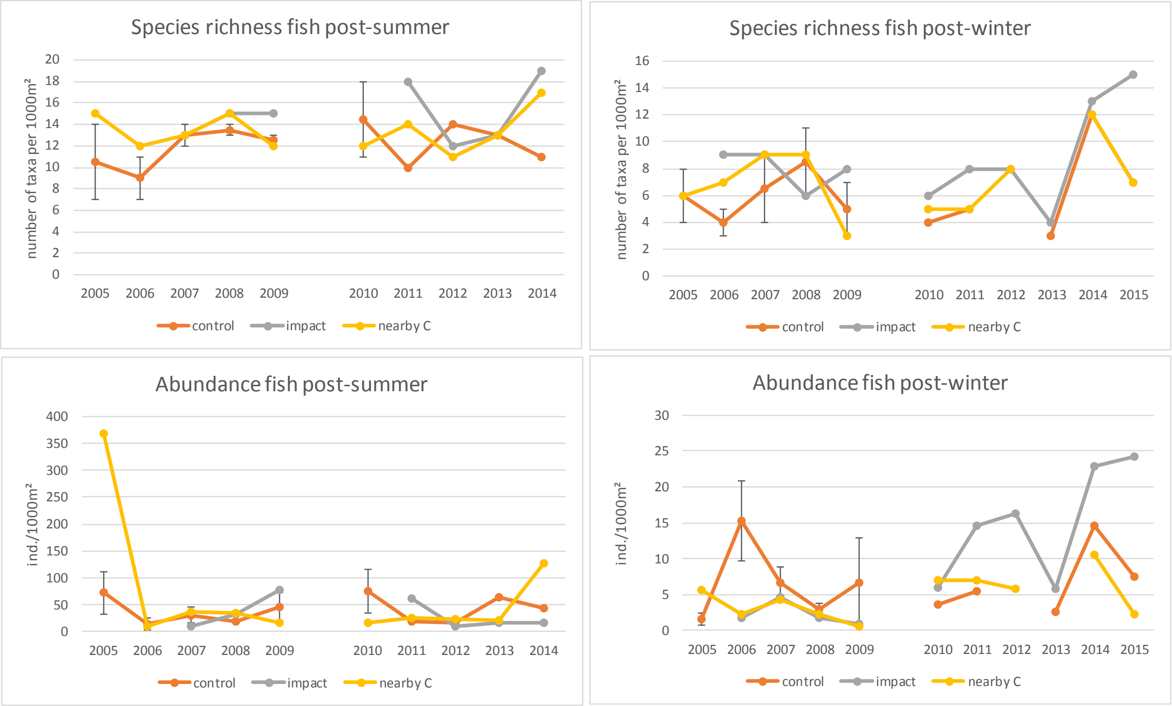
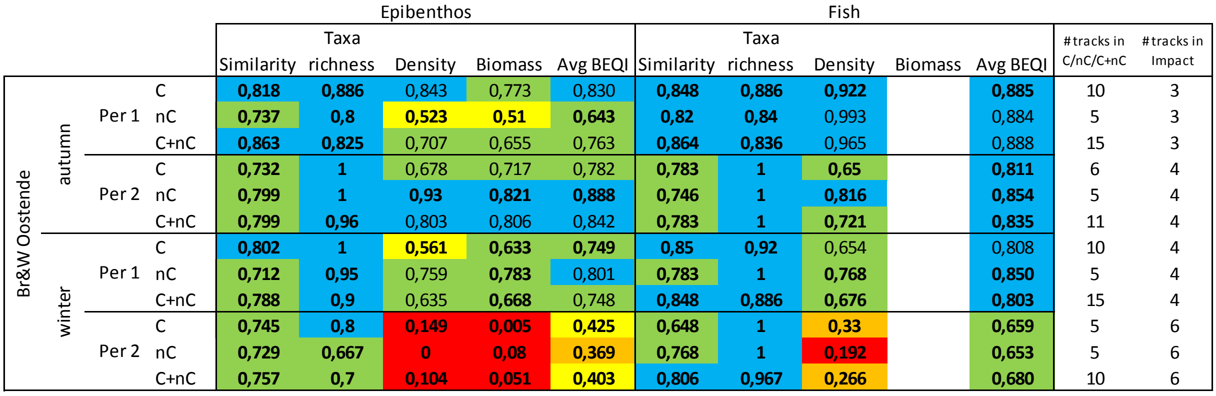


Figure 5.2: Average species richness (above) and density (below) for fish in post-summer (left) and post-winter (right) per year at dumping site OST. One sampling event per year, except for the years 2005-2010 for the control category (2).

With the BEQI analyses, a good too high comparability between the impact samples and the different control categories was found, except for epibenthos in post-winter of period 2 (Table 5.2). This was related to the much higher density and biomass in the impact area compared to the control (Figure 5.1). In the same period, a similar lower BEQI score was found for fish density. In most cases, the assessment based on the different control categories revealed similar scores, except for nearby control in post-summer period 1. In that particular case, the densities were higher than in the impact area. For epibenthos the confidence of the assessments (especially density and biomass) was mostly low. This is due to the low number of impact samples and the higher variability in characteristics between the tracks compared to fish.

Table 5.2: BEQI scores for comparison of the impact samples with the control (c), nearby control (nC) or control + nearby control (C+nC) set for the two assessment periods for dumping site OST. Scores in bold indicate that the confidence is good or moderate, other-wise low to very poor. The colours indicate the boundaries of the different classes (blue: high; green: good; yellow: mode-rate; orange: poor; red: bad comparability).



				Epibenthos					Fish						
				Similarity	Taxa richness	Density	Biomass	Avg BEQI	Similarity	Taxa richness	Density	Biomass	Avg BEQI	#tracks in C/nC/C+nC	#tracks in Impact
Br&W Oostende	autumn	Per 1	C	**0,818**	**0,886**	0,843	0,773	0,830	**0,848**	**0,886**	**0,922**		**0,885**	10	3
			nC	**0,737**	**0,8**	**0,523**	**0,51**	**0,643**	**0,82**	**0,84**	0,993		0,884	5	3
			C+nC	**0,863**	**0,825**	0,707	0,655	0,763	**0,864**	**0,836**	0,965		0,888	15	3
		Per 2	C	**0,732**	**1**	0,678	0,717	0,782	**0,783**	**1**	**0,65**		**0,811**	6	4
			nC	**0,799**	**1**	**0,93**	**0,821**	**0,888**	**0,746**	**1**	**0,816**		**0,854**	5	4
			C+nC	**0,799**	**0,96**	0,803	0,806	0,842	**0,783**	**1**	**0,721**		**0,835**	11	4
	winter	Per 1	C	**0,802**	**1**	**0,561**	**0,633**	**0,749**	**0,85**	**0,92**	0,654		0,808	10	4
			nC	**0,712**	**0,95**	0,759	**0,783**	0,801	**0,783**	**1**	**0,768**		**0,850**	5	4
			C+nC	**0,788**	**0,9**	0,635	**0,668**	0,748	**0,848**	**0,886**	**0,676**		**0,803**	15	4
		Per 2	C	**0,745**	**0,8**	**0,149**	**0,005**	**0,425**	**0,648**	**1**	**0,33**		**0,659**	5	6
			nC	**0,729**	**0,667**	**0**	**0,08**	**0,369**	**0,768**	**1**	**0,192**		**0,653**	5	6
			C+nC	**0,757**	**0,7**	**0,104**	**0,051**	**0,403**	**0,806**	**0,967**	**0,266**		**0,680**	10	6

At the **dumping site ZBO**, the species richness and abundance of the epibenthos and fish clearly showed the same pattern over time (Figures 5.3 and 5.4). This was especially obvious for epibenthic species richness in post-winter of period 2, where a simultaneous decrease in species richness in was found in 2013 and 2015 for the three categories. For fish, the best correspondence was found in post-summer of period 1 and post-winter of period 2. The epibenthic and fish species richness and abundance in post-summer was generally lower in the impact area compared to the control areas. In the post-winter series, the impact values were not consistently higher or lower between the categories over the years. The species richness and densities of fish and epibenthos were clearly higher in the post-summer period compared to post-winter, except for the epibenthic species richness.

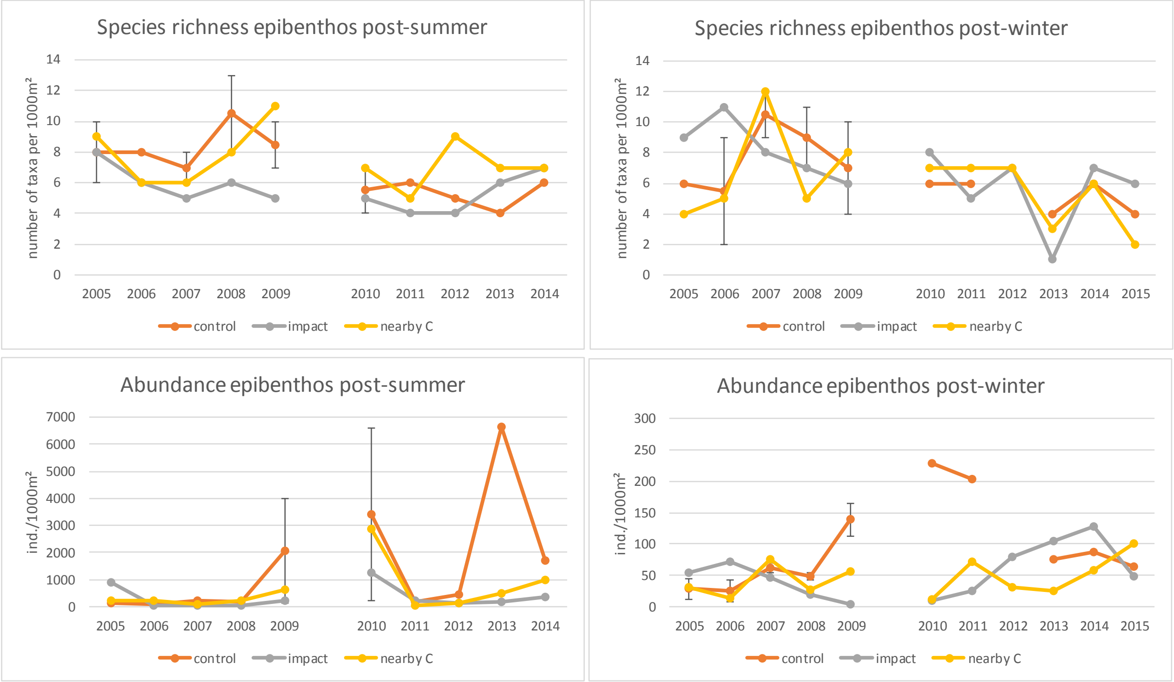


Figure 5.3: Average species richness (above) and density (below) for epibenthos in post-summer (left) and post-winter (right) per year at dumping site ZBO. One sampling event per year, except for the years 2005-2010 for the control category (two).

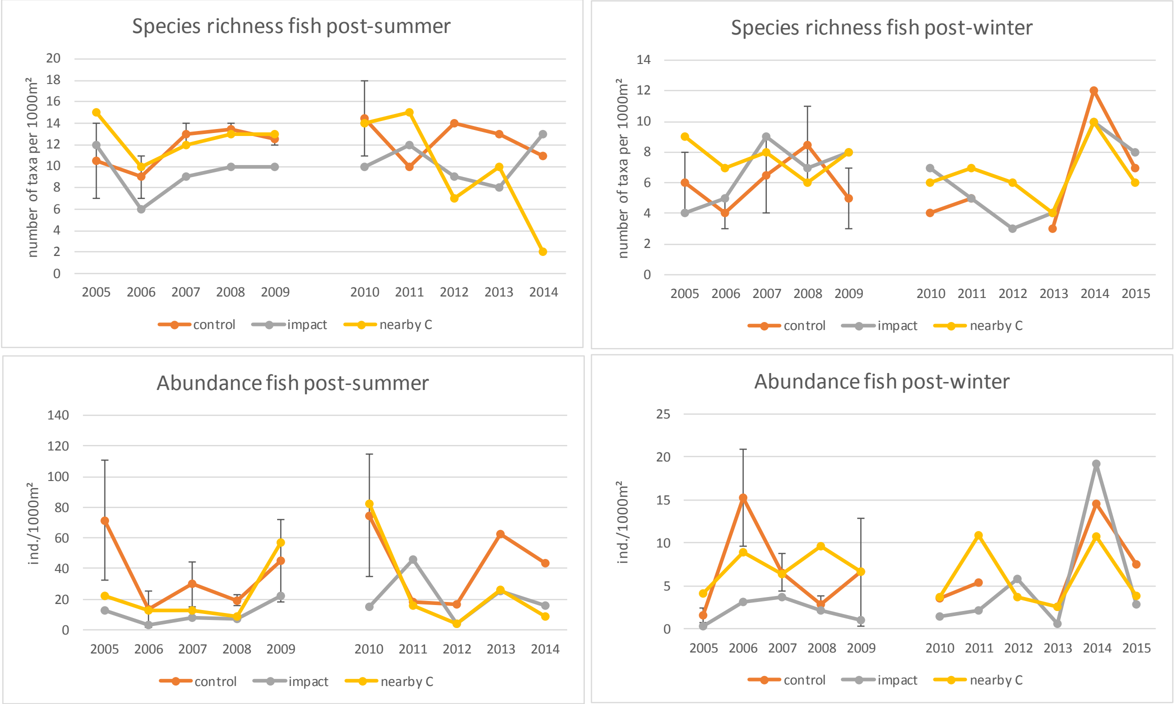


Figure 5.4: Average species richness (above) and density (below) for fish fauna in post-summer (left) and post-winter (right) per year at dumping site ZBO. One sampling event per year, except for the years 2005-2010 for the control category (two).

For epibenthos, a high comparability between impact and control categories was found for period 1, and to a lesser extent for period 2, with the BEQI. The confidence of the epibenthos assessment was only good for the post-winter assessments. For fish, this comparability was good in most cases, for post-summer and post-winter period. The latter was related to a lower taxa richness (e.g. post-summer period 1) or density (e.g. post-winter and post-summer period 1) in the impact area (Figure 5.4).

Table 5.3: BEQI scores for comparison of the impact samples with the control (c), nearby control (nC) or control + nearby control (C+nC) set for the two assessment periods for dumping site ZBO. Scores in bold indicate good or moderate confidence, otherwise low to very poor. The colours indicate the boundaries of the different classes (blue: high; green: good; yellow: moderate; orange: poor; red: bad comparability).

				Epibenthos					Fish						
				Similarity	Taxa richness	Density	Biomass	Avg BEQI	Similarity	Taxa richness	Density	Biomass	Avg BEQI	#tracks in C/nC/C+nC	#tracks in Impact
Br&W Zeebrugge Oost	autumn	Per 1	C	**0,779**	**0,7**	0,985	0,986	0,863	**0,729**	**0,6**	**0,437**		**0,589**	10	3
			nC	**0,659**	**0,8**	**0,897**	**0,844**	**0,800**	**0,753**	**0,667**	**0,568**		**0,663**	5	3
			C+nC	**0,765**	**0,667**	0,993	0,998	0,856	**0,744**	**0,6**	**0,518**		**0,621**	15	3
		Per 2	C	**0,729**	**0,8**	0,611	0,646	0,697	**0,703**	**0,68**	**0,526**		**0,636**	6	4
			nC	**0,782**	**0,6**	0,743	**0,752**	0,719	**0,782**	**0,867**	**0,899**		**0,849**	5	4
			C+nC	**0,762**	**0,6**	0,651	0,694	0,677	**0,782**	**0,72**	**0,699**		**0,734**	11	4
	winter	Per 1	C	**0,868**	**0,933**	**0,727**	**0,735**	**0,816**	**0,812**	**0,88**	**0,611**		**0,768**	10	4
			nC	**0,838**	**1**	**0,96**	**0,546**	**0,836**	**0,686**	**0,867**	**0,222**		**0,592**	5	4
			C+nC	**0,885**	**0,88**	**0,784**	**0,87**	**0,855**	**0,793**	**0,822**	**0,437**		**0,684**	15	4
		Per 2	C	**0,696**	**1**	**0,524**	**0,605**	**0,706**	**0,704**	**0,767**	**0,801**		**0,757**	5	6
			nC	**0,672**	**1**	**0,698**	**0,668**	**0,760**	**0,735**	**0,8**	**0,9**		**0,812**	5	6
			C+nC	**0,775**	**1**	**0,801**	**0,817**	**0,848**	**0,782**	**0,75**	**0,84**		**0,791**	10	6

Fine muddy sand area (*Abra alba* habitat): Dumping sites NWP and S1.

The species richness and density values of the epibenthos in this habitat were of the same order of magnitude between seasons, but they varied a lot between the years (Figure 5.5). For fish on the other hand, there was a seasonal difference in species richness and abundance (Figure 5.6). The highest epibenthos densities were related to high densities of the brittle star *Ophiura ophiura* or the sea star *Asterias rubens*.

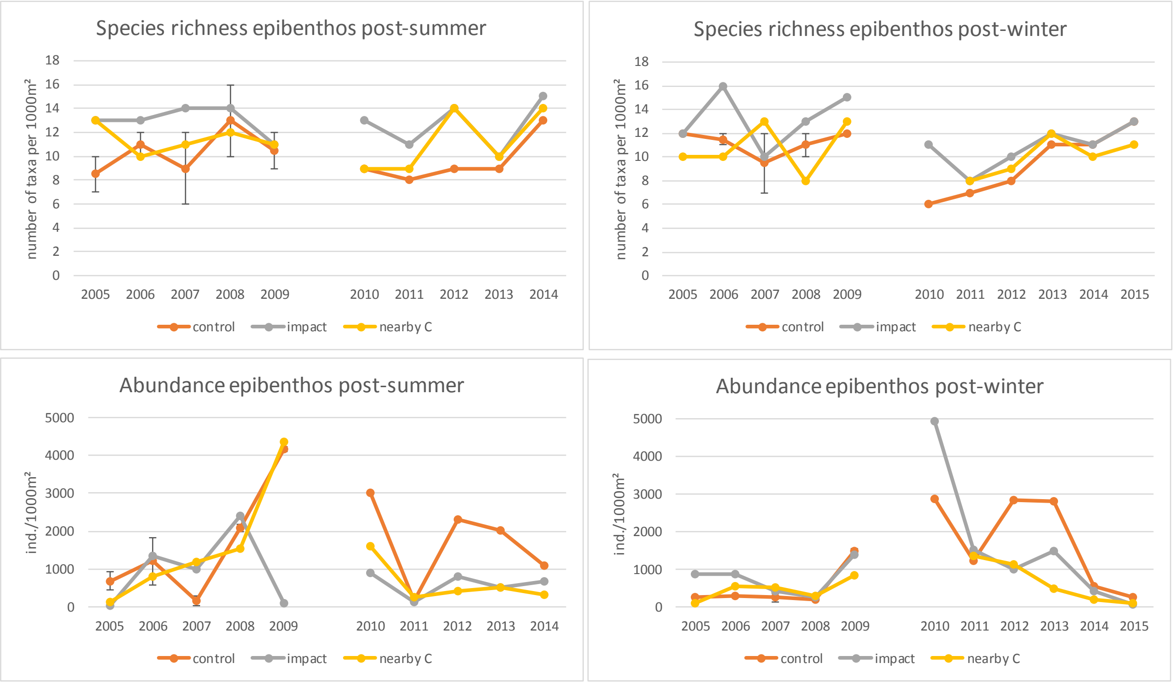


Figure 5.5: Average species richness (above) and density (below) for epibenthos in post-summer (left) and post-winter (right) per year at dumping site NWP. One sampling event per year, except for the years 2005-2010 for the control category (two).

At **dumping site NWP**, patterns in species richness and density were similar over the years for the three categories. However, in 2009, the epibenthic density was very low in the impact area compared to the control (Figure 5.5). The epibenthic species richness was generally highest in the impact data, but densities were lower than those in the control data. The patterns for fish were quite similar, especially for the species richness in post-summer: parallel patterns were observed between the three categories over the years. In certain years, fish density showed some differences between the categories, but these were not consistent.

BEQI indicator analyses showed that the epibenthos and fish characteristics of the impact were in good to high correspondence with the control (Table 5.4), which is in line with the observations over time (Figures 5.5 and 5.6). The confidence of the assessment was good or moderate in all cases. Epibenthos richness was highest in the impact area, but density and biomass showed a variable pattern in comparability. In post-winter of period 2, for example, a low comparability was noted (cfr. high densities in 2010 for impact). In general, the post-winter period 1 assessment for fish and epibenthos showed the lowest comparability between the categories.

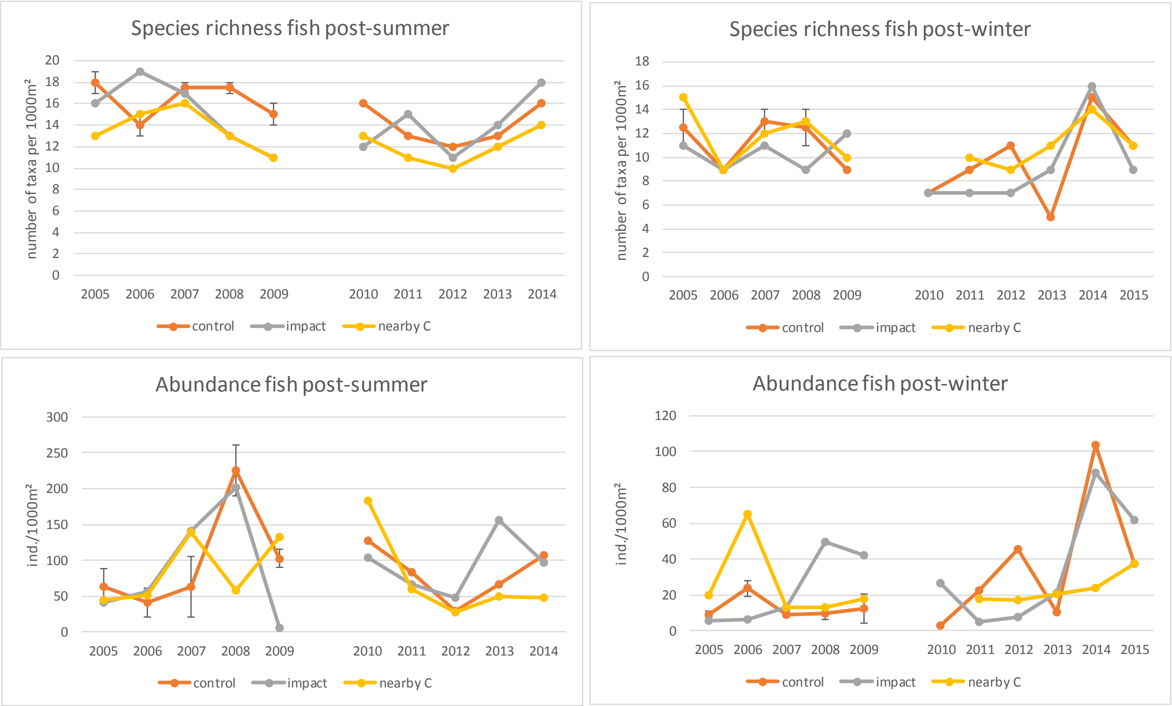


Figure 5.6: Average species richness (above) and density (below) for fish fauna in post-summer (left) and post-winter (right) per year at dumping site NWP. One sampling event per year, except for the years 2005-2010 for the control category (2 events).

Table 5.4: BEQI scores for comparison of the impact samples with the control (c), nearby control (nC) or control + nearby control (C+nC) set for the two assessment periods for dumping site NWP. Scores in bold indicate a good to moderate confidence, otherwise low to very poor. The colours indicate the boundaries of the different classes (blue: high; green: good; yellow: moderate; orange: poor; red: bad comparability).

			Epibenthos					Fish						
			Similarity	Taxa richness	Density	Biomass	Avg BEQI	Similarity	Taxa richness	Density	Biomass	Avg BEQI	#tracks in C/nC/C+nC	#tracks in Impact
Nieuwpoort	autumn	Per 1	C	**0,703**	**0,92**	**0,732**	**0,719**	**0,769**	**0,802**	**0,867**	**0,926**		**0,865**	10	5
			nC	**0,731**	**1**	**0,751**	**0,745**	**0,807**	**0,723**	**1**	**0,945**		**0,889**	5	5
			C+nC	**0,761**	**0,85**	**0,75**	**0,732**	**0,773**	**0,819**	**0,867**	**0,987**		**0,797**	15	5
		Per 2	C	**0,735**	**1**	**0,47**	**0,634**	**0,710**	**0,758**	**0,933**	**0,786**		**0,826**	5	5
			nC	**0,777**	**1**	**0,999**	**0,91**	**0,922**	**0,782**	**1**	**0,795**		**0,859**	5	5
			C+nC	**0,782**	**1**	**0,688**	**0,738**	**0,802**	**0,775**	**0,95**	**0,782**		**0,813**	10	5
	winter	Per 1	C	**0,693**	**0,92**	**0,745**	**0,56**	**0,730**	**0,762**	**0,75**	**0,497**		**0,670**	10	5
			nC	**0,702**	**1**	**0,524**	**0,419**	**0,661**	**0,742**	**0,733**	**0,948**		**0,808**	5	5
			C+nC	**0,751**	**0,9**	**0,688**	**0,517**	**0,714**	**0,769**	**0,7**	**0,775**		**0,701**	15	5
		Per 2	C	**0,692**	**1**	**0,87**	**0,842**	**0,851**	**0,74**	**1**	**0,846**		**0,862**	6	6
			nC	**0,686**	**1**	**0,32**	**0,193**	**0,550**	**0,779**	**1**	**0,483**		**0,754**	5	6
			C+nC	**0,729**	**1**	**0,794**	**0,798**	**0,830**	**0,796**	**0,84**	**0,853**		**0,821**	11	6

At **dumping site S1**, the epibenthos species richness showed a similar pattern over time between the categories, with in period 2 constantly lower species richness in the impact area (Figure 5.7). Post-summer densities of epibenthos showed much higher abundances in the nearby control tracks compared to the other two categories. In period 2, the density was similarly lowest in the impact area. Fish characteristics showed a slightly different pattern, with higher species richness and lower densities in the impact area, especially in post-summer of period 2. Otherwise, the parameter patterns were similar over the years and between categories.

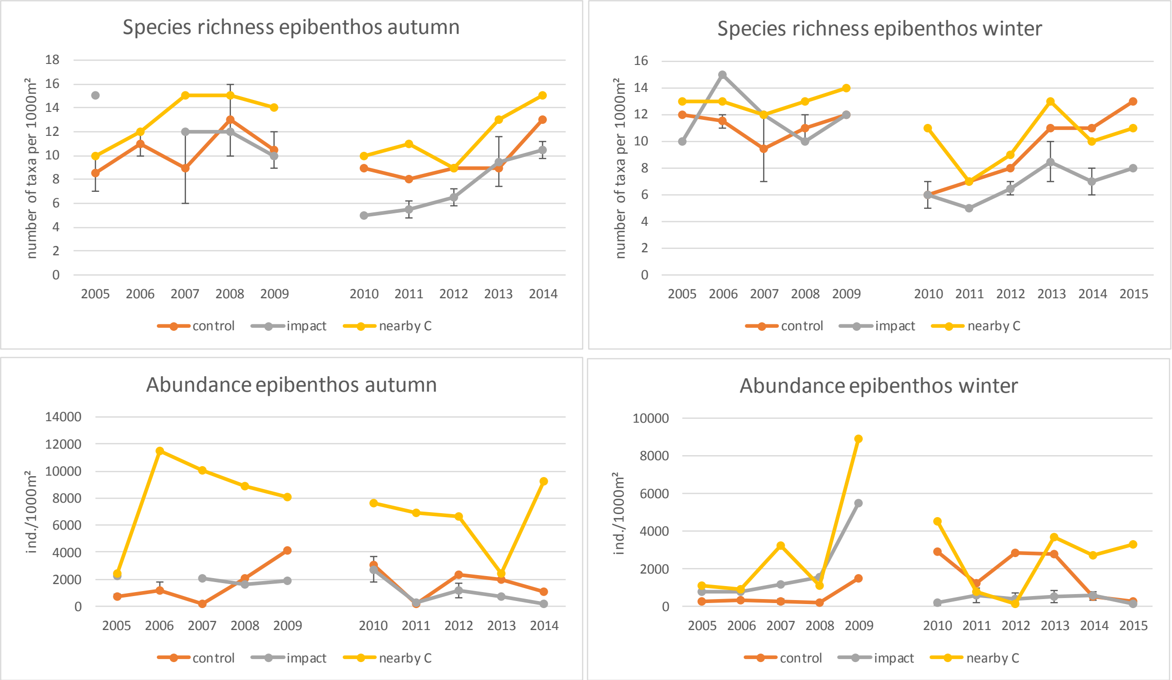


Figure 5.7: Average species richness (above) and density (below) for epibenthos in post-summer (left) and post-winter (right) per year at dumping site S1. One sampling event per year, except for the years 2005-2010 for the control category (two) and for the impact category in period 2 (2010-2015).

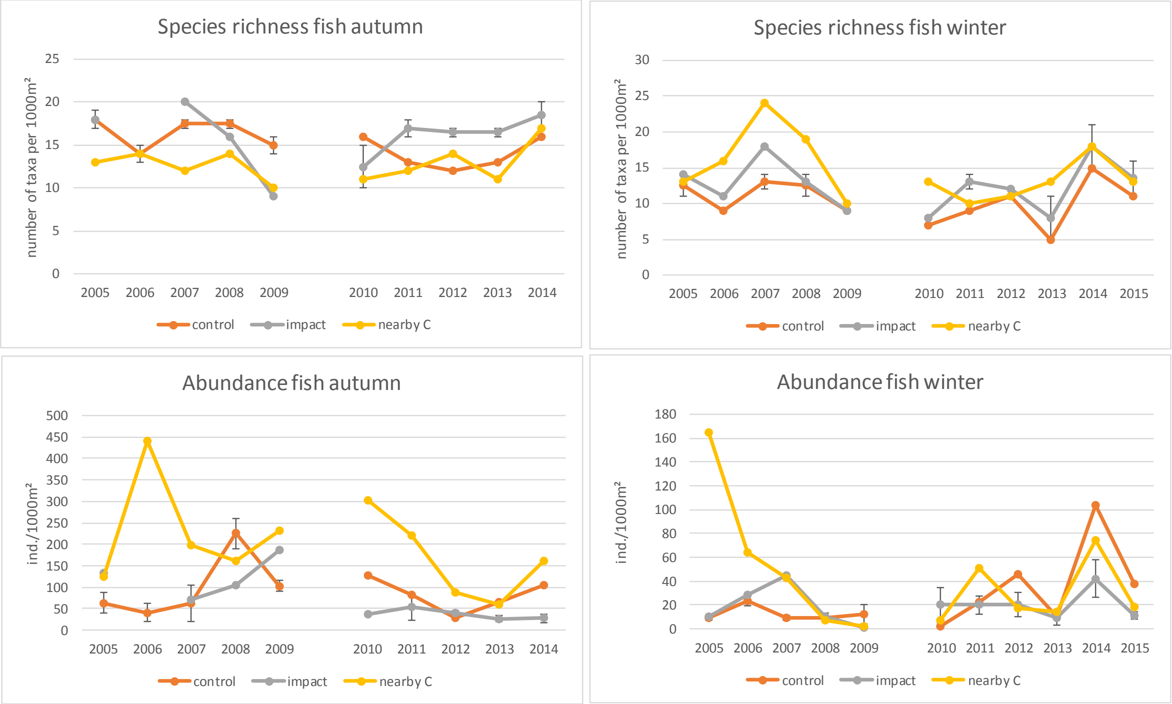


Figure 5.8: Average species richness (above) and density (below) for fish fauna in post-summer (left) and post-winter (right) per year at dumping site S1. One sampling event per year, except for the years 2005-2010 for the control category (two) and for the impact category in period 2 (2010-2015).

For period 1, the BEQI assessment for fish showed a good or high comparability between the categories (Figure 5.8). For epibenthos, comparability varied depending on the categories compared. Moderate scores in the assessments were related to the large difference in density and biomass between the categories. For period 2, the BEQI assessment showed a good comparability for fish, but a poor to moderate comparability for epibenthos. The latter is related to lower scores for richness and species composition and very low scores for density and biomass. Density differences in fish were most pronounced in post-summer, resulting in the lowest BEQI values.

Table 5.5: BEQI scores for comparison of the impact samples with the control (c), nearby control (nC) or control + nearby control (C+nC) set for the two assessment periods at dumping site S1. Scores in bold indicate good or moderate confidence, otherwise low to very poor. The colours indicate the boundaries of the different classes (blue: high; green: good; yellow: moderate; orange: poor; red: bad comparability).

				Epibenthos					Fish						
				Similarity	Taxa richness	Density	Biomass	Avg BEQI	Similarity	Taxa richness	Density	Biomass	Avg BEQI	#tracks in C/nC/C+nC	#tracks in Impact
Br&W S1	autumn	Per 1	C	**0,781**	**0,9**	**0,88**	**0,898**	**0,865**	**0,827**	**0,8**	**0,798**		**0,808**	10	4
			nC	**0,73**	**0,9**	**0,249**	**0,349**	**0,557**	**0,793**	**1**	**0,519**		**0,771**	5	4
			C+nC	**0,851**	**0,825**	0,74	0,707	0,781	**0,852**	**0,831**	**0,919**		**0,867**	15	4
		Per 2	C												
			nC												
			C+nC	**0,585**	**0,7**	**0,254**	**0,267**	**0,452**	**0,645**	**1**	**0,278**		**0,641**	10	10
	winter	Per 1	C	**0,73**	**0,8**	**0,168**	**0,448**	**0,537**	**0,759**	**0,867**	**0,624**		**0,750**	10	5
			nC	**0,749**	**0,8**	**0,804**	**0,644**	**0,749**	0,825	0,667	0,657		0,716	5	5
			C+nC	**0,843**	**0,733**	0,831	**0,876**	0,821	0,887	0,767	0,958		0,871	15	5
		Per 2	C												
			nC												
			C+nC	**0,591**	**0,533**	**0,184**	**0,23**	**0,385**	**0,747**	**0,933**	**0,638**		**0,773**	12	12

Nepthys cirrosa **habitat (Vlakte van de Raan): Dumping site S2**

The species richness values for epibenthos were more or less the same over time for the control category, but more variable for the two other categories (Figure 5.9). In the post-winter series, the values between impact and nearby-control followed the same pattern in the first period, but they showed an opposite pattern in the second period. The epibenthic density showed a similar pattern and similar values for impact and nearby-control over the years, but the values were generally much higher for the control samples (with a high variability in the values, as indicated by the standard deviation). This variation was mostly caused by variation in the occurrence of the brittle star *Ophiura ophiura*. The species richness for the fish fauna was very similar over the years between the categories, except in 2008. This was also more or less the case for fish densities, except for the years 2008 and 2011 in post-summer and 2013-2014 in post-winter. At dumping site S2, the comparability between the impact and control categories for fish was high (with good confidence). Only in two cases, the densities were higher in the impact area compared to the nearby control site (Table 5.6). For epibenthos, there was a similar high (or good) comparability between the categories (Figure 5.10).

Table 5.6: BEQI scores for comparison of the impact samples with the control (c), nearby control (nC) or control + nearby control (C+nC) set for the two assessment periods at dumping site S2. Scores in bold indicate good or moderate confidence, otherwise low to very poor confidence. A correspondence score colour is given on the average values, where blue is high, green good, yellow moderate and orange poor correspondence.

				Epibenthos					Fish						
				Similarity	Taxa richness	Density	Biomass	Avg BEQI	Similarity	Taxa richness	Density	Biomass	Avg BEQI	#tracks in C/nC/C+nC	#tracks in Impact
Br&W LS2	autumn	Per 1	C	**0,738**	**0,8**	**0,76**	**0,936**	**0,809**	**0,825**	**0,886**	**0,971**		**0,894**	10	5
			nC	**0,771**	**0,9**	0,909	0,869	0,862	**0,863**	**0,72**	0,919		0,834	5	5
			C+nC	**0,806**	**0,8**	**0,801**	0,943	0,838	**0,849**	**0,8**	**0,997**		**0,882**	15	5
		Per 2	C	**0,758**	**0,8**	**0,67**	**0,784**	**0,753**	**0,851**	**0,855**	**1**		**0,902**	20	5
			nC	**0,789**	**1**	**0,868**	**0,832**	**0,872**	**0,821**	**0,8**	**0,228**		**0,616**	5	5
			C+nC	**0,777**	**0,8**	**0,7**	**0,824**	**0,775**	**0,861**	**0,833**	**0,915**		**0,870**	25	5
	winter	Per 1	C	**0,819**	**0,857**	0,718	0,779	0,793	**0,854**	**0,914**	**0,638**		**0,802**	10	5
			nC	**0,875**	**1**	**0,867**	**0,798**	**0,885**	**0,776**	**0,933**	**0,725**		**0,811**	5	5
			C+nC	**0,849**	**0,85**	0,76	0,785	0,811	**0,849**	**0,84**	**0,945**		**0,878**	15	5
		Per 2	C	**0,754**	**0,84**	**0,503**	0,479	0,644	**0,868**	**0,733**	**0,914**		**0,838**	24	6
			nC	**0,811**	**0,75**	**0,96**	**0,995**	**0,879**	**0,821**	**0,767**	**0,289**		**0,626**	6	6
			C+nC	**0,791**	**0,818**	**0,618**	0,608	0,709	**0,867**	**0,72**	**0,852**		**0,813**	30	6

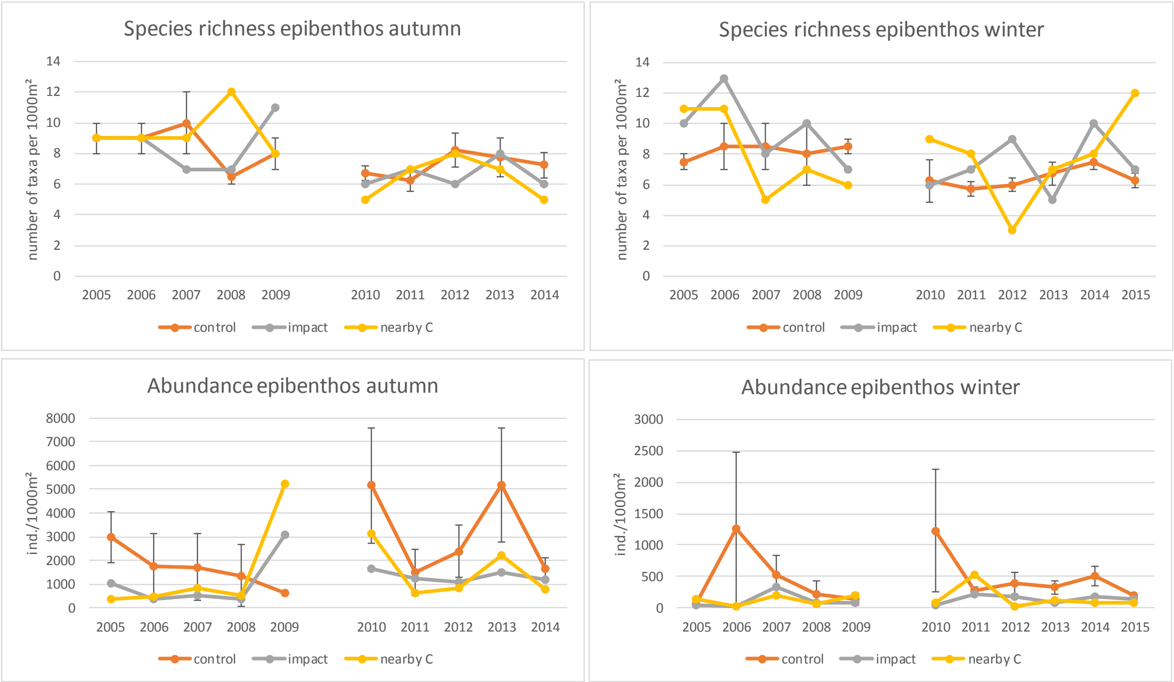


Figure 5.9: Average species richness (above) and density (below) for epibenthos in post-summer (left) and post-winter (right) per year at dumping site S2. One sampling event per year, except for the control category (two in period 1 to four in period 2).

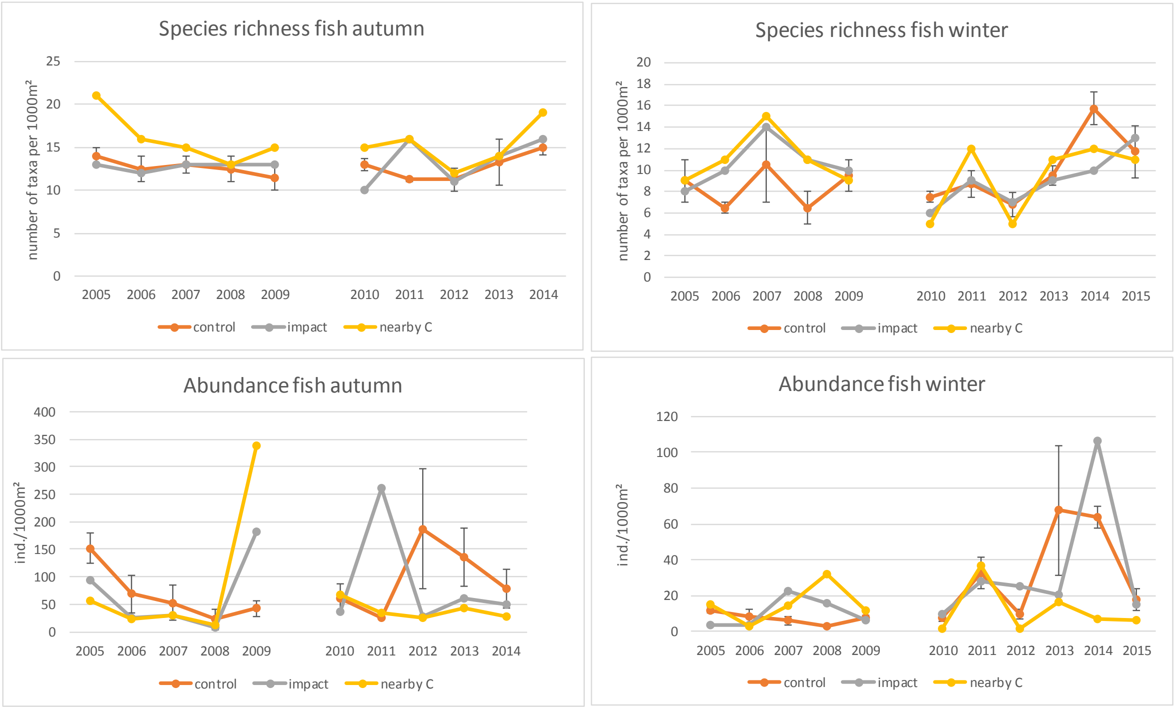


Figure 5.10: Average species richness (above) and density (below) for fish fauna in post-summer (left) and post-winter (right) per year at dumping site S2. One sampling event per year, except for the control category (two in period 1 to four in period 2).

5.1.3 Discussion and conclusion

Epibenthos and fish species richness and densities generally showed similar patterns over time, indicating that natural temporal variation was the main driver of observed patterns. Still, differences in density and biomass were observed in some years, mainly due to patterns in occurrence of specific species (e.g. brittle star *O. ophiura*) having a patchy distribution. Due to their high natural variability, observing positive or negative influences on epibenthos and fish as a result of an anthropogenic activity is difficult, especially when the influence is expected to be low.

Based on analyses encompassing a ten-year period, we can now state that the influence of dumping itself is minimal: the characteristics in the impact area are in line with those in the nearby-control and overall control. At the dumping site S1, however, the species richness and densities were clearly ànd consistently lower in the impact area, especially for epibenthos. This indicates a deterioration of the area. The bottom morphology and sedimentology at this site have changed due to the chronic dumping activities (Van Hoey et al. 2012) and that has influenced the epibenthic and fish status. This process was not detected with the sampling strategy of period 1. At that time, the tracks were longer and the impact track also sampled the richer fauna just outside the dumping site (cfr. nearby control track). The fish fauna seems to be less influenced, presumably due to its higher mobility. However, the observed lower density may indicate that this area is less profitable as a feeding area (lower food availability compared to the surrounding area).

An unexpected observation within the study is the occurrence of higher values of species richness and density of fish and epibenthos in the impact area of OST. The "positive" influence, most clearly observed in post-winter of period 2, may be a result of fisheries exclusion. Fisheries activity analyses showed that the dumping sites in the Belgian coast are avoided by fishermen (Van Hoey et al. 2014; Pecceu et al. 2014), since catches in the area contain a lot of mud. Consequently, fishing at dumping sites implies a higher risk of net rupture and contaminated catches.

In the light of a more efficient and appropriate monitoring design, future monitoring of the epibenthic and fish fauna should

1/ incorporate more impact tracks within the impacted areas to increase power, as done at S1 or at least to try to fit them within the area. Practically difficult to execute due to the small sizes of the area and sampling inconstancies related to beam uplifting and

2/ incorporate an extra control site within the *Macoma balthica* and *Abra alba* habitats, in order to fully cover the variability and to have a balanced design for S1.

3/ reduce the number of control tracks at the Vlakte van de Raan, since analyses show that the variability can be adequately covered with a lower number of samples

4/ consider whether sampling at OST and ZBO is cost-effective, given the high risk of net damage and rupture due to the abundance of obstacles (stones, wood).

5/ focus on sampling more intensively in one season or incorporate conversion factors between seasons. This would increase the confidence of the assessments and tone down the seasonal effects in the analyses.

Conclusion: Despite the statistically suboptimal sampling design, the analyses clearly show that direct influence of dumping on the epibenthic and fish fauna is minimal, except at sites where intense dumping has resulted in changes in bottom morphology (e.g. S1).

5.2 Changes in the structural and functional characteristics of the macrofauna

In this chapter, the influence of the dumping of dredged material on macrobenthos is evaluated. Macrobenthos can be defined as the organisms that live in the sediment (infauna) for the better part of their life, and that are retained on a 1mm-meshed sieve. They are closely associated with the sediment and play an important role in the marine ecosystem (Braeckman et al. 2010; Stief 2013). Consequently, they can be used as bio-indicators in relation to human activities, including the dumping of dredged material (Wildish and Thomas 1985; Bilyard 1978; Soule 1988; Rees et al. 1992; Simonini et al. 2005; Rees et al. 2006). Any changes in the macrobenthos are triggered by habitat creation/modification, smothering of the fauna and changes in bathymetry, or sediment input towards the seabed (Morton 1977; Maurer et al. 1983; Delvalls et al. 2004; Ware et al. 2009; Essink 1999). Since macrobenthic species differ in their sensitivity/tolerance towards disturbance, the results of an impact evaluation study should be considered by the benthic community present at the site. In the Belgian part of the North Sea, dumping sites are located in three different habitat types. These habitat differences are taken into account during monitoring and assessment in the current study (Table

5.1) (Van Hoey et al. 2012). Species assemblages that are used to a certain degree of stress (e.g. North Sea storms), are expected to recover faster after a disturbance event than assemblages occurring in a more stable environment. Stress resistant assemblages are usually characterized by life-history traits that facilitate the recolonization process, i.e. short living opportunistic species (Bolam et al. 2003). Hence, next to changes in the structural characteristics such as diversity, density and biomass, also changes in functional characteristics (life-history traits) are considered in the current study. A dedicated control-impact monitoring design (number of samples and the degree of coverage of the study area) was worked out for each dredge dumping site and carried out since 2006. The design was optimized in 2010 (Van Hoey et al. 2009; 2012). Since the sampling design ensures the reliability of the obtained results, it was again re-evaluated during the present study in order to optimize the monitoring program 2017-2021.

5.2.1 Material and Methods

The macrobenthos was sampled with a Van Veen grab (0.1 m²), and sieved fixed (<2010) or alive (2010 onwards) on a 1 mm sieve. Fixation was done with 8 % formaldehyde seawater solution. The samples were stained with eosin to facilitate sorting. Species were identified to species level when possible, and counted. The macrobenthos monitoring (sampling, processing and analyzing) was executed following the ISO standard (ISO 16665:2005(E)) ("Water quality – Guidelines for quantitative sampling and sample processing of marine soft-bottom macrofauna"). This procedure is under accreditation since 24/05/2011 under the BELAC ISO17025 norm (ILVO-DIER-ANIMALAB; Certificate N°: BELAC T-315; 28/04/2016).

For this study, we used the autumn monitoring data of the period 2006-2015 at the 5 dumping sites. Two years were missing: 2009 samples were not analyzed, and there was no sampling campaign in 2015 (Table 5.7). Since 2006, the control/impact design consist of 7 impact (I) and 4 to 6 nearby control (nC) samples at each disposal site. In 2010, the number of nC samples was increased (except for NWP), to allow a confident comparison of the I samples with the nC samples. The availability of overall control stations (fC) varied over time. Based on this design, three assessment categories were considered, by comparing the set of impact samples with nC (except in period 1 and NWP period 2), fC (except for S2 period 2, OST and ZBO period 1) and all control samples (nC+fC) (Table 5.7). Non- confident assessments were related to an insufficient amount of samples or an inadequate sampling per habitat for a specific parameter (e.g. species richness for fC samples in *Macoma balthica* habitat). The latter was already partly solved in 2013, by changing the location of station 140 (now 140bis). The monitoring at the dredge spoil disposal sites NWP and OST was executed only once every two years from 2011 onwards (Van Hoey et al. 2012).

The sampling design matrix and available data consist of a set of 800 samples to assess the influence of the dumping of dredged material at the five dumping sites. A quality control was performed on the dataset and taxa irrelevant to the analysis were removed (Phyla Porifera, Cnidaria, Bryozoa, Nemertina, Nematoda, Mysida, hard substrate fauna such as mussels, barnacles, limpets and *Jassa* spp., records of unidentifiable individuals (catalogued at phylum level), and rare species (species only recorded once in the set of 800 samples)). The total dataset consisted of 133 valid taxa and 198461 individuals. Each habitat is defined by a set of characteristic species (Table 5.8), that usually also define differences in density and abundance between the different assessment categories.

The influence of dumping was assessed by analysing the macrobenthic parameters species richness, species composition (Bray-Curtis similarity), density (ind./m²) and biomass (Wet Weight/m²)). An indicator assessment (BEQI, Benthic Ecosystem Quality Index, www.beqi.eu; see Appendix 3 for details on procedure) was done to score the difference between each assessment category for each sampling year. If the indicator scores were below 0.6 (on a scale between 0 and 1), the characteristics in the impact area were considered to deviate from what is expected based on the control data. This is an objective tool to classify the comparability between two groups of samples.

Table 5.7: Overview of the impact stations, nearby control stations and overall monitoring stations per dumping site, for macrobenthos. No confident BEQI assessment can be made for the shaded assessment categories.

	2006-2009				2010 onwards				Habitat type
	I	nC	fC	nC+fC	I	nC	fC	nC+fC	
NWP	7	4	12-15	16-19	7	4	12	16	*Abra alba* habitat
	LNP01- LNP07	LNP08- LNP11	120, 115, 780, 230; B08		LNP01- LNP07	LNP08- LNP11	120, 115, 780, 230		
S1	11	6	12-15	18-21	11	12	12	24	
	LS1 01- LS1 11	LS1 17- LS1 22	120, 115, 780, 230; B08		LS1 01- LS1 11	LS1 17- LS1 28	120, 115, 780, 230		
S2	9	4	6-12	10-16	7	9	6	14	*Nephtys cirrosa* habitat
	LS2 01(3) - LS2 07	LS2 08 - LS2 11	BO31/B032 BO41/B042		LS2 01 - LS2 07	LS2 08 - LS2 16	B031 B041		
ZBO	7	6	6	12	7	12	(9)	21	*Macoma balthica* habitat
	LZO 01 - LZO 07	LZO 08 - LZO 13	140, ZVL		LZO 01 - LZO 07	LZO 08 - LZO 19	140/140bis, ZVL, ZEB		
OST	7	6	6	12	7	10	9	19	
	LOO 01- LOO 07	LOO 08 - LOO 13	140, ZVL		LOO 01- LOO 07	LOO 08 - LOO 17	140/140bis, ZVL, ZEB		

Table 5.8: Overview of the 5 most dominant taxa regarding total counts (tot. counts) and percentage of occurrence in the samples (% of samples) related to each habitat type. Species in bold are those which are in top 5 of total counts and % of samples.

Abra alba habitat			*Macoma balthica* habitat			*Nephtys cirrosa* habitat		
Taxa	Tot. Counts	% of samples	Taxa	Tot. Counts	% of samples	Taxa	Tot. Counts	% of samples
Owenia fusiformis	54816	43%	**Macoma balthica**	17888	66,00%	**Ensis**	5793	47,20%
Abra alba	14136	65,40%	**Cirratulidae**	4754	69,10%	**Magelona johnstoni**	1158	66,60%
Oligochaeta	9285	75,80%	**Oligochaeta**	4181	64,90%	**Spio**	850	65%
Spiophanes bombyx	7143	75,50%	**Abra alba**	3628	43,90%	**Nephtys cirrosa**	685	80,50%
Kurtiella bidentata	6231	50,70%	Owenia fusiformis	3101	22,10%	**Nephtys juv**	624	75%

5.2.2 Results

Macoma balthica habitat: Dumping site OST and ZBO

In the *Macoma balthica* habitat, in a sandy muddy environment, two dumping sites are present. OST is less frequently used (on average 0.66×10^6 TDM/year [2007-2013]) compared to ZBO (on average 3.21×10^6 TDM/year [2007-2013]). The difference in usage is reflected in the average BEQI scores of each assessment: scores for OST are generally high (high comparability in characteristics between impact and control), scores for ZBO are good (Table 5.9). A similar pattern is observed when the impact is compared with the nC and fC for ZBO. At ZBO, the moderate scores in 2006 and 2007 are related to lower scores for density in 2006, and for density and biomass in 2007. In 2013-2014, the samples taken inside the dumping site were characterized by very low species richness, respectively 9 and 13 taxa, leading to a moderate-poor BEQI score. Figure 5.11 illustrates the slightly decreasing BEQI scores with increasing dumping intensity. In most cases, dumping does not lead to drastic differences (< 0.6 BEQI score) in benthic characteristics in the impact area compared to the control, even at high dumping quantities (>3×10^6 TDM/year).

Table 5.9: BEQI scores for each parameter and the BEQI average score for each year and assessment category. The colours indicate the boundaries of the different classes (blue: high; green: good; yellow: moderate; orange: poor; red: bad comparability). Values indicated in italics were classified as less confident.

	Dumping site Br&W Oostende (OST)						**Dumping site Br&W Zeebrugge-Oost (ZBO)**				
fC+nC	Similarity	No of spp	Density	Biomass	Avg	fC+nC	Similarity	No of spp	Density	Biomass	Avg
2006	0,788	1	*0,902*	*0,765*	0,864	2006	0,53	0,733	0,189	*0,712*	0,541
2007	0,816	1	0,782	0,968	0,892	2007	0,665	0,833	0,224	0,522	0,561
2008	0,853	0,9	0,698	0,387	0,710	2008	0,712	0,7	*0,566*	*0,631*	0,652
2010	0,856	0,87	*0,997*	*0,946*	0,917	2010	0,807	0,8	*0,893*	*0,72*	0,805
2011	0,908	0,853	*0,788*	*0,96*	0,877	2011	0,843	0,855	*0,878*	*0,815*	0,848
2012						2012	0,812	0,7	*0,675*	*0,992*	0,795
2013	0,812	0,95	0,819	0,944	0,881	2013	0,706	0,459	0,811	*0,732*	0,677
2014						2014	0,638	0,386	0,727	*0,94*	0,673
nC	Similarity	No of spp	Density	Biomass	Avg	nC	Similarity	No of spp	Density	Biomass	Avg
2010	0,835	0,724	*0,805*	*0,866*	0,808	2010	0,707	0,725	*0,756*	*0,796*	0,746
2011	0,864	0,785	*0,959*	*0,82*	0,857	2011	0,836	0,847	*0,921*	*0,849*	0,863
2012						2012	0,776	0,657	*0,619*	*0,972*	0,756
2013	0,776	1	0,782	*0,749*	0,827	2013	0,695	0,459	*0,666*	*0,678*	0,625
2014						2014	0,622	0,415	0,599	*0,8*	0,609
						fC	Similarity	No of spp	Density	Biomass	Avg
						2010	0,621	1	*0,761*	*0,655*	0,759
						2011	0,575	1	0,153	0,768	0,624
						2012	0,602	1	0,807	0,937	0,837
						2013	0,611	0,557	0,604	*0,842*	0,654
						2014	0,641	0,415	0,772	0,784	0,653

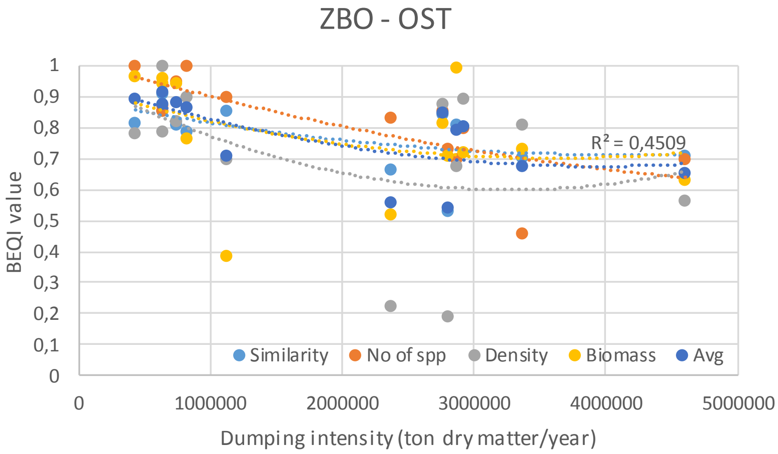


Figure 5.11: Dumping sites ZBO and OST. Relation between dumping intensity (ton dry matter/year) and the BEQI values for each parameter (I versus fC+nC). The trend line is a polynomial order 2. The R² of the average BEQI value is displayed.

Abra alba habitat: Dumping sites NWP and S1

The dumping sites NWP and S1 are located in an environment with fine muddy sand, inhabited by the *Abra alba* community. This valuable community is characterized by a high diversity and high densities of benthic fauna (Van Hoey et al. 2004; Derous et al. 2008). S1 is very intensively used, with an average yearly dumping intensity of 6.33×10^6 TDM/year [2007-2013]. At site NWP, the dumping intensity is much lower (0.16×10^6 TDM/year). This is clearly reflected in the BEQI scores for each assessment year: scores are very low for S1 (poor-moderate comparability) and good-high comparability for NWP. For S1 all BEQI parameters show comparability lower than good. The number of species was classified as moderate, as a result of the lower species richness in the impact data set compared to the control data set (both in nC as fC). The parameters density and biomass were generally classified as bad, as a result of the much lower values in the impact data set. For the comparison impact-nC, this difference is not always that pronounced (poor-moderate to good). The moderate score for similarity (proxy for species composition) indicates that there is a clear difference in species composition between the impact data set and the control. The scores were slightly higher since 2011, due to changes in sampling design (more nC samples, better covering the surroundings of dumping site S1). The response of the macrobenthic characteristics in the *Abra alba* habitat in relation to the dumping intensity clearly shows a decreasing trend, which is most pronounced for the parameters density and biomass (Figure 5.12).

Table 5.10: BEQI scores for each parameter and the BEQI average score for each year and assessment category. The colours indicate the boundaries of the different classes (blue: high; green: good; yellow: moderate; orange: poor; red: bad comparability). Values indicated in italics were classified as less confident.

	Dumping site Nieuwpoort (NWP)						**Dumping site Br&W S1 (S1)**				
fC+nC	Similarity	No of spp	Density	Biomass	Avg	fC+nC	Similarity	No of spp	Density	Biomass	Avg
2006	0,789	0,829	0,959	*0,886*	0,866	2006	0,357	0,413	0,08	0,184	0,259
2007	0,772	0,8	0,452	0,632	0,664	2007	0,452	0,447	0,116	0,045	0,265
2008	0,747	0,767	*0,483*	*0,483*	0,620	2008	0,333	0,339	0,052	0,011	0,184
2010	0,817	0,833	*0,822*	*0,994*	0,867	2010	0,46	0,429	0,047	0,037	0,243
2011	0,814	0,727	*0,777*	*0,795*	0,778	2011	0,551	0,471	0,224	0,602	0,462
2012						2012	0,516	0,418	0,51	0,133	0,394
2013						2013	0,588	0,503	0,37	0,173	0,409
2014	0,778	0,7	0,738	*0,775*	0,748	2014	0,52	0,476	0,347	0,407	0,438
						nC	Similarity	No of spp	Density	Biomass	Avg
						2010	0,509	0,462	0,056	0,081	0,277
						2011	0,539	0,528	0,342	0,603	0,503
						2012	0,55	0,478	0,683	0,21	0,480
						2013	0,621	0,557	0,581	0,303	0,516
						2014	0,56	0,536	0,575	0,612	0,571
fC	Similarity	No of spp	Density	Biomass	Avg	fC	Similarity	No of spp	Density	Biomass	Avg
2006	0,745	0,859	0,99	*0,916*	0,878	2006	0,333	0,396	0,059	0,142	0,233
2007	0,75	0,815	0,455	0,612	0,658	2007	0,403	0,467	0,089	0,034	0,248
2008	0,711	0,8	0,423	0,386	0,580	2008	0,309	0,344	0,043	0,011	0,177
2010	0,802	0,892	*0,759*	*0,914*	0,842	2010	0,398	0,49	0,039	0,023	0,238
2011	0,808	0,785	0,783	0,971	0,837	2011	0,497	0,528	0,166	0,597	0,447
2012						2012	0,45	0,468	0,361	0,099	0,345
2013						2013	0,515	0,547	0,26	0,113	0,359
2014	0,734	0,756	0,748	0,914	0,788	2014	0,445	0,5	0,271	0,286	0,376

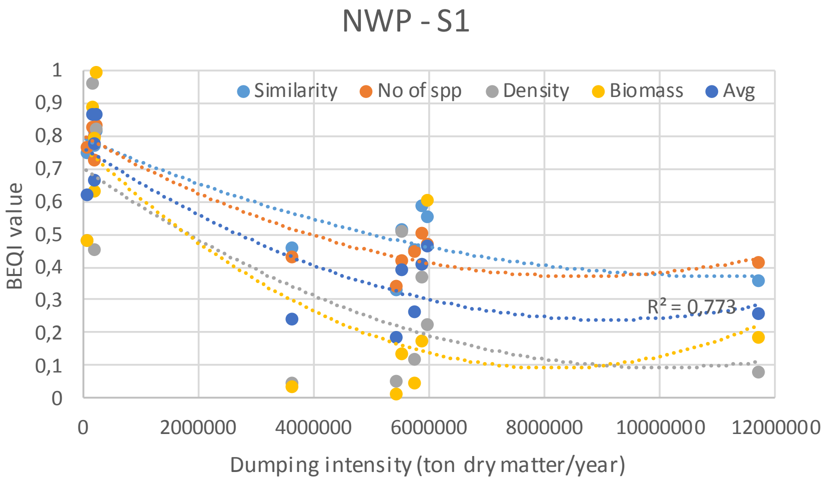


Figure 5.12: Dumping sites NWP and S1. Relation between dumping intensity (ton dry matter/year) and the BEQI values for each parameter (I versus fC+nC). The trend line is a polynomial order 2. The R^2 of the average BEQI value is displayed.

Nephtys cirrosa habitat (Vlakte van de Raan): Dumping site S2

Dumping site S2 is located near the top of the sandbank ‘Vlakte van de Raan’, where the environment is characterized by fine to medium sand, and which is inhabited by the *Nephtys cirrosa* community. The comparability between impact data and control showed to be good too high in most cases, except for the year 2011. In 2011, much higher densities of the Polychaete *Spio spp.* were found in the impact area. The year 2012 also showed a deviation in density and biomass between impact and nC, due to higher densities of *Ensis spp.* in the impact area. This deviation was not classified as bad in the comparison of impact and all control data (nC +fC), due to the presence of *Ensis spp.* in the fC data. Nevertheless, the low confidence of the assessment for density and biomass in 2012 indicated a high variability. The lowest BEQI scores were seen for periods in which the area was subjected to the highest dumping intensities (Figure 5.13). This resulted in an opposite scoring pattern for density- biomass and number of species-similarity.

Table 5.11: BEQI scores for each parameter and the BEQI average score for each year and assessment category. The colours indicate the boundaries of the different classes (blue: high; green: good; yellow: moderate; orange: poor; red: bad comparability). Values indicated in italics were classified as less confident.

	Dumping site Br&W S2				
fC+nC	Similarity	No of spp	Density	Biomass	Avg
2006	0,651	0,833	0,512	*0,688*	0,671
2007	0,676	0,8	0,513	*0,767*	0,689
2008	0,747	0,96	0,905	*0,981*	0,898
2010	0,867	0,877	0,4	0,303	0,612
2011	0,871	0,892	0,171	*0,171*	0,526
2012	0,831	0,817	*0,803*	*0,941*	0,848
2013	0,837	0,8	0,891	0,768	0,824
2014	0,867	0,9	0,831	0,938	0,884
nC	Similarity	No of spp	Density	Biomass	Avg
2010	0,814	0,85	0,504	0,447	0,654
2011	0,818	0,943	0,258	0,173	0,548
2012	0,737	1	0,142	*0,116*	0,499
2013	0,771	0,7	0,798	*0,85*	0,780
2014	0,832	0,867	0,933	0,936	0,892

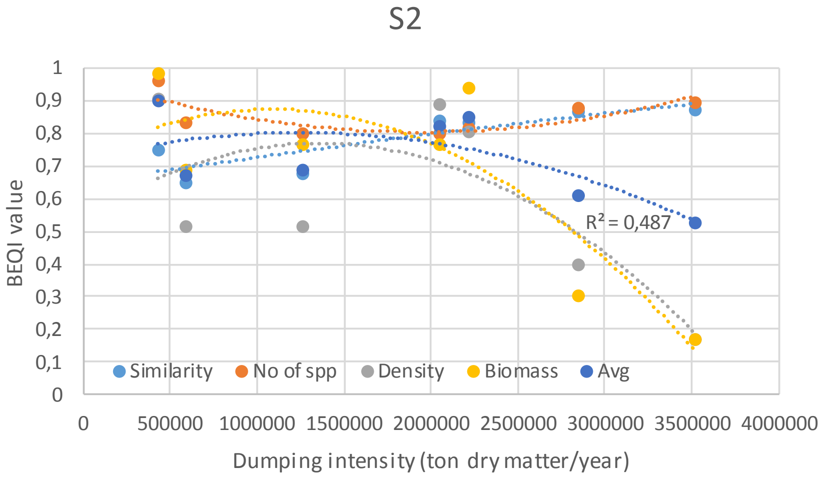


Figure 5.13: Dumping site S2. Relation between dumping intensity (ton dry matter/year) and the BEQI values for each parameter (I versus fC+nC). The trend line is a polynomial order 2. The R² of the average BEQI value is displayed.

5.2.3 Discussion and conclusions

The response of macrobenthos to the dumping of dredged material depends on two factors: (1) the sensitivity of the resident habitat and (2) the dumping intensity. Dumping of dredged mud had a very limited influence at ZBO, were the environment is already muddy and where the *Macoma balthica* resides. This community has natural low species richness and the density of benthic fauna is generally low, due to the naturally occurring anoxic conditions in the top layers and intense disturbance by waves and currents. Consequently, the extra disturbance in the form of dumping of dredged material has a minor influence on the macrobenthic characteristics. Additionally, this habitat is dominated by tolerant species, such as Oligochaeta, *Cirratulidae* spp and *M. balthica* (Table 5.1). Their life-history strategy enables them to quickly recover after disturbance, by means of high recruitment, short life span (*Oligochaeta*) or low mobility (*M. balthica)* (Budd and Rayment 2001).

Dumping mud in in the rich and fine sandy *Abra alba* habitat has a more pronounced influence, because chronic dumping changes the local sedimentology and prevents full recovery. This was clearly observed at S1, where the species richness, densities and biomass deviated from the observations at the control sites. The area of S1 has been frequently and intensely disturbed (cfr. highest dumping intensities) and that resulted in sediment and bathymetry changes. This was clear from the sediment profile imaging analyses (see §5.3). Under these conditions, the benthic community is unable to recover, leading to deterioration and a slightly deviating species composition. The characteristic species of the *Abra alba* habitat, such as the tube builders *Owenia fusiformis* and *Lanice conchilega,* are virtually gone in the dumping site, but they still dominate the surroundings. On the other hand, species like *Magelona johnstoni, Microphthalmus spp.* and *Ophelia borealis* have become more abundant. The latter two species clearly indicating that the sediment became sandier.

At NWP, in the same habitat but with a lower dumping intensity, no obvious influence of dumping was observed for macrobenthos. At site S2, located in a sandier environment (*Nephthys cirrosa* habitat) and with moderate dumping intensity, a 'positive' pattern was observed, with higher densities of certain species and slightly higher species richness. This was confirmed in De Backer et al. (2014). In general, this habitat is characterized by low densities and biomass and no obvious density dominance of certain species (cfr *N. cirrosa*, Table 5.1). This is due to the 'clean' uniform sedimentology. When these conditions are disturbed, by for example adding mud (probably also extra organic material), some species can profit increase their densities (e.g. *Spio spp* and *Ensis spp*. in 2011-2012). However, based on the current data and dumping intensities at S2, it is difficult to determine at which impact level the macrobenthic habitat status really changed.

The analyses performed in the study show that the indicator assessments and related confidence levels are influenced by a number of factors: differences in sampling design, selection of sets of 'control' data, species patchiness, and variation in recruitment success. Such influences were minimized by using different assessment categories and by optimizing coverage of natural variability. Nevertheless, the results indicate that further optimization is required to increase the confidence of the assessments. At the current level of confidence however, there is already strong evidence that the overall influence of dumping on the macrobenthic fauna in the Belgian coastal area depends on both the sensitivity of the habitat and on the intensity level of dumping.

5.3 The use of sediment profile imaging (SPI)

The application of optical complementary techniques in benthic assessments has been proven to be appropriate (Germano et al. 2011). One of the optical techniques, also applicable in more turbid areas, is the sediment profile imagery camera (SPI), which provides a rapid assessment of the environment (sediment characteristics and associated fauna) and potential impacts (Birchenough et al. 2006, 2012a, 2012b; Germano et al. 2011; Nilsson and Rosenberg 2000; Rhoads and Germano 1982; Wilson et al. 2009; Van Hoey et al. 2013). The SPI camera has a clear advantage over conventional sampling devices, as it is a quick tool delivering an undisturbed image of the sediment and presence/absence of biotic structures (e.g. burrows, tubes) with limited time needed for analysis (Germano et al. 2011). In contrast, grab samples (which are also quickly taken) enable a quantitative estimation of the biological data (e.g. species, densities and biomass) and the sediment characteristics, but these analyses are labour intensive and costly. Each technique can provide a different, yet complementary perspective on the benthic community condition (Wilson et al., 2009). Therefore, the applicability of this technique was tested by assessing the benthic habitat conditions at the dredge dumping site S1. SPI sampling was performed at the regular monitoring locations (except 3 nearby control locations) accompanied with 22 extra locations along two transects (Figure 5.14). This was executed at two sampling campaigns, one at 21 November 2014 and one at 16 or 22 July 2015. Some of the locations were sampled at both dates to detect if there are differences over time. Different aspects of 101 pictures (two to four per location) were analysed, as SPI penetration depth, visual sediment description, a-redox discontinuity layer (a-RPD), presences of different types of fauna (Figures 5.14 and 5.15) mud blocks or irregular mud marks in the sandy sediment (Figure 5.14).

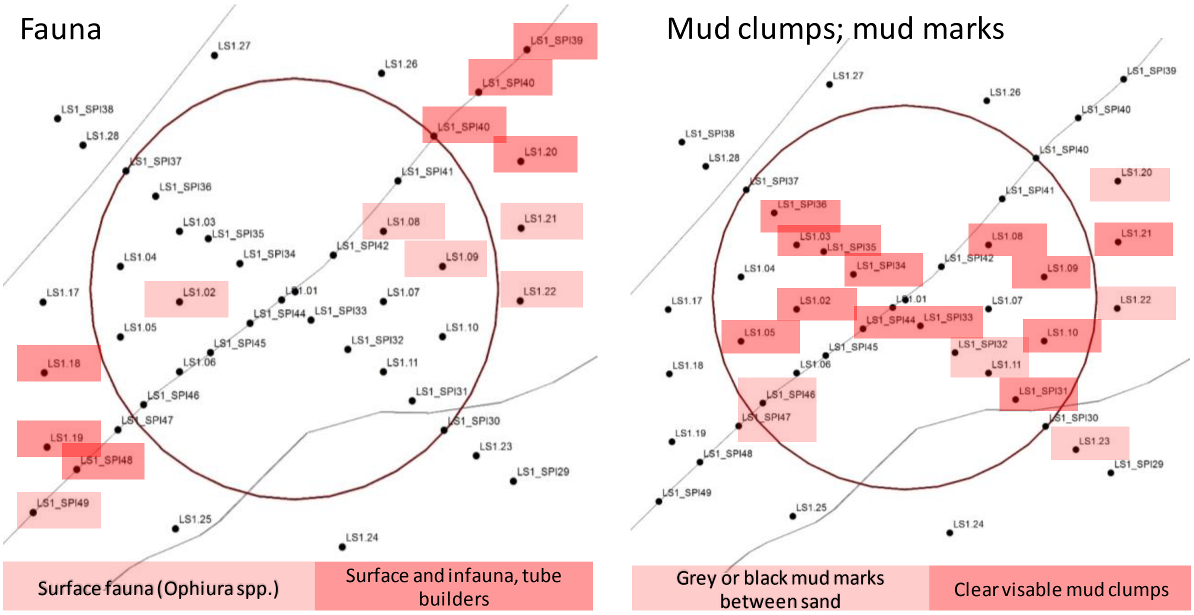


Figure 5.14: Sediment profile imaging (SPI) samples at dumping site S1 with indication at which locations some fauna or mud blocks-marks were clearly visible on the pictures.

The SPI penetration depth varies between 4 and 16 cm, and depends on the sedimentological conditions. Visually, we could classify the sedimentology as medium sand, with presence of mud and shell fragments, especially within the dredged dumping site. The stations with the presence of fauna were more characterized by fine muddy sand. This visual sediment description is fast but rather subjective; therefore a more standardized protocol needs to be developed for it. Regarding the a-RPD layer, no consistent pattern could be observed and really depends on the presence of mud within the sediment, which could vary a lot regarding depth. The conditions regarding sedimentology and a-RPD can give some indication on the habitat potential and occurring fauna (Van Hoey et al. 2013), but in this case a more detailed, quantitative analyses on the images is required. An analysis of the fauna (Figures 5.14 and 5.15) on the pictures revealed clearly the presence of surface fauna (brittle stars, *Ophiura spp.*) and tube building polychaetes (mainly *Lanice conchilega*). Infauna or burrows were more difficult to detect, except the presence of *Echinocardium cordatum* (sea urchin). This fauna was clearly found outside the dumping site in the south west and north east part, whereas it was hard to detect any fauna inside the dumping site (except some brittle stars).

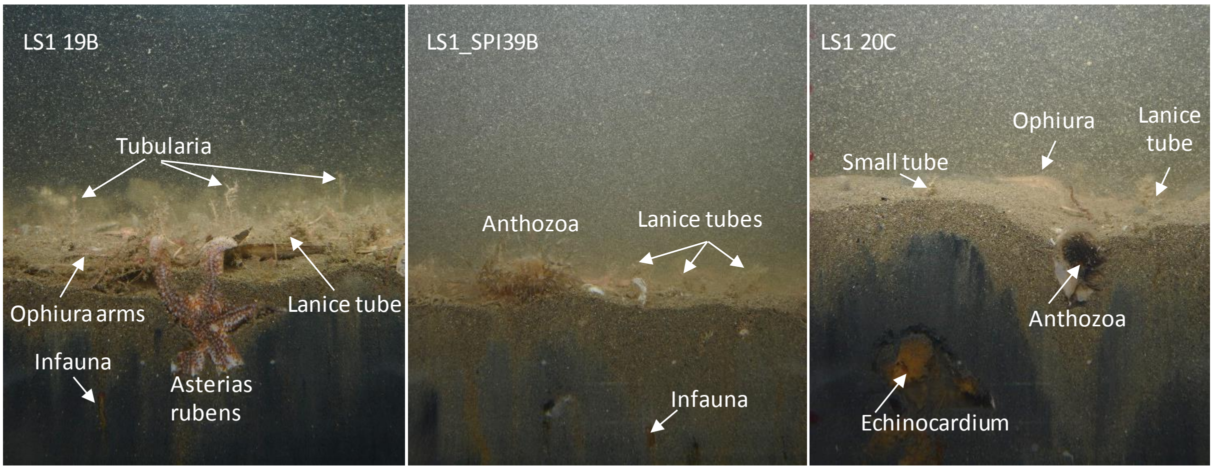


Figure 5.15: Some example pictures at dumping site S1 with indication of the fauna.

A clear signal of possible influence of the dumping activity on the sediment composition could be detected by the presence of mud clumps on or in the sediment (Figure 5.16). These traces were clearly found within and at the north east-east site of the dredged dumping site (Figure 5.14).

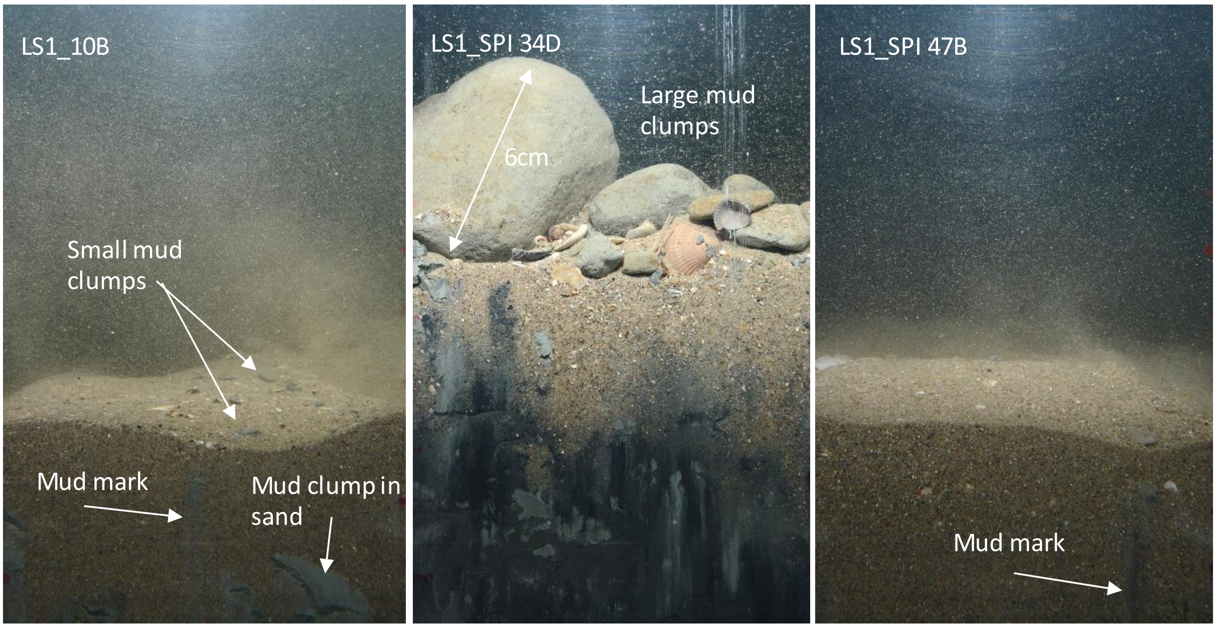


Figure 5.16: Some example pictures at dumping site S1 with indication of different types of dumped mud.

The major surplus value of the SPI camera is that it provides a clear view of the sediment characteristics and organization (layering) at a certain location (Germano et al. 2011). The presence of fauna can also quickly be detected, but mainly the larger individuals (brittle stars, Anthozoa, tube builders) and no infauna, which is the dominating fauna fraction in our grab samples. This visual type of information cannot directly be extracted from grab sample images and analyses, as the sediment structure is not conserved when a Van Veen sample is opened. It is clear that this SPI technology gives complementary information to the classic monitoring, but nothing can be found regarding the occurrence of the infauna.

In order to further use of this technology for bottom status assessment, a more standardized analyses protocol need to be developed. Next to it, this technology needs to be applied at the other dredged dumping sites. At least, this SPI analyses allow a quick screening technique of an area (e.g. Van Hoey et al. 2013), which is useful for sites subjected to changing conditions (e.g. dumping site S2).

5.4 Evaluation of the chemical status of the dumping sites

The chemical status of dumping sites is monitored by evaluating concentrations of organic and inorganic contaminants in sediment and biota, evaluating the presence of marine litter and evaluating cumulative effects on fish health by the determination of fish diseases.

Sediment samples for the routine chemical monitoring taken into account in this report were taken from 2005 to 2014, dividing each dumping site in three zones: (1) the actual dumping site (DMP), (2) the directly impacted zone (IMZ), i.e. outside but less than 0.3 nautical mile away from the actual dumping site and (3) control samples taken on longer distance from the dumping site (REF). Biota samples used for this report were taken from 2002 to 2015. Shrimp (*Crangon crangon*), starfish (*Asterias rubens*) and swimming crab (*Liocarcinus holsatus*, *Liocarcinus marmareus*) were sampled at the three zones.

Statistical analysis on organic and inorganic contaminant time series was done by a linear mixed-effect model in R (Version 2.15.3). The model included the factors time, time^2, dumping site, season and the interaction time:DMP. Normality was evaluated for each model by a histogram and qq-plot of the residuals. Time and dumping site were always included in the model as the objective was two-fold: (1) the identification of significant time trends and (2) the evaluation of the effect of dredged material dumping. All other factors were removed one by one when not significant (α=0.05), starting with the interaction time:DMP. The factor season was included since seasonal effects may occur between samples taken in March (post-winter) or September-October (post-summer). An interaction time:DMP was included since time trends could be different at dumping sites versus control zone. When interaction was significant, the model was applied on each zone separately. Time^2 was included to identify non-linear time trends. Outliers were removed from the sediment model by a sequential process when Cooks distance was larger than 0.2 (De Witte et al. 2016).

Sediment data was compared to background assessment concentrations (BAC) and environmental assessment criteria (EAC). BAC values indicate whether contamination levels are “near background” (for naturally occurring substances) or “close to zero” (for man-made substances). EAC values represent the contaminant concentration in the environment below which no chronic effects are expected to occur in marine species, including the most sensitive species (OSPAR 2009). Values are normalised to 2.5% total organic carbon (PAH, PCB) or 5% Al (Hg, Pb, Cd) in order to compare with BAC and EAC values. For PAH, Cd, Hg and Pb, no EAC values were proposed by OSPAR. Effect Range Low (ERL) values, developed by US-EPA, are given, not normalised to TOC or Al. ERL values also indicate the concentration below which effects are not likely (OSPAR 2009). The ERL value is defined as the lower tenth percentile of the data set of concentrations in sediments which were associated with biological effects. Adverse effects on organisms are rarely observed when concentrations fall below the ERL value, and the ERL therefore has some parallels with the philosophy underlying the OSPAR EACs and WFD EQSs (De Witte et al. 2016).

5.4.1 Organic contaminants

The routine analysis of organic contaminants at the dumping sites involves polychlorobiphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in marine sediments and biota. Analytical methods are described in De Witte et al. (2014, 2016). PAH sediment data starts in 2008. PAH biota data is split in 2-time series due to a method change: time series 1 from 2002 to 2011 and time series 2 from 2013 to 2015. Table 5.12 summarizes time series, with for PAH biota including the longest series, i.e. PAH time series 1. Detailed modelling results are given in annex. For the analysis of PCB, the sum of 7 PCB, suggested by OSPAR for environmental monitoring (OSPAR 2010a), was made. This sum includes IUPAC numbers CB28, CB52, CB101, CB118, CB138, CB153 and CB180. For the PAH sediment analysis, the sum of the 16 priority PAH, as defined by the United States Environmental Protection Agency (US-EPA), was compared (Donata 2010). These include naphthalene, acenaphtylene, acenaphtene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene and benzo(g,h,i)perylene.

Table 5.12: Summary of the monitoring of organic contaminants on dumping sites: sediment data. Zone refers to the area for which the model is valid. ALL reflects a model applicable to all zones. Number of removed outliers is given between brackets (De Witte et al. 2016).

	Zone	Data points	Time effect	Time trend remark	DS effect	Season effect
PCB						
S1	ALL	223 (2)	No		No	No
S2	ALL	105	No		No	No
ZBO	ALL	193	Yes	Increase followed by slight decrease	No	No
OST	ALL	178 (2)	Yes	Increase	No	Higher post-winter
NWP	ALL	145	No		No	No
PAH						
S1	ALL	127 (1)	Yes	Decrease	DMP lower	No
S2	ALL	53 (3)	No		No	No
ZBO	REF	36 (1)	No			No
ZBO	DMP	61	Yes	Decrease		No
ZBO	IMZ	28	No			No
OST	ALL	118 (2)	No		No	No
NWP	ALL	97 (1)	No		No	No

Table 5.13: Summary of the monitoring of organic contaminants on dumping sites: biota data.

	Data points	Time effect	Time trend remark	DS effect	Season effect
PCB-shrimp					
S1	68	Yes	Decrease	No	Higher post-winter
S2	52	Yes	Decrease	No	Higher post-winter
ZBO	52	Yes	Decrease	No	Higher post-winter
OST	35	No		No	Higher post-winter
NWP	52	Yes	Decrease	No	Higher post-winter
PCB-starfish					
S1	60	Yes	Decrease	No	Higher post-winter
S2	33	No		No	No
ZBO	40	No		No	No
OST	29	No		No	No
NWP	67	No		No	No
PCB-swimming crab					
S1	33	Yes	First decrease, than increase	REF lower	No
S2	35	Yes	Decrease	No	No
ZBO	33	No		No	Lower post-winter
OST	19	No		No	Lower post-winter
NWP	37	No		No	Lower post-winter
PAH-shrimp					
S1	43	Yes	Decrease which is flattening	No	No
S2	30	Yes	Decrease followed by slight increase	No	No
ZBO	41	Yes	Decrease followed by slight increase	No	Higher post-winter
OST	24	Yes	Decrease which is flattening	No	No
NWP	45	Yes	Decrease	No	No
PAH-starfish					
S1	34	No		No	No
S2	20	No		No	No
ZBO	30	No		No	No
NWP	38	No		No	Higher post-winter
PAH – swimming crab					
S1	18	No		No	No
S2	17	No		No	Higher post-winter
ZBO	18	No		No	No
NWP	25	No		No	No

For PAH biota, sum was limited to 15 priority PAH, excluding naphthalene, for time series 1 and 12 priority PAH, excluding naphthalene, acenaphtylene, acenaphtene and fluorene for time series 2. Table 5.14 compares individual PCB and PAH data of 2013-2014, averaged and normalised for each dumping site, with BAC, EAC and ERL data.

PCB and PAH sediment data were equal or lower at the actual dumping sites and the IMZ compared to the control sites (REF) (Table 5.12). This is confirmed by measurements in marine biota (Table 5.13), where none of the PAH times series and only 1 PCB time series (PCB in swimming crab at S1) reveal an effect of dumping dredged material. It can be concluded that dumping of dredged material has no local impact on PCB and PAH concentrations at or nearby the dumping sites. Nevertheless, PCB and PAH concentrations are still clearly elevated compared to BAC. Moreover, proposed EAC values are exceeded for CB118 at all dumping sites as well as corresponding control zones (Table 5.14). No decrease of PCB sediment concentrations was found between 2005 and 2014; it even slightly increased at dumping sites ZBO and OST with respectively 36% and 19%, comparing 2005-2006 to 2013-2014 data. This is contrast with shrimp data, for which PCB concentrations decreased at S1 (-19%), S2 (-44%), ZBO (-36%) and NWP (-52%) comparing 2005-2007 to 2013-2015 data, but stayed constant at OST.

*Table 5.14: Comparison with EAC (PCB) and ERL (PAH and metals) data at dumping sites 2013-2014 data. Cd and Pb values are reported in mg.kg^{-1} d.w.. All other values are reported in µg.kg^{-1} d.w. All data are normalised to 2.5% TOC (PAH, PCB) or 5% Al (Hg, Cd, Pb). BAC values are normalised to 2.5% TOC or 5% Al, EAC values are normalised to 2.5% TOC, ERL values are not normalised (De Witte et al. 2016). *Exceedance of EAC*

	S1	S2	ZBO	OST	NWP	BAC	**EAC**/ ERL
Naphthalene	22.8 ± 8.9	54.3 ± 17.1	41.9 ± 9.2	40.0 ± 12.2	37.6 ± 15.1	8	160
Phenanthrene	33.6 ± 12.8	72.5 ± 21.7	56.7 ± 11.0	56.8 ± 11.0	47.9 ± 15.4	32	240
Anthracene	13.5 ± 5.5	25.5 ± 8.0	23.0 ± 5.2	21.6 ± 3.8	19.7 ± 7.0	5	85
Fluoranthene	64.0 ± 24.6	132.9 ± 37.3	112.8 ± 26.7	111.3 ± 25.6	99.0 ± 42.6	39	600
Pyrene	48.3 ± 17.9	98.8 ± 28.5	81.4 ± 19.4	80.8 ± 19.8	73.7 ± 32.7	24	665
Benzo[a]anthracene	27.4 ± 10.7	58.8 ± 17.5	48.3 ± 11.4	48.2 ± 10.0	45.5 ± 19.9	16	261
Chrysene	25.1 ± 9.3	52.8 ± 17.1	38.8 ± 8.5	41.7 ± 7.3	37.2 ± 13.7	20	384
Benzo[a]pyrene	32.1 ± 13.3	68.2 ± 23.4	56.0 ± 13.0	56.8 ± 11.6	55.8 ± 21.1	30	430
Benzo[ghi]perylene	29.7 ± 12.2	61.9 ± 16.3	52.4 ± 11.0	54.3 ± 7.9	52.5 ± 15.1	80	85
Indeno[123cd]pyrene	34.7 ± 14.5	69.0 ± 18.0	64.0 ± 16.7	63.3 ± 14.4	63.3 ± 24.2	103	240
CB28	0.39 ± 0.16	0.78 ± 0.18	0.72 ± 0.15	0.64 ± 0.22	0.57 ± 0.22	0.22	**1.7**
CB52	0.48 ± 0.25	0.43 ± 0.20	0.54 ± 0.15	0.48 ± 0.09	0.43 ± 0.07	0.12	**2.7**
CB101	1.03 ± 0.36	1.15 ± 0.27	1.07 ± 0.23	1.03 ± 0.25	0.98 ± 0.24	0.14	**3.0**
CB118	0.97 ± 0.24*	1.41 ± 0.38*	1.22 ± 0.26*	1.22 ± 0.37*	1.26 ± 0.34*	0.17	**0.6**
CB138	0.89 ± 0.21	1.32 ± 0.30	1.17 ± 0.24	1.14 ± 0.38	1.23 ± 0.27	0.15	**7.9**
CB153	1.41 ± 0.34	2.01 ± 0.36	2.03 ± 0.43	1.84 ± 0.48	1.77 ± 0.52	0.19	**40**
CB180	0.46 ± 0.25	0.59 ± 0.16	0.80 ± 0.25	0.64 ± 0.19	0.48 ± 0.22	0.10	**12**
Hg	66.1 ± 33.1	178.0 ±29.7	176.3 ± 36.9	175.9 ± 22.8	167.1 ± 23.2	70	150
Cd	0.15 ± 0.06	0.37 ± 0.08	0.37 ± 0.05	0.38 ± 0.06	0.35 ± 0.06	0.31	1.2
Pb	22.8 ± 5.1	37.4 ± 5.1	36.0 ± 4.6	37.6 ± 4.1	41.7 ± 4.3	38	47

The use of PCB is banned since mid-80s (OSPAR 2012). Laane et al. (1999) measured a decrease up to 80% in 1981 till 1996 in sediment of the Dutch coastal zone. This sediment data suggests, in accordance with Roose et al. (2005) for 1991-2001 and the Ospar Quality Status Report (OSPAR 2010b) for 1998-2007 that inputs from rivers, atmospheric deposition and dumping of dredged material are of the same order of magnitude as the dilution, outputs and losses at the Belgian part of the North Sea (BPNS) during the last 10 to 15 years (De Witte et al. 2016). This is strengthened by the measurement of high PCB concentrations at local points within the harbour of Oostende (sampling scheme at Figure 5.17, detailed results in appendix 4). The steady state for PCB in sediments suggests that a levelling off of the PCB decrease in shrimp may be expected. For all PCBs, in particular CB118, time monitoring stays important.

PAH sediment concentrations revealed a downward trend at dumping sites S1 and ZBO of 14% and 12% respectively; comparing 2008-2009 with 2013-2014 data while no trend was observed at S2, OST and NWP dumping sites. In biota, the downward trend in shrimp PAH concentrations is flattening or slightly increasing again, pointing out the importance of follow up.

5.4.2 Inorganic contaminants

The routine analysis of inorganic contaminants at the dumping sites involves As, Cd, Cr, Cu, Hg, Ni, Pb, Zn in marine sediments and biota. Fe and Al are measured as normalizers for sediment analysis. Analytical methods for sediment analysis are described in De Witte et al. (2016). For heavy metal analysis on biota, microwave extraction with HNO_3 is performed, followed by ICP-MS or ICP-OES quantification. Mercury is determined by dry combustion with oxygen and Au-adsorption by an AMA254 Hg analyser. Tables 5.15 and 5.16 summarize time series. Detailed modelling results are given in annex. Table 5.14 compares heavy metal data of 2013-2014, averaged and normalised for each dumping site, with BAC, EAC and ERL data.

Concentrations of Cd, Pb and Cr are decreasing at S1, ZBO, OST and NWP. Decreases vary from 10% (OST) to 37% (S1) for Pb/Al ratios, 16% (OST) to 51% (S1) for Cd/AL ratios and 17% (ZBO) to 28% (OST) for Cr/Al ratios when comparing 2005-2006 to 2013-2014 (De Witte et al., 2016). For Cd and Pb, this decrease is also reflected in a strong decrease in heavy metal concentrations for shrimp (Cd, Pb) and starfish (Cd). For Cr, trends in biota are not significant or even slightly increasing for starfish at S2, ZBO and NWP. Concentrations of As decreased at every dumping site from 2005 to 2013, followed by an increase at the end of each time series which should be closely monitored next years.

Hg and Cu sediment concentrations reveal a decreasing trend at most dumping sites. However, for each of these elements, an opposite trend could also be noticed. Hg/Al ratios decrease at S1, ZBO, OST and NWP, varying from 11% (OST) to 45% (S1) whereas an increase of 62% is noticed at S2. In biota, a decreasing trend is found at most sludge dumping sites for Hg in swimming crab but not for Hg in shrimp. Cu/Al concentrations decrease at S1 and NWP with 18 and 28%, respectively. At OST and S2, however, there was an increase of Cu/Al ratios of 17% and 28%, respectively, between 2006 and 2014. Cu biota concentrations strongly decreased in shrimp from 2005 to 2015, with reductions of 39 to 67%, comparing 2005-2007 with 2013-2015 data, but not in starfish and swimming crab. Ni concentrations were constant at every dumping site, except for a decrease at NWP. Ni/Al ratio decreased with 33% from 2005-2006 to 2013-2014.

A decrease of sediment Cu, Cd, Pb, Cr and Hg concentrations at most dumping sites can be related to stringent pollution control measures (OSPAR, 2010b). Trends in contamination in marine sediments are not always reflected in biota data, where trends can be less expressed or even opposite. This indicates the time leg between control measures and their effects on marine biota.

At S2, heavy metal trends are not in line with other dumping sites, with Hg concentrations even increasing. At 2005-2006, Hg levels at S2 were low (99.9 $\mu g.kg^{-1}$ d.w.), increasing to 147 $\mu g.kg^{-1}$ d.w. in 2013-2014. At this remote site, the yearly dumping rate of dredged material strongly increased from 2009-2014 compared to 2005-2008 without clear difference in origin of the dredged material. It is suggested that increased dumping rates resulted in higher contaminant loads which opposed natural trends. Although Hg levels are still lower than ERL values and even lower than Hg levels of ZBO (163 $\mu g.kg^{-1}$ d.w.), this increasing trend should be conscientiously followed in time (De Witte et al. 2016).

Upwards trends in Zn were noted in sediment values of dumping sites OST and NWP, with of Zn/Al ratio increase of respectively 29% and 18% from 2005-2006 to 2013-2014, despite the least intensive use of these sites in comparison with the other sites and the low impacted dredged spoil they receive. In biota, information is dual, since Zn-concentrations in shrimp are decreasing while starfish and swimming crab concentrations are not decreasing or even increasing at OST, ZBO and S2. After the ban on Pb and triorganotin, Cu and Zn based paints are dominating the marine antifouling market (Turner 2010). High concentrations of Cu and Zn are reported in harbours nearby boat- and shipyards. These compounds may enter the marine environment through leaching or by the release of fine paint particles during blasting of boat hulls (Berto et al. 2012; Costa and Wallner-Kersanach 2013; Singh and Turner 2009; Turner 2010; Ytreberg et al. 2010). Ytreberg et al. (2010) report substantially higher Zn concentrations in leisure boat paints compared to paints for professional ship hulls. Since OST and NWP sites both contain a relative large marina, a possible link is suggested.

To investigate a relationship between Zn and/or Cu contamination with antifouling agents and time trends at dumping sites, additional harbour sampling was performed.

Complete results are given in appendix 4; sampling points are shown in Figure 5.17. Four sampling points in the harbour of Nieuwpoort were located close to a shipyard (HNP06-HNP09). However, none of these locations revealed increased Cu and Zn concentrations. The boatyards in Nieuwpoort have adapted strict environmental measures between 2000 and 2010, catching rinsing water and paint spills. In combination with frequent dredging, it can be concluded that Cu and Zn sources are limited and that pollution in the upper sediment layers has already been dredged and dumped at the dumping site. In contrast, HOO04 and HOO08 in the harbour of Oostende reveal increased concentrations during both and HOO07 during one harbour sampling campaign. HOO04 and HOO08 are located inside a dock, which is not routinely dredged. It contains an active and the remains of a historic shipyard, and a small metallurgical company. HOO07 is nearby the active shipyard. Whereas most heavy metal concentrations show a slight increase at HOO04, HOO07 and HOO08 compared to other

Table 5.15: Summary of the monitoring of inorganic contaminants on dumping sites: sediment data. Zone refers to the area for which the model is valid. ALL reflects a model applicable to all zones. Number of removed outliers is given between brackets (De Witte et al., 2016).

	Zone	Data points	Time effect	Time trend remark	DS effect	Season effect
				As		
S1	ALL	220 (1)	Yes	Decrease followed by increase	IMZ lower	No
S2	REF	44	Yes	Decrease followed by increase		No
S2	DMP	68	Yes	Decrease followed by increase		No
S2	IMZ	23	Yes	Decrease followed by increase		No
ZBO	ALL	183	Yes	Decrease followed by increase	No	No
OST	REF	44	Yes	Decrease followed by increase		No
OST	DMP	81	Yes	Decrease followed by increase		No
OST	IMZ	42	Yes	Decrease followed by increase		No
NWP	ALL	126	Yes	Decrease followed by increase	No	Lower post-winter
				Cd		
S1	ALL	227	Yes	Decrease which is flattening	No	No
S2	ALL	147 (1)	No		No	No
ZBO	REF	66	No			No
ZBO	DMP	94	Yes	Decrease		No
ZBO	IMZ	42	Yes	Decrease followed by increase		No
OST	ALL	178 (1)	Yes	Decrease which is flattening	No	Lower post-winter
NWP	REF	43 (1)	No			No
NWP	DMP	69 (1)	Yes	Decrease which is flattening		No
NWP	IMZ	26	Yes	Decrease which is flattening		Lower post-winter
				Cr		
S1	ALL	235 (2)	Yes	Decrease which is flattening	IMZ lower	No
S2	ALL	149	No		No	No
ZBO	REF	67	No			No
ZBO	DMP	94	Yes	Decrease which is flattening		Higher post-winter
ZBO	IMZ	42	Yes	Decrease which is flattening		No
OST	ALL	182	Yes	Decrease which is flattening	No	No
NWP	ALL	138 (2)	Yes	Decrease	No	No
				Cu		
S1	ALL	237	Yes	Decrease which is flattening	No	Lower post-winter
S2	ALL	148 (1)	No		No	No
ZBO	ALL	202 (1)	Yes	Decrease which is flattening	No	No
OST	REF	54	No			No
OST	DMP	87	Yes	Increase		No
OST	IMZ	42	No			No
NWP	ALL	140	Yes	Decrease which is flattening	DMP higher	Lower post-winter
				Hg		
S1	REF	60	No			No
S1	DMP	149	Yes	Decrease		No
S1	IMZ	28	No			No
S2	ALL	136	Yes	Increase	No	Lower post-winter
ZBO	REF	67	No	Decrease followed by increase		No
ZBO	DMP	94	Yes	Decrease		No
ZBO	IMZ	42	Yes	Decrease which is flattening		Higher post-winter
OST	ALL	178 (4)	Yes	Decrease which is flattening	No	No
NWP	ALL	139	Yes	Decrease	DMP higher	Higher post-winter
				Ni		
S1	ALL	236 (1)	No		IMZ lower	Lower post-winter
S2	ALL	149	No	Increase followed by decrease	No	No
ZBO	ALL	203	No		No	No
OST	ALL	182	No		No	Lower post-winter
NWP	ALL	139 (1)	Yes	Decrease	No	Lower post-winter
				Pb		
S1	ALL	237	Yes	Decrease which is flattening	DMP lower	No
S2	ALL	148 (1)	Yes	Decrease which is flattening	No	No
ZBO	ALL	203	Yes	Decrease	No	No
OST	ALL	181 (1)	Yes	Decrease which is flattening	No	No
NWP	ALL	140	Yes	Decrease which is flattening		Lower post-winter
				Zn		
S1	REF	60	Yes	Increase		No
S1	DMP	149	No			Lower post-winter
S1	IMZ	28	No			No
S2	ALL	149	No		No	No
ZBO	ALL	203	No		DMP lower	No
OST	ALL	179 (3)	Yes	Increase which is flattening	No	No
NWP	REF	44	Yes	Increase		Lower post-winter
NWP	DMP	70	Yes	Increase		No
NWP	IMZ	26	No			No

Table 5.16: Summary of the monitoring of inorganic contaminants on dumping sites: biota data.

	Data points	Time effect	Time trend remark	DS effect	Season effect
Cd-shrimp					
S1	72	Yes	Decrease	No	Higher post-winter
S2	57	Yes	Decrease	No	Higher post-winter
ZBO	71	Yes	Decrease which is strenghtening	No	Higher post-winter
OST	47	Yes	Small increase followed by strong decrease	No	Higher post-winter
NWP	65	Yes	Decrease	No	No
Cd-starfish					
S1	66	Yes	Decrease	No	No
S2	40	Yes	Decrease	No	No
ZBO	62	Yes	Decrease	No	Higher post-winter
OST	38	No		No	No
NWP	76	Yes	Decrease	No	No
Cd-swimming crab					
S1	67	No		No	Higher post-winter
S2	40	No		No	No
ZBO	67	No		No	No
OST	33	No		No	No
NWP	52	No		No	No
Cr-shrimp					
S1	66	No		No	No
S2	50	No		No	No
ZBO	66	No		No	No
OST	44	No		No	No
NWP	60	No		No	No
Cr-starfish					
S1	66	No		No	Higher post-winter
S2	40	Yes	Increase	No	Higher post-winter
ZBO	63	Yes	Increase	No	No
OST	37	No		No	No
NWP	75	Yes	Increase	No	No
Cr-swimming crab					
S1	64	No		No	No
S2	40	No		No	No
ZBO	64	No		No	No
OST	30	Yes	Increase followed by decrease	No	No
NWP	49	No		No	No
Cu-shrimp					
S1	72	Yes	Decrease which is strengthening	No	No
S2	57	Yes	Decrease which is strengthening	No	No
ZBO	72	Yes	Decrease which is strengthening	No	No
OST	47	Yes	Decrease	No	No
NWP	65	Yes	Decrease which is strengthening	No	Higher post-winter
Cu-starfish					
S1	66	No		No	No
S2	38	No		No	No
ZBO	61	No		No	No
OST	38	No		No	No
NWP	76	No		No	No
Cu-swimming crab					
S1	68	No		No	Higher post-winter
S2	40	Yes	Increase followed by decrease	No	No
ZBO	68	No		No	No
OST	33	No		No	No
NWP	51	No		No	Higher post-winter

	Data points	Time effect	Time trend remark	DS effect	Season effect
Hg-shrimp					
S1	72	Yes	Increase	No	Higher post-winter
S2	57	No		No	No
ZBO	71	No		No	No
OST	47	No		No	No
NWP	65	No		No	No
Hg-starfish					
S1	60	Yes	Decrease followed by increase	No	No
S2	40	No		No	No
ZBO	52	Yes	Decrease followed by slight increase	No	No
OST	38	No		No	Lower post-winter
NWP	76	Yes	Increase	No	No
Hg-swimming crab					
S1	68	Yes	Decrease	No	No
S2	40	Yes	Decrease	No	No
ZBO	68	Yes	Slight increase followed by decrease	No	No
OST	33	No		No	No
NWP	52	Yes	Decrease which is strengthening	No	No
Pb-shrimp					
S1	72	No		No	No
S2	57	Yes	Decrease	No	No
ZBO	72	Yes	Decrease	No	No
OST	47	Yes	Small increase followed by strong decrease	No	No
NWP	65	Yes	Small increase followed by strong decrease	No	No
Pb-starfish					
S1	66	No		No	No
S2	40	Yes	Increase followed by decrease	No	No
ZBO	63	Yes	Increase followed by decrease	No	Higher post-winter
OST	37	Yes	Increase followed by decrease	No	No
NWP	76	Yes	Increase	No	No
Pb-swimming crab					
S1	68	No		No	No
S2	40	No		No	No
ZBO	68	No		No	No
OST	33	No		No	No
NWP	52	No		No	Higher post-winter
Zn-shrimp					
S1	72	Yes	Decrease	No	Higher post-winter
S2	56	Yes	Decrease	No	Higher post-winter
ZBO	72	Yes	Decrease	No	Higher post-winter
OST	47	Yes	Decrease	No	Higher post-winter
NWP	65	Yes	Decrease	No	Higher post-winter
Zn-starfish					
S1	64	No		No	Higher post-winter
S2	40	Yes	Increase	No	Higher post-winter
ZBO	63	Yes	Increase	No	Higher post-winter
OST	38	Yes	Small decrease followed by increase	No	Higher post-winter
NWP	76	No		No	No
Zn-swimming crab					
S1	68	No		No	No
S2	40	No		No	No
ZBO	68	No		No	Higher post-winter
OST	33	Yes	Increase	No	Higher post-winter
NWP	52	No		No	No

harbour sampling points, concentrations of PCB, Zn and Cu are extremely high, clearly linked to these sources. Due to remobilisation of heavy metals, diffusion, turbidity and tidal working, this will also affect the dredging zones in the harbour of Oostende and its dumping site to some extent. This was shown at HOO07, where Cu and Zn concentrations at 2014 sampling were also elevated in the dredging zones. The size of this harbour effect is unclear and it is, by consequence, not sure this may lead to a significant increase of Cu and Zn concentrations at OST dumping site. Strict monitoring should be continued to follow up these trends. If shipyards play an important role in the level of Cu and Zn concentrations at dumping sites, concentrations at OST are expected to further increase while a decrease can be expected at NWP due to the pollution control measures.

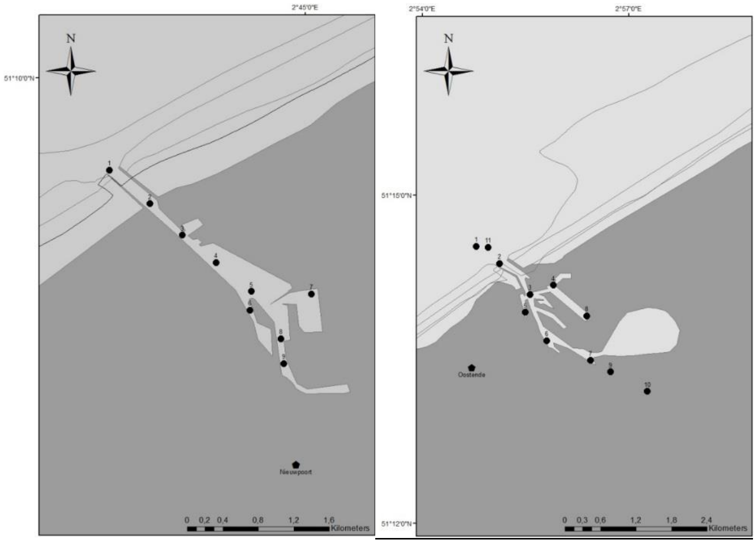


Figure 5.17: Overview of sampling locations at (left) harbour of Nieuwpoort, (right) harbour of Ostend.

5.4.3 Emerging contaminants

In cooperation with VITO, a preliminary screening of emerging contaminants present in water and sediments of the shipping track in and towards harbour Zeebrugge and the Westerscheldt was performed. This area was selected for screening samples as possible source of contaminants towards the dumping sites. A toxicity evaluation done by VITO revealed much higher toxicity in this area compared to Buitenratel, Oostdyck, Hinderbank, Kwintebank or Thorthonbank. Tests were done by Microtox toxicity testing, which is based on the luminescence of *Vibrio fischeri*. Results indicated that microtoxicity of marine sediments on the BPNS was mainly caused by strongly adsorbed contaminants.

An extraction on OASIS HLB cartridges with methanol and ethyl acetate was applied on the water samples prior to LC-MS analysis, whereas a liquid-liquid extraction with dichloromethane was done at pH 11 and 2 for GC-MS screening. Sediment extraction was done by an acetonitrile extraction (LC-MS) or sonication with acetone or dichloromethane (GC-MS).

The GC-MS screening revealed especially fatty acids and esters. However, due to the high amount of sulphur and phthalates, identification of traces of organic contaminants was hampered. The LC-MS screening, on contrary, revealed presence of phthalates and phthalate metabolites, organophosphates and organophosphate metabolites, perfluorinated compounds, parabens, nonylphenols, amidotrizoic acid (radio contrast agent), benzotriazoles, different pesticides and pharmaceutics as well as cationic surfactants. A list of compounds identified is given in annex. It is important to state that the preliminary screening is only indicative since there was no confirmation by retention time. Based on this qualitative screening, a quantitative determination of pesticides was performed on sediment samples by Fytolab. Sediment samples were taken by a Van Veen grab in September 2013 at the shipping track of harbour Zeebrugge and in March 2014 at the central point of each dumping site. No pesticides were found at concentrations higher than the reporting limit for more than 300 pesticides. In annex, an overview of the investigated pesticides with the corresponding reporting limit is given. In 2017-2021, more work will be conducted to look for a broader range of non-routinely monitored organic contaminants.

5.5 Marine litter

Indicator 10.1 (Characteristics of litter in the marine and coastal environment) of Descriptor 10 of the Marine Strategy Framework Directive (MSFD) includes the trends in the amounts of litter deposited on the seafloor, with analysis of its composition, spatial distribution and, where possible, source according to the Commission Decision (2010/477/EU). The protocol and the data sheets for the assessment of seafloor litter were derived from IBTS protocols according to the MSFD GES Technical Subgroup on Marine Litter (ICES/IBTS 2012; Galgani et al. 2013). Different litter categories were defined in accordance with types of litter found at regional level, enabling to define common main categories. The main categories have a hierarchical system including subcategories. It considers 6 main categories of material (plastics, metal, rubber, glass/ceramics, natural products, miscellaneous), each with various subcategories to classify each litter item (ICES/IBTS 2012). Data on litter is reported as average number of items/haul on impact or control locations for sampling campaigns during 2013-2016. The seafloor surface covered by 1 haul represents on average 1.5 ha. For each dumping site, three zones were defined: (1) the actual dumping site (DMP), (2) the directly impacted zone nearby the dumping site (IMZ), and (3) control samples taken on longer distance from the dumping site (REF).

Based on the average number of items litter, the highest amount of litter for dumping site OST was observed on DMP (31 ± 43.5 items/haul) (Figure 5.18). During the period 2013-2016, the number of litter items varied between 6 and 119 per haul at dumping site OST. In general, temporal variations were observed for the recorded abundancy of litter, which is also indicated by the high values for the standard variation. On the REF 140bis, only plastic debris (93%) and natural products (7%) were recorded, while on dumping site OST and IMZ OST, a wider range of materials was observed. Heavy litter items such as glass, ceramics or metals were only observed at dumping site OST and IMZ OST. Plastic comprised 79% of the litter items at dumping site OST and 57% at IMZ OST. The higher number of recorded litter on the impact area and the occurrence of heavy litter items on and near the impact area may give an indication of additional pollution by dredging activities.

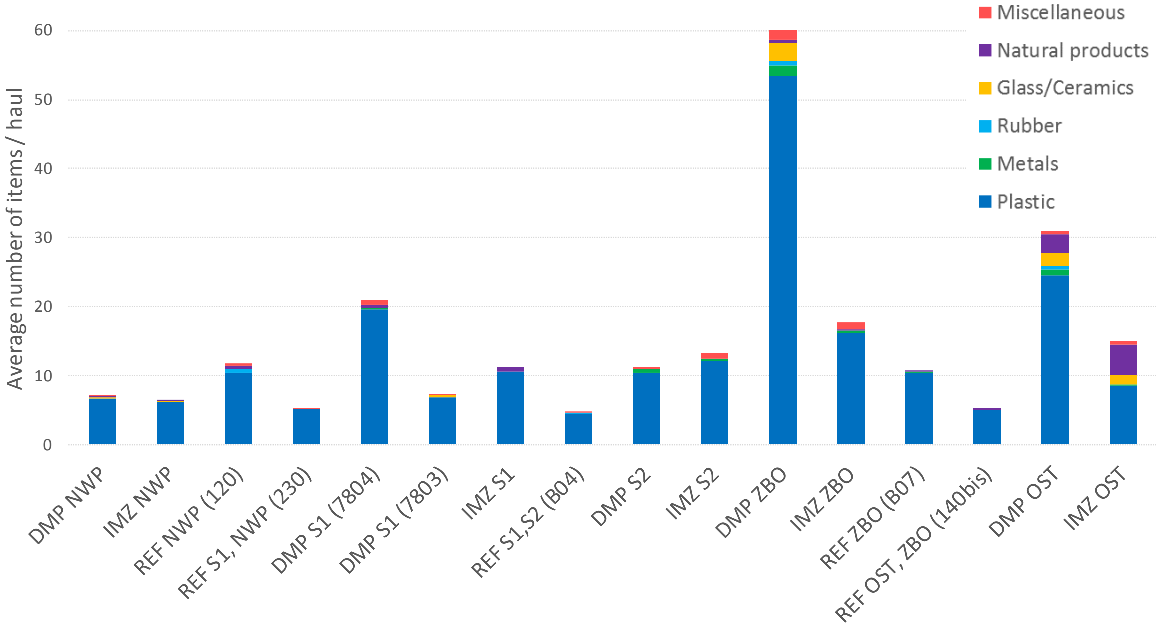


Figure 5.18: Average abundancies of marine litter during the period 2013-2016, reported as average number of items/haul at the actual dumping site (DMP), the directly impacted zone *(IMZ) and the* control samples taken on longer distance from the dumping site (REF). *Marine litter items were classified into the 6 main categories (Plastic, Metals, Rubber, Glass/Ceramics, Natural products, Miscellaneous).*

On average, the highest amount of debris for dumping site S1 was observed at DMP 7804 (21 ± 36.9 items/haul), and the lowest at REF 230 and B04 (Figure 5.18). Again, temporal variations in the abundancy of litter were recorded. On all reference and impact locations, plastic debris comprised the main litter category (92 – 96%). No clear differences in debris composition were observed between the locations. Glass or ceramics items were only observed on IMZ S1, which were probably deposited on or close to this dumping site.

Average amounts of litter were comparable at dumping site S2 (11.3 ± 13.2) and IMZ S2 (13.3 ± 16.0 items/haul) 2, and only slightly higher compared to REF B04 (Figure 5.18). Again, plastics were predominant on all locations (91–93%). Remarkably, metal items were only observed on and nearby the dredging spoil dumping site (4–5%), which were probably deposited on or close to this dumping site.

A spectacularly high abundancy of debris was recorded at dumping site ZBO with an average of 60.3 ± 96.6 items/haul (Figure 5.18). During the period 2013-2016, the number of litter items varied between 13 and 257 per haul at dumping site ZBO, also indicating strong temporal variations. The extremely high value of 257 items/haul obtained during September 2014 is responsible for the high average abundancy of litter at dumping site ZBO. Despite of this high abundancy of litter, no accumulation was observed during the following sampling campaigns. This suggest that debris, mainly plastic (89%), is transported to other locations at sea, which could explain the temporal variation. Metal items were recorded at dumping site ZBO (2%), IMZ ZBO (1%) and REF B07 (2%); while glass or ceramics were only observed on dumping site ZBO (4%). The high abundancy of litter on the impact area and the occurrence of heavy litter items on and near the impact area may give an indication of additional pollution by dredging activities.

The lowest amounts of debris were observed on dumping site NWP (< 10 items/haul) (Figure 5.18). Glass or ceramics items were only observed at dumping site NWP and IMZ WP, but not at REF 120 and REF230, which were probably deposited on or close to this dumping site.

From 2013-2016 data, it can be concluded that plastics were predominant on all dumping sites and control sites (57-96%), which suggests that these areas could be affected by microplastic pollution too. Rubbers, metals, glass or ceramics and miscellaneous categories contributed each with low percentages (<10%). Metals, glass and ceramics are not expected to travel long distances and are probably deposited close to the sampling site. These heavy materials were observed on and in the close proximity of all five dumping sites and only on the control site REF B07. Based on the occurrence of these heavy items and the higher average abundancy of debris on impact sites, substantial amounts of debris are expected to be derived from dredging activities. In general, marine litter abundancy is expected to be affected by several factors including: marine traffic, riverine inputs, geomorphology, population density of nearby cities and human activities at sea. Despite of the higher abundancy of litter on some impact locations, no accumulation was observed during the following sampling campaigns. This suggests that debris, mainly plastic, is transported to other locations at sea, which explains the temporal variation. Due to the relatively small time-frame, trend analysis is still limited and the impact of dredge disposal cannot be fully assessed based on this dataset. This underlines the need for more sampling periods and additional sampling locations, and the need for long term trends based on marine litter data.

5.6 Fish diseases

Fish diseases are considered to be an appropriate indicator for environmental changes because the outbreak of a disease represents an end-point of biological significance integrating all environmental factors affecting fish health. In Belgium, the evaluation of externally visible fish diseases was included in the Marine Strategy Framework Directive, which was formally adopted by the European Union in July 2008 (2008/56/EC). Indicator 8.2 (Effects of contaminants) of Descriptor 8 includes the prevalence of externally visible diseases and parasites on dab (*Limanda limanda*) according to the OSPAR JAMP guideline on Integrated Guidelines for the Integrated Monitoring and Assessment of Contaminants. The diseases and parasites of fish were determined according to the ICES Training guide for identification (Bucke et al. 1996). Data on fish diseases is reported as average observed prevalence (%) for sampling campaigns during 2010-2015/2016. It is problematic to define background levels or environmental assessment criteria for fish disease data due to the natural variation in disease prevalence on a temporal and regional scale. As a consequence, long-term prevalence data (since 2000) is used as a guideline.

5.6.1 Parasites

The overall observed prevalence of the trematode *Stephanostomum baccatum* was prominently lower in the sampling period 2010-2016 compared to 2000-2010 (Figure 5.19). This parasite was almost not recorded (prevalence <1%) in the period 2010-2016. The most abundant parasite on dab, was *Glugea stephani* (7-15%), on all sampled locations of the BPNS (Figure 5.19). In general, parasitic infections were more abundant in coastal areas compared to offshore areas. No clear differences in disease profile could be observed between dumping sites and other location on the BPNS.

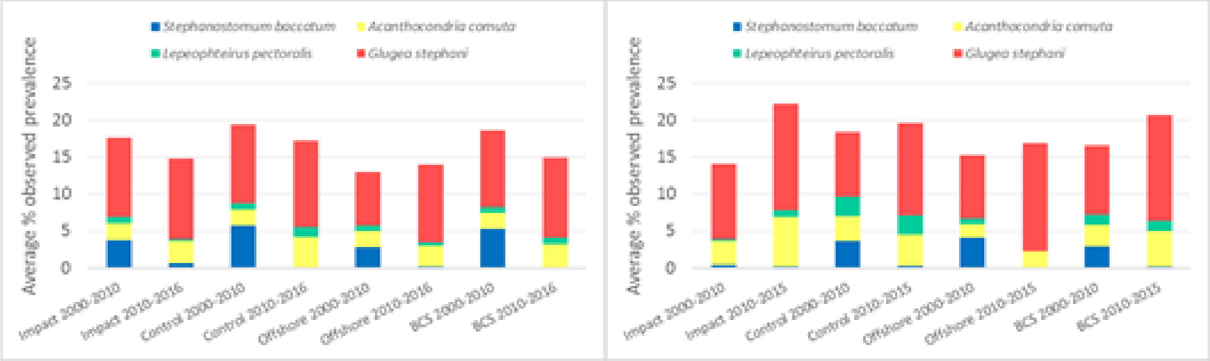


Figure 5.19: Average observed prevalence (%) of four parasites on dab during February/March (left) and September/October (right) 2000-2010 and 2010-2015/2016 on or nearby dumping sites (impact), coastal areas (control), offshore areas and the BCS.

5.6.2 Deformations, infections and nodules

Especially skin ulcers, skeletal malformations, liver nodules, skin papilloma's and lymphocystis can provide valuable information on changes in the environmental health and may act as an 'alarm bell'. As lymphocystis has not been detected on dab on the BPNS since 2007 (with some uncommon exceptions), this disease was not included in Figure 5.20. The disease profile of dab in February/March is clearly different from that in September/October (Figure 5.20; Figure 5.19), especially for the prevalence of epidermal papilloma. A clear increase of dab with skin ulceration was recorded for the sampling period 2010-2015/2016 on all sampling locations. This is mainly due to the remarkably high prevalence in 2011-2014 (Devriese et al. 2015). In general, a sudden increase in the prevalence of skin ulceration points at changes in the environmental conditions. Based on these severe diseases, no major difference could be observed between the dumping site, the control areas and the BPNS.

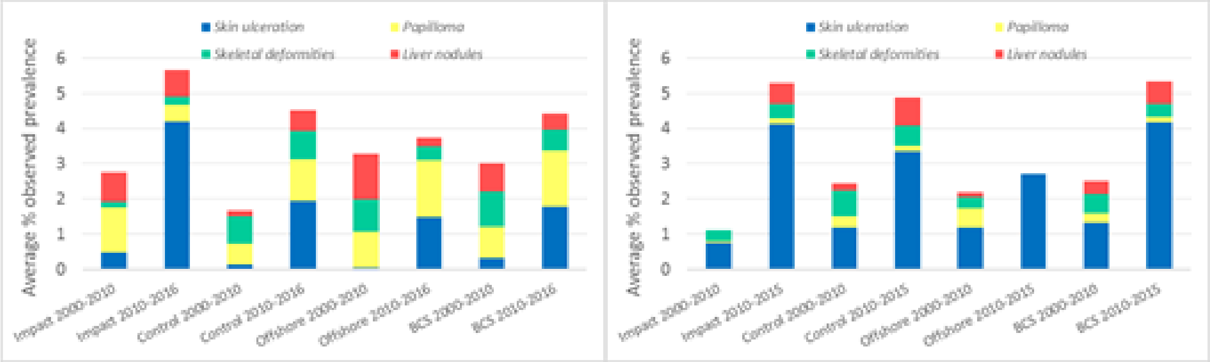


Figure 5.20: Average observed prevalence (%) of four diseases on dab during February/March (left) and September/October (right) 2000-2010 and 2010-2015/2016 on or nearby dumping sites (impact), coastal areas (control), offshore areas and the BPNS.

5.6.3 Fish disease index

The fish disease index (FDI) was adapted from Lang and Wosniok (2008) (ICES 2012), based on presence/absence of nine key diseases (including 3 parasites) and disease-specific weighting factors. The severity grade scaling for each key disease was not incorporated. Low FDI values represent healthy and high FDI values represent diseased fish. For the assessment of fish disease index data, mean FDI values must be reported for each sampling area. In Figure 5.21, mean FDI values were visualized for areas on and nearby dumping sites (impact) and other areas on the BPNS. Based on the mean FDI values, no significant (ANOVA, p=0.8) difference was observed between dumping sites and other locations on the BPNS.

5.6.4 Conclusions

Most of the observed anomalies were due to parasitical infections. Severe diseases such as skin ulcers, skeletal malformations, liver nodules, skin papillomas and lymphocystis, which might indicate effects of pollution, were rare on the investigated zones of the BPNS. No outstanding differences could be detected on the basis of fish diseases between the dumping sites and the control zones. Since diseases are considered as an integrative and ecologically relevant indicator of exposure to environmental stress, it is recommended to monitor fish diseases as indicators in the context of assessing the impact of stressors on the marine environment (Lang et al. 2016) whereas the FDI approach is a strong tool suitable for the assessment of ecosystem health. Taken into account the habitat of individual fish, determination of fish diseases is mainly an indicator for the status of a larger area, e.g. the BPNS and will therefore not be continued for dumping site assessments.

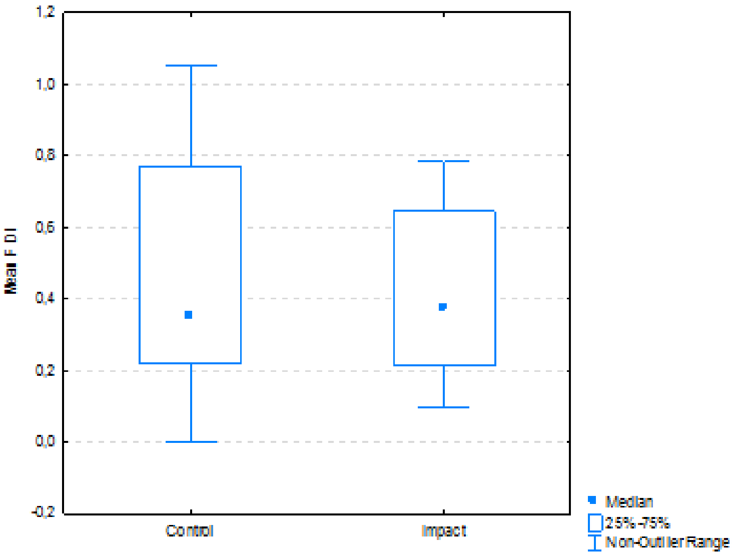


Figure 5.21: Mean FDI values for areas on and nearby dumping sites (Impact) and other areas on the BPNS (Control) during September/October 2014.

6. Implemented projects and studies

6.1. Field study alternative dumping location west of Zeebrugge

On the Belgian Continental Shelf five locations have been designed for the dumping of dredged material originating from maintenance dredging in harbours and waterways. Depending on the location, significant amounts of the disposed matter may recirculate in suspension or as high concentrated benthic layers back to the dredging areas, increasing thus the volume to be dredged and disposed. About 3×10^6 tons of dry matter (TDM) per year of the total amount of approximately 5×10^6 TDM mainly fine-grained sediments that is dredged in the harbour of Zeebrugge is disposed on the dumping site ZBO. Modelling results, carried out in the framework of the MOMO project (Van den Eynde and Fettweis 2006) have shown that a significant part of the disposed sediments on ZBO recirculates back to the dredging locations (harbour, shipping lanes). It was suggested that a relocation of the dumping site to another location at equal distance to the dredging area could reduce this recirculation, by making a better use of the local hydrodynamic conditions. A preliminary study was carried out using numerical models, and resulted in a series of possible alternative dumping sites to the West of Zeebrugge (Fettweis et al. 2011). Based on the modelling results, a one year field study was set up in 2013-2014. The following paragraphs give a general overview of the study, for more detailed information the reader is referred to Fettweis et al. (2016).

6.1.1 The study site

The outer harbour of Zeebrugge, situated in the Belgian nearshore area (see paragraph 4.1) is reclaimed from the sea and is protected from it by two breakwaters, each about 4 km in length (Vanlede and Dujardin 2014), see Figure 6.1. The harbour mouth is in open connection to the sea. The open water surface is 6×10^6 m², which gives a tidal volume of 24×10^6 m³. The cross-sectional surface between the harbour and sea is about 12,000 m². The sediment exchange between the harbour and the sea is caused mainly by horizontal and to a lesser extend vertical exchange at the harbour mouth (Vanlede and Dujardin 2014).

6.1.2 Methodology and results

The field study lasted for 1 year and consisted of eleven months of disposing the dredged material on the existing dumping site ZBO, which induces recirculation of the disposed material back to the dredging sites, and of a one month period (further called 'field experiment') with dumping on an alternative site (ZBW) with limited recirculation, see Figure 6.1. In total about 3×10^6 TDM have been dredged and disposed during the period March 2013 – March 2014 on the sites of ZBO and ZBW. Of this total, 0.41×10^6 TDM (14% of the amount) were disposed on the ZBW site during the one month field experiment. The dumping on site ZBW occurred between 21 October 2013 and 20 November 2013. The 11 month period of dumping on site ZBO (further called 'dumping as usual') was situated between February 2013 and March 2014. Besides the monitoring station MOW1, where data are available since 2005 (Fettweis and Baeye 2015), a second station (WZ-buoy) outside the harbour and four inside the harbour were installed during the field study.

Outside the harbour, current velocity, salinity, SPM concentration and altimetry were collected with tripods at MOW1, located about 5 km offshore, and at WZ-buoy located at about 2 km from the harbour entrance (Figure 6.1). Both measuring stations are situated in the influence zone from dispersion of dredged material dumping at ZBO (Van den Eynde and Fettweis 2006). Inside the harbour current velocity, salinity and SPM concentration were measured at four locations (Sterneneiland, Albert II dock, LNG and Hermespier) at two points in the water column, respectively about 2 m below MLLWS and about 2 mab.

The number of data at WZ-buoy comprises 254 (OBS), 310 (Aquadopp) and 320 LISST tidal cycles; and at MOW1 about 1390 (LISST) and 2430 (ADP, OBS) tidal cycles collected during different seasonal, tidal, and meteorological conditions. To every tidal cycle classification, parameters were assigned that take into account seasons, tidal range, alongshore current, and the significant wave height. Each tidal cycle starts at high water (HW) and finishes at the following HW and was resampled to obtain 50 data points per cycle (i.e., every 15 min). The tidal cycles of each class were then ensemble averaged, and the standard error was calculated. The standard error estimates how far the sample mean is likely to be from the population mean and will decrease with increasing sample size.

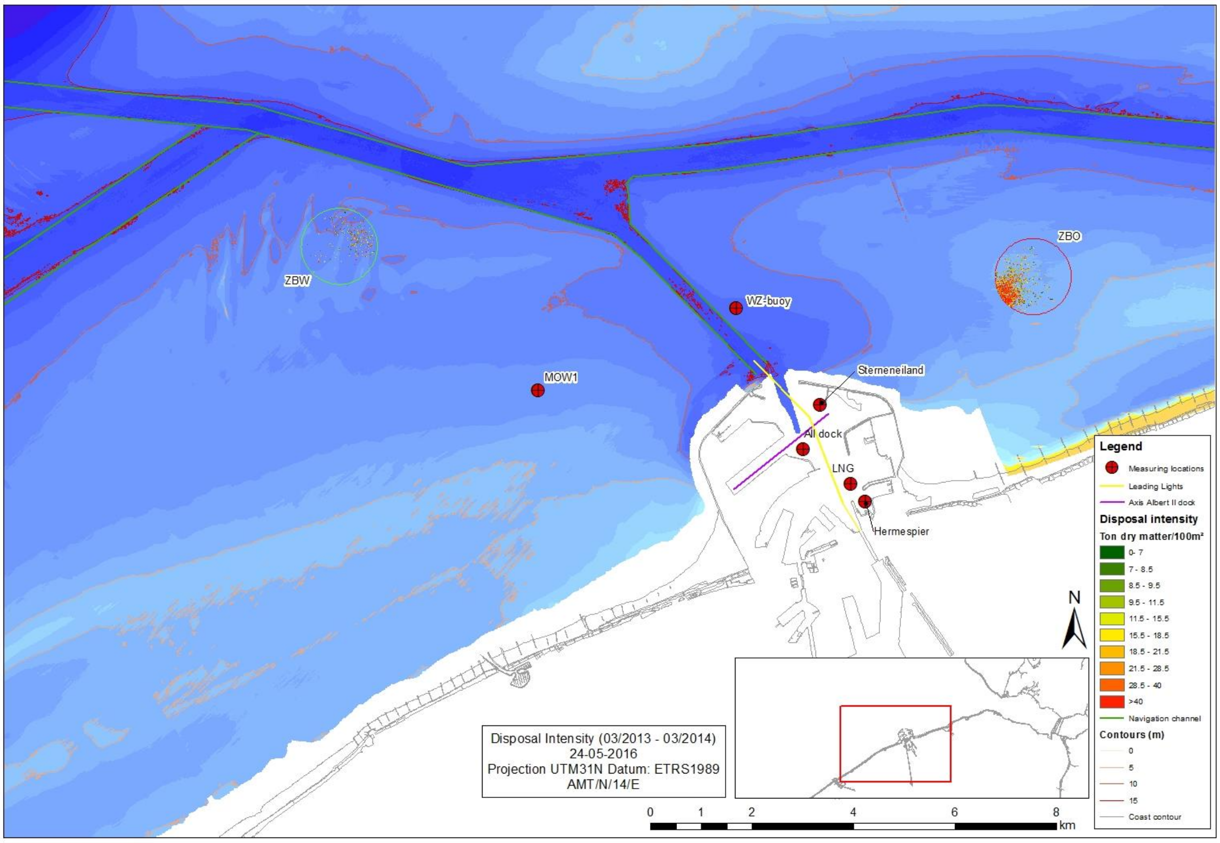


Figure 6.1: Map of the Belgian coastal area (southern North Sea) showing the measurement stations outside (MOW1, WZ-Buoy) and inside the port of Zeebrugge (Hermespier, LNG, Albert II dock (AII dock) and Sterneneiland), the regular dumping site ZBO and the dumping site ZBW used during the field experiment. The background consists of bathymetry and of the dredging and dumping intensity during 2013.

In order to take spring-neap cycles, seasonality and meteorology as much as possible into account, the evaluation of the field experiment was based on a 15 days periods prior to the field experiment (T0: 06-20/10/2013), a 15 days period during the winter 2013 (Winter 1: 28/01-13/02/2013) and the winter 2013 with dumping on ZBO (winter-ZBO); the field experiment was also divided in two 15 days periods (ZBW1: 21/10-05/11/2013, ZBW2: 06/11-21/11/2013), see Figure 6.2. A comparison of the ensemble averaged SPM concentrations during these different periods as well as during winters of 2005-2012 is shown in Figure 6.3 for the MOW1 station. Similar results have been found at the WZ-buoy location for the ADP derived SPM concentrations. The data indicate that the SPM concentration was higher during the 2013 winter with dumping on ZBO than during the previous winters. The data also show that the difference between T0 and ZBW1 is more pronounced during ebb (from about 3 h before to 3 h after LW) and at the beginning of flood. The dumping site ZBO is situated in ebb direction of the measurement sites and the decrease in concentration is thus in line with expectations. Further the ZBW2 period is more similar with the T0 than the ZBW1 period. The averaged values (see Fettweis et al. 2016)) show that variations in SPM concentrations due to waves, seasons or dumping are more visible in the near bed layer than higher up in the water column.

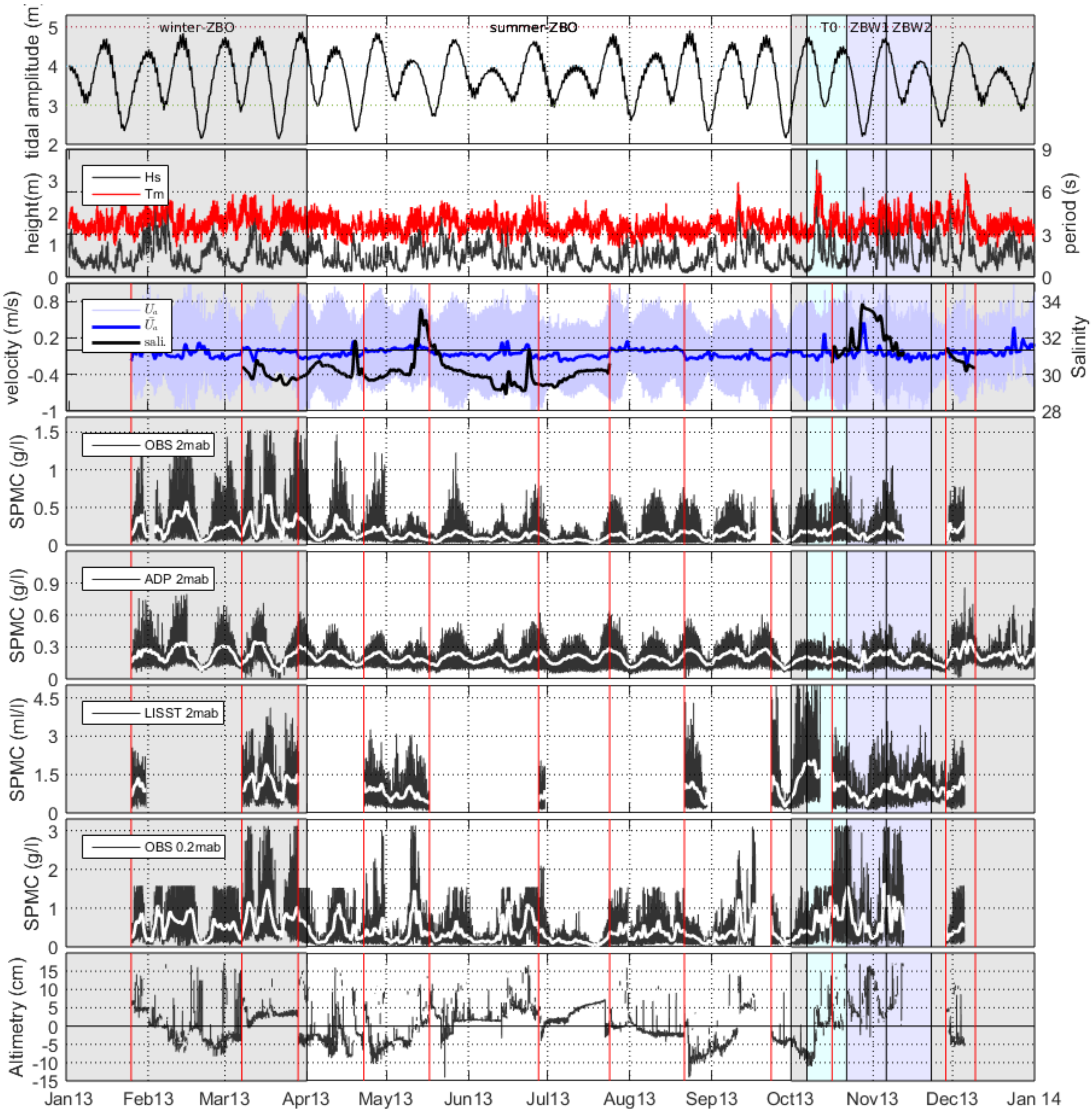


Figure 6.2: MOW1 location, 1 January 2013 – 31 December 2013 time series of tidal amplitude, significant wave height (H_s) and mean wave period (T_m), alongshore currents (U_a), residual alongshore currents (positive is towards the NE, negative towards the SW) and salinity; SPM mass and volume concentration at 2 and 0.2 mab (SPMC) for ADP and OBS; and altimetry (decrease: erosion, increase: accretion). Red lines indicate the start/end of a tripod deployment.

6.1.3 Discussion

The results based on time-series measurements at two fixed location outside the harbour and 4 stations inside the harbour and on echo soundings and density measurements inside the harbour before, during and after the relocation of a dumping site did not indicate unambiguously that the relocation resulted in a decrease of the SPM concentration outside and a reduction of the siltation inside the harbour. The main reason for this is that the most important changes in tidal averaged SPM concentration at MOW1 are due to tidal range (70% higher during spring than neap tide), waves (27% at 0.2 mab and 24% at 2 mab higher during high (>1.2m) than low (<0.6m) waves), seasons (30% at 0.2 mab and 65% at 2 mab higher in winter than summer) and residual alongshore flow (19% at 0.2 mab and 25% at 2 mab higher during SW-ward than NE-ward directed residual alongshore). In order to detect these changes, the evaluation of the field experiment was based on statistical testing together with an analysis of the environmental conditions. The null hypotheses to be tested are: 1) the SPM concentration at the measuring locations outside the harbour is the same during the field experiment (ZBW) and during dumping as usual (T0, winter-ZBO) and 2) the siltation in the harbour during the field experiment (ZBW) is the same than during dumping as usual (T0, winter-ZBO).

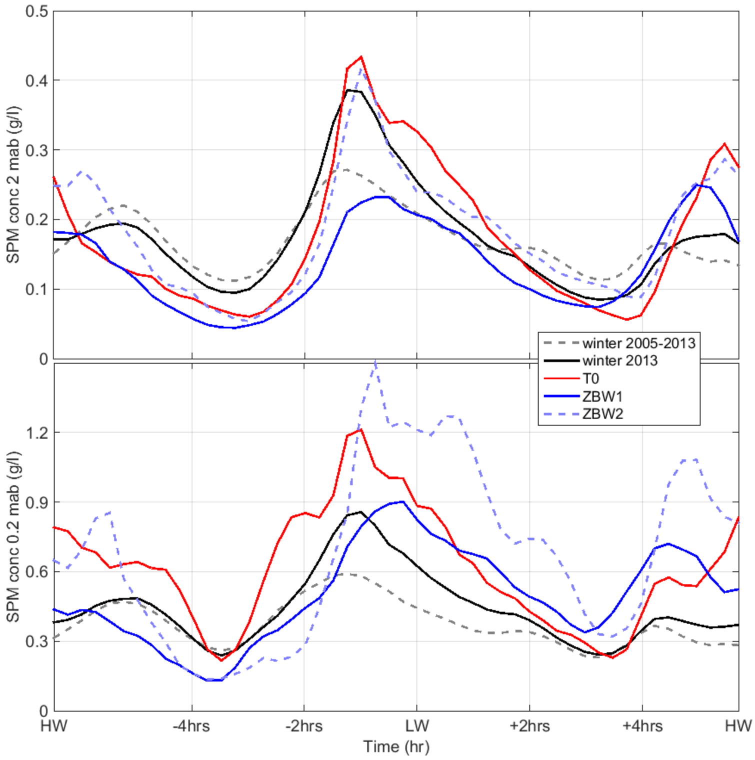


Figure 6.3: MOW1, ensemble averaged OBS-derived SPM concentration at 2 and 0.2 mab during a tidal cycle for different periods in winter (winter 2013: without ZBW1+ZBW2; T0: 6-20/10/2013, ZBW1:21/10-5/11/2013, ZBW2: 6-21/11/2013).

Statistical analysis outside the port

The evaluation of the first null hypothesis is based on Wilcoxon's test. The P-values, which are the probability of obtaining results equal or more extreme than what was actually observed, when the null hypothesis is true, indicate that the mean SPM concentration during winter-ZBO and ZBW1 and winter-ZBO and ZBW2 are - depending on the height of the OBS above the bed - not always statistically different, and therefore the null hypothesis fails partially to be rejected. Further, due to the fact that various forces change SPM concentration, 15 days periods within the winter of 2013 can be found to have statistically different means than the winter-ZBO (e.g. T0), although no change in dumping has occurred. Also 15 days periods with different dumping strategy have statistically similar mean SPM concentrations. Another way of statistically looking at the data is to calculate the probability that the SPM concentration during a certain period is higher/lower than during another period. This was done by randomly sample the population of SPM concentration during both periods and to compare the values. The results indicate that the probability of having a lower OBS-derived SPM concentration during the field experiment than during T0 is 55% (ZBW1: 41%; ZBW2: 53%) at 0.2 mab and 44% (ZBW1: 35%; ZBW2: 53%) at 2 mab, which slightly more than just by chance. The probability distributions of the OBS derived SPM concentrations are shown in Figure 6.4. The geometric mean SPM concentrations are within one standard deviation of each other and illustrate that the natural variability of SPM concentration is higher than the human induced one at the measuring locations.

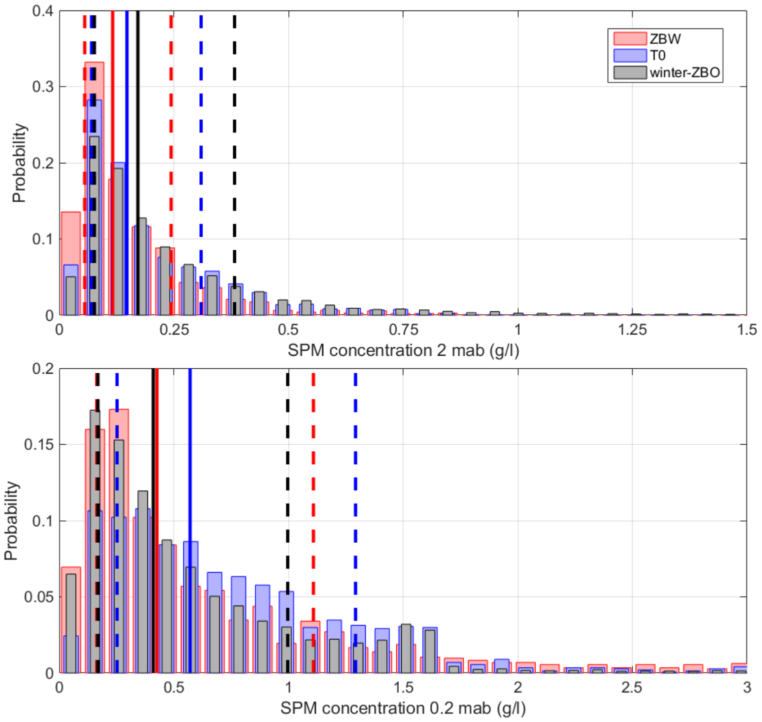


*Figure 6.4: Probability distribution of SPM concentration measured at MOW1 at 2 mab and 0.2 mab. The black line shows geometric mean SPM concentration for the winter data with dumping on ZBO. The blue and red lines are geometric mean SPM concentration for the T0 period and ZBW1 period respectively. The dashed lines are */ one standard deviation. The higher probability around 1.5 g/l is due to saturation of the lower OBS.*

Statistical testing is based on the assumption that the sample is representative for the whole population. The large data set available at MOW1 (2005-2013) can be seen as a representative subsample of the whole population of SPM concentration with dumping on site ZBO. However, some doubts can be formulated, given the large variability due to random natural forcing, that the one month period with dumping on ZBW is a representative subsample. Further, statistical testing assumes that the samples are independent if they come from unrelated populations and the samples do not affect each other. These assumptions are not guaranteed within our experiment as it is not only the forcing that influence SPM concentrations but also the sediment availability that is depending on the siltation history.

Environmental analysis outside the harbour

The field experiment (ZBW) was characterized by variable winds from mainly W to SW direction. The wind velocities were higher during the field experiment than during the 2013 winter with dumping on ZBO. This resulted in strongly variable residual alongshore currents and a higher frequency of strong negative and positive residual alongshore currents and also higher significant wave heights than during the 2013 winter with dumping on ZBO. The OBS derived SPM concentrations at 0.2 and 2 mab were lower in both stations outside the harbour during the first 15 days of the field experiment (ZBW1) than during T0. The mean in situ OBS derived SPM concentration at MOW1 was about 140 mg/l at 0.2 mab and about 30 mg/l at 2 mab lower during ZBW1 than during T0. This equals a reduction of the averaged SPM concentration by 20% during ZBW1, which is larger than the model result. The effects during ZBW2 were lower (-15 mg/l at 0.2 mab and +30 mg/l at 2 mab), and correspond with a reduction by about 8% (0.2 mab) and an increase by about 7% (2 mab) as compared with T0, which is thus less than predicted by the model. The different results for ZBW1 and ZBW2 were triggered by the occurrence of two storm periods with high waves during ZBW2 and by the differences in residual alongshore currents (ZBW1: U_a=+1.4cm/s; ZBW2: U_a=-9.7cm/s). If we consider only data measured during low wave activity (H_s<0.6m) then the 0.2 mab OBS derived SPM concentration at MOW1 during ZBW1 (ZBW2) is about 40% (15%) lower than during T0. Same results at 2 mab are not conclusive as wave influences are mainly concentrated in the near bed layer and thus other forces (tidal range) dominate more the signal at 2 mab (Fettweis and Baeye 2015). The positive (NE-ward directed) residual alongshore currents during ZBW1 explain the larger decrease in SPM concentration during ZBW1 than during ZBW2, when a SW-ward directed residual alongshore currents was prevailing.

The results from the LISST derived SPM volume concentration at MOW1 during different periods support those of the OBS, but are more pronounced. The mean ADP derived SPM concentration during ZBW1 indicate a decrease of about 2% at MOW1 and 10% at WZ buoy as compared with the T0 period. The differences are thus less pronounced and are probably caused by the higher uncertainty in the ADP than the OBS derived data, due to the fact that the model is a simplification of reality and that the echo intensity of the backscattered acoustic signal gives a good indication of SPM concentration variation if the particle size distribution and characteristics remain the same (Thorne and Hurther 2014; Rai and Kumar 2015). The results of all sensors are, however, in line with the fact that the positive (NE-ward directed) residual alongshore flow was responsible for the lower SPM concentration during ZBW1 than T0, and that the higher waves together with a stronger negative residual alongshore flow were responsible for the almost similar SPM concentration during ZBW2 and T0.

Analysis of SPM concentration and thickness of the mud layer inside the harbour

All measurement locations inside the harbour show increasing SPM concentrations for T0 over ZBW1 to ZBW2. A t-test for non-normal distributions (Wilcoxon's test) was used to investigate whether these increases are statistically significant at a 95% confidence level. The null hypothesis of this test is that the mean values of the populations are identical. In addition, a Welch test (one-sided t-test) was used to calculate the confidence interval around the difference between the mean of the populations (Welsh difference) at the same confidence level as the Wilcoxon test.

Seven 15 day periods were investigated: T0, ZBW1, ZBW2 and two periods with comparable meteorological conditions as ZBW1 and ZBW2, both in summer (summer 1, summer 2) and winter (winter 2, winter 3). Under equal meteorological circumstances one would expect SPM concentrations to rise from summer conditions, over T0 to winter conditions. Due to the use of an alternative dumping site, SPM concentrations during ZBW1 and ZBW2 should be lower or at least should not rise as much as between T0 and typical winter conditions. The tests show low p-values results for most locations, indicating that the mean SPM values are significantly different. In contrast to what was expected, especially when comparing the first half of the experiment, the mean of the summer population is only slightly lower or even higher (summer 1) than the mean of the T0 period. This could indicate that meteorological influences are as important as seasonal variation. For the other populations a steady increase of mean SPM concentrations can be observed for T0 over ZBW1 and ZBW2 to similar winter conditions. Only for the location LNG Upper it can be proved that the mean SPM concentration during the experiment was at least 1.7 mg/l lower than during T0 and 17.4 mg/l lower than during winter. For most other locations the increase in mean SPM concentration from ZBW1 and ZBW2 to similar winter conditions is of the same order of magnitude as the increase from T0 to winter conditions. This gives the impression that the field experiment caused a (relative) decrease of SPM concentrations inside the harbour. However, the statistical tests are not conclusive, because of the large spread on the confidence intervals. Meteorological and seasonal differences probably have a bigger influence on the observed SPM concentrations inside the harbour than the use of an alternative dumping site.

Figure 6.5 shows that the mud volume in the harbour (defined as the difference between the 33 kHz and the 210 kHz echo soundings) during the T0 period was exceptionally low. This could provoke higher sedimentation rates during the period thereafter (ZBW1). The distribution of the mud volume changes per day in the Albert II dock is shown in Figure 6.5 for different periods with respect to the mud volumes during periods ZBW1 and ZBW2. The figure shows that no significant increase was seen in the rates of mud volume accretion during the first half of the field experiment. During the second half of the experiment (ZBW2) even a slight (although statistically not significant) decrease can be observed in the Albert II dock, which could point to a lower sedimentation in the harbour of Zeebrugge due to the relocation of the dumping site.

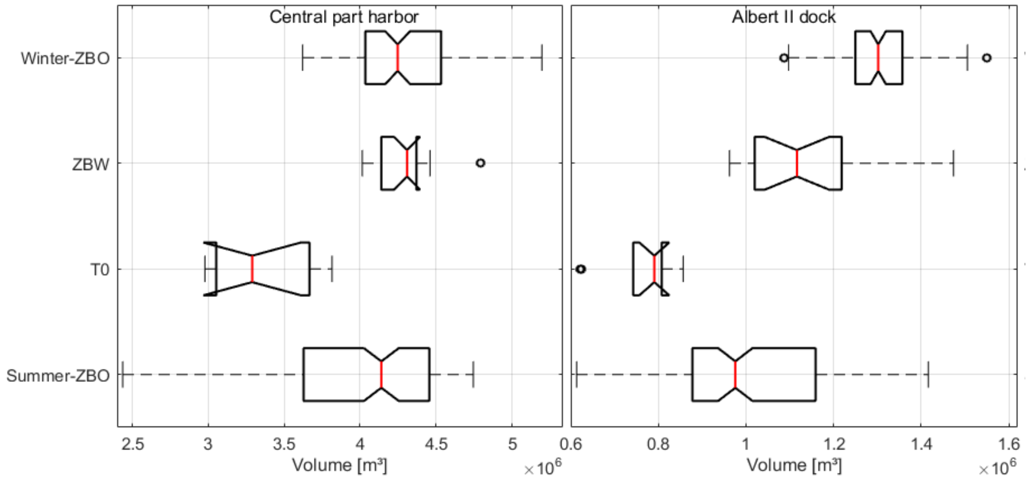


Figure 6.5: Mud volume in the central part of the harbour and in the Albert II dock during different periods. The mud volume has been calculated from the differences between the 33 kHz and the 210 kHz echo soundings.

6.1.4 Conclusion

The mean SPM concentrations at MOW1 is about 10% higher when the dredged matter is disposed at ZBO site; this represents a probability of 55% to have higher SPM concentration than using the alternative (ZBW). The results show that tidal range, random events and seasons have a stronger influence on the SPM concentration signal than the relocation of the dumping site. The conclusion of the measurements apparently shows that the SPM concentration decreases after relocation of the dumping site but indicate stronger (first half of field experiment) or weaker (second half of field experiment) effects that are, however, supported by the environmental conditions. Inside the harbour, the influence of relocation of the dumping site on SPM concentration and mud volumes is even more attenuated by seasonal and random effects. As a consequence, a statistical significant difference in SPM concentration or mud volume inside the harbour could not be found. The statistical tests also revealed that the duration of the field experiment was too short (1 month) to separate the effect of the relocation of the dumping site from the data with clear statistical significance.

The results indicate that on the long run and with the assumptions that the forcing as well as the geometry and bathymetry of the harbour will not change, a reduction of the dredging volumes is to be expected when dumping site ZBW will be in use. The results of the field study may have consequences on the management of dumping operations as the effectiveness of the dumping site depends on environmental conditions, which are inherently associated with chaotic or random behaviour. Changes in hydrodynamics, e.g. that are induced by changes in weather types, influence the direction of the residual currents and thus also of the residual SPM transport. A dumping site that is efficient during most of the time may induce recirculation of the disposed matter back to the dredging places during other weather types. Dumping strategies should therefore allocate sites in a flexible way based on short-term predictions of environmental conditions and sediment dynamics. Developments in line with a flexible dumping strategy should encompass the recalibration and validation of the numerical model in order to obtain results over long periods of time that show the optimal use of dumping sites for forecasted weather conditions.

6.2. Remediation dredging works in the old fishing harbour of Zeebrugge

6.2.1 Situation assignment

Historic soil contamination was identified in the old fishing harbour (Oude Vissershaven) of Zeebrugge. In 1990 a moratorium was installed, preventing any maintenance dredging works to be performed in Prince Albert I-dock and the Tijdok (Tidal dock). In the meantime the mud deposited in both docks reduced the accessibility of the quay berths and increased the difficulty to ensure the safety navigation at certain locations. A sampling programme based on layered sampling was drawn up in consultation with RBINS OD Nature-MUMM and OVAM. The sampling locations of 2001 were resampled in July 2011, so that a comparison could be made with prior data. In order to technically perform the dredging, various mixed samples were made per layer of 50 cm divided in the two dredging zones, i.e. Prince Albert-dock and Tidal dock. The analyses were performed and assessed against the sediment quality criteria for disposal at sea on the one hand and for re-use as soil or raw material on the other hand.

Figure 6.6: Dredging works of contaminated sediments in the Tidal dock of the old fishing harbour in Zeebrugge (upper) and the lagoon site for the polluted material in the inner port of Zeebrugge (below).

6.2.2 Dredging plan

On the basis of the gauge readings approximately 120,000 m³ of mud needed to be dredged in order to achieve the general target depths. Approximately 30,000 m³ has been deposited after 2001. Depending on the practical feasibility to clear the harbour, the dredging was split up into two implementation phases. As the maintenance dredging and the remediation dredging are carried out separately, a dredging plan was drawn up by hedging the various performance phases. After consultation with all the parties involved, the dredging in the Tidal dock was performed end of 2012 and the dredging in Prince Albert I-dock early 2014.

Tidal dock

The upper layers up to a depth of -25 dm LAT consisted of non-polluted dredged material. Transport of this non-polluted dredged material to sea is regarded as maintenance dredging. In order to incorporate the necessary guarantees that no polluted dredged material is dumped, the depth for maintenance dredging was set at -22 dm LAT. Any other slitting, mainly dredged material with historic contamination was transferred to the lagoon site in the inner port of Zeebrugge. The dredged material was transferred to a contractor for further use or processing of the dredged material on land. This dredging is the actual remediation dredging.

Prince Albert I-dock

The non-polluted dredged material was located up to a depth of -30dm LAT. The maintenance dredging was performed up to a depth of -27dm LAT, the remaining package was cleaned in the same way as for the Tidal dock.

6.2.3 Dumping permit

On the basis of the document in proof that referred to the abovementioned analyses and the plan, a request was made with RBINS OD Nature MUMM to dump the dredged material of the maintenance dredging works. The dumping permit was issued on 15.09.2012 with reference BS/2012/01 by RBINS OD Nature MUMM.

6.2.4 Completion of maintenance dredging

The maintenance dredging was performed in the Tidal dock between 6 and 25 November 2012 and in the Prince Albert I-dock between 22 and 27 January 2014. Measurements were made on 29 October and 23 November 2012 in the Tidal dock, in order to exactly locate the zones for the maintenance works. The dredged zones were measured on 16, 23 and 26 November 2012. During the works a limited over-depth was dredged with respect to the targeted depth, but without passing the boundaries between the recent and historic mud deposits. The zones in the Prince Albert I-dock were measured on 15 and 21 January 2014. It was decided for organisational reasons to limit the maintenance dredging to the second access bridge of the yacht club. The limited volume of unpolluted dredged material was removed as dredged material available for decontamination. The dredged zone was measured on 27 January 2014, whereby practically no over-depths were established.

A total of 30,100 m³ (23,200 m³ from the Tidal dock and 6,900 m³ from Prince Albert I-dock) was dumped in accordance with the dumping license.

6.2.5 Completion of remediation dredging

The pollution controlled dredging in the Tidal dock was performed between 25 November and 13 December 2012. The final bearing of the maintenance dredging was used as the initial bearing for the pollution control works. The dredged zoned was measured on 10, 11 and 17 December 2012. The zone to be dredged in the Prince Albert I-dock were initially measured on 15, 21, 24 and 27 January and on 6, 7 and 15 February 2014 and finally measured on 12, 13, 15, 17, 21, 24, 27 and 28 February and 5 March 2014.

A total of 96,000 m³ (41,400 m³ from the Tidal dock and 54,600 m³ from the Prince Albert I-dock) was transported to the processing site, where a release certificate was generated by way of proof of transfer of the dredged material to the contractor responsible for the processing and disposal. The pollution control dredging was fully completed until the indicated target depths.

6.2.6 Conclusion

The remediation dredging in the old fishing harbour was completed pursuant to the conditions of the dumping license. A total of 30,100 m³ of non-polluted material was deposited on the dumpsite and 96,000 m³ polluted material was transported to the processing site.

6.3. Alternative dumping method in the marinas of Nieuwpoort and Blankenberge

Each year 250,000 m³ and 80,000 m³ of mud are dredged in the marinas of Nieuwpoort and Blankenberge respectively. Currently, such quantities are removed in the following way: dredging through cutter piston, transfer of the material in loading barges and dumping at sea in the designated dumping sites. This requires the commitment of additional seagoing dredging equipment and makes the dredging work weather depending. Methods that increase the efficiency of the dredging works by optimising the dumping of dredged material are searched for.

6.3.1 Research question

It is advisable to examine whether the dredging works in the coastal marinas and the dumping of dredged material can be carried out in a more efficient and environmentally friendly and economic way. A change of the dumping method requires an adjustment of the law of January 20th 1999 on the protection of the marine environment in the sea areas under the jurisdiction of Belgium. The modification of the dumping site requires the designation of a new dumping site in the Marine Spatial Plan.

It will be investigated, through a pilot project in Nieuwpoort or Blankenberge, whether it is possible to discharge the dredged material via a fixed pressurised pipe at a location closer to the coast. Hereby different intermediate scenarios will be examined. Since in this way there is no longer any berth time required for attaching and detaching seafaring barges, the efficiency of the cutter piston can be considerably increased. Also berth time of the cutter piston because of bad weather conditions is greatly reduced. Before setting up the test and further investigate the environmental impact, the technical feasibility and the possible financial impact has been investigated.

6.3.2 Market research

The technical feasibility of a change in the dumping strategy and what profits can be achieved with this has been examined with the current market parties. Two alternatives have been examined on the one hand changing the dumping location on the o other hand the changing the dumping method.

Alternative dumping site for ZBO
An alternative dumping site to the west of the port of Zeebrugge for the dumping site for ZBO has been investigated, see chapter 6.1. For the dredging works in the harbour of Blankenberge this would be a shortening of the sailing distance from 13.5 to 8.5 km. This would result in a performance advantage in the dredging cycle causing the unit prices to be influenced positively. With regard to the small dredging quantities in the harbour of Blankenberge it is not appropriate to look for a further dumping location closer to the harbour of Blankenberge.

Moving the dumping location for Nieuwpoort, currently located 13 km from the harbour, closer to the port would give a direct benefit of the efficiency. From the current dredging cycle an optimum is already achieved if the dumping location is moved 4 km closer to the harbour. In view of the method of implementation not being adapted, one only needs to look to the sailing route and depth of this trail and the dumping site. There are no technical restrictions to this.

The yield of efficiency by the optimisation of the current dredging cycle is estimated at 10 to 15 %.

Changed dumping method
The possibility of discharging the dredged material through a fixed pressurised pipe to a location at 1 km and 3 km from the coast has been investigated. Hereby one has looked at the technical limitations and the efficiency gains. The placing of a sunken pipe up to 3 km in sea comes up against a number of technical limitations:

- The construction and maintenance of a sunken pipe on the bottom is very difficult. This is due to the small diameter of the pipes needed, which is due to the limited capacity of the type of cutter pistons that can be deployed in the marina harbour boxes. Such small pipes have a too limited own weight and quickly become a toy of the currents in this area.

- Because of the limited pump flow of this cutter piston, the critical speed in the pipe is not achieved over such a distance. The use of one or more intermediate booster stations is therefore required. This gives an additional impact on the shore side that must also be investigated.

The placing of a sunken pipe up to 1 km in the sea comes up against similar restrictions, yet with a pipe that is 2 km shorter.

The market research has shown that there is a financial profit of 10% to 20% to be obtained depending on the exact circumstances and the duration of the contract which has an impact on the depreciation period of the investments. In addition, it is evident that there is an adequate profit to be obtained on dredging return. Because there are no more berth times for the switching of barges, one can quasi dredge in a continuous regime. This means that the dredging work in the ports can be carried out much more quickly, a fact which currently clashes with the limitation to make the marinas available in the same short time needed to carry out this dredging work. This has the possible effect that the dredging regime of 168u/week must be reduced back to 120u/week. This has a positive impact on the overload in the harbour because one dredges no longer at night, whilst the compulsory berth time is detrimental to the financial efficiency gains.

6.3.3 Conclusions

Both alternatives (the moving of the dumping location or changing the dumping methodology with revised dumping location) can be regarded as equivalent as for efficiency gains.

It is expected that the revised dumping method will have a larger (+/-) environmental impact.

Further research of the effective impact of the two alternatives will be started.

The carrying out of a pilot project with extensive monitoring is therefore advisable.

7. Dredged material dumping framed in the Marine Strategy Framework Directive.

Since 2010, the Marine Strategy Framework Directive (MSFD) is in place for the Belgian marine waters. This directive strives for a sustainable management of the maritime activities, in order to have a good environmental status (GES) in 2020. The debate on a sustainable performance of human activities impacting the marine environment needs to be more objectively structured and scrutinized. For this, the assessment criteria developed under the EU Nature Directives (MSFD) can form the basis for a scientifically, more uniform environmental impact assessment (EIA). The list of criteria, funded by operational indicators allows a more objective assessment of the degree of impact on the marine ecosystem across human activities. In this chapter, the alliance of the MSFD Directive requirements and the assessment of the influence of the activity of dumping of dredged material on the marine ecosystem are made. The dumping of dredged material has effects on the water surface, in the water column and on the seabed. These effects are followed up in a joint monitoring program, coordinated by ILVO and RBINS, and which are part of the Belgian MSFD monitoring program.

Table 7.1: Overview of the 10 relevant MSFD environmental targets to be considered in relation to the assessment of the influence of dredged material disposal on the marine environment.

Discriptor	indicator	
1 - 4 - 6	7	The spatial extent and distribution of the EUNIS level 3 habitats (sandy mud to mud, muddy sands to sands and coarse grained sediments), as well as that of gravel beds fluctuate - relative to the reference state as described in Initial Assessment - within a margin limited to the accuracy of the current distribution maps
1 - 4 - 6	10	The Ecological Quality Ratio as determined by BEQI, indicative for benthic ecosystem structure and quality, has a minimum value of 0,60 in each of the habitat types (Commission Decision 2008/915/EC)
1 - 4 - 6	11	Positive trend in median adult density (or frequency of occurrence) of at least one species within the long-lived and/or slowly reproducing and key engineering benthic species groups in both mud to muddy sands and pure fine to coarse sands
1 - 4 - 6	12	Spring median benthic bioturbation potential (BPc) in the *Abra alba* habitat type is higher than 100.
7	29	An impact demands consideration if one of the following conditions – related to the bottom stress on a 14 days spring tide/neap tide cycle as computed by validated mathematical models – is met: (i) there is an increase of more than 10% of the mean bottom shear stress (ii) the variation of the ratio between the duration of the bottom shear stress and the duration of the erosion is outside the "- 5%, + 5%" range
7	30	This consideration demanding impact remains within a distance equal to the root square of the surface occupied by this activity and taken from its external limit
7	31	All developments must comply with the existing regulatory regime (e.g. EIA, SEA, and Habitats Directives) and regulatory assessments must be undertaken in such a way that takes into consideration any potential impacts arising from permanent changes in hydrographical conditions, including cumulative effects, at the most appropriate spatial scales following the guidance prepared to this end
8	33	Biota: concentrations of Hg, Hexachlorobenzene and Hexachlorobutadienne are equal to or less than their EQS. (Directive 2008/105/EC)
8	36	Biota and sediments: substances for which OSPAR has defined EAC‟s, even on a provisional basis, have concentrations that are equal to or less than their EAC‟s. (OSPAR JAMP)
10	46	Negative trend in the annual evolution of the quantities of litter collected at sea. (OSPAR recommendation 2010/19)

The description of GES is based on eleven descriptors: biological diversity, non-indigenous species, population of commercial fish/shellfish, elements of marine food web/reproduction, eutrophication, sea floor integrity, alteration of hydrographical conditions, contaminants, contaminant in seafood, marine litter and energy incl. underwater noise. For those 11 descriptors, Belgian has defined 50 environmental targets, with associated indicators. In order to frame the influence of dredged material dumping on the marine environment into the MSFD context, the members of the 'dredging' technical working group have evaluated the relevance of those 50 targets for this activity. Only the targets with a clear, direct link to pressures related to the activity were considered. Targets evaluating aspects whereof the contribution of the dredged dumping activity is indefinable or indirect effects were not considered. Based on this, 10 MSFD targets (Table 7.1) were found having certain relevance and are related to the evaluation of the characteristics of the bottom fauna, chemical pollution and physical changes of the disposal areas. For those targets, we describe in this chapter if a dedicated status assessment is possible and to which result it (can) lead, based on the specific indicator developments or status of the monitoring program behind it. Based on this information, the effect of the activity on the ecosystem itself can be evaluated, monitoring optimized and appropriate management measures be taken in relation to the requirements of the EU Directives.

Target 7: Spatial extent and distribution of EUNIS level 3 habitats

The spatial extent and distribution of EUNIS level 3 habitats is mostly relevant for the dredging process when new dumping locations are being defined, which may cause a shift in the habitat type if the deposited sediment differs from the local sediment. No new dumping locations have been defined over the past reporting period. For existing dumping locations, the effect of a possible change in level 3 habitats is expected to be small, compared to the total area that is considered. Nevertheless, the mathematical considerations regarding this target are in development for the moment and applied on sand aggregate extraction activities as case (Montereale Gavazzi et al. 2016). For the future, this environmental target needs to be determined for the dredging and dredge disposal activity as well.

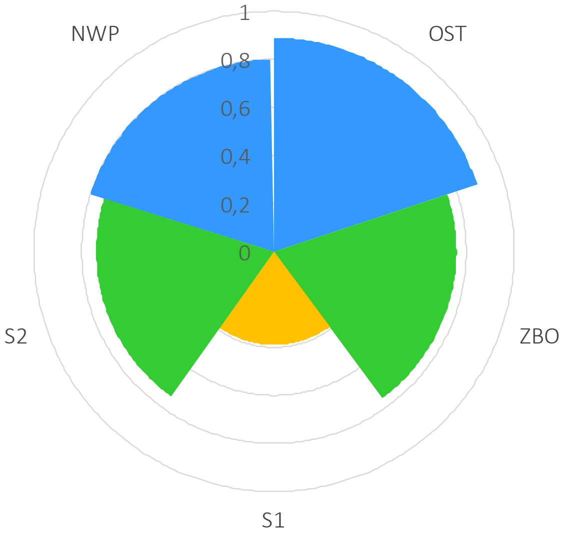


Figure 7.1: Average BEQI score per dumping site for the period 2010-2014.

Target 10: The Ecological Quality Ratio (EQR) as determined by BEQI

For MSFD purpose, the average EQR values, determined by the BEQI by comparison impact with all control samples (nearby and overall control samples) (see chapter 5) for the period 2010-2014 are used to assess the benthic habitat condition at the five disposal sites (Figure 7.1). On average, the benthic habitat conditions within the dumping area is highly comparable with the control for dumping site OST (EQR=0.89) and NWP (EQR=0.80). A good comparability between impact and control is measured for dumping site S2 (EQR=0.74) and ZBO (EQR=0.76). Only at dumping site S1 (EQR=0.39), this comparability is poor, indicating a degraded benthic habitat condition. The benthic habitat condition of the total influenced sea bottom by dredged material disposal, is assessed as moderate (EQR=0.58), when weighting these EQR scores in relation to the impacted area (size of the dumping site). This moderate status can be entirely related to the changed habitat condition at dumping site S1, which is by far the largest dumping area (53% of total surface). The benthic habitat condition is slightly degraded, as a result of dumping of dredged material, but the influenced area (13.7 km²) is only a minor part of the total Belgian bottom surface (3454 km²).

Target 11: Positive trend in median adult density of at least one species within the long-lived and/or slowly reproducing and key engineering benthic species groups

Currently, different benthic species are proposed in the category long-lived and/or slowly reproducing and key engineering species, with some of the species of the mud to muddy sands habitats occurring in the areas of the dumping sites (Table 7.2). Regarding the large bivalves, the collected data does not give a good representation of the occurrence of those species, as firstly a Van Veen grab goes not deep enough into the sediment to sample adult individuals and secondly no discrimination on life stage or length measurements are performed on the sampled individuals. This currently does not allow to make appropriate trend analyses for those species.

Table 7.2: Examples of long-lived and/or slowly reproducing and key engineering species in muddy to muddy sands and 'clean' fine to gravel containing sands.

	Long-lived and/or slowly reproducing species	Important structuring species
Mud to muddy sand	Large bivalves, as *Venerupis corrugata, Mya truncata* and *Lutraria angustor*	Large tube builders, as *Lanice conchilega, Owenia fusiformis* and *Lagis koreni*
	Other big organisms, as *Buccinum undatum* and *Aprodita aculeata*	Big burrowing organisms, as *Callianssa spp*.
Sand to gravelly sand	Large bivalves, as *Laevicardium crassum, Glcymeris glycemeris* and *Dosinia exoleta*	Big burrowing organisms, as *Upogebia deltaura* and *Corystes cassivelanus*
	Other big organisms, as *Cancer pagurus, Echinocardium cordatum* and *Brachiostoma lanceolatum*	

The large tube builders are regularly present within and especially in the surroundings of the dumping sites (cf *Owenia fusiformis*). A shortcoming to perform trend analyses on adult densities is that no life stage or length measurements are performed. Also the density of tube builders, especially *Lanice conchilega* is underestimated by Van Veen grab sampling and counting of the individuals alone (Van Hoey et al. 2006). Nevertheless, a simple trend analyses for those species were made, based on the dredge disposal monitoring dataset of 2006-2014 (Figures 7.1 and 7.2). This was evaluated to check whether the occurrence of those species are possible influenced by the dumping of dredged material.

For the three species, the trend over time is very similar in the three sub-datasets, i.e. the data of the dumping site (DMP), of the nearby control site (IMZ) and of the control site data (REF), with simultaneous increase or decreases over time. The average densities of *L. conchilega* can vary a lot over time, but are mostly present in lower densities in the impact data than in the control areas. The same pattern, but more pronounced for *O. fusiformis*, with in some years (2010) very high densities This species is (nearly) absent in the dredge disposal sites, except in the year 2010. Based on this preliminary analysis, it cannot be excluded that the dredge disposal activity has a certain influence on those tube building species.

The polychaete *Lagis koreni* is a species that is frequently found in the *Macoma balthica* habitat (muddy habitat) and the *Abra alba* habitat (muddy fine sand). The occurrence over time is different between both habitats, with density peaks on different moments, except for the period 2012-2013. The average density of *L. koreni* is very similar over time in the impact (DMP), nearby control (IMZ) and control (REF) data set. A negative influence of the dumping activity on this species could not be found from these observations.

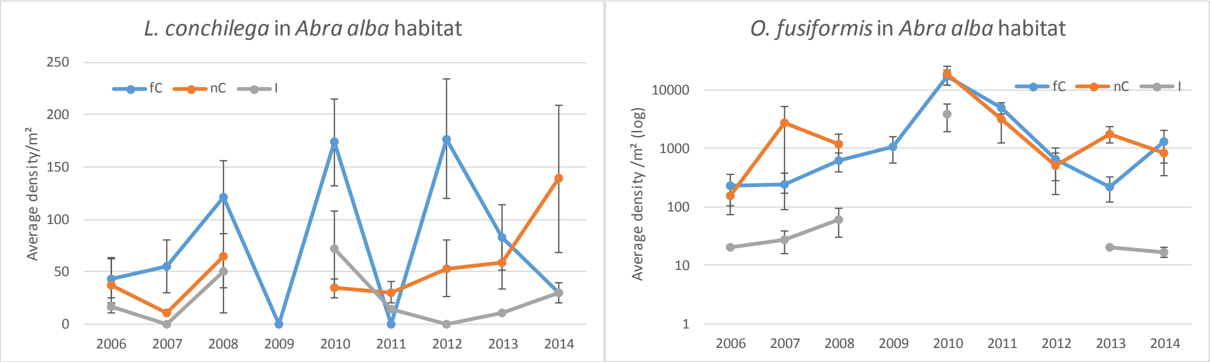


Figure 7.2: Average density trend of Lanice conchilega (left) and Owenia fusiformis (right) in the Abra alba habitat with indication of the standard error. The trends are visualized separately for impact (I), nearby control (nC) and overall control (fC) datasets.

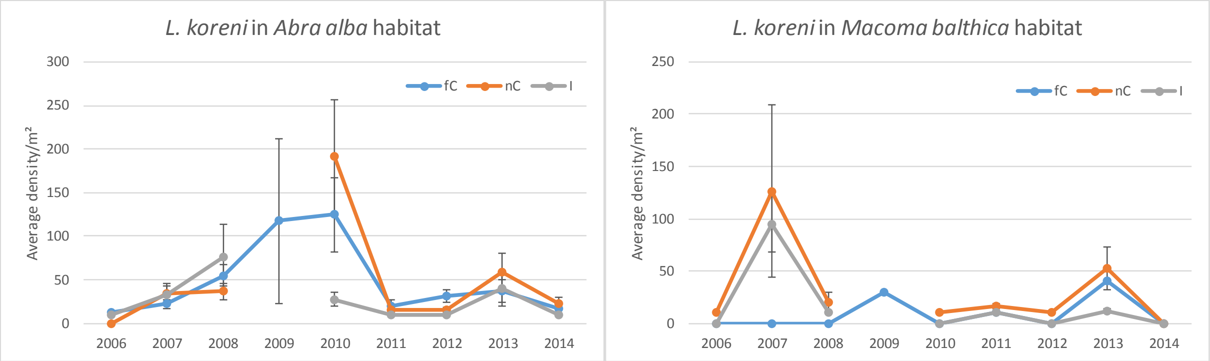


Figure 7.3: Average density trend of Lagis koreni in the Abra alba habitat (left) and Macoma balthica habitat (right) with indication of the standard error. The trends are visualized separately for impact (I), nearby control (nC) and overall control (fC) datasets.

Target 12: Benthic bioturbation potential in the *Abra alba* habitat

This indicator is not yet operational, as the classification of macrobenthic species in Belgian marine waters towards their mobility and reworking function needs to be updated and checked, based on the available international species-bioturbation list (Queiros et al. 2014). In addition to this, the baseline target of 100 needs to be corrected, as it was set for samples taken in spring, whereas the current MSFD benthos monitoring is executed in autumn. Therefore, this target cannot be evaluated for the moment.

Target 29-30-31: Hydro morphological changes

These targets are intended to detect hydro-morphological changes by using the bed shear stress as parameter that relates the interaction between the hydrodynamics and the sea bed and that can indicate changes induced by human activities. Human activities need consideration when the bottom shear stress, calculated with a validated numerical model, changes with more than 10% at a specified distance of the activity.

Possible effects of dumping on the hydro-morphology are to be expected when there are significant changes in bathymetry and sediment composition at or around the dumping sites. The effect of dumping of sandy material generally remains very local (Dufour and Van Lancker 2008). The effects of dumping of fine-grained sediments (mud) may influence the seabed composition in a larger area around the dumping site as the dumped material is quickly resuspended and transported away from the site. Changes in seabed composition can, in turn, influence the hydrodynamics. However, with unchanged dredging and dumping routines no constant monitoring is needed, as those changes will only be relevant over a longer timescale. The tools to quantify these effects are currently being developed, see Van den Eynde (2016a, 2016b). They have not yet been applied to dumping sites, however, results are available for large scale sand extraction scenarios in the Hinderbank area. They show that changes in bottom stress in the area where no impact is allowed remains limited to less than 6% of the area (Van den Eynde 2016a, 2016b). As the water depth for this case study was rather deep, and the wave influence limited, these conclusions cannot directly be extrapolated towards dumping sites that are located in shallower waters.

Target 33: Hg, HCB and HCBD in biota

Environmental Quality Standard (EQS) values for mercury (Hg), hexachlorobenzene (HCB) and hexachlorobutadiene (HCBD) in biota are expressed on wet weight basis and set as, respectively, 20 µg kg^{1}, 10 µg kg^{-1} and 55 µg kg^{-1}. In the Belgian marine environment, HCB and HCBD concentrations are much lower than EQS limits. Analysis on *Platichtys flesus* and *Mytulis edulis* from the Belgian Part of the North Sea in 2015 revealed HCB concentrations below 0.065 µg kg^{-1} ww, concentrations of HCBD were always below limit of quantification, i.e. below 0.625 µg kg^{-1} ww for *Mytulis edulis* and below 0.025 µg.kg^{-1} ww for *Platichtys flesus*. In contrast to HCBD and HCB, Hg values do exceed EQS values for all monitored species (*Platichtys flesus*, *Mytulis edulis*, *Crangon crangon*, *Liocarcinus sp.*, *Asterias rubens*) at every dumping site (DMP) as well as each reference zone (REF). At most dumping sites, the impacted zone does not reveal higher Hg values than reference zones. At dumping site LNP, however, the impacted zone reveals higher Hg concentrations although trend is decreasing. At S2 dumping site, Hg trends are increasing. Detailed follow up of Hg concentrations in time is essential.

Target 36: Substances for which OSPAR has defined EAC's

Within the chapter on chemical monitoring at dumping sites, sediment EAC (or ERL) values are presented for polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and heavy metals. Although concentrations are clearly elevated compared to background assessment values EAC or ERL values are not exceeded for most compounds. For PCBs, CB118 exceeds EAC limits on all impact as well as reference samples. ERL values of heavy metals and PAHs are difficult to compare since no normalization is applied to ERL values and analysis was done on the <63 µm fraction. However, given the fact that contaminants occur at higher concentration in the fine fraction, whole samples analysis will result in lower concentrations, not exceeding ERL values.

Target 46: Negative trend in the annual evolution of the quantities of litter collected at sea.

This target is related to the MSFD criteria 10.1 (Characteristics of litter in the marine and coastal environment) of Descriptor 10 and includes the trends in the amounts of litter deposited on the seafloor, with analysis of its composition, spatial distribution and, where possible, source according to the Commission Decision (2010/477/EU). Dumping of dredged material at sea can displace large amounts of harbour litter into the sea. Therefore, litter recording was taken up in the monitoring and based on 6 sampling events (period 2012-2013). Plastics were found predominant on all dumping and control sites (57% - 96%). Rubbers, metals, glass or ceramics and miscellaneous categories contributed each with low percentages (< 10%). As this monitoring is only executed in a limited time frame, no real trend analyses can be delivered. Beside it, it has to be investigated, which part of this litter result from the displacement from the harbours by dredging. This underlines the need for more sampling periods and additional sampling locations, and the need for long term trends based on marine litter data.

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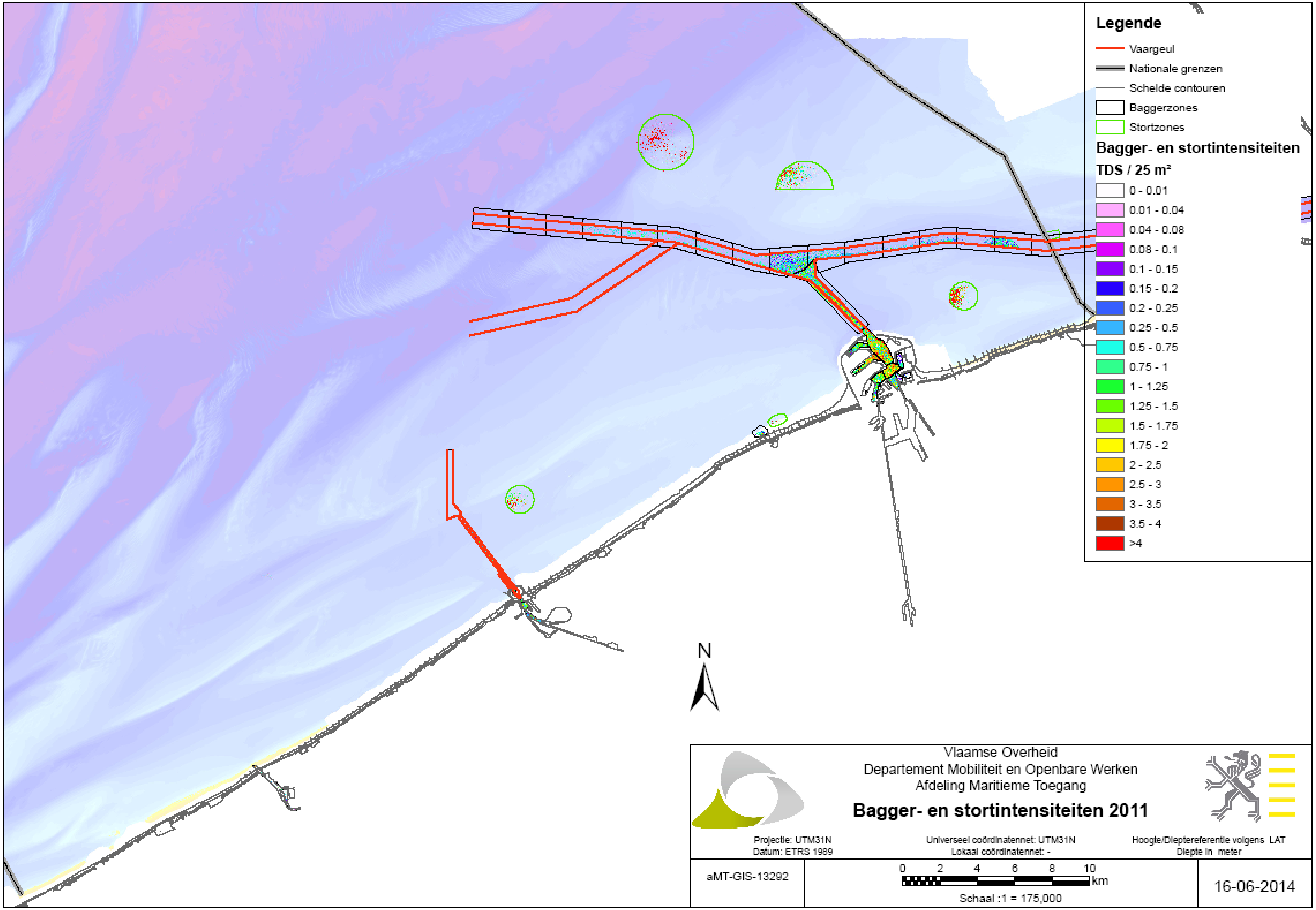
Abbreviations and definitions

ADP	Acoustic Doppler Profiler, measured current velocity and turbulence in one point.
ADV	Acoustic Doppler Velocimeter, measured current velocity in a vertical profile.
BAC	Background Assessment Concentrations
BCS	Belgian Continental Shelf
BEQI	Benthic Ecosystem Quality Index, www.beqi.eu
BPNS	Belgian Part of the North Sea
DMP	actual dumping site
d.w.	dry weight
EAC	Environmental Assessment Criteria
EIA	Environmental Impact Assessment
ERL	Effect Range Low values as developed by US-EPA
EQR	Ecological Quality Ratio
EQS	Environmental Quality Standard
FDI	Fish Disease Index
Fluid mud	suspension of cohesive sediments at a concentration beyond the gelling point (10 to 100 g/l). The suspension behaves non-Newtonian and its dynamics are fairly independent of the flow in the water column (Winterwerp 1999).
GES	Good Environmental Status
HCB	hexachlorobenzene
HCBD	hexachlorobutadiene
HCMS	High Concentrated Mud Suspensions is a suspension of cohesive sediments of a few 100 mg/l up to a few g/l. The suspension behaves Newtonian and is interacting with the turbulent flow field (Winterwerp 1999).
IMZ	directly impacted zone outside but less than 0.3 nautical mile away from the DMP
Ind	individuals
LAT	Lowest Astronomical Tide
LISST	Laser In-Situ Scattering and Transmissometer, measured particle size distribution and volume concentration
mab	meter above bed
MSFD	Marine Strategy Framework Directive
MLLWS	Mean Lowest Low Water at Spring tide
NAO	North Atlantic Oscillation
OBS	Optical Backscatter Sensor, measures turbidity
OVAM	Openbare Vlaamse Afvalstoffenmaatschappij
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorobiphenyls
PSD	Particles Size Distribution
REF	reference samples taken on longer distance from the dumping site than IMZ
SPM	Suspended Particulate Matter
TDM	Ton Dry Matter
TOC	Total Organic Carbon
VITO	Vlaams Instituut voor Technologisch Onderzoek
WFD	Water Framework Directive
ww	wet weight

Appendix 1: Dredging and dumping intensity maps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Nationale grenzen
Schelde contouren
Baggerzones
Stortzones
Bagger- en stortintensiteiten
TDS / 25 m²
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0.01 - 0.04
0.04 - 0.08
0.08 - 0.1
0.1 - 0.15
0.15 - 0.2
0.2 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
1 - 1.25
1.25 - 1.5
1.5 - 1.75
1.75 - 2
2 - 2.5
2.5 - 3
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3.5 - 4
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Vlaamse Overheid
Departement Mobiliteit en Openbare Werken
Afdeling Maritieme Toegang
Bagger- en stortintensiteiten 2011
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Datum: ETRS 1989
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Lokaal coördinatennet: -
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km
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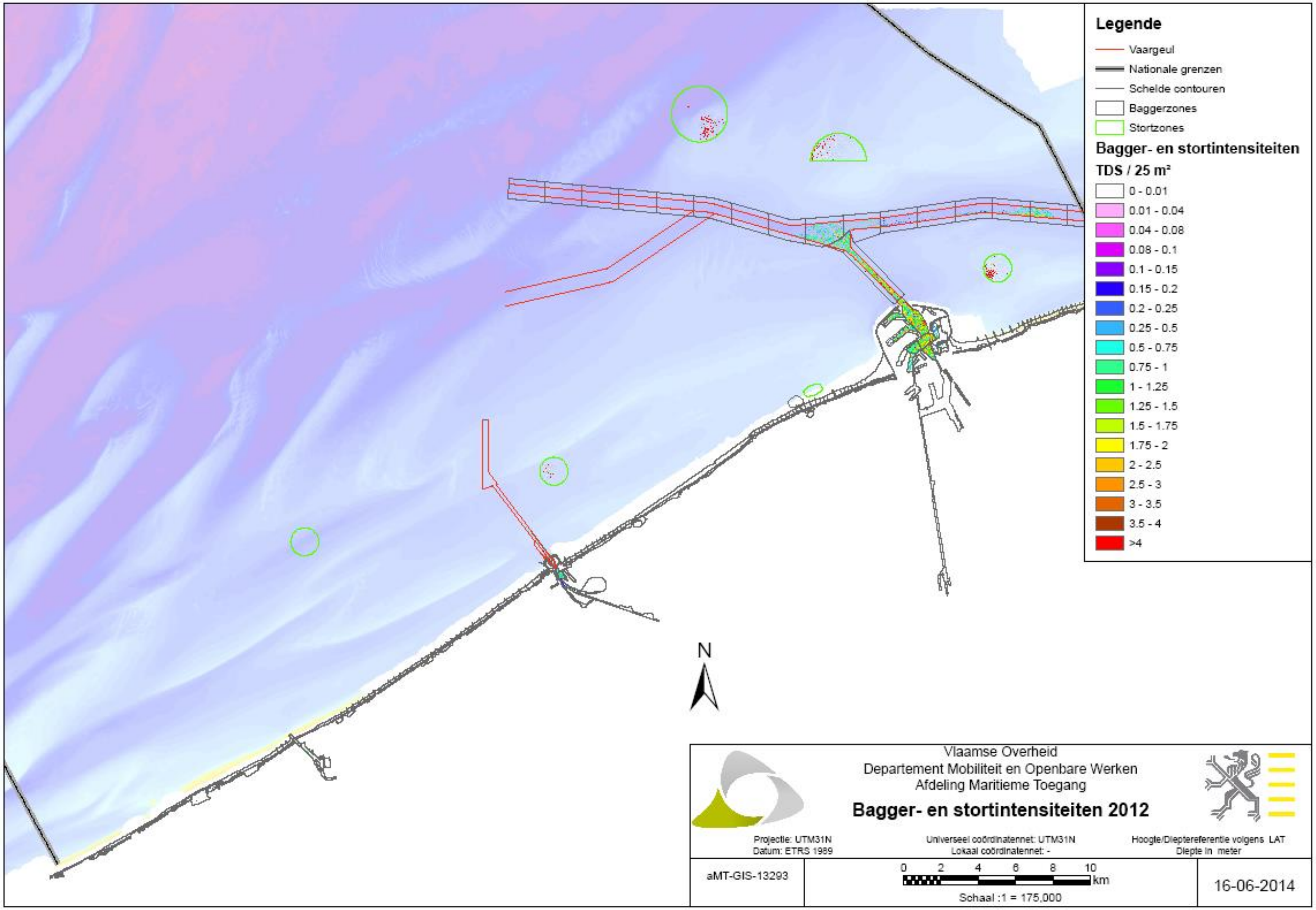
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Vaargeul
Nationale grenzen
Schelde contouren
Baggerzones
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Bagger- en stortintensiteiten
TDS / 25 m²
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Departement Mobiliteit en Openbare Werken
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Bagger- en stortintensiteiten 2012
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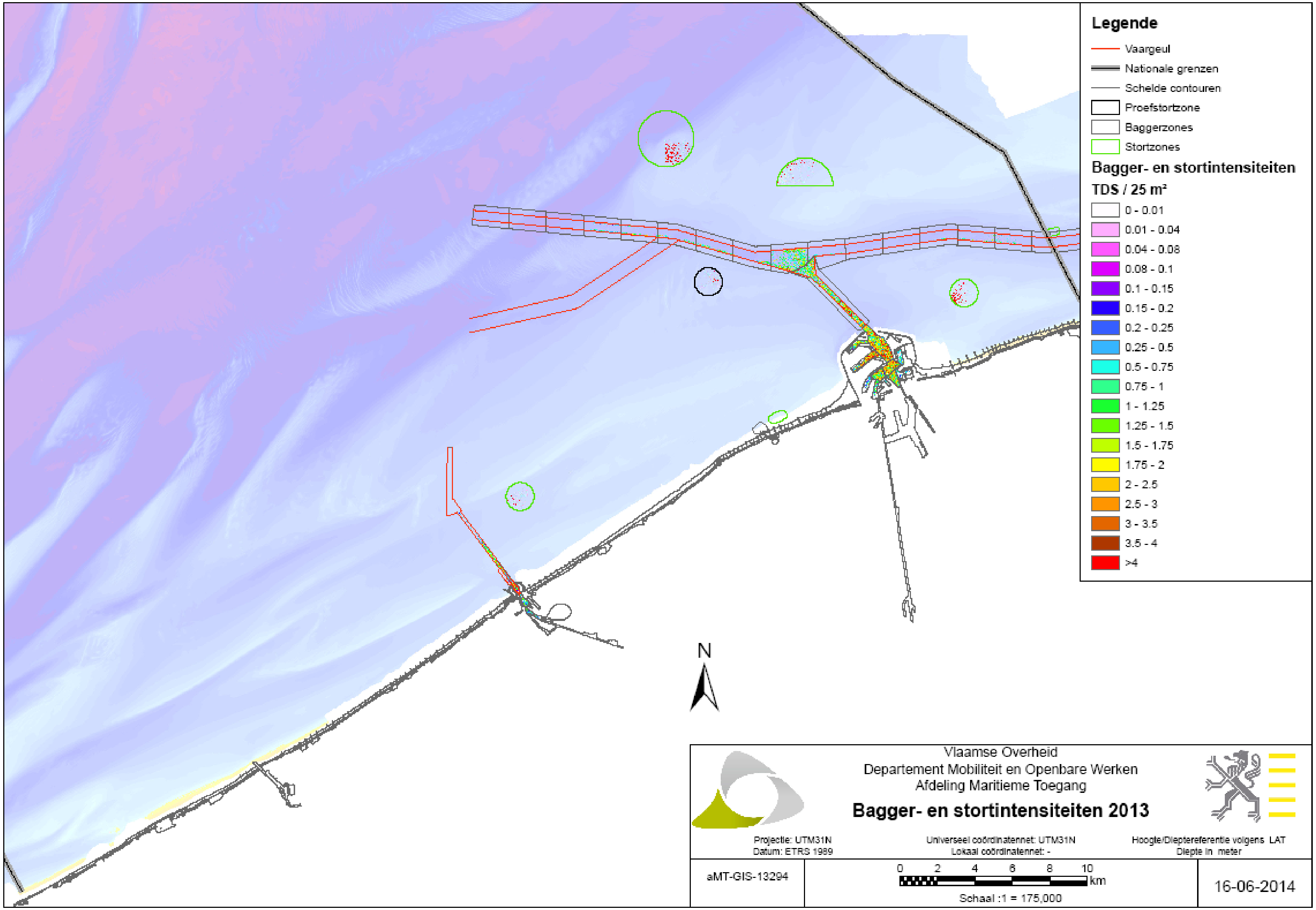

Vlaamse Overheid
Departement Mobiliteit en Openbare Werken
Afdeling Maritieme Toegang

Bagger- en stortintensiteiten 2013

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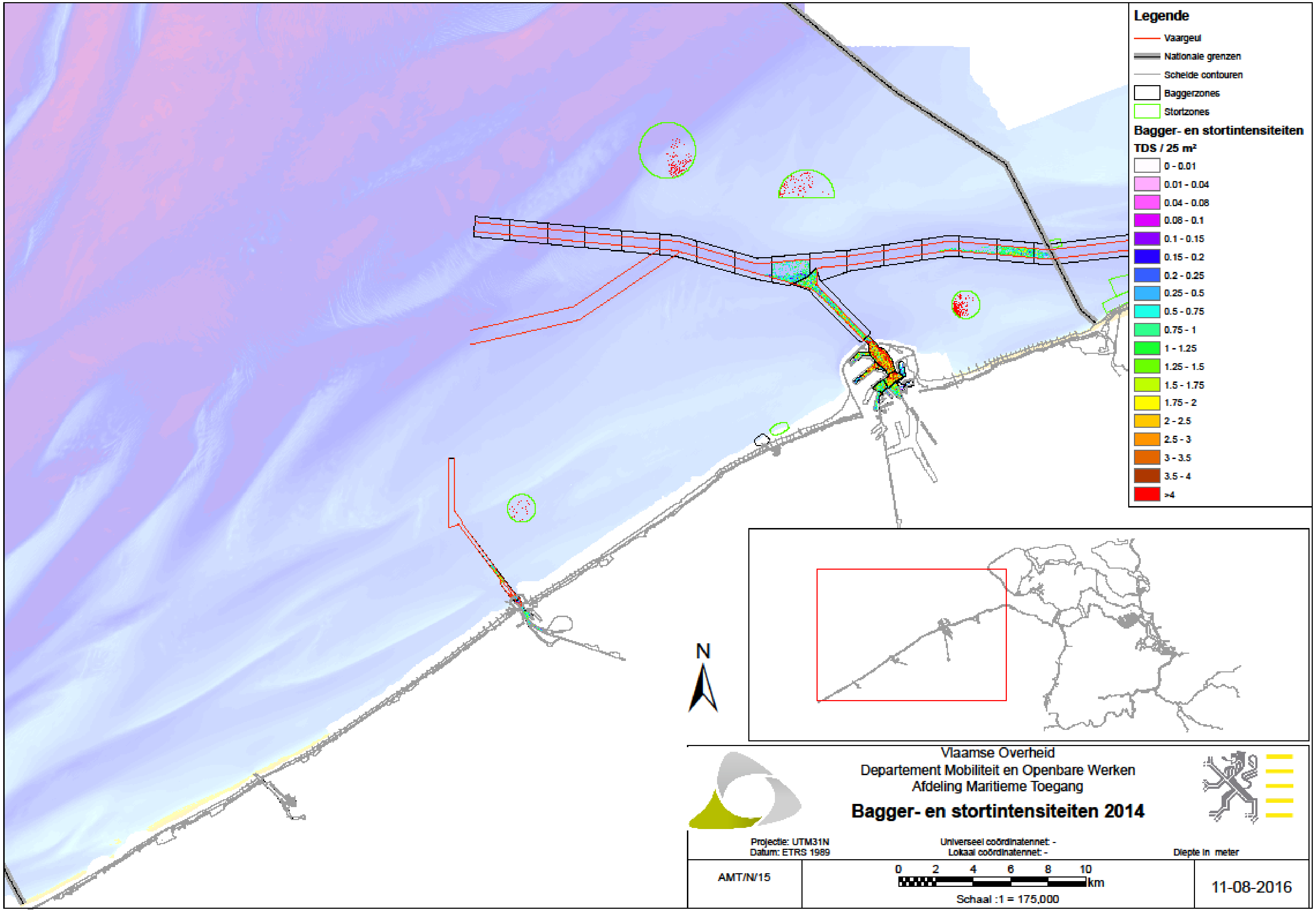
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Nationale grenzen
Schelde contouren
Baggerzones
Stortzones
Bagger- en stortintensiteiten
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0.01 - 0.04
0.04 - 0.08
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3 - 3.5
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Vlaamse Overheid
Departement Mobiliteit en Openbare Werken
Afdeling Maritieme Toegang
Bagger- en stortintensiteiten 2014
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Datum: ETRS 1989
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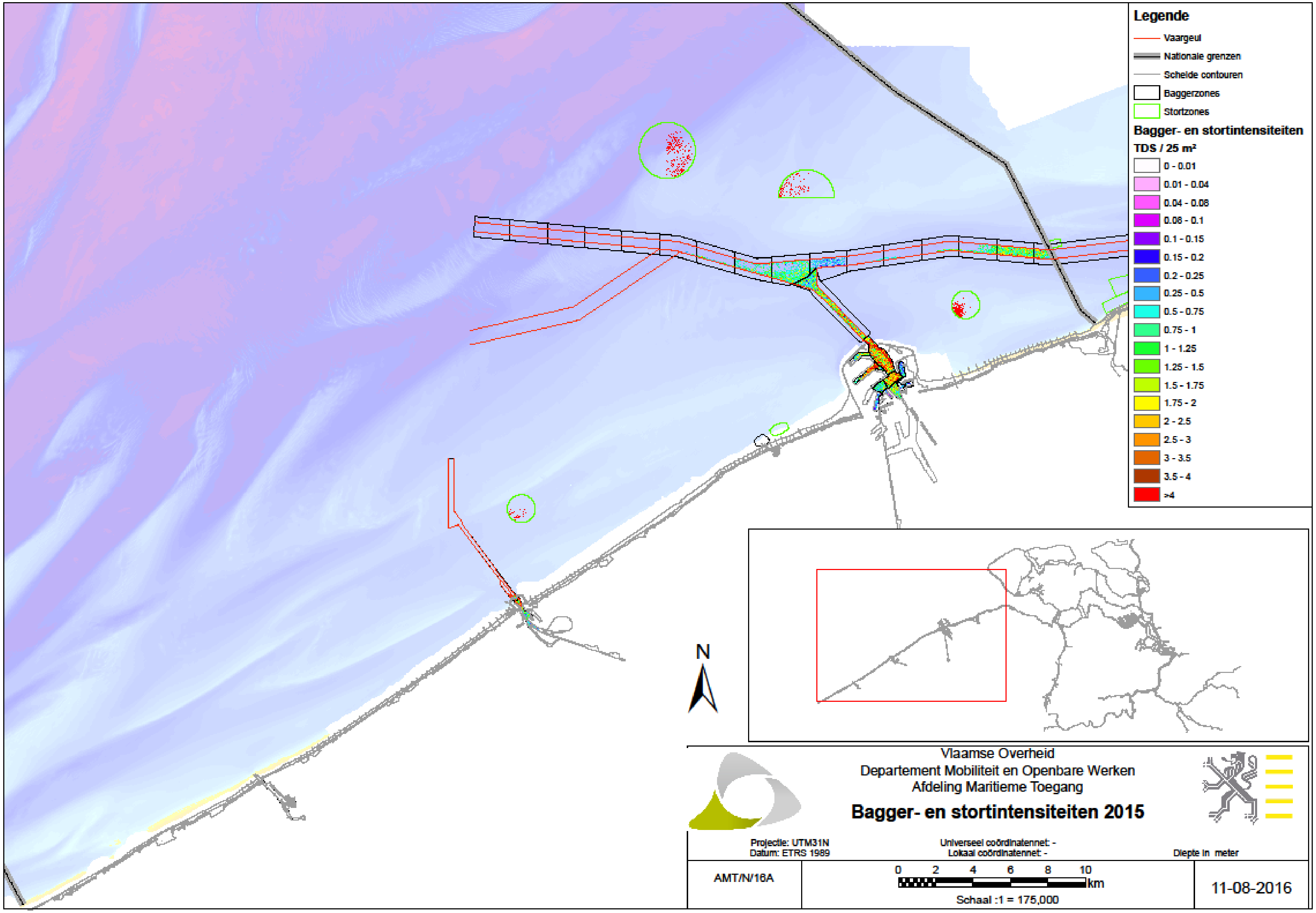
11-08-2016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Nationale grenzen
Schelde contouren
Baggerzones
Stortzones
Bagger- en stortintensiteiten
TDS / 25 m²
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0.01 - 0.04
0.04 - 0.08
0.08 - 0.1
0.1 - 0.15
0.15 - 0.2
0.2 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
1 - 1.25
1.25 - 1.5
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2.5 - 3
3 - 3.5
3.5 - 4
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Vlaamse Overheid
Departement Mobiliteit en Openbare Werken
Afdeling Maritieme Toegang
Bagger- en stortintensiteiten 2015
Projectie: UTM31N
Datum: ETRS 1989
Universeel coördinatennet: -
Lokaal coördinatennet: -
Diepte in meter
AMT/N/16A
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km
Schaal :1 = 175,000
11-08-2016

Appendix 2: Habitat type analysis for epibenthos and demersal fish

Based on the multivariate community analysis on the entire dataset (Figure A2.1), the habitat type for each dumping and control side was determined (Table 5.1). In general, the epi- and fish fauna did not differ substantially between the sampling sites in the Belgian coastal area. Three clusters can be distinguished, which are clearly linked to the macrobenthic habitats (Van Hoey et al., 2004). Cluster one includes sampling sites located in the *Abra alba* habitat (fine muddy sand). Sampling sites of cluster two are located in a muddy environment (*Macoma balthica* habitat). The third cluster group contains the sampling sites located on shallow sandbanks characterized by fine sand with low mud content (*Nephtys cirrosa* habitat). Based on their position and affinity with the defined cluster groups, dumping sites were linked to the three habitats (Table 5.1). Within control sites, station 230 changed from cluster 1 to cluster 3 after the change in sample strategy (short-long). Site B10, which is located in the Netherlands, was no longer sampled after 2010 due to practical reasons (dipclear procedure) and because of the very high variability in fauna characteristics over time. The same holds true for sampling side B07, at which the high variability caused high densities of *Abra alba* at specific sampling events.

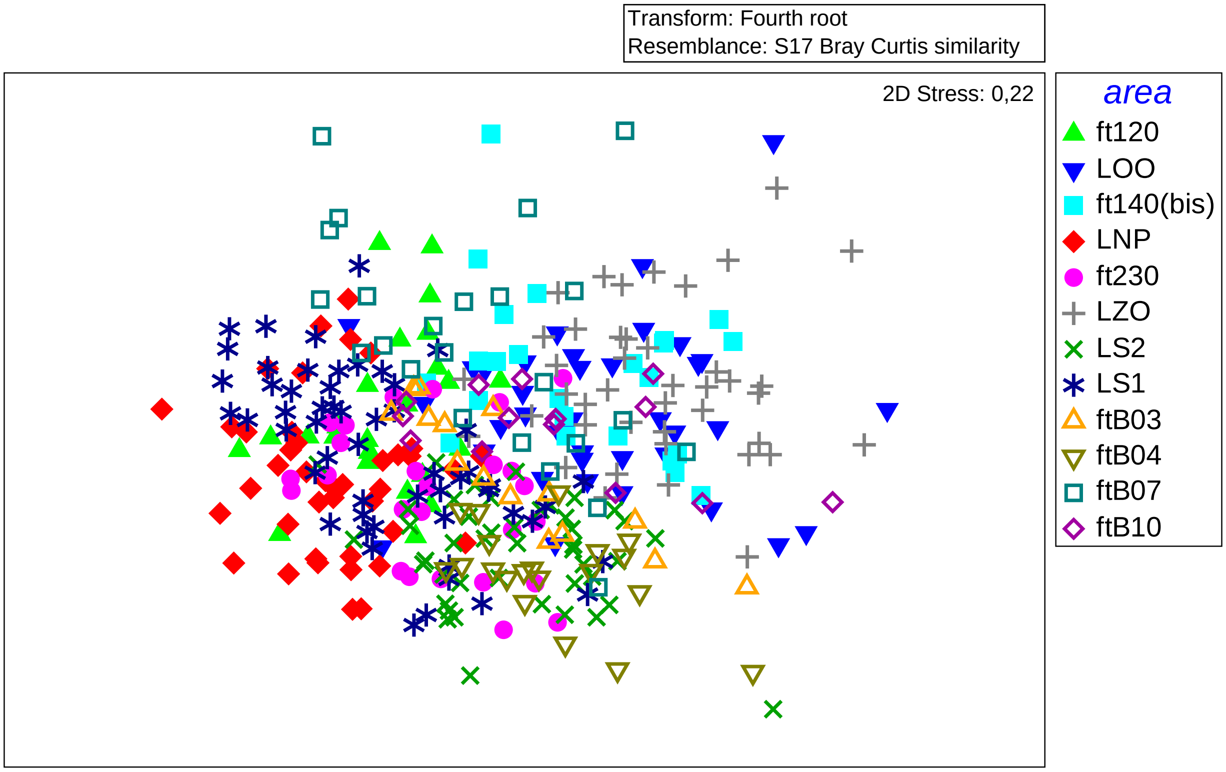
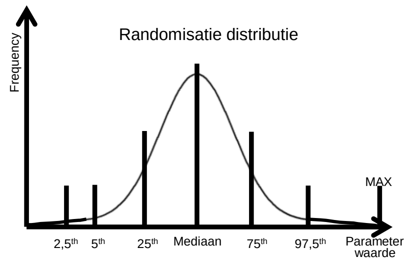


Figure A2.1: Multidimensional scaling plot of the epibenthos-fish dataset, with indication of the different sampling locations.

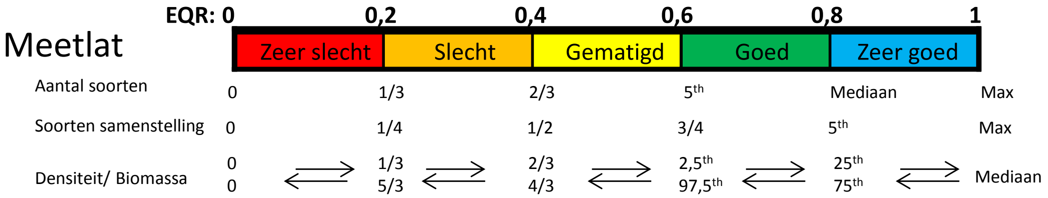
Appendix 3: BEQI procedure

Procedure BEQI berekening

Stap 1) Randomisatie (boots-trapping) van parameter waarden (vb. aantal soorten, densiteit) uit controle dataset voor bepaalde staalname inspanning (vb 1m²) voor het bekomen van de parameter distributie, waaruit de grenswaarden per klasse (zeer slecht tot zeer goed) wordt bepaald.



Stap 2) Aan een vaste meetlat (geschaald tussen 0-1; 0,2 verschil per klasse) worden bepaalde waarden (vb mediaan, max, percentiel) uit de randomisatie distributie gekoppeld voor iedere klasse grens.

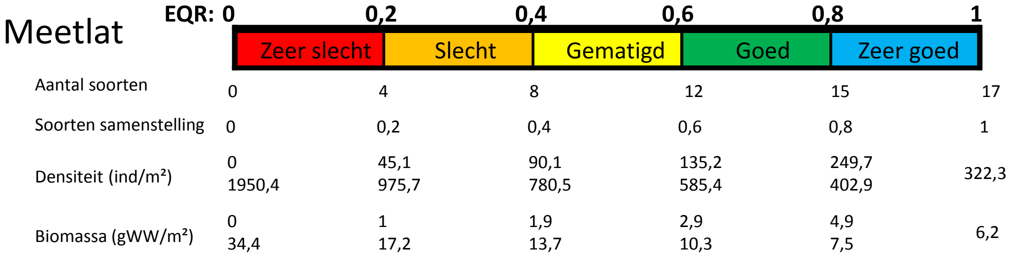


Meetlat

Zeer slecht | Slecht | Gematigd | Goed | Zeer goed

	EQR: 0	0,2	0,4	0,6	0,8	1
Aantal soorten	0	1/3	2/3	5th	Mediaan	Max
Soorten samenstelling	0	1/4	1/2	3/4	5th	Max
Densiteit/ Biomassa	0 0	1/3 5/3	2/3 4/3	2,5th 97,5th	25th 75th	Mediaan

Stap 3) Deze meetlat genereert dan parameter grenswaarden per klasse voor iedere parameter op basis van wat er waargenomen wordt in de controle dataset.

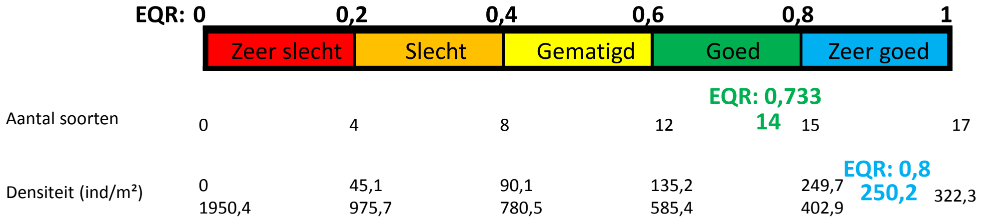


Meetlat

Zeer slecht | Slecht | Gematigd | Goed | Zeer goed

	EQR: 0	0,2	0,4	0,6	0,8	1
Aantal soorten	0	4	8	12	15	17
Soorten samenstelling	0	0,2	0,4	0,6	0,8	1
Densiteit (ind/m²)	0 1950,4	45,1 975,7	90,1 780,5	135,2 585,4	249,7 402,9	322,3
Biomassa (gWW/m²)	0 34,4	1 17,2	1,9 13,7	2,9 10,3	4,9 7,5	6,2

Stap 4) Aftoetsing van de parameter waarde in de impact dataset op deze meetlat om de EQR waarde te bepalen.



Zeer slecht | Slecht | Gematigd | Goed | Zeer goed

	EQR: 0	0,2	0,4	0,6	0,8	1
Aantal soorten	0	4	8	12	15	17
Densiteit (ind/m²)	0 1950,4	45,1 975,7	90,1 780,5	135,2 585,4	249,7 402,9	322,3

EQR: 0,733
14

EQR: 0,8
250,2

Appendix 4: Chemical evaluation of dumping sites

Table A4.1: Summary of statistical models for sediment data. Zone refers to the area for which the model is valid. ALL reflects a model applicable to all zones. DS1 = the effect of DMP (1) versus zone REF (0). DS2 =the effect of zone IMZ (2) versus zone REF (1). Season: effect of post-winter (1) versus post-summer (0). Time 1 = Post-winter 2005. (De Witte et al., 2016).

	Zone	Intercept	Time	Time^2	DS1	DS2	Season
				PCB			
S1	ALL	6.354 ± 0.869	-0.046 ± 0.050		-0.805 ± 0.785	0.314 ± 1.030	
S2	ALL	9.490 ± 1.171	-0.105 ± 0.078		-2.164 ± 1.075	-0.353 ± 1.823	
ZBO	ALL	2.739 ± 1.248	0.916 ± 0.174	-0.041 ± 0.008	-1.055 ± 1.197	-2.263 ± 1.307	
OST	ALL	4.18 ± 0.87	0.096 ± 0.035		0.131 ± 0.894	-0.365 ± 0.989	0.878 ± 0.333
NWP	ALL	4.332 ± 1.223	0.456 ± 0.245	-0.023 ± 0.011	0.682 ± 0.561	-0.001 ± 0.738	
				PAH			
S1	ALL	611.78 ± 6724	-10.88 ± 3.650		-151.78 ± 51.81	106.74 ± 64.38	
S2	ALL	443.62 ± 158.03	15.68 ± 9.35		-75.27 ± 110.79		
ZBO	REF	502.47 ± 149.89	6.667 ± 6.590				
ZBO	DMP	754.56 ± 82.87	-14.43 ± 5.40				
ZBO	IMZ	370.58 ± 65.38	4.036 ± 4.839				
OST	ALL	869.41 ± 211.84	-62.18 ± 33.09	2.704 ± 1.257	52.27 ± 74.28	65.02 ± 80.90	
NWP	ALL	558.38 ± 38.83	-3.015 ± 2.559		32.73 ± 23.15	40.83 ± 30.28	
				Al			
S1	ALL	5.777 ± 0.270	-0.404 ± 0.049	0.020 ± 0.002	0.478 ± 0.159	-0.279 ± 0.225	-0.597 ± 0.123
S2	REF	3.322 ± 0.359	-0.080 ± 0.071	0.007 ± 0.003			
S2	DMP	5.762 ± 0.543	-0.406 ± 0.101	0.018 ± 0.005			-0.707 ± 0.200
S2	IMZ	6.134 ± 0.827	-0.513 ± 0.154	0.023 ± 0.007			-1.057 ± 0.412
ZBO	REF	3.753 ± 0.351	-0.160 ± 0.072	0.009 ± 0.003			
ZBO	DMP	6.625 ± 0.429	-0.601 ± 0.084	0.028 ± 0.004		-0.422 ± 0.170	
ZBO	IMZ	5.568 ± 0.613	-0.348 ± 0.117	0.014 ± 0.005			-0.579 ± 0.262
OST	ALL	5.459 ± 0.225	-0.353 ± 0.043	0.017 ± 0.002	-0.182 ± 0.107	-0.234 ± 0.127	-0.438 ± 0.087
NWP	ALL	4.177 ± 0.251	-0.158 ± 0.045	0.009 ± 0.002	0.078 ± 0.103	0.022 ± 0.132	-0.396 ± 0.096
				Fe			
S1	ALL	1.749 ± 0.238	0.189 ± 0.042	-0.006 ± 0.002	0.353 ± 0.176	-0.456 ± 0.231	
S2	ALL	1.848 ± 0.224	0.027 ± 0.009		0.370 ± 0.253	0.237 ± 0.304	
ZBO	REF	1.742 ± 0.129	0.030 ± 0.009				
ZBO	DMP	2.499 ± 0.141	0.004 ± 0.010				
ZBO	IMZ	2.819 ± 0.212	-0.041 ± 0.016				-0.387 ± 0.168
OST	REF	1.425 ± 0.279	0.155 ± 0.041	-0.005 ± 0.002			
OST	DMP	2.203 ± 0.117	0.012 ± 0.008				
OST	IMZ	2.300 ± 0.147	0.002 ± 0.012				
NWP	ALL	1.666 ± 0.149	0.121 ± 0.029	-0.005 ± 0.001	0.025 ± 0.067	-0.030 ± 0.086	
				As			
S1	ALL	23.20 ± 2.08	-1.953 ± 0.270	0.093 ± 0.014	-2.381 ± 1.970	-6.817 ± 2.374	
S2	REF	22.03 ± 1.84	-2.243 ± 0.433	0.091 ± 0.022			
S2	DMP	19.25 ± 1.90	-2.122 ± 0.387	0.097 ± 0.018			
S2	IMZ	14.93 ± 3.21	-2.157 ± 0.664	0.116 ± 0.018			
ZBO	ALL	16.88 ± 1.16	-1.418 ± 0.221	0.057 ± 0.010	0.001 ± 0.785	-1.061 ± 0.888	
OST	REF	19.69 ± 2.01	-1.885 ± 0.427	0.075 ± 0.021			
OST	DMP	17.68 ± 1.32	-2.064 ± 0.252	0.097 ± 0.012			
OST	IMZ	18.39 ± 1.83	-2.040 ± 0.368	0.090 ± 0.017			
NWP	ALL	18.82 ± 1.28	-1.744 ± 0.239	-0.068 ± 0.011	0.401 ± 0609	-0.006 ± 0.757	-1.496 ± 0.593
				Cd			
S1	ALL	0.452 ± 0.039	-0.024 ± 0.006	0.0007 ± 0.0003	-0.043 ± 0.035	0.051 ± 0.043	
S2	ALL	0.357 ± 0.033	-0.002 ± 0.002		-0.042 ± 0.035	-0.072 ± 0.044	
ZBO	REF	0.327 ± 0.034	-0.003 ± 0.003				
ZBO	DMP	0.530 ± 0.029	-0.012 ± 0.003				
ZBO	IMZ	0.602 ± 0.063	-0.045 ± 0.012	0.002 ± 0.001			
OST	ALL	0.619 ± 0.047	-0.045 ± 0.006	0.0018 ± 0.0003	-0.049 ± 0.044	-0.001 ± 0.048	-0.051 ± 0.012
NWP	REF	0.394 ± 0.042	-0.004 ± 0.003				
NWP	DMP	0.616 ± 0.064	-0.036 ± 0.012	0.001 ± 0.001			
NWP	IMZ	0.978 ± 0.096	-0.093 ± 0.018	0.003 ± 0.001			-0.107 ± 0.045
				Cr			
S1	ALL	99.24 ± 5.65	-3.821 ± 1.119	0.159 ± 0.053	5.978 ± 3.251	-12.21 ± 4.80	
S2	ALL	69.069 ± 5.062	-0.131 ± 0.260		2.778 ± 5.389	4.973 ± 6.773	
ZBO	REF	65.22 ± 4.68	-0.152 ± 0.353				
ZBO	DMP	99.955 ± 9.116	-6.220 ± 1.764	0.231 ± 0.080			8.632 ± 3.541
ZBO	IMZ	106.29 ± 9.79	-6.836 ± 1.957	0.221 ± 0.087			
OST	ALL	95.51 ± 6.07	-4.838 ± 0.961	0.188 ± 0.043	-0.671 ± 4.925	-2.910 ± 5.495	
NWP	ALL	75.36 ± 3.04	-0.556 ± 0.190		0.487 ± 2.560	0.673 ± 3.224	
				Cu			
S1	ALL	21.97 ± 1.23	-0.554 ± 0.200	0.019 ± 0.010	-1.292 ± 0.919	-2.347 ± 1.187	-2.168 ± 0.495
S2	ALL	17.477 ± 1.078	-0.075 ± 0.075		-0.244 ± 0.927	-0.033 ± 1.280	
ZBO	ALL	19.22 ± 1.66	-0.776 ± 0.264	0.028 ± 0.012	-0.025 ± 1.382	-1.972 ± 1.533	
OST	REF	17.89 ± 2.59	-0.182 ± 0.110				
OST	DMP	13.16 ± 1.49	0.198 ± 0.079				
OST	IMZ	15.75 ± 1.92	-0.064 ± 0.087				
NWP	ALL	22.92 ± 1.64	-0.982 ± 0.291	0.032 ± 0.013	3.052 ± 0.858	1.234 ± 1.065	-1.800 ± 0.623
				Hg			
S1	REF	143.29 ± 35.00	2.982 ± 6.861	-0.170 ± 0.308			
S1	DMP	142.60 ± 9.84	-3.726 ± 0.930				
S1	IMZ	191.90 ± 25.15	-1.97 ± 1.72				
S2	ALL	116.79 ± 12.08	2.482 ± 0.651		-9.079 ± 9.701	-2.370 ± 12.507	-15.37 ± 7.03
ZBO	REF	158.38 ± 17.43	-6.901 ± 3.681	0.347 ± 0.166			
ZBO	DMP	231.55 ± 17.57	-4.306 ± 1.320				
ZBO	IMZ	245.08 ± 25.08	-19.45 ± 4.50	0.723 ± 0.200			25.30 ± 10.15
OST	ALL	213.35 ± 16.49	-8.892 ± 2.637	0.332 ± 0.119	6.922 ± 12.996	10.971 ± 14.518	
NWP	ALL	159.83 ± 6.16	-1.701 ± 0.369		17.747 ± 4.334	14.859 ± 5.623	13.59 ± 4.06
				Ni			
S1	ALL	29.44 ± 1.65	-0.039 ± 0.077		-1.060 ± 1.517	-6.203 ± 1.932	-3.398 ± 0.754
S2	ALL	17.260 ± 2.723	1.373 ± 0.533	-0.059 ± 0.024	0.092 ± 1.750	2.064 ± 2.296	
ZBO	ALL	21.94 ± 1.62	-0.062 ± 0.068		-0.870 ± 1.721	-2.835 ± 1.908	
OST	ALL	24.03 ± 1.80	-0.043 ± 0.062		-1.784 ± 1.926	-2.905 ± 2.109	-1.818 ± 0.598
NWP	ALL	31.03 ± 1.11	-0.504 ± 0.066		0.949 ± 0.761	0.101 ± 0.986	-4.728 ± 0.713
				Pb			
S1	ALL	43.42 ± 2.54	-1.580 ± 0.454	0.060 ± 0.022	-6.885 ± 1.814	-3.040 ± 2.407	
S2	ALL	45.68 ± 4.11	-2.065 ± 0.697	0.084 ± 0.032	-6.410 3.369	-3.679 ± 4.182	
ZBO	ALL	35.5 ± 3.01	-0.479 ± 0.141		4.654 ± 3.082	-2.725 ± 3.445	
OST	ALL	48.66 ± 3.73	-2.606 ± 0.596	0.108 ± 0.027	-1.936 ± 2.951	-0.230 ± 3.301	
NWP	ALL	58.07 ± 4.02	-3.689 ± 0.741	0.134 ± 0.741	2.143 ± 1.680	2.041 ± 2.188	-3.921 ± 1.590
				Zn			
S1	REF	124.26 ± 31.91	4.786 ± 1.896				
S1	DMP	144.12 ± 11.42	0.524 ± 0.739				-20.36 ± 6.85
S1	IMZ	131.82 ± 15.48	-0.561 ± 1.131				
S2	ALL	183.85 ± 18.86	0.853 ± 1.276		-32.621 ± 17.158	36.234 ± 23.301	
ZBO	ALL	184.39 ± 21.31	-1.09 ± 0.87		-49.97 ± 22.75	-65.01 ± 25.17	
OST	ALL	88.26 ± 20.15	6.406 ± 2.077	-0.242 ± 0.093	11.63 ± 21.20	-8.95 ± 23.11	
NWP	REF	119.39 ± 15.04	2.203 ± 0.632				-13.92 ± 6.511

Table A4.2: Summary of statistical models for biota data. Zone refers to the area for which the model is valid. DS1 = the effect of DMP (1) versus zone REF (0). DS2 = the effect of zone IMZ (2) versus zone REF (1). Season: effect of post-summer (1) versus post-winter (0). Time 1 = Post-winter 2002.

	Intercept	Time	Time^2	DS1	DS2	Season
PCB- shrimp						
S1	199.08 ± 32.907	-3.604 ± 1.534	-	-9.217 ± 19.802	-9.630 ±22.736	-46.407 ± 17.591
S1	334.81 ± 51.275	-8.177 ± 2.414	-	-4.958 ± 29.901	-25.742 ± 41.774	-110.32 ± 27.540
ZBO	435.31 ± 71.577	-10.748 ± 3.627	-	42.447 ± 47.559	1.635 ± 67.045	-196.04 ± 42.409
OST	131.09 ± 27.040	0.148 ± 1.146	-	-5.195 ± 13.134	-7.730 ± 18.063	-64.154 ± 13.440
NWP	265.05 ± 40.598	-5.879 ± 2.196	-	17.247 ± 30.171	-0.187 ± 44.015	-104.61 ± 24.975
PCB- starfish						
S1	432.91 ± 68.949	-5.362 ± 2.558	-	53.385 ± 61.178	35.323 ± 77.077	-61.294 ± 24.594
S1	3.926 ± 2.154	-0.051 ± 0.145	-	-0.837 ± 1.251	-	-
ZBO	533.79 ± 80.427	-8.071 ± 4.300	-	210.36 ± 49.917	-	-
OST	442.20 ± 158.52	-0.726 ± 7.836	-	-50.843 ± 79.532	-11.756 ± 103.67	-
NWP	270.95 ± 38.149	-1.037 ± 2.059	-	18.945 ± 26.246	0.602 ± 37.871	-
PCB- crab						
S1	865.88 ± 257.04	-79.666 ± 32.258	2.474 ± 0.902	255.90 ± 63.223	366.95 ± 72.903	-
S1	779.01 ± 123.88	-10.111 ± 4.613	-	-77.765 ± 137.37	54.492 ± 161.19	-
ZBO	809.50 ± 192.02	-10.646 ± 7.930	-	106.27 ± 202.72	310.57 ± 112.71	-
OST	777.21 ± 281.78	-12.668 ± 11.987	-	-73.953 ± 148.61	427.13 ± 180.92	-
NWP	706.98 ± 105.32	-3.639 ± 5.965	-	-3.698 ± 73.024	187.18 ± 68.853	-
PAH- shrimp – period 1						
S1	8.704 ± 1.171	-0.811 ± 0.223	0.021 ± 0.009	0.364 ± 0.656	0.409 ± 0.712	-
S1	13.404 ± 1.987	-1.521 ± 0.0390	0.046 ± 0.016	0.792 ± 1.043	-	-
ZBO	12.482 ± 1.272	-1.357 ± 0.245	0.045 ± 0.011	0.298 ± 0.868	-1.845 ± 0.711	-
OST	8.750 ± 2.040	-0.924 ± 0.294	0.027 ± 0.013	0.278 ± 2.193	-	-
NWP	8.773 ± 2.003	-0.402 ± 0.129	-	-1.576 ± 2.890	-	-
PAH- starfish-period1						
S1	4.851 ± 1.241	-0.146 ± 0.078	-	-0.351 ± 0.789	0.562 ± 0.834	-
S2	3.926 ± 2.154	-0.051 ± 0.145	-	-0.837 ± 1.251	-	-
ZBO	5.571 ± 2.327	-0.145 ± 0.152	-	1.357 ± 1.251	4.512 ± 2.519	-
NWP	4.562 ± 0.822	-0.054 ± 0.056	-	-0.162 ± 0.482	-1.390 ± 0.459	-
PAH- crab-period1						
S1	18.125 ± 5.727	-0.740 ± 0.419	-	-1.400 ± 2.980	-0.174 ± 3.173	-
S2	7.187 ± 2.610	0.256 ± 0.150	-	-1.096 ± 0.150	-5.633 ± 1.134	-
ZBO	9.833 ± 5.993	-0.111 ± 0.409	-	5.180 ± 2.133	-	-
NWP	6.169 ± 2.905	0.143 ± 0.220	-	-1.391 ± 1.628	-	-
PAH- shrimp-period2						
S1	-64.670 ± 19.186	5.210 ± 1.538	-0.103 ± 0.031	0.078 ± 0.098	0.019 ± 0.131	-0.358 ± 0.103
S1	-0.829 ± 1.079	0.060 ± 0.043	-	-0.088 ± 0.167	-0.038 ± 0.146	-
ZBO	-1.410 ± 1.029	0.094 ± 0.041	-	0.088 ± 0.133	-0.101 ± 0.133	-0.359 ± 0.106
OST	-0.818 ± 3.960	0.067 ± 0.153	-	0.131 ± 1.442	0.173 ± 1.444	-
NWP	-3.023 ± 1.860	0.144 ± 0.074	-	0.487 ± 0.269	0.117 ± 0.242	-
PAH- starfish-period2						
S1	-11.600 ± 20.008	0.543 ± 0.814	-	2.420 ± 3.701	-0.761 ± 4.319	-
S1	-0.829 ± 1.079	0.060 ± 0.043	-	-0.088 ± 0.167	-0.038 ± 0.146	-
ZBO	0.383 ± 1.725	0.070 ± 0.069	-	-0.085 ± 0.210	-	-
OST	-	-	-	-	-	-
NWP	5.131 ± 3.629	-0.131 ± 0.145	-	0.573 ± 0.518	-0.672 ± 0.518	-

	Intercept	Time	Time^2	DS1	DS2	Season
PAH- crab-period2						
S1	-	-	-	-	-	-
S1	-	-	-	-	-	-
ZBO	-	-	-	-	-	-
OST	-	-	-	-	-	-
NWP	-	-	-	-	-	-
Cd-shrimp						
S1	104.394 ± 9.700	-3.411 ± 0.506	-	0.915 ± 7.630	-9.902 ± 8.848	-17.469 ± 6.639
S1	113.13 ± 9.850	-3.809 ± 0.535	-	11.591 ± 8.005	6.526 ± 11.481	-26.224 ± 7.239
ZBO	68.851 ± 13.505	2.064 ± 1.961	-0.166 ± 0.067	6.238 ± 11.891	-7.569 ± 14.240	-28.467 ± 6.545
OST	45.624 ± 13.847	2.750 ± 2.018	-0.159 ± 0.066	-4.470 ± 7.089	-10.987 ± 9.956	-18.099 ± 6.149
NWP	85.109 ± 10.979	-3.002 ± 0.696	-	-8.444 ± 13.382	-0.405 ± 19.952	-
Cd-starfish						
S1	167.97 ± 20.737	-4.971 ± 1.171	-	10.215 ± 17.956	9.170 ± 19.647	
S1	119.21 ± 16.902	-2.716 ± 1.000	-	5.843 ± 16.781	0.922 ± 24.104	
ZBO	102.65 ± 15.167	-2.249 ± 0.839	-	30.931 ± 18.432	3.490 ± 25.391	
OST	76.998 ± 13.807	-1.152 ± 0.878	-	6.247 ± 12.015	-12.580 ± 17.951	
NWP	174.65 ± 21.577	-5.104 ± 1.344	-	11.057 ± 22.149	-4.563 ± 32.894	
Cd-crab						
S1	98.586 ± 16.612	0.570 ± 0.931	-	23.418 ± 15.773	19.489 ± 17.763	-33.358 ± 13.492
S1	100.32 ± 16.315	-0.973 ± 0.946	-	14.000 ± 14.778	17.989 ± 28.499	-
ZBO	90.321 ± 10.127	-0.529 ± 0.699	-	-8.872 ± 16.229	40.553 ± 31.692	-
OST	110.45 ± 30.031	-1.533 ± 1.202	-	7.714 ± 38.765	22.560 ± 45.051	-
NWP	70.472 ± 10.044	1.033 ± 0.784	-	4.597 ± 11.446	-	-
Cr- shrimp						
S1	0.484 ± 0.299	0.000 ± 0.013	-	0.239 ± 0.284	0.225 ± 0.356	-
S1	0.457 ± 0.219	0.001 ± 0.013	-	0.229 ± 0.192	0.205 ± 0.0283	-
ZBO	0.314 ± 0.163	0.010 ± 0.011	-	0.386 ± 0.179	-0.334 ± 0.260	-
OST	0.273 ± 0.230	0.012 ± 0.015	-	0.337 ± 0.206	-0.180 ± 0.303	-
NWP	0.348 ± 0.115	0.005 ± 0.007	-	0.071 ± 0.148	0.012 ± 0.221	-
Cr-starfish						
S1	1.555 ± 0.865	0.047 ± 0.028	-	-0.697 ± 0.926	-1.058 ± 1.191	-0.771 ± 0.316
S1	1.561 ± 1.148	0.056 ± 0.022	-	-1.591 ± 1.846	-0.513 ± 1.876	-0.818 ± 0.302
ZBO	0.159 ± 0.380	0.051 ± 0.024	-	0.237 ± 0.385	1.114 ± 0.646	-
OST	0.479 ± 0.428	0.029 ± 0.027	-	-0.053 ± 0.372	0.334 ± 0.593	-
NWP	0.154 ± 0.305	0.065 ± 0.019	-	-0.296 ± 0.313	-0.394 ± 0.492	-
Cr-crab						
S1	0.483 ± 0.795	0.003 ± 0.028	-	0.936 ± 0.892	0.625 ± 1.085	-
S1	0.858 ± 0.336	-0.012 ± 0.019	-	0.029 ± 0.304	-0.213 ± 0.586	-
ZBO	0.368 ± 0.212	0.016 ± 0.016	-	0.467 ± 0.318	-0.235 ± 0.657	-
OST	-0.128 ± 0.449	0.140 ± 0.076	-0.006 ± 0.003	0.851 ± 0.304	0.761 ± 0.580	-
NWP	0.441 ± 0.198	0.016 ± 0.016	-	0.063 ± 0.222	-	-

	Intercept	Time	Time^2	DS1	DS2	Season
Cu-shrimp						
S1	11.150 ± 1.797	0.139 ± 0.268	-0.018 ± 0.871	0.276 ± 0.871	-0.466 ±1.026	-
S1	9.134 ± 2.311	0.451 ± 0.359	-0.029 ± 0.012	1.292 ± 1.214	-0.103 ± 1.675	-
ZBO	9.810 ± 1.822	0.474 ± 0.289	-0.030 ± 0.010	-1.029 ± 1.238	-1.066 ± 1.724	-
OST	15.996 ± 1.378	-0.455 ± 0.085	-	-1.725 ± 1.226	-2.084 ± 1.739	-
NWP	9.762 ± 1.658	0.312 ± 0.245	-0.021 ± 0.009	-2.722 ± 1.567	-1.031 ± 2.076	-1.789 ± 0.860
Cu-starfish						
S1	1.573 ± 0.459	0.000 ± 0.020	-	0.279 ± 0.444	0.183 ± 0.543	-
S1	2.762 ± 0.586	-0.045 ± 0.034	-	-0.278 ± 0.566	-0.213 ± 0.809	-
ZBO	2.281 ± 0.456	-0.037 ± 0.024	-	0.474 ± 0.580	0.196 ± 0.767	-
OST	1.356 ± 0.314	0.006 ± 0.020	-	0.162 ± 0.273	0.291 ± 0.409	-
NWP	1.119 ± 0.263	0.021 ± 0.013	-	-0.050 ± 0.345	-0.378 ± 0.420	-
Cu-crab						
S1	10.283 ± 1.341	-0.020 ± 0.073	-	2.421 ± 1.201	2.266 ± 1.351	-3.165 ± 1.031
S1	3.433 ± 2.689	1.117 ± 0.428	-0.040 ± 0.014	0.152 ± 1.453	1.608 ± 2.711	-
ZBO	9.097 ± 1.244	-0.031 ± 0.086	-	1.374 ± 1.892	1.044 ± 3.900	-
OST	8.293 ± 1.154	0.034 ± 0.077	-	-0.526 ± 1.198	0.748 ± 2.145	-
NWP	8.646 ± 1.058	0.108 ± 0.075	-	-1.240 ± 1.062	-2.477 ± 0.905	-
Hg-shrimp						
S1	54.170 ± 6.958	0.823 ± 0.363	-	7.720 ± 5.475	-7.848 ± 6.50	-9.723 ± 4.764
S1	56.641 ± 9.169	0.420 ± 0.516	-	5.755 ± 7.763	8.721 ± 11.136	-
ZBO	47.299 ± 6.213	0.670 ± 0.340	-	-4.709 ± 7.766	12.232 ± 9.525	-
OST	41.439 ± 6.346	0.782 ± 0.392	-	2.867 ± 5.649	-1.271 ± 8.012	-
NWP	45.115 ± 7.327	0.653 ± 0.366	-	-3.114 ± 10.536	3.230 ± 13.085	-
Hg-starfish						
S1	154.77 ± 23.618	-12.197 ± 2.881	0.347 ± 0.083	9.003 ± 6.559	18.493 ± 7.711	-
S1	41.852 ± 8.019	0.786 ± 0.474	-	2.450 ± 7.961	-5.815 ± 11.435	-
ZBO	160.21 ± 26.186	-11.719 ± 3.292	0.302 ± 0.097	8.217 ± 5.870	10.959 ± 9.573	-
OST	40.606 ± 7.714	0.130 ± 0.475	-	5.418 ± 6.471	5.957 ± 9.644	12.321 ± 5.637
NWP	28.628 ± 8.451	1.204 ± 0.235	-	-7.871 ± 13.656	-9.376 ± 14.304	-
Hg-crab						
S1	78.067 ± 9.069	-1.547 ± 0.533	-	12.303 ± 9.103	1.547 ± 10.247	-
S1	89.624 ± 10.360	-1.960 ± 0.060	-	7.258 ± 9.384	10.018 ± 18.097	-
ZBO	52.567 ± 10.038	3.743 ± 1.736	-0.169 ± 0.060	2.423 ± 9.694	7.621 ± 19.830	-
OST	73.220 ± 9.812	-0.939 ± 0.653	-	7.461 ± 10.183	0.083 ± 18.237	-
NWP	50.487 ± 12.012	2.982 ± 2.081	-0.167 ±0.079	6.045 ± 9.164	-	-

	Intercept	Time	Time^2	DS1	DS2	Season
Pb- shrimp						
S1	85.157 ± 65.696	8.977 ± 7.598	-0.531 ± 0.248	47.691 ± 54.400	-4.149 ± 70.721	-
S1	222.63 ± 32.278	-9.269 ± 1.817	-	-9.676 ± 27.330	13.178 ± 39.205	-
ZBO	228.44 ± 35.719	-9.473 ± 2.289	-	100.93 ± 37.712	-3.813 ± 54.366	-
OST	100.56 ± 57.845	13.754 ± 8.257	-0.757 ± 0.272	17.854 ± 39.677	-9.174 ± 48.440	-
NWP	76.150 ± 33.307	8.676 ± 5.512	-0.493 ± 0.195	-6.455 ± 24.444	-9.675 ± 38.691	-
Pb-starfish						
S1	161.95 ± 136.58	2.366 ± 5.140	-	220.01 ± 139.63	391.20 ± 175.61	-
S1	-71.441 ± 84.193	47.044 ± 14.251	-1.350 ± 0.502	-110.23 ± 54.236	-63.252 ± 75.333	-
ZBO	-17.542 ± 98.764	56.406 ± 15.826	-1.777 ± 0.552	158.46 ± 63.330	40.248 ± 105.66	-112.96 ± 54.244
OST	-24.814 ± 122.36	45.333 ± 18.666	-1.336 ± 0.631	-27.249 ± 71.467	-110.128 ± 112.05	-
NWP	104.70 ± 25.177	4.555 ± 1.569	-	-13.485 ± 25.845	-42.527 ± 38.383	-
Pb-crab						
S1	122.78 ± 50.741	-1.999 ± 2.002	-	57.803 ± 53.045	74.830 ± 65.503	-
S1	101.45 ± 40.404	0.524 ± 1.1901	-	-4.590 ± 43.430	-48.413 ± 63.325	-
ZBO	113.28 ± 25.896	1.205 ± 1.787	-	59.100 ± 39.404	13.165 ± 81.200	-
OST	167.28 ± 58.932	-3.150 ± 3.921	-	109.29 ± 61.160	36.053 ± 109.53	-
NWP	172.55 ± 41.930	-1.111 ± 2.778	-	5.858 ± 50.308	-81.706 ± 33.842	-
Zn- shrimp						
S1	32.534 ± 1.465	-0.567 ± 0.076	-	-0.330 ± 1.153	-0.557 ± 1.337	-5.128 ± 1.003
S1	30.592 ± 1.563	-0.508 ± 0.085	-	0.618 ± 1.264	0.405 ± 1.912	-5.750 ± 1.153
ZBO	29.764 ± 1.308	-0.446 ± 0.080	-	-2.459 ± 1.303	-1.260 ± 1.882	-4.852 ± 1.075
OST	29.291 ± 1.715	-0.429 ± 0.099	-	-2.620 ± 1.432	-1.761 ± 2.031	-3.358 ± 1.255
NWP	31.125 ± 1.438	-0.458 ± 0.089	-	-1.445 ± 1.554	-0.703 ± 2.480	-5.542 ± 1.235
Zn-starfish						
S1	41.512 ± 5.782	0.373 ± 0.207	-	-6.115 ± 5.823	2.544 ± 7.331	-9.553 ± 2.415
S1	37.815 ± 6.148	0.946 ± 0.344	-	-14.025 ± 5.872	-4.794 ± 8.216	-12.193 ± 4.892
ZBO	39.123 ± 4.987	0.819 ± 0.265	-	-0.689 ± 5.750	0.990 ± 8.081	-17.072 ± 3.636
OST	49.252 ± 8.344	-2.289 ± 1.248	0.114 ± 0.042	0.173 ± 4.808	4.329 ± 7.055	-14.557 ± 4.118
NWP	32.186 ± 3.290	0.243 ± 0.205	-	-2.708 ± 3.377	-0.353 ± 5.016	-
Zn-crab						
S1	29.808 ± 2.977	0.017 ± 0.175	-	-3.590 ± 2.988	-2.324 ± 3.363	-
S1	28.266 ± 4.247	-0.010 ± 0.246	-	-0.997 ± 3.847	-0.819 ± 7.419	-
ZBO	28.967 ± 2.226	0.230 ± 0.142	-	1.967 ± 3.150	-7.460 ± 6.304	-10.250 ± 2.168
OST	25.373 ± 1.945	0.416 ± 0.122	-	-1.262 ± 1.852	-0.660 ± 3.325	-9.896 ± 1.751
NWP	28.835 ± 3.415	-0.073 ± 0.268	-	-1.654 ± 3.866	-	-

Table A4.3: Results of harbour analysis 2013: HNP = harbour Nieuwpoort, HOO = harbour Oostende. STDEV = standard deviation, RSD = relative standard deviation. All results are reported in dry weight (De Witte et al., 2016).

	PCB	PAH	Cd	Pb	Cr	Hg	Cu	Zn	Ni	Al	Fe	TOC
	ng.g^{-1}	ng.g^{-1}	ng.g^{-1}	µg.g^{-1}	µg.g^{-1}	ng.g^{-1}	µg.g^{-1}	µg.g^{-1}	µg.g^{-1}	%	%	%
HNP01	4.4	259	344	29.1	50.8	87	11.8	409	16.4	2.5	1.4	2.0
HNP02	4.9	597	319	30.4	63.3	115	15.8	121	19.6	4.0	2.3	2.5
HNP03	5.6	487	273	29.3	62.9	107	18.5	142	19.1	3.9	2.2	2.3
HNP04	5.0	519	261	29.5	66.1	129	20.1	145	20.9	4.1	2.4	2.4
HNP05	4.1	482	154	25.5	66.6	121	16.4	100	19.7	4.2	2.2	2.3
HNP06	4.6	561	205	27.4	64.8	118	14.6	103	20.1	4.1	2.3	2.3
HNP07	5.5	626	225	30.2	68.7	137	19.4	121	21.3	4.3	2.5	2.7
HNP08	4.1	489	170	26.0	67.1	124	17.9	118	20.3	4.3	2.3	2.0
HNP09	5.5	615	213	30.1	70.7	155	16.8	118	21.9	4.4	2.5	2.5
Average	4.8	515	241	28.6	64.5	121	16.8	153	19.9	4.0	2.2	2.3
Stdev	0.6	111	64	1.9	5.7	19	2.6	97	1.6	0.6	0.3	0.2
RSD (%)	9.3	21.6	26.7	6.5	8.8	15.7	15.3	63.6	7.9	14.5	14.1	9.8
HOO01	5.9	675	395	33.6	78.6	172	21.1	127	24.7	4.9	2.9	2.5
HOO02	6.6	691	394	32.2	68.1	146	20.1	114	21.8	4.2	2.5	2.9
HOO03	5.3	845	453	38.6	81.0	185	25.0	136	25.3	4.8	3.0	2.8
HOO04	20.4	1466	655	40.3	78.3	212	192.1	571	24.9	4.7	2.8	3.5
HOO05	7.4	1065	382	31.5	74.0	175	44.1	154	24.2	4.5	2.8	2.7
HOO06	9.2	1099	488	35.3	83.2	203	29.9	165	25.7	4.9	3.0	2.8
HOO07	15.8	1771	694	45.2	89.8	221	1640.7	1212	27.3	4.6	3.0	3.1
HOO08	50.8	2150	654	43.4	79.4	259	322.4	752	24.7	4.6	2.9	3.7
HOO10	2.4	113	223	21.1	79.2	33	15.9	116	27.3	5.6	3.7	2.2
HOO11	9.8	1027	519	35.2	74.2	262	19.0	145	23.5	4.2	2.8	2.5
Average	13.4	1090	486	35.6	78.6	187	233.0	349	25.0	4.7	2.9	2.9
Stdev	14.2	585	149	6.9	5.8	65	504.9	376	1.7	0.4	0.3	0.5
RSD (%)	86.6	43.3	30.6	19.3	7.4	35.0	216.7	107.7	6.6	8.4	10.4	15.8

Table A4.4: Results of harbour analysis 2014: HNP = harbour Nieuwpoort, HOO = harbour Oostende. STDEV = standard deviation, RSD = relative standard deviation. All results are reported in dry weight (De Witte et al., 2016). ([1] No data available)

	PCB	PAH	Cd	Pb	Cr	Hg	Cu	Zn	Ni	Al	Fe	TOC
	ng.g^{-1}	ng.g^{-1}	ng.g^{-1}	µg.g^{-1}	µg.g^{-1}	ng.g^{-1}	µg.g^{-1}	µg.g^{-1}	µg.g^{-1}	%	%	%
HNP01	4.5	457	304	30.8	56.3	114	15.2	143	18.5	3.5	2.3	2.3
HNP02	3.7	309	221	22.9	47.0	72	8.4	77	15.3	3.0	1.9	2.6
HNP03	3.0	387	245	26.4	53.6	89	11.3	95	17.0	3.4	2.0	2.7
HNP04	4.7	396	254	26.5	54.3	93	11.9	99	17.2	3.4	2.1	2.6
HNP05	5.9	508	328	31.3	62.4	120	17.8	122	19.8	3.8	2.4	2.7
HNP06	4.5	406	236	30.0	62.7	109	14.4	97	20.0	4.0	2.4	2.3
HNP07	[1]	457	296	32.1	63.2	109	18.3	107	20.7	4.0	2.5	2.4
HNP08	5.9	571	262	37.0	72.3	160	15.6	113	21.8	4.3	2.6	2.4
HNP09	3.7	390	226	27.7	57.8	99	12.5	87	18.2	3.7	2.2	2.4
Average	4.5	431	264	29.4	58.8	107	13.9	104	18.7	3.7	2.3	2.5
Stdev	1.0	77	38	4.1	7.3	25	3.2	20	2.0	0.4	0.2	0.1
RSD (%)	23.1	17.8	14.3	13.9	12.4	23.0	22.9	18.9	10.9	10.7	11.0	5.7
HOO02	4.6	614	273	40.1	58.1	121	16.6	114	19.2	3.7	2.2	2.3
HOO03	6.5	710	307	33.6	64.3	147	19.4	113	19.6	4.0	2.4	2.6
HOO04	16.9	1312	535	41.2	79.4	211	151.7	453	23.4	4.6	2.6	3.2
HOO05	6.9	770	346	31.0	61.8	132	24.8	121	19.3	3.8	2.3	2.7
HOO06	6.6	906	424	34.1	72.7	168	22.2	136	20.9	4.2	2.5	2.7
HOO07	8.8	1064	542	39.3	75.1	185	28.3	143	22.2	4.1	2.7	3.0
HOO08	53.9	1910	605	49.5	77.9	238	286.5	789	22.9	4.4	2.7	3.8
HOO10	<2.00	89	152	21.7	69.2	46	10.4	69	23.1	4.9	2.9	2.1
HOO11	5.9	659	370	32.9	63.0	139	14.9	135	20.0	3.9	2.4	2.4
Average	12.3	893	395	35.9	69.0	154	63.9	230	21.2	4.2	2.5	2.8
Stdev	16.1	508	146	7.8	7.7	56	94.4	238	1.7	0.4	0.2	0.5
RSD (%)	130.7	56.9	37.0	21.7	11.1	36.3	147.8	103	8.2	9.7	8.8	17.8

Table A4.5: Results of LC-MS screening of water and sediment samples at harbour Zeebrugge. Sampling period: March 2012. Compounds are not confirmed by retention time.

Water		Sediment	
Compound	Group	Compound	Group
Isobutyl paraben	Personal care	Methyl paraben	Personal care
di-iso-butyl phosphate	Plasticizer metabolite	Ethyl paraben	Personal care
di-n-butyl phosphate	Plasticizer metabolite	Amidotrizoic acid	Pharmaceutical
Mono-n-butyl phosphate	Plasticizer metabolite	Propyl paraben	Personal care
Mono-isobutyl phthalate	Plasticizer metabolite	Isobutyl paraben	Personal care
Diphenyl phosphate	Plasticizer metabolite	Mono-ethylhexyl phthalate	Plasticizer
Mono-ethylexyl phosphate	Plasticizer metabolite	Perfluorooctanesulfonamide	PFC
Nonafluorobutane sulfonic acid	PFC	Heptadecafluorooctane sulfonic acid	PFC
Tridecafluorohexane sulfonic acid	PFC	Nonylphenol	Plasticizer
Heptadecafluorooctane sulfonic acid	PFC	Phorate oxon	Insecticide
Paraquat dichloride	Pesticide	Isoamyl methoxycinnamate	Personal care
4-methyl-1H-benzotriazole	Anti-corrosion	Dimethachlor	Herbicide
5-methyl-1H-benzotriazole	Anti-corrosion	Terbufos oxon sulfoxide	Insecticide
Isoprocarb	Pesticide	Propetamphos	Insecticide
Isoproturon	Pesticide	C16 Pyridinium	Surfactant
Mexacarbate	Insecticide	Parathion	Insecticide
C12 ATMA	Surfactant	Phosphamidon	Insecticide
C14 ATMA	Surfactant	Famphur oxon	Insecticide
C16 ATMA	Surfactant	Naptalam sodium	Herbicide
C18 ATMA	Surfactant	Dicyclohexyl phthalate	Plasticizer
C14 DADMA	Surfactant	Inabenifide	Growth regulator
D16 DADMA	Surfactant	Resmethrin	Insecticide
Tris-n-butyl phosphate	Plasticizer	Thiophanate-methyl	Fungicide
Dodemorph	Pesticide	Famphur	Insecticide
Tridemorph	Fungicide	Triflumizole	Fungicide
Triphenyl phosphate	Plasticizer	Benfluralin	Herbicide
Indanofan	Herbicide	Trifluralin	Herbicide
Flumioxan	Herbicide	Tebufenozide	Insecticide
Tritolyl phosphate	Plasticizer	Diethylhexyl phthalate	Plasticizer
Diethylhexyl phosphater	Plasticizer	Azoxystrobin	Fungicide
Tris-2-butoxyethyl phopshate	Plasticizer	Cyflufenamid	Fungicide
Di-isononyl phosphate	Plasticizer	Benfuracarb	Insecticide
		Oxytetracyline	Pharmaceutical
		Chlorantraniliprole	Insecticide

Table A4.6: Reporting limits of pesticides, analysed by Fytolab on March 2014 sediment samples.

LMS – RES50-LC-MSMS – Fytolab accredited							
2-(1-naftyl)acetamide	0,01 mg/kg	6-benzyladenine	0,01 mg/kg	acephate	0,02 mg/kg	acetamiprid	0,01 mg/kg
acibenzolar - TOTAL	0,01 mg/kg	acibenzolar-acid	0,01 mg/kg	acibenzolar-S-methyl	0,01 mg/kg	aldicarb	0,01 mg/kg
aldicarb - TOTAL	0,01 mg/kg	aldicarb-sulfone	0,01 mg/kg	aldicarb-sulfoxide	0,01 mg/kg	allethrin	0,01 mg/kg
ametryn	0,01 mg/kg	amidosulfuron	0,01 mg/kg	amisulbrom	0,01 mg/kg	atrazine	0,01 mg/kg
azaconazole	0,01 mg/kg	azadirachtin	0,01 mg/kg	azamethiphos	0,01 mg/kg	azimsulfuron	0,01 mg/kg
azinphos-ethyl	0,01 mg/kg	azinphos-methyl	0,01 mg/kg	azoxystrobin	0,01 mg/kg	beflubutamid	0,01 mg/kg
bendiocarb	0,01 mg/kg	benfuracarb	0,01 mg/kg	bensulfuron-methyl	0,01 mg/kg	benthiavalicarb-isopropyl	0,01 mg/kg
bispyribac-sodium	0,01 mg/kg	bitertanol	0,02 mg/kg	bixafen	0,01 mg/kg	boscalid	0,02 mg/kg
bromacil	0,01 mg/kg	bromfenvinphos-methyl	0,01 mg/kg	bromuconazole	0,01 mg/kg	bupirimate	0,01 mg/kg
buprofezin	0,01 mg/kg	carbaryl	0,01 mg/kg	carbendazim (BCM)	0,01 mg/kg	carbetamide	0,01 mg/kg
carbofuran	0,01 mg/kg	carbofuran (3-OH-)	0,01 mg/kg	carbofuran - TOTAL	0,01 mg/kg	carbosulfan	0,05 mg/kg
carboxin	0,01 mg/kg	carfentrazone-ethyl	0,01 mg/kg	chlorantraniliprole	0,01 mg/kg	chlorbromuron	0,01 mg/kg
chlorfenvinphos (total)	0,01 mg/kg	chlorfluazuron	0,01 mg/kg	chloridazon	0,01 mg/kg	chlorotoluron	0,01 mg/kg
chloroxuron	0,01 mg/kg	chlorsulfuron	0,01 mg/kg	cinerin I	0,01 mg/kg	cinerin II	0,01 mg/kg
clethodim	0,01 mg/kg	clethodim - TOTAL	0,01 mg/kg	clodinafop	0,01 mg/kg	clodinafop - TOTAL	0,01 mg/kg
clodinafop-propargyl	0,01 mg/kg	clofentezine	0,01 mg/kg	clomazone	0,01 mg/kg	cloquintocet-mexyl	0,01 mg/kg
clothianidin	0,01 mg/kg	cyazofamid	0,01 mg/kg	cyclanilide	0,01 mg/kg	cymiazole	0,01 mg/kg
cymoxanil	0,01 mg/kg	cyproconazole	0,01 mg/kg	cyprodinil	0,01 mg/kg	demeton-s-methyl	0,006 mg/kg
demeton-S-methyl-sulfon	0,006 mg/kg	desmethylpirimicarb	0,01 mg/kg	diclobutrazol	0,01 mg/kg	dicrotophos	0,01 mg/kg
diethofencarb	0,01 mg/kg	difenoconazole	0,01 mg/kg	diflubenzuron	0,01 mg/kg	diflufenican	0,01 mg/kg
dikegulac	0,01 mg/kg	dimethenamid	0,01 mg/kg	dimethoate	0,01 mg/kg	dimethoate - TOTAL	0,003 mg/kg
dimethomorph	0,01 mg/kg	dimoxystrobin	0,01 mg/kg	diniconazole	0,01 mg/kg	dinotefuran	0,01 mg/kg
disulfoton	0,003 mg/kg	disulfoton - TOTAL	0,003 mg/kg	disulfoton-sulfone	0,003 mg/kg	disulfoton-sulfoxide	0,003 mg/kg
diuron	0,01 mg/kg	dodemorph	0,01 mg/kg	dodine	0,02 mg/kg	epoxiconazole	0,01 mg/kg
ethametsulfuron-methyl	0,01 mg/kg	ethiofencarb	0,01 mg/kg	ethiofencarb - TOTAL	0,01 mg/kg	ethiofencarb-sulfone	0,01 mg/kg
ethiofencarb-sulfoxide	0,01 mg/kg	ethirimol	0,01 mg/kg	ethoxysulfuron	0,01 mg/kg	etoxazole	0,01 mg/kg
fenamidone	0,01 mg/kg	fenamiphos	0,02 mg/kg	fenamiphos - TOTAL	0,02 mg/kg	fenamiphos-sulfone	0,01 mg/kg
fenamiphos-sulfoxide	0,01 mg/kg	fenarimol	0,01 mg/kg	fenazaquin	0,01 mg/kg	fenbuconazole	0,01 mg/kg
fenhexamid	0,01 mg/kg	fenobucarb	0,01 mg/kg	fenoxaprop-P	0,01 mg/kg	fenoxaprop-P-ethyl	0,01 mg/kg
fenoxycarb	0,01 mg/kg	fenpiclonil	0,01 mg/kg	fenpropidin	0,01 mg/kg	fenpyroximate	0,01 mg/kg
fensulfothion	0,003 mg/kg	fensulfothion - TOTAL	0,003 mg/kg	fensulfothion-sulfone	0,003 mg/kg	fenthion	0,01 mg/kg
fenthion - TOTAL	0,01 mg/kg	fenthion-sulfone	0,05 mg/kg	fenthion-sulfoxide	0,01 mg/kg	fenuron	0,01 mg/kg
flazasulfuron	0,01 mg/kg	flonicamid	0,01 mg/kg	florasulam	0,01 mg/kg	fluazifop-P	0,01 mg/kg
fluazifop-P - TOTAL	0,01 mg/kg	fluazifop-P-butyl	0,01 mg/kg	fluazinam	0,02 mg/kg	flubendiamide	0,01 mg/kg
flufenacet	0,01 mg/kg	flufenoxuron	0,01 mg/kg	fluopicolide	0,01 mg/kg	fluopyram	0,01 mg/kg
fluoxastrobin	0,01 mg/kg	flupyrsulfuron-methyl-sodium	0,01 mg/kg	fluquinconazole	0,01 mg/kg	flurochloridone	0,01 mg/kg
fluroxypyr	0,02 mg/kg	flurtamone	0,01 mg/kg	flusilazole	0,01 mg/kg	flutolanil	0,01 mg/kg
flutriafol	0,01 mg/kg	fonofos	0,01 mg/kg	foramsulfuron	0,01 mg/kg	forchlorfenuron	0,01 mg/kg
fosthiazate	0,01 mg/kg	fuberidazole	0,01 mg/kg	furalaxyl	0,01 mg/kg	furathiocarb	0,01 mg/kg
haloxyfop - TOTAAL	0,003 mg/kg	haloxyfop-methyl	0,003 mg/kg	haloxyfop-R	0,003 mg/kg	hexaconazole	0,01 mg/kg
hexazinone	0,01 mg/kg	hexythiazox	0,01 mg/kg	imazalil	0,01 mg/kg	imazamox	0,01 mg/kg
imazapyr	0,01 mg/kg	imazosulfuron	0,01 mg/kg	imidacloprid	0,01 mg/kg	indoxacarb	0,01 mg/kg
iodosulfuron-methyl	0,01 mg/kg	iprobenfos	0,01 mg/kg	iprovalicarb	0,01 mg/kg	isonoruron	0,01 mg/kg
isoprothiolane	0,01 mg/kg	isoproturon	0,01 mg/kg	isoxaben	0,01 mg/kg	kresoxim-methyl	0,01 mg/kg
lenacil	0,01 mg/kg	linuron	0,01 mg/kg	lufenuron	0,02 mg/kg	mandipropamid	0,01 mg/kg
mefenpyr-diethyl	0,01 mg/kg	mepanipyrim	0,01 mg/kg	mepanipyrim - TOTAL	0,01 mg/kg	mepanipyrim-2-hydroxypropyl	0,01 mg/kg
mesosulfuron	0,01 mg/kg	mesosulfuron-methyl	0,01 mg/kg	metaflumizone	0,01 mg/kg	metalaxyl + metalaxyl-M	0,01 mg/kg
metamitron	0,01 mg/kg	metazachlor	0,01 mg/kg	metconazole	0,01 mg/kg	methabenzthiazuron	0,01 mg/kg
methamidophos	0,01 mg/kg	methiocarb	0,01 mg/kg	methiocarb - TOTAL	0,01 mg/kg	methiocarb-sulfone	0,02 mg/kg
methiocarb-sulfoxide	0,01 mg/kg	methomyl	0,01 mg/kg	methoprotryne	0,01 mg/kg	methoxyfenozide	0,01 mg/kg
metobromuron	0,01 mg/kg	metolachlor (including metolachlor-S)	0,01 mg/kg	metosulam	0,01 mg/kg	metoxuron	0,01 mg/kg
metsulfuron-methyl	0,01 mg/kg	molinate	0,01 mg/kg	monocrotophos	0,01 mg/kg	monolinuron	0,02 mg/kg
monuron	0,01 mg/kg	myclobutanil	0,01 mg/kg	napropamide	0,01 mg/kg	nicosulfuron	0,01 mg/kg

nitenpyram	0,01 mg/kg	novaluron	0,01 mg/kg	nuarimol	0,01 mg/kg	ofurace	0,01 mg/kg
omethoate	0,003 mg/kg	oxadixyl	0,01 mg/kg	oxamyl	0,01 mg/kg	oxycarboxin	0,01 mg/kg
oxydemeton-methyl	0,006 mg/kg	paclobutrazol	0,01 mg/kg	penconazole	0,01 mg/kg	pencycuron	0,01 mg/kg
penoxsulam	0,01 mg/kg	pethoxamid	0,01 mg/kg	phenmedipham	0,01 mg/kg	phenthoate	0,01 mg/kg
phosphamidon	0,01 mg/kg	phoxim	0,01 mg/kg	picolinafen	0,01 mg/kg	picoxystrobin	0,01 mg/kg
pinoxaden	0,01 mg/kg	pirimicarb	0,01 mg/kg	pirimicarb - TOTAL	0,01 mg/kg	prochloraz	0,01 mg/kg
profenofos	0,01 mg/kg	promecarb	0,01 mg/kg	propachlor	0,01 mg/kg	propaquizafop	0,01 mg/kg
propham (IPC)	0,01 mg/kg	propiconazole	0,01 mg/kg	propoxur	0,01 mg/kg	propyzamide	0,01 mg/kg
proquinazid	0,01 mg/kg	prosulfocarb	0,01 mg/kg	prosulfuron	0,01 mg/kg	prothioconazole	0,01 mg/kg
prothioconazole - TOTAL	0,01 mg/kg	prothioconazole(desthio-	0,01 mg/kg	pymetrozine	0,01 mg/kg	pyraclofos	0,01 mg/kg
pyraclostrobin	0,01 mg/kg	pyraflufen-ethyl	0,01 mg/kg	pyrethrin I	0,01 mg/kg	pyrethrin II	0,01 mg/kg
pyrethrins	0,01 mg/kg	pyridaphenthion	0,01 mg/kg	pyrifenox	0,01 mg/kg	pyrimethanil	0,01 mg/kg
quinclorac	0,01 mg/kg	quinoxyfen	0,01 mg/kg	quizalofop	0,01 mg/kg	quizalofop-ethyl	0,01 mg/kg
rimsulfuron	0,01 mg/kg	rotenone	0,01 mg/kg	sethoxydim	0,01 mg/kg	siduron	0,01 mg/kg
simazine	0,01 mg/kg	spinosad - TOTAL	0,01 mg/kg	spinosyn A	0,01 mg/kg	spinosyn D	0,01 mg/kg
spirotetramat - TOTAL	0,01 mg/kg	spirotetramat_	0,01 mg/kg	spirotetramat-enol	0,01 mg/kg	spirotetramat-enol-glucoside	0,01 mg/kg
spirotetramat-keto-hydrox	0,01 mg/kg	spirotetramat-mono-hydrox	0,01 mg/kg	spiroxamine	0,01 mg/kg	sulfosulfuron	0,01 mg/kg
tebuconazole	0,01 mg/kg	tebufenozide	0,01 mg/kg	tebufenpyrad	0,01 mg/kg	tepraloxydim	0,01 mg/kg
terbufos	0,003 mg/kg	tetraconazole	0,01 mg/kg	tetramethrin	0,01 mg/kg	thiabendazole	0,01 mg/kg
thiacloprid	0,01 mg/kg	thiamethoxam	0,02 mg/kg	thiamethoxam - TOTAL	0,02 mg/kg	thifensulfuron-methyl	0,01 mg/kg
thiobencarb	0,01 mg/kg	thiodicarb	0,01 mg/kg	thiodicarb + methomyl	0,01 mg/kg	thiophanate-methyl	0,05 mg/kg
triadimefon	0,01 mg/kg	triadimenol	0,01 mg/kg	triadimenol + triadimefon	0,01 mg/kg	triasulfuron	0,01 mg/kg
triazophos	0,01 mg/kg	tribenuron-methyl	0,02 mg/kg	trichlorfon	0,01 mg/kg	tricyclazole	0,01 mg/kg
tridemorph	0,01 mg/kg	trifloxystrobin	0,01 mg/kg	triflumizole	0,01 mg/kg	triflumuron	0,01 mg/kg
triflusulfuron-methyl	0,01 mg/kg	triforine	0,01 mg/kg	trinexapac-ethyl	0,02 mg/kg	triticonazole	0,01 mg/kg
vamidothion	0,01 mg/kg	zoxamide	0,01 mg/kg				
GMS – RES60-LC-MSMS – Fytolab accredited							
3-chlooraniline	0,01 mg/kg	acetochlor	0,01 mg/kg	aclonifen	0,01 mg/kg	acrinathrin	0,01 mg/kg
alachlor	0,01 mg/kg	aldrin	0,01 mg/kg	benalaxyl (includ-	0,01 mg/kg	benfluralin	0,01 mg/kg
benzoylprop-ethyl	0,01 mg/kg	bifenazate	0,05 mg/kg	bifenox	0,01 mg/kg	bifenthrin	0,01 mg/kg
biphenyl	0,1 mg/kg	bromofos (bromofos-methyl)	0,02 mg/kg	bromophos-ethyl	0,01 mg/kg	bromopropylate	0,01 mg/kg
butachlor	0,01 mg/kg	butafenacil	0,01 mg/kg	butralin	0,01 mg/kg	butylate	0,01 mg/kg
cadusafos	0,006 mg/kg	carbophenothion	0,01 mg/kg	chinomethionat	0,02 mg/kg	chlorbenside	0,01 mg/kg
chlordane (sum of cis- +	0,01 mg/kg	chlordimeform	0,05 mg/kg	chlorfenapyr	0,02 mg/kg	chlorfenson	0,01 mg/kg
chlormephos	0,01 mg/kg	chlorobenzilate	0,01 mg/kg	chloroneb	0,01 mg/kg	chlorothalonil	0,01 mg/kg
chlorpropham	0,01 mg/kg	chlorpropham - TOTAL	0,01 mg/kg	chlorpyrifos-ethyl	0,005 mg/kg	chlorpyrifos-methyl	0,01 mg/kg
chlorthal-dimethyl (DCPA)	0,01 mg/kg	chlozolinate	0,01 mg/kg	coumaphos	0,01 mg/kg	crimidine	0,01 mg/kg
cyanofenphos	0,01 mg/kg	cycloate	0,01 mg/kg	cyflufenamid	0,01 mg/kg	cyfluthrin (sum of isomers)	0,01 mg/kg
cyhalofop-butyl	0,01 mg/kg	cyhalothrin (lambda-)	0,01 mg/kg	cypermethrin (sum	0,01 mg/kg	DBCP	0,1 mg/kg
DDD (o,p'-)	0,01 mg/kg	DDD (p,p'-) = TDE	0,01 mg/kg	DDE (o,p')	0,01 mg/kg	DDE (p,p')	0,01 mg/kg
DDT - TOTAAL	0,01 mg/kg	DDT (o,p')	0,01 mg/kg	DDT (p,p')	0,01 mg/kg	DEET (N,N-diethyl-M-	0,02 mg/kg
deltamethrin	0,01 mg/kg	desmetryn	0,01 mg/kg	diazinon	0,01 mg/kg	dichlobenil	0,01 mg/kg
dichlofenthion	0,01 mg/kg	dichlofluanid	0,05 mg/kg	dichlormid	0,01 mg/kg	dichlorvos	0,01 mg/kg
diclofop-methyl	0,01 mg/kg	diclofop-methyl - TOTAL	0,01 mg/kg	dicloran	0,01 mg/kg	dicofol (o,p')	0,01 mg/kg
dicofol (p,p')	0,01 mg/kg	dicofol (sum of isomers)	0,01 mg/kg	dieldrin	0,01 mg/kg	dieldrin - TOTAL	0,01 mg/kg
dimethachlor	0,01 mg/kg	diphenylamine	0,05 mg/kg	ditalimfos	0,01 mg/kg	DMST	0,05 mg/kg
edifenphos	0,01 mg/kg	endosulfan - TOTAL	0,01 mg/kg	endosulfan (alpha-)	0,01 mg/kg	endosulfan (beta-)	0,01 mg/kg
endosulfan (sulphate-)	0,01 mg/kg	endrin	0,01 mg/kg	EPN	0,01 mg/kg	EPTC	0,01 mg/kg
esfenvaleraat	0,01 mg/kg	ethalfluralin	0,01 mg/kg	ethion	0,01 mg/kg	ethofumesate	0,01 mg/kg
ethofumesate - TOTAL	0,01 mg/kg	ethofumesate-2-keto	0,01 mg/kg	ethoprophos	0,008 mg/kg	etofenprox	0,01 mg/kg
etridiazole	0,05 mg/kg	etrimfos	0,01 mg/kg	famoxadone	0,01 mg/kg	fenchlorphos	0,01 mg/kg
fenitrothion	0,01 mg/kg	fenpropathrin	0,01 mg/kg	fenpropimorph	0,01 mg/kg	fenson	0,01 mg/kg
fenvalerate	0,01 mg/kg	fipronil	0,004 mg/kg	fipronil - TOTAL	0,004 mg/kg	fipronil-sulfone	0,01 mg/kg
flucythrinate (sum	0,01 mg/kg	fludioxonil	0,01 mg/kg	flumetralin	0,01 mg/kg	fluthiacet-methyl	0,05 mg/kg
fluvalinate (tau-) (sum	0,01 mg/kg	formothion	0,01 mg/kg	HCH - TOTAL	0,01 mg/kg	HCH (alpha-)	0,01 mg/kg
HCH (beta-)	0,01 mg/kg	HCH (delta-)	0,01 mg/kg	HCH (epsilon-)	0,01 mg/kg	heptachlor	0,01 mg/kg
heptachlor - TOTAL	0,01 mg/kg	heptachlor epoxyde	0,02 mg/kg	heptenophos	0,01 mg/kg	hexachlorbenzene (HCB)	0,003 mg/kg
imazamethabenz	0,01 mg/kg	ipconazole	0,05 mg/kg	iprodione	0,01 mg/kg	isocarbophos	0,01 mg/kg

isofenphos (-ethyl)	0,01	mg/kg	isofenphos-methyl	0,01	mg/kg	isoprocarb	0,01	mg/kg	isoxadifen-ethyl	0,01	mg/kg
lindane (HCH-gamma)	0,01	mg/kg	malaoxon	0,01	mg/kg	malathion	0,01	mg/kg	malathion - TOTAL	0,01	mg/kg
mecarbam	0,02	mg/kg	mepronil	0,01	mg/kg	methacrifos	0,01	mg/kg	methidathion	0,01	mg/kg
methoprene	0,01	mg/kg	methoxychlor	0,01	mg/kg	metrafenone	0,01	mg/kg	metribuzin	0,01	mg/kg
mevinphos (sum of isomers)	0,01	mg/kg	mirex	0,01	mg/kg	nitralin	0,01	mg/kg	nitrofen	0,003	mg/kg
nitrothal-isopropyl	0,01	mg/kg	oxadiargyl	0,01	mg/kg	oxadiazon	0,01	mg/kg	oxychlordane	0,01	mg/kg
oxyfluorfen	0,01	mg/kg	paraoxon-ethyl	0,05	mg/kg	paraoxon-methyl	0,01	mg/kg	parathion (-ethyl)	0,01	mg/kg
parathion-methyl	0,01	mg/kg	parathion-methyl - TOTAL	0,01	mg/kg	pebulate	0,01	mg/kg	pendimethalin	0,01	mg/kg
pentachloroaniline (PCA)	0,01	mg/kg	pentachloroanisol	0,01	mg/kg	permethrin (sum of isomers)	0,01	mg/kg	phenothrin	0,02	mg/kg
phenylphenol (ortho-)	0,05	mg/kg	phorate	0,01	mg/kg	phosalone	0,01	mg/kg	phosmet	0,01	mg/kg
phosmet - TOTAL	0,01	mg/kg	phosmet-oxon	0,05	mg/kg	piperonyl butoxide	0,01	mg/kg	pirimiphos-ethyl	0,01	mg/kg
pirimiphos-methyl	0,01	mg/kg	pretilachlor	0,01	mg/kg	procymidone	0,01	mg/kg	profluralin	0,01	mg/kg
prometryn	0,01	mg/kg	propanil	0,05	mg/kg	propargite	0,05	mg/kg	prothiofos	0,01	mg/kg
pyrazophos	0,01	mg/kg	pyridaben	0,01	mg/kg	pyriproxyfen	0,01	mg/kg	pyroquilon	0,01	mg/kg
quinalphos	0,01	mg/kg	quintozene	0,01	mg/kg	quintozene - TOTAL	0,01	mg/kg	S421	0,02	mg/kg
silthiofam	0,01	mg/kg	spirodiclofen	0,01	mg/kg	spiromesifen	0,01	mg/kg	sulfotep	0,01	mg/kg
sulprofos	0,01	mg/kg	TCMTB	0,02	mg/kg	tecnazene (TCNB)	0,01	mg/kg	tefluthrin	0,01	mg/kg
terbacil	0,01	mg/kg	terbuthylazine	0,01	mg/kg	terbutryn	0,01	mg/kg	tetrachlorvinphos	0,01	mg/kg
tetradifon	0,01	mg/kg	tiocarbazil	0,05	mg/kg	tolclofos-methyl	0,01	mg/kg	tolfenpyrad	0,01	mg/kg
tolylfluanid - TOTAL	0,05	mg/kg	tolylfluanide	0,05	mg/kg	transfluthrin	0,02	mg/kg	tri-allate	0,01	mg/kg
trifluralin	0,01	mg/kg	vinclozolin	0,01	mg/kg	vinclozolin - TOTAL	0,01	mg/kg			