Syntheserapport over de effecten op het mariene milieu van baggerspeciestortingen
(vergunningsperiode 2006-'08)

Brigitte Lauwaert[1], Karen Bekaert[2], Miguel Berteloot[3], Dirk De Brauwer[4], Michael Fettweis[1], Hans Hillewaert[2], Stefan Hoffman[2], Kris Hostens[2], Koen Mergaert[4], Ine Moulaert[2], Koen Parmentier[2], Gert Vanhoey[2], Johan Verstraeten[3]

Rapport uitgevoerd door BMM[1], ILVO[2], AK[3] en aMT[4], conform art. 10 van het K.B. van 12 maart 2000 ter definiëring van de procedure voor machtiging van het storten in de Noordzee van bepaalde stoffen en materialen.

BL/2008/01

Colofon

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1 Samenvatting

1.1 Inleiding

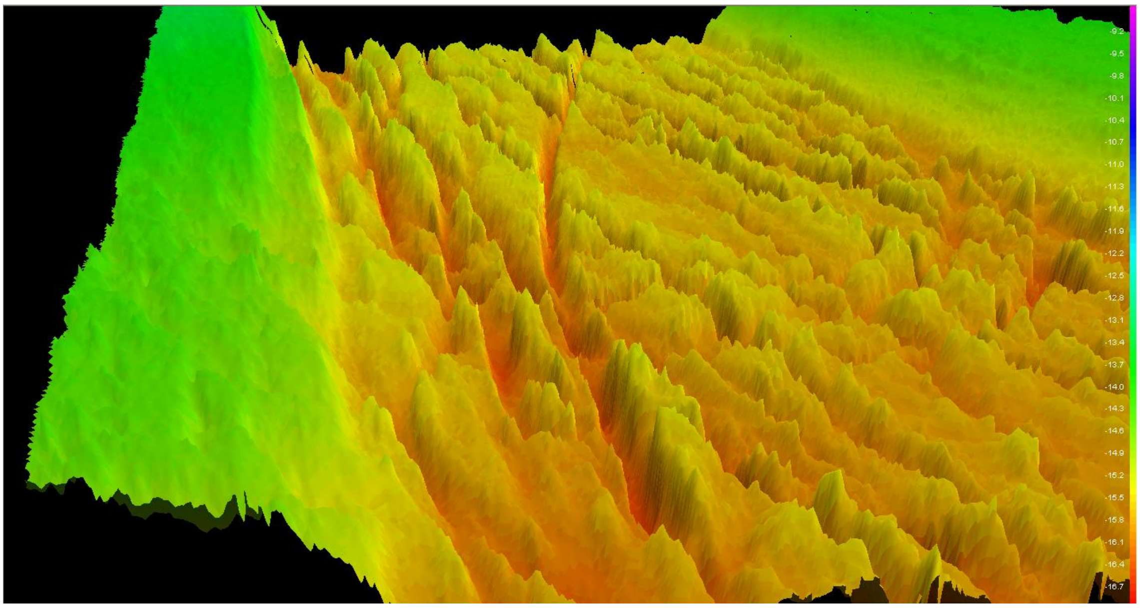
Voor het instandhouden van de maritieme toegangswegen tot de Belgische kusthavens en het op diepte houden van de kusthavens zelf, wordt er gebaggerd (Vlaamse bevoegdheid). Bij het baggeren maakt men een onderscheid tussen onderhoudsbaggerwerken (bijna continu) en verdiepingsbaggerwerken (initiële verdieping van een gebied). Het totale volume aan baggerspecie wordt in zee gestort. De bevoegdheid voor het storten in zee van baggerspecie valt onder de federale regering. Het beheer van baggermateriaal is in België dan ook een gemengde bevoegdheid. Hiertoe werd op 12 juni 1990 en gewijzigd op 6 september 2000 een samenwerkingsakkoord afgesloten tussen het Vlaamse Gewest en de federale regering.

Bij beslissing van de Vlaamse regering op 7 oktober 2005 valt het beheer van baggerwerken in de maritieme toegangswegen en de kusthavens onder de Afdeling Maritieme Toegang (Departement Mobiliteit en Openbare Werken) en het beheer van de baggerwerken in de jachthavens onder het Agentschap voor Maritieme Dienstverlening en Kust. Het Departement en het Agentschap vallen onder het Vlaamse Ministerie van Mobiliteit en Openbare werken, één van de dertien beleidsdomeinen die operationeel werden op 1 april 2006.

Het dumpen in zee van baggerspecie wordt uitgevoerd conform de MMM-wet van 20 januari 1999 en een vergunning wordt gegeven overeenkomstig de procedure gedefinieerd in het K.B. van 12 maart 2000. Overeenkomstig art. 10 van dit K.B. dient een syntheseverslag te worden opgesteld per machtigingsperiode, vergezeld van aanbevelingen ter ondersteuning van de ontwikkeling van een versterkt milieubeleid. Op internationaal vlak valt het dumpen in zee van baggerspecie onder het regionaal OSPAR Verdrag (1992) en het Verdrag (1972) en Protocol van Londen (1996). Deze verdragen en hun richtlijnen houden rekening met de aanwezigheid van contaminanten in het sediment en of alternatief *beneficial use* mogelijk is. Het implementeren van de richtlijnen gebeurt o.a. door het vastleggen van *action levels* (sedimentkwaliteitscriteria), de keuze van de dumpingsites en een permanent monitoring- en onderzoeksprogramma dienen te worden uitgevoerd.

1.2 Bagger- en stortactiviteiten

De Vlaamse Hydrografie, een deel van het Agentschap voor Maritieme Dienstverlening en Kust, heeft een monitoringprogramma van de dumping sites dat vnl. bestaat uit bathymetrische metingen die een idee geven van de evolutie van de zeebodem in deze gebieden en waarbij wordt gebruik gemaakt van singlebeam en multibeam-metingen. Het belang van deze monitoring is de laatste jaren toegenomen in het bijzonder door de toenemende diepgang van de schepen, waardoor de vereiste baggeractiviteiten teneinde de veilige toegang van deze schepen tot de havens te kunnen verzekeren, afhankelijk zijn van een regelmatige en zeer nauwkeurige dieptemetingen. Het resultaat van een multibeamopname in de Pas van het Zand wordt gegeven in Figuur 1.1.



Figuur 1.1 Sectie van de Pas van het Zand. Tracks van baggeractiviteit zijn duidelijk te zien in deze multibeam-opname (juli 2007)

In de vergunningsperiode 2006 – 2008 werden vier vergunningen gegeven voor storten in zee van baggerspecie aan de Afdeling Maritieme Toegang (kusthavens en vaargeulen) en drie vergunningen aan het Agentschap voor Maritieme Dienstverlening en Kust (jachthavens). In elke vergunning wordt een gemiddelde en maximale hoeveelheid baggerspecie vermeld die per jaar mag gestort worden op een welbepaalde loswal, hierbij wordt onderscheid gemaakt tussen onderhouds- en verdiepings-baggerspecie. De vergunninghouder wordt wel aangemaand om de gemiddelde hoeveelheid niet te overschrijden.

De hoeveelheden in zee gestorte baggerspecie zijn bijgehouden sedert 1991, het jaar waarin de eerste vergunningen voor storten in zee van baggerspecie werden afgeleverd.

In Tabel 1.1 en 1.2 wordt een overzicht gegeven van de in zee gestorte (onderhouds- en verdie-pings-)baggerspecie in het baggerjaar 2005 – 2006 (Tabel 1.1) 2006 -2007 (Tabel 1.2). De data voor het jaar 2007 – 2008 zijn nog niet volledig en zijn daarom nog niet vermeld.

Tabel 1.1 Hoeveelheid in zee gestorte baggerspecie, TDS (1 april 2005 – 31 maart 2006) – Groen: vergunninghouder Afdeling Maritieme Toegang

Baggerplaats	Stortplaats					
	Br.&W. S1	Br.&W. S2	Br.&W. Zeebrugge Oost	Br.&W. Oostende	Br.&W. Nieuwpoort	TOTAAL
Scheur Oost	121.528	57.733				179.261
Scheur West	247.798	427.737				675.535
Pas van het Zand	1.662.563	627.199				2.289.762
CDNB Zeebrugge	985.234	121.971	1.267.494			2.374.699
Toegangsgeul Oostende				402.445		402.445
Haven Oostende				197.460		197.460
Nieuwe Toegangsgeul Oostende						
Haven en Voorhaven Zeebrugge			1.689.783			1.689.783
Toegangsgeul Blankenberge						
Toegangsgeul Nieuwpoort						
Haven Blankenberge			16.268			16.268
Haven Nieuwpoort					61.020	61.020
TOTAAL	3.017.123	1.234.640	2.973.545	599.905	61.020	7.886.233

Tabel 1.2Hoeveelheid in zee gestorte baggerspecie, TDS (1 april 2006 – 31 maart 2007) – Groen: vergunninghouder Afdeling Maritieme Toegang; Beige: vergunninghouder Agentschap Maritieme Dienstverlening en Kust.

Baggerplaats	Stortplaats					
	Br.&W. S1	Br.&W. S2	Br.&W. Zeebrugge Oost	Br.&W. Oostende	Br.&W. Nieuwpoort	TOTAAL
Scheur Oost	1.810.359	71.592				1.881.951
Scheur West	5.153.138	72.771				5.225.909
Pas van het Zand	2.425.208	361.323				2.786.531
CDNB Zeebrugge	1.323.236	163.072	672.417			2.158.725
Toegangsgeul Oostende				581.831		581.831
Haven Oostende				231.449		231.449
Nieuwe Toegangsgeul Oostende						
Haven en Voorhaven Zeebrugge		32.205	2.037.593	6.385		2.069.798
Jachthaven Oostende				6.385		6.385
Toegangsgeul Blankenberge			86.762			86.762
Toegangsgeul Nieuwpoort					37.496	37.496
Oude Vlotkom Nieuwpoort					106.945	106.945
Vaargeul en havengeul Nieuwpoort					32.787	32.787
Haven Blankenberge						
Haven Nieuwpoort					1.041	1.041
TOTAAL	10.711.941	700.963	2.796.772	819.665	178.269	15.207.610

De aanzienlijke verhoging in de hoeveelheid in zee gestorte baggerspecie in het jaar 2006 – 2007 is te wijten aan de uitvoering van verdiepingsbaggerwerken in Scheur Oost, Scheur West, Pas van het Zand en het CDNB Zeebrugge.

De kaart geeft visueel de bagger- en stortintensiteitkaarten weer die gebruikt worden voor validatie van de modellen en voor het definiëren van monitoringpunten.

In de toegangsgeul van Blankenberge werd in maart 2007, 40.000 m³ zand gebaggerd dat werd gebruikt voor strandvoeding te Wenduine en in november 2007 werd 50.000 m³ zand gebaggerd dat eveneens werd gebruikt voor strandvoeding.

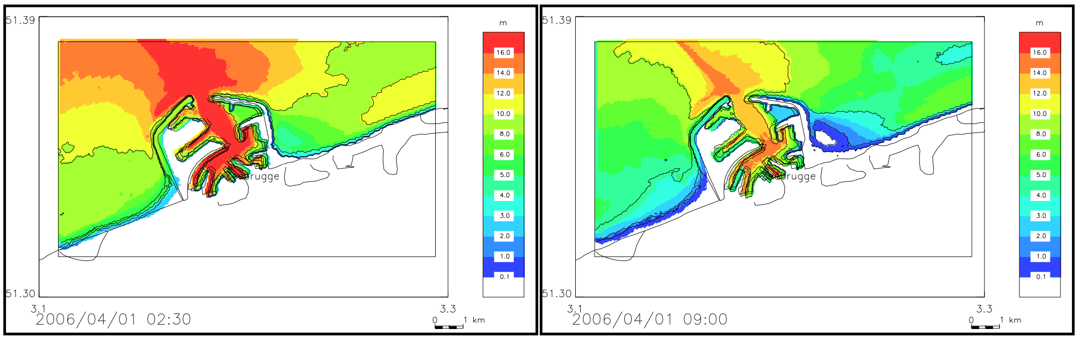
1.3 Het MOMO onderzoekprogramma van de BMM

In dit hoofdstuk worden de resultaten voorgesteld uit het MOMO project dat werd uitgevoerd door de BMM tussen 2006 en begin 2008 in het kader van de algemene en permanente verplichtingen van monitoring en evaluatie van de effecten van alle menselijke activiteiten op het mariene ecosysteem waaraan België gebonden is in overeenstemming met het Verdrag betreffende de bescherming van het mariene milieu van de noordoostelijke Atlantische Oceaan (1992, OSPAR-Verdrag). Het onderzoek kadert in de algemene doelstelling om de baggerwerken op het Belgisch Continentaal Plat (BCP) en in de kusthavens te verminderen, door enerzijds de sedimentatie te verminderen in de baggerplaatsen en anderzijds efficiënter te storten.

In het bijzonder is bij het opstellen van de taken voor de periode april 2006 - maart 2008 rekening gehouden met de aanbevelingen voor de minister ter ondersteuning van de ontwikkeling van een versterkt milieubeleid zoals geformuleerd in Lauwaert *et al.* (2006). Het opstellen van een globale strategie voor het gebied ten oosten van Zeebrugge was één van de aanbevelingen. De ontwikkeling van een 3D hydrodynamisch detailmodel van het gebied rond Zeebrugge (sectie 6.2), de uitbreiding van het bestaande sedimenttransportmodel (sectie 6.5) en de studie van de antropogene invloed op het cohesieve sedimenttransport in de Belgische kustzone (sectie 6.3) moeten in dit kader worden gesitueerd. Studies die rekening houden met de aanbevelingen over het verhogen van de stortefficiëntie en het bestuderen van het globale cohesieve sedimenttransport, worden voorgesteld secties 6.4–6.6. Hieronder wordt in het kort de belangrijkste resultaten en conclusies uit het onderzoek samengevat.

1.3.1 Numeriek model van het gebied rond Zeebrugge

Voor de berekening van het fijnkorrelige sedimenttransport in het kustgebied en ter hoogte van de haven van Zeebrugge werd een fijnmazig model opgesteld dat rekening kan houden met zones die tijdens laagwater droog komen te liggen (Figuur 1.2). Hiervoor werd een zogenoemd *wetting-drying* schema in het hydrodynamische model geïmplementeerd. Deze aanpassing laat een nauwkeurige simulatie toe van de stromingen in ondiepe gebieden en verhindert dat een minimum diepte moet worden opgelegd om numerieke redenen. Het *wetting-drying* schema werd gevalideerd voor zowel het Scheldemodel tussen Vlissingen en Antwerpen met zijn vele zandbanken als ook voor het nieuwe detailmodel van het gebied rond Zeebrugge met zijn brede stranden en zijn zandbank ter hoogte van Heist.



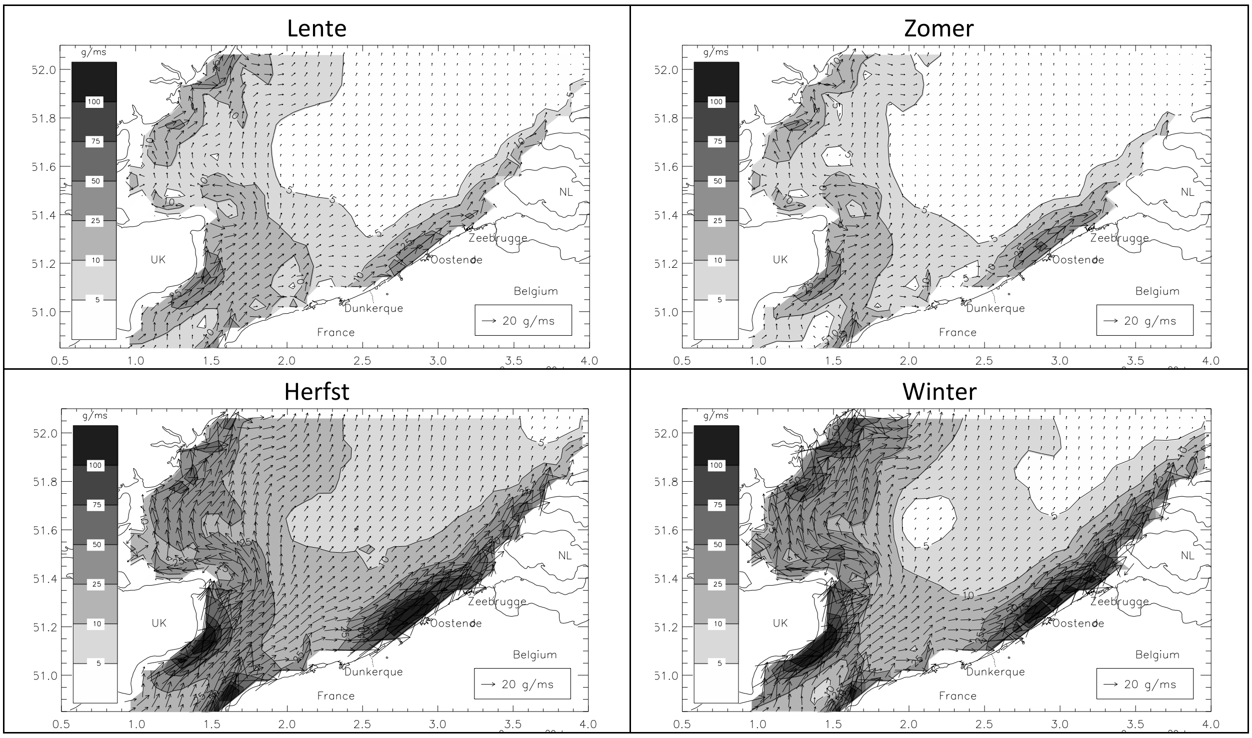
Figuur 1.2 Model van het gebied rond Zeebrugge. Links wordt de waterdiepte getoond bij hoogwater en rechts bij laagwater tijdens een springtij. Merk op dat de zandbank ten oosten van Zeebrugge onder water ligt gedurende hoogwater en droogvalt tijdens laagwater.

1.3.2 Invloed van antropogene activiteiten op de verdeling van cohesieve sedimenten

De effecten van grote ingenieurswerken (verdieping vaargeulen, bouw van de buitenhaven van Zeebrugge) op de verspreiding van cohesieve sedimenten werd bestudeerd rekening houdend met de natuurlijk optredende veranderingen. In een dynamisch kustgebied is de natuurlijke variabiliteit immers heel hoog en moet worden getracht deze van de antropogene invloeden te onderscheiden. Een belangrijke vraag is in hoeverre is de fysische omgeving (hydrodynamica, sedimenttransport, sedimentologie en morfologie) het resultaat van natuurlijke veranderingen of van antropogene activiteiten? In het beschouwde gebied kunnen verschillende soorten slib worden aangetroffen, in het bijzonder vers slib, Holoceen slib en Tertiaire klei. Het effect van de menselijke ingrepen ten opzichte van de natuurlijke processen werden bestudeerd door de huidige verdeling van vers afgezet slib en van slib- en kleikeien te vergelijken met deze van 100 jaar geleden. Verder werden numerieke modellen ingezet om de verdeling van het suspensiemateriaal te simuleren voor een huidige toestand en een toestand voor de uitbouw van Zeebrugge. De historische sedimentdata zijn afkomstig van Gilson's dataset opgesteld in het begin van de 20ste eeuw. De kwaliteit van deze data is hoog en kon daarom gebruikt worden als de belangrijkste databron om de evolutie van de verdeling van cohesieve sedimenten tijdens de laatste eeuw te reconstrueren. De verwerking van de historische en recente data werd vooral gebaseerd op 'velddata' (beschrijvingen van de consolidatie, dikte van de lagen), op morfologische evoluties en—voor wat betreft de recente stalen—ook op radioactiviteitmetingen en gamma densitometrie. De resultaten tonen dat de verdeling van verse sliblagen en van het suspensiemateriaal verandert is tijdens de laatste 100 jaar tengevolge van de menselijke ingrepen in het gebied. Tegenwoordig zijn de meeste zachte slibafzettingen het gevolg van menselijke ingrepen in het systeem, zoals het storten van baggerspecie, het verdiepen van vaargeulen en de bouw en uitbreiding van (vooral) de haven van Zeebrugge. Zowel het gebied met verse slibafzettingen rond Zeebrugge als ook het turbiditeitsmaximum strekt zich tegenwoordig meer richting zee uit dan 100 jaar geleden.

1.3.3 Transport van suspensie materiaal in de zuidelijke Noordzee

Satellietbeelden (SeaWiFS), in situ metingen (getijdencyclus en momentopnamen) werden gecombineerd met de resultaten van een 2D hydrodynamisch numeriek model om het langdurige suspensietransport in de zuidelijke Noordzee te berekenen. Uit de berekeningen kon de totale hoeveelheid aan suspensiemateriaal die de Noordzee via de Straat van Dover binnenstroomt nauwkeuriger worden geschat op 31.74×10^6 ton, zie Figuur 1.3. Hoewel satellietbeelden een overzicht van de suspensieconcentratie in een groot gebied geven, kunnen zij de onzekerheid van sedimenttransportberekeningen niet wegnemen. Dit heeft te maken met het feit dat de suspensieconcentratie varieert als functie van getij, wind, springtij-doodtij cycli en seizoenen. De korte termijnvariaties (getij, springtij-doodtij) werden niet teruggevonden in de satellietbeelden, terwijl seizoensgebonden variaties wel duidelijk konden waargenomen worden. Daarenboven is de suspensieconcentratie in satellietbeelden over het algemeen lager dan uit in situ metingen. Er werd daarom onderzocht of de suspensieconcentratie uit satellietbeelden gebruikt kan worden voor langdurige sedimenttransportberekeningen door de variabiliteit van de suspensieconcentratie uit in situ metingen te vergelijken met deze uit satellietbeelden. De belangrijkste beperkingen van satellietbeelden zijn gerelateerd aan het feit dat satellietdata getuigen zijn van goede weersomstandigheden (wolkenvrij), terwijl in situ metingen, die vanuit een schip worden uitgevoerd, ook tijdens slechtere weersomstandigheden kunnen gebeuren. Verder is de tijdsresolutie van satellietbeelden nog te laag, zodat pieken in de suspensieconcentratie dikwijls niet worden opgemeten. Er wordt beklemtoond dat de metingen van suspensieconcentratie zeker gedurende een getijcyclus moeten worden uitgevoerd in gebieden met een hoge turbiditeit om een representatieve waarde te bekomen.



Figuur 1.3 Gemiddelden per seizoen van het suspensietransport (in g/ms) in de zuidelijke Noordzee. De x- en y-coördinaten zijn longitude (°E) en latitude (°N) respectivelijk.

1.3.4 Sedimentdynamica in de Belgische kustzone

De sedimentdynamica werd bestudeerd om een beter inzicht te bekomen in de heersende processen met als doel het numerieke sedimenttransportmodel te verbeteren zodat de betrouwbaarheid toeneemt van gesimuleerde scenario's. Drie verschillende soorten metingen worden voorgesteld, met name suspensiemateriaal verzameld met een centrifuge aan boord van de Belgica, langdurige metingen van suspensieconcentratie en partikelgrootte met een tripode en gelijkaardige metingen vanuit de Belgica gedurende een getijdencyclus. Uit de meetdata werd de effectieve densiteit en de valsnelheid van het suspensiemateriaal berekend.

Het suspensiemateriaal bestaat uit zeer fijne primaire partikels met een mediane korrelgrootte van 2 μm in de kustzone, 3 μm ter hoogte van de Kwintebank en 7 μm op de Hinderbanken. Het gehalte aan organisch materiaal en calciet bedraagt gemiddeld 7.5% en 49% respectievelijk, dit zijn hogere waarden dan in de bodemsedimenten.

De klassieke oceanografische meettechnieken die vanuit een schip worden uitgevoerd of het vrij recente meer en meer in voege zijnde gebruik van satellietbeelden levert een dataset op dat beperkt is tot (vrij) goede meteorologische condities. Daarenboven is de informatie van uiteraard de satellietbeelden en deels ook de klassieke metingen beperkt tot de oppervlaktelaag. Metingen dicht tegen de bodem, waar de belangrijkste sedimenttransporten zich afspelen, zijn niet mogelijk met deze technieken. Met behulp van een tripode konden tijdsseries worden verzameld van SPM concentratie en partikelgrootte in functie van variërende hydrodynamische omstandigheden (inclusief stormperioden en seizoenen) en dit dicht tegen de bodem. In totaal werd de tripode gedurende 241 dagen verankerd en dit ter hoogte van de Kwintebank, Oostende en vooral Zeebrugge. De belangrijkste bevindingen over SPM concentratie variatie zijn de sterke invloed van stormen en de richting ervan (SW of NW), het belang van meteorologisch/hydrodynamische voorgeschiedenis (een vorige storm kan al suspensiemateriaal aangevoerd/geërodeerd hebben) en het feit dat doodtij-springtijcycli meestal een ondergeschikte invloed uitoefenen. Verder kon uit de data afgeleid worden dat zich regelmatig dicht tegen de bodem een laag met hoge slibconcentratie (>3 g/l) vormt en dat dit het gevolg is van de aanwezigheid van hoge slibconcentraties tijdens vooral stormige periodes (erosie, resuspensie, transport). Uit de metingen blijkt dat deze laag over een vrij lange tijdspanne kan blijven bestaan. Het ontstaan, de ruimtelijke verdeling en het verdwijnen van een hooggeconcentreerde suspensielaag dicht tegen de bodem moet verder in detail bestudeerd worden in de toekomst, gezien zijn waarschijnlijk grote invloed op de sedimentatie van fijnkorrelig materiaal in de baggergebieden.

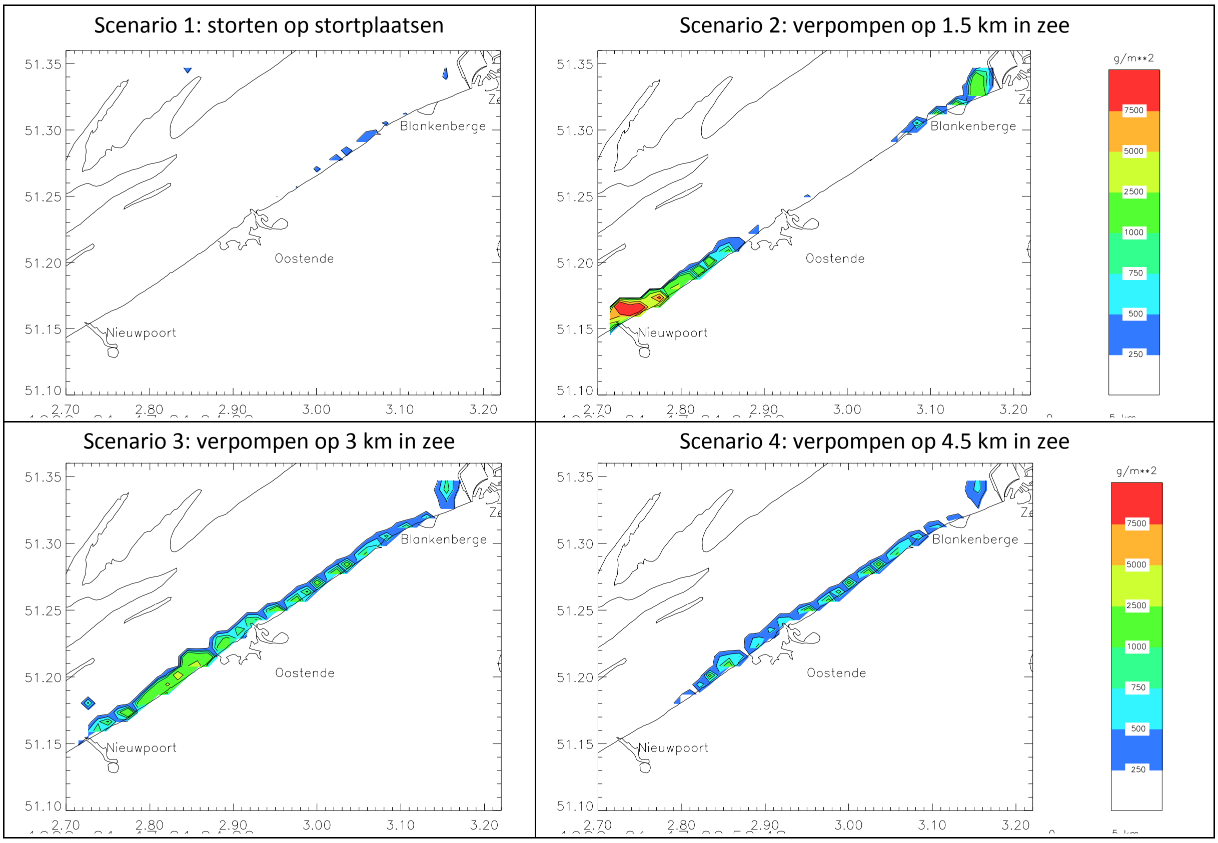
De uit de metingen berekende effectieve densiteit en valsnelheid zijn van dezelfde grootte orde als waarden vermeld in de literatuur. Zowel de langdurige als de 13-uursmetingen duiden op een gemiddeld lagere valsnelheid van de vlokken in de kustzone t.o.v. de Vlaamse Banken (13-uursmeting 0,6 t.o.v 0,7 mm/s; Langdurige metingen: 0,3 t.o.v. 2,0 mm/s). Daardoor zullen de vlokken in de kustzone gemakkelijker in suspensie blijven wat het voorkomen van een turbiditeitsmaximum voor de kust bevordert.

Metingen van valsnelheid zijn altijd verbonden met fouten als gevolg van onnauwkeurigheid van de meetinstrumenten, het gebrek aan juistheid van de meting en de statistische aard van vlokgrootteverdelingen en effecieve densiteiten. Deze fouten treden zowel op bij directe als indirecte methoden om de valsnelheid te bepalen. Foutenberekeningen hebben aangetoond dat de relatieve standaardafwijking op de valsnelheid tengevolge van statistische fouten 100%. Deze statistische fout zal altijd hoog zijn bij natuurlijke vlokken of partikels en kan daarom niet verminderd worden door de nauwkeurigheid van het meetinstrument te verhogen. Een belangrijk deel van onze kennis over flocculatie en cohesieve sedimentdynamica (depositie en erosie) is gebaseerd op metingen. De fouten geassocieerd met indirecte (of directe) valsnelheidmetingen zijn van nature uit heel groot en dit vooral tengevolge van de statistische aard van het proces; de totale fout zal nog hoger zijn omdat systematische fouten door de onnauwkeurigheid van de meetinstrumenten niet werden beschouwd. Het wordt aanbevolen om bij het modelleren van het cohesieve sedimenttransport (minstens) de statistische onzekerheid in rekening te brengen via de standaardafwijking of door een vlokgrootteverdeling in het numerieke model in te voeren.

Een flocculatiemodel laat toe om de valsnelheid in een sedimenttransportmodel te berekenen in functie van een aantal parameters. Berekeningen habben getoond dat met eenvoudige flocculatiemodellen kan niet altijd een voldoende overeenkomst met de uit metingen berekende valsnelheid worden bekomen. De kwaliteit van deze modellen (zoals het machtsfunctiemodel) is afhankelijk van plaats en tijd. Meer complexe modellen, met een betere weergave van de fysische of biologisch-fysische processen zijn nodig om een goede overeenkomst te bekomen tussen meting en modelresultaat.

1.3.5 Modellering van het storten van baggerspecie uit Nieuwpoort en Blankenberge

De baggerspecie uit de havens van Nieuwpoort en Blankenberge, wordt gestort op de stortplaatsen Br.&W. Nieuwpoort en Br.&W. Zeebrugge Oost. Overwogen wordt om de baggerspecie, die voornamelijk uit fijnkorrelig materiaal bestaat, via een vaste leiding in zee te pompen. Een sedimenttransportmodel werd opgezet om de verspreiding van baggerspecie door storten op Br.&W. Nieuwpoort en Br.&W. Zeebrugge Oost en door het rechtstreeks verpompen in zee te simuleren. De hoeveelheid baggerspecie uit de havens van Blankenberge en Nieuwpoort is gering. Het storten van het materiaal op de baggerstortplaatsen heeft – onder de huidige toegelaten omstandigheden (storten op stortplaatsen) een gering effect op de slibafzetting en slibconcentratie op het BCP en in de kustzone. Bij het verpompen van de specie via een vaste leiding in zee zijn de effecten belangrijker: een groot deel van het gestorte materiaal zal in de kust- en strandzone afgezet worden. De maximale (getijgemiddelde) slibafzetting (16 kg/m^2 of 1,3 cm) wordt gesimuleerd in het scenario waar het slib op 1,5 km van het strand wordt gepompt en is juist ten oosten van Nieuwpoort gelegen. Enkel door de vaste leiding verder in zee te verplaatsen kan de hoeveelheid slib in de strandzone tot aanvaardbare hoeveelheden dalen, zie Figuur 1.4.



Figuur 1.4 Slibafzetting in de kustzone na 14 dagen voor de huidige toestand (storten op Br.&W. Nieuwpoort en Br.&W. Zeebrugge Oost, scenario 1) en voor 3 seario's waarbij het baggermateriaal in zee wordt gepompt op respectievelijk 1.5 km (scenario 2), 3 km (scenario 3) en 4.5 km (scenario 4) van de kustlijn.

1.4 Onderzoek ILVO

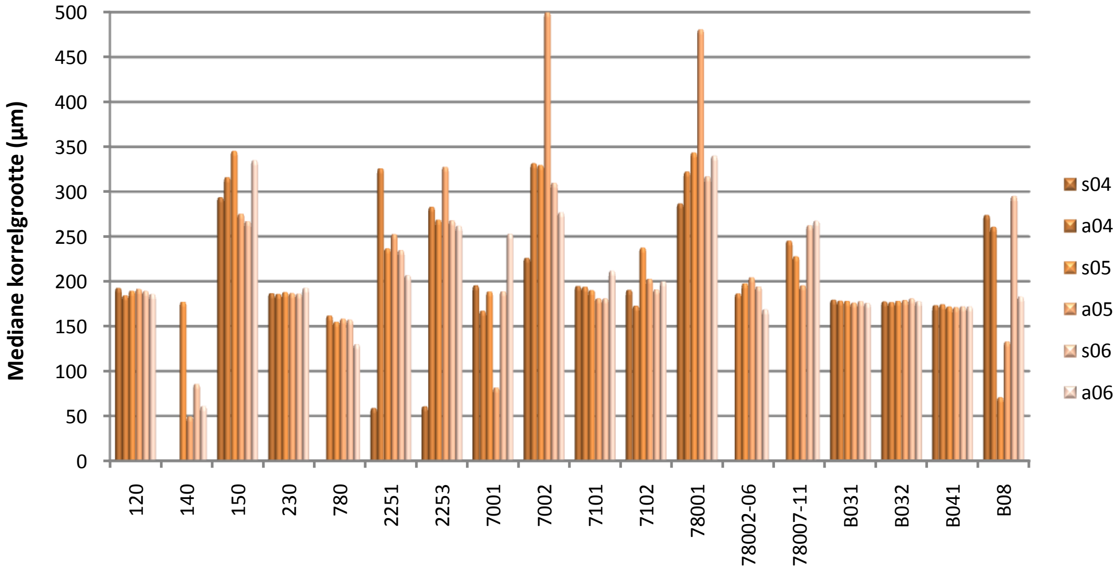
In dit hoofdstuk worden de resultaten weergegeven van het onderzoeksprogramma uitgevoerd door ILVO - Eenheid Dier – Visserij in de periode 2006-2007. Dit omvat de monitoring van het sediment en bodemorganismen (macrobenthos, epibenthos en demersale vis), qua granulometrie (7.4), biologie (7.5 en 7.6), histopathologie (7.7), biochemie (7.8) en chemie (7.9 en 7.10).

De bemonsterde zones omvatten de vijf loswallen (Nieuwpoort, Oostende, Zeebrugge Oost, S2 en S1), de 'randgebieden' van de loswallen en enkele referentiezones. De stalen worden gewoonlijk verzameld aan boord van de R.V. Belgica. Door een defect van de Belgica werden in verschillende campagnes enkele Van Veen stalen gecollecteerd aan boord van de Zeeleeuw en Ter Streep.

Voor het chemisch luik zijn de resultaten gebaseerd op de voor- en najaarscampagnes van 2005 en 2006. Voor de andere luiken zijn de resultaten beperkt tot de voor- en najaarscampagnes van 2006. Dit heeft vooral te maken met het feit dat in 2006 de staalnamestrategie volledig werd aangepast voor alle loswallen, waarbij rekening werd gehouden met de beschikbare stortintensiteitgegevens. Daardoor is een vergelijking met gegevens verzameld in 2005 minder eenvoudig. Op de vijf loswallen werd voor het sediment en het macrobenthos de staalname met een Van Veen grijper sterk uitgebreid. De staalname met een 8-meter boomkor werd in alle zones verdubbeld (1 binnen en 1 buiten de stortzone), maar wordt in bepaalde zones nog steeds bemoeilijkt, door hoge slibconcentraties, bryozoa en hydrozoa of slechte weersomstandigheden, waardoor een deel van de najaarscampagne in 2006 niet kon worden uitgevoerd.

1.4.1 Granulometrie

De granulometrische karakteristieken van de loswallen kunnen zowel in ruimte als in tijd sterk variëren. Dit is gezien de stortactiviteiten die daar plaatsvinden zeker te verwachten. Vooral het zeer lokale karakter van de intensiteit van de stortingen beïnvloed de mediane korrelgrootte. Toch kunnen we over langere perioden spreken van een vrij constante granulometrie.



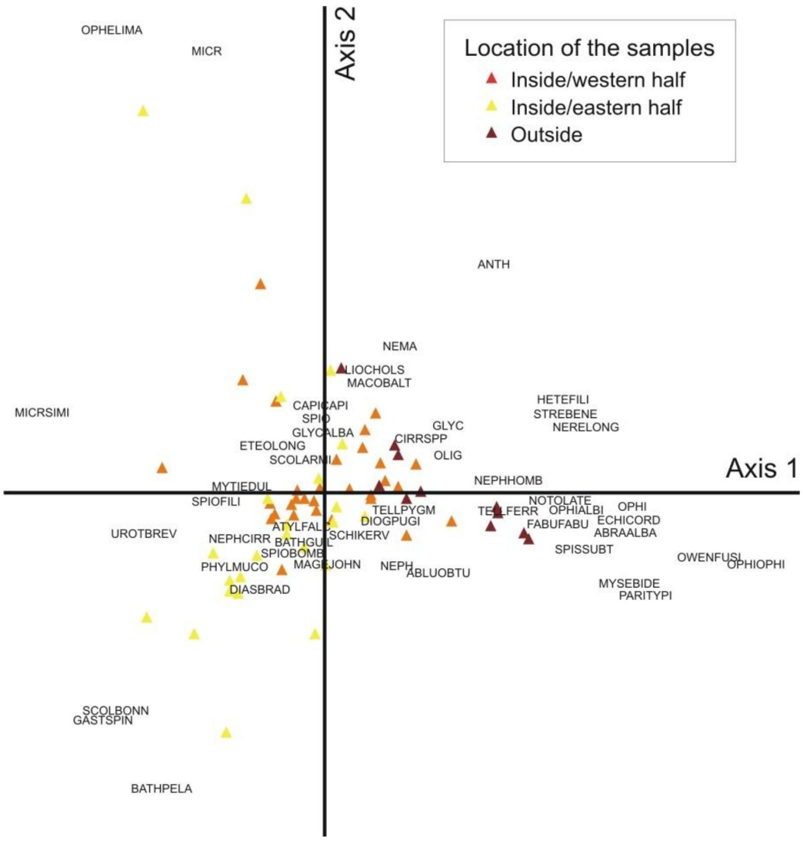
Figuur 1.5 Evolutie van de mediane korrelgrootte gedurende de periode 2004-2006 van enkele monitoringpunten in de lente (s) en de herfst (a).

1.4.2 Macrobenthos

Het macrobenthos werd bemonsterd met een Van Veengrijper. De belangrijkste gemeenschapsparameters (densiteit, aantal soorten en Shannon-Wiener diversiteitsindex) werden aangewend voor een gemeenschapsanalyse in ruimte en tijd. De resultaten zijn beperkt tot twee staalnamecampagnes (voor- en najaar 2006), in het centrum en in de onmiddellijke nabijheid van de vijf loswallen: S1, S2, Zeebrugge Oost, Oostende en Nieuwpoort. Daarenboven werden nog enkele andere locaties als referentiestations meegenomen. De invloed van het lossen van baggerspecie op de mariene gemeenschappen van het Belgisch Continentaal Plat, kan niet worden veralgemeend vanwege de duidelijke verschillen tussen de locaties en de frequentie, de samenstelling en de hoeveelheden van het gestorte materiaal.

De verscheidene loswallen liggen verspreid over een relatief kleine oppervlakte op een maximale afstand van 15 km van de kust. Dit kleine deel van de Zuidelijke Noordzee wordt gekenmerkt door een hoge diversiteit in sedimentsamenstelling en bijbehorende macrobenthische gemeenschappen. De ruimtelijke variatie binnen dit gebied leidt ertoe dat de stalen zich in drie onderscheidbare groepen afsplitsen.

Verstoorde condities worden vastgesteld voor de loswallen S1, Zeebrugge Oost en Oostende. Bovendien vertoonde één staal van de loswal S2 een duidelijk verschil met de andere stalen van die site. Niettegenstaande het feit dat het dagelijks lossen van grote hoeveelheden gebaggerd materiaal een belangrijke oorzaak zijn voor het verstoren van het lokale sediment en bijbehorende fauna, blijft het echter onduidelijk in hoeverre deze omstandigheden uitsluitend aan de baggerlosactiviteiten te wijten zijn. Daarenboven werden ook enkele monitoringpunten gelegen buiten de voor storten toegekende zones als verstoord gevonden (zie Figuur 1.6).



Figuur 1.6 Multivariate analyse (RA) van de stalen van loswal S1 tonen verschillen aan tussen de binnen- (westelijke en oostelijke helft) en buitengelegen staalname locaties.

1.4.3 Epibenthos

Het epibenthos en de demersale vissen werden bemonsterd met een 8 meter garnalenkor. Soortenrijkdom, diversiteit, densiteit en biomassa zijn de biologische karakteristieken die worden voorgesteld in dit rapport. Daarnaast werden een aantal multivariate analyses uitgevoerd om mogelijke verschillen tussen bagger- en referentiezones aan te tonen.

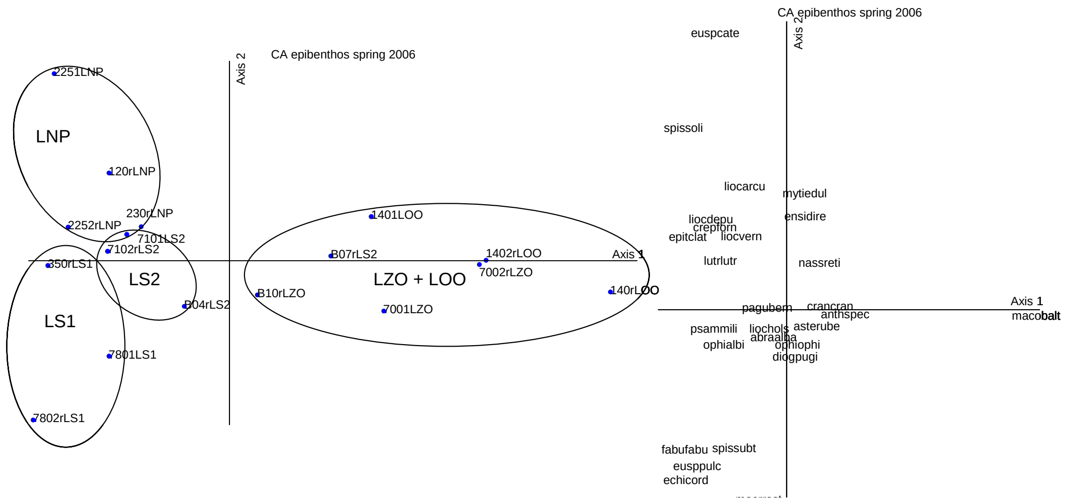
In alle zones samen werden in totaal 49 epibenthische soorten genoteerd in 2006. De temporele en ruimtelijke variatie was hoog in alle univariate parameters. In alle loswallen en referentiezones werden lagere waarden genoteerd voor densiteit en biomassa in het voorjaar, terwijl de soortenrijkdom en diversiteit iets hoger lagen t.o.v. het najaar.

Er was een heel sterke dominantie van slangsterren (*Ophiura ophiura* en *O. albida*) in bijna alle stalen van 2006. In vergelijking met 2005 werden een lagere soortenrijkdom en diversiteit genoteerd in 2006. Het epibenthos in de loswallen en in de referentiezones van Oostende en Zeebrugge waren gekarakteriseerd door een lage densiteit, biomassa en soortenrijkdom in vergelijking met de hogere waarden in Nieuwpoort en in de meer offshore gelegen zones (Br.&W. S1 en Br.&W. S2).

Er was geen éénduidig verschil in de biologische parameters tussen de loswallen en de referentiezones wat betreft het epibenthos in voor- en najaar 2006, behalve voor een aantal referentieboomkorstalen (B07 en 7802) met extreem hoge densiteitwaarden, die niet direct te verklaren zijn.

De verschillende staalnamepunten in en rond de loswallen clusteren grotendeels samen per loswalzone in de multivariate analyses. Dit kan erop wijzen dat in 2006 de impact van het storten van baggerspecie op het epibenthos minimaal was. Dit was het meest duidelijk voor Loswal Nieuwpoort waar het epibenthos in de loswal en in de referentiezone er rond het best vergelijkbaar was. Dit is mogelijks gerelateerd aan de lage stortintensiteit in loswal Nieuwpoort in vergelijking met de andere zones.

Daarnaast is er een duidelijke scheiding van de clusters (loswal + referentiezone) per gebied voor Nieuwpoort, Br.&W. S1 en Br.&W. S2, terwijl de clusters van Oostende en Zeebrugge meer op elkaar lijken. Tegelijk wijkt het epibenthos in en rond loswal Oostende en Zeebrugge meer af van de overige drie loswallen, wat vooral te wijten is aan de ruimtelijke zonatie op het Belgisch deel van de Noordzee.



Figuur 1.7 Correspondentie analyse van het epibenthos in voorjaar 2006

Demersale vis

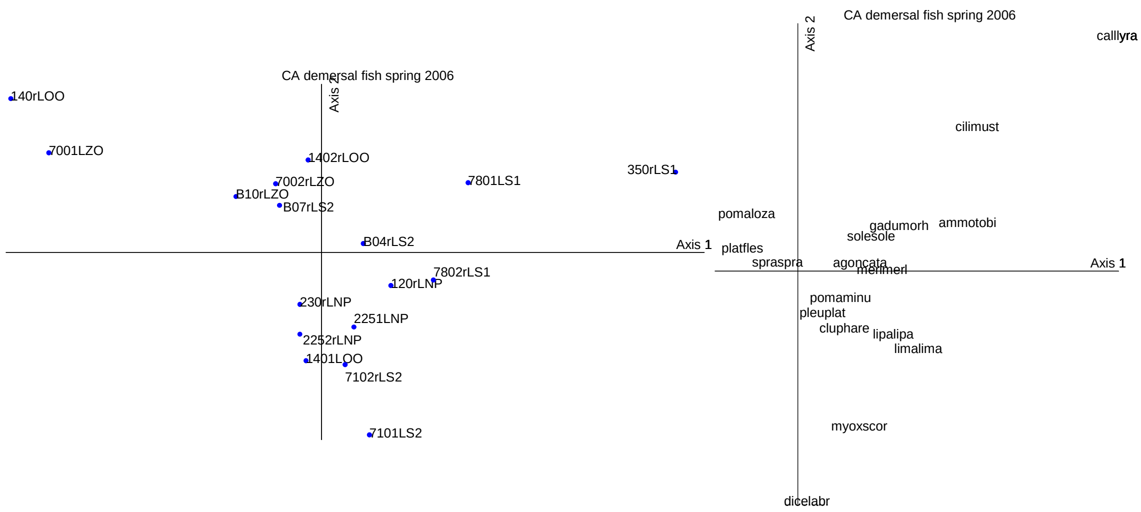
In alle zones samen werden in totaal 43 demersale vissoorten genoteerd in voor- en najaar 2006. De temporele en ruimtelijke variatie was hoog in alle univariate parameters.

Er was een heel sterke dominantie van sprot *Sprattus sprattus* en grondels *Pomatoschistus* spp. in bijna alle stalen van 2006, zowel in het voor- als najaar. In vergelijking met 2005 was de densiteit voor de demersale visgemeenschap veel lager in 2006, vooral te wijten aan de lage densiteit aan platvissen (Pleuronectiformes).

Er was geen duidelijk verschil in de biologische parameters tussen de loswallen en de referentiezones wat betreft de demersale vissen in voor- en najaar 2006. Nochtans is er geen éénduidige clustering van de staalnames in de loswallen met hun respectievelijke referentiezones in de multivariate analyses. In de plaats daarvan lijkt de clustering vooral gebaseerd te zijn op gelijkenissen qua dominantie van bepaalde soorten.

Hoewel voor de meeste boomkor stalen een hoge similariteit werd genoteerd tussen de loswallen en de randzones, is dit niet het geval voor loswal Zeebrugge Oost. Dit is mogelijks gerelateerd aan de hoge stortintensiteit en het type gestort materiaal (fijn slib) in deze loswal.

Voor de andere loswallen kan geconcludeerd worden dat er geen directe impact kan worden aangetoond van het storten van baggerspecie op de demersale visfauna. De reden daarvoor lijkt logisch, omdat demersale vissen zeer mobiel zijn, en dus snel de loswallen kunnen verlaten en opnieuw recoloniseren vanuit de omliggende gebieden.



Figuur 1.8 Correspondentie analyse van de demersale visfauna in voorjaar 2006.

1.4.4 Histopathologie en (bio)chemie

Voor dit onderzoeksluik werden zowel sedimentstalen verzameld als een aantal epibenthische soorten en enkele demersale vissoorten.

Bij enkele commerciële rond- en platvissoorten wordt aan boord bepaald welke goed waarneembare visziekten zich voordoen op het Belgisch Continentaal Plat (BCP). Visziekten geïnduceerd door vervuiling waren zeldzaam, en nooit te relateren met het lossen van baggerspecie. De meest voorkomende visziekten werden veroorzaakt door parasieten. Door de mobiliteit van de onderzochte vissen moet de interpretatie van de data met de nodige omzichtigheid gebeuren.

De biochemische indicatoren werden getest op juveniele scharretjes. Deze waren consistent met de observaties dat EROD activiteit seizoenaal geïnduceerd word. Extreme niveaus van inductie werden niet waargenomen. De seizoenale variatie hangt samen met het winterse voedselgebrek, de vertering van de vetreserves en daaropvolgende vrijstelling van de in het vetweefsel opgestapelde contaminanten. Het is treffend dat deze inductie niet wordt waargenomen wanneer de vetreserves worden aangelegd, terwijl de contaminanten dan eveneens in het systeem circuleren. Verschil tussen baggerloswallen en referentiepunten waren insignificant.

Chemische vervuiling van het sediment is vrij beperkt, enkel eenmalig worden extreme waarden genoteerd bij staalnames op specifieke punten. Voor sediment blijven deze beperkt, voor PCB's worden de hoogste waarden gevonden in de Scheldemonding, de voornaamste bron van deze stoffen naar het BCP.

De resultaten voor OCP's zijn vergelijkbaar. Uitzonderlijke waarden zijn niet enkel op de baggerloswallen te vinden, de hoogste waarde werd genoteerd op meer dan 40 km uit de kust. De gemiddelde waarden voor het BCP zijn vrij laag.

PBDE waarden zijn meetbaar op bij alle staalname. Dat is niet echt een verassing, maar wijst er toch op dat een voortdurende evaluatie van de te meten parameters, en een mogelijkheid tot aanpassing ervan, primordiaal zijn voor een goede strategie.

Van de organotin componenten zijn enkel butyltinverbindingen meetbaat, de waarden zijn beduidend hoger dan de vooropgestelde kwaliteitscriteria, en het volgen van deze stoffen is heel belangrijk, gezien hun hoge toxiciteit en notoire milieu-impact.

Zware metalen in sediment zijn variabel, enkel Hg vertoont stabiele concentraties, en dus vermoedelijk een vrij homogene verdeling, dankzij de lange en zware inspanning om de input van Hg in het milieu te reduceren.

Cr gehalten zijn hoog, in grootte vergelijkbaar met Zn. Omdat Cr in bepaalde oxydatietoestanden sterker toxisch is dan in andere, lijkt het aangeraden te bekijken of deze speciatie kan worden uitgevoerd.

Epibenthos stalen (garnaal, krab, schelpdieren, zeesterren) vertonen sterk schommelende PAK concentraties. Hoge waarden in bepaalde organismen zijn zelden te linken aan hoge waarden in andere op dezelfde plaats tijdens dezelfde campagne. De totale waarden zijn zelden onrustwekkend, maar hoog genoeg om blijvende aandacht te vereisen.

PCB's in vis (grondels, pitvis, harnasman) zijn normaal, in schaaldieren daarentegen zijn de gehalten soms hoog en tegen de limiet voor menselijke consumptie. Van een zekere verstoring is sprake. De rechtstreekse link met baggerlosactiviteiten is onmogelijk te leggen In schelpdieren, zeester en zeeanemoon zijn de warden het laagst.

OCP's zijn voornamelijk beperkt tot de DDT familie producten, hoewel DDT en minderheid van de contaminatie uitmaakt. De effecten van de ban van DDT zijn duidelijk, maar het zal nog een hele tijd duren eer alle producten verdwenen zullen zijn. Hogere waarden op baggerloswallen zijn niet uitzonderlijk, de reden daarvan is nog onduidelijk.

Wat metalen betreft zijn er weinig problemen binnen de epibenthische gemeenschap, al zijn de waarden voor Pb nogal hoog.

De nieuwe staalname strategie toont een aantal bijzondere fenomenen, het volhouden ervan gedurende meerder jaren zal duidelijk maken wat het belang van de plotse uitschieters op het milieu kan zijn.

1.5 Monitoringsprogramma 2007 van de baggerplaatsen

Op de 40ste vergadering van de Ambtelijke Werkgroep (16.11.06), opgericht in het kader van het Samenwerkingsakkoord tussen het Vlaamse Gewest en de federale regering (zie inleiding), werd beslist tot de uitvoering van een nieuw monitoringprogramma van de baggerplaatsen. Dezelfde oefening werd uitgevoerd in 1990 en 2000. De doelstelling van deze monitoring is het nagaan van de kwaliteit van de baggerspecie in 2007 (beter, slechter, ...) ten opzichte van de resultaten van de monitoringscampagnes in 1990 en 2000, het vastleggen van nieuwe concentraties voor de berekening van de contaminantvrachten in het kader van de OSPAR rapportage en een onderscheid kunnen maken tussen de kwaliteit van onderhouds- en verdiepingsbaggerspecie. De posities van de monitoringpunten (zie kaarten) zijn dezelfde als in de vorige monitoringjaren. In 2007 werd ook opdracht gegeven voor het nemen van een aantal referentiemonsters, hetgeen niet het geval was in 1990 en 2000.

De Vlaamse Regering, Departement Mobiliteit en Openbare Werken, heeft opdracht gegeven aan ECOREM voor het uitvoeren van de studie voor wat betreft de fysico-chemische kenmerken van de baggerspecie en de bepaling van de organische en anorganische contaminanten. De resultaten van deze studie worden hier kort besproken aangezien het rapport nog maar net werd afgeleverd in draft-vorm. In een tweede fase worden de resultaten verwacht van een ecotoxicologische studie die werd uitgevoerd op een aantal van de stalen genomen door ECOREM. Deze analyses zijn evenwel nog niet klaar en zullen in een volgende syntheseverslag worden besproken. Een gedetailleerde bespreking van dit monitoringprogramma 2007 ontbreekt aan dit rapport aangezien het draft rapport zoals hoger vermeld eigenlijk werd aangeleverd na de deadline voor het inleveren van teksten.

Hierna volgen een aantal tabellen met resultaten die de vergelijking weergeven tussen de resultaten van de analyses 1990, 2000 en 2007 en de toetsing ervan aan de sedimentkwaliteitscriteria (zie hoofdstuk 5) Alle resultaten kunnen in het Engelstalige gedeelte van het rapport worden weergevonden.

Tabel 1.3 Voorhaven Zeebrugge

Parameter	Streef-waarde	Grens-waarde	Eenheid	Gemiddelde 1990	Gemiddelde 2001	Gemiddelde 2007
Elementen						
Arseen (As)	20	100	ppm	14,0	18,0	16
Cadmium (Cd)	2,5	7	ppm	2,73	0,57	0,61
Chroom (Cr)	60	220	ppm	44,7	71,6	61
Koper (Cu)	20	100	ppm	24,8	19,8	19,6
Kwik (Hg)	0,3	1,5	ppm	0,43	0,21	0,20
Nikkel (Ni)	70	280	ppm	23,1	21,5	19
Lood (Pb)	70	350	ppm	76,8	39,8	35
Zink (Zn)	160	500	ppm	167	139	109
PAKs						
PAK's 16 EPA (som)	70	180	µg/goc	35	54	<25,59
PCB's						
PCB's (7) (som)	2	2	µg/goc	0	0	0,262
TBT	3	7	ppb	21,7	57,5	45

Legende

conc.	: concentratie < streefwaarde
conc.	: streefwaarde ≤ concentratie < grenswaarde
conc.	: grenswaarde ≤ concentratie

Tabel 1.4 Haven Blankenberge

Parameter	Streef-waarde	Grens-waarde	Eenheid	Gemiddelde 1990	Gemiddelde 2001	Gemiddelde 2007
Elementen						
Arseen(As)	20	100	ppm	13,7	17,4	15
Cadmium (Cd)	2,5	7	ppm	2,41	0,36	0,52
Chroom (Cr)	60	220	ppm	18,9	60,9	55
Koper (Cu)	20	100	ppm	19,9	16	17,3
Kwik (Hg)	0,3	1,5	ppm	0,35	0,17	0,15
Nikkel (Ni)	70	280	ppm	23,9	19	18
Lood (Pb)	70	350	ppm	51,7	34,9	33
Zink (Zn)	160	500	ppm	120	103	94
PAK's						
PAK's 16 EPA (som)	70	180	µg/goc	23	52	30,1
PCB's						
PCB's (7) (som)	2	2	µg/goc	0	0	0,27
TBT	3	7	ppb	41,3	59,8	19,7

Legende

conc.	: concentratie < streefwaarde
conc.	: streefwaarde ≤ concentratie < grenswaarde
conc.	: grenswaarde ≤ concentratie

2 Opvolging aanbevelingen Syntheserapport 2006

Voor het uitvoeren van baggerwerken worden de laatste jaren schepen met grotere diepgang en tonnenmaat ingezet. Hierdoor komt het storten op de stortplaats Br.&W. Zeebrugge Oost in het gedrang, waardoor zich op middellange termijn een verplaatsing van deze stortplaats opdringt. De nabijheid van een speciale beschermingszone in het kader van het K.B. van 14.10.05 (tot instelling van speciale beschermingszones en speciale zones voor natuurbehoud in de zeegebieden onder de rechtsbevoegdheid van België) en de oude munitiestortplaats "Paardenmarkt" zullen een belangrijke invloed hebben op de voornoemde verplaatsing, Het verdient dus aanbeveling om te zoeken naar een oplossing die eventueel een antwoord kan bieden voor het geheel van de problematiek in dit gebied.

Het onderzoek naar een globale strategie voor het gebied ten oosten van Zeebrugge, waarin de beschermde gebieden, een verplaatsing van de stortplaats, de morfologische evolutie van de zandbank ter hoogte van Heist, de munitiestortplaats Paardenmarkt en de kusterosie ter hoogte van Knokke is opgenomen, werd door de BMM opgestart. Een 3D hydrodynamisch detailmodel van het gebied rond Zeebrugge werd ontwikkeld (sectie 1.3.1) en een studie van de flocculatieprocessen op het BCP opgestart. Het doel hiervan is de kwaliteit van de numerieke voorspellingen van het sedimenttransportmodel te verbeteren (sectie 1.3.4). De impact van de grote infrastructuurwerken uitgevoerd tijdens de laatste eeuw (uitbouw van Zeebrugge, verdiepingen van vaargeulen, stortingen van baggerspecie) op de verdeling van slib werd bestudeerd door de huidige situatie te vergelijken met een historische situatie (sectie 1.3.2). Hierbij werden numerieke modellen en recente en in situ sedimentstalen gebruikt.

Onderzoek naar het getijdengebonden storten van baggerspecie dient verdere bijzondere aandacht te krijgen ten einde de lange termijn doelstelling, nl. het verminderen van de recirculatie van de gestorte baggerspecie naar de vaargeulen, te realiseren.

Er is momenteel nog onvoldoende inzicht in de efficiëntie van de stortplaatsen. Het wordt aanbevolen een studie op te starten waarin de totale hoeveelheid slib die de Belgische kustzone binnenstroomt te vergelijken met de gemiddelde verblijfstijd van het slib in de kustzone. Deze berekeningen zullen belangrijke informatie kunnen leveren over de efficiëntie van de stortplaatsen.

Met deze beide aanbevelingen werd rekening gehouden in het onderzoek naar het globaal transport van gesuspendeerd material in de zuidelijke Noordzee (sectie 1.3.3); de dynamica van de fijnkorrelige sedimenten op het BCP (sectie 1.3.4) en in de modellering van de stortoperaties te Blankenberge en Nieuwpoort (sectie 1.3.5).

De metingen die gedurende de laatste jaren met behulp van een tripode werden uitgevoerd, gaven belangrijke nieuwe inzichten in het slibdynamisch systeem voor onze kust. Het wordt daarom aanbevolen om de mogelijkheid te onderzoeken om een (quasi) continu registrerend meetstation te voorzien.

Uit het onderzoek bleek dat een verdubbeling van de tripode de meest haalbare optie voor een (quasi) continu registrerend meetstation is. Het aankoopdossier voor een tweede tripode werd opgestart, er wordt voorzien dat de tripode gedurende 2008 operationeel zal komen

De technische werkgroep die gedurende de vorige vergunningsperiode werd opgericht, heeft o.a. geresulteerd in een verbeterde monitoringstrategie en uitwisseling van gegevens tussen de verschillende betrokken partijen. Het wordt aanbevolen deze samenwerking verder te zetten en meer in het bijzonder te intensifiëren.

De Technische werkgroep kwam op regelmatige tijdstippen samen tijdens de voorbije vergunningsperiode. Daarnaast was er een intensieve samenwerking tussen verschillende betrokken partijen, o.a. tussen WL en BMM. Ook het doorsturen van de stortgegevens door MOW naar ILVO is gebeurd

De monitoringstrategie voor biologisch en chemisch onderzoek die gedurende de laatste twee jaar werd toegepast op de loswal S1, dient te worden uitgebreid naar de andere loswallen, dit in functie van de stortintensiteitkaarten, storthoeveelheden en oppervlakte van de loswal.

De halfjaarlijkse monitoringstrategie werd in 2006 volledig aangepast. Op en rond de vijf loswallen wordt nu een veelvoud aan stalen genomen, zowel voor macrobenthos als epibenthos en demersale vis (sectie 1.4.3). Daardoor krijgen we een beter idee over de mogelijke effecten van het storten op de biologische en chemische samenstelling in, op de rand en in de nabijheid van de loswallen. Deze strategie vergt natuurlijk wel meer inspanning, zowel qua staalname als qua verwerking, maar zal zeker gedurende de komende jaren verder worden gevolgd.

Teneinde een beter inzicht te kunnen krijgen in de relatie tussen de gebaggerde specie en het sediment en de biota uit de stalen bemonsterd op de loswallen, wordt het aanbevolen dat tussen aMT en ILVO een protocol wordt afgesproken voor het bekomen van stalen uit het beun van baggerschepen op het ogenblik dat de monitoringcampagnes van het ILVO plaatsvinden.

Er werd een eenmalige staalname uitgevoerd tijdens de campagne in het voorjaar 2006. De resultaten daarvan werden kort weergegeven in een voortgangsrapport. Er was blijkbaar wel een probleem qua staalname, omdat geprobeerd werd om de stalen uit 'het midden' van de beun te nemen. Een vergelijkbare staalname zal herhaald worden in de komende vergunningsperiode, waarbij stalen worden genomen aan het begin van de stortpijp. Er werden eveneens een tiental macrobenthosstalen verzameld uit de haven van Zeebrugge tijdens de monitoring uitgevoerd in het najaar 2007 door MOW-aMT. Deze moeten nog verwerkt worden.

Voor meerdere invertebraten en vissen moet het onderzoek naar organische contaminanten, naar analogie met zware metalen, op punt worden gesteld. Zo wordt aanbevolen om na te gaan of de set determinanten moet worden uitgebreid, en hoe de eventuele nieuwe parameters correct kunnen worden bepaald.

Het protocol voor de bepaling van PAK's en PCB's in diverse biota werd ondertussen grotendeels op punt gesteld. Voor de bepaling van andere contaminanten wordt er gestreefd naar een samenwerking met andere instituten. Voor een uitbreiding van de set determinanten naar 'nieuwe' contaminanten moet nog verder onderzoek gebeuren. Dit gebeurt o.a. binnen diverse ICES werkgroepen, waaraan ILVO en BMM actief deelnemen.

Teneinde het syntheseverslag een internationale dimensie te kunnen geven, wordt het aanbevolen om de toekomstige syntheseverslagen in het Engels op te stellen met hierbij gevoegd een samenvatting in het Nederlands.

Zoals gebeurd is in dit syntheseverslag

3 Aanbevelingen voor de minister

- Onderzoek naar alternatieve stortschema's (zoals getijgebonden) dient bijzondere aandacht te krijgen ten einde de lange termijn doelstelling, nl. het verminderen van de recirculatie van gestort baggermateriaal naar de baggerplaatsen, te realiseren. Er wordt voorgesteld om het onderzoek te richten op de stortplaats Br.&W. Zeebrugge Oost. Er zal aandacht geschonken moeten worden aan de invloed van getij en wind op de recirculatie en aan de invloed van een verplaatsing van de stortplaats op de te baggeren hoeveelheden.

- Het lijkt aangewezen om een onderscheid te maken tussen onderhouds- en verdiepingsbaggerwerken. Voor onderhoudsbaggerwerken zijn de werkjaren veranderd en gelijkgesteld met kalenderjaren. De vergunningen zullen dan ook worden opgemaakt voor kalenderjaren, tot nu toe dus 2 jaar. Aangezien nu een overgangsperiode is, zullen de nieuwe vergunningen verleend worden tot eind december 2009 en nieuwe (volgende) aanvragen dienen dan te gebeuren voor de periode januari 2010 – december 2011.

- Aanvragen en vergunningen voor verdiepingswerken zullen aangevraagd en vergund worden voor de periode waarin deze uitgevoerd worden en dus niet de kalenderjaren volgen zoals voor onderhoudsbaggerwerken die quasi continu uitgevoerd worden. Bij de aanvragen voor verdiepingsbaggerwerken dient het technische dossier te worden aangevuld met een deel milieu-effecten waarvan de inhoud dient vastgelegd te worden door de ambtelijke werkgroep binnen een termijn van 3 maanden, d.w.z. ten laatste tegen eind mei 2008.

- De technische werkgroep dient te onderzoeken tegen de volgende vergunningsperiode of een update van de sedimentkwaliteitscriteria zich niet stilaan opdringt hierbij gebruik makend van de resultaten van het grote monitoringsprogramma van de baggerplaatsen.
  De kostprijs voor het storten van baggerspecie uit de havens van Nieuwpoort en Blankenberge naar de respectieve baggerloswallen Nieuwpoort en Br.&W. Zeebrugge Oost is niet verwaarloosbaar. Een geïntegreerd onderzoek naar de technische, economische, ecologische en reglementaire haalbaarheid van een stortpijpleiding voor Nieuwpoort en Blankenberge zal worden opgestart door MD&K. Daarbij wordt er input gegeven door BMM d.m.v. modelsimulaties en door ILVO wat betreft de ecologische consequenties van het eventueel dichter bij Nieuwpoort en Blankenberge 'lozen' van de baggerspecie.

- De problemen rond stortplaats Zeebrugge Oost moeten dringend worden aangepakt. De huidige stortplaats komt te snel 'vol' waardoor de baggerschepen moeilijker op de loswal geraken. Het model van BMM toont aan dat het beter zou zijn om de stortplaats te verleggen ten westen van Zeebrugge. Indien daar effectief plannen toe zouden zijn, moet er een T0 situatie worden bepaald door ILVO wat betreft de huidige toestand van het benthos in dit gebied. Daartoe is input vanuit BMM en MOW-aMT vereist om de 'beste' locatie van deze nieuwe stortplaats te bepalen.

- Een geïntegreerde samenwerking tussen de drie partners, inclusief een socio-economisch en reglementair luik, moet de mogelijkheden van het overstorten over de dam van Zeebrugge nagaan. Daarbij moet gekeken worden naar het transport van het gestorte materiaal, de suspensietijd en -plaats (ev. materiaal in suspensie houden binnen Zeebrugge zelf), het effect op het bodemleven (en ev. de vogels) binnen en buiten de havenmuren, en een kosten-baten analyse, waarbij ook rekening wordt gehouden met de onkosten van de overige baggerwerkzaamheden. Er wordt nagegaan in hoeverre we hieromtrent een nieuw samenwerkingsproject kunnen opstarten.

- Tijdens de vorige vergunningsperiode waren er nog problemen met het maken van de stortintensiteitskaarten. Ondertussen is het software programma van MOW-aMT volledig operationeel. Er zal worden afgesproken hoe en met welke regelmaat de stortintensiteitsgegevens – en kaarten kunnen worden aangeleverd aan ILVO. Extra gegevens die daarbij nodig zijn, is in welk kwadrant wordt gestort, waar het materiaal vandaan komt, hoeveel en wanneer er wordt gestort. Ondertussen wordt ook afgesproken om de baggerplanning door MOW-aMT wekelijks door te mailen, niet alleen naar BMM maar ook naar ILVO.

- Er wordt ook nagegaan of er extra informatie over het sedimenttype (uit de dagboekverslagen van de baggeraars) kan worden geïnformatiseerd binnen het BIS programma van MOW-aMT. Daartoe zal MOW-aMT in eerste instantie nagaan welke gegevens er nu reeds worden genoteerd.

- Teneinde een betere vergelijking te kunnen maken tussen het benthos in de gebaggerde specie en het sediment op de loswallen, zullen er in de komende vergunningsperiode Van Veen stalen worden genomen in diverse baggerzones met de Oostende 11 (tijdens dieptelodingen) door ILVO, in samenspraak met MOW-aMT.

Synthesis report on the effects of dredged material disposal on the marine environment
(licensing period 2006-'08)

Brigitte Lauwaert[1], Karen Bekaert[2], Miguel Berteloot[3], Dirk De Brauwer[4], Michael Fettweis[1], Hans Hillewaert[2], Stefan Hoffman[2], Kris Hostens[2], Koen Mergaert[4], Ine Moulaert[2], Koen Parmentier[2], Gert Vanhoey[2], Johan Verstraeten[3]

Report by MUMM[1], ILVO[2], CD[3] and aMT[4], conform art. 10 of the R.D. of 12 March 2000 defining the procedure for licensing of disposal in the North Sea of certain substances and materials.

BL/2008/01

Colofon

Synthesis report on the effects of dredged material disposal on the marine environment (licensing period 2006-'08).

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Report made according to article 10 of the royal decree of 12th of March 2000 defining the procedures for licensing the dumping of certain matters and materials in the North Sea.

BL/2008/01

4 Introduction

To conserve the maritime access channels to the Belgian coastal harbours and to maintain the depth of the Flemish coastal harbours dredging is needed (Flemish competence) in order to guarantee safe maritime transport. A distinction is being made between maintenance and capital dredging. Maintenance dredging is the periodical removal of material, typically sand and silt deposited by nature through river flow, tidal currents or wave action in areas previously dredged. Capital dredging is the initial deepening of an area such as a channel, harbour or berthing facility, but can also include excavation of underwater trenches for cables, pipelines, tunnels and other civil engineering works. The total volume of dredged material which can be more or less contaminated is being dumped at sea. The competence for dumping at sea falls under the federal government. Therefore, the management of dredged material in Belgium is a mixed competence. On the 12th of June 1990, a cooperation agreement was signed between the federal government and the Flemish region, amended by the cooperation agreement of the 6th of September 2000.

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 of 12th of March 2000. Corresponding to article 10 of this procedure a "synthesis report" has to be established for the Minister which has the North Sea under his competences. The synthesis report needs to include recommendations which support the development of an enforced environmental management.

The Flemish Government divided her authority into thirteen Policy Councils. By Decree of the Flemish Government of 7 October 2005, it was decided that the Maritime Access Division should become the implementing division within the Department under the Policy Council of the Flemish Minister for Public Works. In the same Decree the Flemish Government decided to install the Agency for Maritime Services and Coast. The decision was implemented on 1 April 2006.

The Maritime Access Division maintains all maritime access channels to the Flemish ports of Oostende, Zeebrugge, Gent and Antwerpen. The Coast Division of the Agency for Maritime Services and Coast maintains the Flemish Coastal Marinas of Nieuwpoort, Oostende, Blankenberge and Zeebrugge.

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 programme has to be carried out.

5 Dredging and dumping activities

5.1 Bathymetric measurements in dumping grounds for dredged materials

The Flemish Hydrography, a part of the Coastal Division has a program for monitoring activities in dumping grounds for dredged materials off the Belgian Coast. These consist mainly of bathymetric measurements. The study of the data resulting from these measurements gives an idea of the evolution of the bottom of the sea in these areas.

Some of the dumping grounds cover fairly large areas (e.g. S1 area = 70 km^2). In order to map areas of this size in an efficient way, a combination of singlebeam and multibeam echosounding techniques is used. When using singlebeam, depth measurements are made that follow the track sailed by the survey ship, with each 'ping' resulting in one depth. Multibeam measurements result in several hundred depth values for each 'ping'. These depth values are distributed evenly towards port and starboard over the opening angle of the multibeam system.

While multibeam measurements have the advantage of being able to offer full bottom coverage, they cannot fully replace singlebeam measurements. Singlebeam measurements are made simultaneously at two different frequencies (33 kHz and 210 kHz). The higher frequency can detect the top of a silt layer, the lower frequency will result in a measurement of the solid seabed. Using two frequencies for depth measurements makes perfect sense in areas such as the Belgian Continental Shelf: the presence of large quantities of silt is sometimes a major problem for the fairways that give access to the ports of Zeebrugge. So, information about these silt layers is important for dredging as well as for navigation. Special techniques (e.g. Navitracker) have been developed to monitor these silt layers and to determine the navigational seafloor in an accurate way.

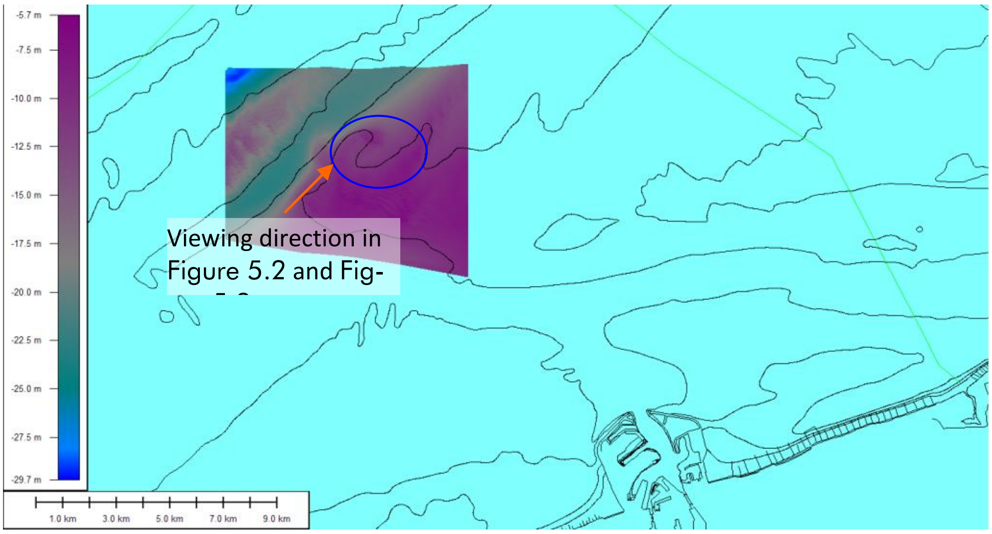


Figure 5.1 Location of the S1 dumping ground. The area in the blue circle is the main focus of dumping activities in 2006 and 2007.

Figure 5.2 and Figure 5.3 show the evolution on the sea bed on dumping ground S1 (see Figure 5.1) between July 2006 and April 2007. A distinct accretion, directly related to dumping activities, is clearly visible.

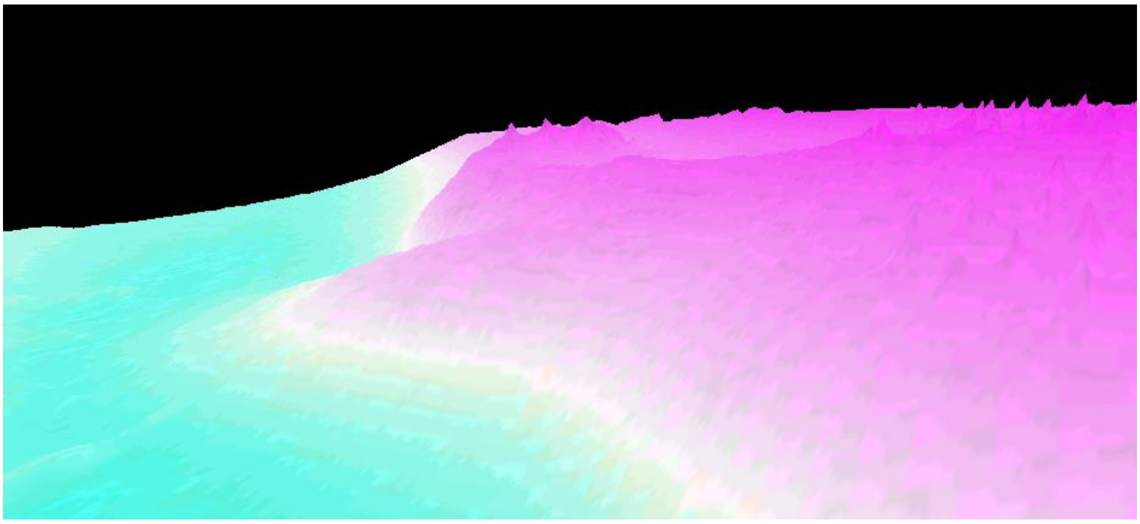


Figure 5.2 Central area of the S1 dumping ground (July 2006).
The area shown covers the blue circle of Figure 5.1.

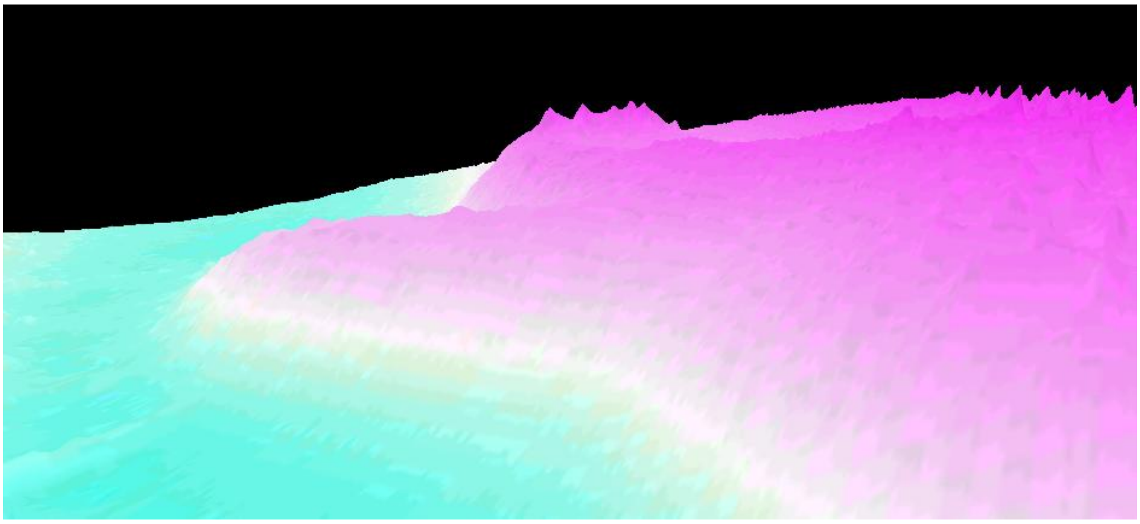


Figure 5.3 Central area of the S1 dumping ground (April 2007).
The area shown covers the blue circle of Figure 5.1.

Table 5.1 gives an overview of the different measuring techniques (Singlebeam, Multibeam) that were used for the monitoring of the dumping grounds on the Belgian Continental Shelf.

Table 5.1 Overview of monitoring measurements in the different dumping grounds

Dumping ground	2006	2007
Oostende	SB	MB
Nieuwpoort	SB	SB
Zeebrugge Oost	SB	SB
S1	SB	SB
Central area S1	SB	SB
S2	SB	SB[1]
S2 central area	SB	SB

[1] finished in 2008

In recent years the application of multibeam measurements for the Flemish Hydrography has shifted towards the dredged areas, fairways as well as harbours and ports. Especially with the ever increasing draught of ships, and the required dredging activities to give these ships safe access to the ports, regular and very detailed depth measurements are a necessity. The result of such a multibeam measurement of the ‘Pas van het Zand’ fairway to Zeebrugge is shown in Figure 5.4, and one from the harbour of Blankenberge (Figure 5.5)

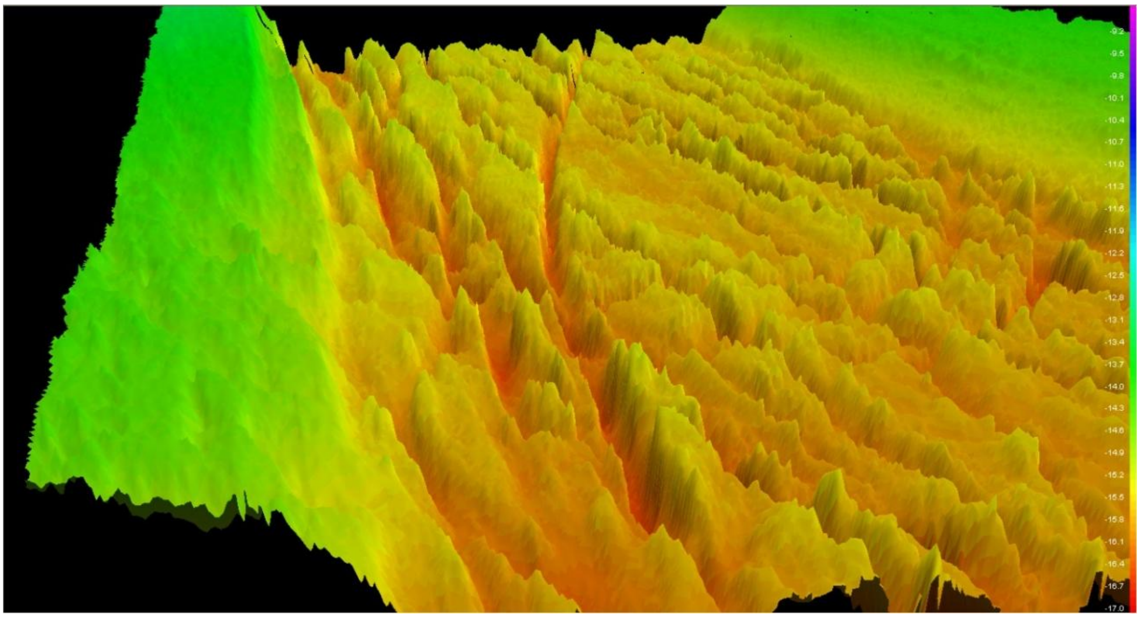


Figure 5.4 Section of the ‘Pas van Het Zand’ fairway to Zeebrugge. Tracks resulting from dredging for the recent deepening program can be seen clearly in this multibeam measurement. (July 2007)

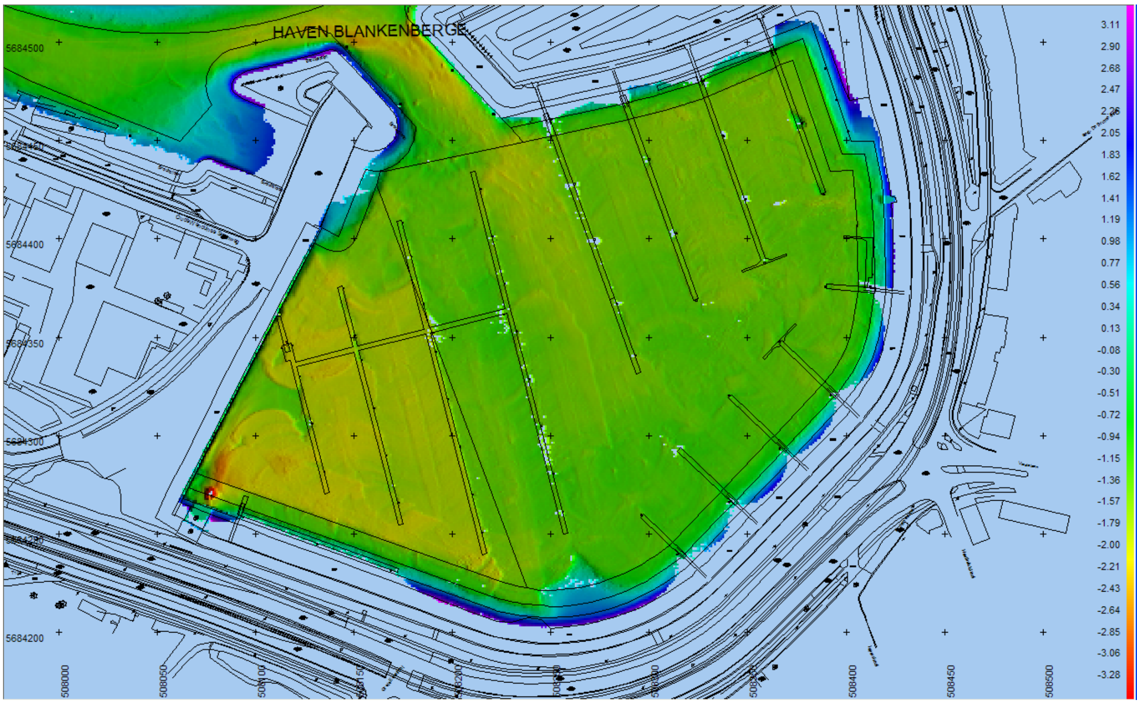


Figure 5.5 Blankenberge Marina. This multibeam measurement shows tracks resulting from dredging that uses a ‘sweeping’ technique to reach under pontoons. (January 2008)

5.2 Dredging Activities

Since 2006, the Coastal Division from the Flemish Government Agency for Maritime and Coastal Services is responsible for maintaining the accessibility in the fishing harbours and the marinas at the Belgian coast. These are located in Nieuwpoort, Oostende, Blankenberge and Zeebrugge.

The Maritime Access Division of the Department of Public Works maintains all maritime access channels to the Flemish ports of Oostende, Zeebrugge, Gent and Antwerpen.

The dredging companies are assigned after a European tender procedure. In former years dredging years started 1st of April and ended 31st of March (and permit years were following the same period). After the last tender procedure dredging years are following calendar years. The first (dredging) calendar year started 1st of January 2006.

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 a certain dredging technique is dependent upon the site, the hydrodynamical 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 5,000 to 10,000 m^3.

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.

5.3 Dumping Activities

5.3.1 Quantities permitted

In the former licensing period April 2006 – March 2008, four permits were granted to the Maritime Access Division and three permits were granted 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 Table 5.2Table 5.3. It should be noted that the permits holder is requested to not exceed the average quantities. The dumping sites are given in the accompanying map.

5.3.2 Quantities dumped

Table 5.4 gives an overview of the quantities dumped at sea since 1991 at the different dumping sites.

Table 5.5 and Table 5.6 give the quantities of dredged material per dredging site and the respective dumping sites.

The map is giving a visual image of the dredging and dumping intensity for the period April 1st 2006 – March 31st 2007. The dredging intensity gives a view on the intensity of dredging at a certain place over a defined period. They show that most places are under sedimentation. The dumping intensity gives a view on 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 5.2 Maximum permitted quantities (TDM = tonnes dry matter) per dredging site per year.
Validity period : 01.04.2006–31.03.2008

Dredging site	**Dumping area**						
	type	**Br.&W. S1**	**Br.&W. S2**	**Br.&W. Zeebrugge Oost**	**Br.&W. Oostende**	**Br.&W. Nieuwpoort**	**Total**
Centraal deel nieuwe buitenhaven, Voorhaven Zeebrugge and Pas van het Zand	Maintenance	7,150,000	2,400,000	5,500,000			15,050,000
	Capital						
Pas van het Zand	Maintenance						
	Capital	4,400,000	550,000				4,950,000
Scheur Oost	Maintenance	2,800,000	500,000				3,300,000
	Capital	1,210,000	66,000				1,276,000
Scheur West	Maintenance	2,800,000	500,000				3,300,000
	Capital	3,960,000	209,000				4,169,000
Centraal deel nieuwe buitenhaven	Maintenance			5,500,000			5,500,000
	Capital						
Haven and voorhaven Zeebrugge	Maintenance			3,000,000			3,000,000
	Capital						
Haven van Oostende	Maintenance				700,000		700,000
	Capital						
Stroombank en ingangsgeul Oostende	Maintenance				900,000		900,000
	Capital						
Nieuwe toegangsgeul Oostende	Maintenance						
	Capital				1,500,000		1,500,000
Toegangsgeul Nieuwpoort	Maintenance					100,000	100,000
	Capital						
Vaar- en havengeul Nieuwpoort	Maintenance					300,000	300,000
	Capital						
Oude Vlotkom, nieuwe jachthaven, Nieuwpoort	Maintenance					800,000	800,000
	Capital						
Toegangsgeul Blankenberge	Maintenance			100,000			100,000
	Capital						
Vaargeul en spuikom Blankenberge	Maintenance			500,000			500,000
	Capital						
Jachthaven van Oostende	Maintenance			150,000			150,000
	Capital						
Total	Maintenance	12,750,000	3,400,000	14,750,000	1,600,000	1,200,000	33,700,000
	Capital	9,570,000	825,000		1,500,000		11,895,000
Overall total		22,320,000	4,225,000	14,750,000	3,100,000	1,200,000	45,595,000

Table 5.3 Average permitted quantities (TDM = tonnes dry matter) per dredging site per year.
Validity period : 01.04.2006–31.03.2008

Dredging site	Dumping area						
	type	Br.&W. S1	Br.&W. S2	Br.&W. Zeebrugge Oost	Br.&W. Oostende	Br.&W. Nieuwpoort	Total
Centraal deel nieuwe buitenhaven, Voorhaven Zeebrugge en Pas van het Zand	Maintenance	6,400,000	2,000,000	5,500,000			13,900,000
	Capital						
Pas van het Zand	Maintenance						
	Capital	4,000,000	500,000				4,500,000
Scheur Oost	Maintenance	2,300,000	300,000				2,600,000
	Capital	1,100,000	60,000				1,160,000
Scheur West	Maintenance	2,300,000	300,000				2,600,000
	Capital	3,600,000	190,000				3,790,000
Centraal deel nieuwe buitenhaven	Maintenance			3,900,000			3,900,000
	Capital						
Haven en voorhaven Zeebrugge	Maintenance			2,000,000			2,000,000
	Capital						
Haven van Oostende	Maintenance				500,000		500,000
	Capital						
Stroombank en ingangsgeul Oostende	Maintenance				500,000		500,000
	Capital						
Nieuwe toegangsgeul Oostende	Maintenance						
	Capital				1,000,000		1,000,000
Toegangsgeul Nieuwpoort	Maintenance					70,000	70,000
	Capital						
Vaar- en havengeul Nieuwpoort	Maintenance					200,000	200,000
	Capital						
Oude Vlotkom, nieuwe jachthaven, Nieuwpoort	Maintenance					500,000	500,000
	Capital						
Toegangsgeul Blankenberge	Maintenance			70,000			70,000
	Capital						
Vaargeul en spuikom Blankenberge	Maintenance			300,000			300,000
	Capital						
Jachthaven van Oostende	Maintenance			100,000			100,000
	Capital						
Total	Maintenance	11,000,000	2,600,000	11,870,000	1,000,000	770,000	27,240,000
	Capital	8,700,000	750,000		1,000,000		10,450,000
Overall total		19,700,000	3,350,000	11,870,000	2,000,000	770,000	37,690,000

Table 5.4 Quantities dumped dredged material per permit year

Quantities dumped in wet tonnes(*)								
period	**Br.&W. S1**	**Br.&W. S2**	**Br.&W. Zeebrugge Oost**	**Br.&W. Oostende**	**Br.&W. Nieuwpoort**	**Br.&W. R4 (**)**	**Br.&W. 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	**Br.&W. S1**	**Br.&W. S2**	**Br.&W. Zeebrugge Oost**	**Br.&W. Oostende**	**Br.&W. Nieuwpoort**	**Br.&W. R4**	**Br.&W. 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*

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

5.3.3 Beneficial use

To keep the channel passage to Blankenberge accessible, maintenance on a very regular basis is needed. Wind and stream patterns cause a rapid influx of sand from the nearby beaches. As a consequence of this, the chemical and morphological quality of this sand is very high. 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. At international level, beneficial use of dredged material is being stimulated.

On two occasions, dredged material from the access channel to Blankenberge was beneficially used to reinforce coastal defence on the nearby shores.

A first certificate was obtained in March 2007, for a total amount of 40,000 m^3 sand. During March and April, the dredged material was re-used on the beach of Wenduine. A second certificate was obtained in November 2007, for a total of 50,000 m^3, which was used in November and December 2007.

Table 5.5 Quantities dumped dredged material (TDM) per dredging site and respective dumping site (1 April 2005 – 31 March 2006)

Dredging site	**Dumping site**						
		Br.&W. S1	**Br.&W. S2**	**Br.&W. Zeebrugge Oost**	**Br.&W. Oostende**	**Br.&W. Nieuwpoort**	**TOTAL**
Scheur Oost	Maintenance	121,528	57,733				179,261
	Capital						
	TOTAL	121,528	57,733				179,261
Scheur West	Maintenance	247,798	427,737				675,535
	Capital						
	TOTAL	247,798	427,737				675,535
Pas van het Zand	Maintenance	1,662,563	627,199				2,289,762
	Capital						
	TOTAL	1,662,563	627,199				2,289,762
CDNB Zeebrugge	Maintenance	985,234	121,971	1,267,494			2,374,699
	Capital						
	TOTAL	985,234	121,971	1,267,494			2,374,699
Toegangsgeul Oostende	Maintenance				402,445		402,445
	Capital						
	TOTAL				402,445		402,445
Haven Oostende	Maintenance				197,460		197,460
	Capital						
	TOTAL				197,460		197,460
Nieuwe toegangsgeul Oostende	Maintenance						
	Capital						
	TOTAL						
Haven en voorhaven Zeebrugge	Maintenance			1,689,783			1,689,783
	Capital						
	TOTAL			1,689,783			1,689,783
Toegangsgeul Blankenberge	Maintenance						
	Capital						
	TOTAL						
Toegangsgeul Nieuwpoort	Maintenance						
	Capital						
	TOTAL						
Haven Blankenberge	Maintenance			16,268			16,268
	Capital						
	TOTAL			16,268			16,268
Haven Nieuwpoort	Maintenance					61,020	61,020
	Capital						
	TOTAL					61,020	61,020
	TOTAL	3,017,123	1,234,640	2,973,545	599,905	61,020	7,886,233

Table 5.6 Quantities dumped dredged material (TDM) per dredging site and respective dumping site (1 April 2006 – 31 March 2007)

Dredging site	**Dumping site**						
		Br.&W. S1	**Br.&W. S2**	**Br.&W. Zeebrugge Oost**	**Br.&W. Oostende**	**Br.&W. Nieuwpoort**	**TOTAL**
Scheur Oost	Maintenance	644,692	71,592				716,284
	Capital	1,165,667					1,165,667
	TOTAL	1,810,359	71,592				1,881,951
Scheur West	Maintenance	892,464	72,771				965235
	Capital	4,260,674					4,260,674
	TOTAL	5,153,138	72,771				5,225,909
Pas van het Zand	Maintenance	658,967	144,276				803,243
	Capital	1,766,241	217,047				1,983,288
	TOTAL	2,425,208	361,323				2,786,531
CDNB Zeebrugge	Maintenance	723,200	103,604	434,099			1,260,903
	Capital	600,036	59,468	238,318			897,822
	TOTAL	1,323,236	163,072	672,417			2,158,725
Toegangsgeul Oostende	Maintenance				581,831		581,831
	Capital						
	TOTAL				581,831		581,831
Haven Oostende	Maintenance				231,449		231,449
	Capital						
	TOTAL				231,449		231,449
Haven en voorhaven Zeebrugge	Maintenance			1,873,967			1,873,967
	Capital		32,205	163,626			195,831
	TOTAL		32,205	2,037,593			2,069,798
Nieuwe toegangsgeul Oostende	Maintenance						
	Capital						
	TOTAL						
Jachthaven Oostende	Maintenance				6,385		6,385
	Capital						
	TOTAL				6,385		6,385
Toegangsgeul Blankenberge	Maintenance			86,762			86,762
	Capital						
	TOTAL			86,762			86,762
Toegangsgeul Nieuwpoort	Maintenance					37,496	37,496
	Capital						
	TOTAL					37,496	37,496
Oude Vlotkom Nieuwpoort	Maintenance					106,945	106,945
	Capital						
	TOTAL					106,945	106,945
Vaargeul en havengeul Nieuwpoort	Maintenance					32,787	32,787
	Capital						
	TOTAL					32,787	32,787
Haven Blankenberge	Maintenance						
	Capital						
	TOTAL						
Haven Nieuwpoort	Maintenance					1,041	1,041
	Capital						
	TOTAL					1,041	1,041
	TOTAL	10,711,941	700,963	2,796,772	819,665	178,269	15,207,610

6 Results from MUMM's research programme MOMO

6.1 Introduction

In this chapter results of the MOMO project are presented that have been carried out at MUMM between 2006 and beginning of 2008 in the framework of the general and permanent duties of monitoring and evaluation of the effects of all human activities on the marine ecosystem to which Belgium is committed conform the treaty concerning the protection of the marine environment of the North-Eastern Atlantic Ocean (1992, OSPAR-treaty). The MOMO project focuses on monitoring and modelling of cohesive sediment transport and the evaluation of the effects on the marine ecosystem due to dredging and dumping operations. The combination of monitoring and modelling provides information on the transport of this fine fraction and is therefore fundamental to answer questions on composition, origin and residence time of mud on the BCS, the change in characteristics due to dredging and dumping, natural variability, the impact on the marine ecosystem especially due to alterations of habitats, the estimation of the net input of hazardous substances in the marine environment and the possibilities to reduce these last two items.

The general aim of the research of the MOMO project is to provide scientific information which allow to reduce dredging works on the BCS and in the coastal harbours by reducing sedimentation at the dredging locations and/or organising more efficiently the dumping operations. Reduction in sedimentation can be obtained by reducing the water exchange between port and sea. Efficient dumping means the choice of an optimal dumping ground as function of the predicted physical (wind, currents, waves, sediment transport, recirculation), economical (distance, size of dredging vessel) and ecological aspects.

In the current MOMO project, which has been set up for the period April 2006 - March 2008, the recommendations for the minister have been taken into account in order to support the development of a sound environmental politics, as described in Lauwaert *et al.* (2006). Research dealing with the first recommendation, i.e. search for a global strategy for the area east of Zeebrugge (environmental protection areas, relocation of dumping site Br.&W. Zeebrugge Oost, ammunition dumping site 'Paardemarkt', development of an island east of Zeebrugge, coastal erosion at Knokke) has been started up with the development of a detailed 3D numerical model of the Zeebrugge area (section 6.2) and a flocculation model (section 6.5), and the study on the anthropogenic influence on the cohesive sediment distribution using historic and recent field data (section 6.3). The latter is important to identify the anthropogenic effects, to assess environmental impacts and to set up a sustainable marine environmental policy. The second (dumping depending on tides, recirculation of dumped matter) and third recommendation (study on the global cohesive sediment transport on the BCS) have been integrated in the research on SPM transport in the southern North Sea (section 6.4); SPM dynamics in the BCS (section 6.5), and in modelling of dumping operations at Blankenberge and Nieuwpoort harbours (section 6.6).

6.2 Development of a 3D numerical model of the Zeebrugge area

In order to simulate the fine sediment transport in the Zeebrugge area a model has been developed that can take into account wetting and drying of inter-tidal areas (see Fettweis *et al.*, 2006c). Future applications of the model will be e.g. the study of optimal dumping time and sites.

The hydrodynamics are modelled using the 3D COHERENS model (Luyten *et al.*, 1999). The model solves the momentum equation, the continuity equation and the equations of temperature and salinity. A new grid has been set up for a model of the Zeebrugge area. The bathymetry has been provided by the Ministry of the Flemish Community and is also based on the model of De Mulder (2006). The model grid has a resolution of 1.667" × 2.8571", which corresponds to about 50 m × 50 m. The resolution is 5 times higher than the resolution of the MU-BCZFIN model, with which it is coupled. The model has 246 × 151 grid points and 10 layers in the vertical.

The COHERENS model has been adapted such that grid points may become dry or wet during simulation. This "wetting-drying" scheme gives a better representation of bathymetry in shallow areas, because no minimum depth has to be used for numerical reason. The implemented scheme is based on the work of Uchiyama (2004). The status of every grid point is checked during every 2D time step. If the total water depth is smaller than a defined value, then the neighbouring points are verified, and possibly the decision is taken that the grid point becomes dry. In this case the water depth is kept constant at a minimum of a few cm until the grid point is flooded again. With this method mass conservation is guaranteed. The wetting/drying scheme has been validated for 2D as well as 3D applications of the Scheldt estuary between Vlissingen and Antwerpen, where lot of inter-tidal areas occur, and for the model of the Zeebrugge area, see Figure 6.1.

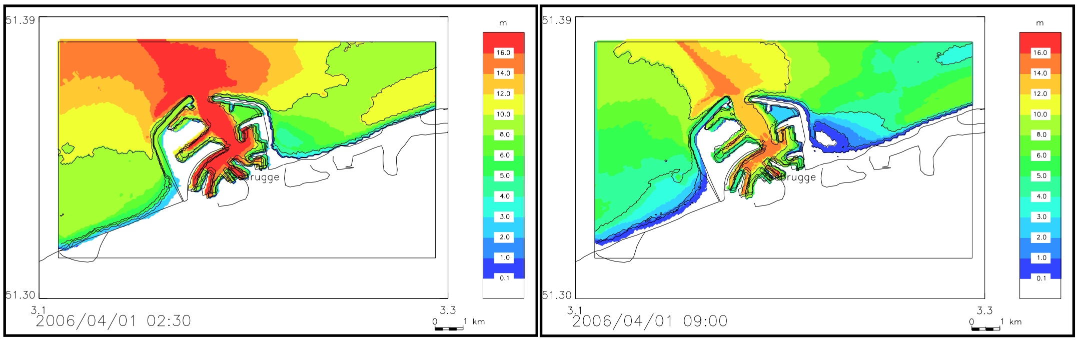


Figure 6.1 Wetting/drying scheme applied to the model of the Zeebrugge area. Left is shown the water depth at high water and right at low water during spring tide. Remark that the sand bank east of Zeebrugge is flooded during high water and dry during low water.

6.3 Influence of anthropogenic activities on the cohesive sediment distribution

There are an increasing number of studies dealing with the impact of anthropogenic activities on the physical environment (e.g. Mai & Bartholomä, 2000; Flemming, 2002; Jaffe *et al.*, 2007; Van Lancker, *et al.*, 2007ab; Van den Eynde *et al.*, 2008). The socio-economic pressure to implement large scale projects (harbour extension, deepening of navigation channels, installation of new dumping sites, construction of windmill farms, aggregate extraction), which will possibly be reinforced by future climate change impacts, will steadily increase and detailed information on the natural situation is needed in order to identify the anthropogenic effects, to assess environmental impacts and to set up a sustainable marine environmental policy.

Cohesive sediment processes have a major influence on coastal ecosystems. The distribution is affected by human activities such as port development, dredging and dumping and aggregate extraction. These activities have further major impacts on the environment, due to shoreline erosion and bathymetrical, morphological and hydrodynamical changes and eventually degradation or total loss of natural habitats. In a dynamic coastal area, such as the southern North Sea, the natural variability of cohesive sediment processes due to tides and meteorological effects is very high as also the human impact. A major question to be answered is to which extend is the physical environment (hydrodynamics, sediment transport, sedimentology and morphology) the result of natural changes and/or anthropogenic activities? For example, to what extent has the distribution of cohesive sediments and suspended particulate matter (SPM) changed due to dredging and dumping activities or port constructions? Are the human impacts local or do they have a wider influence? If the impacts are local then comparison between a natural and human affected neighbouring area could give indications to what extent anthropogenic activities have changed the environment. In case of cohesive sediments very often large areas are affected and the identification of the human impacts requires understanding of how the natural variability has been affected by human activities. Alterations of the cohesive sediment distribution in such human stressed environments are to be expected because engineering, together with the dredging and dumping works, results often in hydrodynamic conditions, which are not in equilibrium with present bathymetrical situations. In order to identify to which extent the changes are natural and/or anthropogenically induced, long-term records of sediment distribution and bathymetry needs to be available.

The human impact on the cohesive sediment distribution along the Belgian-Dutch coast due to the construction of the port of Zeebrugge (southern North Sea) in the 1900's and the 1980's has been investigated (see Fettweis et al, 2007a). There is clear evidence of long-term net inflow of SPM into the North Sea through the Dover Strait and the SPM is concentrated in front of the Belgian-Dutch coast before being transported further towards the northeast (see above). The Belgian-Dutch coastal area is thus the first obstruction in the global North Sea SPM transport system. Despite the natural morphological evolution occurring in the area, the question is raised how the distribution of cohesive sediments and the local and global SPM transport may have changed due to increasing human impact. The impact of anthropogenic activities in the past (port construction, deepening of navigation channel) on the distribution of cohesive sediments in the Belgian-Dutch nearshore zone (southern North Sea), taking into account the natural changes has been investigated. In a dynamic coastal area, such as the southern North Sea, is the natural variability of cohesive sediment processes due to tides and meteorological effects very high as is also the human impact. Important changes can occur naturally in sediments within a short time span, while changes on longer time scales (decades, centuries) of unmonitored human activities can hardly be assessed. In the area, recently deposited mud, Holocene mud and Tertiary clays occur; the latter outcropping locally. The effects of human impact vs. natural processes have been investigated by comparing the distribution of freshly deposited to very soft consolidated mud and mud and clay pebbles from 100 years ago and today and by modelling present and historic suspended sediment situations. The historic data of Gilson have been used to describe the cohesive sediment distribution in the beginning of the 20th century in the Belgian-Dutch near shore area. The quality of the sample descriptions is very high due to the available metadata. Moreover, the data have proven to be a major reference to understand the evolution of the local cohesive sediment distributions. The processing of the historic and recent data was mainly based on field descriptions of the samples (consolidation, thickness) and on morphological evolution; emphasis was put on the occurrence of thick layers (>30 cm) of freshly deposited to very soft consolidated mud and on the distribution of clay and mud pebbles. The results indicate that the distribution of fresh mud and suspended sediments has changed during the last 100 years due to human impact in the area. Most of the present depositions of thick layers of fresh mud (>30 cm) have been induced by anthropogenic operations, such as dumping, deepening of the navigation channels and construction and extension of the port of Zeebrugge. The area with fresh mud around Zeebrugge as well as the centre of the turbidity maximum extends today more towards offshore than 100 years ago.

6.4 SPM transport in the southern North Sea

Extensive scientific literature on the residual SPM transport through the Dover Strait exists; the values vary between $[2.5 - 57.8] \times 10^6$ t/yr (Eisma, 1981; van Alphen, 1990; Lafite *et al.*, 1993; Velegrakis *et al.*, 1997; McManus & Prandle, 1997). These big differences reflect partially the high temporal and spatial variability of the influx but have their origin also in the way the SPM measurements have been carried out, in the small number of SPM concentration measurements on which the calculations were based as well as the differences in the way the residual SPM transport was calculated. Accurate knowledge of the SPM flux through the Dover Strait is important in order to set up a sediment budget of the BCS, to identify the sources and sinks of mud and to study the influence of anthropogenic activities, such as dredging and dumping on the local cohesive sediment transport.

A study was carried out where satellite images (SeaWiFS), in situ measurements and a hydrodynamic numerical model have been combined to calculate the long term averaged SPM transport through the Dover Strait and in the southern North Sea (Fettweis *et al.*, 2007b). For the Belgian continental shelf about 60 (partially) cloud free images per year are available. In order to cope with the fact that only surface values are available, the method presented by Van den Eynde *et al.* (2006) has been applied in which in situ measurements of SPM concentrations during a tidal cycle and satellite images have been used to calculate the depth averaged SPM concentration distribution. The low time resolution prevents an accurate computation of the sediment flux when using:

$$T = \int_0^t \int_0^h u(z,t)c(z,t)dzdt \quad \text{(Eq. 6.1)}$$

where T is the sediment flux per unit width, h is the water depth, $u(z,t)$ is the current velocity normal to the section and $c(z,t)$ the SPM concentration. Prandle *et al.* (1996) wrote that the SPM dynamics in tidal waters are mainly determined by water depth h, eddy diffusivity K_z and settling velocity w and that the residual transport closely approximates

$$T \approx \int_0^t \int_0^h u(z,t)dzdt \int_0^t \int_0^h c(z,t)dzdt \quad \text{(Eq. 6.2)}$$

when $K_z > wh$. In coastal waters, such as the southern North Sea, with a water depth between 10-50 m and a K_z of 0.01 m^2/s the settling velocity must be <1 mm/s. This is a value in agreement with measured settling velocities of flocs in the southern North Sea (see section 6.5).

6.4.1 Methods

6.4.1.1 SPM concentration maps derived from satellite images

The SPM concentration maps derived from satellite images have been obtained in two steps. First the SeaWiFS images were processed. SeaWiFS measures the reflected sunlight at the Top Of Atmosphere (TOA) at 8 bands from the visible to near infrared wavelengths. The SeaDAS 4.5 software, extended to turbid waters (Ruddick *et al.*, 2000) was used to process these TOA radiances into atmospherically corrected reflectance by removing atmosphere contributions and sea-water interface effect and finally providing the water-leaving reflectance spectrum. A bio-optical model, which has been designed for Belgian coastal waters, was used to calculate SPM concentration. The next step in the processing was to multiply the surface SPM concentration values by area-specific correction factors in order to obtain vertical averaged SPM concentrations. These correction factors, which vary during a tidal cycle, represent the ratio between surface and depth-averaged SPM concentration and were derived from in situ tidal SPM concentration profiles taken on the BCS (Van den Eynde *et al.*, 2006).

6.4.1.2 Measurements and instruments

The SPM concentration data have been collected from the R/V Belgica as snapshots or during tidal cycles. The tidal cycle measurements have been measured between March 1999 and February 2005 using a Sea-Bird SBE09 SCTD carousel sampling system, which was kept at least 4.5 m below the surface and about 3 m above the bottom. Every 20 minutes a Niskin bottle was closed, resulting in about 40 samples per tidal cycle. Every hour the carousel was taken on board of the vessel and the water samples were filtered on board using pre-weighted GF/C filters, which were later dried and weighed to obtain SPM concentration. In the framework of MUMM's Monitoring Program snapshots of SPM concentration were sampled at 3 m below surface. The procedure of sampling is similar to that described above, except that they are not made throughout the tidal cycle.

6.4.1.3 Hydrodynamic model description

The residual water transport and discharge has been modelled using the public domain 3D hydrodynamic COHERENS model (Luyten *et al.*, 1999), see above. For the current application a 2D implementation of the COHERENS model to the northwest European continental shelf was used. The model grid has a resolution of 5′ (=0.0833°) in longitude and 2.5′ (=0.0417°) in latitude (about 5 km × 5 km). Meteorological surface forcing is from the forecasts of the UK Meteorological Office at Bracknell. Four semi-diurnal (M_2, S_2, N_2, K_2) and four diurnal tidal components (O_1, K_1, P_1, Q_1) are used to force the tidal elevation on the open boundaries of the continental shelf model.

6.4.2 SPM concentration and transport in the southern North Sea

In total 362 SeaWiFS images were collected from September 1997 to April 2004. Among these images, 172 scenes are entirely cloud-free. Most of the 362 images have been affected by less than 30% of clouds which were flagged during the processing of SPM concentration maps. The images have been grouped per season and have been processed to obtain vertically averaged SPM concentration, 37% of the images are from spring, 27% from summer, 13% from autumn and 23% from winter. A map of the seasonal surface and vertically averaged SPM concentration is given in Figure 6.2 and Figure 6.3 respectively. The maximum surface SPM concentrations in the southern North Sea are situated between 75-100 mg/l during autumn and winter and 25-50 mg/l during spring and summer. The highest values are found in the Belgian-Dutch coastal zone and in the mouth of the Thames estuary. In the Dover Strait the maxima are limited to about 15 mg/l (summer) up to 50 mg/l (winter). The meteorological data from the UKMO together with information on cloud cover from the satellite imagery have been used to calculate the mean wind speed at station 330 during cloudy and cloud-free sky conditions in the satellite pictures.

The SPM concentration has been measured during 38 tidal cycles between March 1999 and February 2005 from the R/V Belgica. The results presented in Fig. Figure 6.4 show the mean SPM concentration distribution in the different stations. The SPM concentration has also been measured in the framework of MUMM's Monitoring Program; these data are snapshots of SPM concentration at 3 m below surface and have thus not been measured throughout the tidal cycle. Only stations with at least 10 samples have been selected; in total 719 samples are available for the period 1987-2004.

Table 6.1 Residual SPM transport between January 1997 and December 2003 (10^6 t/season or year) through the Dover Strait and through a cross section at 51.9° N (positive is to the N). The SPM concentrations have been vertically corrected to obtain depth averaged concentrations. 'Dover Strait – 51.9°N' is the difference between inflow and outflow, positive means a higher SPM flux into the southern North Sea than out of it.

	spring	summer	autumn	winter	year
Dover Strait	3.00	4.19	14.02	10.53	31.74
51.9°N	6.30	4.45	14.80	15.57	41.12
Dover Strait – 51.9°N	-3.00	-0.26	-0.78	-5.04	-9.08

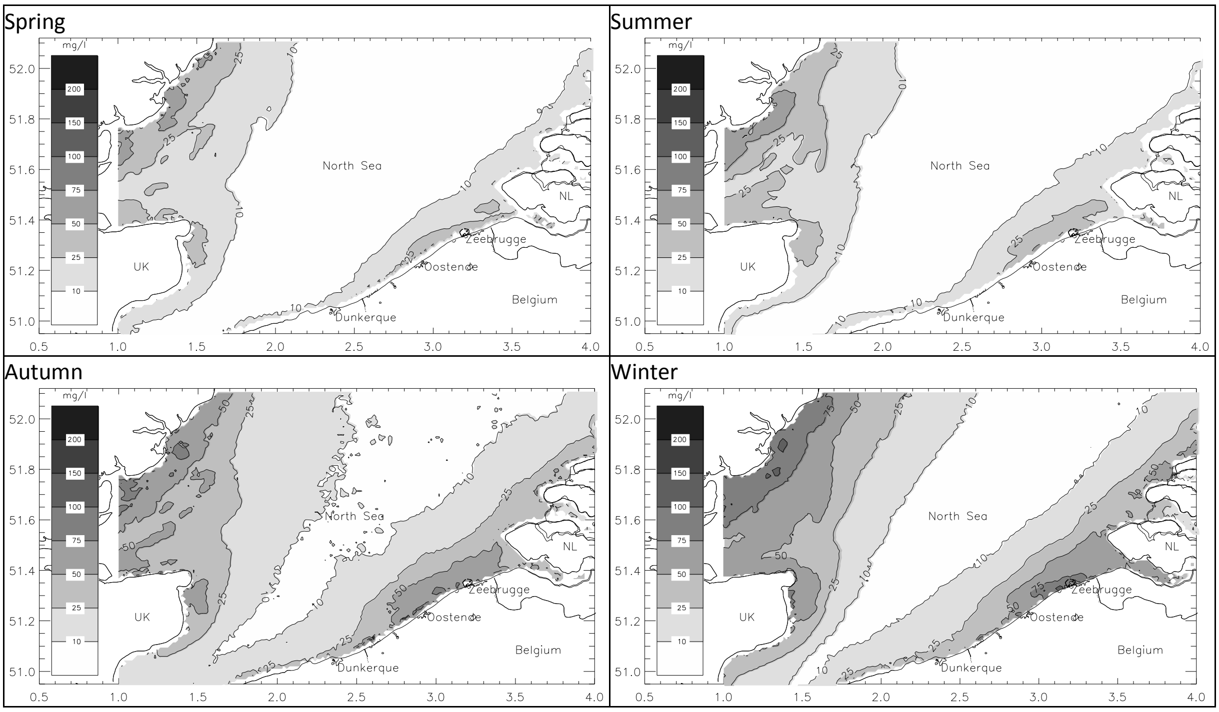


Figure 6.2 Seasonal averages of SPM surface concentration in the southern North Sea derived from 362 SeaWiFS images (1997-2004). The x- and y-coordinates are in Longitude (°E) and Latitude (°N) respectively.

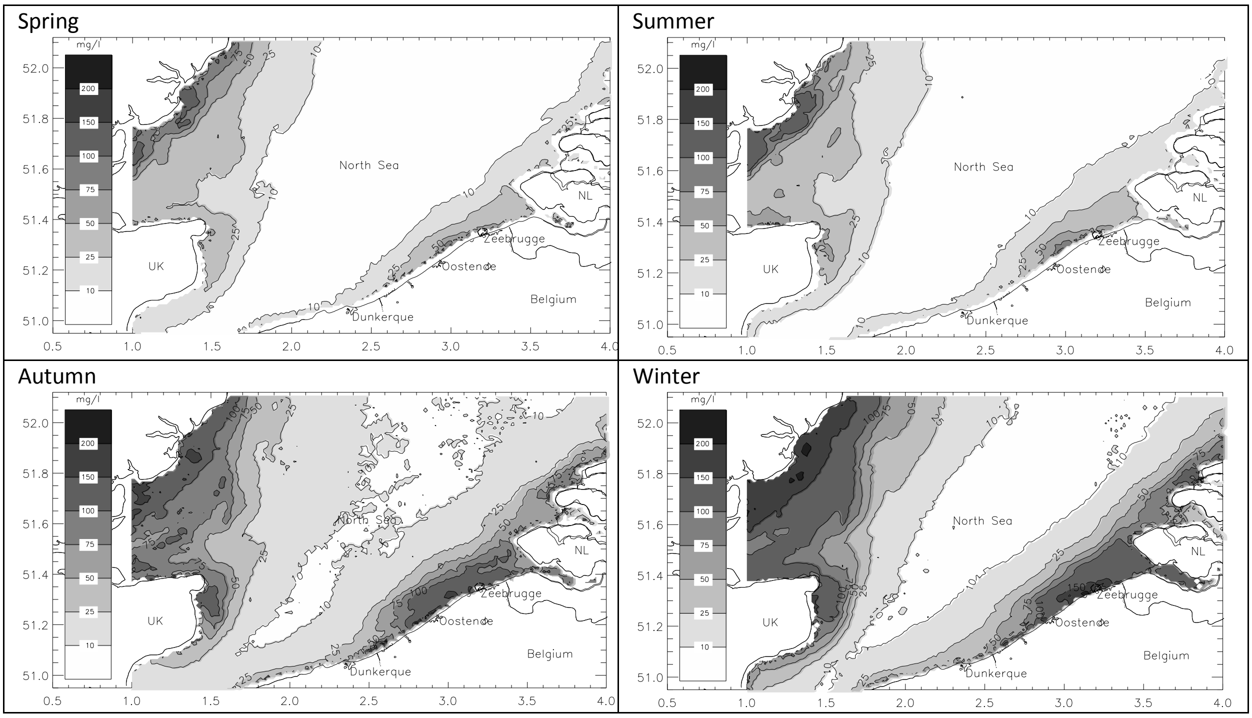


Figure 6.3 Seasonal averages of vertically corrected SPM concentration in the southern North Sea derived from 362 SeaWiFS images (1997-2004). The x- and y-coordinates are in Longitude (°E) and Latitude (°N) respectively.

The SPM transport has been calculated using Eq. 6.2, see Figure 6.5; the net sediment flux through the Dover Strait (51.0° N) and through a cross section at 51.9° N is shown in Table 3.1. The SPM transport per year through the Dover Strait amounts to 31.74×10^6 t; from which about 40% flows through the English and 60% through the French part of the Strait. It can be seen that the SPM transport values are of the same order of magnitude as most of the recently published ones: 19.2×10^6 t/yr (Lafite *et al.*, 1993), $[21.6\pm2.1]\times10^6$ t/yr (Velegrakis *et al.*, 1997), and 44.4×10^6 t/yr (McManus & Prandle, 1997).

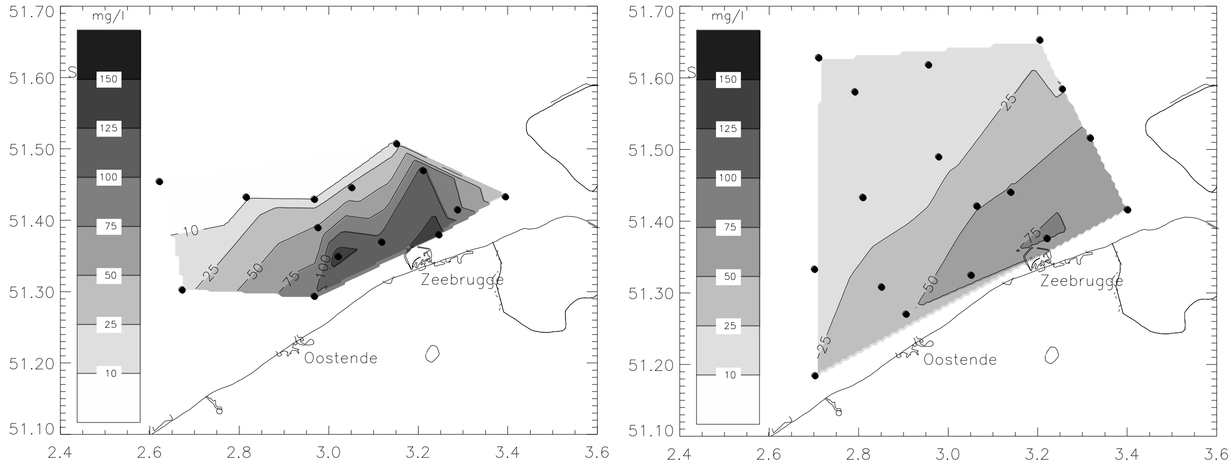


Figure 6.4 Mean of SPM concentrations from (left) the tidal cycle stations during the period 1999-2005. The samples have been taken at about 3 m from the bottom and (right) 'snapshot' samples collected during the period 1987-2004. The samples have been taken at 3 m below the surface.

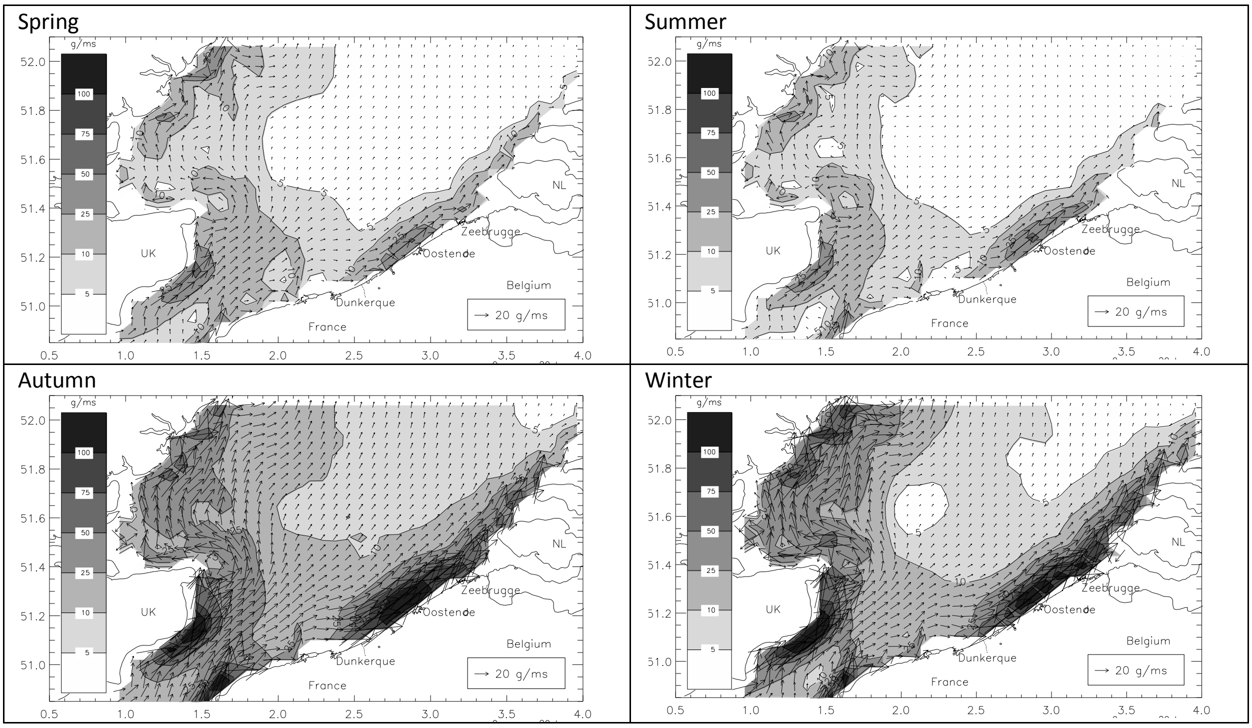


Figure 6.5 Seasonal averaged SPM transport per unit width (g/ms) in the southern North Sea The SPM transport calculated using Eq. 6.2. The vertically averaged SPM concentration values have been used. The x- and y-coordinates are in Longitude (°E) and Latitude (°N) respectively.

6.4.3 Discussion

The transport through the Dover Strait and the 51.9° N section have to be more or less in equilibrium, because the major source of SPM in the area is the Dover Strait and no significant deposition areas of mud exist in the Southern Bight (Eisma, 1981). Local SPM sources are rivers, seafloor and coastal erosion, and primary production. Accurate values do not exist; the Thames supplies $\pm0.7\times10^6$ t/yr (Dyer & Moffat, 1998), the Rhine $\pm1.7\times10^6$ t/yr (Eisma, 1981) and erosion of the Holocene mud layers in the Belgian coastal area is estimated as 0-2.4×10^6 t/yr (Bastin, 1974) or ± 3×10^6 t/yr (Fettweis & Van den Eynde, 2003). The total input of SPM from these sources is thus between 2.4×10^6 and 5.4×10^6 t/yr. The SPM input is probably higher because primary production, seafloor erosion outside the Belgian coastal area and coastal erosion are not included. The difference between inflow and outflow is 9.08×10^6 t/yr.

The satellite images provide synoptic views of SPM concentration but do not take away the uncertainty of SPM transport. This is due to the fact that (1) not enough SPM concentration measurements are available to correct the satellite images, (2) SPM concentration varies as a function of tide, wind, spring-neap tidal cycles and seasons, and (3) experimental observations are always subject to uncertainties. The short term variations (tidal, spring-neap tidal cycle) have not been found back in the satellite images, however seasonal variations are clearly visible. The satellite images are correlated with good weather conditions; increased SPM concentration due to higher wave erosion is seldom to be expected in these images.

The representativeness of SPM concentration maps derived from satellites for calculating long term averaged transports has been investigated by comparing the SPM concentration variability from in situ measurements with those of remote sensing data. The results indicate that the variability in the tidal cycle measurements increases with increasing SPM concentration. This means that in the coastal turbidity maximum zone the SPM concentration variations are high during a tidal cycle, whereas outside or at the edge of the turbidity maximum, where the SPM concentrations are low, the tidal variability is also low. The 'snapshot' SPM concentration measured in MUMM's monitoring stations is generally lower and the variability higher when compared with the tidal cycle measurements. The variability in the pixels of the satellite images indicates that (1) the SPM concentrations are generally lower from satellite data than from in situ tidal cycle measurements, (2) the variability decreases for lower and higher SPM concentrations and has a maximum at about 20 mg/l during spring and summer and at about 40 mg/l during autumn and winter, (3) the relative variability is of the same order of magnitude in most pixels as in the in situ tidal measurements (20-80%) except during spring and summer when relative variability's of up to 140% have been calculated and (4) that the very high variability at low concentrations is also found in the in situ 'snapshot' measurements from MUMM's monitoring stations.

The maximum SPM concentration from satellite images is about 75-100 mg/l (surface) and 150-200 mg/l (depth averaged), whereas the maximum from in situ 'snapshot' measurements is 680 mg/l and from tidal cycle measurements nearly 1000 mg/l. Satellite images and in situ measurements from MUMM's monitoring stations are both snapshots of SPM concentration during a tidal cycle and have been sampled at or near the surface. The decreasing variability in satellite images and in the 'snapshot' in situ measurements with increasing SPM concentration could be explained if most of the SPM in the Belgian coastal zone during a tidal cycle would occur in the bottom layer of the water column and would thus be invisible for satellites or near surface sampling. Tidal measurements however indicate that strong vertical gradients and high SPM concentrations only occur during about 1/3 of the tidal cycle and that during the rest of the cycle the SPM stratification and concentration is much lower. The low variability at higher concentration is probably an artefact of the fact that the algorithm for processing the satellite images is underestimating the SPM concentration at higher values. The very high variability at low concentrations could be due to short-lived events, such as storms or high river runoff, which increases locally the SPM concentration significantly and which moves the turbidity maximum zone more towards the coast or more offshore. During winter and autumn, the SPM concentration is already high and these events are therefore statistically less significant.

Measurements in the Dover Strait, where the SPM concentration is generally low (<10 mg/l), have indicated that the vertical gradient is negligible most of the time (Van Alphen, 1990). The tidal cycle measurements in the Belgian coastal zone show that the vertical SPM concentration variation is low in low SPM concentration areas, therefore satellite images may give a good estimate of the total SPM concentration. In areas with higher turbidity the vertical variation during a tidal cycle is important and corrections have to be applied to obtain depth averaged values.

6.5 Floc dynamics in the Belgian coastal zone

Knowledge on cohesive sediment transport processes is required to predict the distribution of suspended and deposited cohesive sediments in natural or anthropogenically created environments such as navigation channels and harbours. Below the results of tidal cycle and long term measurements of SPM concentration, flow velocity and floc size from the Belgian coastal zone are presented. Settling of mud flocs is controlled by floc size and density and hence also determines the transport of cohesive sediments. Flocculation/deflocculation is the process of floc formation and break-up which has a direct impact on settling velocity. The settling velocity is a function of the particle size and excess (also called effective) density, and can be described by Stokes' Law under the assumption that the particle Reynolds number is smaller than one. However, because the SPM consists of a population of flocs with heterogeneous sizes, densities, and shapes (e.g. Eisma & Kalf, 1987; Van Leussen, 1994), the settling velocity of mud flocs in natural environments will vary and, in the case of very large particles, could therefore depart from Stokes' Law. Measuring the floc settling velocity is hampered by technical limitations owing to their size and resistance against shear stresses, properties which may be altered if flocs are taken out of the environment where they were formed. Furthermore, experimental observations are always subject to uncertainties that can be typically attributed to random measurement errors (lack of precision), systematic errors (lack of accuracy), human error, and intrinsic variable stochasticity.

Two different methods exist for sampling settling velocity: direct and indirect ones. Direct methods are typically carried out *in situ* (or even in the lab), see e.g. Dyer *et al.* (1996) and Eisma *et al.* (1996). The LISST100 has become a standard measuring instrument for particle size spectra and volume concentrations for applications in sea and estuarine waters (e.g. Agrawal & Pottsmith, 2000; Gartner *et al.*, 2001; Fugate & Friederichs, 2002; Chang *et al.*, 2006; Fettweis *et al.*, 2006b; Curran *et al.*, 2007). However, neither the excess density nor the settling velocity can be directly measured by this instrument; Mikkelsen & Pejrup (2001) have presented an indirect method to calculate the settling velocity based on LISST 100 results together with SPM concentration measurements. A similar method has been used in the present study.

The aim of floc dynamic measurements and settling velocity calculations is eventually to implement and validate a flocculation module in the cohesive sediment transport model. Some existing flocculation models are presented below and the results are compared with the observations.

6.5.1 Measuring procedure

The field data presented here were collected from the R/V Belgica during 8 tidal cycles between February 2003 and July 2005; the vessel was moored to maintain the position during the tidal cycle (see Figure 6.6). The measurements were carried out in the coastal turbidity maximum (MOW1, Br.&W. Oostende) and further offshore (Kwintebank, Hinderbank). A Sea-Bird SBE09 SCTD carousel sampling system (containing twelve 10 litre Niskin bottles) with an OBS, were kept at least 4.5 m below the surface and about 3 m above the bottom. The LISST 100C (range 2.5-500 μm) was attached directly to the carousel sampling system from March 2004 onward; before that the LISST 100C was suspended in the water at about 10 m away from the carousel. From March 2004 onward, all the data was thus collected at almost the same locations.

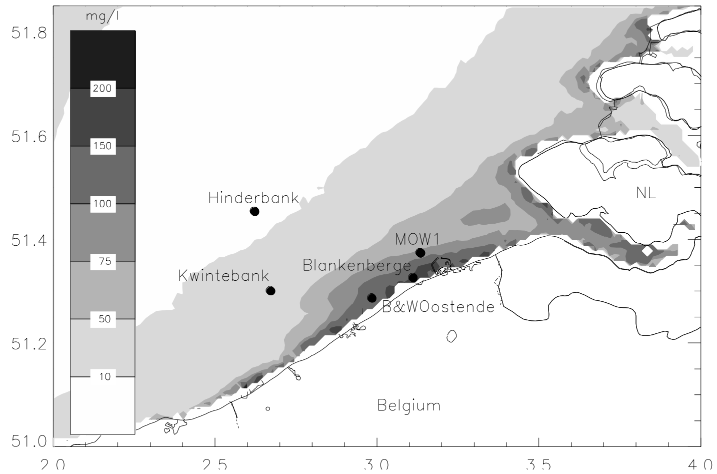


Figure 6.6 The locations of tidal cycle and tripod measurement locations are shown. The background is the yearly averages of vertically averaged SPM concentration derived from 362 SeaWiFS images (1997-2004).

A Niskin bottle was closed every 20 minutes, thus resulting in about 40 samples per tidal cycle. The carousel was taken onboard the vessel every hour. Three sub samples were then filtered onboard from each water sample using pre-weighed filters (Whatman GF/C). In total, 120 filtrations were thus carried out per tidal cycle. After filtration, the filters were rinsed with Milli-Q water (± 50 ml) to remove the salt, dried and weighed to obtain the SPM concentration. Every hour, a fourth sub-sample was filtered onboard to analyse for POC and PON concentration.

SPM samples were collected on board of the vessel with a centrifuge in order to determine the median primary particle size and density. The samples were first treated with H_2O_2 and 1N HCl to remove organic and carbonate fraction. The dispersed samples were analysed for grain size using a Sedigraph 5100 for the fraction <75 μm and sieves for the coarser fraction. The TOC content was measured by weight loss after burning at 430°C of a sample dried at 105°C.

Between 2003 and 2006 a benthic lander (tripod) has been moored 14 times in the Belgian coastal area (Fettweis *et al.*, 2007c). The tripod allows to measure current velocity, SPM concentration, suspended particle size, salinity and temperature during a longer period (>5 days). Until February 2005 a Sea-Bird SBE19 CTD system with three OBS was used, from April 2005 on a SonTek 3 MHz ADP, a SonTek 5 MHz ADVOcean, a Sea-Bird SBE37 CT system, two OBS and two SonTek Hydra systems for data acquisition and battery supply have been used.

6.5.2 Measurement results

6.5.2.1 Primary particle size and density

Primary particles are the individual constituents of a floc. Knowledge of primary particle size and density is necessary to calculate settling velocity from the measurements (see below). The primary particle size spectra of the SPM were analysed on 5 samples using the Sedigraph 5100. The mean particle sizes per location was 7.2±3.0 μm on the Hinderbank (offshore), 2.1±1.5 μm on the Kwintebank (at the edge of the turbidity maximum), and 1.1 ± 3.7 μm in the turbidity maximum (near Oostende).

The averages of TOC, $CaCO_3$ and silicate (>80% clay and silt) contents in the SPM from the offshore area (Kwintebank and Hinderbank) were 7.6%, 52.1% and 40.3%, respectively, and from the coastal turbidity maximum area (Oostende) 7.1%, 37.1% and 55.9%, respectively. The density of the primary particles has been calculated as the weighted sum of the density of the silicate, carbonate, and organic fractions. The density of the clay minerals varies and is situated between 2300-2700 kg/m³, while the density of the other minerals (carbonate and quartz) is between 2600-2800 kg/m³, and that of the organic matter between 900-1300 kg/m³ (Pilatti *et al.*, 2006). It was not possible to accurately calculate the density of the particulate matter in the SPM on the basis of the given information and was thus estimated from the weighted average of the silicate, $CaCO_3$ and TOC fractions as 2498 kg/m³ ± 197 kg/m³ (offshore) and 2475 kg/m³ ± 217 kg/m³ (coastal turbidity maximum).

6.5.2.2 Long term measurements

A detailed discussion of the measurements can be found in Fettweis *et al.* (2007c). In total 241 days of data have been collected on the Kwintebank, and at Br.&W. Oostende, MOW1 and Blankenberge (Fig. 3.6). Important results on SPM concentration variations are the strong influence of storms and their direction (SW or NW), the importance of the meteorological/hydrodynamic previous history (e.g. a previous storm might have brought/eroded all the suspended matter) and the fact that neap-spring tidal cycles have most of the time a minor influence.

In Figure 6.7 some results are shown for a deployment at MOW1 (15 May 2006 – 15 June 2006). The figure indicates that tides and storms have a major influence on SPM concentration variation. Up to day 11 strong SW wind and high waves prevail, which resulted in an increase in salinity, a transport of SPM towards the NE and a decrease of SPM concentration when the less turbid and more saline Channel water arrives. The high SPM concentration (frequently >3 g/l) near the bottom (SPM1), which can be related to the storm events, is in contrast with the much lower SPM concentration at 2 m above the bottom (<1 g/l). The high SPM concentration bottom layer was maintained during several tidal cycles (Figure 6.8) after the storm and is possibly related to the concept of saturation concentration as discussed by Winterwerp (2001). The formation, spatial distribution and disappearance of near bottom high SPM concentration layers have probably an important influence on sedimentation of mud in harbours and navigation channels.

6.5.2.3 Tidal cycle measurements

The SPM concentration was measured by OBS and filtration of sea water. The OBS have been calibrated by drawing a calibration curve between the signal and the SPM concentration; the latter has been obtained from filtration of water samples taken immediately adjacent to the sensor. The particle size distributions measured with the LISST100C during the individual tidal cycles are illustrated in Figure 6.9. These data show that a rising tail occurs in the largest size classes in 6 of the 8 tidal cycles. Maxima in the smallest size class occur in 3 tidal cycles. If the maxima in the smallest and largest size class are not related to the actual size distribution, then the calculation of the average floc size, volume concentration, and standard deviation will be uncertain. The mean floc size and the standard deviation have been calculated from the particle sizes spectra of the LISST using the methods of moments (Folk, 1966). The average of all mean floc sizes, SPM concentration and standard deviations per tidal cycle is given in Table 6.2.

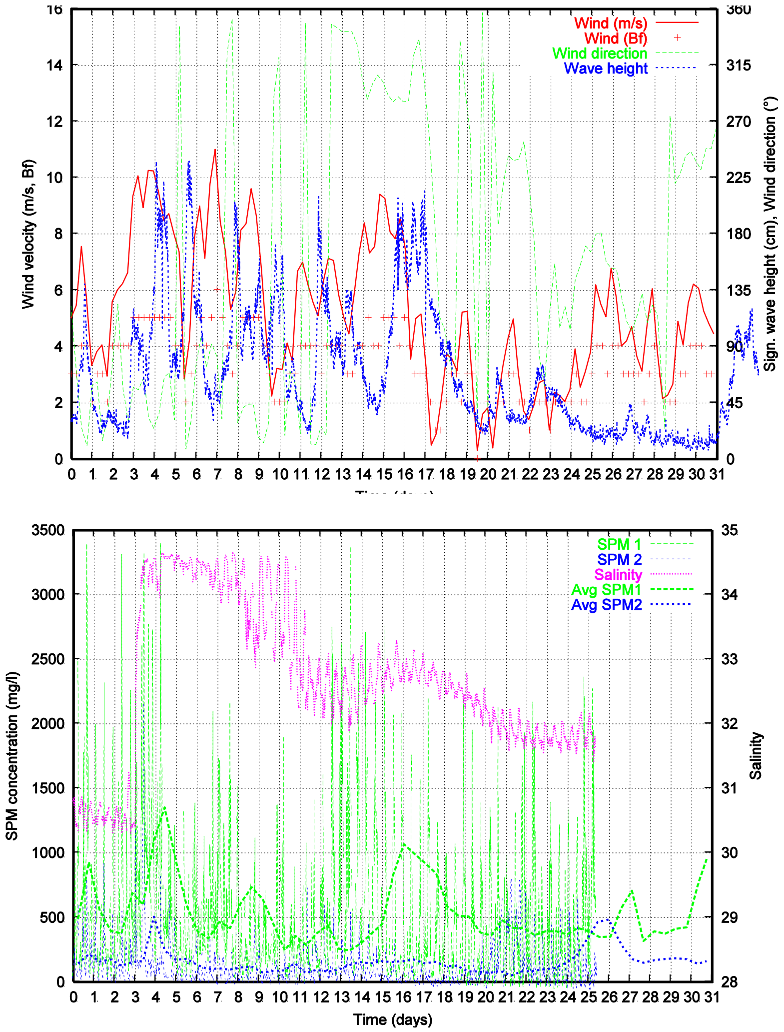


Figure 6.7 Long-term measurement at MOW1 (15 May – 15 June 2006). SPM1 (SPM2) is the OBS at 0.2 m (2 m) from the bottom. Direction of wind is: 0°/360°=E, 90°=N, 180°=W, 270°=S.

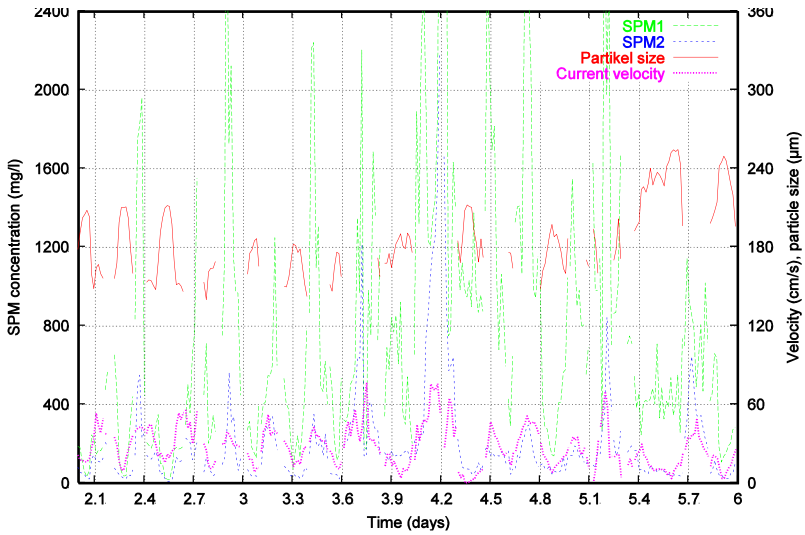


Figure 6.8 Long-term measurement at MOW1 (15 May – 15 June 2006); detail of SPM concentration, particle size and current velocity between day 2 and 6 are shown. SPM1 (SPM2) is the OBS at 0.2 m (2 m) from the bottom.

6.5.3 Calculation of excess density and settling velocity of mud flocs from measurements

By describing mud flocs with the fractal theory (Meakin, 1991, Van Leussen, 1994), the floc excess density can be written as (Kranenburg, 1994):

$$\Delta\rho = \rho_f - \rho_w \propto (\rho_p - \rho_w)\left[\frac{D_f}{D_p}\right]^{nf-3} \qquad \text{(Eq. 6.3)}$$

where $\Delta\rho$ is the excess density; ρ_f, ρ_w, and ρ_p are the floc, water, and primary particle densities, respectively; D_f and D_p are the floc and primary particle sizes, respectively, and nf is the floc fractal dimension. The primary particle is defined as the first-order constituent of a floc and may consists of clay or other silicate minerals, carbonate and organic particles. D_p can, for example, be represented by the median diameter of the single grains in the flocs. Because ρ_p, ρ_w and D_p can be considered independent variables, Eq. 6.3 can be reduced to

$$\Delta\rho = k_a D_f^{\,nf-3} \qquad \text{(Eq. 6.4)}$$

with k_a as a correlation parameter. If $\Delta\rho$ and D_f are known, then the fractal dimension can be derived using a linear regression on a log-log plot. By doing so, it is assumed that nf is constant. This assumption, however, has recently been questioned (e.g. Khelifa & Hill, 2006; Maggi *et al.*, 2007, and Maggi, 2007).

The excess floc density can be calculated if the floc and water densities are known. The water density was derived from conductivity, temperature, and pressure measurements collected by the CTD and calculated using the formulas presented in Fofonoff & Millard (1983). The floc density can be expressed as:

$$\rho_f = \frac{M_f}{V_f} \qquad \text{(Eq. 6.5)}$$

with V_f the floc volume and M_f the floc mass per unit volume. The water and primary particle mass per unit volume can be written as $M_w=\rho_w V_w$ and $M_p=\rho_p V_p$, respectively, with V_w and V_p the water and primary particle volumes in the floc. The floc density (Eq. 6.5) can eventually be calculated with M_f written as:

$$M_f = M_p + M_w = M_p + \rho_w (V_f - V_p) = M_p + \rho_w \left(V_f - \frac{M_p}{\rho_p}\right) \qquad \text{(Eq. 6.6)}$$

The fall velocity, w_s, for flocs with fractal structure can be written as (Winterwerp, 1998):

$$w_s = \frac{\alpha}{18\,\beta}\frac{(\rho_p - \rho_w)}{\eta}\, g\, D_p^{3-nf}\, \frac{D_f^{\,nf-1}}{1+0.15\,\mathrm{Re}^{0.687}} \qquad \text{(Eq. 6.7)}$$

where Re is the floc-Reynolds number, g is the gravitational acceleration, η is the molecular viscosity of water ($\approx 1.4\times10^{-3}$ kg/ms), and α and β are shape factors.

M_p was measured with an OBS and through filtration; V_f and D_f were measured with a LISST 100C. The density of primary particles, ρ_p, was calculated on the basis of the floc constituents. The density was obtained from the size distribution (using a Sedigraph) of the primary particles (D_p) and the $CaCO_3$ and total organic (TOC) contents. The fractal dimension was derived from a linear regression on a log-log plot of excess density and floc size.

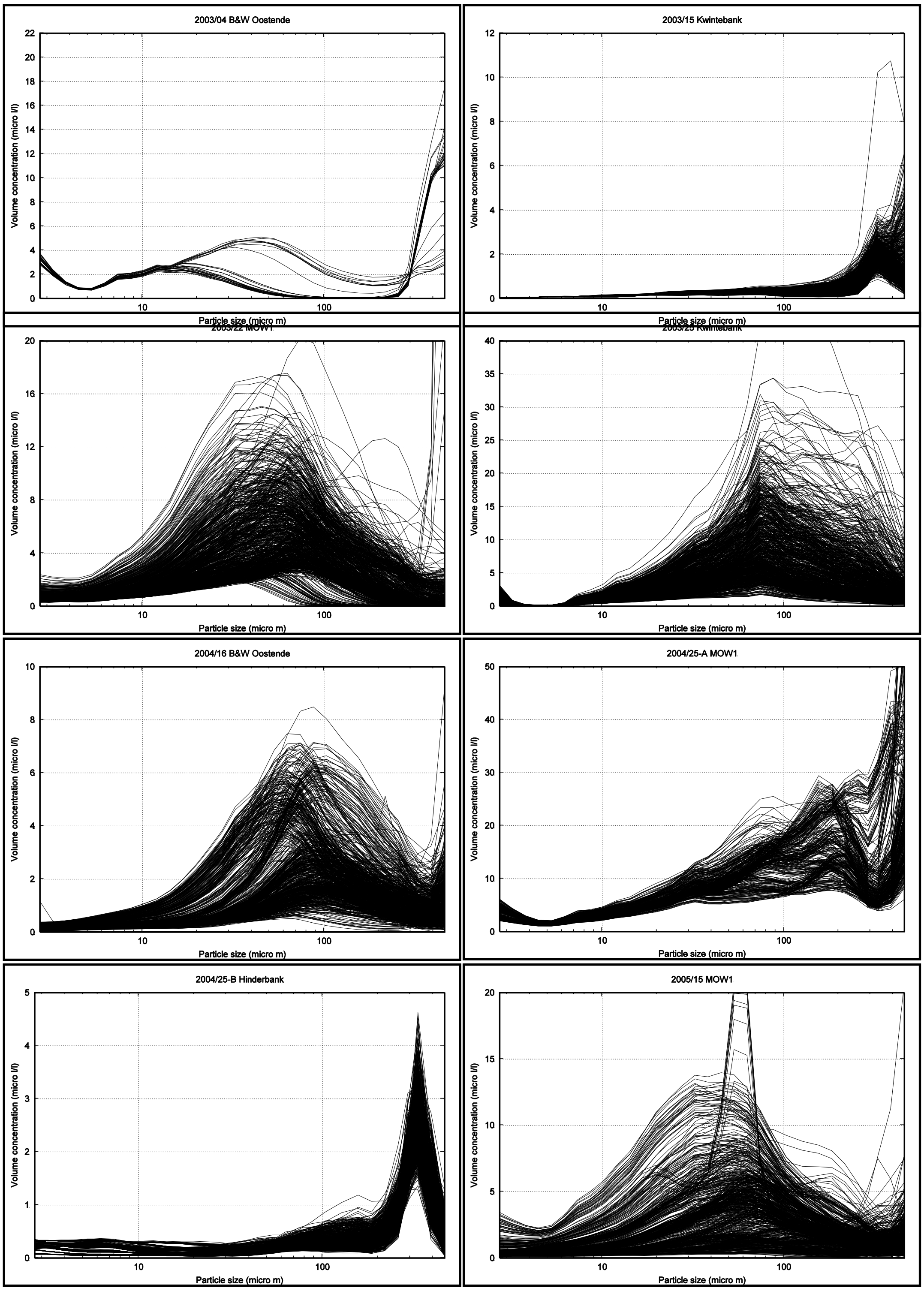


Figure 6.9 Particle (floc) size distribution of the SPM measured by the LISST as a function of volume concentration during 8 tidal cycles. Note that only the distributions with a transmission greater then 20% are shown.

Table 6.2 Tidal averages of SPM concentration from filtration (mg/l), floc size D_f (μm), excess density $\Delta\rho$ (kg/m^3), fractal dimension nf and settling velocity (mm/s), also indicated is the standard deviation. The fractal dimension has been obtained from a linear regression of all data per tidal cycle on a log-log plot. Remark that *nf* (and thus also w_s) is unrealistic (>3) in 3 campaigns.

Nr	**Location**	**SPM ± stdv**	**D_f ± stdv**	**$\Delta\rho$ ± stdv**	**nf ± stdv**	**w_s ± stdv**
2003/04	Br.&W. Oos-tende	281 ± 224	52 ± 23	706 ± 58	3.02 ± 0.21	1.45 ± 1.29
2003/15	Kwintebank	4.5 ± 1.1	160 ± 38	226 ± 16	2.06 ± 0.02	0.20 ± 0.14
2003/22	MOW1	48 ± 22	44 ± 14	451 ± 42	1.46 ± 0.05	0.003 ± 0.015
2003/25	Kwintebank	27 ± 12	75 ± 20	160 ± 14	2.08 ± 0.04	0.09 ± 0.07
2004/16	Br.&W. Oos-tende	32 ± 14	81 ± 22	600 ± 49	3.23 ± 0.06	8.43 ± 8.27
2004/25-A	MOW1	89 ± 54	88 ± 25	117 ± 10	1.72 ± 0.03	0.01 ± 0.05
2004/25-B	Hinderbank	3.6 ± 1.3	115 ± 34	161 ± 21	3.25 ± 0.03	12.27 ± 8.30
2005/15-B	MOW1	104 ± 89	62 ± 19	906 ± 77	2.19 ± 0.04	0.07 ± 0.18

6.5.3.1 Results

The results for excess density and fractal dimension are presented in Table 6.2 and Figure 6.10 for 8 tidal cycle measurements. The averages of the excess density over the measurement cycle indicate that the excess density of the flocs is situated between 113 kg/m^3 and 886 kg/m^3. In the literature, by comparison, values for the excess density of about 50 kg/m^3 (or lower) up to 300 kg/m^3 have been reported (e.g. Winterwerp, 1998). The fractal dimensions are between 1.46 and 2.59; typical values reported in the literature are between 1.7 and 2.25 (Lick *et al.*, 1993; Ten Brinke & Dronkers, 1993; Kranenburg, 1994; Winterwerp, *et al.* 2006). The averages of the settling velocities from the tidal cycle measurements are between 0.003-1.00 mm/s, and from the long term measurements between 0.01-2 mm/s, and are of the same order of magnitude as values reported in the literature (Van Leussen, 1994; Fugate & Friederichs, 2003; Winterwerp *et al.*, 2006) (see Figure 6.10 and Figure 6.11).

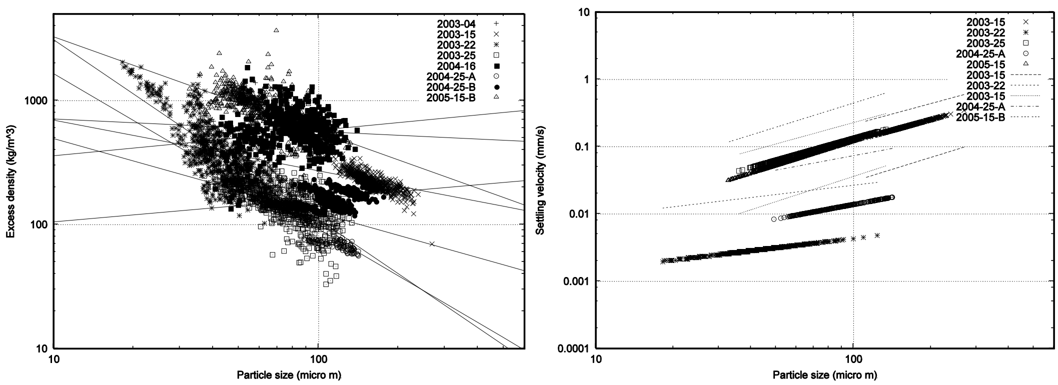


Figure 6.10 (a) Excess density calculated with Eq. 6.1 as a function of floc size for the in Figure 6.9 presented tidal cycle measurements, also shown are the regression lines. (b) Settling velocity as a function of floc size calculated with the modified Stokes' Law (Eq. 6.7). The lines represent w_s ± standard deviation.

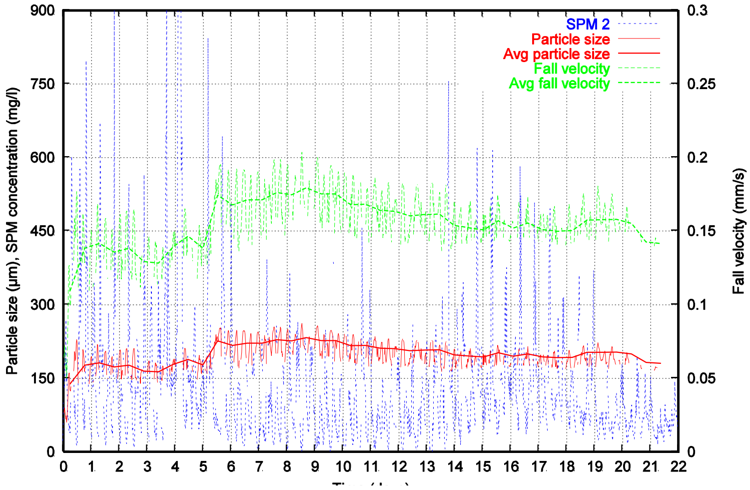


Figure 6.11 Long-term measurement at MOW1 (15 May – 15 June 2006), SPM concentration (2 m above bottom), suspended particle size and fall velocity (Eq. 6.7).

6.5.3.2 Uncertainty on excess density and settling velocity of mud flocs

Direct or indirect measurements of excess density and settling velocity are inherently associated with uncertainties (errors) due to a lack of accuracy of the measuring instruments, inadequate precision of the observations, and the statistical nature of the variables (floc size, primary particle size and primary particle density). When using observations, some understanding of the uncertainties is needed. Based on the theory of error propagation, we have estimated the error of the excess density and the settling velocity of mud flocs using the measurement data of OBS, SPM filtration, LISST 100C, CTD and Sedigraph. The measurements were carried out between 2003 and 2005 in the southern North Sea in the course of 8 tidal cycles. The excess density was calculated based on fractal description of mud flocs and using floc and water density data as is described above. The water density was derived from CTD measurements and the floc density was calculated using SPM concentration, particle volume concentration, and water and primary particle densities. The settling velocities of flocs were calculated using Eq. 6.3.

The results have been described in detail in Fettweis (2008) and show that the relative standard deviations for excess density, fractal dimension and settling velocity are about 10%, 2.5% and 100%, respectively (see Table 6.2). These uncertainties should be regarded as lower limits of the real error because the errors due to inaccuracies of the OBS, LISST and Sedigraph have been excluded as they are unknown. From the results it was found that the statistical error of excess density was dominated by uncertainties of SPM concentration and primary particle density, and for fall velocity by uncertainties of primary particle and floc sizes, respectively. These statistical uncertainties will always be high when dealing with natural flocs or particles and cannot be reduced by increasing the accuracy of the instruments. They should therefore be taken into account when modelling cohesive sediment transport, either by using the calculated standard deviations for settling velocity, or by introducing a floc size (settling velocity) distribution in the transport model.

6.5.4 Flocculation models

The fall velocity of flocs is a crucial parameter in cohesive sediment transport modelling and increases with increasing suspended particulate matter (SPM) concentration up to about 2-10 g/l; at higher concentrations hindered settling occurs and the fall velocity decreases (Berlamont *et al.*, 1993). A conceptual model that describes the effects of shear stress and SPM concentration on the median particle size has been presented by Dyer (1989). The measurements presented above have shown that the size of the aggregates is significantly smaller in the coastal turbidity maximum area. The processes responsible for the occurrence of smaller aggregate size in the coastal zone compared with the more offshore location are the higher turbulence; the smaller time available for the aggregates to grow up to an equilibrium size; the higher deposition of mud, resulting in a break-up of the flocs and the lower ratio between organic matter concentration and SPM concentration, which may limit the size of the flocs (Fettweis et al, 2006b).

Different models have been presented in literature. The simplest one is a constant fall velocity. The power function model ($w_s = kC^m$) has been proposed by different authors, Dyer (1989) mentions values for *m* of 0.6 (Humber), 1.4 (Scheldt) and 2.6 (Elbe). The power function model with dissipation ($w_s = kC^m (1+aG)/(1+bG^2)$) has been proposed by Van Leussen (1994), in which $G = \sqrt{\varepsilon/\nu} = \nu/\lambda_0^2$, with ε the turbulent dissipation per mass, ν the kinematic viscosity and λ_0 the Kolmogorov micro scale of turbulence; *k*, *m*, *a* and *b* are empirical coefficients. The model has been applied during EU COSINUS project by Violeau *et al.* (2002) on the Weser estuary with *k*=0.035, *m*=1, *a*=0.4 en *b*=0.05. Van der Lee (2000) underlines that no unique relation between SPM concentration and settling velocity exists, because it depends on time and location. He proposed a simple model in which the settling velocity is calculated as a function of tide:

$$w_s = a + b\cos\left(\frac{2\pi}{T}(t+c)\right) \qquad \text{(Eq. 6.8)}$$

where *T* is the tidal period (12.4 h), *t* time (in h) related to high water and *a*, *b* and *c* are empirical constants that represent the average settling velocity, the range of settling velocities, and the phase difference between minimal settling velocity and high water.

We have calculated the fall velocity using some of the above presented models and have compared the results with those from the measurements. The engineering floc model (see the approach of Van der Lee, 2000) relates the fall velocity to the SPM concentration and takes into account variations during tidal and neap-spring tidal cycle; this models gives the good results, surely when taking into account the uncertainty of 100% on the measured value. The simple flocculation models, such as the power function model, are not able to always give satisfactory results. It seems that the quality of the model results depends on location and time, which would mean that more complicated models that take into account a better representation of the physics (Winterwerp, 1998, Spearman & Roberts, 2002, Winterwerp *et al.*, 2006, Baugh & Manning, 2007), or the bioflocculation (Maggi, personal communication) are needed to obtain a better agreement between measurements and model results.

6.6 Modelling of dumping of dredged matter at Nieuwpoort and Blankenberge

The dredged matter from Nieuwpoort (±70000 TDM) and Blankenberge (±15000 TDM) harbour is dumped on the dumping sites Br.&W. Nieuwpoort and Br.&W. Zeebrugge Oost, respectively (Lauwaert *et al.*, 2006). Based on economical reasons, the ministry of the Flemish community takes into consideration to pump the dredged matter directly through a pipeline in sea. The major concern is that the dredged matter could be deposited on the beach. Numerical simulations have been carried out to simulate the distribution of fine matter using dumping or pumping (see Fettweis *et al.*, 2006a). The simulations have been carried out with the 2D cohesive sediment transport model described in Fettweis & Van den Eynde (2003) using a grid size of about 750 × 750 m². The results of a 2D hydrodynamic model (without meteorological effects) have been used to calculate the mud transport. The aim of the modelling is to simulate the distribution of mud through a pipeline at different distances from the shoreline.

It was assumed that dredging works and pumping have been carried out continuously until the yearly average quantity of dredged matter is reached. The following sediment parameters have been used: critical shear stress for erosion 0.5 Pa, erosion constant 0.12×10^{-3} kg/m²/s, critical shear stress for deposition 0.5 Pa, constant settling velocity of 2 mm/s. The simulation have been carried out over a spring-neap cycle, pumping (dumping) started at springtide. No mud is entering through the open boundaries or through erosion of the parent bed. The simulations have been compared with the current situation, where the dredged matter is dumped on the dumping sites. Four different scenarios have been considered. In scenario 1 is the dredged matter dumped on Br.&W. Nieuwpoort and Br.&W. Zeebrugge Oost during a period corresponding with the time necessary to pump the matter through a pipeline of 300 mm diameter. The dredged matter is pumped through a pipeline in scenario's 2-4, they differ by the distance the end of the pipe is situated in sea (2: 1.5 km, 3: 3 km, 4: 4.5 km).

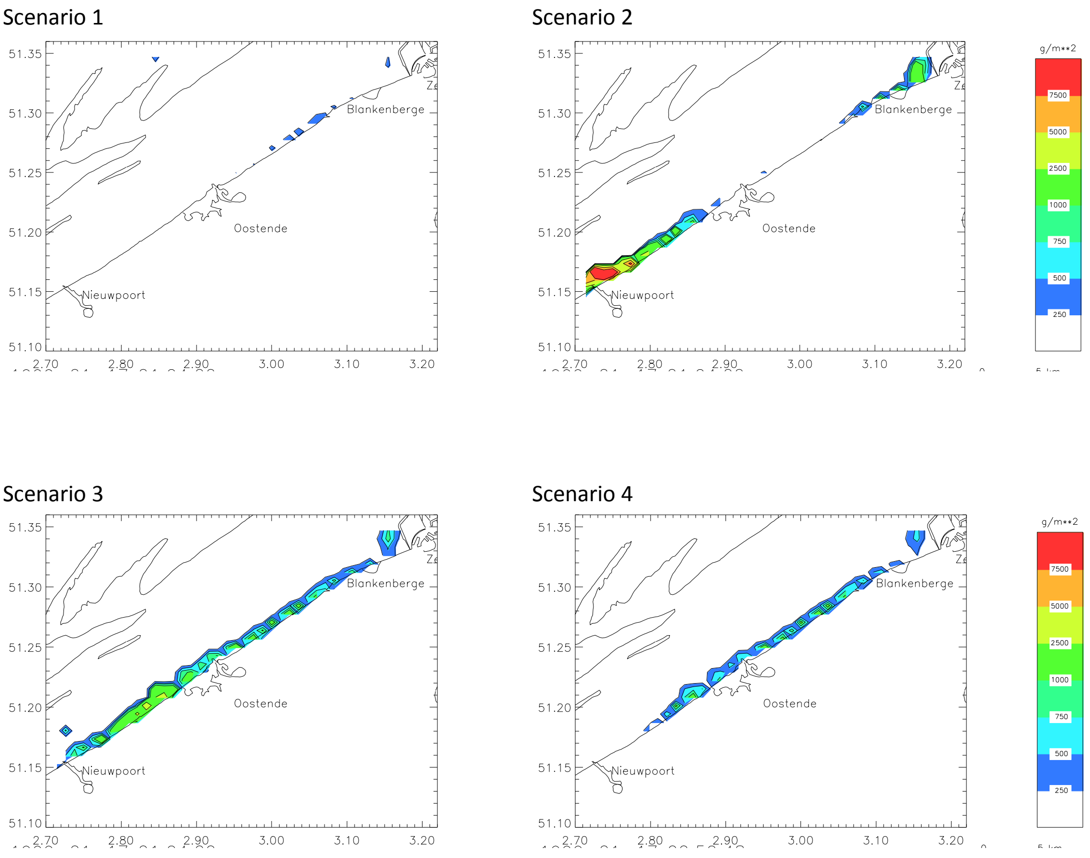


Figure 6.12 Mud deposition in the coastal area after 14 days for the present situation (dumping on the dumping sites, scenario 1) and three scenario's with pumping at respectively 1.5 km (scenario 2), 3 km (scenario 3) and 4.5 km (scenario 4) from the shore line.

The dumping of the dredged matter on the dumping sites has a minor effect on the mud distribution and the SPM concentration in the coastal area (scenario 1). The SPM concentration is maximal 80 mg/l on the dumping site. The mud deposits are spread out over a big area and are therefore small (<0.5 kg/m^2); higher mud deposits (±1 kg/m^2) have been simulated west of the Pas van het Zand and near Zeebrugge, see also the results of tide dependent dumping (Fettweis *et al.*, 2005). When the mud is pumped in sea, then the effects are more pronounced, because part of the dredged matter will be deposited in the coastal area and on the beach, depending on the distance between shoreline and ending of the pipeline in sea. The maximum mud deposition after 14 days is 0.5 kg/m^3 (scenario 1), 16.1 kg/m^2 (scenario 2), 4.2 kg/m^3 (scenario 3) and 1.4 kg/m^3 (scenario 4), see Figure 6.12. The simulations indicate that in scenario 1 about 6% of the total dumped matter is deposited in the coastal area. This mud is mainly from Br.&W. Nieuwpoort, with the exception of a small quantity west of Zeebrugge. 95% of the pumped mud in scenario 2 is still situated on the bottom between Nieuwpoort and Oostende after 14 days. The amount of mud can only be decreased by pumping further away from the shoreline: at 3 km 51 % and at 4.5 km 27% of the mud can still be found on the bottom after 14 days.

6.7 Conclusions

6.7.1 Influence of anthropogenic activities on cohesive sediment distribution

In the Belgian-Dutch nearshore zone, cohesive sediments of different ages occur, ranging from Tertiary clays up to freshly deposited mud. The major conclusions are:

1. Comparing the actual situation with the situation 100 years ago, it seems that around Zeebrugge the area with fresh mud extends, at present more towards the offshore.
2. Most of the present depositions of thick layers of fresh mud (>30 cm) have been induced by anthropogenic operations, such as dumping, deepening of the navigation channels and construction and extension of the port of Zeebrugge.
3. The centre of the turbidity maximum area has shifted in the last 100 years in a more offshore direction. This is explained by the slight decrease in SPM concentration near the dredging areas, due to high siltation rates and the increase in SPM concentration on the offshore dumping places (such as Br.&W. S1).

6.7.2 SPM transport in the southern North Sea

Satellite images, in situ measurements and hydrodynamic model results have been combined to calculate the long term SPM flux in the southern North Sea. The results indicate a flux through the Dover Strait of 31.74×10^6 t/yr. The SPM transport is probably too low, because the SPM concentration is underestimated in the satellite imagery. Satellite images are, however, a major source of SPM concentration data and are the only way to obtain a spatial distribution for large areas, but they underestimate the SPM concentration. In order to calculate more accurately the total sediment flux further in situ measurements and/or numerical model results are needed to obtain vertical profiles of SPM concentration and to improve the algorithm for processing and correcting the satellite images.

6.7.3 Floc dynamics

The settling of mud flocs has a major influence on the transport of cohesive sediments; it is furthermore an important parameter in sediment transport models. Three different types of measurements have been presented:

1. Samples of the SPM have been analysed for primary particle size and density.
2. The long-term measurements using a tripod have shown that the wind has a major influence on the SPM concentration in the coastal area, due to its effect on the origin of the coastal water masses and due to the formation of a near bottom high concentrated SPM layer. The latter has probably a major influence on mud depositon in the dredging areas.
3. The tidal cycle measurements from a vessel and also the long-term measurements have been used to calculate excess density and settling velocity of the mud flocs and the uncertainty on the measurements. Measurements are inherently associated with uncertainties due to a lack of accuracy of the measuring instruments and due to the statistical nature of particle size distributions (and excess densities) in the suspended matter. These errors occur when using both direct or indirect methods to obtain settling velocities. A comprehensive analysis of uncertainties of an indirect method to calculate settling velocity has been presented.

Our results underline that the statistical nature of flocculation processes and settling velocity must be taken into account when modelling cohesive sediment transport, i.e. by at least one standard deviation of settling velocity based on measurements, or by introducing a floc size (and settling velocity) distribution in the transport model.

7 Scientific programme ILVO-Fisheries

7.1 General introduction

This chapter summarizes the results of the research work undertaken by ILVO-Fisheries in the framework of the study towards the 'biological, chemical and biochemical monitoring of sediment and bottom fauna at the dredged disposal sites off the Belgian coast'.

This task is taken up as a protocol between ILVO-Fisheries and MOW-aMT of 5 September 2003, in accordance with art. 9 of MB 29.03.2004 and art. 10 of KB 12.03.2000.

The program consists of a physico-chemical, biological, histopathological, bio-chemical, and chemical part and has the aim of studying the effects of dredge disposal dumping on the marine environment through the research of:

- The physical and organic composition of the sediment;
- The bottom fauna: the macrobenthos, epibenthos and demersal fish;
- An-organic and organic contaminants in sediment and biota;
- Biochemical and histopathological characteristics in biota

Through the integration of all the data the impact of dredge disposal on the environment and the fisheries can be evaluated.

Samples are taken twice a year, once in spring and once in autumn. This report summarizes the results of the four sampling campaigns of 2005 and 2006 for the chemical part, and of the two sampling campaigns of 2006 for the other parts.

7.2 Reports

7.2.1 Scientific reports Belgica

Hostens K., Moulaert I., Hillewaert H., Mathys M., Roche M. & Degrendele K. (2005) Wetenschappelijk verslag Belgica campagne ST0504a,b,c. Rapport DVZ-Belgica 2005/1, 26 p.

Hostens K., Mathys M. & Hillewaert H. (2005) Wetenschappelijk verslag Belgica campagne ST0523. Rapport DVZ-Belgica 2005/2, 20 p.

Hostens K. & Hillewaert H. (2005) Wetenschappelijk verslag Belgica campagne ST0525. Rapport DVZ-Belgica 2005/3, 14 p.

Hostens K., Moulaert I., Hillewaert H., Degrendele K., Knockaert M. (2006). Cruise report Belgica, Campaign ST2006/04a,b,c. ILVO-Monitoring. Report ILVO-Belgica 2006/1, 29 pp.

Hostens K., Moulaert I., Hillewaert H., Mathys M. (2006). Cruise report Belgica, Campaign ST2006/20a,b,c, ILVO-Monitoring. Report ILVO-Belgica 2006/2, 19 pp.

Hostens K., Moulaert I., Hillewaert H. (2006). Cruise report Ter Streep. Report ILVO-Ter Streep 2006/1, 11 pp.

Moulaert I. (2006). Cruise report Belgica, Campaign ST2006/20d, ILVO-Monitoring. Report ILVO-Belgica 2006/3, 9 pp.

Degrendele K., Hostens K., Hillewaert H. (2007). Cruise report Belgica, Campaign ST2007/06. Report ILVO-Belgica 2007/1, 16 pp.

Hostens K., Moulaert I., Hillewaert H. (2007). Cruise report Belgica, Campaign ST2007/07ab, ILVO-Monitoring. Report ILVO-Belgica 2007/2, 21 pp.

Hostens K., Moulaert I., Hillewaert H. (2007). Cruise report Belgica, Campaign ST2007/22ab, ILVO-Monitoring. Report ILVO-Belgica 2007/3, 24 pp.

Hillewaert H., Hostens K. (2007). Cruise report Belgica, Campaign ST2007/23, part ILVO. Report ILVO-Belgica 2007/4, 23 pp.

7.2.2 Progress reports

Hostens K., Moulaert I., Parmentier K., Bekaert K., Hoffman S. en Hillewaert H. (2006) Voortgangsrapportage betreffende de uitvoering van de werkzaamheden opgenomen in het protocol tussen het Centrum voor Landbouwkundig Onderzoek – DEPARTEMENT ZEEVISSERIJ (CLO/DvZ) en de Administratie Waterwegen en Zeewezen – AFDELING MARITIEME TOEGANG, ondertekend op datum van 5 september 2003. PERIODE 1 Juli 2005 – 31 December 2005. Rapport DVZ-Bagger 2006/1, 7p

Moulaert I., Hostens K. & Raemaekers M. (2005) Voortgangsrapportage betreffende de uitvoering van de werkzaamheden opgenomen in het protocol tussen het Centrum voor Landbouwkundig Onderzoek – DEPARTEMENT ZEEVISSERIJ (CLO/DvZ) en de Administratie Waterwegen en Zeewezen – AFDELING MARITIEME TOEGANG, ondertekend op datum van 5 september 2003. PERIODE 1 Januari 2005 – 31 Juni 2005. Rapport DV-Bagger 2005/1, 7p.

Moulaert I., Hostens K., Parmentier K., Bekaert K., Hoffman S., Hillewaert H. (2006) Voortgangsrapportage betreffende de uitvoering van de werkzaamheden opgenomen in het protocol tussen het Centrum voor Landbouwkundig Onderzoek – DEPARTEMENT ZEEVISSERIJ (CLO/DvZ) en de Administratie Waterwegen en Zeewezen – AFDELING MARITIEME TOEGANG, ondertekend op datum van 5 september 2003. PERIODE 1 Januari 2006 – 30 Juni 2006. Rapport DVZ-Bagger 2006/2, 7p.

Moulaert I., Hostens K., Parmentier K., Bekaert K., Hoffman S., Hillewaert H., Wittoeck J. (2007) Voortgangsrapportage effecten baggerlossingen, periode 1 juli 2006 – 31 december 2006. Rapport ILVO-DVI-Bagger 2007/1, 9 p

Moulaert I., Hostens K., Parmentier K., Bekaert K.. Hoffman S., Hillewaert H., Wittoeck J. (2007) Voortgangsrapportage effecten baggerlossingen, periode 1 januari 2007 – 30 juni 2007. Rapport ILVO-DVI-Bagger 2007/2, 9 p.

Moulaert I., Hostens K., Parmentier K., Bekaert K.. Hoffman S., Hillewaert H., Wittoeck J. (in prep) Voortgangsrapportage effecten baggerlossingen, periode 1 juli 2007 – 31 december 2007. Rapport ILVO-DVI-Bagger 2008/1, 10 p.

7.2.3 Reports

Derous S., Verfaillie E., Van Lancker V., Courtens W., Stienen E., Hostens K., Moulaert I., Hillewaert H., Mees J., Deneudt K., Deckers P., Cuvelier D., Vincx M., Degraer S. (2007) BWZee: A biological valuation map for the Belgian part of the North Sea. Final report. PODO-II, Belspo-project. 99 p (+ annexes)

MIRA (2006) Milieurapport Vlaanderen, Achtergronddocument 2006, Kust & zee, Goffin A., Lescrauwaet A.-K, Calewaert J.-B., Mees J., Seys J., Delbare D., Demaré W, Hostens K., Moulaert I., Parmentier K., Redant F., Mergaert K., Vanhooreweder B., Maes F., De Meyer P., Belpaeme K., Maelfait H., Degraer S., De Maersschalck V., Derous S., Gheskiere T., Vanaverbeke J., Van Hoey G., Kuijken E., Stienen E., Haelters J., Kerckhof F., Overloop S., Peeters B. Vlaamse Milieumaatschappij, www.milieurapport.be

7.2.4 Papers

Derous S., Agardy T., Hillewaert H., Hostens K., Jamieson G., Lieberknecht L., Mees J., Moulaert I., Olenin S., Paelinckx D., Rabaut M., Rachor E., Roff J., Stienen E., Van der Wal J.T., Van Lancker V., Verfaillie E., Vincx M., Weslawki J.M., Degraer S. (2007) A concept for biological valuation in the marine environment. Oceanologia, 49 (1): 99-128.

Moulaert I., Hostens K., Hillewaert H., Wittoeck J. (2007) Spatial variation of the macrobenthos species and communities of the Belgian Continental Shelf and the relation to environmental variation. ICES CM 2007/A.:09:1-13

Derous S., Austen M., Claus S., Daan N., Dauvin J.-C., Deneudt K., Depestele J., Desroy N., Heessen H., Hostens K., Husum Marboe A., Lescrauwaet A.-K., Moreno M., Moulaert I., Paelinckx D., Rabaut M., Rees H., Ressurreição A., Roff J., Talhadas Santos P., Speybroeck J., Stienen E., Tatarek A., Ter Hofstede R., Vincx M., Zarzycki T., Degraer S. (2007) Building on the concept for marine biological valuation with respect to translating it to a practical protocol: Viewpoints derived from a joint ENCORA-MARBEF initiative, and adaptation of the concept. Oceanologia 49 (4):1-8

7.2.5 Books

Degraer S., Wittoeck J., Appeltans W., Cooreman K., Deprez T., Hillewaert H., Hostens K., Mees J., Vanden Berghe W., Vincx M. (2006). De macrobenthosatlas van het Belgisch deel van de Noordzee. Federaal Wetenschapsbeleid D/2005/1191/5, 164 pp. ISBN 90-810081-5-3

Degraer S., Wittoeck J., Appeltans W., Cooreman K., Deprez T., Hillewaert H., Hostens K., Mees J., Vanden Berghe W., Vincx M. (2006). The macrobenthos atlas of the Belgian part of the North Sea. Belgian Science Policy D/2005/1191/3, 164 pp. ISBN 90-810081-6-1

Degraer S., Wittoeck J., Appeltans W., Cooreman K., Deprez T., Hillewaert H., Hostens K., Mees J., Vanden Berghe W., Vincx M. (2006). L'atlas du macrobenthos de la partie Belge de la Mer du Nord. Politique Scientifique Fédérale D/2005/1191/4, 164 pp. ISBN 90-810081-7-X

7.2.6 Presentations

Bekaert K., Hillewaert H., Hoffman S. (2007) Fish diseases and parasites on the Belgian Continental Shelf. In: Mees J., Seys J. (Ed.) (2007). VLIZ Young Scientists' Day, Brugge (B). book of abstracts. VLIZ Special Publication, 39: 20.

Derous S., Verfaillie E., Van Lancker V., Courtens W., Stienen E., Hostens K., Moulaert I., Hillewaert H., Mees J., Deneudt K., Deckers P., Cuvelier D., Vincx M., Degraer S. (2007) A marine biological valuation map for the Belgian part of the North Sea. In: Mees J., Seys J. (Ed.) (2007). VLIZ Young Scientists' Day, Brugge (B): book of abstracts. VLIZ Special Publication, 39: pp. 34.

Hostens K., Moulaert I. (2006) De epi-, macro- en visfauna op de Vlakte van de Raan. In: Coosen J., Mees J., Seys J., Fockedey N. (eds.). Studiedag: De Vlakte van de Raan van onder het stof gehaald, Oostende (B). VLIZ special Publication, 35, 116-135

Hostens K., Moulaert I., Hillewaert H., Wittoeck J., Goes B. (2007): Effecten van menselijke activiteiten op het mariene bodemleven. Netwerkdag ILVO-Visserij, Oostende (B).

Moulaert I., Hostens K., Derous S., Courtens W., Cuvelier D., Deckers P., Deneudt K., Hillewaert H., Mees J. Rabaut M., Stienen E., van Lancker V., Verfaillie E., Vincx M., Degraer S. (2007) BWZee: Development and application of the marine biological valuation concept to the Belgian part of the North Sea. ICES Symposium: Environmental indicators: utility in meeting regulatory needs, London, UK. Programme and abstracts, Tue 3.

Moulaert I., Hostens K., Hillewaert H. and Wittoeck J. (2007) Spatial variation of the macrobenthos species and communities of the Belgian Continental Shelf and the relation to environmental variation. 2007 ICES ASC Handbook, p 89.

Parmentier K. (2007) Langlevende organische contaminanten in biota en sediment. Netwerkdag ILVO-Visserij, Oostende (B).

7.3 Study area

The sampling locations were spread along the shallow coastal zone (max 20 km offshore) of the Belgian Part of the North Sea. All five dumping sites are located within this geographic zone: S1 (Br.&W. S1), S2 (Br.&W. S2), Zeebrugge Oost (Br.&W. Zeebrugge Oost), Oostende (Br.&W. Oostende) and Nieuwpoort (Br.&W. Nieuwpoort)

The sampled sites are (1) the five dumping sites; (2) the two former dumping sites (S3 en R4) and (3) some reference locations (See Map).

According to the information on the amount of dredged material dumped daily, dumping site S1 was the main dumping site used on the Belgian Continental Shelf. Also at the dumping site Zeebrugge Oost a high amount of dredged material was dumped on a regular basis. Dumping site Oostende is used less frequently, although during some periods a high amount of material is dumped. Dumping sites of Nieuwpoort and S2 are infrequently used and receive only a small amount of material. During both the spring and autumn campaigns, different dredging vessels were active on the dumping sites S1 and Zeebrugge Oost and at the Oostende dumping site (only in spring).

Samples were taken from the RV Belgica, Zeeleeuw and Ter Streep. The sampling strategy varies according to the ecosystem sampled and will be explained later in the text.

7.4 Sediment

7.4.1 Introduction

Knowing the physical composition of the sediment is an important prerequisite for both biological and chemical analyses.

Macrobenthos, on the one hand, is closely associated with the sea bottom and changes in the substrate can have repercussions for the composition of the benthic communities.

On the other hand, there is the reality that small silty particles rather than course sand grains facilitate adsorption of chemical contaminants.

7.4.2 Sampling strategy

The year 2006 is characterized by the consolidation of a rather profound change in sampling strategy. Unlike in previous years where only one extra Van Veen grab was taken for granulometric analysis, from 2006 onwards, a sediment core was obtained from every single Van Veen. This practice enables us to relate sediment conditions directly to the benthic community of each sample.

The additional Van Veen for sediment analysis was kept for the study of organic contaminants and heavy metals.

Five dumping sites for dredging sludge were monitored. Additionally a few reference areas were investigated. Every dumping zone was sampled with a fixed grid of at least 11 sampling locations. Details about this monitoring programme can be found in the final licensing report. (Hostens *et al.*)

7.4.3 Results

Dumping sites

Median grain measurements are given in Figure 7.1 toFigure 7.3

Br.&W. Nieuwpoort and Br.&W. S2 were characterized by a rather stable and uniform median grain size of respective between 250 and 350 μm and between 200 and 300 μm.

The other three dumping sites, though also quite stable, were characterized by local higher variability, probably due to the larger amount of deposits and non-uniform way in which the dredged material was deposited.

The median grain size on Br.&W. Oostende varied from just over 50 μm to over 250 μm, with the highest values found on the south-eastern side. Br.&W. S1 yielded mostly values around 200 μm with peaks up to 500 μm, mostly on the eastern side of the dumping zone where deposit was lowest. Br.&W. Zeebrugge Oost varied from just over 50 μm to 450 μm, with the highest value on the western side of the dumping zone.

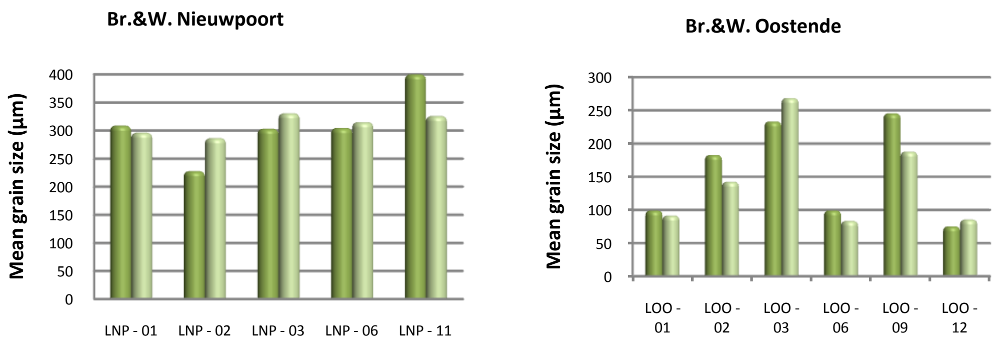


Figure 7.1 Median grain size 2006 for Br.&W. Nieuwpoort and Br.&W. Oostende

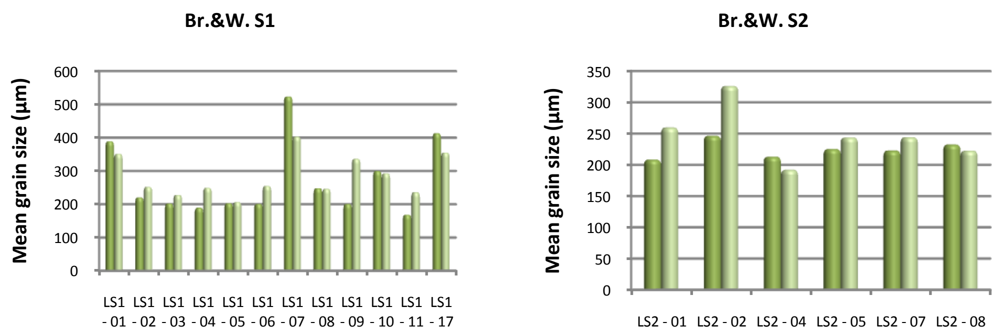


Figure 7.2 Median grain size 2006 for Br.&W. S1 and Br.&W. S2

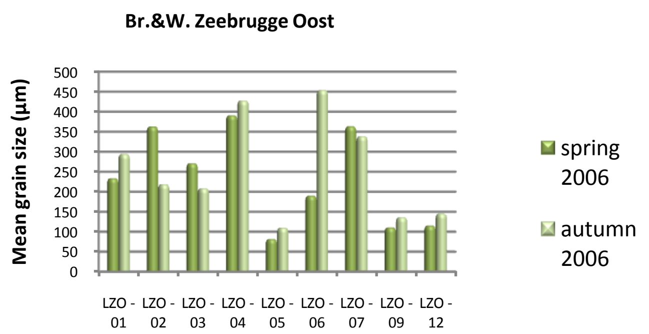


Figure 7.3 Median grain size 2006 for Br.&W. Zeebrugge Oost

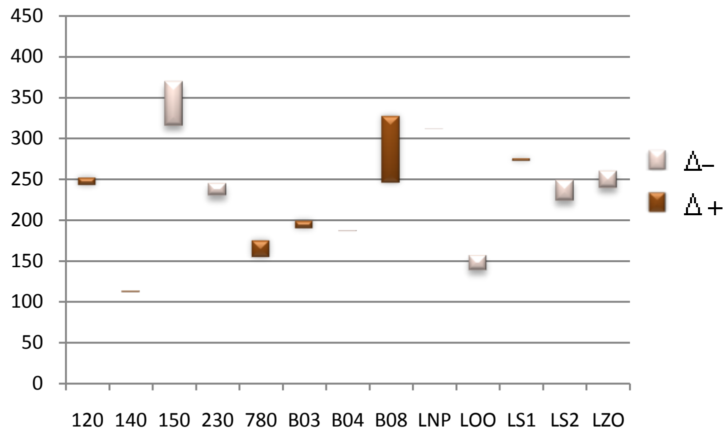


Figure 7.4 Difference between average median grain size in spring and autumn. The height of the bar gives the difference with low and high limits. White bars show a negative change (Δ–), brown bars a positive change (Δ+).

Generally spoken, there was little variation between spring and autumn deposits. Figure 7.4 shows differences of median grain size in 2006 between spring and autumn sampling. Only in at the east coast (150 and B08) was there a noticeable difference, a refinement at the mouth of the Scheldt (150) and a slight coarsening at station B08 (south of Vlakte van de Raan).

Comparison 2004-2006

A comparison over six seasons (spring 2004 to autumn 2006) shows that with the expected exception of most of the dumping zones and the somewhat unexplained station B08, sampling stations in Belgian coastal waters possess a rather stable granulometric composition (Figure 7.5), despite the dynamics of the regional sea. Fluctuation in the dumping sites can be attributed to the disposal activities there taking place.

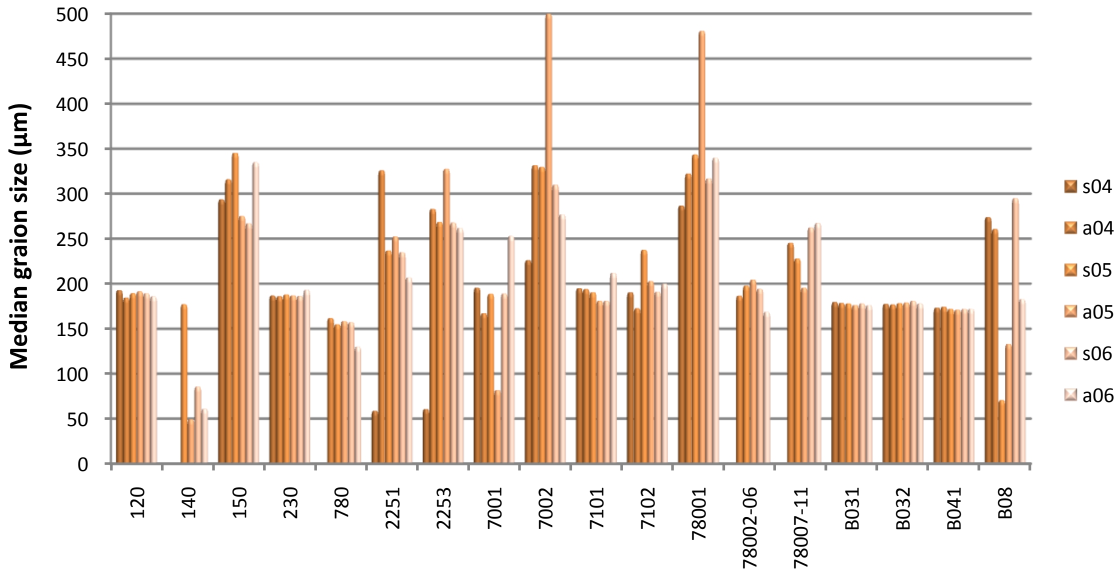


Figure 7.5 Comparison of three years of median grain size at selected sampling stations in spring (s) and autumn (a).

7.4.4 Conclusions

Granulometric properties of the dumping sites can be quite variable in space and time, which due to the activities taking place on those sites is to be expected. Especially because intensive depositing not always takes place on the same spots. This results in considerable localized influence of dredge disposal.

7.5 Macrobenthos

7.5.1 Introduction

Macrobenthic organisms described in this report are all species that live during the largest part of their life in the sediment and that are retained on a sieve of 1 mm. Macrobenthos is highly important in the marine system for the remineralisation and transformation of organic material and as a food source for higher epibenthic organisms and demersal fish.

The most important representatives are Polychaeta, Oligochaeta and Nematoda, Crustacea (mainly Amphipoda and Cumacea), Mollusca (mainly Bivalvia), Echinodermata (mainly Ophiuroidea and Echinoidea) and Cnidaria (Anthozoa).

Macrobenthic organisms are for the largest part of their lifecycle closely associated with the sediment and have a low mobility. Climate (e.g. cold winters and heavy storms), food supply, predation, but also anthropogenic impacts (e.g. dumping of dredged material) can have serious repercussions on these resident populations. Therefore the macrobenthos is highly appropriate as an indicator for the state of the marine environment as well as for possible changes from natural and anthropogenic disturbances.

7.5.2 Sampling strategy

The macrobenthos was sampled with a Van Veen grab (0,1 m^2). The macrobenthic samples were fixed in a formaldehyde-seawater solution before being washed over a 1 mm sieve in the lab and subsequently coloured with eosin. Using a binocular, macrobenthic specimens were sorted, identified and counted, if possible up to species level.

The main community characteristics (total abundance, number of species and Shannon-wiener diversity index) were used for spatial and temporal comparisons.

The results are restricted to 2 sampling campaigns during 1 year (spring and autumn of 2006). At the five dumping sites (Br.&W. S1, Br.&W. S2, Br.&W. Zeebrugge Oost, Br.&W. Oostende and Br.&W. Nieuwpoort) a detailed sampling strategy was used. Apart from samples taken in the centre of the dumping site, a number of grabs were taken inside the boundaries of the site, as well as in the immediate surroundings. (see Map). At each location 1 Van Veen grab was taken.

The former dumping sites (S3 and R4) were sampled by taking 3 replicates in each of the centres as well as 3 replicates on the boundary line in the direction of the residual current. These data can be used as reference data for Br.&W. S2, equally located on the Vlakte van de Raan, as the dumping sites S3 and R4 are no longer used and were only used a few times in 2000-2001.

Some other locations were also sampled for reference data. Location 120, near Nieuwpoort; 230, near Oostende; 140, in front of Wenduine; ZVL, east of the harbour of Zeebrugge; 780, 1 km north of dumping site S1; 150 and B08, near the mouth of the Western Scheldt; and 250, on the Vlakte van de Raan. At each of these locations 3 replicas were sampled. (see Map)

7.5.3 Results

7.5.3.1 General

In total 140 different macrobenthic species were found in the samples of the both the dumping and reference sites in the two sampling campaigns of 2006. 40% belonged to the polychaetes, 28% were oligochaetes, 15% nematodes and 11% molluscs. All 3 univariate indices (density, species richness and Shannon-Wiener diversity index) showed high variations, spatially between the different sampling locations as well as temporally between the different sampling seasons (Figure 7.6).

Comparing all samples from both the dumping sites and the reference locations, using univariate and multivariate measures, 3 main groups of samples can be divided. For some dumping sites all samples belong to 1 group, whereas the samples from some dumping site are more diverse and belong to different groups. All samples from the dumping site Nieuwpoort and the outside samples from the Br.&W. S1 make up Group I together with reference locations 120, 230, ZG03 and 780. This group is characterised by the highest density, species number and diversity. The samples from Br.&W. S2 make up Group II, together with the other locations on the Vlakte van de Raan (B031, B032, B041, B042 and 250). This group has the lowest densities, but a medium species richness and diversity. Group 3 is composed of all samples from Br.&W. Oostende and Br.&W. Zeebrugge Oost and reference locations 140 and ZVL. This last group has relatively high densities, but mainly caused by 1 or 2 species, resulting in very species richness and diversities. The samples from dumping site S1 are scattered over group I, II or somewhere in between. This separation into these 3 distinct groups was similarly found in previous studies and is expected according to the geographic location of the sites. The fact that the samples from dumping site S1 do not belong to 1 single group and are even in between different groups, is probably a result from (1) the positioning of the site on the boarder between the shallow Vlakte van de Raan and the deeper gully northwest of it and (2) from the high amount of dredged material dumped each day.

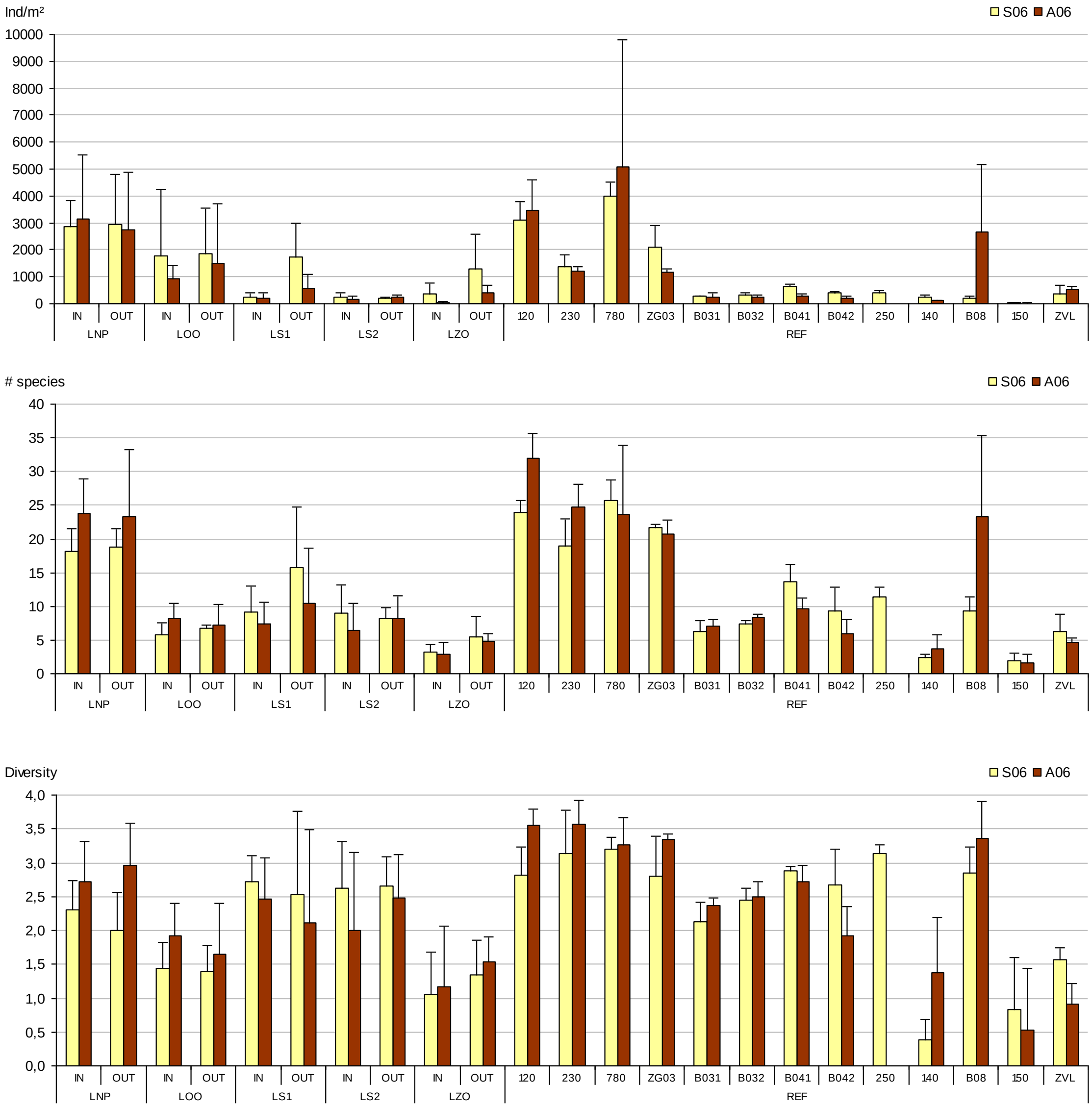


Figure 7.6 Average number of individuals per m², number of species and Shannon-Wiener diversity index for the dumping and reference sites for spring and autumn 2006

7.5.3.2 Results per dumping site

Br.&W. Nieuwpoort

According to the data from the dumped quantities on the different sites, no material was dumped on Br.&W. Nieuwpoort at least one month prior to our sampling campaigns.

In total 6470 individuals were counted, which makes an average of 2940 ind/m². More then 65% of this was taken up by nematodes and oligochaetes and the polychaete species *Scoloplos armiger* and *Heteromastus filiformis* accounted for another 15 %. 86 different species were counted; 37 different Polychaete species, 24 crustacean species and 15 mollusc species (Figure 7.8a).

Spring samples had a slightly lower number of individuals and number of species. Mainly crustaceans were counted in lower numbers in the spring samples compared to the autumn samples (Figure 7.8a).

Within the dumping site, seven samples were taken, and four were taken outside the legal border. All univariate parameters were more or less comparable for the samples from in and from outside the dumping site (Figure 7.7). The proportion of total density taken up by Nematodes was bigger for the outside samples (Figure 7.8b). Also results from multivariate community analyses indicate that the variation between the different sampling locations, both in and outside the dumping site, was very low. A shift in the community composition was apparent between sampling seasons, spring and autumn (Figure 7.9).

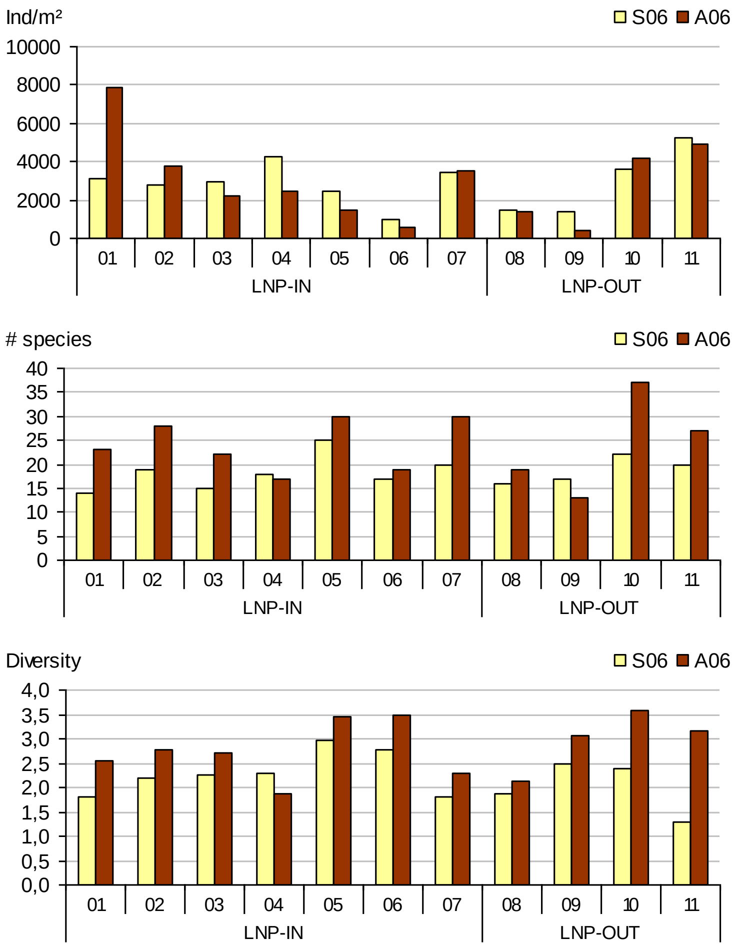


Figure 7.7 Average number of individuals per m², number of species and Shannon-Wiener diversity index for Br.&W. Nieuwpoort for spring and autumn 2006.

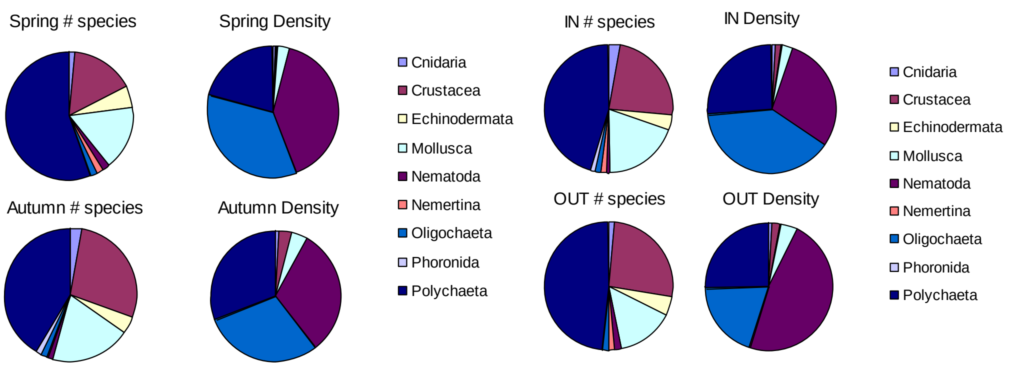


Figure 7.8 Proportion of the different taxa in density and number of species: (a) spring vs. autumn samples and (b) inside vs. outside samples.

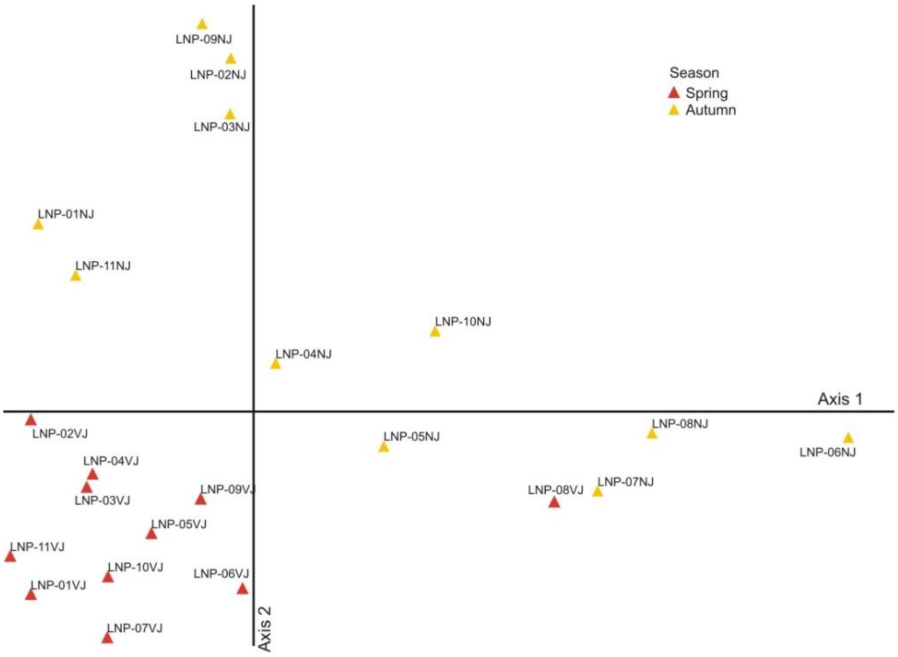


Figure 7.9 Multivariate analysis (RA) of the samples from Br.&W. Nieuwpoort indicating the difference between spring and autumn samples.

Br.&W. Oostende

In contrast to Br.&W. Nieuwpoort where no dredged material was dumped prior to the sampling, a high amount of material was dumped daily in the two weeks prior to the spring sampling. No material was dumped in the weeks prior to the autumn sampling.

In total 3700 individuals were counted, which makes an average of 1540 ind/m^2. More then 53% of this was taken up by oligochaetes and the polychaete Cirratulidae species accounted for another 34%. 35 different species were counted; 18 different polychaete species, 7 crustacean species and 5 mollusc species (Figure 7.11).

Autumn samples had a slightly lower number of individuals but the different number of species that were found was clearly higher in the autumn samples. Mainly polychaetes and crustaceans were counted in lower numbers in the spring samples (respectively 8 and 1) compared to the autumn samples (18 and 7) (Figure 7.11).

Within the dumping site, seven samples were taken, and six were taken outside the legal border. Low number of individuals, species and diversity values were found both inside and outside the dumping site (Figure 7.10). The samples from outside the dumping site were characterised by a slightly higher number of oligochaetes and a lower number of polychaetes (Figure 7.11). The multivariate community analyses did not show any clear difference between the samples located inside or outside the dumping site, nor did it show any clear shift between both sampling seasons. Some autumn samples did separate from the rest because of the presence of some species like *Nepthys cirrosa*, *Magelona johnstoni* and *Spio* spp. This is caused by the difference in sediment composition (more sand, less mud).

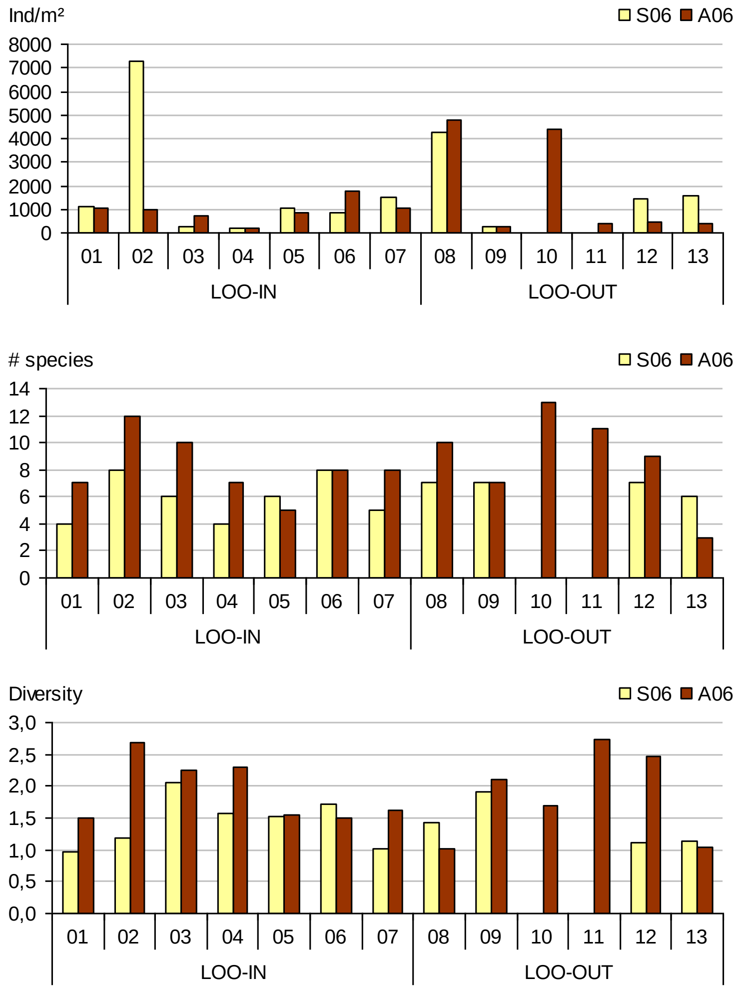


Figure 7.10 Average number of individuals per m², number of species and Shannon-Wiener diversity index for Br.&W. Oostende for spring and autumn 2006.

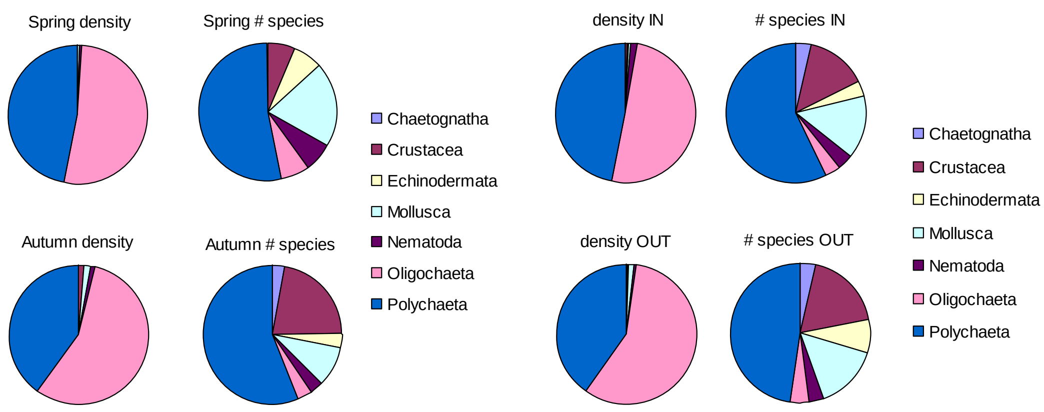


Figure 7.11 Proportion of the different taxa in density and number of species: (a) spring vs. autumn samples and (b) inside vs outside samples.

Br.&W. Zeebrugge Oost

According to the data from the dumping activities, high amounts of dredged material were dumped during as well as daily in the weeks preceding the spring and autumn samplings. From our observations during the campaigns it seems that most dredged material is dumped as close as possible to the harbour of Zeebrugge (the western part of the dumping site).

In total 1300 individuals were counted, which makes an average 500 ind/m². Almost 55% of the counted individuals were Cirratulidae species and another 35% were oligochaetes. 23 different species were counted; 12 different polychaete species and four mollusc species (Figure 7.13a).

Autumn samples had a much higher number of individuals but the number of different species that were found was fairly equal in both seasons (Figure 7.12).

Within the dumping site, seven samples were taken, and six were taken outside the legal boundary. Low number of individuals, species and diversity values were found both inside and outside the dumping site, but clearly some higher peaks in density were found outside the dumping site, caused by the high number of Cirratulidae species (Figure 7.12). The multivariate community analyses did not show any clear difference between the samples located inside or outside the dumping site, nor did it show any clear shift between both sampling seasons.

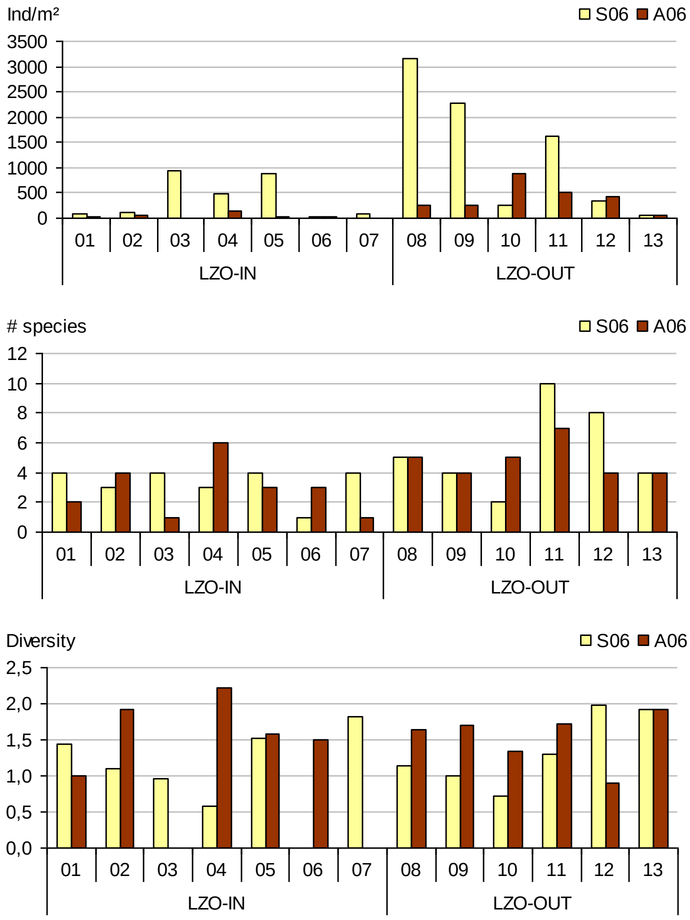


Figure 7.12 Average number of individuals per m², number of species and Shannon-Wiener diversity index for Br.&W. Zeebrugge Oost dumping site for spring and autumn 2006.

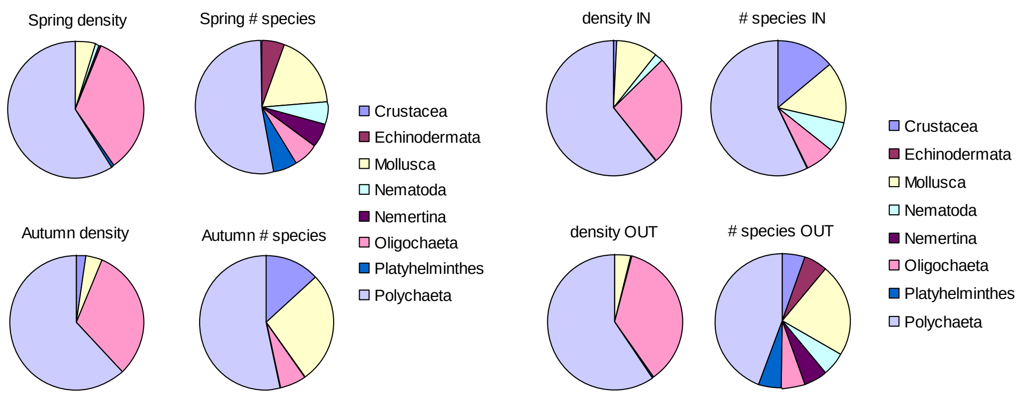


Figure 7.13 Proportion of the different taxa in density and number of species: (a) spring vs. autumn samples and (b) inside vs. outside samples.

Br.&W. S2

In contrast to some larger dumping sites, Br.&W. S2 is used less frequently. The spring campaign was preceded with only one day of dumping a relatively small amount of dredged material (one day before) and the autumn campaign was preceded with no dumping activities during 2 weeks.

In total 5770 individuals were counted, which makes an average of only 260 ind/m². In contrast to the other dumping sites so far, not only 2 taxa are dominating, but 5: The bivalve *Ensis directus* and the polychaete *Nepthys cirrosa* each represent 15% or total density and the juvenile *Nepthys* species, *Spio* species and the amphipod *Bathyporeia elegans* account each for about 10%. 42 different species were counted; 17 different polychaete species, 12 crustacean species and 7 mollusc species.

Autumn samples had a smaller number of individuals, caused mainly by a smaller number of molluscs (Figure 7.14). The total number of different species that were found was fairly equal in both seasons, but a higher diversity in crustacean species was found in autumn, whereas more different Polychaete species were found in spring (Figure 7.15a).

Within the dumping site, seven samples were taken, and four were taken outside the legal boundary. The number of individuals, species and diversity were comparable both inside and outside the dumping site, except for the spring samples of locations 2 and 3 and the autumn samples of 2 and 6 where very low values were found (Figure 7.14). The proportion of the different taxa was similar for the outside and inside samples (Figure 7.15b). The multivariate community analyses did not show any clear difference between the samples located inside or outside the dumping site, nor did it show any clear shift between both sampling seasons.

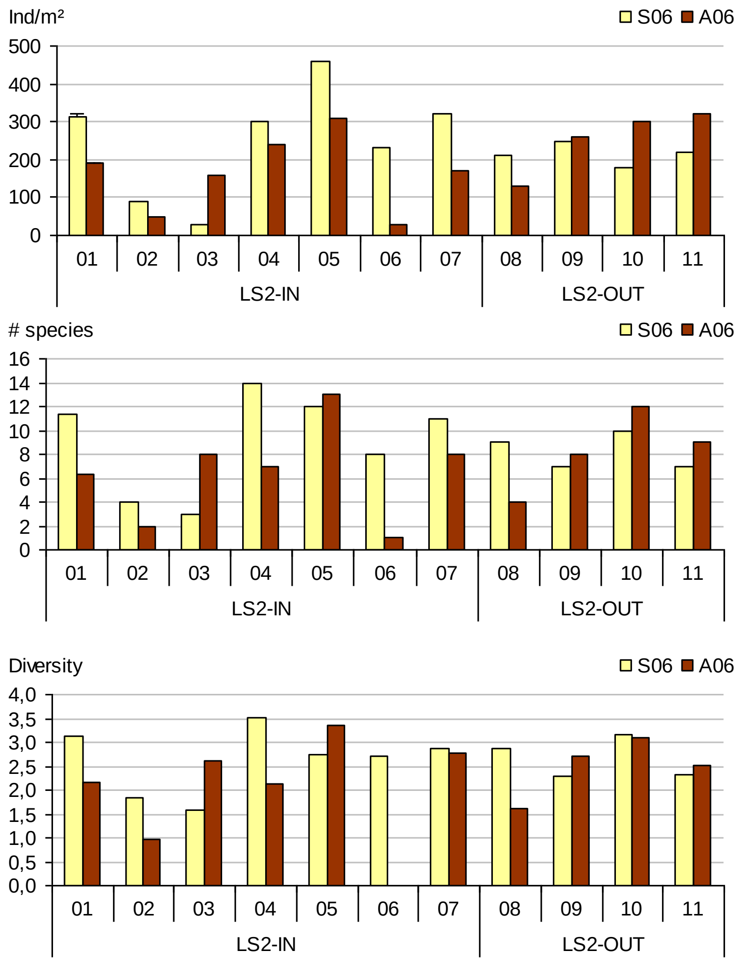


Figure 7.14 Average number of individuals per m², number of species and Shannon-Wiener diversity index for Br.&W. S2 for spring and autumn 2006.

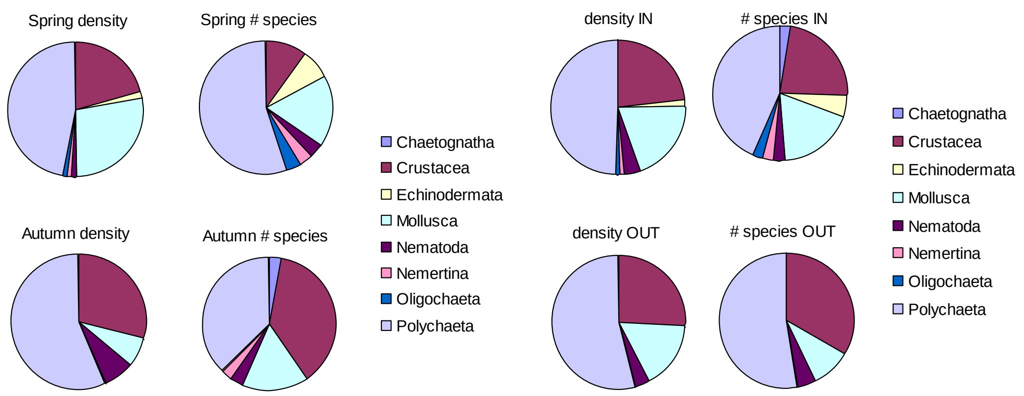


Figure 7.15 Proportion of the different taxa in density and number of species: (a) spring vs. autumn samples and (b) inside vs outside samples.

Br.&W. S1

This site is the main dumping site on the Belgian Continental Shelf. High amounts of dredged material were dumped daily prior and during both the spring and autumn samplings. From observations made during the campaigns, it seems that the western and southern parts of the site are more regularly used for dumping.

In 2006 a total of 1840 individuals were counted, which makes an average of 570 ind/m^2. Oligochaetes represented again the biggest part with 31%, followed by nematodes and the tube building polychaetes *Owenia fusiformis*, each representing 7% of total density. 67 different species were counted; 28 different polychaete species, 17 crustacean species and 12 mollusc species.

Autumn samples had a smaller number of individuals, caused mainly by a smaller number of oligochaetes and polychaete. The relative proportion of polychaetes in total density was clearly higher in the autumn samples, whereas the proportion of density taken up by the oligochaetes was lower (Figure 7.17a). The total number of different species that were found was equal in both seasons (52).

Within the dumping site, eleven samples were taken, and six were taken outside the legal boundary. For the spring samples, the number of individuals found was clearly higher in four samples from outside the dumping sites (Figure 7.16). Two outside samples showed similar low densities as from the inside samples. For the autumn samples only two of the outside samples had higher densities. In general it can be seen that the eastern outside samples have higher densities, species richness and diversity. Oligochaetes took up a larger part of total density in the outside samples compared to the inside samples. The proportion of the different taxa in number of different species was similar in both inside and outside the dumping site (Figure 7.17b).

As the sampling strategy for this dumping site (at least for the inside samples) was similar since 2004, data can be compared for the period 2004-2006 (Figure 7.16). No big changes could be found over this period in density, species number or diversity. Generally low values were found for all stations during the period 2004-2006 (Figure 7.16).

The multivariate community analyses indicate that mainly the samples from the eastern half of the dumping site are characterised by a different community composition. Species like *Gastrosaccus spinifer*, *Bathyporeia* spp., *Nepthys cirrosa* and *Magelona johnstoni* are more prominent in this part of the dumping site. These samples are located on the shallower parts of the dumping site and therefore species like these, who are more common in the shallower area of the Vlakte van de Raan occur in this part. In the samples from the western half of the dumping site and the samples from outside, other species are present that are more common in the more diverse and rich macrobenthic areas as well as mud favouring species. The eastern outside samples are separated from the rest of the samples which is mainly caused by the more numerous presences of *Owenia fusiformis*, *Ophiura* species and some bivalves like *Abra alba* and *Spisula subtruncata* in these outside samples (Figure 7.18).

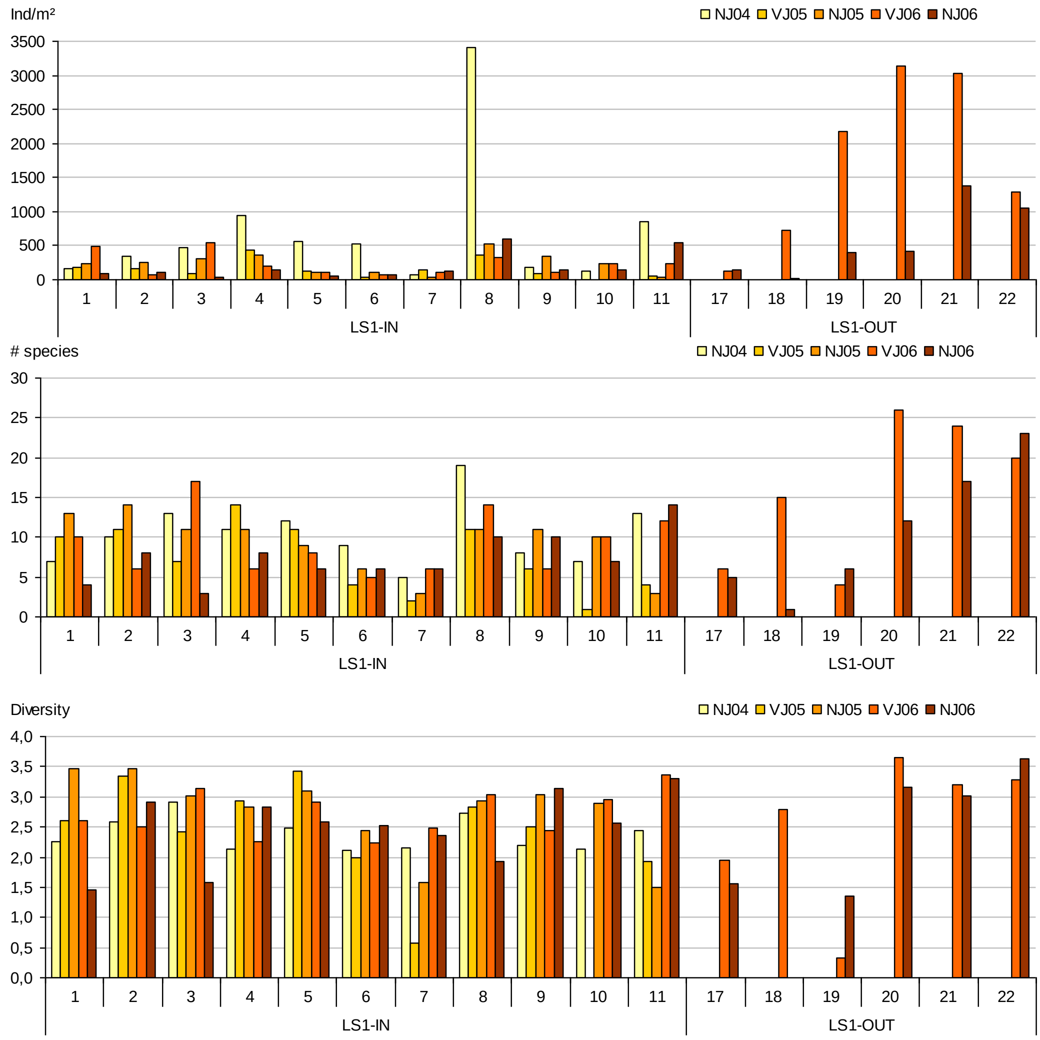


Figure 7.16 Average number of individuals per m², number of species and Shannon-Wiener diversity index for Br.&W. S1 for the period autumn 2004-autumn 2006.

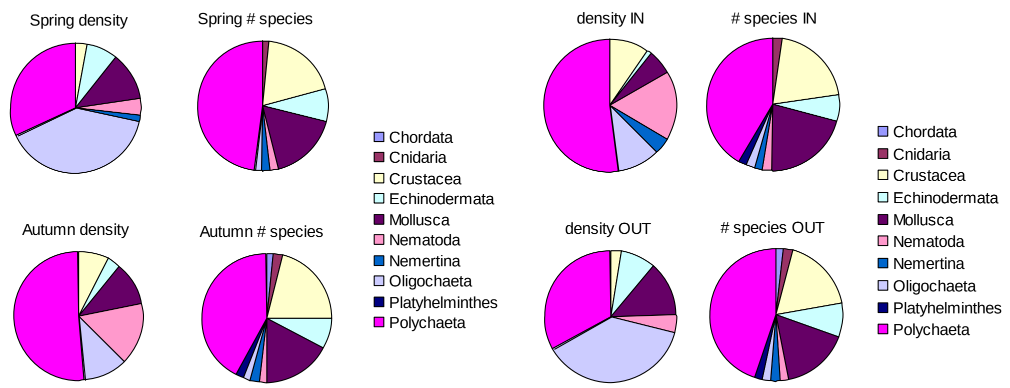


Figure 7.17 Proportion of the different taxa in density and number of species: (a) spring vs. autumn samples and (b) inside vs. outside samples.

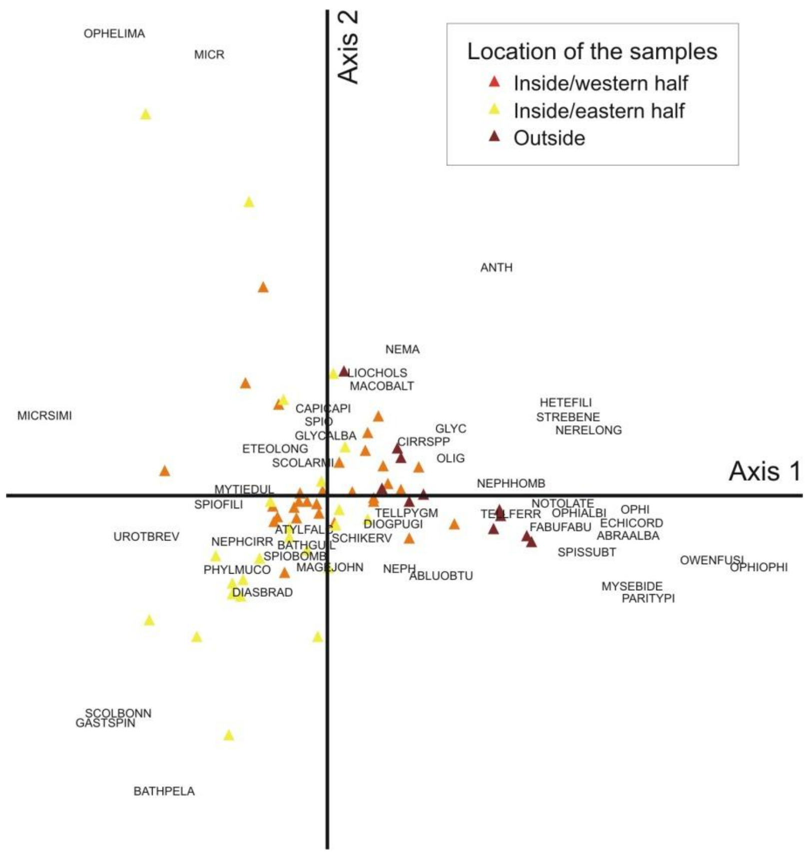


Figure 7.18 Multivariate analysis (RA) of the samples from Br.&W. S1 indicating the difference between inside (western and eastern half) and outside samples.

7.5.4 Discussion

The different dumping sites are spread over a relatively small area running maximum 15km offshore. This small area of the Southern North Sea is characterised by a high diversity in sediment composition and macrobenthic communities. The separation in 3 distinct groups of samples is caused by the spatial variation within this area (Moulaert *et al.*, 2007). In order to make better conclusions and exclude this natural variation it is best to examine each dumping site separately and compare each site with the reference areas that they are supposed to be best comparable to, based on the geographic location, depth and sediment composition.

According to the different criteria mentioned above, the samples from the western half of Br.&W. S1 should be best comparable to the highly diverse and rich samples of reference locations like 120, 230 and 780. Also the samples, located just outside the western part of the dumping site are clearly under the influence of the dumping activities as the densities and number of species found is much lower then the reference locations. The samples in the eastern half of the dumping site, where less dredged material is dumped, have a shallower depth and are thus be more comparable to the community found on the Vlakte van de Raan.

Br.&W. Zeebrugge Oost is located in a shallow area close to the harbour of Zeebrugge. The area is characterised by a high variation in sediment composition, ranging from almost pure shell fragments to very fine mud (See Figure 7.19 below). This is probably a result of the local hydrodynamic conditions and the dumping activities and results in a low species richness and diversity of the local macrobenthos. The close by reference station ZVL has similar values for density, species richness and diversity and a similar species composition, but also this location might probably under high impacts from the harbour and its dredging/dumping activities.

Figure 7.19 High variation in sediment composition, ranging from almost pure shell fragments to very fine mud

Br.&W. Oostende is located in an area of high mud content, although in some locations in the autumn samples, mainly sand was found with a small layer of mud on top. The spring samples from the same locations were almost entirely composed of mud. As dumping only took place before and during the spring campaign and not during or before the weeks of the autumn campaign, it can be concluded that the sandy sediment composition found in autumn is a more natural one. Dumping thus has an effect on the sediment and the benthos.

The dumping site Br.&W. S2, located on the shallow Vlakte van de Raan, has a very stable sediment composition, comparable to the other locations sampled in the area (the two former dumping sites S3 and R4). Although the density values found in this area are low, this is not caused by any dumping activities, but rather by environmental factors influencing and determining the macrobenthos (sediment composition, depth, hydrodynamics, water quality, etc.). One autumn sample yielded extremely low density and diversity, which is probably linked to the presence of a mud layer (see picture to the right). It is unknown if this is a result from the dumping activities.

Br.&W. Nieuwpoort has the highest density, species richness and diversity of all dumping sites. It is characterised by muddy sand with some shell fragments. The community found here is similar to communities on the reference locations 120, 230, ZG03 and 780.

Figure 7.20 Sediment composition at Nieuwpoort dumping site

7.5.5 Conclusions

The influence of dumping on the Belgian Continental Shelf can not be generalized due to the variation apparent within the area and the differences in the frequency of dumping, amount of dredged material dumped, origin of the material, etc.

It can be concluded that disturbed conditions can be found for the dumping site Br.&W. S1 as well as for Br.&W. Zeebrugge Oost and Br.&W. Oostende. Also one sample from dumping site S2 showed a clear difference from the other samples. Whether all this is a result of the dumping activities remains unclear, but it is very likely that the high amounts of dredged material dumped daily on these site are a major cause of the disturbed sediment and associated fauna. It can also be concluded that even some of the samples taken outside the limits of the different dumping sites are in disturbed conditions.

7.6 Epibenthos and demersal fish

7.6.1 Introduction

In this report, epibenthos and demersal fish fauna are defined as organisms living on or in the proximity of the sea bottom and which are efficiently sampled with a beam trawl. Together with the macrobenthos, the epibenthos forms an important food source for seabirds and juvenile fish. Recursively, epibenthos and small demersal fish species comprise an important food source for exploitable stages of commercial fish species and seabirds, and some species are directly exploited by humans.

The most important representatives of the epibenthos are: crustaceans (mainly shrimps Caridea, crabs Brachyura and hermit crabs Anomura), echinoderms (mainly brittle stars Ophiuroidea, sea stars Asteroidea and sea urchins Echinoidea), molluscs (mainly bivalves, gastropods and cephalopods) and sea anemones (Anthozoa). The demersal fish fauna mainly comprises clupeids (herring, sprat), perciform fish (sea bass, gobies, red mullet), flatfish (Pleuronectiformes) and gadoids (cod, whiting, bib).

Epibenthic organisms and demersal fish are rather mobile and as such may suffer less the consequences of dredge disposal. Moreover, other factors such as climatological variability, year class strength and anthropogenic influences on a larger scale (more widely than the BCS) may mask the possible impact of human interventions within the BCS on the epibenthos and the demersal fish fauna. Several studies have shown that an important correlation exists between the presence of these ecosystem components and their habitat. Discharging dredge sludge can change the composition of the substrate and the toxicity in the environment, which makes the dumping zones and their direct neighbourhood less suitable as foraging area or resting spot. Furthermore, a good knowledge of the physical processes (i.e. hydrodynamics and geomorphology) is required to interpret the changes in biological parameters, such as diversity, density and biomass.

7.6.2 Sampling strategy

The epibenthos and demersal fish are sampled with an 8 meter beam trawl with a fine-meshed shrimp net (stretched mesh width 22 mm in the codend) and a bolder chain but no tickler chains. The beam trawl is dragged during 30 minutes at an average speed of 4 knots over the bottom. The demersal fish were sorted on board, determined, measured and/or counted or wet weighed. The same procedure was followed for the deep-frozen subsamples of the epibenthos (and gobies) in the lab.

Species richness, Shannon-Wiener diversity index, density and biomass are the biological characteristics presented in this report. Also, a number of multivariate analysis are carried out for the epibenthos and demersal fish separately, based on the reduced and 4^{th} root transformed density data.

The results are limited to two sampling campaigns during spring and autumn of 2006. Since 2005 a new sampling strategy is used for the epibenthos and demersal fish. At the five dumping sites (Br.&W. Nieuwpoort, Br.&W. Oostende, Br.&W. Zeebrugge Oost, Br.&W. S2 en Br.&W. S1) one fish track is sampled in spring and autumn within the boundaries of the dumping site itself (e.g. 700**1**) and one in the direct vicinity (at the boarder) of these dumping sites (e.g. 700**2**). Next, also some reference zones were sampled: fish track 120 near Weststroombank and track 230 near Oostendebank as reference for dumping site Nieuwpoort; track 140 near Wenduinebank for Br.&W. Oostende; track B10 near the Scheldt mouth for Br.&W. Zeebrugge Oost; tracks B07 and B04 near the former spare dumping sites R04 and S03 for dumping site Br.&W. S2; and track 350 near Steendiep for dumping site Br.&W. S1 (see Map)

Sampling at 1401 failed twice in autumn 2006, due to bryozoans/hydrozoans ('hair') and mud filling up the net already after a few minutes. No sampling was performed at fish track 350 due to bad weather conditions and the cancelling of a large part of the autumn campaign. Also the sampling at fish track 7801 failed three times in the autumn campaign. Due to the huge sample weight, the beam trawl was turned around when hauling, and the

A-frame and net winch rope broke. The third sample contained 1600 litres of dredged material (i.e. hard mud and dredge material that had been dumped previously on the same day). Sampling time at 7001 was halved, due to large amounts of black fluid mud. Also for the spring campaign a first sampling at 7001 failed due to large amounts of black fluid mud, but this one could be repeated.

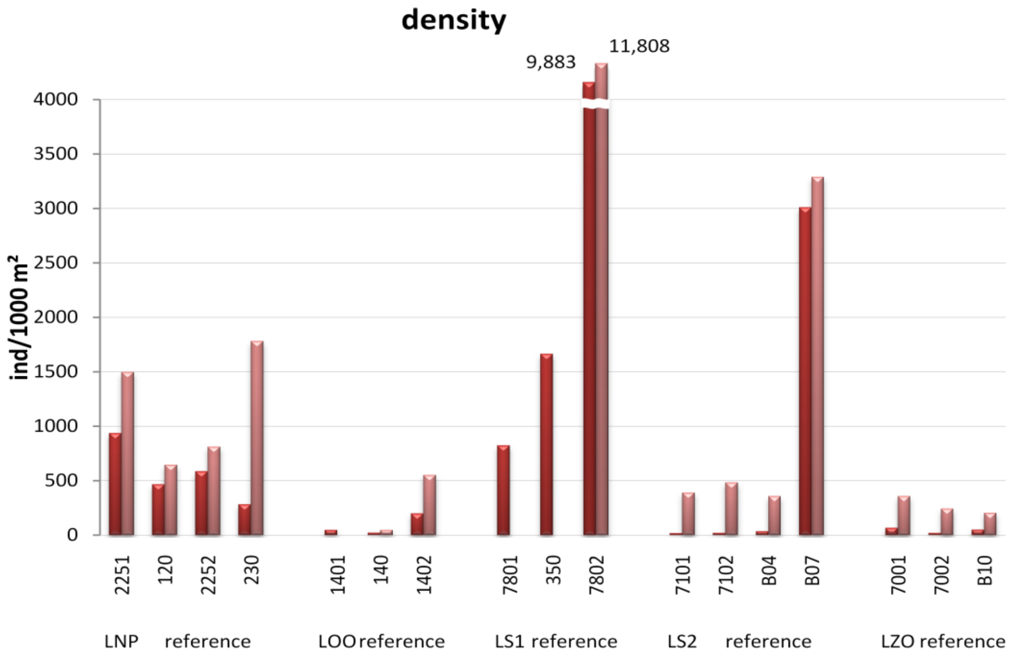
7.6.3 Results epibenthos

7.6.3.1 Overall

A total of 49 epibenthic species were found in the year 2006 (spring + autumn) in the dredging and reference sites. All the univariate parameters (density, biomass, species richness and diversity) showed high variations, spatially between the different sampling sites as well as temporally between spring and autumn (Figure 7.21). In all cases the spring density and biomass were lower than in autumn (the amplitude of the difference varied between the locations), whereas the species richness and diversity were in most cases a little bit lower in autumn compared to spring.

7.6.3.2 Results per dumping site

The variation in univariate parameters is visualised in Figure 7.21 and will be discussed per dumping site.



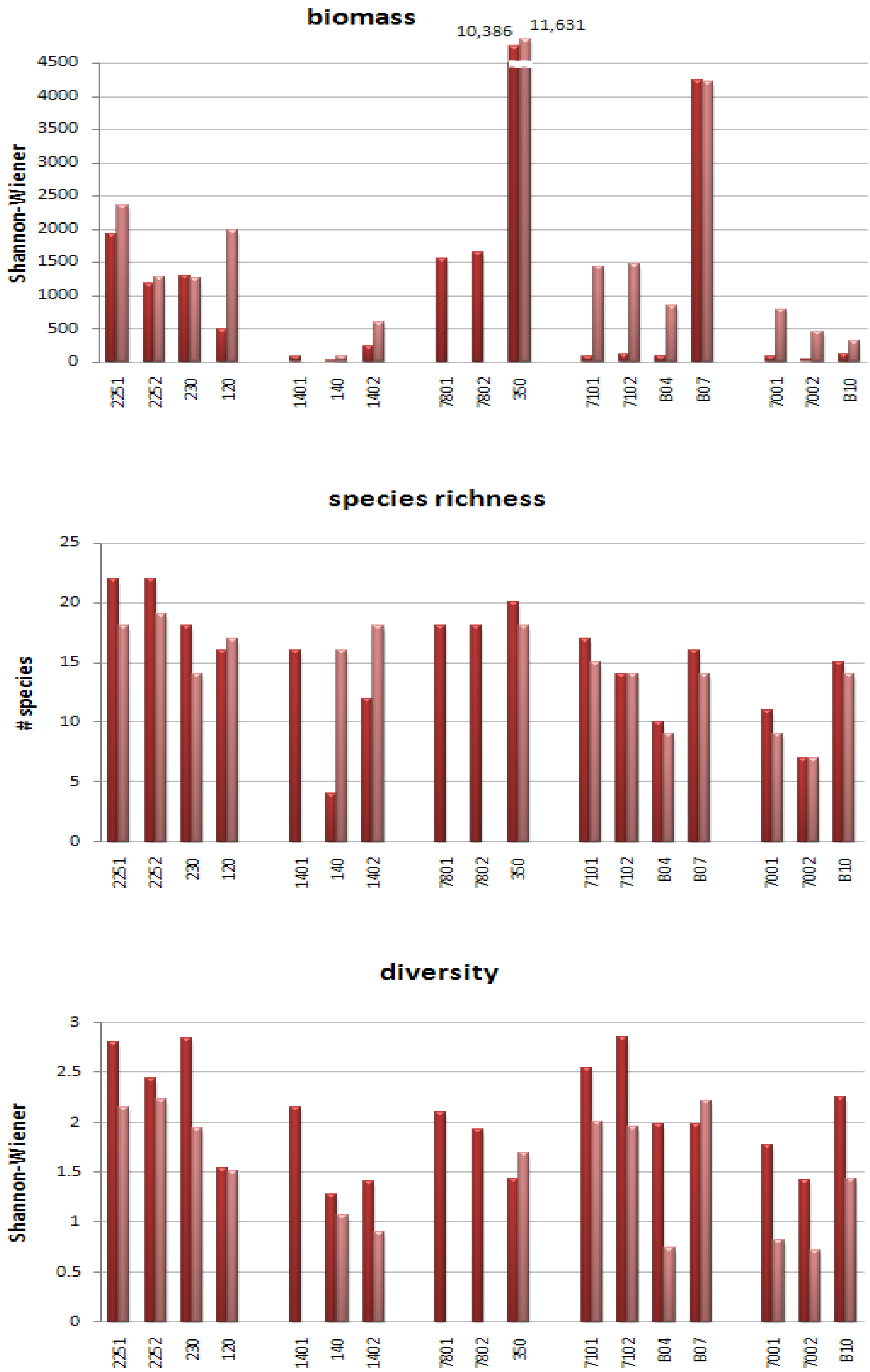


Figure 7.21 Average epibenthos density (ind/1000 m²), biomass (gWW/1000 m²), species richness and Shannon-wiener diversity index of the dumping sites, neighbouring sites and some reference sites for spring (red boxes) and autumn (pink boxes) of the year 2006.

Table 7.1 Proportion of the different taxa/ phyla in density (percentage) for all stations in spring and autumn 2006.

			Arthropoda				Cnidaria	Mollusca				Echinodermata			
season	**station**	**area**	**Anomura**	**Brachyura**	**Caridea**	**ALL**	**Cnidaria**	**Bivalvia**	**Gastropoda**	**Cephalopoda**	**ALL**	**Echinoidea**	**Asteroidea**	**Ophiuroidea**	**ALL**
spring	2251	LNP	3	1	16	**20**	**0.5**	4	38	-	**42**	0.1	1	36	**37**
	2252	ref LNP	6	7	33	**46**	**3**	2	7	-	**9**	0.4	1	41	**42**
	230	ref LNP	3	2	15	**19**	**0.4**	1	5	-	**6**	-	0.2	75	**75**
	120	ref LNP	0.3	3	34	**37**	**5**	3	25	-	**28**	0.1	1	29	**30**
	1401	LOO	1	2	25	**28**	**7**	55	3	-	**58**	-	1	6	**7**
	1402	ref LOO	0.2	<0.1	9	**9**	**3**	73	7	-	**80**	-	1	7	**8**
	140	ref LOO	-	-	34	**34**	**2**	60	-	-	**60**	-	-	4	**4**
	7801	LS1	2	1	11	**15**	**1**	6	2	-	**8**	0.1	3	74	**76**
	7802	ref LS1	1	1	2	**3**	**0.1**	1	0.2	-	**1**	2	1	93	**95**
	350	ref LS1	4	1	19	**24**	**0.3**	0.5	1	-	**1**	0.3	1	73	**75**
	7101	LS2	13	8	51	**72**	**3**	13	1	-	**15**	5	1	5	**10**
	7102	ref LS2	19	15	16	**50**	**2**	5	0.5	-	**6**	5	1	36	**42**
	B04	ref LS2	5	3	48	**55**	**2**	0.4	1	-	**1**	-	11	30	**41**
	B07	ref LS2	1	0.1	9	**10**	**0.2**	17	8	-	**25**	-	10	56	**65**
	7001	LZO	-	0.1	18	**18**	**1**	65	0.5	-	**66**	-	2	13	**15**
	7002	ref LZO	-	0.5	63	**64**	**20**	15	0.5	-	**15**	-	-	1	**1**
	B10	ref LZO	11	2	57	**69**	**6**	6	4	-	**10**	-	13	1	**15**
autumn	2251	LNP	5	3	15	**23**	**1**	2	14	-	**16**	-	0.5	60	**60**
	120	ref LNP	1	10	44	**55**	**0.2**	1	14	-	**16**	-	1	29	**30**
	2252	ref LNP	2	5	42	**50**	**0.1**	1	6	-	**7**	-	-	43	**43**
	230	ref LNP	2	3	31	**36**	**-**	1	3	-	**4**	0.1	-	60	**60**
	1401	LOO													
	140	ref LOO	1	3	84	**88**	**1**	3	2	-	**5**	-	0.2	6	**6**
	1402	ref LOO	0.3	1	84	**85**	**0.2**	13	1	-	**14**	<0.1	0.1	1	**1**
	7801	LS1													
	7802	ref LS1	1	1	8	**10**	**0.2**	1	2	-	**3**	1	0.3	85	**87**
	350	ref LS1													
	7101	LS2	3	7	58	**68**	**-**	9	3	-	**12**	-	1	18	**19**
	7102	ref LS2	17	16	57	**90**	**0.1**	0.2	3	0.2	**3**	-	-	6	**6**
	B04	ref LS2	3	9	87	**99**	**-**	0.1	0.4	0.2	**1**	-	0.2	0.1	**0.3**
	B07	ref LS2	7	1	32	**40**	**-**	4	32	0.3	**36**	-	0.1	23	**23**
	7001	LZO	0.1	2	15	**17**	**<0.1**	83	-	-	**83**	-	0.4	-	**0.4**
	7002	ref LZO	-	4	89	**93**	**-**	2	-	0.4	**2**	-	-	4	**4**
	B10	ref LZO	2	3	77	**82**	**1**	12	5	-	**17**	-	0.1	0.1	**0.3**

Br.&W. Nieuwpoort

The density and biomass at the dumping site of Br.&W. Nieuwpoort were highest of all dumping sites in both seasons, with respectively 940 – 1500 ind/1000 m^2 and 1920 – 2350 gWW/1000 m^2 (spring – autumn) (Figure 7.21). 38% of the density was taken up by Gastropoda (mainly *Nassarius reticulatus*) and 36% by Ophiuroidea (*Ophiura albida and O. ophiura*) in spring, whereas for autumn 60% was taken up by Ophiuroidea (mainly *O. ophiura*) and only 15% by Gastropoda (mainly *Crepidula fornicata* and *N. reticulatus*) (Table 4.1). In terms of biomass, the higher mentioned species were dominant, together with the seastar *Asterias rubens* for both seasons. Of all dumping sites, this site was the most diverse, with a species richness of 22 -18 species (spring – autumn) and a Shannon index of 2.8 – 2.1 (Figure 7.21).

In the reference sites (neighbouring site 2252 and reference sites 120 and 230), no obvious differences in univariate parameters were found compared to the dumping site. All parameters were equal or lower for the reference sites than in the dumping zone. The dominant species in the reference sites for spring were *Crangon crangon and* Ophiuroidea (*O. ophiura* and *O. albida*) (Table 7.1). Only in reference zone 120, *C. fornicata* reached high densities. In autumn, the density was mainly dominated by *C. crangon* and *O. ophiura*.

In the correspondence analysis (Figure 7.22 and Figure 7.24) and in the cluster analysis (Figure 7.23 and Figure 7.25), Br.&W. Nieuwpoort and its reference sites were clustering together in both seasons due to their similarity in species composition. Typical but not abundant species for these sites were *Liocarcinus depurator, Euspira catena, Ensis directus, Liocarcinus vernalis* and *Lutraria lutraria* (Figure 7.22).

In spring, the samples in the dumping and neighbouring site were also characterised by a lot of empty *Ensis* and oyster shells.

Br.&W. Oostende

This dumping site was only sampled in spring and was characterised by a low density (45 ind/1000 m^2) and biomass (70 gWW/1000 m^2), but a relatively high species richness (16 species) and diversity (Shannon of 2.2) (Figure 7.21). 58% of the density was taken up by Bivalvia (*Macoma balthica*) and 25% by Caridea (*C. crangon*) (Table 7.1). In terms of biomass, these species were important together with *A. rubens* and *Anthozoa species*.

In spring, the track in the vicinity of the dumping site (1402), showed higher values for density (200 ind/1000 m^2) and biomass (230 gWW/1000 m^2), but the species richness (12 species) and diversity (Shannon of 1.4) were lower (Figure 7.21). For the reference site 140, the density (20 ind/1000 m^2) and biomass (30 gWW/1000 m^2) were very low, just like the species richness (4 species) (Figure 7.21). Bivalvia (*M. balthica*) amounted up to 73% of the density at the reference sites in spring, whereas in autumn the Caridea (*C. crangon*) were dominating density (up to 84%). A comparison between the reference sites and the dumping site for autumn was not possible. Generally, the species richness is much higher for the reference sites in autumn compared to spring, but the diversity is lower, due to the strong dominance of *Crangon crangon*.

In the correspondence analysis and cluster analysis (Figure 7.22 to Figure 7.25), Br.&W. Oostende and its reference sites are clustering more or less together in spring, together with Br.&W. Zeebrugge Oost and its reference sites. *M. balthica* is a typical species for those sites.

Br.&W. Zeebrugge Oost

This dumping site was characterised by a low density (65 ind/1000 m^2) and biomass (75 gWW/1000 m^2), with intermediate values for species richness (11 species) and diversity (Shannon of 1.8) in spring (Figure 7.21). In autumn, the density (360 ind/1000 m^2) and biomass (780 gWW/1000 m^2) was much higher. 65% of the density was taken up by *M. balthica* and 18% by *C. crangon* in spring, whereas in autumn *M. balthica* dominates for 83% in density and *C. crangon* for 15% (Table 7.1). The parameter values and the species composition were almost identical to those of the dumping site of Br.&W. Oostende, which explains the similarity between both dumping sites. The beam trawl samples at the dumping site were characterised by mud and a lot of empty oyster shells.

For spring, the track in the vicinity of the dumping site (7002) and the reference site (B10) showed a comparable low density and biomass, whereas the species richness was lower for site 7002 (7 species) and higher for site B10 (15 species) (Figure 7.21). Similar to the situation at Oostende, the species richness was comparable between spring and autumn, but the diversity was much lower in autumn than in spring, due to the strong dominance of *C. crangon* in autumn (up to 89% of the total density) (Table 7.1).

In the correspondence analysis and cluster analysis (Figures 4.19-4.22), the dumping site of Zeebrugge Oost and its reference sites were clustering more or less together in spring, together with Br.&W. Oostende and its reference sites. *Macoma balthica* is a typical species for Br.&W. Zeebrugge Oost.

Br.&W. S2

The epibenthos at dumping site Br.&W. S2 was characterised by a low density in spring (20 ind/1000 m^2) and a density which was more than 20 times higher in autumn (390 ind/1000 m^2) (Figure 7.21). Biomass showed the same pattern with a spring biomass of 80 gWW/1000 m^2 and an autumn biomass of 1430 gWW/1000 m^2. Arthropoda (mainly *C. crangon* and Anomura) made up to 72% of the density in spring and in terms of biomass, the bivalve *Ensis directus* was most important (Table 7.1). In autumn, 58% of the density was taken up by the Caridea (*C. crangon*) and the Ophiuroidea (*O. ophiura*). In terms of biomass, the bivalve *E. directus* was the most important species, next to *C. crangon* and *L. holsatus*. The species richness (17 – 15 species) and diversity (Shannon of 2.5 – 2) at Br.&W. S2 were relatively high (Figure 7.21). The diversity was lower in autumn due to the dominance of *C. crangon*.

The reference sites for dumping site Br.&W. S2 showed a similar pattern and values (low density – biomass in spring and high density – biomass in autumn), except for site B07, which showed very high density (3000 – 3300 ind/1000 m^2) and biomass (4200 – 4200 gWW/1000 m^2) values in spring and autumn (Figure 7.21). The species richness and diversity were a little bit lower in the reference sites compared to the dumping site. At the reference sites (7102 and B04), Arthropoda made up the highest proportion of the density (50% – 55%), besides Ophiuroidea (36% – 30%) (Table 7.1). The mean difference between these two sites is the fact that Caridea (*C. crangon*) dominated within the Arthropoda for station B04, whereas at site 7102 the density was more equally distributed between Anomura, Brachyura and Caridea. In autumn, the density was dominated at both sites by the Caridea (*C. crangon*). At reference station B07, the dominating species in density and biomass were *O. ophiura, M. balthica* and *A. rubens* in spring and *C. crangon, N. reticulatus* and *O. ophiura* in autumn.

In the cluster and correspondence analysis (Figure 7.22 to Figure 7.25) Br.&W. S2 and its reference sites clustered together in both seasons, except site B07, which showed in the cluster analysis more correspondence with the sites of the dumping area of Br.&W. Nieuwpoort and Br.&W. S1 (Figure 7.23).

Br.&W. S1

Br.&W. S1 was only sampled in spring and was characterised by a relatively high density (820 ind/1000 m^2) and biomass (1540 gWW/1000 m^2) (Figure 7.21). 74% of the density was taken up by Ophiuroidea (*O. ophiura* and *Ophiura albida*) (Table 7.1). In terms of biomass, *A. rubens* and *C. crangon* were also very important. The species richness at site S1 was relatively high (18 species).

At the reference sites for dumping site Br.&W. S1, the track in the vicinity of the dumping site (7802) showed extremely high density (9900 – 11800 ind/1000 m^2) and biomass (10400 – 11600 gWW/1000 m^2) values in both seasons, which was caused by very high densities of Ophiuroidea (93 – 85% of the total density) (*O. ophiura* and *O. albida*) (Figure 7.21 and Table 7.1). The high density and biomass in spring at reference site 350 was also caused by high densities of Ophiuroidea (*O. ophiura* and *O. albida*). The species richness and diversity at the reference sites were comparable with those values at the dumping site.

In the cluster and correspondence analysis (Figure 7.22 to Figure 7.25), the dumping site and its reference stations were clustering together in spring. In autumn no comparison could be made, due to the lack of samples at some sites. Some typical, but less frequent species, characterising this site were *Euspira pulchellus, Tellina fabula, Echinocardium cordatum, Macropodia rostrata* and *Spisula subtruncata*.

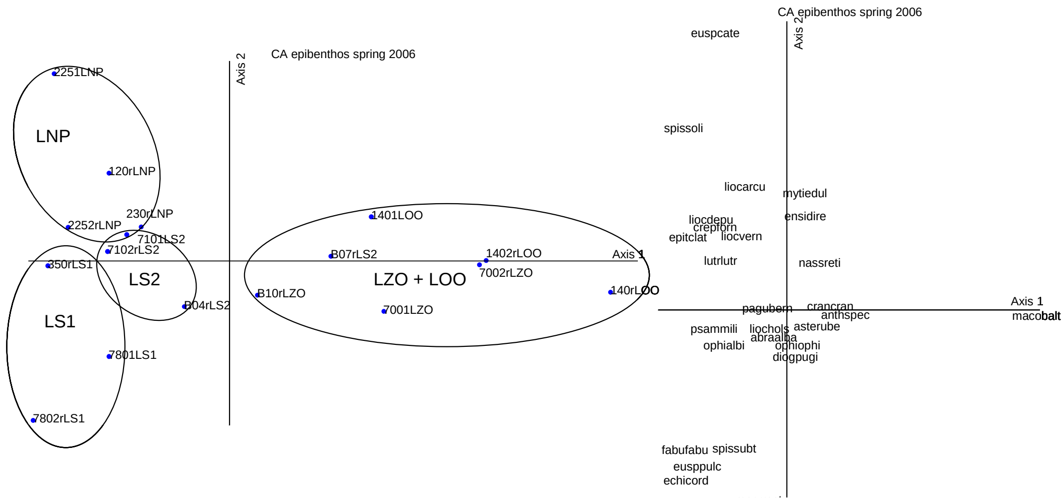


Figure 7.22 Correspondence analysis of the epibenthos samples of spring 2006

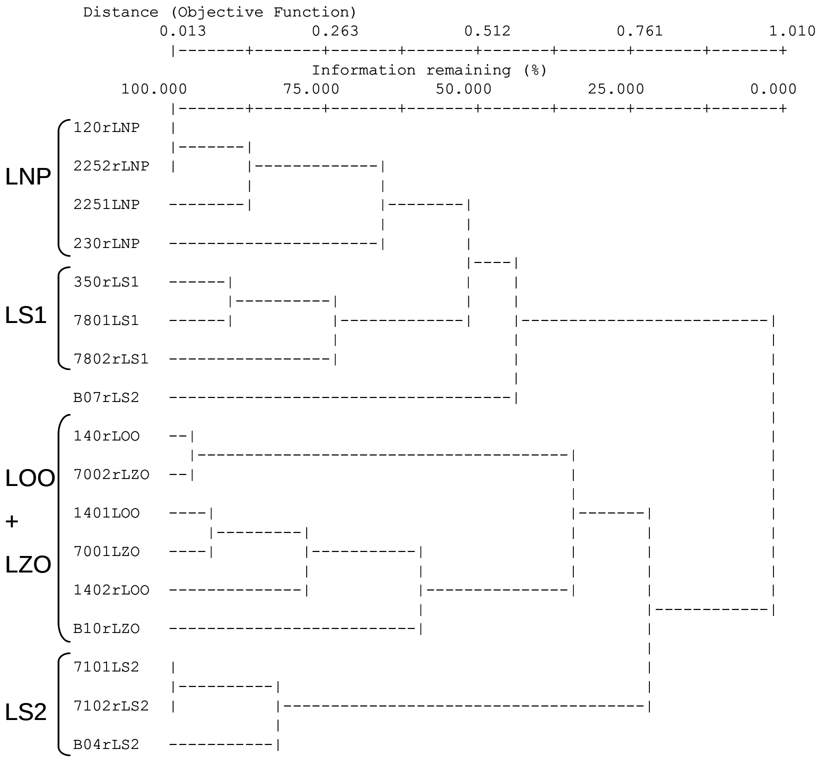


Figure 7.23 Cluster analysis (Bray Curtis similarity, Group average) of the epibenthos samples of spring 2006

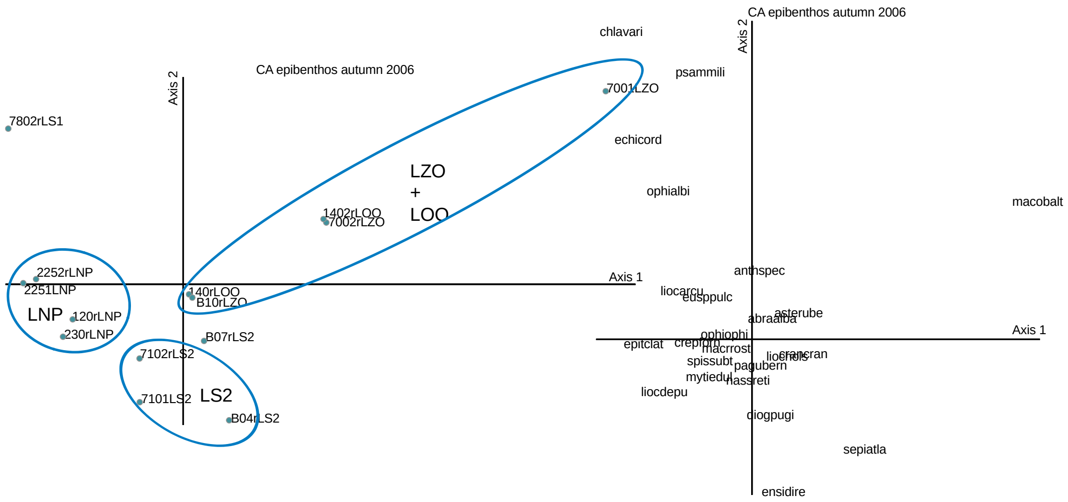


Figure 7.24 Correspondence analysis of the epibenthos samples of autumn 2006

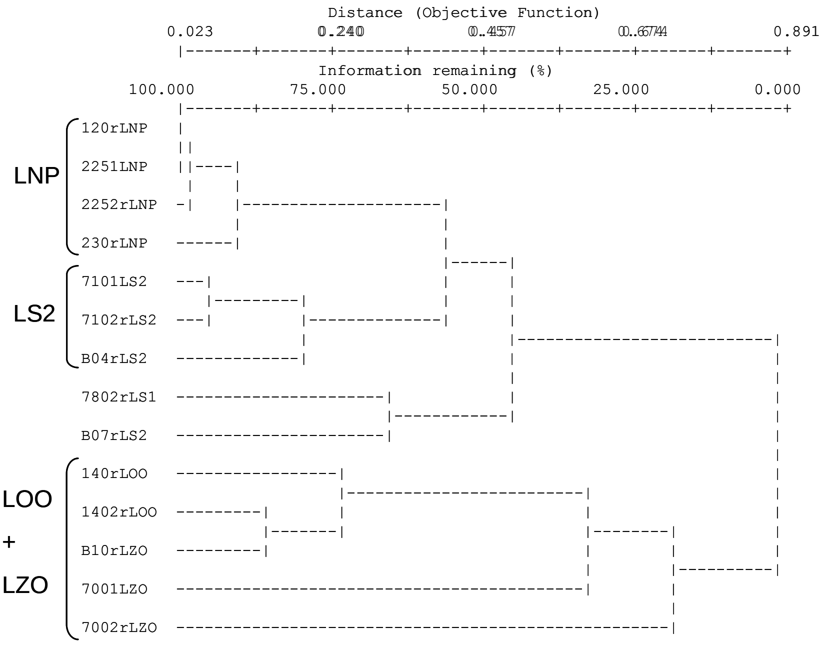


Figure 7.25 Cluster analysis (Bray Curtis similarity, Group average) of the epibenthos samples of autumn 2006

7.6.3.3 Comparison dumping sites – reference sites

The patterns in the epibenthos samples of 2006 were mainly linked to spatial differences on the Belgian Continental Shelf. Where the epibenthos at the dumping and reference sites of Oostende and Zeebrugge were characterised by low densities, biomass and species richness compared to higher values for the more offshore sites (Br.&W. S1and Br.&W. S2) and the site at Nieuwpoort. This is mainly related to the influence of the Western Scheldt on the north-eastern part of the Belgian coast, which is reflected in a higher turbidity of the water, higher concentration of mud particles in the water and sediment in this area.

Due to this large spatial variation between the dumping sites, the sampling strategy was changed in 2005. Before, each dumping site was separately examined by comparing each site with the reference sites that they are supposed to be best comparable to, based on the geographic location, depth and sediment composition.

By analysing the epibenthos results of spring and autumn 2006, no obvious differences between the dumping sites and their reference sites were found. The dumping site of Nieuwpoort was most comparable with its reference sites, which could be the result of the very low dumping intensity, compared to the other sites. The reference site B07 of dumping site Br.&W. S2 and reference site 7802 of dumping site Br.&W. S1 divided from this pattern in 2006.

There can be concluded that no obvious direct impact of dredging disposal is found on the epibenthos, which can be related to the fact that epibenthos is mobile and can recolonize the impacted area quickly from the surrounding areas.

7.6.3.4 Conclusions

- There was a strong dominance of the brittle stars (*Ophiura ophiura* and *O. albida*) in almost all samples in 2006.
- Compared to 2005, a lower species richness and diversity was noted in 2006.
- The different areas (Nieuwpoort, Br.&W. S1 and Br.&W. S2) clustered separately. The areas in and around Br.&W. Oostende and Br.&W. Zeebrugge Oost clustered together and showed a high similarity, indicating a dominance of spatial variation.
- No obvious difference in biological parameters (density, biomass, species richness and diversity) were found between impact sites and reference sites in spring and autumn 2006, except for some beam trawl samples (B07, 7802).
- In the multivariate analyses the dumping sites and their reference sites clustered almost together, which can be an indication of almost no impact of dredging disposal on the epibenthos in 2006.

7.6.4 Results demersal fish

7.6.4.1 Overall

A total of 43 fish species were found in the year 2006 (spring + autumn) in the dumping and reference sites. All the univariate parameters (density, biomass, species richness and diversity) showed high variations, spatially between the different sampling sites as well as temporally between spring and autumn. The species *Sprattus sprattus* and *Pomatoschistus* species were the most dominant fish species in the year 2006.

7.6.4.2 Results per dumping site

The variation in univariate parameters is visualised in Figure 7.26 and will be discussed per dumping site.

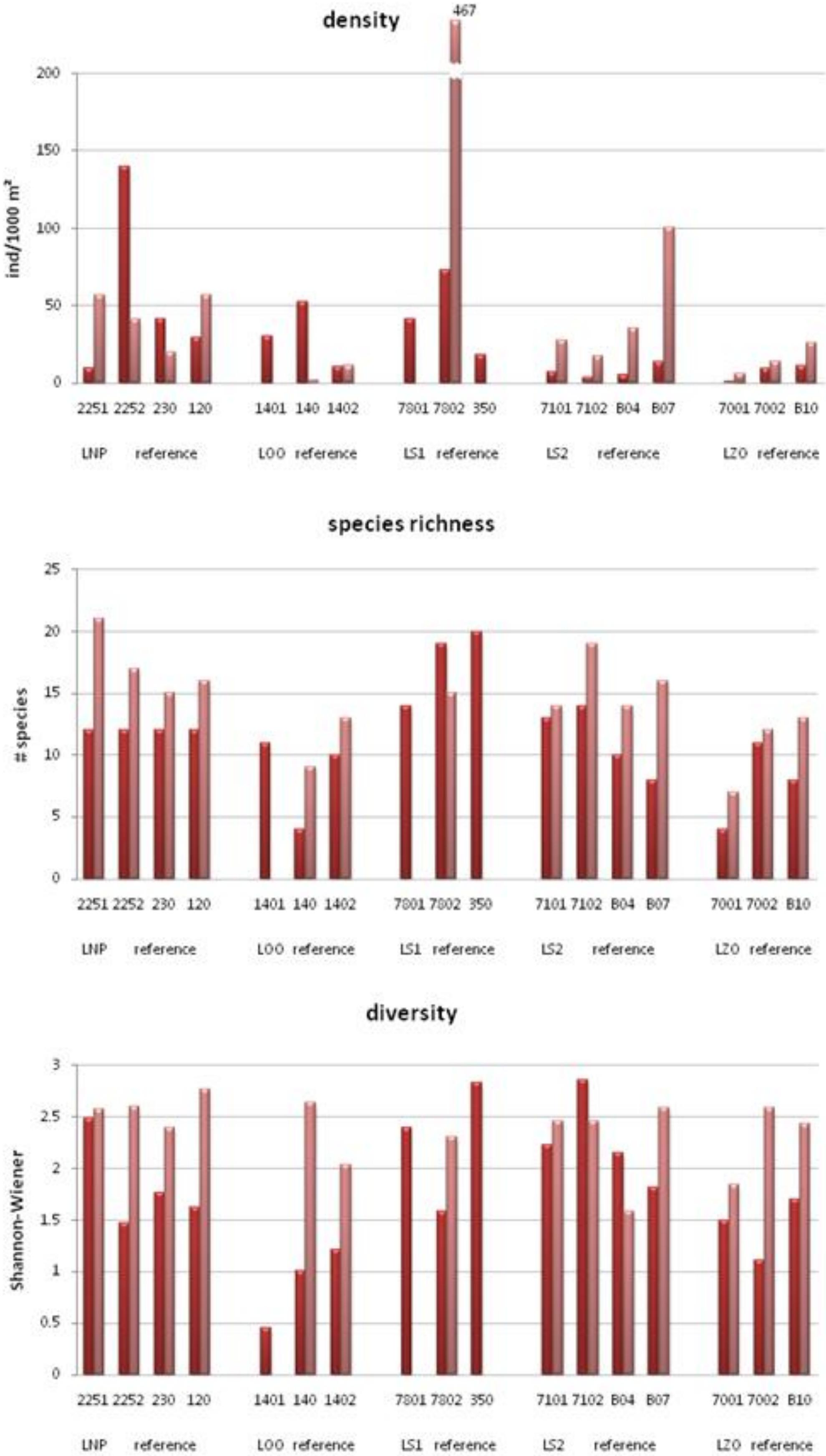


Figure 7.26 Average demersal fish density (ind/1000 m^2), species richness and Shannon-wiener diversity index of the dumping sites, neighbouring sites and some reference sites for spring (red boxes) and autumn (pink boxes) of the year 2006.

Table 7.2 Proportion of the different taxa in density (percentage) for all station in spring and autumn 2006.

season	station	area	Atheriniformes	Chondrichthyes	Clupeiformes	Gadiformes	Perciformes	Pleuronectiformes	Scorpaeniformes	Syngnathiformes
spring	2251	LNP	-	-	40	0.3	36	18	6	-
	2252	ref LNP	-	-	54	0.1	45	1	0.4	-
	230	ref LNP	-	-	33	-	63	4	1	-
	120	ref LNP	-	-	4	2	82	11	1	-
	1401	LOO	0.2	-	95	0.4	3	1	1	-
	1402	ref LOO	-	-	79	1	18	2	1	-
	140	ref LOO	-	-	62	-	38	0.3	-	0.3
	7801	LS1	-	-	30	0.3	25	28	16	-
	7802	ref LS1	-	-	11	0.3	12	74	3	-
	350	ref LS1	-	-	9	7	32	49	3	-
	7101	LS2	-	-	55	0.5	25	16	2	1
	7102	ref LS2	-	-	20	1	26	49	3	1
	B04	ref LS2	-	-	27	-	62	9	1	1
	B07	ref LS2	-	-	11	0.2	77	9	2	-
	7001	LZO	-	-	39	-	49	12	-	-
	7002	ref LZO	-	-	4	1	92	3	1	-
	B10	ref LZO	-	-	12	-	79	8	1	-
autumn	2251	LNP	-	-	0.2	10	37	15	38	-
	2252	ref LNP	-	-	1	4	69	21	5	-
	230	ref LNP	-	-	1	19	65	10	5	-
	120	ref LNP	-	0.1	0.2	41	37	16	5	-
	1401	LOO								
	140	ref LOO	-	-	2	20	51	27	-	-
	1402	ref LOO	-	-	3	4	52	36	5	1
	7801	LS1								
	7802	ref LS1	-	<0.1	6	4	24	29	37	-
	350	ref LS1								
	7101	LS2	-	-	7	3	38	51	2	-
	7102	ref LS2	-	-	58	5	22	10	5	-
	B04	ref LS2	-	-	1	4	90	3	1	-
	B07	ref LS2	-	-	0.3	15	53	28	4	-
	7001	LZO	-	-	52	8	30	9	2	-
	7002	ref LZO	-	-	8	47	36	6	4	-
	B10	ref LZO	-	-	0.1	14	55	31	1	-

Br.&W. Nieuwpoort

The demersal fish density at Br.&W. Nieuwpoort was low (10 ind/1000 m^2) in spring and much higher in autumn (55 ind/1000 m^2) (Figure 7.26). 40% of the density was taken up by Clupeiformes (mainly *Sprattus sprattus*) and 36% by Perciformes (mainly *Pomatoschistus minutus*) (Table 7.2). Pleuronectiformes represented 18% of the total density. The number of species was 12 in spring and 21 in autumn, the latter being the highest species richness value recorded in 2006.

The density in spring at the reference sites of Nieuwpoort was much higher, but lower or equal in autumn (Figure 7.26). The very high density at site 2252 in spring is due to high densities of *S. sprattus* (75 ind/1000 m^2) and *Pomatoschistus* species (65 ind/1000 m^2). The species richness was similar at the reference sites in spring and a little bit lower in autumn compared to the dumping site. The diversity (Shannon index) at the reference sites was low in spring, due to the dominance of *S. sprattus* and *Pomatoschistus* species.

It can be concluded that the area of Nieuwpoort is characterised as the most diverse and as the site with the highest densities of all sampling areas. In 2006, this area showed the highest densities of Pleuronectiformes. The correspondence analysis (Figure 7.27 and Figure 7.29) and the cluster analysis (Figure 7.28 and Figure 7.30) showed a clustering in spring of the reference sites of Nieuwpoort, together with Br.&W. S1 sites. Also in autumn these samples were clustering more or less together.

Br.&W. Oostende

This dumping site was only sampled in spring and was characterised by a density of 30 ind/1000 m^2 and a species richness of 11 species, but a very low diversity (Shannon of 0.5) (Figure 7.26). 95% of the density was taken up by Clupeiformes (*S. sprattus*).

The reference sites of the dumping site of Br.&W. Oostende showed a relatively high density, caused by high densities of *S. sprattus* (up to 79% of the total density). At the reference sites there was a switch of a dominance of Clupeiformes in spring to a dominance of Perciformes in autumn.

In the multivariate analysis (Figure 7.27 to Figure 7.30), the dumping site and its references were clustering more or less together and they showed no particular similarity with other sites.

Br.&W. Zeebrugge Oost

The dumping site of Br.&W. Zeebrugge Oost was characterised in both seasons by a low density (1 and 6 ind/1000 m^2) and a low species richness (4 and 7 species) (Figure 7.26). In spring, 38% and

49% of the density was taken up by respectively Clupeiformes and Perciformes (Table 7.2) and the same dominance pattern was detected in autumn. There were a few fish species present at this site.

The reference sites of Zeebrugge oost were characterised in both seasons by higher densities, species richness and diversity than the dumping site. In spring, the dominating species were Perciformes (79 and 92% of the total density), whereas in autumn also Gadiformes (in 7002) and Pleuronectiformes (in B10) were important.

In the cluster and the correspondence analysis, the track within the dumping site and the track in its vicinity did not cluster together, which is in contrast with the situation at the other sites.

Br.&W. S2

The dumping site Br.&W. S2 was characterised by a density of 7 ind/1000 m² in spring and 28 ind/1000 m² in autumn (Figure 7.26). In spring, 55% of the density was taken up by Clupeiformes, whereas in autumn the Pleuronectiformes dominated (51%) (Table 7.2). The species richness and diversity were high in both seasons, compared to other sites.

The density, species richness and diversity at the reference sites of Br.&W. S2 showed the same patterns, with a higher density and species richness in autumn compared to spring (Figure 7.26). The reference sites B07 and B04 were a little bit different in their species composition compared to the dumping site and the neighbouring site, which was also shown in the multivariate analysis (Figure 7.27 to Figure 7.30). In B07 and B04, the Perciformes (*Pomatoschistus*) dominated, whereas in 7101 and 7102, *S. sprattus* dominated. In the cluster and correspondence analysis, the sample in the dumping site and neighbouring site were clustering together.

Br.&W. S1

This dumping site was only sampled in spring and was characterised by a relatively high density (41 ind/1000 m²) and species richness (14 species) (Figure 7.26). There was no specific dominance of one taxon in spring (Table 7.2), but the Pleuronectiformes were rather abundant in this area.

In this area, only at site 7802 a sample was taken in autumn, characterized by very high densities (470 ind/1000 m²). Consequently no comparison between the seasons could be made for this area. In spring, reference site 7802 showed more similarity with the dumping site than station 350, which is characterised by low densities and a high diversity. Br.&W. S1 and its neighbouring site show a high similarity with the sites of Nieuwpoort, based on the multivariate analysis (Figures Figure 7.27 to Figure 7.30).

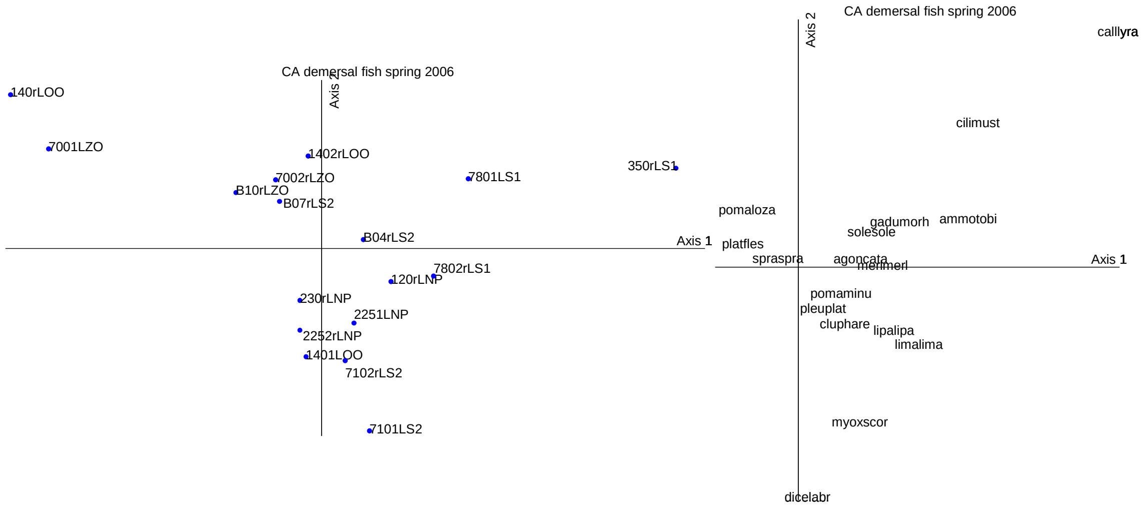


Figure 7.27 Correspondence analysis of the demersal fish samples of spring 2006

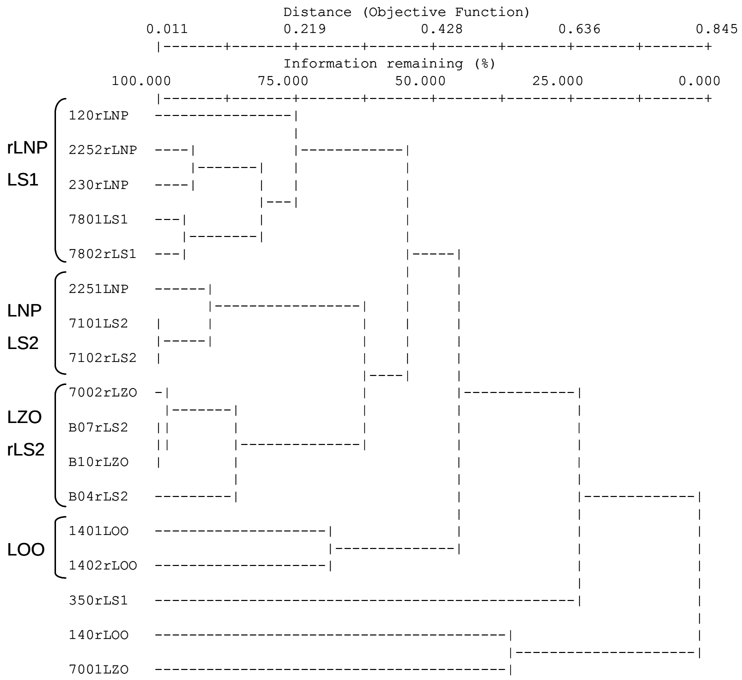


Figure 7.28 Cluster analysis (Bray Curtis similarity, Group average) demersal fish spring 2006

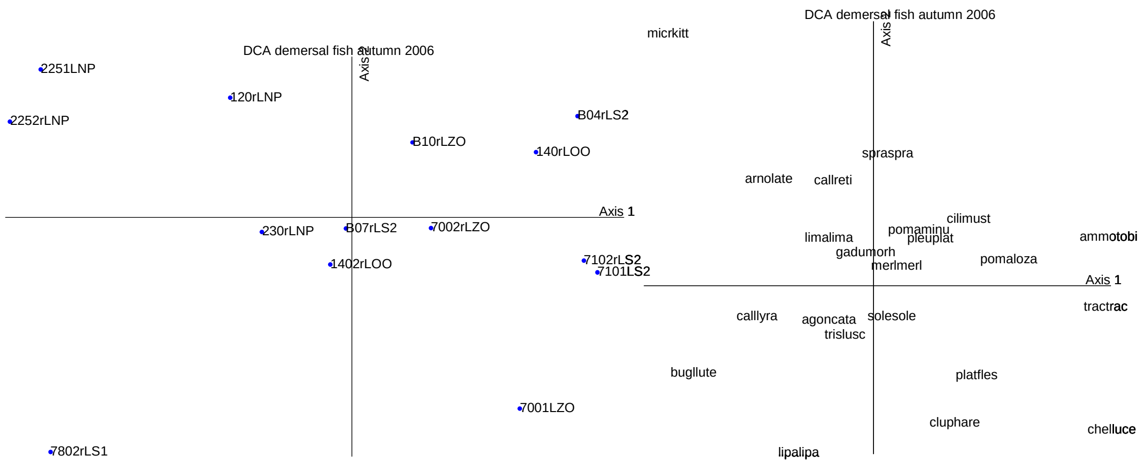


Figure 7.29 Correspondence analysis of the demersal fish samples of autumn 2006

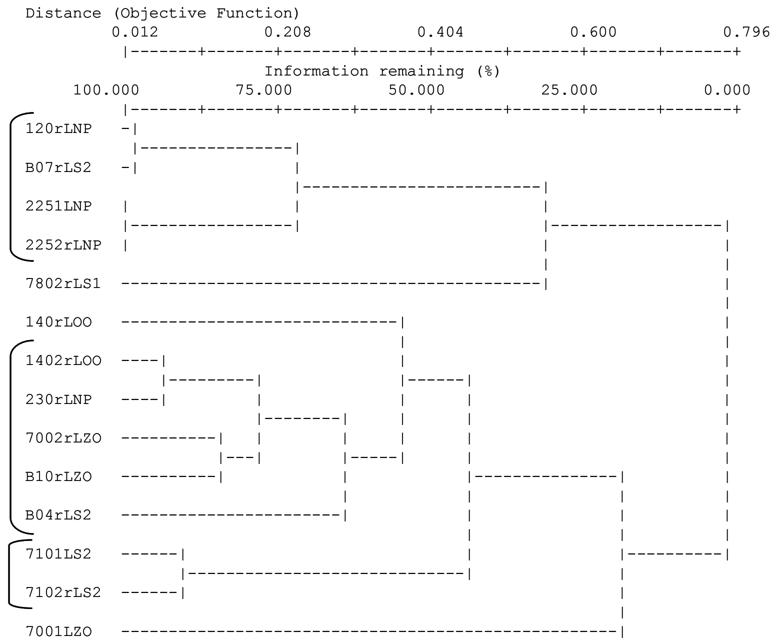


Figure 7.30 Cluster analysis (Bray Curtis similarity, Group average) demersal fish autumn 2006

7.6.4.3 Comparison dumping site – reference sites

The patterns in the demersal fish samples of 2006 were less linked to spatial differences on the Belgian Continental Shelf. The spatial pattern was not as obvious as for the epibenthos. The multivariate analysis of the demersal fish species shows mainly a clustering following the dominance of *Sprattus sprattus* and *Pomatoschistus* spp., which was not always regionally linked. This seems logical as fish species are less dependent on bottom type and are more mobile.

Based on the above described results, it was clear that for 2006 there were no obvious differences between most dumping sites and the corresponding reference sites for demersal fish. A high similarity between the beam trawl samples in the dumping site and in the vicinity of the site was found. Only for Br.&W. Zeebrugge Oost, a clear difference was found, with a lower density and species richness, but also a lack of clustering of the sites in the multivariate analysis. The Br.&W. Nieuwpoort and Br.&W. S2 showed most similarity which their reference sites, probably as a result of the low intensity or even absence of dumping in these areas.

There can be concluded that no obvious direct impact of dredging disposal is found on demersal fish. This can be related to the fact that demersal fish is very mobile and can recolonize the impacted area quickly from the surrounding areas. Only the low amount of fish species found at the dumping site of Br.&W. Zeebrugge Oost can be a result of the high dredge dumping and type of dredged material).

7.6.4.4 Conclusions

- The most abundant fish species were *Sprattus sprattus* and *Pomatoschistus* spp. both in spring and autumn 2006.
- In 2006 the density of the demersal fish was very low compared to 2005, especially for Pleuronectiformes.
- The multivariate analyses showed no clear clustering of the dumping sites with their respective reference samples. Instead, the clustering was mainly based on the similarity in the dominance of certain species.
- There is a high similarity between the beam trawl samples in the dumping site and in the vicinity of the site, except for Br.&W. Zeebrugge Oost, which may be related to high dredge dumping (and type of dredged material) at this site.

7.7 Fish diseases

7.7.1 Introduction

Disease studies of wild marine fish have a long tradition in many ICES Countries. They are often integrated with other types of biological and chemical investigations as part of national and international monitoring programmes aiming at an assessment of the marine environment and the pollution caused by human activities. Particularly in the beginning, controversies arose regarding the cause-effect relationships between contaminants and fish diseases and the usefulness of fish disease surveys as part of monitoring programmes of biological effects of contaminants. Today, it is generally accepted that studies of externally visible fish diseases may provide information on the occurrence of environmental stress and are therefore considered an important component of monitoring programmes. Especially ulcers, skeletal deformations, nodules and lymphocystis can provide valuable information on changes in environmental health and may act as an "alarm bell".

The aim of this epidemiological study is to monitor and compare the prevalence of diseases and parasites of demersal fish on dredge spoil disposal sites and some references zones on the Belgian Continental Shelf (BCS). Therefore, an important number of infectious and parasitical anomalies of the epidermis, the gills and the mouth of several fish species were recorded. Tumours were not identified as this needs specialised histo-pathological research. In this report, the observations for 2006 (spring and autumn) are described.

7.7.2 Sampling strategy

The sampling zones include in the first place the dredge spoil dumping sites: Br.&W. Nieuwpoort, Br.&W. Oostende, Br.&W. Zeebrugge, Br.&W. S1 and Br.&W. S2 and the three planned reference zones (Westdiep, Steendiep and Raan). In addition, the results of some extra zones, studied in the context of other monitoring programmes, were integrated in this study (Oostende bank, Oostdyck, Buitenratel, Kwintebank, Bligh bank, Scharrebank, some points in the open sea in the north of the BCS, Fairy bank, Hinderbanken and the Gootebank).

Dab (*Limanda limanda*) is an ideal organism for use in monitoring programmes of fish pathology because it is a demersal fish with a small mobility (Bucke *et al.*, 1996). The investigated organisms should both be abundant and exhibit diseases which are easily recognized. In zones were dab has a limited abundance, other flatfish species, preferably flounder, can be used. Roundfish species can be chosen as additional organisms for disease monitoring. In the examined zones, dab was not always sufficiently present. Therefore, the monitoring was extended to most of the commercial flatfish species: plaice (*Pleuronectes platessa*), flounder (*Platichthys flesus*) and Dover sole (*Solea solea*) and round fish: whiting (*Merlangius merlangus*), pouting (*Trisopterus luscus*) and cod (*Gadus morhua*).

When the catch volumes do not meet the minimal requirements for monitoring, the results of similar zones were assembled.

- Reference zone 1 includes the eastern coastal zone of the BCS (Steendiep, Vlakte van de Raan, Gootebank).
- Reference zone 2 includes the coastal zones in the west of the BCS (Westdiep, Oostende bank, Oostdyck, Buitenratel en Kwintebank).
- The third reference zone includes the more northern zones Scharrebank, Bligh bank, Fairybank, the Hinderbanken and the open sea points.

The coordinates of these sampling points are available in Hostens *et al.* (2006). In some zones, the sampling size of certain fish species was too small to be reliable. These results are not taken up in this review.

7.7.3 Results and discussion

Infections, nodules and deformations

Pathologically important diseases of the skin (fins and eyes included), the gills and liver were not or rarely observed on the BCS.

Acute, healing and healed ulcerations were found on dab, flounder and whiting in very low frequencies (between 0.26% and 4.17 %). Flounder showed the highest prevalence: 4 % in zone 2 in spring and 4.17 % in zone 1 in autumn. On the dredge dumping sites a prevalence of 2.1% could be detected on dab in the autumn of 2006. Furthermore, dab showed prevalence varying between 0.39 % and 2.44 % in two reference zones: zone 2 and zone 3 in spring and autumn. Ulcers on whiting were only present in spring in zone 3 (0.26 %).

Epidermal papilloma could only be detected in dab and were all stage 1 lesions (less than 4 lesions per individual). Important skin papillomas were never observed on the BCS. The cause of papilloma on the skin of marine fish is unknown, but a viral aetiology is assumed. In spring 2006, epidermal papillomas were observed on the dredge dumping sites (1.56 %), in reference zone 1 (0.82 %) and in reference zone 3 (0.39 %). In autumn, only zone 1 showed a prevalence of 1.61 %.

Liver nodules were detected in all the sampling zones and on all examined fish species, except on sole. The frequency was very low and varied between 0.77 % and 3.45 %. No significant difference could be detected between the dredge deposit zones and the reference zones.

Lymphocystis is an important disease and has a viral aetiology (Iridovirus). The nodules are the result of hypertrophy of connective tissue cells. The prevalence of lymphocystis on the BCS was very low in recent years, compared to other areas of the North Sea (Mellergaard *et al*, 1997). The disease was detected in spring on the dredge dumping sites on flounder (3.33 %) and dab (1.56 %) and in zone 3 on flounder (0.39 %). It was not detected in autumn 2006.

Skeletal deformations were registered on dab, cod and whiting. In spring, no deformations were noted on the dredge deposit zones, but in zones 1 and 3, prevalence between 0.20 % and 0.41 % was observed. In autumn, a prevalence of 1.05 % and 0.26 % was found on respectively dab and whiting on the dredge deposit sites. In zone 1, dab had a prevalence of 1.61 %.

The presence of pigmentation (hyper-melanisation) fluctuates greatly in time and space. Pigmentation was observed in all flatfish species and in all monitored zones. The highest prevalence was found on dab (12.92 %) and on plaice (11.28 %) in spring in reference zone 3. The dredge deposit zones showed very low prevalence (between 1.56 % en 1.96 %).

Figure 7.31 On the left hyper-melanisation and on the right epidermal papilloma, both on Dab (*Limanda limanda*)

Parasites

Most of the parasitical infections are relatively innocent when they are present in low numbers. The results show that the infection rates can vary considerably in space and time.

The trematode, *Stephanostomum baccatum*, was found in all zones and especially in dab. The individual infection rate was low (1 to 2 parasites per fish). The prevalence was higher in spring (between 3.92 % and 12.19 %) than in autumn (between 0.45 % and 1.61 %).

The skin parasite *Cryptocotyle lingua* (trematode) is present in very variable concentrations on round fish and especially on whiting. The highest concentrations for whiting were found on the dredge deposit sites: 14.25 % in spring and 11.37 % in autumn and in reference zone 1: 13.64 % in spring and 8.31 % in autumn. In the other zones the concentration varied between 1.58 and 6.6 %.

Externally attached copepods, such as *Clavella* on round fish and *Acanthochondria* spp. and *Lepeophteirus* spp. on flatfish are considered harmless. Especially flounder (*Platichthys flesus*) is host to these crustaceans. *Acanthochondria* was registered in high frequencies (between 20 and 47 %) on flounder in all the sampled zones. Dab showed a much lower prevalence (between 0.47 and 2.44 %).

The same is valid for *Lepeophteirus, present* between 20 % and 70.83 % on flounder and between 0.89 % and 1.56 % on dab. *Clavella* was only observed in whiting on the three reference zones. Much higher prevalence was observed in spring (17.41 – 27.27 %) than in autumn (1.73 – 5.78 %). *Clavella* was not observed on the dredge deposit sites in 2006.

The parasite of the intestines*, Glugea stephani*, was only present on dab. The highest prevalence was observed in reference zone 2 (17.07 %) in spring and in reference zone 1 in autumn (8.06 %). The dredge deposit zones had a prevalence of 15.62 % in spring and 4.21 % in autumn.

Figure 7.32 On the left *Lernaeocera branchialis* on Whiting (*Merlangius merlangus*) and on the right *Acanthochondria cornuta* on Flounder (*Platichthys flesus*)

The parasitic copepod, *Lernaeocera branchialis* was noted on the three observed round fish species whiting, cod and pouting. The occurrence varied according to species, sampling place and period. Mostly, one or two individual were present per fish and usually, they disappear without leaving any lesion. The prevalence varied between 0.24 % and 6.86 %, except for pouting where a prevalence of 31.91 % was noted on the dredge deposit zones and of 34.65 % in reference zone 1 in autumn.

7.7.4 Conclusion

Severe diseases such as skin ulcers, nodules, skeletal malformations and lymphocystis, which can indicate effects of pollution, are rare on the investigated zones of the BCS. No significant differences could be detected on the basis of the data between the dredge dumping sites and the reference zones.

Most of the observed anomalies were due to parasites. The presence of these parasites show considerable variation in spatial and temporal distribution, and could not be related to a specific zone.

Finally, it is important to remind the effect of migration on the observed species. On the basis of the migratory properties, flat fish species were chosen as monitoring organisms. The results can, especially for round fish species, be influenced by migration. Therefore, the results rather reflect the health condition of a big area instead of smaller zones like the dredge deposit zones. Nevertheless, some important regional differences in parasitical affection could be observed.

7.8 Biological effects of environmental pollutants on fish populations

7.8.1 Introduction

Studying the possible harmful effects of pollutants present in the marine environment on inhabitant biota is essential in environmental monitoring. In this part, the relationship between the dumping of sludge as a possible source of pollutants and the biological effect on local fish populations is investigated.

The research tools to investigate a possible relationship are, amongst others, the prevalence of fish pathologies and diseases, and the use of biochemical indicators as early warning systems for pollution. Twice a year, in spring and autumn, these parameters are assayed by the Institute for Agricultural and Fisheries Research on the BCS. The results are presented separately and correlated with the concentrations of organic contaminants and heavy metals in biota, sediment and water. Normalisation is done by comparing the results between the sludge dumping zones and reference zones and by taking into account the seasonal variation and the fysico-chemical properties of the water such as temperature and salinity.

7.8.2 Biochemical Indicators of pollution

7.8.2.1 General

The studied biochemical indicators are part of the phase I and phase II detoxification system of biota and are involved in the metabolization of xenobiotics. To assay the activity of the phase I detoxification system, the enzymatic activity of the CYP1A1 protein is measured. The CYP1A1 protein is part of the cytochrome P450 protein family and is induced by low amounts of organic contaminants such as polycyclic aromatic hydrocarbons (PAH's), polychlorinatedbifenyls (PCB's), dibenzodioxins (PCDD's) and dibenzofuranes (PCDF's) that bind to the arylreceptor (ArH). Practically, the CYP1A1 protein is assayed through the EROD (ethoxy-resorufine-O-deethylase) activity: the conversion rate of ethoxyresorufine to resorufin is quantified using spectrofluorimetry. The phase II detoxification activity is assayed through the glutathione-sulfhydryl-transferase (GSH-t) activity which catalyses the addition of glutathione-sulfhydryl to chlorodinitrobenzene (CDNB) as a substrate. The phase II detoxification system renders the apolar organic molecules more water soluble.

EROD is one of the obligatory indicators of pollution under the *Joint Assessment and Monitoring Program (JAMP)* by OSPAR.

All measurements are performed on fresh liver homogenate of individuals of Limanda *limanda* (Dab) smaller then 10cm. The individuals are caught during sampling campaigns with RV Belgica. (See sampling strategy for epibenthos and demersal fish). The activities are normalised to the total protein content. The total protein content is assayed using the BCA test kit (Bichoninnic acid; Pierce) and are converted to BSA equivalents (Bovine serum albumin). *[Roose and Cooreman, in prep.]*

A seasonal model, based on the results from measurements of EROD and GSH-t, correlated to the concentrations of PCB's and PAH's in the liver of dab, has been constructed. For EROD the model shows a strong seasonal variation with a peak in late winter – early spring and low values in autumn. This peak is inversely correlated with the concentration of PCB's in liver fat. The PCB's are set free in the organism when the fat reserves are consumed as the temperature of the water is dropping and food is scarce. For GSH-t, the seasonal activity is moderate, and used to normalise the EROD activity. As a conclusion the model shows that EROD is more induced by PCB's, while GSH-t is more susceptible for higher PAH concentrations.

A baseline for the BCS has been constructed based on results of EROD and GSH-t measurements since 1992.

7.8.2.2 Sampling Strategy

In spring 2006, EROD and GSH-t measurements for samples from dumping sites S1 (Br.&W. S1 – Zeebrugge 7801-7802) and NP (Br.&W. Nieuwpoort – Nieuwpoort 2251-2252) were compared to sample measurements from reference zones 120 [Westdiep], 315, 330 [Gootebank], 340 [Gootebank], 350 [] and 421 [Westhinder]. For dumping sites Br.&W. Zeebrugge Oost (Zeebrugge East 7001-7002), Br.&W. S2 (Zeebrugge 7101-7102) and Br.&W. Oostende (Oostende east) and other reference zones, no dab's smaller <10cm were caught. On every sampling point, a number of 20 dab's should be used.

Due to an breakdown of the spectrofluorimeter, there were no measurements for autumn 2006, spring 2007 and autumn 2007. For autumn 2006, due to a limited campaign time caused by engine troubles on board the RV Belgica, no samples were taken. For spring and autumn 2007, dab samples for the dumping and reference sites were taken where possible and the livers were cut out and stored in liquid nitrogen for later processing. An evaluation will be undertaken to point out if these results are equivalent.

7.8.2.3 Results

The results for spring 2006 show comparable values to measurements in spring former years. Due to the low amounts of dab <10cm caught, there is little statistical significance, and no difference between the dumping zones and the reference zones could be found. For spring 2008, a new spectrofluorimeter will be available so that the samples for 2007 can be processed.

In 2006, livers of mature dab were sampled on different sites during different periods of the year to determine seasonal dioxin variation. The analysis' was finished early in 2008, and the results will be used to improve the model for EROD and GSH-t interaction with organic contaminants. The results will be discussed in the WIKIMON workshop at ICES *(Feb. 2008, K. Cooreman)*

7.8.2.4 Conclusions

The results from the past years clearly show a seasonal variation for EROD and a correlation between EROD activities and PCB concentration in liver and temperature of the seawater. The results of spring 2006 are within the expected range. This allows for EROD and GSH-t to be used as a monitoring tool for pollution. However, a statistical significant difference between reference zones, heavy traffic zones and dumping zones has never been reported. This is partially due to the broad migration patterns of fish and the rapid spreading of sludge after dumping which causes limitations to the use of the technique for spatial resolution.

7.8.2.5 Recommendations

In January 2008, the ILVO-fisheries registered for an inter-calibration test for EROD and total protein measurement within the BEQUALM (Biological Effects Quality Assurance in Monitoring Programs) network. This is necessary to be able to continue to report the gathered data from the past years to ICES. Results will be available by the end of 2008.

For future measurement, and to be able to establish a relationship between dumping sludge and biological effects of organic contaminants, the sampling should be extended to a new model including resident species as molluscs, crustaceans and invertebrates that will allow a higher spatial resolution. However, this requires new measurement protocols and baseline studies. An extension to the sampling protocol would be practical to counteract the effects of climate change, which can lead to a transition of fish populations and lower catches.

It would also be very interesting to extend the number of bio-indicators measured. Studying indicators such *cellular energy allocation* or the formation of DNA-adducts, could give us more insight in the general stress levels of the marine inhabitants and the relationship with dumping sludge.

To start studying the genomic diversity of the inhabitant biota and the effect of dumping sludge on the genomic composition would be a great extension to the research. This would, however, require extra funding.

7.9 Chemical contaminants in sediment

7.9.1 Organic contaminants in sediment

Several organic contaminants are studied in sediment samples from the Belgian Continental Shelf. All analysis was carried out on the fine fraction (<63 µm). Results are expressed as µg/kg dry weight (DW). PCBs and organochlorine pesticides are traditional; the aim is to follow the effects of the ban of most of these substances, together with the effects of dredge dumping. These compounds were analysed by ILVO-Fisheries in Oostende.

Polybrominated biphenylethers (PBDE's) are new in this report, brominated flame retardants being one of the emerging chemicals, with values that claim attention. Organotin compounds are a matter of serious concern, because the BCS is the world's most intense shipping routes, several small ports are present, as well as the port of Antwerp. Both these compounds were analysed by MUMM in Oostende. The high cost of the analysis make that they are analysed for a limited number of sampling stations only.

7.9.1.1 PCBs in sediment

PCBs in sediments have been analysed on the BCS for more than 25 years. Due to the new sampling strategy, with a more intense sampling grid close to dredge dumping sites, the comparability with the old data set is somewhat more difficult, and out of scope of this report.

The PCB congeners analysed are the seven marker PCBs, plus three extra ones, and have IUPAC numbers 28, 31, 52, 101, 105, 118, 138, 153, 156 & 180. All results are expressed are in µg/kgDW

Figure 7.33 describes the situation at dumping site Br.&W. S1. All values are <20 µg/kgDW The main remark is that the fluctuations in the different stations per season and per year are more important than the differences between the stations. Reference statins 330 and 340 show considerably lower values than the dumping site, but in station 780, a very similar pattern to the dumping site is observed.

Values in the center (LS1-01) or the most intense dumping area (LS1-02/LS1-06) show lower values compared to the less intense dumping areas (LS1-07/LS1-11), the highest values on average found in the near reference (LS1-12/LS1-17). Most values are <10 µg/kgDW, so the observations from the previous report are not reproduced, on the contrary.

Values are well in line with previous observations, showing a slow decline of the values for PCBs on the BCS. No specific congeners show extreme values, high values are caused by comparabel contributions from the individual congeners, confirming the analytical accuracy shown in Quasimeme intercomparison exercises.

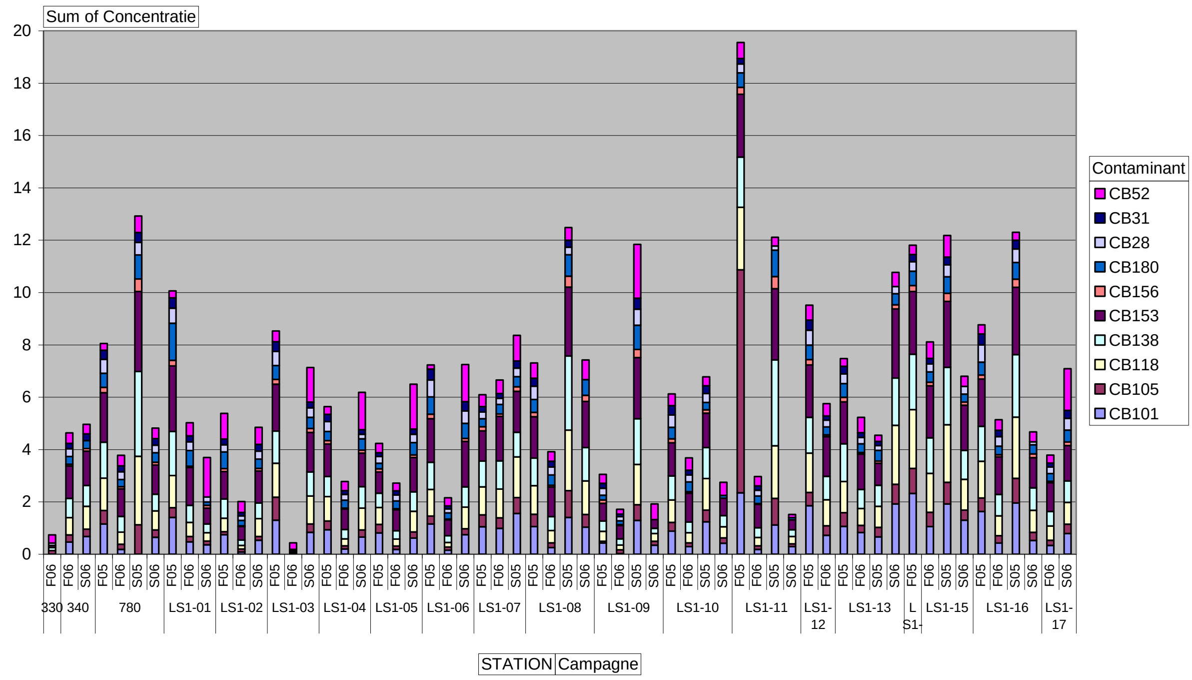


Figure 7.33 PCB concentrations in the period 2005-2006 for sediments (<63µm) from dumping site Br.&W. S1 and reference stations nearby (values in µg/kgDW)

Figure 7.34 shows values for Br.&W. S2 and Br.&W. Zeebrugge Oost, together with some reference stations nearby, and in the mouth of the Scheldt. High values, up to 27 µg/kgDW, are found in the mouth of the Scheldt. In spring 2006, in one station on Br.&W. S2, 15 µg/kgDW was noted, all other values were <10 µg/kgDW In Br.&W. Zeebrugge Oost, no spectacular values were observed, though a lot of stations were sampled on different campaigns. The higher values were for the reference stations and the stations in the mouth of the Scheldt. A considerable amount of the values measured are <5 µg/kgDW

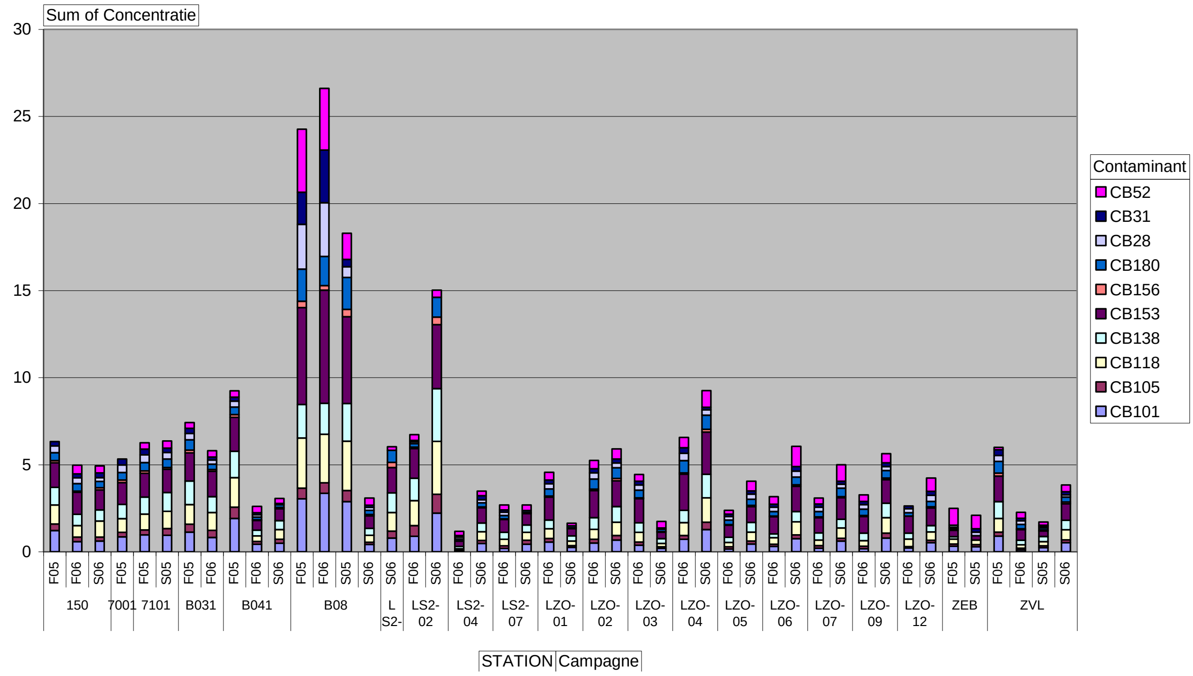


Figure 7.34 PCB concentrations in the period 2005-2006 for sediments (<63μm) from dumping site Br.&W. S2 and Br.&W. Zeebrugge Oost and reference stations nearby (values in μg/kgDW)

Figure 7.35 describes the situation near Br.&W. Oostende and Br.&W. Nieuwpoort. Values close to Oostende are much more variabel compared to Nieuwpoort, but on average lower. Reference stations seem the most stable, indicating that the intense dumping induces more variations in the environmental quality. All values are <10 μg/kgDW

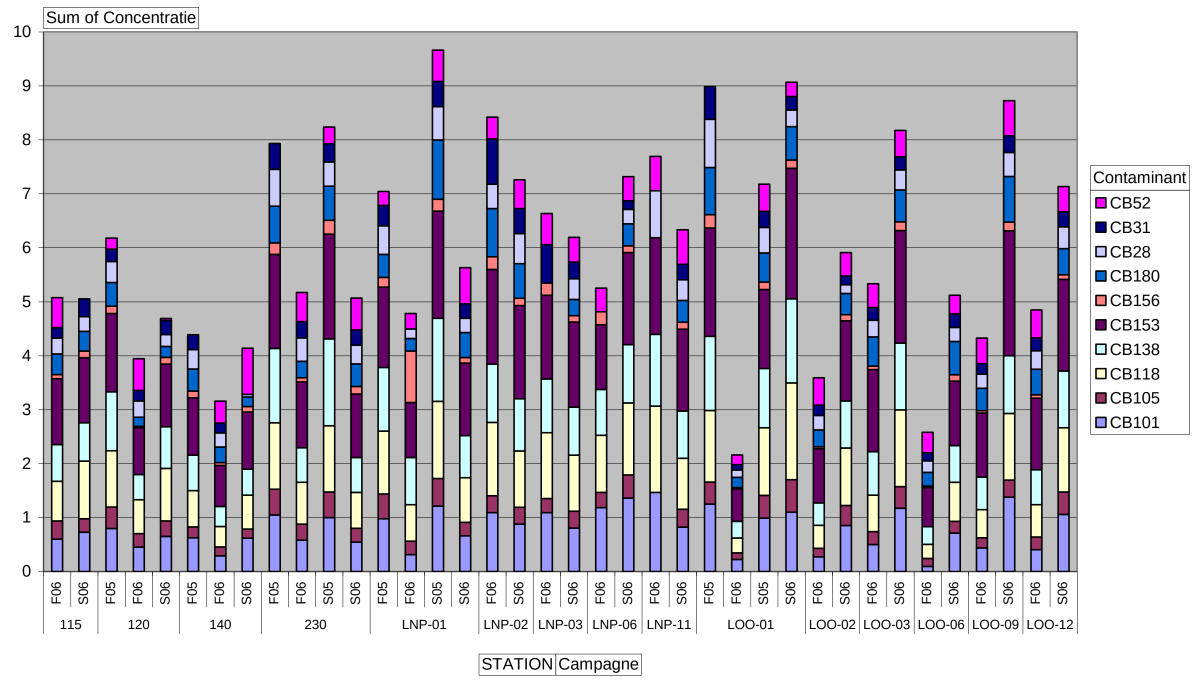


Figure 7.35 PCB concentrations in the period 2005-2006 for sediments (<63μm) from dumping site Br.&W. Nieuwpoort and Br.&W. Oostende and reference stations nearby (values in μg/kgDW)

Finally, Figure 7.36 shows a number of stations quite distant from dredge dumping sites, and even far offshore (up to 75 km out of the coast). Although most values are <10 μg/kgDW, some exceptions reach between 15-20 μg/kgDW The highest values are noted at sampling station 421 and 800, offshore, in clear water with sandy sediments. As these values are higher than most of the dredge dumping sites, the impact of dumping on the chemical quality of the sediments is limited.

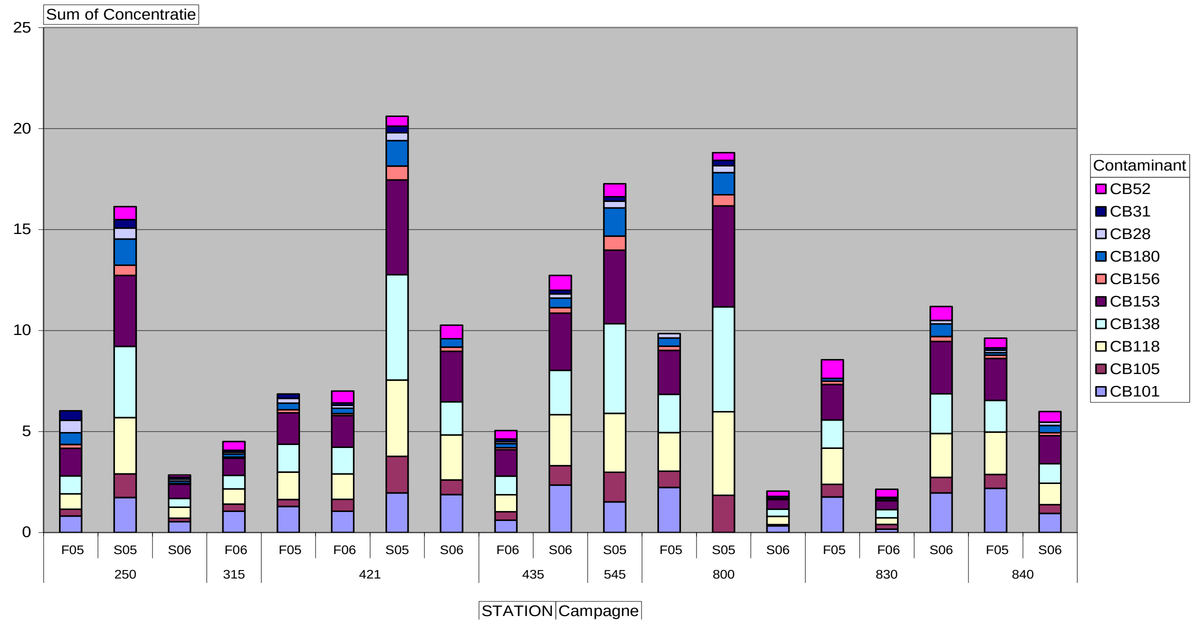


Figure 7.36 PCB concentrations in the period 2005-2006 for sediments (<63μm) from reference stations distant from dredge dumping sites (values in μg/kgDW)

7.9.1.2 OCPs in sediment

For chorinated pesticides, the compounds investigated are DDT and breakdown products TDE and DDE, alpha and gamma hexachlorocyclohexane (α-HCH and lindane), hexachlorobenzene (HCB), dieldrin, endrin and transnonachlor. All results are from the BCS, date from the period 2005-2006, and are expressed in μg/kgDW

Results for dumping site Br.&W. S1 are presented in Figure 7.37 Most of the values are <1.5 μg/kgDW for the sum of all pesticides. One exception mounts up to more than 28 μg/kgDW, but on average concentrations are low and fairly constant.

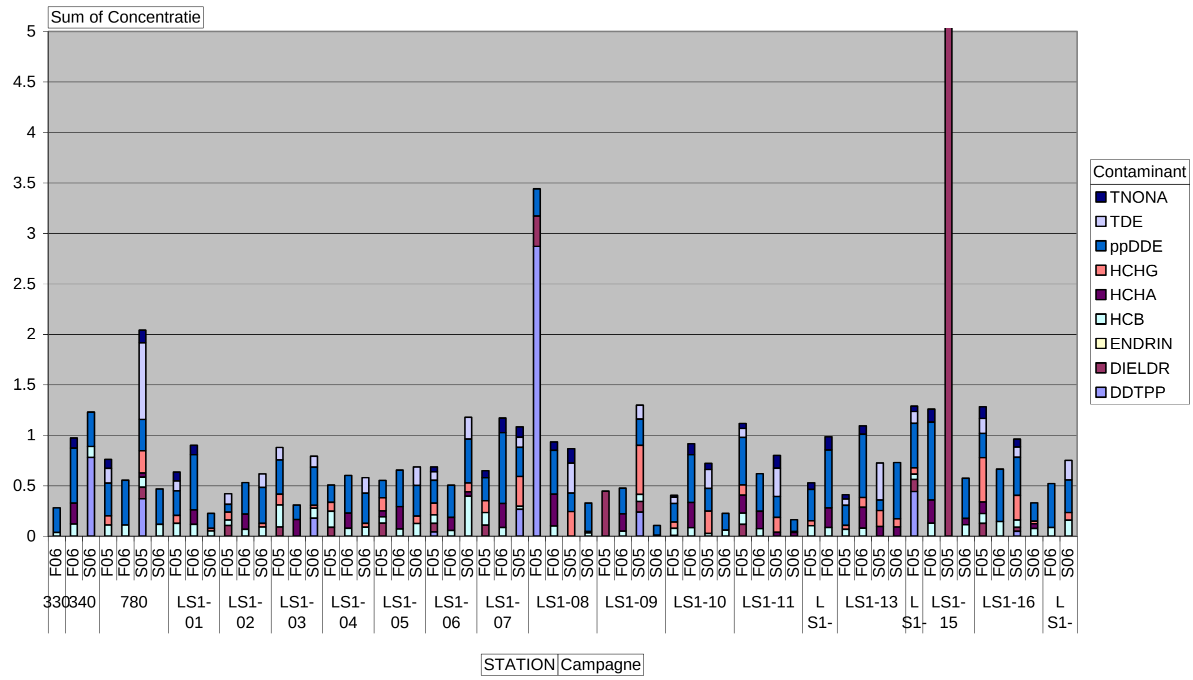


Figure 7.37 Organochlorine pesticide concentrations in the period 2005-2006 for sediments (<63μm) from dumping site Br.&W. S1 and reference stations nearby (values in μg/kgDW)

Near dumping site Br.&W. S2 and Br.&W. Zeebrugge Oost, values are even lower, <1 μg/kgDW, the exceptions are the reference stations, especially the B points located near the mouth of the

Scheldt. This might indicate that the riverine input is the major source for these compounds, as suggested both by their use in agriculture, as major input estimations. Compounds of the DDT family and HCB constitute the major part of the measured products.

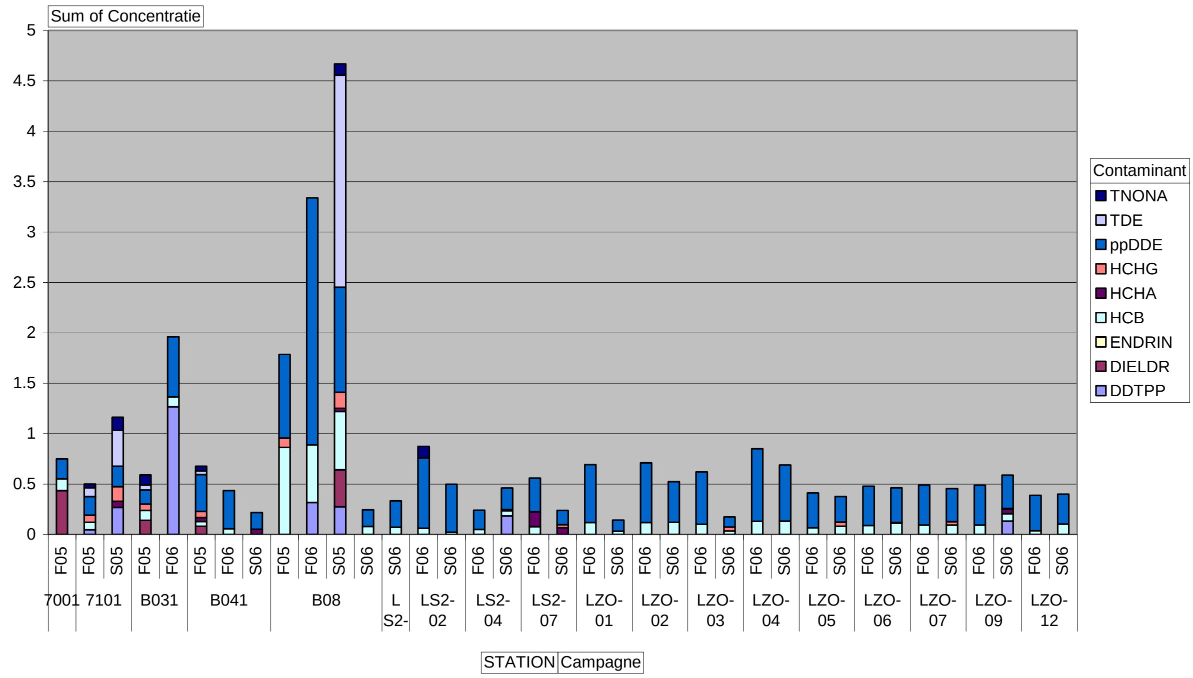


Figure 7.38 Organochlorine pesticide concentrations in the period 2005-2006 for sediments (<63μm) from dumping site Br.&W. S2 and Br.&W. Zeebrugge Oost and reference stations nearby (values in μg/kgDW)

Values in Br.&W. Nieuwpoort and Br.&W. Oostende are slightly higher, but all <2 μg/kgDW the highest value were for station 230, very comparable to the dumping site LNP-01. All values in Oostende were <1 μg/kgDW, and the DDT products constituted the bulk of the pesticides. DDT itself is only found in a limited number of stations, suggesting its slow but sure breakdown.

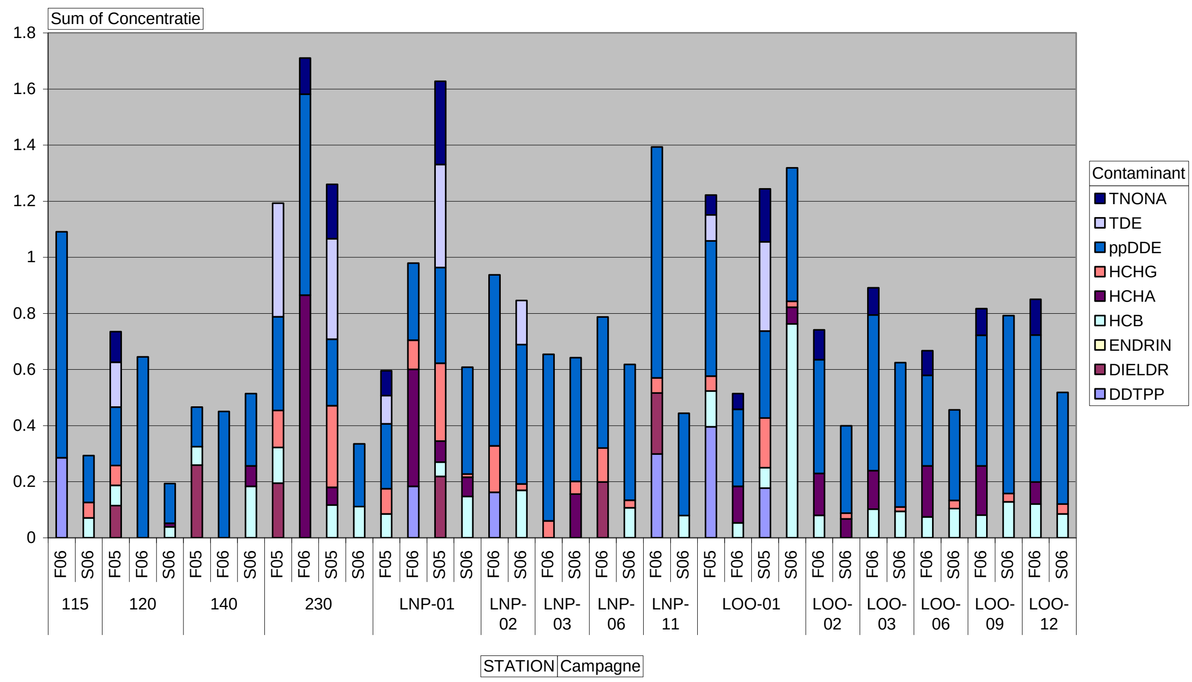


Figure 7.39 Organochlorine pesticide concentrations in the period 2005-2006 for sediments (<63μm) from dumping site Br.&W. S2 and Br.&W. Zeebrugge Oost and reference stations nearby (values in μg/kgDW).

In reference stations, remote from the dumping sites, the coast and river mouths (Figure 7.40) are mostly low, but one station revealed a very high 28 µg/kgDW, and 3 µg/kgDW was found at station 800. In view of the remote location of these station, the observed values are considered high.

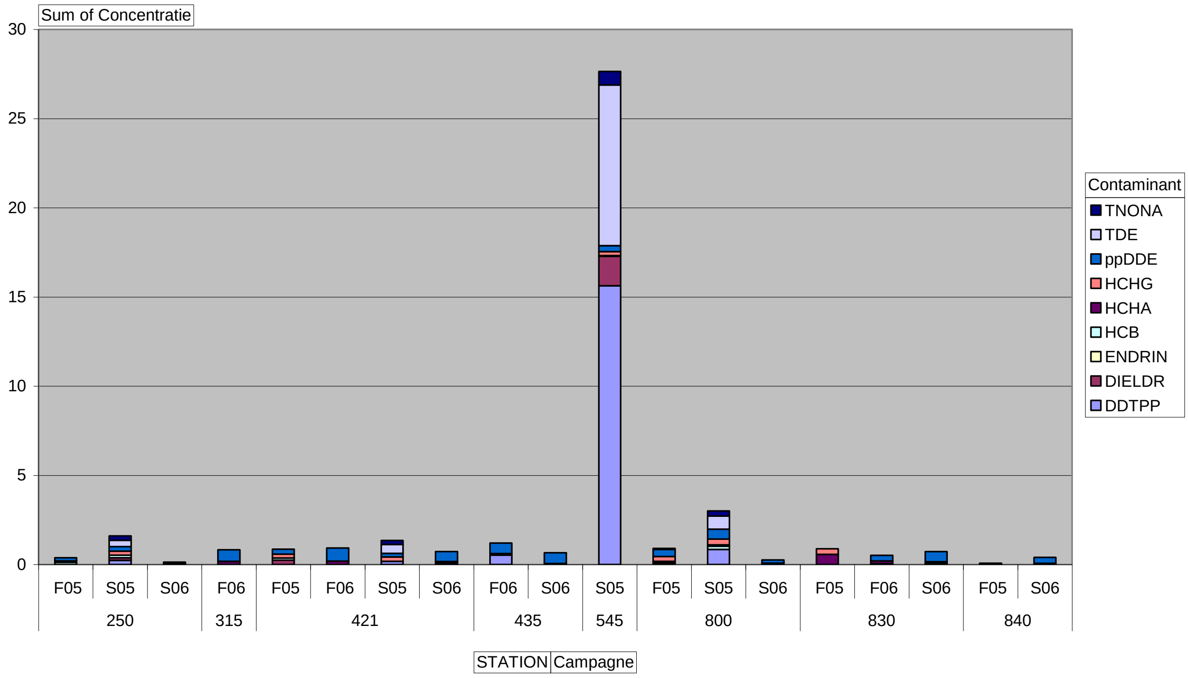


Figure 7.40 Organochlorine pesticide concentrations in the period 2005-2006 for sediments (<63µm) from reference stations remote from dumping sites and coastal influences (values in µg/kgDW).

7.9.1.3 PBDEs in sediment

Brominated flame retardants have a widespread use. Their environmental risk is not negligible, since they are estimated to be more toxic than PCBs. The levels observed in the environment are considerably lower, but are detectable in the majority of sampling stations (Figure 4.38). The congeners analysed have IUPAC numbers 28, 47, 66, 71, 75, 79, 85, 99, 100, 119, 138, 153, 154, 183, 190 & 209. All values originate from 2005, are in µg/kgDW, and for congener 66, 71, 75, 79, 85, 100, 119, 138, 153, 154 & 190 they are all below limit of detection, other values are very close. The only exception is congener 209, on a limited of sampling stations present, and only in spring, in important concentrations. They can be up to 70 (230) and 50 (250) µg/kgDW, all measured in reference stations. The highest values on dredge dumping sites are 11 (1401) and 6 (2251) µg/kgDW The mean portion of the other values are <2.5 µg/kgDW, as are all values in autumn 2005.

These data allow only limited conclusions, but the problem is serious enough for further investigation. More analysis, over a longer period of time, will show more clearly if there is a problem for the environment, and where it might originate from.

The values show little difference between the mouth of the Scheldt and more distant stations as 421 and 545. The problems is obviously not only the flux of substances coming out of the Scheldt, other sources have to be considered as well.

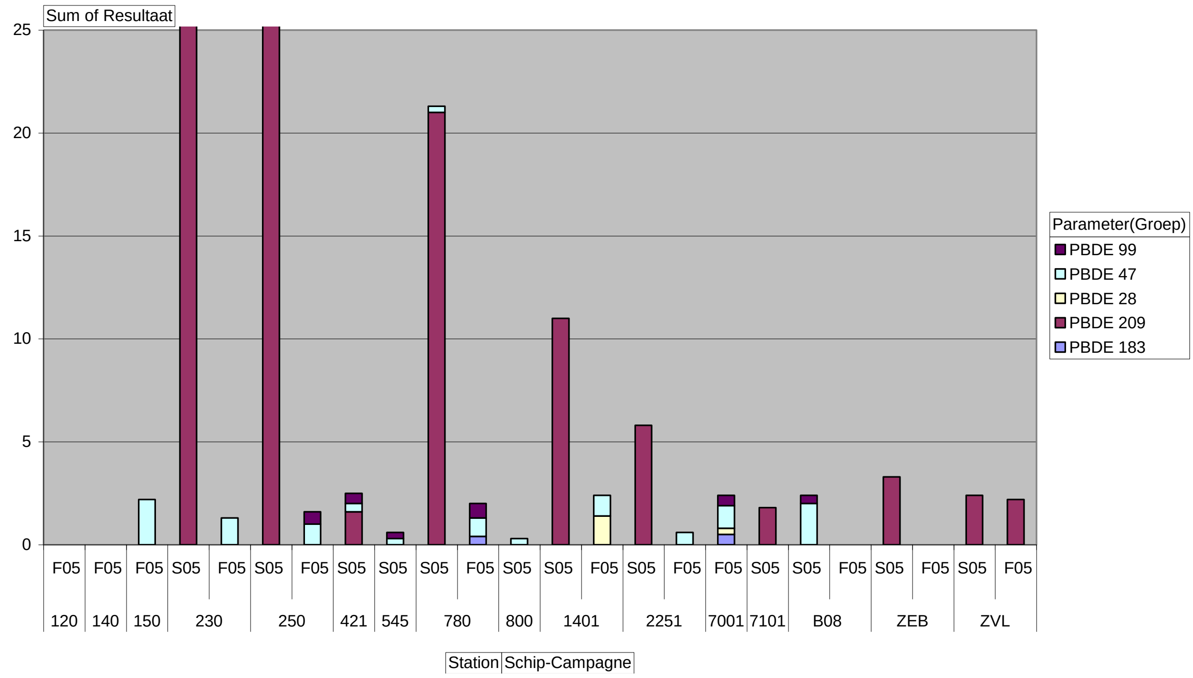


Figure 7.41 PBDEs in sediment of the BCS in spring and autumn 2005, in µg/kgDW

7.9.1.4 Organotin in sediment

Organotin on the BCS is a matter of serious concern. Whilst Phenyltin compounds are under limit of detection on all sampling stations, Butyltin compounds are detectable on all but one sampling point (330; Figure 7.42). Monobutyltin (MBT) is almost omnipresent, and has the highest concentration. But Tributyltin (TBT), the most toxic of the family, is also present on an important fraction of the sampling stations. Dibutyltin (DBT) is less pronounced, suggesting that the conversion from TBT to DBT is by far more difficult than from DBT to MBT. From MBT to Tin seems again a difficult step.

All values are in µg/kgDW expressed as the compoud itself, not as tin, and originate from 2006 samples. The average value is close to 10 µg/kgDW, the highest values being observed close to the mouth of the Scheldt (150). The lowest values are encountered on the B points, adjacent to the mouth. Clear patterns are not noticeable, it will take some more time before the values are <5 µg/kgDW The halflivetime of TBT is estimated as approximately ten years.

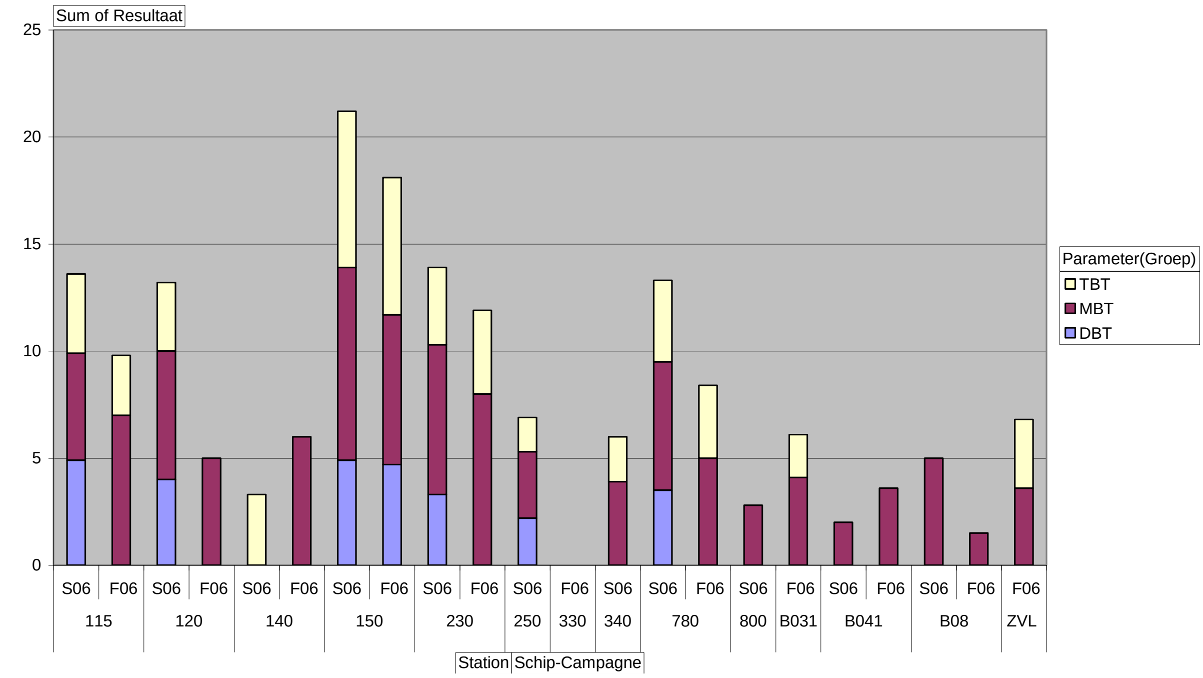


Figure 7.42 Butyltin compounds in sediment of the BCS in the year 2006 (spring & autumn). All results in µg/kgDW (expressed as TBT, DBT or MBT, respectively)

7.9.2 Heavy metals in sediment

Sediment samples are dried and sieved in different fractions before analysis. A lot is to be done about normalisation of analysed concentrations in order to estimate the contamination. Usually, as is the case for organic contaminants, only the fraction <63 µm is analysed. Al content, Li and TOC are also often used as a normalisation factor. In the following sections, the metal analysis of the fraction <63 µm and the fraction <2 mm is discussed. The main reason for bringing in the latter fraction is that on some sandy stations, there is not enough of the fine fraction to be analysed.

7.9.2.1 Fraction <63 µm

The results for metals are generally discussed, and only a limited number of data effectively represented in tables. All values are expressed in mg/kgDW, except for Hg, that is expressed as µg/kgDW

For Hg, most of the values are situated from 150-250 µg/kgDW Few exceptions are found, some in dredge dumping sites, but most in the mouth of the Scheldt estuary, suggesting this river as the major source. Very little variation in the Hg content of sediments on the BCS is to be noticed. A typical example is shown in Figure 7.43 for the dumping sites near Nieuwpoort and Oostende. In station 140, higher values are to be observed, the remainder of the stations showing a quasi uniform content.

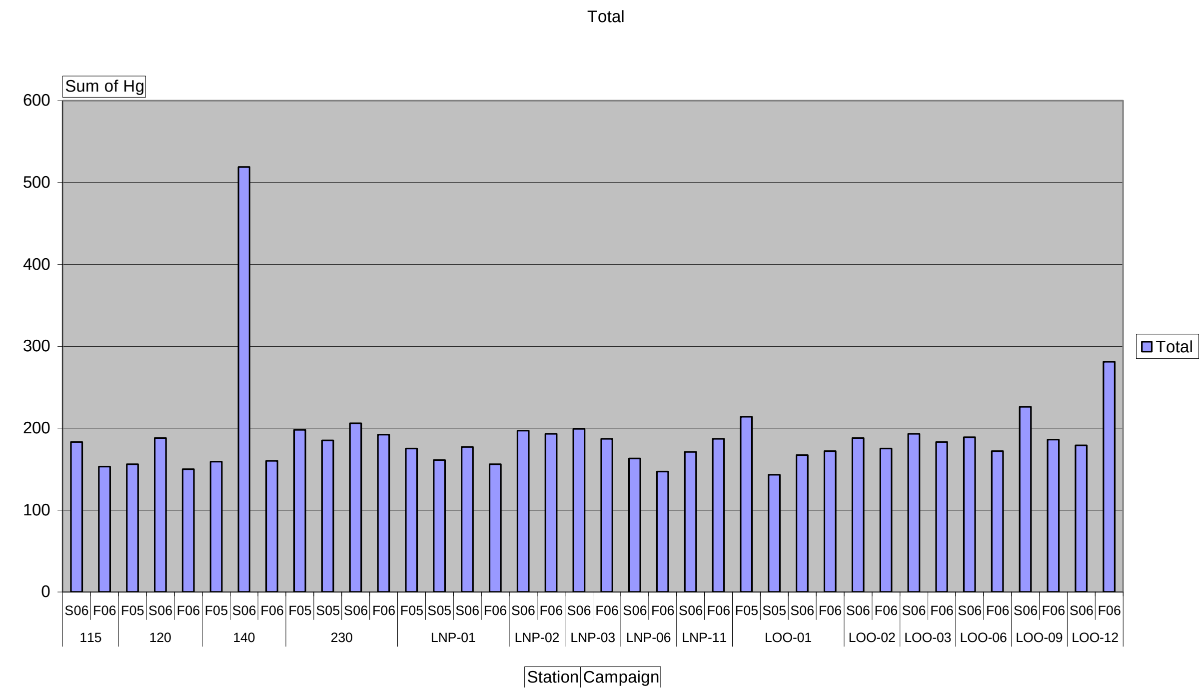


Figure 7.43 Hg content of sediment (<63 µm) from dredge dumping sites Br.&W. Nieuwpoort and Br.&W. Oostende, and reference statins nearby (all results in µg/kgDW)

An overview for Br.&W. S1 for other selected metals, notably As, Cd, Cr, Cu, Ni, Pb and Zn is shown in Figure 7.44 As Remarkably, the higher values are, again, found in the reference station just out of the dredge dumping area (LS1-13/LS1-17).

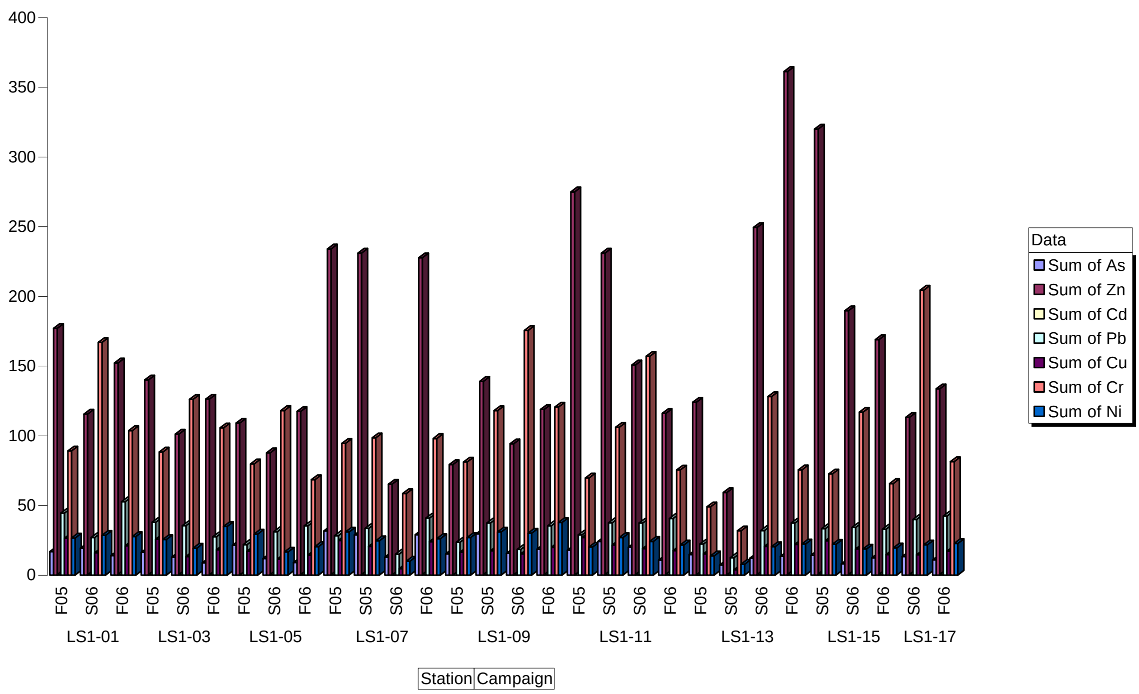


Figure 7.44 Metal (As, Cd, Cr, Cu, Ni, Pb and Zn) content of sediment (<63 µm) from dredge dumping sites Br.&W. S1, and reference stations nearby (all results in µg/kgDW)

Results for dumping site Br.&W. S2 are presented in Figure 7.45. The higher values for Zn might be caused by the location near the Scheldt estuary. Values for Cd are also the highest in station B031. The Cr concentrations are lower than the Zn, except for two points from the dumping site. The highest Pb concentration is also for the Scheldt mouth. Results for Br.&W. Zeebrugge Oost is very comparable, and therefore not shown

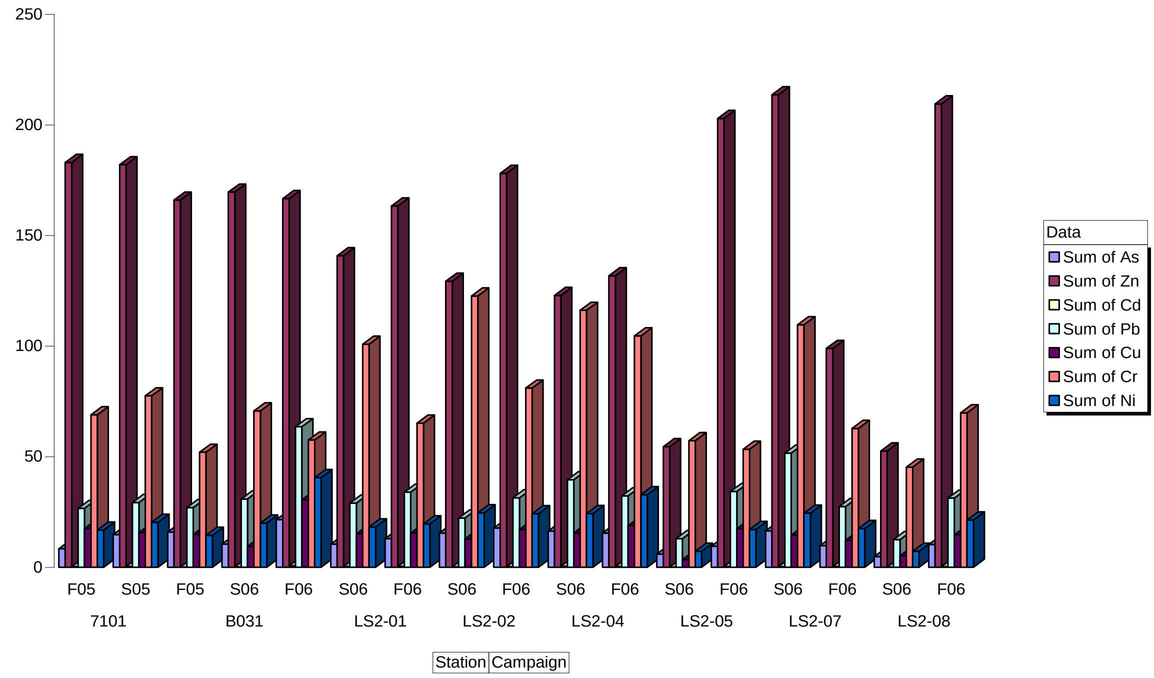


Figure 7.45 Metal (As, Cd, Cr, Cu, Ni, Pb and Zn) content of sediment (<63 μm) from dredge dumping sites Br.&W. S2, and reference stations nearby (all results in μg/kgDW)

An overview for Br.&W. Nieuwpoort for other selected metals, notably As, Cd, Cr, Cu, Ni, Pb and Zn is shown in Figure 7.46 As values are 15 mg/kgDW on average, and fluctuations are low. The highly toxic Cd shows very high values during autumn, mounting uo to 3.4 mg/kgDW, by far higher than the average 0.43 mg/kgDW found on the BCS. Cr values are high as well, comparable or sometimes even higher than for Zn. Cu values are no issue of concern, and also Ni values are fairly normal and stable. Pb on the other hand shows relatively high concentrations, virtually the double than the rest of the BCS. The results for Br.&W. Oostende are very comparable, and therefore not shown.

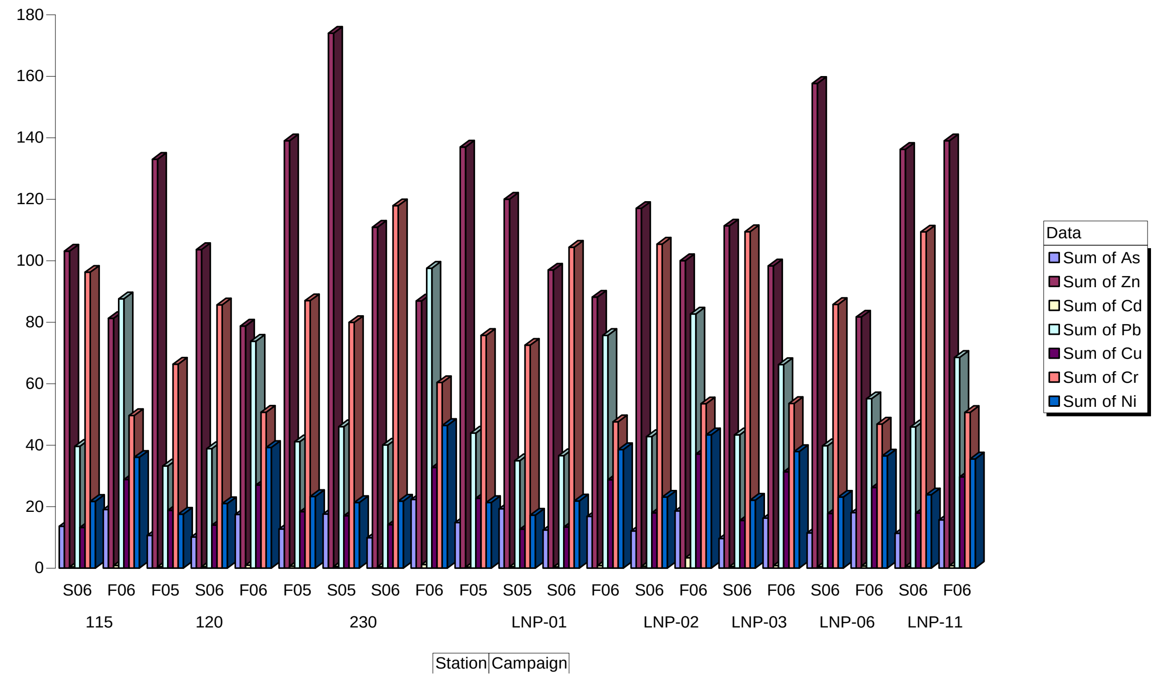


Figure 7.46 Metal (As, Cd, Cr, Cu, Ni, Pb and Zn) content of sediment (<63 μm) from dredge dumping sites Br.&W. Nieuwpoort, and reference stations nearby (all results in μg/kgDW)

7.9.2.2 Fraction <2 mm

Results for the fraction <2mm are incomparable to these of the previous sections, due to reasons stated above.

The global pattern for Br.&W. S1 (Figure 7.47) are that they are roughly comparable, but occasional very high values are more likely to occur in dredge dumping sites. Very high values are noted for Ni and Hg.

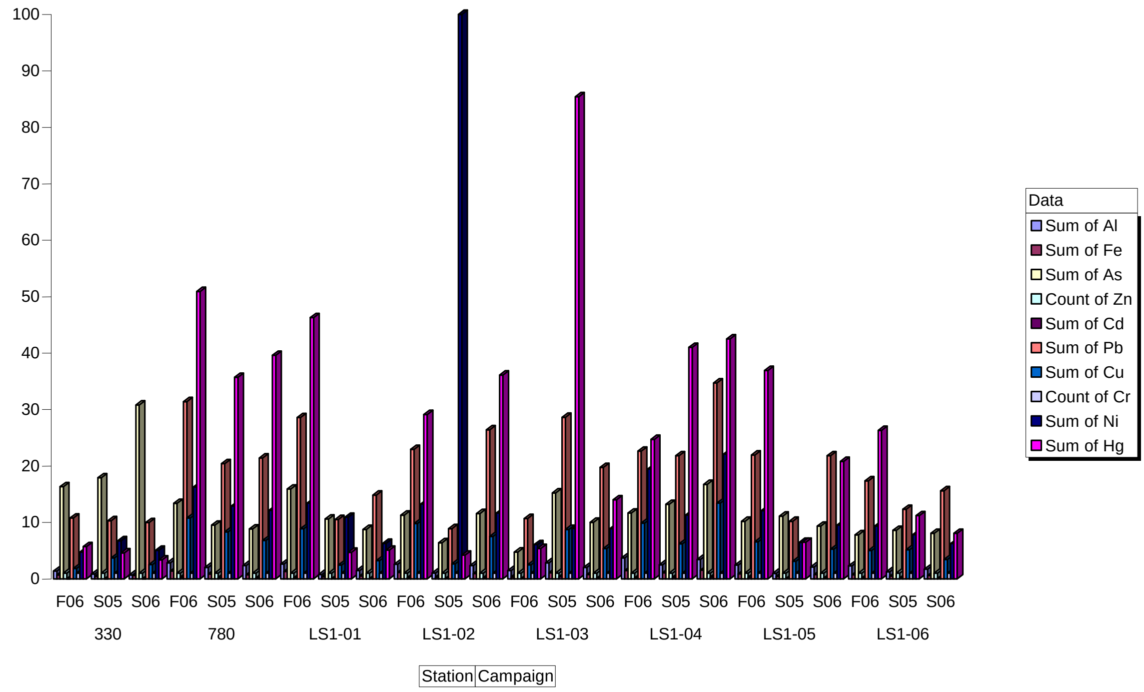


Figure 7.47 Metal (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) content of sediment (<2 mm) from dredge dumping sites Br.&W. S1, and reference stations nearby (all results in mg/kgDW, except for Hg in μg/kgDW)

The values for the other dumping sites, Br.&W. Zeebrugge Oost and Br.&W. S2, are much lower. The highest values are found in station 7001, especially for Hg. The influence of the sediment composition (sand-silt) is however too important to draw any conclusions on contamination out of these results.

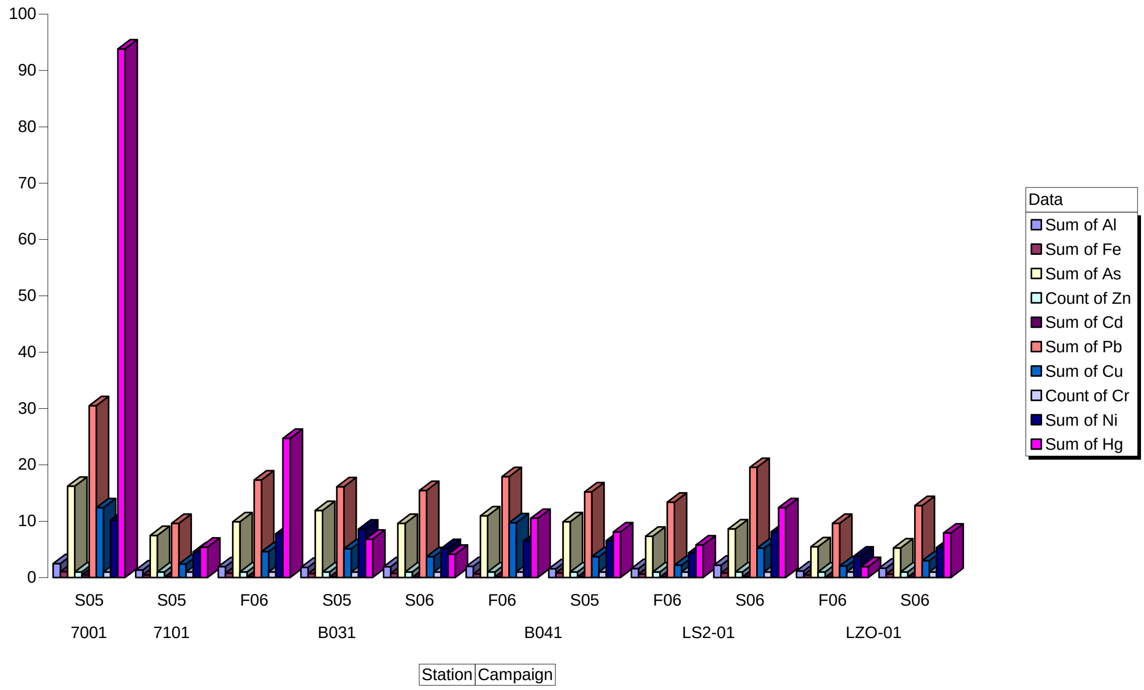


Figure 7.48 Metal (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) content of sediment (<2 mm) from dredge dumping sites Br.&W. S2, Br.&W. Zeebrugge Oost and reference stations nearby (all results in mg/kgDW, except for Hg in µg/kgDW)

7.10 Chemical contaminants in epibenthic species

A number of epibenthic species are collected during sampling campaigns (see above), and analysed for various contaminants. Metals are determined by CODA (Tervuren), organic determinants by ILVO Fisheries in Oostende.

7.10.1 Organic contaminants in epibenthic species

7.10.1.1 PAHs

Introduction

PAHs are known to be rapidly metabolised in higher organisms. All vertebrates seem to have efficient elimination systems, so detection of contamination of PAHs using these organisms can only be done very soon after the spill. The system usually involves a hydroxylation process, followed by an esterification with sulphate or bile acids. The question is whether for fish species, a determination of hydroxy-PAHs is recommendable.

Not all PAHs are equally toxic, and several systems have been developed to normalise for this, and so to obtain one figure presenting the total toxicity of this type of components. Toxicity is normalised to that of benzo-a-pyrene, the most notorious compound, and believed to be the most toxic, although in the meantime several substances where discovered that are by far worse. The normalisation used here is illustrated inTable 7.3, the PAHs mentioned were all analysed in all samples.

Table 7.3 PAH compounds under analysis and their toxic equivalent factors (TEF) as applied for this document (Nisbet & LaGoy, 1992)

Type PAH	TEF
dibenzo(a,h)anthracene	5
benzo(a)pyrene	1
benzo(a)anthracene	0.1
benzo(b)fluoranthene	0.1
benzo(k)fluoranthene	0.1
indeno(1,2,3-c,d)pyrene	0.1
anthracene	0.01
benzo(g,h,i)perylene	0.01

Type PAH	TEF
chrysene	0.01
acenaphtene	0.001
acenaphtylene	0.001
fluoranthene	0.001
fluorene	0.001
phenanthrene	0.001
pyrene	0.001

Results and discussion

PAHs in dragonet and hooknose are hardly detectable, for goby, low values (<1μgTEQ/kgWW) are measured. During Autumn 2005, on track 7101 close to dumping site Br.&W. S2, values of 4 μgTEQ/kgWW In the mouth of the Scheldt estuary, values of 4.2 μgTEQ/kgWW are encountered. Since this one of the world most intense shipping routes, elevated are more likely to have this as a source than that it is influenced by dredge dumping.

There are important variations in the pattern regarding the organism observed. Sea anemone shows very high values near LN, depending on the season from 5-23 μgTEQ/kgWW All other values are <1 μgTEQ/kgWW

Shellfish show high values all over the zone observed, with several values >5 μgTEQ/kgWW, and peak values of 16 (230) to 28 (7001) μgTEQ/kgWW For crustaceans (shrimp, swimming crab and hermit crab), values are low, and high values never related to dredge dumping sites.

Starfish shows very low values (usually <0.3 μgTEQ/kgWW), raising to 1 (7001) and 2 (350) μgTEQ/kgWW

Figure 7.49 shows an overview of all TEQ values for all organisms and all fish tracks. It is obvious that all exceptional values close to dredge dumping sites are due to one organism. High values in reference sites are often caused by several organisms, revealing a more consistent pattern. Care must be taken in order to interpret this results, because all organisms are not encountered at every site. As this might be caused by too high levels of contaminants, we would miss the highest observations. The high values at some dumping sites show that the animals at least still survive.

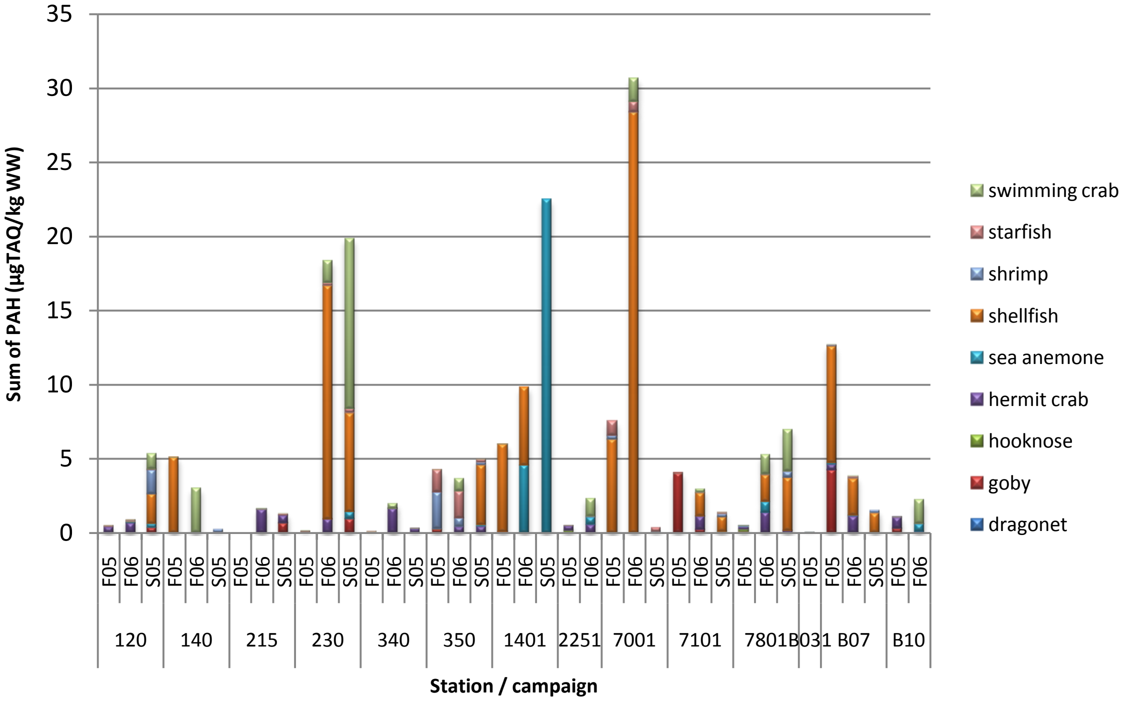


Figure 7.49 Overview of all values (in µgTEQ/kgWW) for all organisms and all fish tracks. Some species missing on certain tracks

7.10.1.2 PCBs

Introduction

The measurement of PCBs in organisms from the Belgian Continental Shelf has a long history. In order to be able to produce a reasonable amount of information, and because of the changes in sampling strategy, only values from 2005-2006 are presented. For the first time, results of both spring and autumn are presented, as in previous years samples from autumn tended to be not analysed.

The PCBs under investigation are the seven marker PCBs plus 3 extra ones (IUPAC numbers 28, 31, 52, 101, 105, 118, 138, 153, 156 & 180). The amount of information is vast, and in order to keep everything comprehensible, a brief summary of the results is given, presented in selected figures. The PCB concentrations are presented as the sum of ten PCBs as mentioned, and expressed on a wet weight basis.

Results and discussion

Amongst fish species, values in dragonet are the lowest, rarely above 2 µg/kgWW, although values on track 340 and 350 have reached close to 9 µg/kgWW Values for goby tend to be a tenfold higher, with absence of extreme values. Higher values can be found on reference sites as well as dredge dumping sites. Hooknose is comparable to goby. Results are found in Figure 7.50.

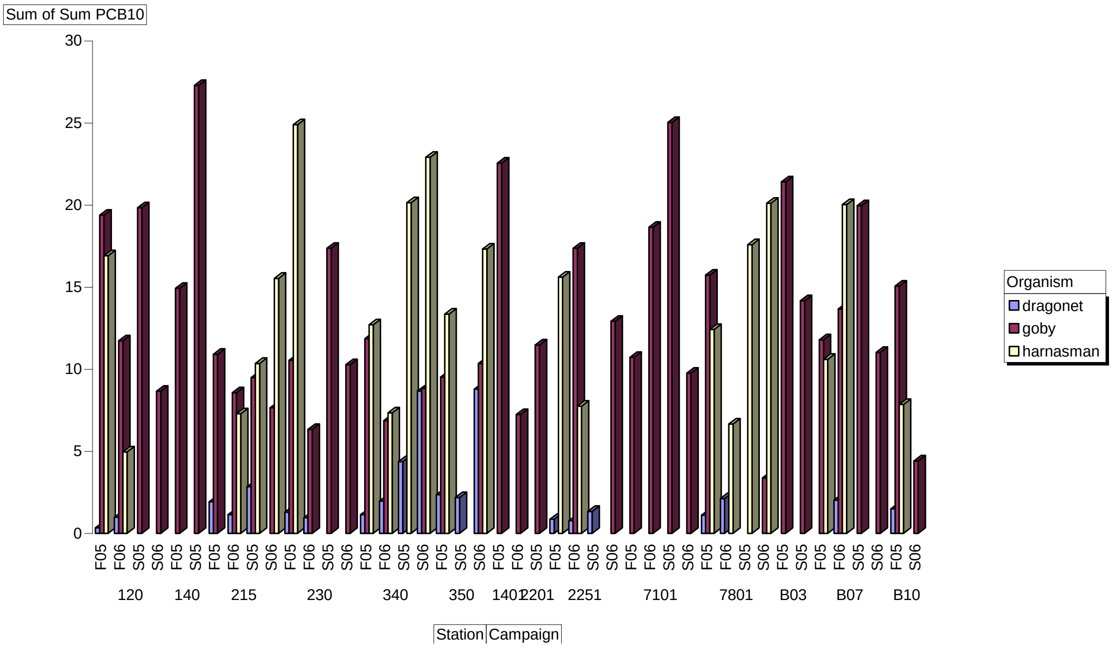


Figure 7.50 Sum of 10 PCBs for different fish species from the BCS (results in µg/kgWW)

Within crustaceans, a lot of variety is found as well. Very low values are measured for shrimp, 75% <2 µg/kgWW Especially near dumping sites, sometimes values up to 6 µg/kgWW are found, and in one reference zone an exceptional value of 18 µg/kgWW was detected. Higher values are found in swimming crab, mostly ranging from 10-25 µg/kgWW The highest values, usually from 30-60 µg/kgWW are observed in hermit crab. As a general rule, the spreading of high and low values is well-balanced all over the BCS. The Figure 7.51 illustrates the relative importance of hermit crab, the low values for shrimp and the intermediate levels for swimming crab. No clear geographical spreading can be deduced from this figure, as one should bear in mind that the absence of hermit crab on a sampling track greatly influences the results.

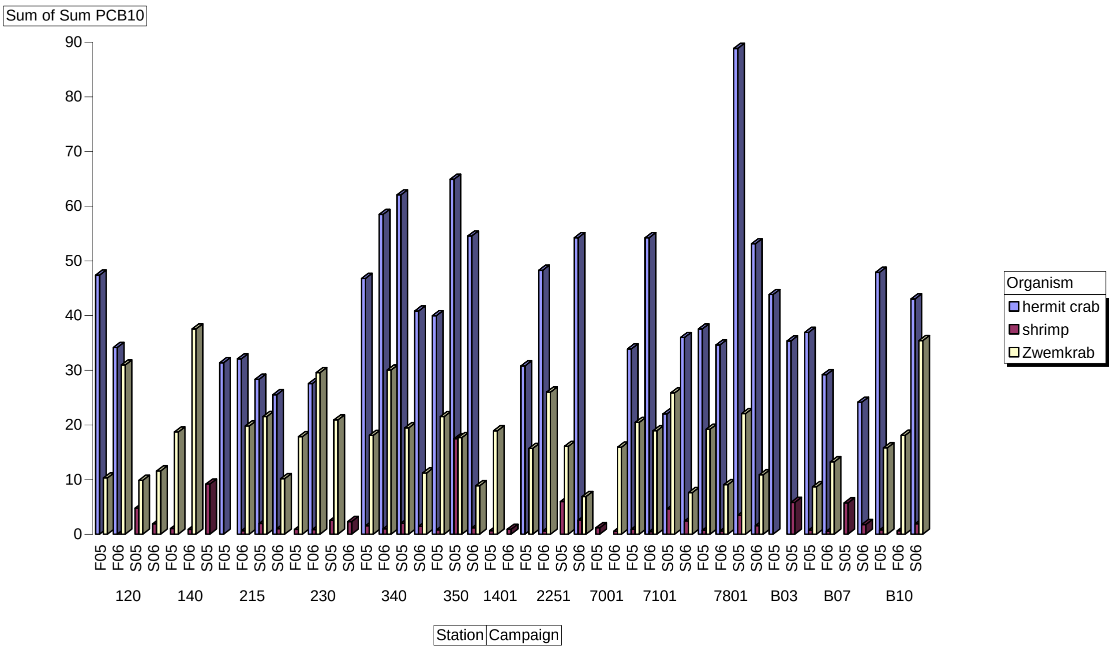


Figure 7.51 Sum of 10 PCBs for different crustaceans from the BCS (results in µg/kgWW)

In shellfish, rather low values from 1-10 µg/kgWW are found, with some exceptions up to 33 µg/kgWW These are typical values measured in mussels from groynes from the Belgian Coast in the framework of other research programmes from ILVO Fisheries, and therefore very unlikely to be caused by dredge dumping, but more to the fact that they are very near the coast.

All values for sea anemone are within 3.5-7 μg/kgWW, and constitute a very stable concentration all over the BCS. For starfish, values are very stable for most reference stations, and vary strongly close to dumping sites, but also the Scheldt mouth. On average, values of 10 μg/kgWW are measured.

7.10.1.3 OCPs

Introduction

Organochlorine pesticides have known a widespread use all over the world, in the war against a number of organisms, especially insects. Most of them are banned, but some manage to persist into the environment due to their very low solubility, their resilience towards breakdown, and in some cases, the use of leftovers still going on, keeping on contaminating the environment.

For DDT, most of the substances is already under the form of its breakdown products TDE and DDE. Only the p,p' derivatives are studied here. Further, hexachlorobenzene (HCB), the alpha and gamma isomers from hexachlorocyclohexane (α-HCH and lindane), dieldrin, endrin and trans-nonachlor are examined. For DDT, only the sum of the three components is discussed (sum DDT), and all results are expressed in μg/kgWW

Results and discussion

For chlorinated pesticides, values from the DDT family are by far more important than the six other components together. Sum DDT is > 1 μg/kgWW for the majority of species and locations, sum of the other pesticides is <<1 μg/kgWW

For fish species, dragonet shows the lowest values for DDT (<1 μg/kgWW, mostly even <0.4), comparable or even lower than the other pesticides. Endrin and α-HCH are rarely found, lindane and transnonachlor almost all the time. For goby, values are comparable to dragonet, for sum DDT however, values are larger, generally in the range 0.7-1.5 μg/kgWW Values for hooknose are comparable to goby, albeit slightly higher.

For crustaceans, there is a comparable story. In shrimp, are observed values are extremely low, putting even more emphasis on the high values encountered exceptionally. Most values for sum DDT are <0.2 μg/kgWW, the high values go up to 5.3 (350) and 5.7 (7801) μg/kgWW For the other pesticides, the sum is generally even <0.12 μg/kgWW, excepted for spring 2005 on track 7801 (2.8 μg/kgWW). Values for hermit crab are much higher, from 1-3 μg/kgWW for sum DDT, and 0.4-0.8 μg/kg w.w for the other pesticides. Note that transnonachlor is dominant, and lindane mostly present. HCB is often in small concentrations; endrin and α-HCH are rarely found. swimming crab is comparable to hermit crab, although values are generally lower. The main difference is the presence of α-HCH in the major part of the samples, and the importance of HCB, equal to transnonachlor, is striking. In Figure 7.52, pesticides in swimming crab are shown, showing the presence of α-HCH.

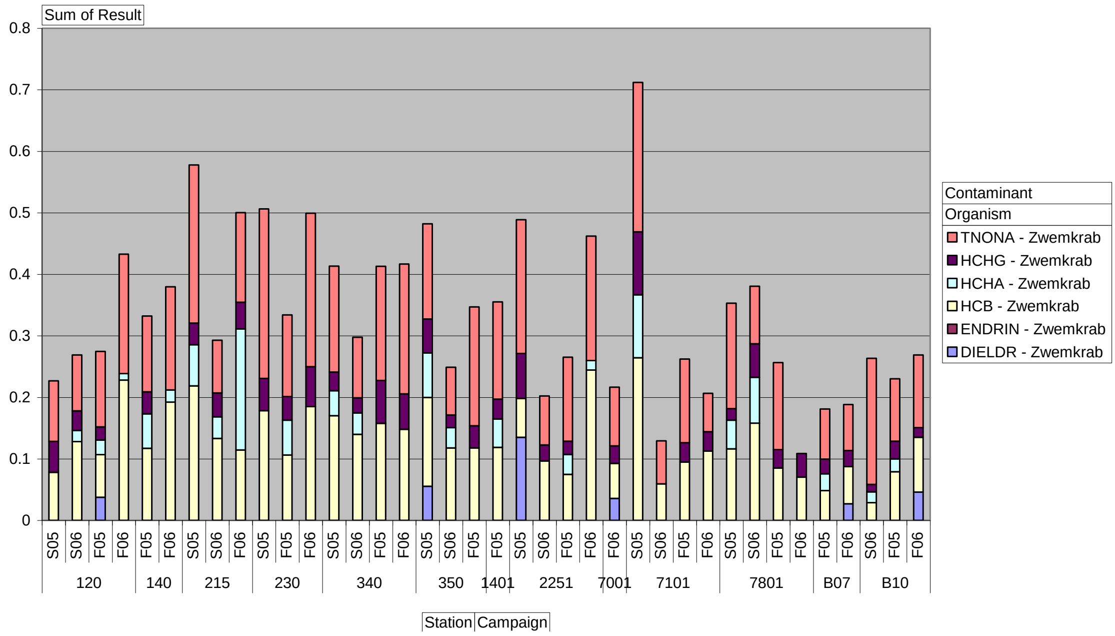


Figure 7.52 pesticides in swimming crab on the BCS (in µg/kgWW)

In shellfish, level of pesticides are very low (<0.25 µg/kgWW), with one exception (7101, spring 2006, where a massive 13.5 µg/kgWW was measured. For sum DDT, values are higher, and highly variable, from 0.1-2.5, the exception (15.5 µg/kgWW) occurring same sampling point, same campaign, indicating that something must have happened over there. There are, however, no comparable effects in any other species under study. Near dredge dumping sites, values are significantly higher than in reference stations.

For sea anemone, the variability for pesticides is high between points and campaigns, but all <1 µg/kgWW For sum DDT, values are more homogenous, from 0.3-0.9 µg/kgWW For starfish, all pesticides are <0.5 µg/kgWW, sum DDT is higher, and ranges from 0.02 – 1.95 µg/kgWW Both the highest and lowest values are found close to a dredge dumping site, i.e. track 2251. Figure 7.53 groups the results for sum DDT for sea anemone, shellfish and starfish. The low values for sea anemone and the high values in shellfish near dumping sites are apparent.

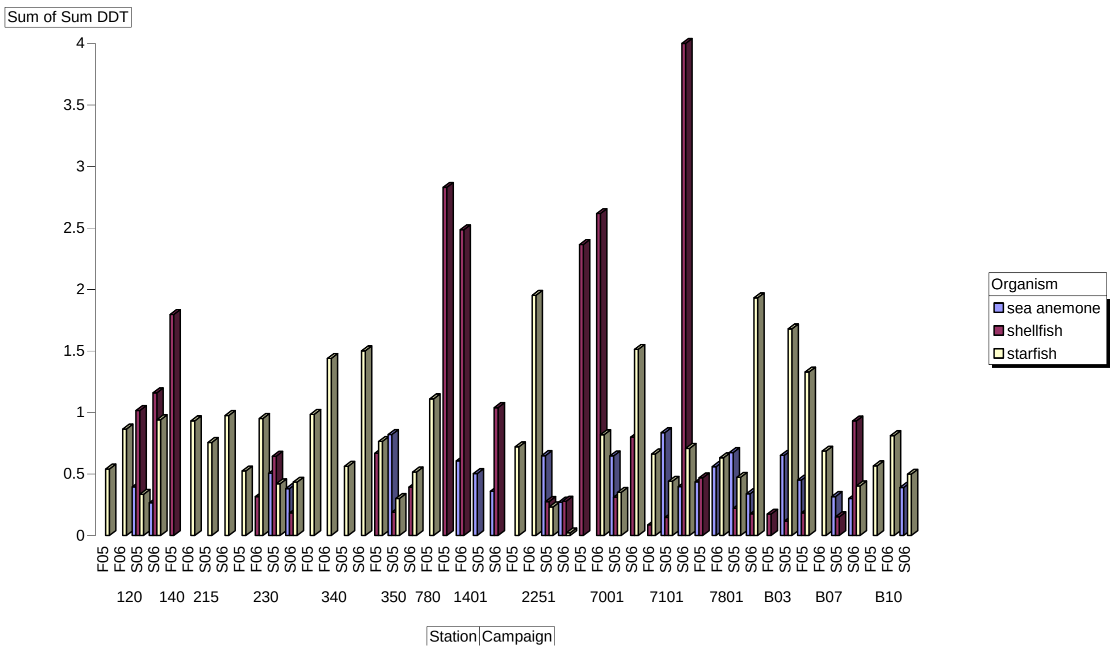


Figure 7.53 Sum DDT for sea anemone, shellfish and starfish on the BCS (in μg/kgWW)

In general, following conclusions can be made: DDT and derivatives are by far the most important on the BCS. Endrin α-HCH are rarely found, except for swimming crab, where the latter is commonly detected. Transnonachlor, lindane and HCB are found in the major part of the samples. Concentrations are typically an order of magnitude lower than PCBs.

7.10.2 Heavy metals in epibenthic species

Introduction

The inorganic analytes are Cd, Cr, Cu, Hg, Pb and Zn. Until now, no speciation analysis is carried out, nor towards oxidation state (e.g. important for Cr), neither to organic complex formation (especially important for Hg). This might change into the future, as the analysing lab (CODA, Tervuren) is developing know-how in that research field. All analysis is reported on a wet weight basis.

Results and discussion

Usually a narrow range values for Cu (0.5-50 mg/kgWW) and Zn (10-50 mg/kgWW) is determined. Very high values for shellfish can be found near dumping sites, and can mount up to 335 mg/kgWW in 1401, and 87.5 mg/kgWW in 7001. But also in the reference tracks 140 and 230, values mount to 100 and 65 mg/kgWW, respectively. Values for Cu in shellfish are parallel, but 10 times lower. For fish species goby, hooknose and dragonet, higher values occur near the mouth of the Scheldt. For hermit crab, Cu values are typically higher than Zn, and no relation with dumping sites can be found. For the other crustaceans under investigation, shrimp and swimming crab, Cu values are comparable to Zn, albeit slightly lower.

For Cd, interestingly, the highest values (0.6-1.2 mg/kgWW) are found on dumping sites in shellfish and swimming crab. Very comparable values (0.5-0.6 mg/kgWW) are found in hermit crab on track 340, more distant from dumping sites, where all (except one) values are <0.2 mg/kgWW). Hg follows the same pattern, with higher values on the dumping sites compared to reference sites, but he maximal values from track 340 and 350. Most values for Hg range from 20-200 μg/kgWW, all exceptions are found in crustaceans.

For Cr, extreme values (>5mk/kgWW) can be found only near dumping sites (7001 & 7801) in shellfish, anemones and swimming crab. Generally, values have a broad range from 0.1-3 mg/kgWW

The spreading for Pb is even wider, with values ranging from non detectable up to 13 mg/kgWW, an average of 0.35 mg/kgWW and a general range from 0.005-1 mg/kgWW to cover 90% of the data. Highest values are found on fish track 7001.

It is quite obvious from the data that exceptional values are encountered almost exclusively close to dumping sites. But these sites do not show a consistent high pattern, elevated concentrations appear occasionally. For lower organisms, which are known to eliminate these products slower, high values are more often encountered, for fish species, the metals are usually already eliminated.

This is adequately described in Figure 7.54 (Trace metals, shells, Cd, Cr, Cu, Hg, Pb & Zn) and Figure 7.55 (Trace metals, dragonet, Cd, Cr, Cu, Hg, Pb & Zn)

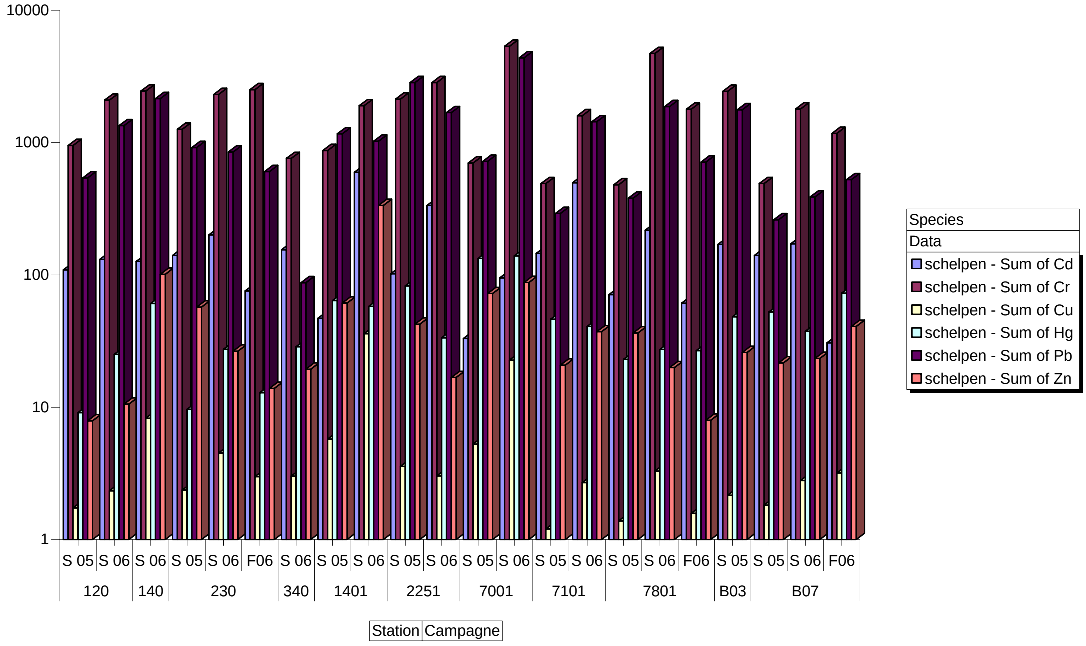


Figure 7.54 Metals in shellfish from distinct fish tracks (Cd, Cr, Hg, Pb (µg/kgWW) & Cu, Zn (mg/kgWW)

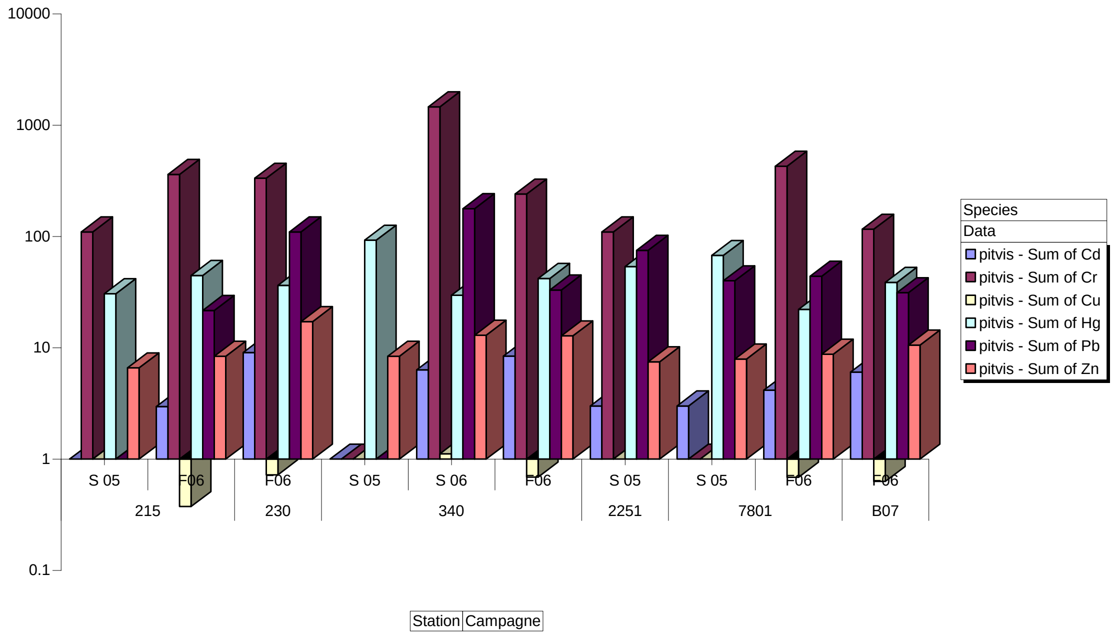


Figure 7.55 Metals in shellfish from distinct fish tracks (Cd, Cr, Hg, Pb (µg/kgWW) & Cu, Zn (mg/kgWW)

8 Monitoring programme 2007 of the dredging areas

8.1 Introduction

At the 40th meeting of the *Ambtelijke Werkgroep* (16 November 2006), installed in the framework of the Cooperation Agreement between the Flemish Region and the Federal Government, it was decided that a new monitoring programme of the dredging areas should be carried out. The same exercise was done in 1990 and 2000. The objective of the monitoring is to be able to make an update of the sediment quality, to make a distinction between sediment quality of *maintenance dredged materials* and *capital dredged material* as well as to be in a better position to report contaminant loads to the OSPAR Commision. The monitoring programme has two phases: characterization of the physical-chemical parameters and eco-toxicological analysis. The latter report is not ready for this report and the results will be incorporated in the next *syntheserappor*".

8.2 Results of the monitoring programme 2007 – Physico-chemical analysis

By order of the Flemish Government, Department of Mobility of Public Works, Maritime Access Division (tender no. 16EF/2007/19), Ecorem has carried out survey operations and a study of the quality of the sediment in the dredging areas (navigation channels, harbours, marinas and some reference points) on the Belgian continental shelf.

Similar survey operations have already been carried in 1989/1990 and in 2000. The purpose of the current survey campaign is to describe the quality of the sediment samples taken in the campaign of 2007 and to compare the results with those from the previous campaigns. All the samples were examinated for their physico-chemical characteristics and for their concentration in organic and inorganic contaminants.

8.2.1 Sampling locations

Table 8.1 Analysed samples (see also maps attached).

Description of the harbour section	Samples
Voorhaven Zeebrugge	From1 till 18
Centraal deel van de Nieuwe Buitenhaven van Zeebrugge	From 20 till 26
Pas van het Zand	From 30 till 35
Scheur Oost en Scheur West	From 36 till 45
Haven van Blankenberge	From 50 till 57
Toegangsgeul haven Blankenberge	Sample 58
Haven van Nieuwpoort	From 60 till 66, 69
Toegangsgeul haven Nieuwpoort	Samples 67 and 68
Haven van Oostende	From 70 till 86
Toegangsgeul haven Oostende	From 87 till 94
Westende	From TS1 till TS4, TS9, TS12, WO2 and WO3
Vlakte van de Raan	WO4, VDR1, VDR3

8.2.2 Sampling

8.2.2.1 Sampling material

Ship

The ship 'Brandaris' is a rescue ship that was reconstructed into a sampling ship. A 'Van Veengrijper' was tightened on the iron cable (that can also be used for rescue purposes). This cable is steered electrically.

The 'Brandaris' is equipped with modern technology like a radar, depth meter, loudhailer, APIRB, Furuno GPS, Simrad GPS, Raytheon GPS and card plotter.

Figure 8.1 The 'Brandaris' has a length of 8.92 m and is 3.40 m wide. The motor of the ship has 500 Pk.

Sampler

The samples were taken by a 'Van Veengrijper', tightened on the iron cable which was steered electrically. The 'Van Veengrijper" has a volume of 12 litres.

Sample buckets

The sampled soft sediments were stored in a plastic sample bucket of 10 litres. The samples were stored in a fridge with a temperature of 4 ± 3°C.

8.2.3 Analyses

8.2.3.1 Analysis parameters

All the samples have been analysed on (wet bulk) density, dry matter, organic matter, distribution of particle size (fraction > 2000μm, fraction < 2000μm, fraction < 1000μm, fraction < 500μm, fraction < 250μm, fraction < 63μm, fraction < 45μm, fraction < 16μm, fraction < 2μm), elements (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn), TPH, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyl (PCB) and tributyltin (TBT).

8.2.3.2 Method references

Table 8.2 Analysis method, technique and method references for each analysis parameter.

Analysis	Analysis method – Technique - Method reference
AES/ICP Lead (Pb)	W0417 - ICP-AES - In accordance with NEN 6966 / CMA 2/I/B
PAH (OVAM/VLAREBO)	W0301 - HPLC - In accordance with CMA 3/B
Grainsize < 1000 µm	W0105 - Sedimentation - In accordance with NEN 5753
Organic Carbon	W2111 - Spectrometry - In acc. with ISO 14235 /CMA 2/II/A.10
Chlorobenzenes	W0255 - GC-MS - In house method
AES/ICP Cadmium (Cd)	W0417 - ICP-AES - In accordance with NEN 6966 / CMA 2/I/B
AES/ICP Nickel (Ni)	W0417 - ICP-AES - In accordance with NEN 6966 / CMA 2/I/B
Grainsize < 250 µm	W0105 - Sedimentation - In accordance with NEN 5753
AES/ICP Zinc (Zn)	W0417 - ICP-AES - In accordance with NEN 6966 / CMA 2/I/B
TPH (GC) OVAM	W0202 - GC/FID - In accordance with CMA 3/R
Grainsize < 2000 µm	W0105 - Sedimentation - In accordance with NEN 5753
Grainsize < 500 µm	W0105 – Sedimentation- In accordance with NEN 5753
TBT	P0902 - External - External method
Volitile Halogenated HC (11)	W0254- HS-GC/MS - In house method
CKW: Vinylchloride	W0254 - HS-GC/MS - In house method
Octane HS	W0254 - HS-GC/MS - CMA 3/E
AES/ICP Chromium (Cr)	W0417 - ICP-AES - In accordance with NEN 6966 / CMA 2/I/B
Grainsize < 2 µm (Lutum) Sedimentatio	W0173 - Sedimentation - In accordance with NEN 5753
Grainsize < 45 µm (Sed.)	W0173 - Sedimentation - In accordance with NEN 5753
Grainsize < 16 µm (Sed.)	W0173 - Sedimentation - In accordance with NEN 5753
AES/ICP Arsenic (As)	W0417 - ICP-AES - In accordance with NEN 6966 / CMA 2/I/B
Digestion OVAM HF	W2107 - Microwave - In accordance with CMA 2/II/A.3
Grainsize < 125 µm	W0105 - Sedimentation - In accordance with NEN 5753
Density	W0114 - Gravimetry - In house method
Dry matter	W0104 - Gravimetry - Equivalent to NEN-ISO 11465 en CMA 2/II
Hexane HS	W0254 - HS-GC/MS - CMA 3/E
Aromates (BTEX)	W0254 - HS-GC/MS - In house method
AES/ICP Copper (Cu)	W0417 - ICP-AES - In accordance with NEN 6966 / CMA 2/I/B
Grainsize < 63 µm	W0105 – Sedimentation - In accordance with NEN 5753
Organochloro pesticides (OCP) OVAM	W0255 - GC-MS - In accordance with CMA 3/I
EOX	W0351 Microcoulometry In house method
AES/ICP Mercury (Hg)	W0417 - ICP-AES I- n house method / Equal EN 1483: 1997 i
Grainsize < 2000 µm, (Mineral parts)	W0105 - Sedimentation - In accordance with NEN 5753
Polychlorobifenyles (PCB) OVAM	W0255 - GC-MS - In accordance with CMA 3/I
Heptane HS	W0254 -
Heptane HS	W0254 - HS-GC/MS - CMA 3/E
Styrene HS	W0254 - HS-GC/MS - In accordance with EN-ISO 10301 and CM

8.3 Summary of results

8.3.1 Comparison analytical results – sediment quality criteria.

The analytical results were compared with the sediment quality criteria which the dredged material has to fulfill to be allowed for dumping at sea. These criteria were defined by MUMM (Management Unit of the North Sea Mathematical Models and have two levels: the target level and the upper level (Table 8.3). If the analysis results exceed the limit set for three of the criteria at the same time, the dredged material may not be dumped at sea. If the result lies between the target value and the limit, the number of samples has to be increased by five and new analyses have to be carried out. If the new analysis results confirm the previous ones, then bioassays prescribed at international level have to be conducted. Negative results from these bioassays may lead to a ban on dumping dredged material from these delimited areas at sea.

Table 8.3 Sediment quality criteria (SQCs)

Chemical	Target value	Limit value
Hg	0.3 ppm	1.5 ppm
Cd	2.5 ppm	7 ppm
Pb	70 ppm	350 ppm
Zn	160 ppm	500 ppm
Ni	70 ppm	280 ppm
As	20 ppm	100 ppm
Cr	60 ppm	220 ppm
Cu	20 ppm	100 ppm
TBT	3 ppb	7 ppb
Mineral oil	14 mg/g_{oc}	36 mg/g_{oc}
PAHs	70 $\mu g/g_{oc}$	180 $\mu g/g_{oc}$
PCBs	2 $\mu g/g_{oc}$	2 $\mu g/g_{oc}$

Table 8.4 Summary of the comparison of the test results for the campaign of 2007 with these standards.

	Elements		**PAH**		**TPH**		**PCB**		**TBT**	
	concentration ≥ target value	concentration ≥ limit value	concentration ≥ target value	concentration ≥ limit value	concentration ≥ target value	concentration ≥ limit value	concentration ≥ target value	concentration ≥ limit value	concentration ≥ target value	concentration ≥ limit value
Voorhaven Zeebrugge	Sample 1-3-4-5-6-7-8-9-10-15-16-17-18	NO	NO	NO	NO	NO	NO	NO	NO	Sample 1 till 18
CDNB Zeebrugge	Sample 20-21-23-26	NO	NO	NO	NO	NO	NO	sample26	NO	Sample 20 till 26
Pas van het Zand	NO	NO	NO	NO	NO	NO	NO	NO	Sample 31-34-35	Sample 33
Scheur Oost en Scheur West	NO	NO	NO	NO	NO	NO	NO	NO	Sample 36-37-38-42-43	Sample 45
Haven Blankenberge	Sample 50-51-53-55-56	NO	NO	NO	NO	Sample 57	NO	NO	NO	Sample 50 till 56
Toegangsgeul Blankenberge	NO	NO	NO	NO	Sample 58	NO	NO	NO	NO	NO
Haven Nieuwpoort	Sample 60-61-62-63-64	NO	NO	NO	NO	NO	NO	NO	Sample 63	NO
Toegangsgeul Nieuwpoort	NO	NO	Sample 67	NO	NO	Sample 68	NO	NO	NO	NO
Haven Oostende	Sample 70-71-72-73-74-75-76-77-78-80-81-84-85-86	Sample 82-83	Sample 79-82	NO	Sample 83	Sample 82	NO	sample 82	Sample 77	Sample 71-82-83 82
Toegangsgeul Oostende	Sample 91-94	NO	NO	NO	Sample 93	NO	NO	NO	Sample 94	NO
Westende	NO	NO	Sample WO2	NO	Sample TS12	Sample TS1, TS2, TS3, TS4,WO3	NO	NO	NO	sample WO2
Vlakte van de Raan	WO4	NO	NO	NO	Sample WO4-VDR1	NO	NO	NO	NO	NO

TBT is the most limiting analysed parameter to describe the quality of the sediments from the North Sea and coastal harbours in Belgium.

In the harbour sections of Zeebrugge and Blankenberge, approx. 94% of the samples exceed the limit value for TBT. In the harbour section of Nieuwpoort and Oostende, approx. 12% of the samples exceed the limit value for TBT while in the Pas van het Zand and Scheur Oost and Scheur West (dredging zones) 12.5 % of the samples exceed the limit value for TBT. For the reference samples (TS1, TS2, TS3, TS4, TS9, TS12, WO2, WO3, WO4, VDR1, VDR3 / no dredging zones) some 10% of the samples exceed the limit value for TBT. The last value is mainly due to sample WO3.

Similar survey operations have already been conducted in 1989/1990 and in 2000. To investigate whether the mean values for the campaigns of 2001 and 2007 are significantly (level 5%) different for a certain analysed parameter and for a certain harbour section, the probability is calculated of finding these observed mean values under the assumption (H_0 hypothesis) that the population means are equal. To calculate these probabilities the student t-test was used. Since the variation may have changed over time, the student t-test for heteroscedastic data was used. A 2-sided test was used because the pollution level of the sediments may have increased or decreased.

8.3.2 Comparison results 1990 – 2000 -2007

Introducing remarks

- The results of the individuals PAH compounds which are used to count the PAH sum is not the same for the campaign of 1990 and for campaign 2000 and 2007. In the campaign of 2000 and 2007 the 16 EPA PAH compounds were used to count the sum (of 16 EPA PAH). In 1990 only the following compounds were used: Naphtalene, Phenanthrene, Anthracene, Fluoranthene Pyrene, Chrysene, Benzo(a)anthracene, Benzo(k)fluoranthene, benzo-α-pyrene, Benzo(a)pyrene, Peylene, Dibenzo(ah)anthracene, Indeno(123cd)pyrene and Benzo(ghi)perylene. Tough both sums can be used as an indicative comparison between the campaign of 1990 and the campaigns of 2000 and 2007;
- In the report 'beproevingsverslag van het onderzoek van 82 monsters sediment' (ref. nr. 01/A 0675), made by Labo Van Vooren in 2001 were no mean values for TPH, so this analysis parameter is not given in the tables belowe;
- In the campaign of 2000, except for the samples 82 and 83, all the results for PCB were similar to the detection limit of <0.070 mg/kg PCB. In the report 'beproevingsverslag van het onderzoek van 82 monsters sediment' (ref. nr. 01/A 0675), made by Labo Van Vooren in 2001, they gave the value zero (0 μg/g oc) to all the averages for PCB. Because of this all the mean values for the campaign of 2000 are 0 μg/goc for PCB.

Table 8.5 Voorhaven Zeebrugge

Parameter	target value	limit value	Unit	average 1990	aver-age 2001	average 2007
Elements						
Arsenic (As)	20	100	ppm	14.0	18.0	16
Cadmium (Cd)	2.5	7	ppm	2.73	0.57	0.61
Chromium (Cr)	60	220	ppm	44.7	71.6	61
Copper (Cu)	20	100	ppm	24.8	19.8	19.6
Mercury (Hg)	0.3	1.5	ppm	0.43	0.21	0.20
Nickel (Ni)	70	280	ppm	23.1	21.5	19
Lead (Pb)	70	350	ppm	76.8	39.8	35
Zinc (Zn)	160	500	ppm	167	139	109
PAH						
PAH 16 EPA (sum)	70	180	µg/goc	35	54	<25.59
PCB						
PCB (7) (sum)	2	2	µg/goc	0	0	0.262
TBT	3	7	ppb	21.7	57.5	45

Legend

conc. : concentration < target value

conc. : target value ≤ concentration < limit value

conc. : limit value ≤ concentration

Table 8.6 Centraal deel Nieuwe buitenhaven Zeebrugge

Parameter	target value	limit value	Unit	average 1990	average 2001	average 2007
Elements						
Arsenic (As)	20	100	ppm	17.4	18.1	17
Cadmium (Cd)	2.5	7	ppm	2.85	0.4	0.63
Chromium (Cr)	60	220	ppm	56.9	66.7	62
Copper (Cu)	20	100	ppm	17.7	15.5	15.3
Mercury (Hg)	0.3	1.5	ppm	0.25	0.17	0.17
Nickel (Ni)	70	280	ppm	27.9	20.6	19
Lead (Pb)	70	350	ppm	60.9	36.4	37
Zinc (Zn)	160	500	ppm	155	119	100
PAH						
PAH 16 EPA (sum)	70	180	µg/goc	10	37	13.81
PCB						
PCB (7) (sum)	2	2	µg/goc	0	0	0.54
TBT	3	7	ppb	/	33.7	11

Legend

conc. : concentration < target value

conc. : target value ≤ concentration < limit value

conc. : limit value ≤ concentration

Table 8.7 Pas van het Zand

Parameter	target value	limit value	Unit	average 1990	average 2001	average 2007
Elements						
Arsenic (As)	20	100	ppm	11.5	11.0	13.2
Cadmium (Cd)	2.5	7	ppm	1.96	0.28	0.6
Chromium (Cr)	60	220	ppm	27.0	34.4	46.5
Copper (Cu)	20	100	ppm	11.5	7.63	9.8
Mercury (Hg)	0.3	1.5	ppm	0.39	0.10	0.1
Nickel (Ni)	70	280	ppm	20.0	10.7	13.7
Lead (Pb)	70	350	ppm	32.3	19.7	25.0
Zinc (Zn)	160	500	ppm	96.2	61.4	70.5
PAH						
PAH 16 EPA (sum)	70	180	µg/goc	13	34	20.4
PCB						
PCB (7) (sum)	2	2	µg/goc	0	0	0.096
TBT	3	7	ppb	/	24.7	5.50

Legend

conc.	: concentration < target value
conc.	: target value ≤ concentration < limit value
conc.	: limit value ≤ concentration

Table 8.8 Scheur Oost and Scheur West

Parameter	target value	limit value	Unit	average 1990	average 2001	average 2007
Elements						
Arsenic (As)	20	100	ppm	10.2	8.84	13
Cadmium (Cd)	2.5	7	ppm	1.87	0.15	0.5
Chromium (Cr)	60	220	ppm	30.9	24.5	41
Copper (Cu)	20	100	ppm	8.99	4.5	8.4
Mercury (Hg)	0.3	1.5	ppm	0.17	0.06	0.11
Nickel (Ni)	70	280	ppm	16.5	8.04	13
Lead (Pb)	70	350	ppm	36.4	12.6	23
Zinc (Zn)	160	500	ppm	79.5	39.6	62
PAH						
PAH 16 EPA (sum)	70	180	µg/goc	13	29 (*)	28.8
PCB						
PCB (7) (sum)	2	2	µg/goc	0	0	0.000
TBT	3	7	ppb	/	15.2	8

Legend

conc.	: concentration < target value
conc.	: target value ≤ concentration < limit value
conc.	: limit value ≤ concentration

(*): The value for PAH 16 EPA as given in the report 'beproevingsverslag van het onderzoek van 82 monsters sediment' (ref. nr. 01/A 0675), made by Labo Van Vooren in 2001, is not the same as we calculated based on the individual results given in this report. We calculated an average of 67,5 µg/goc for PAH.

Table 8.9 Haven Blankenberge

Parameter	target value	limit value	Unit	average 1990	average 2001	average 2007
Elements						
Arsenic (As)	20	100	ppm	13.7	17.4	15
Cadmium (Cd)	2.5	7	ppm	2.41	0.36	0.52
Chromium (Cr)	60	220	ppm	18.9	60.9	55
Copper (Cu)	20	100	ppm	19.9	16	17.3
Mercury (Hg)	0.3	1.5	ppm	0.35	0.17	0.15
Nickel (Ni)	70	280	ppm	23.9	19	18
Lead (Pb)	70	350	ppm	51.7	34.9	33
Zinc (Zn)	160	500	ppm	120	103	94
PAH						
PAH 16 EPA (sum)	70	180	µg/goc	23	52	30.1
PCB						
PCB (7) (sum)	2	2	µg/goc	0	0	0.27
TBT	3	7	ppb	41.3	59.8	19.7

Legend

conc.	: concentration < target value
conc.	: target value ≤ concentration < limit value
conc.	: limit value ≤ concentration

Table 8.10 Toegangsgeul Haven Blankenberge

No calculations of mean values because only sample 68 was taken in this harbour section.

Table 8.11 Haven Nieuwpoort

Parameter	target value	limit value	Unit	average 1990	average 2001	average 2007 (*)
Elements						
Arsenic (As)	20	100	ppm	12.9	13.0	15
Cadmium (Cd)	2.5	7	ppm	2.32	0.40	0.51
Chromium (Cr)	60	220	ppm	26.3	48.1	57
Copper (Cu)	20	100	ppm	17.9	15.4	16
Mercury (Hg)	0.3	1.5	ppm	0.17	0.11	0.14
Nickel (Ni)	70	280	ppm	21.0	15.0	19
Lead (Pb)	70	350	ppm	46.0	30.7	33
Zinc (Zn)	160	500	ppm	104	90.1	96
PAH						
PAH 16 EPA (sum)	70	180	µg/goc	19	32 (**)	19.22
PCB						
PCB (7) (sum)	2	2	µg/goc	0	0	0.000
TBT	3	7	ppb	18	32.6	<1.8

Legend

conc.	: concentration < target value
conc.	: target value ≤ concentration < limit value
conc.	: limit value ≤ concentration

(*): average without sample 69 because this sample wasn't taken in the campaign of 2001 and 2007.

(**): The value for PAH 16 EPA as given in the report '*beproevingsverslag van het onderzoek van 82 monsters sediment*' (ref. nr. 01/A 0675), made by Labo Van Vooren in 2001, is not the same as we calculated based on the individual results given in this report. We calculated an average of 52 µg/goc for PAH.

Table 8.12 Toegangsgeul Haven Nieuwpoort

Parameter	target value	limit value	Unit	average 1990	average 2001	average 2007
Elements						
Arsenic (As)	20	100	ppm	6.10	5.20	10
Cadmium (Cd)	2.5	7	ppm	0.99	0.14	0.4
Chromium (Cr)	60	220	ppm	11.70	12.50	14
Copper (Cu)	20	100	ppm	4.30	2.47	5.0
Mercury (Hg)	0.3	1.5	ppm	0.05	0.00	0.1
Nickel (Ni)	70	280	ppm	8.00	3.66	7
Lead (Pb)	70	350	ppm	19.30	5.58	10
Zinc (Zn)	160	500	ppm	40.3	24.2	19
PAH						
PAH 16 EPA (sum)	70	180	µg/goc	21	13 (*)	89.5
PCB						
PCB (7) (sum)	2	2	µg/goc	0	0	0.87
TBT	3	7	ppb	/	<5	<1.1

Legend

conc.	: concentration < target value
conc.	: target value ≤ concentration < limit value
conc.	: limit value ≤ concentration

(*): The value for PAH 16 EPA as given in the report 'beproevingsverslag van het onderzoek van 82 monsters sediment' (ref. nr. 01/A 0675), made by Labo Van Vooren in 2001, is not the same as we calculated based on the individual results given in this report. We calculated an average of 44 µg/goc for PAH.

Table 8.13 Haven Oostende

Parameter	target value	limit value	Unit	average 1990	average 2001 (*)	average 2007 (*)
Elements						
Arsenic (As)	20	100	ppm	13.1	16.5	17
Cadmium (Cd)	2.5	7	ppm	2.44	0.56	0.55
Chromium (Cr)	60	220	ppm	52.2	59	71
Copper (Cu)	20	100	ppm	27.3	23.0	20
Mercury (Hg)	0.3	1.5	ppm	0.27	0.19	0.17
Nickel (Ni)	70	280	ppm	20.6	18.4	22
Lead (Pb)	70	350	ppm	63.8	18.9	42
Zinc (Zn)	160	500	ppm	151	137	120
PAH						
PAH 16 EPA (sum)	70	180	µg/goc	25	-	30
PCB						
PCB (7) (sum)	2	2	µg/goc	0	0	0.000
TBT	3	7	ppb	27.0	61.2	3.5

Legend

conc. : concentration < target value

conc. : target value ≤ concentration < limit value

conc. : limit value ≤ concentration

(*): in 1990 no samples were taken at the locations 82 and 83.
Because of this, the average values for 2001 and 2007 were calculated without these samples.
The samples 82 and 83 are discussed individually (see full report)

Table 8.14 Toegangsgeul haven Oostende

Parameter	target value	limit value	Unit	average 1990	average 2001	average 2007 (*)
Elements						
Arsenic (As)	20	100	ppm	7.08	9.67	15
Cadmium (Cd)	2.5	7	ppm	0.56	0.19	0.45
Chromium (Cr)	60	220	ppm	14.7	33.3	50
Copper (Cu)	20	100	ppm	5.31	7.35	11.2
Mercury (Hg)	0.3	1.5	ppm	0.08	0.09	0.14
Nickel (Ni)	70	280	ppm	11.2	10.2	16
Lead (Pb)	70	350	ppm	20.9	17.6	30
Zinc (Zn)	160	500	ppm	50.3	57	77
PAH						
PAH 16 EPA (sum)	70	180	µg/goc	18	30 (**)	24.2
PCB						
PCB (7) (sum)	2	2	µg/goc	0	0	0.190
TBT	3	7	ppb	/	63.2	1.9

Legend

conc. : concentration < target value

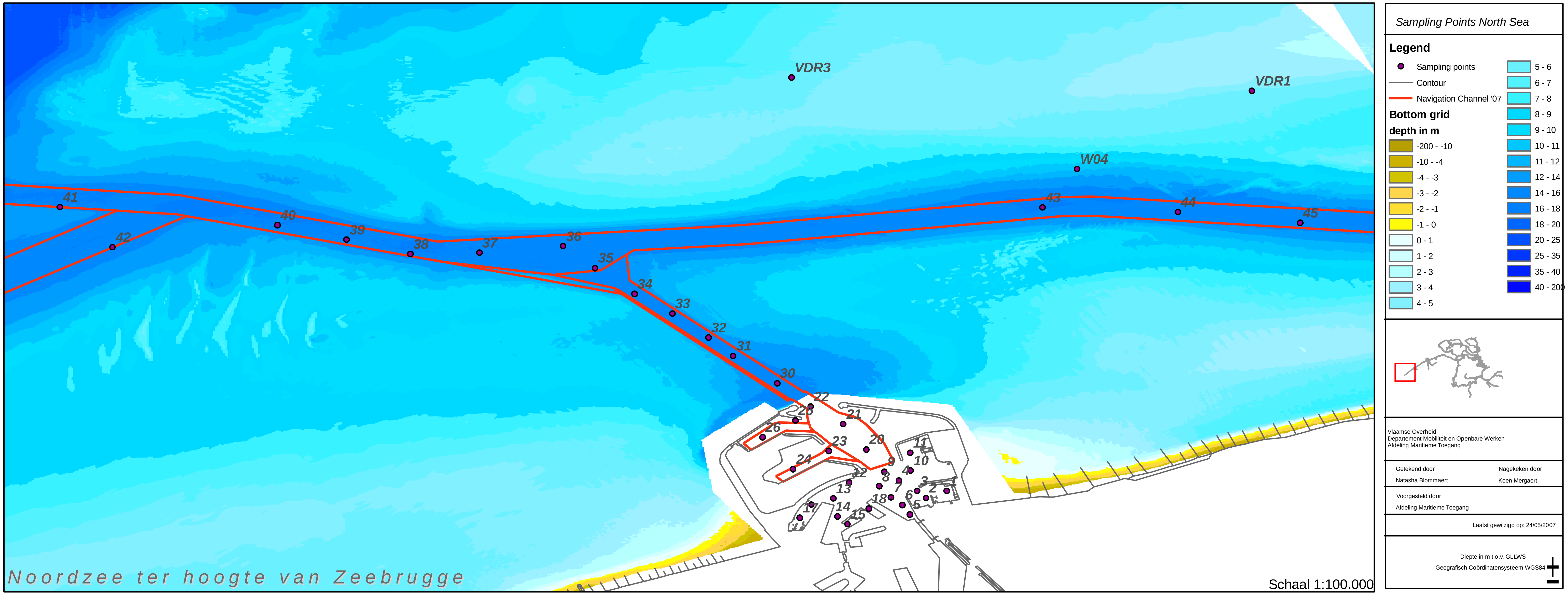
conc. : target value ≤ concentration < limit value

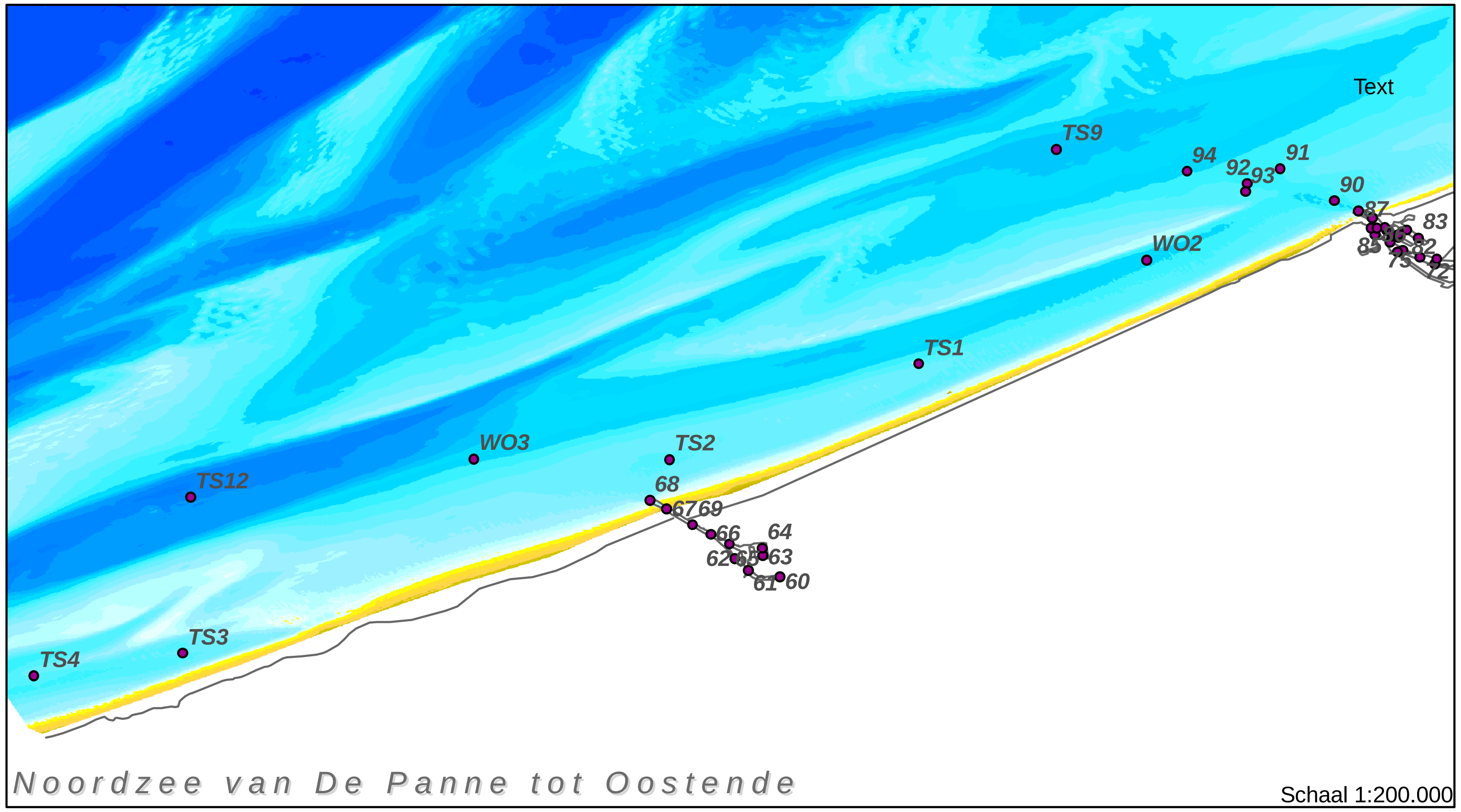
conc. : limit value ≤ concentration

(**): The value for PAH 16 EPA as given in the report 'beproevingsverslag van het onderzoek van 82 monsters sediment' (ref. nr. 01/A 0675), made by Labo Van Vooren in 2001, is not the same as we calculated based on the individual results given in this report. We calculated an average of 642 μg/goc for PAH.

8.4 Final results

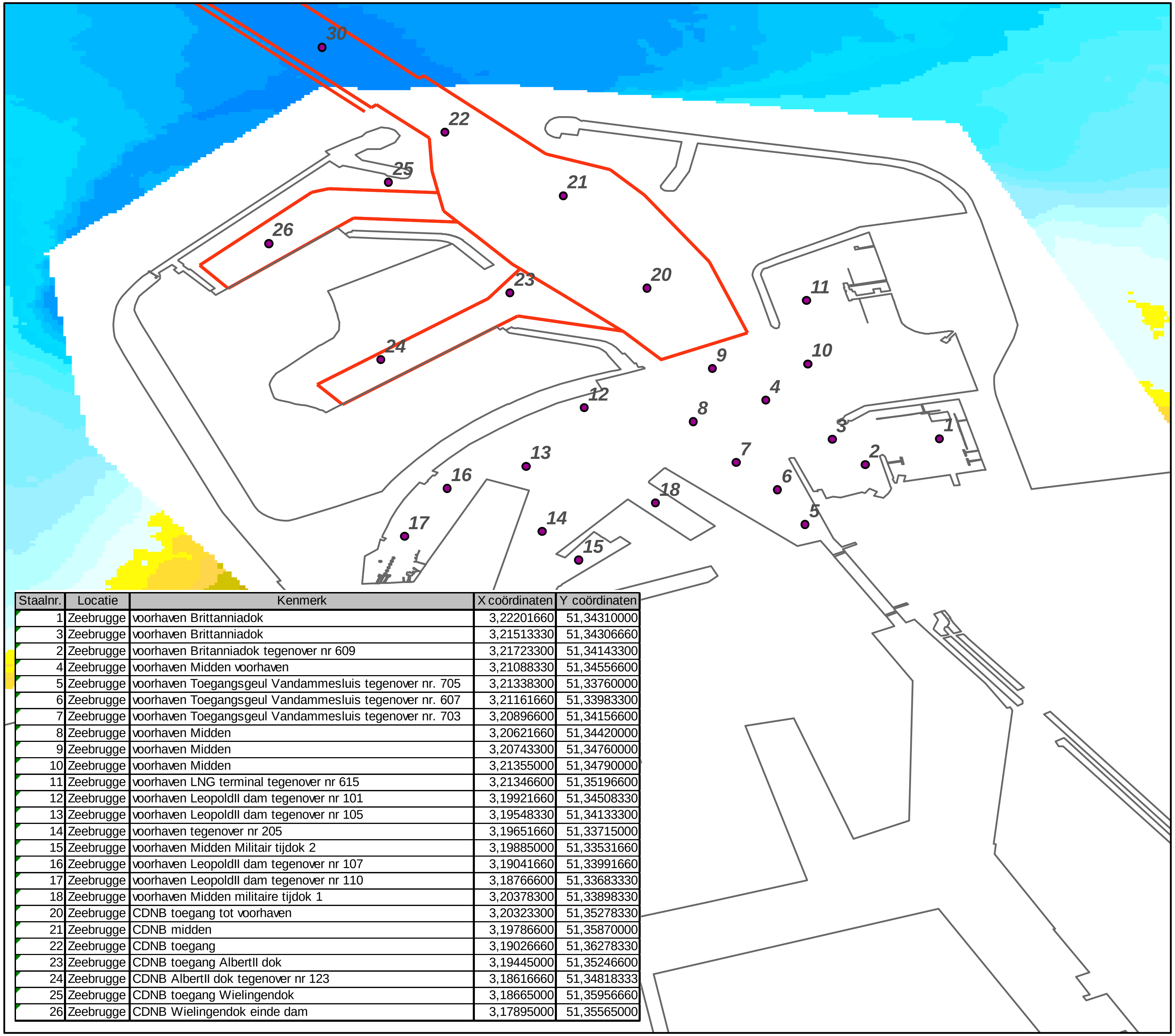
The draft report of Ecorem was received after the deadline for editing this report. Therefore, an in depth analysis could not be added to this "synthesis report".





Staalnr.	Locatie	Kenmerk	X coördinaten	Y coördinaten
30	Noordzee	Pas van Zand	3,18238330	51,36825000
31	Noordzee	Pas van Zand	3,17213300	51,37463300
32	Noordzee	Pas van Zand	3,16631660	51,37893300
33	Noordzee	Pas van Zand	3,15788330	51,38453300
34	Noordzee	Pas van Zand	3,14903300	51,38915000
35	Noordzee	Pas van Zand	3,13986600	51,39520000
36	Noordzee	Scheur West	3,13238330	51,40026600
37	Noordzee	Scheur West	3,11278330	51,39875000
38	Noordzee	Scheur West	3,09668330	51,39841660
39	Noordzee	Scheur West	3,08176600	51,40178330
40	Noordzee	Scheur West	3,06561660	51,40523300
41	Noordzee	Scheur West	3,01473300	51,40940000
42	Noordzee	Scheur West	3,02710000	51,40003300
43	Noordzee	Scheur Oost	3,24440000	51,40935000
44	Noordzee	Scheur Oost	3,27603300	51,40825000
45	Noordzee	Scheur Oost	3,30459900	51,40576600
TS1	Westende	Tussen Zuid- en Weststroombank	2,79335000	51,19543000
TS2	Nieuwpoort	Ten oosten van de havengeul	2,72238000	51,16820000
TS3	De Panne	Potje	2,58365000	51,11295000
TS4	De Panne	Trapegeer	2,54130000	51,10656000
TS9	Mariakerke	De Grote Rede	2,83254000	51,25652000
TS12	Koksijde	Westdiep	2,58596000	51,15743000
WO2	Mariakerke		2,85833000	51,22500000
WO3	Oostduinkerke	Westdiep	2,66667000	51,16833000
W04	Knokke	Bol van Knokke, ten zuiden van de vlakte van de Raan	3,25250000	51,41833000
VDR1	Noordzee	Vlakte van de Raan Oost	3,29335000	51,43661000
VDR3	Noordzee	Vlakte van de Raan West	3,18577000	51,43969000

Sampling points Zeebrugge



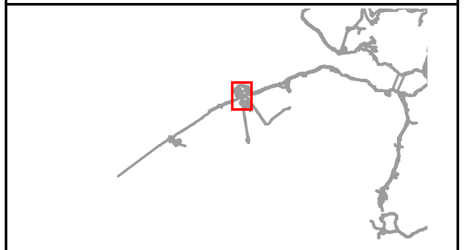
Staalnr.	Locatie	Kenmerk	X coördinaten	Y coördinaten
1	Zeebrugge	voorhaven Brittanniadok	3,22201660	51,34310000
3	Zeebrugge	voorhaven Brittanniadok	3,21513330	51,34306660
2	Zeebrugge	voorhaven Britanniadok tegenover nr 609	3,21723300	51,34143300
4	Zeebrugge	voorhaven Midden voorhaven	3,21088330	51,34556600
5	Zeebrugge	voorhaven Toegangsgeul Vandammesluis tegenover nr. 705	3,21338300	51,33760000
6	Zeebrugge	voorhaven Toegangsgeul Vandammesluis tegenover nr. 607	3,21161660	51,33983300
7	Zeebrugge	voorhaven Toegangsgeul Vandammesluis tegenover nr. 703	3,20896600	51,34156600
8	Zeebrugge	voorhaven Midden	3,20621660	51,34420000
9	Zeebrugge	voorhaven Midden	3,20743300	51,34760000
10	Zeebrugge	voorhaven Midden	3,21355000	51,34790000
11	Zeebrugge	voorhaven LNG terminal tegenover nr 615	3,21346600	51,35196600
12	Zeebrugge	voorhaven LeopoldII dam tegenover nr 101	3,19921660	51,34508330
13	Zeebrugge	voorhaven LeopoldII dam tegenover nr 105	3,19548330	51,34133300
14	Zeebrugge	voorhaven tegenover nr 205	3,19651660	51,33715000
15	Zeebrugge	voorhaven Midden Militair tijdok 2	3,19885000	51,33531660
16	Zeebrugge	voorhaven LeopoldII dam tegenover nr 107	3,19041660	51,33991660
17	Zeebrugge	voorhaven LeopoldII dam tegenover nr 110	3,18766600	51,33683330
18	Zeebrugge	voorhaven Midden militaire tijdok 1	3,20378300	51,33898330
20	Zeebrugge	CDNB toegang tot voorhaven	3,20323300	51,35278330
21	Zeebrugge	CDNB midden	3,19786600	51,35870000
22	Zeebrugge	CDNB toegang	3,19026660	51,36278330
23	Zeebrugge	CDNB toegang AlbertII dok	3,19445000	51,35246600
24	Zeebrugge	CDNB AlbertII dok tegenover nr 123	3,18616660	51,34818333
25	Zeebrugge	CDNB toegang Wielingendok	3,18665000	51,35956660
26	Zeebrugge	CDNB Wielingendok einde dam	3,17895000	51,35565000

Legend

- Sampling points
- Contour
- Navigation channel '07

Bottom grid depth in m

-200 - -10	5 - 6
-10 - -4	6 - 7
-4 - -3	7 - 8
-3 - -2	8 - 9
-2 - -1	9 - 10
-1 - 0	10 - 11
0 - 1	11 - 12
1 - 2	12 - 14
2 - 3	14 - 16
3 - 4	16 - 18
4 - 5	18 - 20
	20 - 25
	25 - 35
	35 - 40
	40 - 200



Vlaamse Overheid
Departement Mobiliteit en Openbare Werken
Afdeling Maritieme Toegang

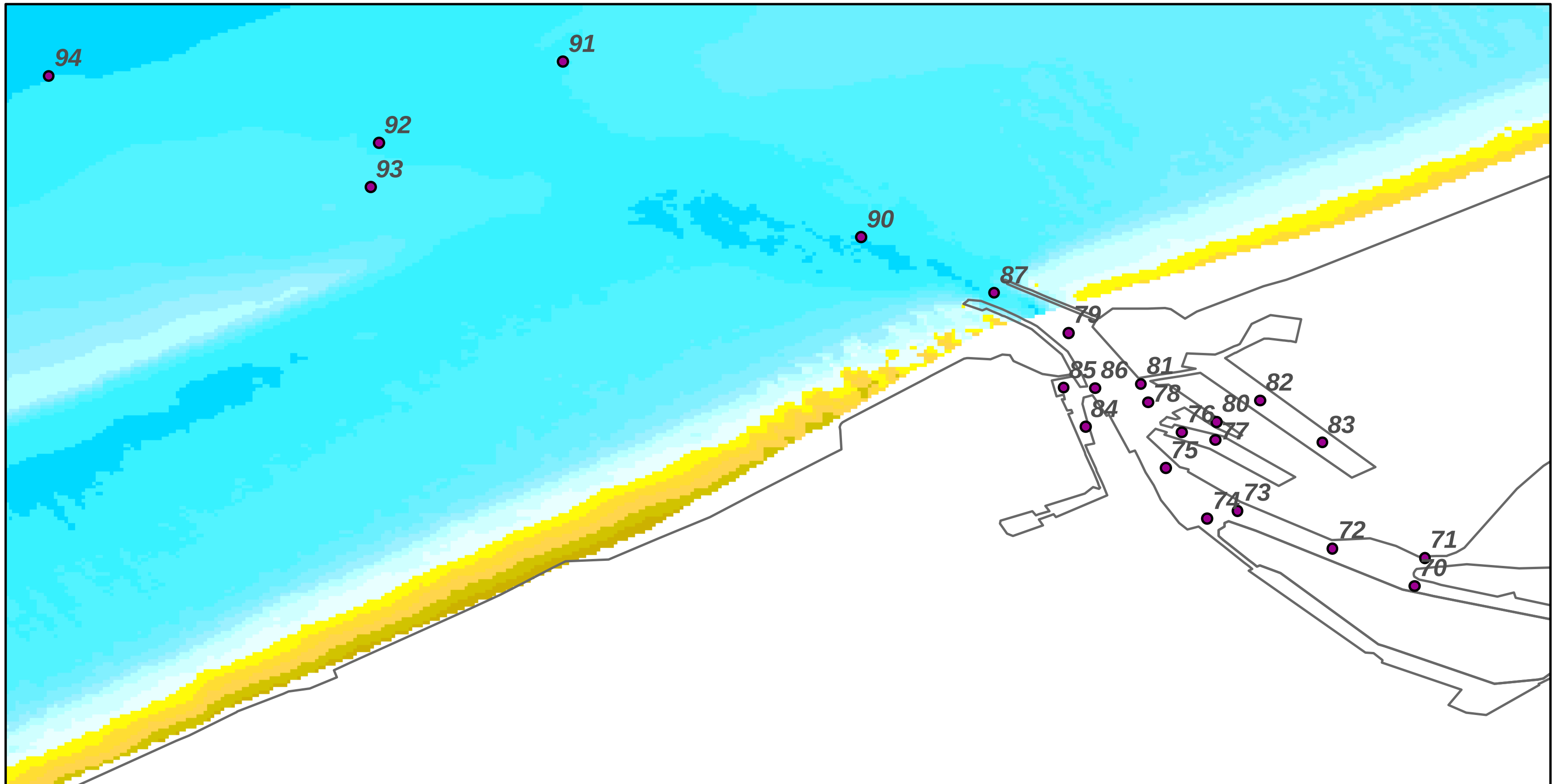
Getekend door: Natasha Blommaert
Nagekeken door: Koen Mergaert

Voorgesteld door: Afdeling Maritieme Toegang

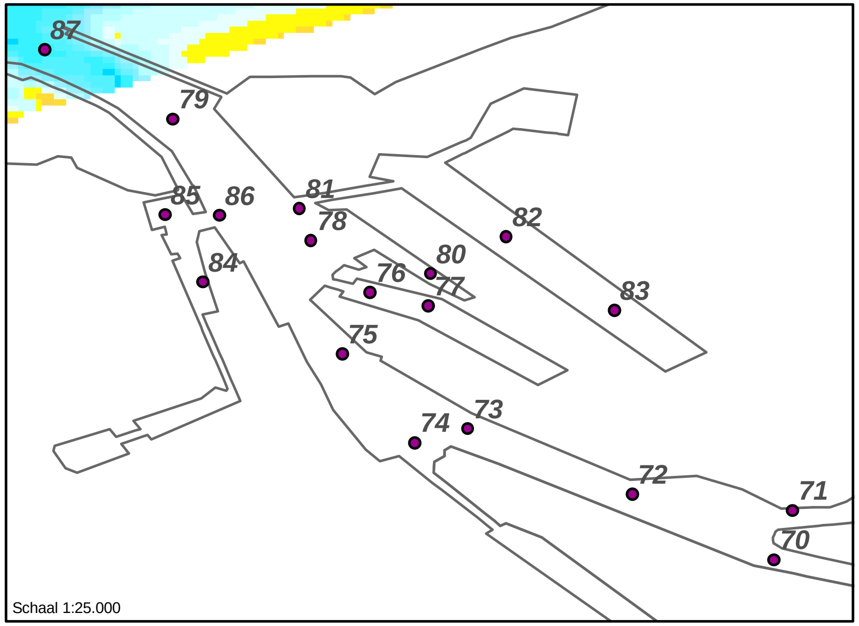
Laatst gewijzigd op: 24/05/2007

Schaal 1:0
Geografisch Coördinatensysteem WGS84
Diepte in m t.o.v. GLLWS

Sampling points Oostende



Staalnr.	Locatie	Kenmerk	X coördinaten	Y coördinaten
70	Oostende	voorhaven voor spuikom	2,94035000	51,22383300
71	Oostende	voorhaven voor kanaal Gent-Oostende	2,94090000	51,22530000
72	Oostende	voorhaven tegenover nr 205	2,93613300	51,22578330
73	Oostende	voorhaven tegenover nr 201	2,93123300	51,22773300
74	Oostende	voorhaven toegang Demeysluis	2,92965000	51,22731660
75	Oostende	voorhaven tegenover nr 104	2,92750000	51,22995000
76	Oostende	voorhaven tegenover nr 503	2,92833000	51,23178330
77	Oostende	Zeewezendok midden	2,93006600	51,23138330
78	Oostende	voorhaven tegenover nr 101	2,92658330	51,23333000
79	Oostende	Havengeul	2,92246600	51,23693300
80	Oostende	Tijdok	2,93013300	51,23233000
81	Oostende	Toegang visserijsluis	2,92623300	51,23428330
82	Oostende	Visserijdok	2,93238330	51,23343300
83	Oostende	Visserijdok	2,93560000	51,23125000
84	Oostende	Montgomerydok	2,92335000	51,23208330
85	Oostende	Montgomerydok	2,92223000	51,23408330
86	Oostende	Toegang Montgomerydok	2,92385000	51,23406660
87	Oostende	Toegang havengeul	2,91865000	51,23900000
90	Oostende	Toegangsgeul	2,91176600	51,24188000
91	Oostende	Toegangsgeul	2,89635000	51,25096600
92	Oostende	Toegangsgeul	2,88683000	51,24676600
93	Oostende	Toegangsgeul	2,88640000	51,24446600
94	Oostende	Toegangsgeul	2,86978330	51,25021660



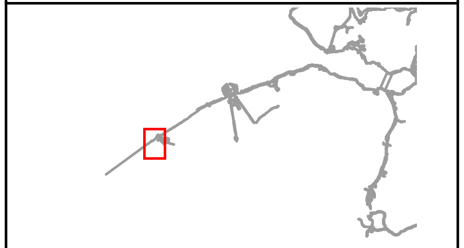
Schaal 1:25.000

Legend

- Sampling points
- Contour
- Navigation channel

Bottom grid
depth in m

- -200 - -10
- -10 - -4
- -4 - -3
- -3 - -2
- -2 - -1
- -1 - 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 25
- 25 - 35
- 35 - 40
- 40 - 200



Vlaamse Overheid
Departement Mobiliteit en Openbare Werken
Afdeling Maritieme Toegang

Getekend door: Natasha Blommaert
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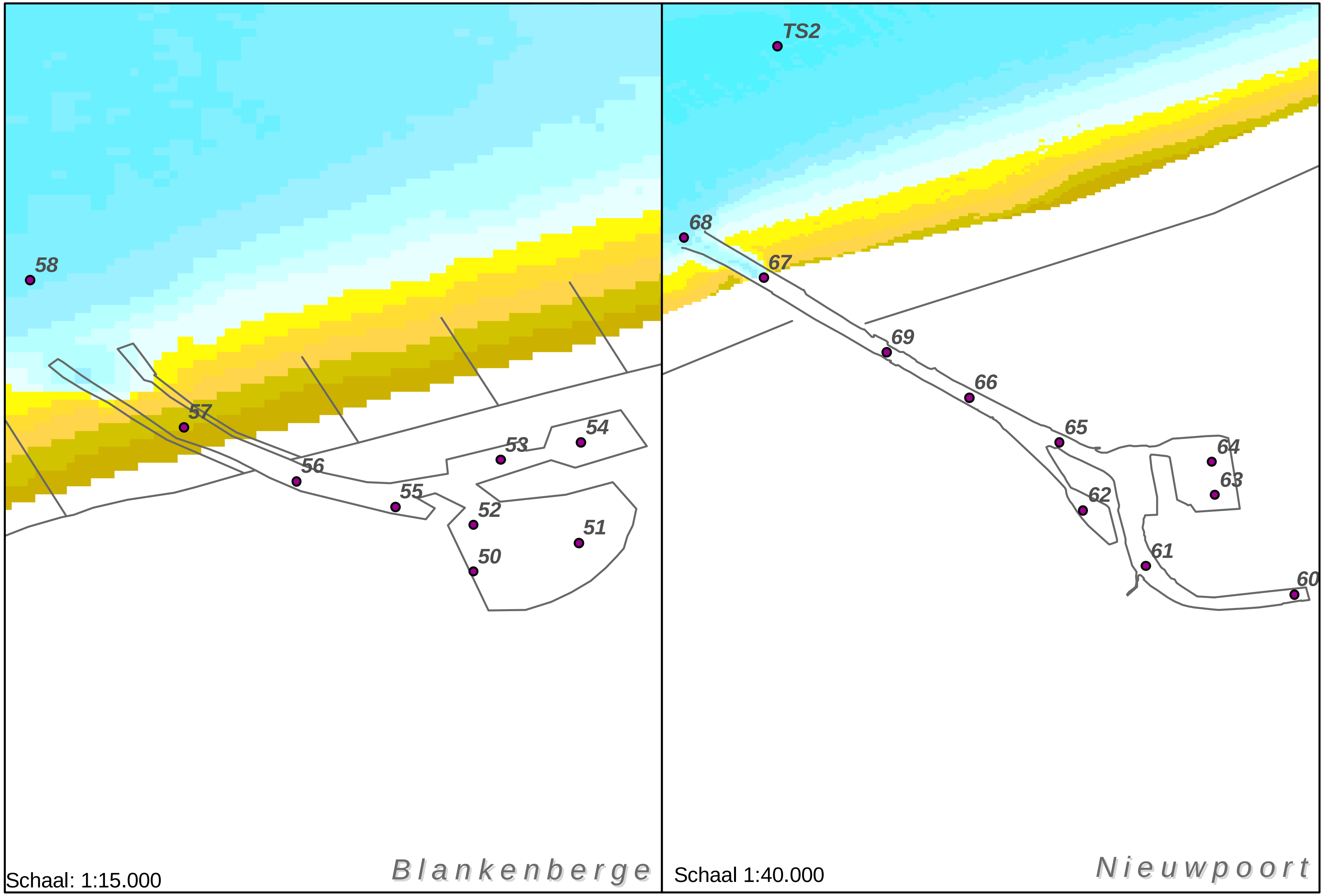
Laatst gewijzigd op: 24/05/2007

Schaal 1:0
Geografisch Coördinatensysteem WGS84
Diepte in m t.o.v. GLLWS



Sampling points Blankenberge and Nieuwpoort

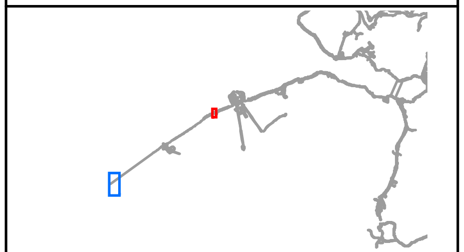
Legend

- Sampling points
- Contour
- Navigation Channel '07

Bottom grid

depth in m

-200 - -10	5 - 6
-10 - -4	6 - 7
-4 - -3	7 - 8
-3 - -2	8 - 9
-2 - -1	9 - 10
-1 - 0	10 - 11
0 - 1	11 - 12
1 - 2	12 - 14
2 - 3	14 - 16
3 - 4	16 - 18
4 - 5	18 - 20
	20 - 25
	25 - 35
	35 - 40
	40 - 200



Staalnr.	Locatie	Kenmerk	X coördinaten	Y coördinaten
50	Blankenberge	Haven spuikom	3,11750000	51,31000000
51	Blankenberge	Haven spuikom	3,11990000	51,31066000
52	Blankenberge	Haven spuikom	3,11750000	51,31106600
53	Blankenberge	Haven tijkom	3,11811660	51,31255000
54	Blankenberge	Haven tijkom	3,11995000	51,31295000
55	Blankenberge	Haven vaargeul	3,11571660	51,31148330
56	Blankenberge	Haven vaargeul	3,11346600	51,31206600
57	Blankenberge	Haven vaargeul	3,11090000	51,31330000
58	Blankenberge	Toegangsgeul	3,10740000	51,31665000

Staalnr.	Locatie	Kenmerk	X coördinaten	Y coördinaten
60	Nieuwpoort	Havengeul	2,75378330	51,13486600
61	Nieuwpoort	Havengeul	2,74476600	51,13660000
62	Nieuwpoort	Jachthaven links	2,74094990	51,13998330
63	Nieuwpoort	Jachthaven rechts	2,74896600	51,14091660
64	Nieuwpoort	Jachthaven rechts	2,74878330	51,14293300
65	Nieuwpoort	Havengeul	2,73951660	51,14411660
66	Nieuwpoort	Havengeul	2,73405000	51,14683300
67	Nieuwpoort	Haventoegang	2,72155000	51,15411833
68	Nieuwpoort	Haventoegang	2,71671660	51,15656600
69	Nieuwpoort	Havengeul	2,72900000	51,14950000

Vlaamse Overheid
Departement Mobiliteit en Openbare Werken
Afdeling Maritieme Toegang

Getekend door: Natasha Blommaert
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Voorgesteld door: Afdeling Maritieme Toegang

Laatst gewijzigd op: 24/05/2007

Diepte in m t.o.v. GLLWS
Geografisch Coördinatensysteem WGS84

9 References

Agrawal, Y.C., Pottsmith, H. C. 2000. Instruments for particle size and settling velocity observations in sediment transport. Marine Geology, 168, 89-114.

Bastin, A. 1974. Regionale sedimentologie en morfologie van de zuidelijke Noordzee en het Scheldt estuarium. PhD thesis, Katholieke Universiteit Leuven, Belgium, 91pp.

Baugh, J. V., Manning, A. J. 2007. An assesment of a new settling velocity parameterisation for cohesive sediment transport modeling. Continental Shelf Research, 27, 1835-1855.

Berlamont, J., Ockenden, M., Toorman, E. & Winterwerp, J. 1993. The characterisation of cohesive sediment properties. Coastal Engineering, 21, 105-128.

Bucke D., Vethaak D., Lang T. & Mellergaard S. (1996) ICES Techniques in Marine Environmental Sciences No. 19, March Common diseases and parasites of fish in the North Atlantic : Training guide for identification. Copenhagen, Denmark.

Calewaert J.-B., Lescrauwaet A.-K., Mees J., Seys J., Hostens K., Redant F., Moulaert I., Raemaekers M., Demaré W., Vanhooreweder B., Mergaert K., Maes F., Douvere F., Belpaeme, K., Maelfait H., Kyramarios M., Tak P., Overloop S., Peeters B. (2005) MIRA- Milieurapport Vlaanderen, Achtergronddocument 2005, Kust en zee. Vlaamse Milieumaatschappij, www.milieurapport.be

Calewaert J.-B., Lescrauwaet A.-K., Mees J., Seys J., Hostens K., Redant F., Moulaert I., Raemaekers M., Demaré W., Belpaeme, K., Maelfait H., Kyramarios M., Tak P., Maes F., Douvere F., Overloop S., Peeters B. (2005) Hoofdstuk 8 Kust en Zee: Te weinig vis, te veel vervuiling. In: Van Steertegem M. (Ed.) (2005) Milieurapport Vlaanderen Thema's MIRA-T 2005. LanooCampus, Leuven, 145-159. www.milieurapport.be

Chang, T.S., Joerdel, O., Flemming, B.W., Bartholomä, A. 2006. The role of particle aggregation/ disaggregation in muddy sediment dynamics and seasonal sediment turnover in a back-barrier tidal basin, East Frisian Wadden Sea, southern North Sea. Marine Geology 235, 49-61.

Cooreman K., Hillewaert H., Raemaekers M. Guns M. & Van Hoeyweghen P. (2001) Biologische monitoring van lossingen van gebaggerd materiaal voor de Belgische kust (1999-2001). Rapport BAG/6, 124 p.

Curran, K.J., Hill, P.S., Milligan, T.G., Mikkelsen, O.A., Law, B.A., Durrieu de Madron, X., Bourrin, F. 2007. Settling velocity, effective density, and mass composition of suspended sediment in a coastal bottom boundary layer, Gulf of Lions, France. Continental Shelf Research, 27, 1408–1421.

De Mulder, T., 2006. Numeriek model voor de haven van Zeebrugge, Deelrapport 1: Opmaak en eerste afregeling van een tweedimensionaal model zonder zout. Waterbouwkundig Laboratorium Borgerhout, Model 643/7, 32 + 14 pp.

Dyer, K. R. 1989. Sediment processes in estuaries: future research requirements. Journal of Geophysical Research, 94, C10, 14327-14339.

Dyer, K. R., Moffat, T. J. 1998. Fluxes of suspended matter in the East Anglian plume, Southern North Sea. Continental Shelf Research, 18, 1311-1331.

Dyer, K.R., Cornelisse, J., Dearnaley, M.P., Fennessy, M.J., Jones, S.E., Kappenberg, J., McCave, I.N., Pejrup, M., Puls, W., van Leussen, W., Wolfstein, K., 1996. A comparison on *in situ* techniques for estuarine floc settling velocity measurements. Journal of Sea Research, 36, 15-29.

Eisma, D. 1981. Supply and deposition of suspended matter in the North Sea. In: Holocene Marine Sedimentation in the North Sea Basin. Nio, D. D., Shuttenhelm, R. T. E., van Weering, T. C. E., (eds.). International Association of Sedimentolgy, Special Publication 5, Blackwell Scientific Publication, 415-428.

Eisma, D., Bale, A.J., Dearnaley, M.P., Fennessy, M.J., van Leussen, W., Maldiney, M.-A., Pfeiffer, A., Wells, J.T. 1996. Intercomparison of *in situ* suspended matter (floc) size measurements. Journal of Sea Research, 36, 3-14.

Eisma, D., Kalf, J. 1987. Distribution, organic content and particle size of suspended matter in the North Sea. Netherlands Journal of Sea Research, 21, 265-285.

Fettweis M., Francken, F., Pison, V., Van den Eynde D. 2006b. Suspended particulate matter dynamics and aggregate sizes in a high turbidity area. Marine Geology, 235, 63-74.

Fettweis, M. 2008. Uncertainty of effective density and settling velocity of mud flocs derived from in situ measurements. Estuarine, Coastal and Shelf Science (accepted).

Fettweis, M., Du Four, I., Zeelmaekers, E., Baeteman, C., Francken, F., Houziaux, J.-S., Mathys, M., Nechad, B., Pison, V., Vandenberghe, N., Van den Eynde, D., Van Lancker, V., Wartel, S. 2007a. Mud Origin, Characterisation and Human Activities (MOCHA). Final Scientific Report, Belgian Science Policy, 59pp.

Fettweis, M., Francken, F. & Van den Eynde, D. 2005. MOnitoring en MOdellering van het cohesieve sedimenttransport en evaluatie van de effecten op het mariene ecosysteem ten gevolge van bagger- en stortoperaties (MOMO). Activiteitsrapport (april 2005 - september 2005). BMM, Brussel. MOMO/2/MF/200512/NL/AR/3, 27pp+app.

Fettweis, M., Francken, F., Van den Eynde, D. 2007c. MOMO activiteitsrapport (oktober 2006 – maart 2007). BMM-rapport MOMO/3/MF/200707/NL/AR/2, 62pp + app.

Fettweis, M., Francken, F., Wartel, S. & Van den Eynde, D. 2006a. MOMO activiteitsrapport (oktober 2005 – maart 2006). BMM-rapport MOMO/2/MF/200606/NL/AR/4, 43pp + app.

Fettweis, M., Nechad, B., Van den Eynde, D. 2007b. An estimate of the suspended particulate matter (SPM) transport in the southern North Sea using SeaWiFS images, in-situ measurements and numerical model results. Continental Shelf Research, 27, 1568-1583.

Fettweis, M., Pison, V., Van den Eynde, D. 2006c. MOMO activiteitsrapport (april 2006 – september 2006). BMM-rapport MOMO/3/MF/200612/NL/AR/1, 14pp + app.

Fettweis, M., Van den Eynde, D. 2003. The mud deposits and the high turbidity in the Belgian-Dutch coastal zone, Southern bight of the North Sea. Continental Shelf Research, 23, 669-691.

Flemming, B. W. 2002. Effects of climate and human interventions on the evolution of the Wadden Sea depositional system (southern North Sea). In: Climate development and history of the North Atlantic Realm, Wefer, G., Berger, W., Behrke, K.-E.,Jansen, E. (eds.), Springer-Verlag, 399-413.

Fofonoff, N.P., Millard, R.C. 1983. Algorithms for computation of fundamental properties of seawater. UNESCO Technical Papers in Marine Science, 44, UNESCO Division of Marine Science, Paris. 53pp.

Folk, R.L. 1966. A review of grain-size parameters. Sedimentology 6: 73-93.

Fugate, D.C, Friederichs, C.T. 2002: Determining concentration and fall velocity of estuarine particle populations using ADV, OBS and LISST, Continental Shelf Research, 22, 1867-1886.

Fugate, D.C., Friederichs, C.T. 2003. Controls on suspended aggregate size in partially mixed estuaries. Estuarine Coastal and Shelf Science, 58, 389-404.

Gartner, J.W., Cheng, R.T., Wang, P.F., Richter, K. 2001: Laboratory and field evaluations of the LISST-100 instrument for suspended particle size distributions, Marine Geology, 175, 199-219.

Hostens K. (2006) Cruise report Belgica, Campaign ST2006/04a,b,c. 29p.

Hostens, K., Moulaert I., Parmentier K., Hillewaert H., Hoffman S., Bekaert K. & Cooreman K. (in prep.). Biologische, chemische en biochemische monitoring van sediment en bodemorganismen bij het lossen van gebaggerd materiaal voor de Belgische kust (2004 - 2005). Rapport BAG/8.

Hostens, K., Moulaert I., Raemaekers M., Hillewaert H. & Cooreman K. (2005). Biologische en chemische monitoring van sediment en bodemorganismen bij het lossen van gebaggerd materiaal voor de Belgische kust (2001 - 2003). Rapport BAG/7, 100 p.

Jaffe, B. E., Smith, R. E., Foxgrover, A. C. 2007. Anthropogenic influence on sedimentation and intertidal mudflat change in San Pablo Bay, California: 1856-1983. Estuarine Coastal and Shelf Science, 73, 175-187.

Khelifa, A., Hill, P.S. 2006. Models for effective density and settling velocity of flocs. Journal of Hydraulic Research, 44, 390-401.

Kranenburg, C. 1994. On the fractal structure of cohesive sediment aggregates. Estuarine Coastal and Shelf Science, 39, 451-460.

Lafite, R., Shimwell, S.J., Nash, L.A., Dupont, J.P., Huault, M.F., Grochowski, N.T.L., Lamboy, J.M., Collins, M.B., 1993. Sub-Task S1: Suspended material fluxes through the Strait of Dover, Hydrodynamics and Biogeochemical Fluxes in the Eastern Channel: Fluxes into the North Sea. FLUXMANCHE I Second annual rep., MAST 0053-C (EDB), 81-106.

Lauwaert, B., De Brauwer, D., Fettweis, M., Hillewaert, H., Hostens, K., Mergaert, K., Moulaert, I., Parmentier, K. & Verstraeten, J. 2006. Syntheserapport over de effecten op het mariene milieu van baggerspeciestortingen (vergunningsperiode 2004-'06). BMM, ILVO & AMT rapport, BL/2006/01, 87pp + app.

Lick, W., Huang, H., Jepsen, R. 1993. Flocculation of fine-grained sediments due to differential settling. Journal of Geophysical Research, 98 (C6), 10279-10288.

Luyten, P. J., Jones, J. E., Proctor, R., Tabor, A., Tett, P., Wild-Allen, K. 1999. COHERENS A Coupled Hydrodynamical-Ecological Model for Regional and Shelf Seas: User Documentation. MUMM report, Brussels. 911pp. [available on CD-ROM: http://www.mumm.ac.be/coherens].

Maggi, F. 2007. Variable fractal dimension: a major control for floc structure and flocculation kinematics of suspended cohesive sediments. Journal of Geophysical Research, 112, C07012.

Maggi, F., Mietta, F., Winterwerp, J.C. 2007. Effect of variable fractal dimension on the floc size distribution of suspended cohesive sediment. Journal of Hydrology, 343, 43-55.

Mai, S., Bartholomä, A. 2000. The missing mud flats of the Waddeb Sea: a reconstruction of sediments and accomodation space lost in the wake of land reclamation. In: Muddy Coast Dynamics and Resource Management. Flemming, B. W., Delafontaine, M. T., Liebezeit, G. (eds.), Elsevier, Proc. Marine Science, 2, 257-272.

McManus, J.P., Prandle, D. 1997. Development of a model to reproduce observed suspended sediment distributions in the southern North Sea using Principal Component Analysis and Multiple Linear Regression. Continental Shelf Research, 17, 761-778.

Meakin, P. 1991. Fractal aggregates in geophysics. Review of Geophysics, 29, 317-354

Mellergaard S., Nielsen E. (1997) Epidemiology of lymphocystis, epidermal papilloma and skin ulcers in common dab *Limanda limanda* along the west coast of Denmark. Dis Aquat Org, Vol. 30: 151-163. p 151 – 163.

Mikkelsen, O. A., Pejrup, M. 2001. The use of a LISST-100 laser particle sizer for in-situ estimates of floc size, density and settling velocity. Geo-Marine Letters, 20, 187-195.

Moulaert I, Hostens K, Hillewaert H and Wittoeck J (2007) Spatial variation of the macrobenthos species and communities of the Belgian Continental Shelf and the relation to environmental variation. ICES CM 2007/A:09

Moulaert I. & Hillewaert H., Evaluation of dredging disposal on the macrobenthos of the Belgian Continental Shelf. In: Report of the Study Group on Ecological Quality Objectives for Sensitive and for Opportunistic Benthos Species (SGSOBS). ICES CM 2004/ACE:01,15

Pilatti, M.A., Ghiberto, P.J., Imhoff, S. 2006. Application of a general relationship between soil particle density and organic matter to mollisols of Santa Fe (Argentina). 18th World Congress of Soil Science, USA.

Prandle, D., Ballard, G., Flatt, D., Harrison, A. J., Jones, S. E., Knight, P. J., Loch, S. G., McManus, J. P., Player, R., Tappin, A. 1996. Combining modelling and monitoring to determine fluxes of water, dissolved and particulate metals through the Dover Strait. Continental Shelf Research, 16, 237-257.

Ruddick, K., Ovidio, F., Rijkeboer, M. 2000. Atmospheric correction of SeaWiFS imagery for turbid coastal and inland waters. Applied Optics, 39, 897-912.

Spearman, J. R., Roberts, W. 2002. Comparison of flocculation models for applied sediment transport modelling. In: Fine sediment dynamics in the marine environment. Winterwerp, J. C., Kranenburg, C. (eds.). Proc. Marine Science, 5, 277-293.

Ten Brinke, W.B.M., Dronkers, J. 1993. Physical and biotic aspects of fine-sediment import in the OosterScheldt tidal basin (The Netherlands). Netherlands Journal of Sea Research, 31, 19-36.

Uchiyama, Y., 2004. Wetting and drying scheme for POM and its application to San Francisco Bay. Proc. 6th Int. Conf. on Hydrodynamics, Perth, Australia.

Van Alphen, J. S. L. J. 1990. A mud balance for Belgian-Dutch coastal waters between 1969 and 1986. Netherlands Journal of Sea Research, 25, 19-30.

Van den Eynde, D., Giardino, A., Portilla, J., Fettweis, M., Francken, F., Monbaliu, J. 2008. Modelling the effects of sand extraction on the sediment transport due to tides on the Kwinte Bank. J. Coastal Res. (in press).

Van den Eynde, D., Nechad, B., Fettweis, M. & Francken, F. 2006. Seasonal variability of suspended particulate matter observed from SeaWiFS images near the Belgian coast. In: Estuarine and Coastal Fine Sediment Dynamics. Maa, J. P.-Y., Sanford, L. P., Schoelhammer, D. H. (eds.). Proc. Marine Science, 8, 291-311.

van der Lee, W. T. B. 2000. The settling of mud flocs in the Dollard estuary, The Netherlands. PhD thesis, Univ. Utrecht, The Netherlands, 133pp.

Van Lancker, V., Du Four, I., Verfaillie, E., Deleu, S., Schelfaut, K., Fettweis, M., Van den Eynde, D., Francken, F., Monbaliu, J., Giardino, A., Portilla, J., Lanckneus, J., Moerkerke, G. and Degraer, S. 2007b. Management, research and budgetting of aggregates in shelf seas related to end-users (Marebasse). Final Scientific Report. Belgian Science Policy, 125pp.

Van Lancker, V.; Deleu, S., Bellec, V., Du Four, I., Schelfaut, K., Verfaillie, E., Fettweis, M., Van den Eynde, D., Francken, F., Monbaliu, J., Giardino, A., Portilla, J., Lanckneus, J., Moerkerke, G., Degraer, S. 2007a. MAREBASSE: Bridging gaps with other disciplines and end-users. In: Science and sustainable management of the North Sea: Belgian case studies. Calewaert, J.-B., Maes, F. (eds.), Academia Press, 83-136.

van Leussen, W. 1994. Estuarine macroflocs and their role in fine-grained sediment transport. PhD thesis, Univ. Utrecht, The Netherlands, 488pp.

Velegrakis, A.F., Bishop, C., Lafite, R., Oikonomou, E.K., Lecouturier, M., Collins, M.B., 1997. Sub-Task S3: Investigation of meso- and macro-scale sediment transport, Hydrodynamics Biogeochemical Processes and Fluxes in the Channel. FLUXMANCHE II Final report, MAST II, MAS2CT940089, 128-143.

Violeau, D., Bourban, S., Cheviet, C., Markofsky, M., Petersen, O., Roberts, W., Spearman, J., Toorman, E., Vested, H.J., Weilbeer, H. 2002. Numerical simulation of cohesive sediment transport: intercomparison of several numerical models. In: Fine sediment dynamics in the marine environment. Winterwerp, J. C., Kranenburg, C. (eds.). Proc. Marine Science, 5, 75-89.

Winterwerp, J. 1998. A simple model for turbulence induced flocculation of cohesive sediments. Journal of Hydraulic Research, 36, 309-326.

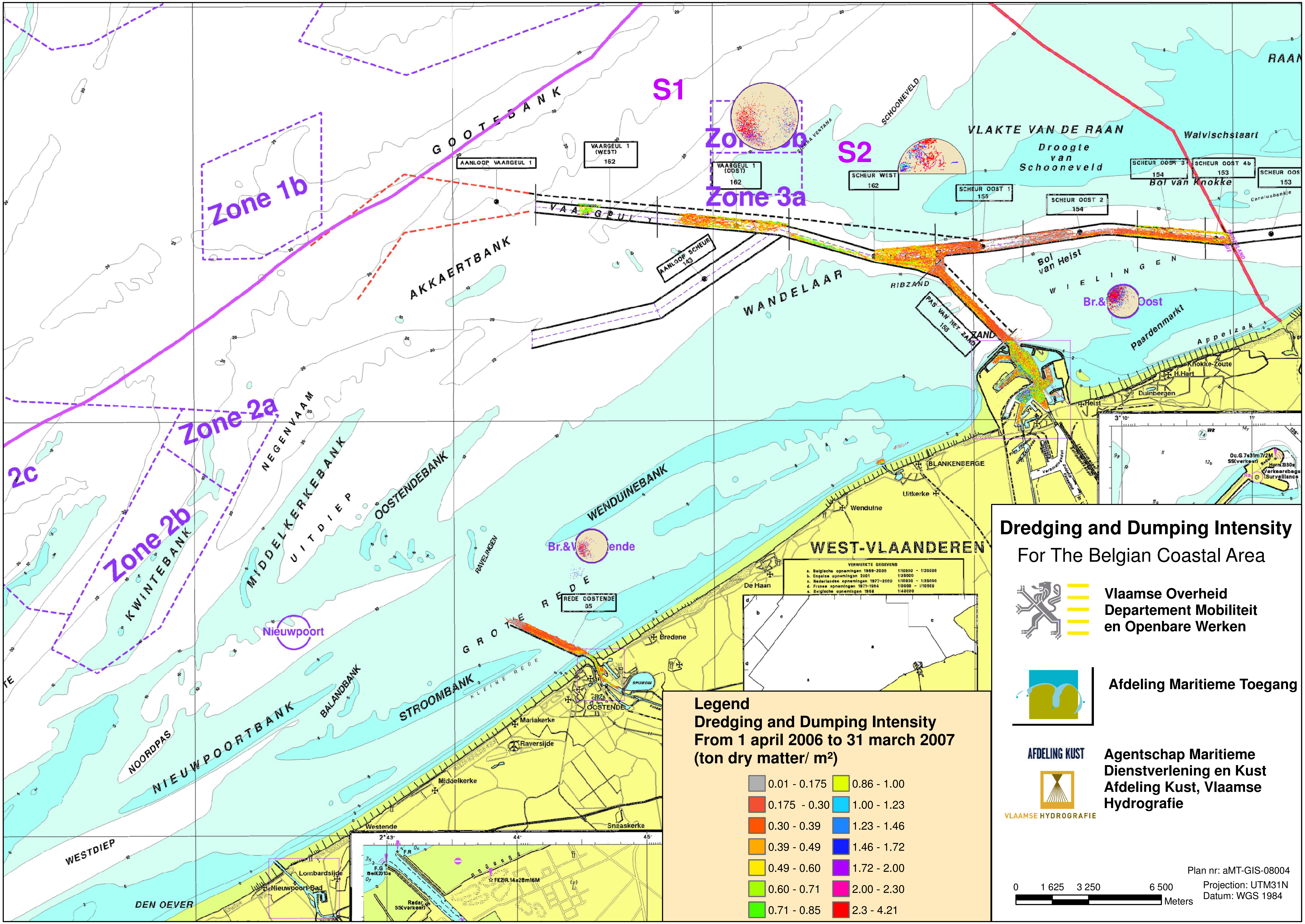
Winterwerp, J. 2001. Stratification effects by cohesive and non-cohesive sediment. Journal of Geophysical Research, 106 (C10), 22559-22574.

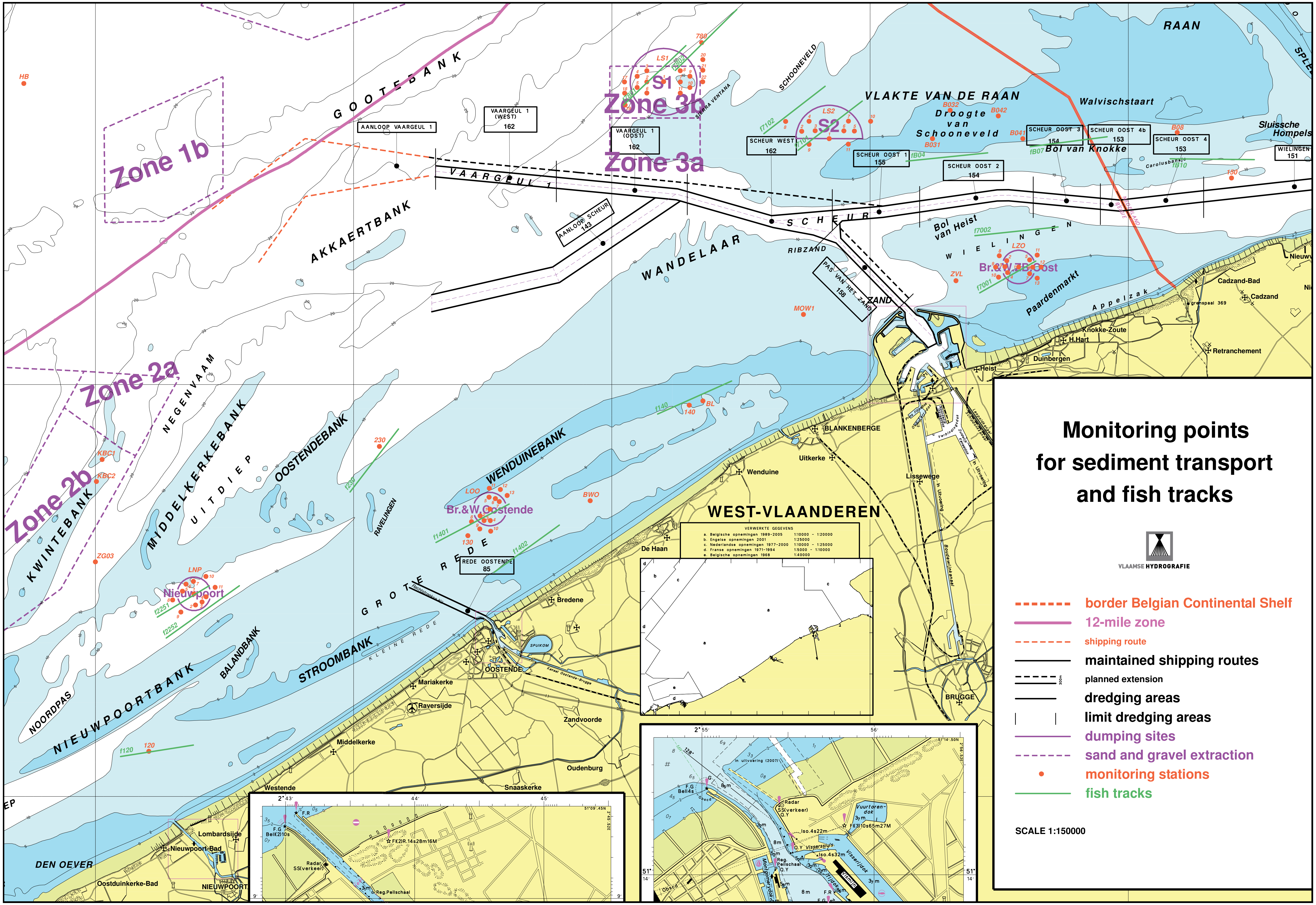
Winterwerp, J., Manning, A.J., Martens, C., De Mulder, T., Vanlede, J. 2006. A heuristic formula for turbulence-induced flocculation of cohesive sediment. Estuarine, Coastal and Shelf Science, 68, 195-207.

Wittoeck J., Hostens K., Hillewaert H., Cooreman K., Vandenberghe E., Mees J., Deprez T., Vincx M. & Degraer S. (2005) Long-term trends of the macrobenthos of the Belgian Continental Shelf (MACROBEL): final report. Belgian Federal Science Policy Office, 66p.

10 Abbreviations

ADCP	Acoustic Doppler Current Profiler
BCS	Belgian Continental Shelf
LISST	Laser In-Situ Scattering and Transmissometer
LNP	Br.&W. Nieuwpoort
LOO	Br.&W. Oostende
LS1	Br.&W. S1
LS2	Br.&W. S2
LZO	Br.&W. Zeebrugge Oost
OBS	Optical Backscatter Sensor
OM	Organic Matter
POC	Particulate Organic Carbon
PON	Particulate Organic Nitrogen
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SPM	Suspended Particulate Matter
TDM	Tons of Dry Matter
TOA	Top Of Atmosphere
TOC	Total Organic Carbon
UKMO	United Kingdom Meteorological Office


Dredging and Dumping Intensity
For The Belgian Coastal Area
Vlaamse Overheid
Departement Mobiliteit
en Openbare Werken
Afdeling Maritieme Toegang
AFDELING KUST
Agentschap Maritieme
Dienstverlening en Kust
Afdeling Kust, Vlaamse
Hydrografie
VLAAMSE HYDROGRAFIE
Legend
Dredging and Dumping Intensity
From 1 april 2006 to 31 march 2007
(ton dry matter/ m²)
0.01 - 0.175
0.175 - 0.30
0.30 - 0.39
0.39 - 0.49
0.49 - 0.60
0.60 - 0.71
0.71 - 0.85
0.86 - 1.00
1.00 - 1.23
1.23 - 1.46
1.46 - 1.72
1.72 - 2.00
2.00 - 2.30
2.3 - 4.21
Plan nr: aMT-GIS-08004
Projection: UTM31N
Datum: WGS 1984
0
1 625
3 250
6 500
Meters
S1
S2
Zone 1b
Zone 2a
Zone 2b
2c
Zone 3a
Nieuwpoort
Br.&W. Oost
GOOTEBANK
AKKAERTBANK
WANDELAAR
VLAKTE VAN DE RAAN
Droogte van Schooneveld
Walvischstaart
Bol van Knokke
Bol van Heist
WIELINGEN
Paardenmarkt
Appelzak
SCHOONEVELD
RIBZAND
PAS VAN HET ZAND
AANLOOP VAARGEUL 1
VAARGEUL 1 (WEST) 162
VAARGEUL 1 (OOST) 162
SCHEUR WEST 162
SCHEUR OOST 1 155
SCHEUR OOST 2 154
SCHEUR OOST 3 154
SCHEUR OOST 4b 153
AANLOOP SCHEUR 143
REDE OOSTENDE 85
NEGENVAAM
MIDDELKERKEBANK
UITDIEP
OOSTENDEBANK
WENDUINEBANK
KWINTEBANK
RAVELINGEN
GROTE REDE
KLEINE REDE
STROOMBANK
BALANDBANK
NIEUWPOORTBANK
NOORDPAS
WESTDIEP
DEN OEVER
WEST-VLAANDEREN
BLANKENBERGE
Uitkerke
Wenduine
De Haan
Bredene
OOSTENDE
Mariakerke
Raversijde
Middelkerke
Westende
Snaaskerke
Lombardsijde
Nieuwpoort-Bad
Knokke-Zoute
Duinbergen
Heist
RAAN


Monitoring points for sediment transport and fish tracks
VLAAMSE HYDROGRAFIE
border Belgian Continental Shelf
12-mile zone
shipping route
maintained shipping routes
planned extension
dredging areas
limit dredging areas
dumping sites
sand and gravel extraction
monitoring stations
fish tracks
SCALE 1:150000
WEST-VLAANDEREN
Zone 1b
Zone 2a
Zone 2b
Zone 3a
Zone 3b
S1
S2
Br.&W.Oostende
Br.&W.ZB-Oost
Nieuwpoort
GOOTEBANK
AKKAERTBANK
WANDELAAR
VLAKTE VAN DE RAAN
Droogte van Schooneveld
RAAN
Walvischstaart
Bol van Knokke
Bol van Heist
WIELINGEN
Paardenmarkt
Appelzak
SCHEUR
VAARGEUL 1
RIBZAND
PAS VAN HET ZAND
SCHOONEVELD
NEGENVAAM
MIDDELKERKEBANK
UITDIEP
OOSTENDEBANK
WENDUINEBANK
RAVELINGEN
KWINTEBANK
GROTE REDE
KLEINE REDE
STROOMBANK
BALANDBANK
NIEUWPOORTBANK
NOORDPAS
DEN OEVER
AANLOOP VAARGEUL 1
VAARGEUL 1 (WEST) 162
VAARGEUL 1 (OOST) 162
SCHEUR WEST 162
SCHEUR OOST 1 155
SCHEUR OOST 2 154
SCHEUR OOST 3 154
SCHEUR OOST 4b 153
SCHEUR OOST 4 153
WIELINGEN 151
AANLOOP SCHEUR 143
PAS VAN HET ZAND 158
REDE OOSTENDE 85
BLANKENBERGE
Wenduine
Uitkerke
Lissewege
De Haan
Bredene
OOSTENDE
Mariakerke
Raversijde
Middelkerke
Westende
Lombardsijde
Nieuwpoort-Bad
NIEUWPOORT
Oostduinkerke-Bad
Zandvoorde
Oudenburg
Snaaskerke
BRUGGE
Heist
Duinbergen
Knokke-Zoute
Cadzand-Bad
Cadzand
Retranchement
Sluissche Hompels
VERWERKTE GEGEVENS
a. Belgische opnemingen 1989-2005 1:10000 - 1:20000
b. Engelse opnemingen 2001 1:25000
c. Nederlandse opnemingen 1977-2000 1:10000 - 1:25000
d. Franse opnemingen 1971-1994 1:5000 - 1:10000
e. Belgische opnemingen 1968 1:40000