



**Final Report**

**FEHMARNBELT FIXED LINK  
MARINE BIOLOGY SERVICES (FEMA)**

**Marine Soil - Baseline**

**Seabed Chemistry of the Fehmarnbelt Area**

**Including Assessment of Chemical Risks of Sediment  
Suspension**

**E1TR0056 - Volume II**



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Model software geographic plots: Also data from Farvandsvæsenet and Bundesamt für Seeschifffahrt und Hydrographie

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#### Note to the reader:

In this report the time for start of construction is artificially set to 1 October 2014 for the tunnel and 1 January 2015 for the bridge alternative. In the Danish EIA (VVM) and the German EIA (UVS/LBP) absolute year references are not used. Instead the time references are relative to start of construction works. In the VVM the same time reference is used for tunnel and bridge, i.e. year 0 corresponds to 2014/start of tunnel construction; year 1 corresponds to 2015/start of bridge construction etc. In the UVS/LBP individual time references are used for tunnel and bridge, i.e. for tunnel construction year 1 is equivalent to 2014 (construction starts 1 October in year 1) and for bridge construction year 1 is equivalent to 2015 (construction starts 1st January).

## **APPENDICES**

- A Position, date of sampling, depth at station, sediment core length and comments related to sampling of sediments
- B Dry weight, loss on ignition and concentration of total nitrogen and total phosphorus in sediments
- C Raw data from nutrient elutriate test
- D Concentration of heavy metals in sediments
- E Concentration of persistent organic pollutants in sediments
- F Sediment oxygen consumption (raw data)
- G Relation between sediment dry weight and sediment density
- H Cumulative grain size distribution of surface sediments



## **List of Abbreviations and Acronyms**

As	Arsenic (heavy metal)
BLST	Nature Protection Agency under Ministry for Environment
BOD	Biological Oxygen Demand
BSH	German Federal Maritime and Hydrographic Agency (coordinates marine monitoring)
Cd	Cadmium (heavy metal)
Cr	Chromium (heavy metal)
Cu	Copper (heavy metal)
CVAAS	Atomic Absorption Spectrometry using cold vapour technique
Danish EPA	Danish Environmental Protection Agency
DBT	Dibutyltin
DDD	1,1-dichloro-2,2-bis(p-chlorophenyl)ethane
DDE	1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene
DDT	1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane
DIN	Dissolved inorganic nitrogen (sum of NO <sub>2</sub> -N, NO <sub>3</sub> -N, NH <sub>4</sub> -N)
DO	Dissolved oxygen
DW	Dry Weight
ERL	Effects Range Low (10 <sup>th</sup> percentiles on an ordered list of pollutant concentrations in sediments found that co-occur with any biological effect)
ETAAS	Atomic Absorption Spectrometry using graphite furnace
GCMS	Gas Chromatography / Mass Spectrometry
H Ac	Higher Action level (SQG used by the Danish EPA)
HBC	Hexachlorbenzene
Hg	Mercury (heavy metal)
HPLC	High-Performance Liquid Chromatography
ICES	International Council for the Exploration of the Sea (ICES coordinates and promotes marine research in the North Atlantic)
L Ac	Lower Action level (SQG used by the Danish EPA, concentrations below L Ac are considered unproblematic)
LOI	Loss on Ignition (equivalent to organic content)
MBT	Monobutyltin
Ni	Nickel (heavy metal)
O <sub>2</sub>	Oxygen
OSPAR	Oslo and Paris Commission (to protect NE Atlantic against land and sea based pollution)
PAH	Polynuclear Aromatic Hydrocarbons
Pb	Lead (heavy metal)
PBC	Polychlorinated biphenyl
PBDE	Polybrominated diphenyl ether (flame retardant)
POP	Persistent organic pollutants (not a chemical group)
R1, R2	German SQG (Richtwerte – concentrations below R1 are considered unproblematic)
SQG	Sediment Quality Guidelines
TBT	Tributyltin
Tot-N	Total nitrogen (include both inorganic and organic bound nitrogen)
Tot-P	Total phosphorus (include both inorganic and organic bound phosphorus)
Zn	Zinc (heavy metal)



## **SUMMARY AND CONCLUSION**

The Sediment Chemistry Report describes the results of the sediment sampling and subsequent analysis for pollutants, nutrients and release of nutrients as well as consumption of oxygen under suspension of sediment (simulating a dredging situation). The field sampling included 18 sampling stations along the Fixed Link alignment corridor, and surface and sub-surface analysis of the sediment chemistry. The samples were collected using a gravity corer. The pollutant concentrations in the Fehmarnbelt sediments were compared to international Sediment Quality Guidelines (SQG) in order to assess if the suspended sediment pose a risk during dredging. Furthermore, possible release of nutrients as well as consumption of oxygen was calculated based on the resuspension of sediments in laboratory experiments.

### ***Nitrogen and phosphorus in sediments***

The concentration of total nitrogen and total phosphorus in sediments was clearly related to the loss on ignition suggesting that a major part of nutrients is bound to organic matter. According to German regulation concentrations of nutrients (total phosphorus and total nitrogen) in sediments are to be considered in the approval procedure for disposal of dredged sediments, using 'Richtwerte' for phosphorus and nitrogen at 500 mg P and 1500 mg N per kg dry sediment (Table 0.1). Averaged over all samples concentration of phosphorus was 30% below the 'Richtwerte' and concentration of nitrogen was 63% below the 'Richtwerte'.

A key issue when dredging large volumes in coastal areas that are already classified as eutrophic is the risk for further stimulation of phytoplankton growth due to release of inorganic nutrients. To that end elutriate tests were carried out to quantify the mobility of sediment nutrients under conditions simulating dredging operations. The tests showed that total release of inorganic nitrogen across all samples averaged 0.43%, while P-release (phosphate) was higher namely 0.95% of sediment content. Release of inorganic nitrogen was dominated by  $\text{NH}_4$ ; on average amounting to 84% of total DIN release. The percentage release was unrelated to depth strata and LOI content in sediments.

With a maximum daily dredging intensity of 40,000 m<sup>3</sup>, an average release of inorganic nitrogen of ca. 1 kg N/d and an average release of phosphorus (as phosphate) of ca. 4 kg P/d can be expected. These can be compared to the daily nutrient demand by phytoplankton within a 100 m wide zone along the entire alignment (18 km) for nitrogen of 250 Kg N and for phosphorus of 35 kg P. These figures indicate that release of nitrogen probably is unproblematic. In the Fehmarnbelt phytoplankton production is potentially limited by nutrients from March through September and evaluated on the ratio between inorganic nutrients nitrogen rather than phosphorus is the most limiting nutrient. Therefore, an additional small source of phosphate will most likely not lead to higher primary production, or stimulate blooms of cyanobacteria.

### ***Heavy metals and persistent organic pollutants***

Overall, the concentration of heavy metals and organic pollutants (HCB, DDTs, PCBs, PAHs, TBT) in surface sediments was low compared to the lower range of sediment quality guidelines (SQG). The measured concentrations are compared to national (Danish and German) and international guidelines (Table 0.1).



Table 0.1 Sediment quality guidelines (ERL values from Buchman 2008; OSPAR values from OSPAR (2009); Danish EPA values from BLST, 2008). German values from Anon 2009. Values in bold are used in the evaluation of sediment quality. n.a. = no criteria defined

Element / Compound	ERL	OSPAR	Danish EPA/BLST		German#	
			L Ac	H Ac	R1	R2
Arsenic (As) (mg/kg)	<b>8.2</b>	25	20	60	20	60
Cadmium (Cd) -	1.2	0.37	<b>0.4</b>	2.5	2	6
Chromium (Cr) -	81	81	<b>50</b>	270	90	270
Copper (Cu) -	34	27	<b>20</b>	90	70	210
Lead (Pb) -	46.7	38	<b>40</b>	200	100	300
Mercury (Hg) -	<b>0.15</b>	0.07	0.25	1	0.4	1.2
Nickel (Ni) -	<b>20.9</b>	36	30	60	70	210
Zinc (Zn) -	150	122	<b>130</b>	500	250	750
PAH sum -	<b>4*</b>	0.25	3**	30**	3*	9*
DDT sum (µg/kg)	<b>1.58</b>	n.a.	n.a.	n.a.	22	66
PCB sum (7 con) -	23	1.09	<b>20</b>	200	40	120
HCB	n.a.	n.a.	n.a.	n.a.	<b>2</b>	6
TBT -	n.a.	0	<b>7</b>	200	20	300
Tot-P (mg/kg)	n.a.	n.a.	n.a.	n.a.	500	
Tot-N -	n.a.	n.a.	n.a.	n.a.	1500	

# heavy metals in <20 µm fraction, POPs in < 63 µm fraction, Tot-N, Tot-P in bulk samples;

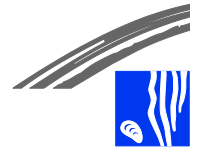
\*sum of 16 compounds; \*\* sum of 9 compounds

The low end of SQG represents values of pollutants that are considered not to cause environmental impacts. Averaged over the entire alignment corridor, concentration of persistent organic pollutants in surface sediments was between 4 and 15 times lower than the lowest SQG (TBT: 6.5 times lower, PCB: 4 times lower; DDT: 5 times lower. PAH: 15 times lower). In one sample concentration of PCBs exceeded the low SQG values by a factor of 3.5. The elevated concentration at this station is probably related to pollution from an object either lost or dumped at sea. Considering that organic pollutants occur in slightly elevated concentrations in the upper 10-12 cm only, and that these surface concentrations are below the lowest SQG and further that, the pollutant levels approach background concentrations below, the spread and release of organic pollutants connected to dredging can be considered as unproblematic.

Averaged over the entire alignment corridor the concentration of heavy metals in surface sediments was between 2.5 (nickel) and 13 (mercury) times below the lowest SQG. Concentration of arsenic was below the detection limit in all samples. Concentration of copper was on level with the lowest SQG in two samples from one station, while nickel concentrations slightly exceeded the lowest SQG at two stations. It is noteworthy that these elevated concentrations of nickel still were below the concentration defined as representing 'background' by the Oslo-Paris Commission. Less than one meter below the surface, seabed soils are of pre-industrial origin and thus represent soil types with only natural occurrence of heavy metals. Along with presence of low concentrations in surface sediments (0-1 m) and background levels in the sediment depth range of 1-12m, the spread and release of heavy metals connected to dredging, must be considered as unproblematic.

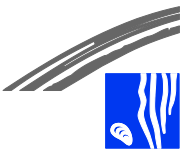
### **Oxygen consumption of dredged sediments**

During dredging, oxidation of sulphides and ferrous iron accumulated in the sediments (pore water) can lead to reduction in concentration of oxygen in the water column. An evaluation of the potential impacts of oxygen uptake from suspended sediments under dredging operations is based on a calculated daily oxygen uptake



based on elutriate tests as outlined for nutrient release (see above). The oxygen demand of sediments was low but increased with organic content of sediments. Assuming a maximum dredging rate of 40,000 m<sup>3</sup> per day and a spill rate of 3%, an average uptake of 186 kg O<sub>2</sub> (136-362 kg O<sub>2</sub>) per day can be expected. Except for very local phenomena during calm periods oxygen depressions in the water column is not likely.





## **1 INTRODUCTION**

One of the potential sources of nutrients, toxic substances and oxygen demand which are of environmental concern is dredged sediment. Release of nutrients during dredging and disposal can add to eutrophication by stimulating phytoplankton growth, mobilization of heavy metals and persistent organic pollutants can lead to exceedance of water quality criteria potentially affecting aquatic organisms and, disposal of contaminated sediments can pose a risk to sedentary organisms. Given that about 20 million cubic meters of sediments and soil may be dredged in the Fehmarnbelt link works it is necessary to quantify the potential sources of nutrients, oxygen demand and toxic substances.

### **1.1 Review of historical data**

Three sources hold recent historical data for pollutants and nutrients in sediments from the Fehmarnbelt:

- The Danish National Environmental Research Institute, NERI, part of Århus University, has one sediment sampling station in the western part of the Fehmarnbelt area. At this station, surface sediments were analysed for heavy metals and persistent organic pollutants in 2001 and 2008
- The German Federal Maritime and Hydrographic Agency (BSH) samples two areas in the Mecklenburg Bight for sediment contaminants. At these areas, surface sediments were analysed for heavy metals and persistent organic pollutants in 2000 and 2008.
- The Fehmarnbelt feasibility study (1996-1998) sampled several stations along the stipulated fixed link alignment and analysed for nutrients and heavy metals (COWI-Lahmeyer 1998). For nutrients (total nitrogen and total phosphorus) surface concentrations were measured at 14 positions, and at three positions subsurface nutrient concentrations were also measured. Potential nutrient release under aerobic and anaerobic conditions was measured in 9 samples in shake bottle tests. For pollutants, concentration and release of heavy metals in elutriate tests were carried out in 5 sediment samples sampled from 5 different positions.

#### **1.1.1 Sediment nutrients**

Main findings from the feasibility study (COWI-Lahmeyer 1998) were that 1) nitrogen concentration was strongly related to the loss on ignition of sediment, 2) sediments of marine origin (mainly surface samples) had higher nitrogen content than soils of freshwater origin even after correcting for loss on ignition (i.e. organic content). For phosphorus, the concentration was only weakly linked to loss on ignition indicating that phosphorus exists in many forms and compounds in the sediment.

#### **1.1.2 Nutrient release**

Nutrient release from sediments was small in all cases investigated in the feasibility study but varied according to sediment types and sample treatment (COWI-Lahmeyer 1998). Overall, between 0 and 2% of the sediment content of phosphorus could be released (lowest amount but highest percentage for sandy sediments), with a typical value of 0.1% of the sediment content. The release of nitrogen was more variable with several subsoil samples showing uptake of inorganic nitrogen.

#### **1.1.3 Oxygen uptake**

In the feasibility study, oxygen consumption of stirred sediments of the Link corridor varied according to sediment types with sandy sediments showing the lowest consumption (0.01-0.03 kg O<sub>2</sub>/m<sup>3</sup>/d), clay till and melt water clay having an intermediate consumption (0.07-0.3 kg O<sub>2</sub>/m<sup>3</sup>/d), and organic rich sediments (surface



detritus, subsurface mud and peat) had the highest oxygen consumption (0.13-0.55 kg O<sub>2</sub>/m<sup>3</sup>/d) (COWI-Lahmeyer 1998). It was characteristic for all soil samples that oxygen consumption was highest initially (1-6 h) probably due to oxidation of reduced substances such as H<sub>2</sub>S in pore water. The major part of oxygen consumption took part during the initial 6-24h, after which oxygen consumption rate became constant at a lower level probably reflecting mineralisation of organic matter.

#### **1.1.4 Sediment pollutants**

In the feasibility study, the heavy metal concentration along the proposed link was in a low range in the top layer, while the concentration in the subsurface soil was even lower representing the pre-industrial background level (COWI-Lahmeyer 1998). Elutriate tests showed that release of metals (shake-bottle test) was low; typically amounting to one percentage of the total content.

In the Mecklenburg Bight (BSH sampling) located far away from the area to be dredged heavy metal concentrations in sediments suggest that the benthic invertebrate community most likely is affected at the innermost stations (Cd: 0.4-4.3 mg/kg DW; Cu: 43-168 mg/kg DW, Pb: 122-1662 mg/kg DW), and it cannot be ruled out that effects also occur at the outermost Mecklenburg Bight (data downloaded from ICES contaminant database).

In the western part of the Fehmarnbelt area (boundary between Great Belt and Kiel Bight, NERI sampling) concentrations of heavy metals (Pb, Cd, Cu, Hg, Ni and Zn) and persistent organic pollutants (PAH, PCB, DDT's) were below levels that could lead to concern or even below detection limits (brominated flame retardants such as PBDE) in the surface sediments.



## **2 BASELINE FIELD STUDY 2009-2010 - MATERIALS AND METHODS**

This section presents the material and methods for the data sets collected during the sediment sampling and subsequent analysis, utilised for the sediment baseline assessment and the preliminary impact assessment in this report.

### **2.1 Investigation area**

The focus of this baseline study is the area where dredging will take place, i.e. the Fixed Link alignment corridor (see Figure 2.2). In this area, sampling was conducted in 2009 for analyses of nutrients and pollutant and conduction of experiments as mentioned under objectives.

#### **2.1.1 Sampling**

During a 'sediment' cruise 11-12 November 2009 sediment samples were taken using a gravity corer, consisting of an exchangeable 8 cm diameter stainless steel tube (length 3-6 m) and fitted with an inner PVC tube. Exchangeable weights mounted on the top of the sampler allowed the corer to penetrate down to 3 m into the sediment (Figure 2.1).



*Figure 2-1 Sampling of sediment cores using a weighted 'gravity sampler'.*

After returning to the laboratory at DHI the PVC tubes with sediment cores were cut in appropriate lengths (30 cm to 100 cm sections) for easy storage and supernatant water from the upper section of each core were carefully pipetted off. PVC tubes were closed in both ends using DBI lids and stored cold at 0-4 °C.

The location of sampling stations appears in Figure 2.2. Details about cores are summarised in Appendix A and type of analysis carried out on these samples is listed in Table 2.1.

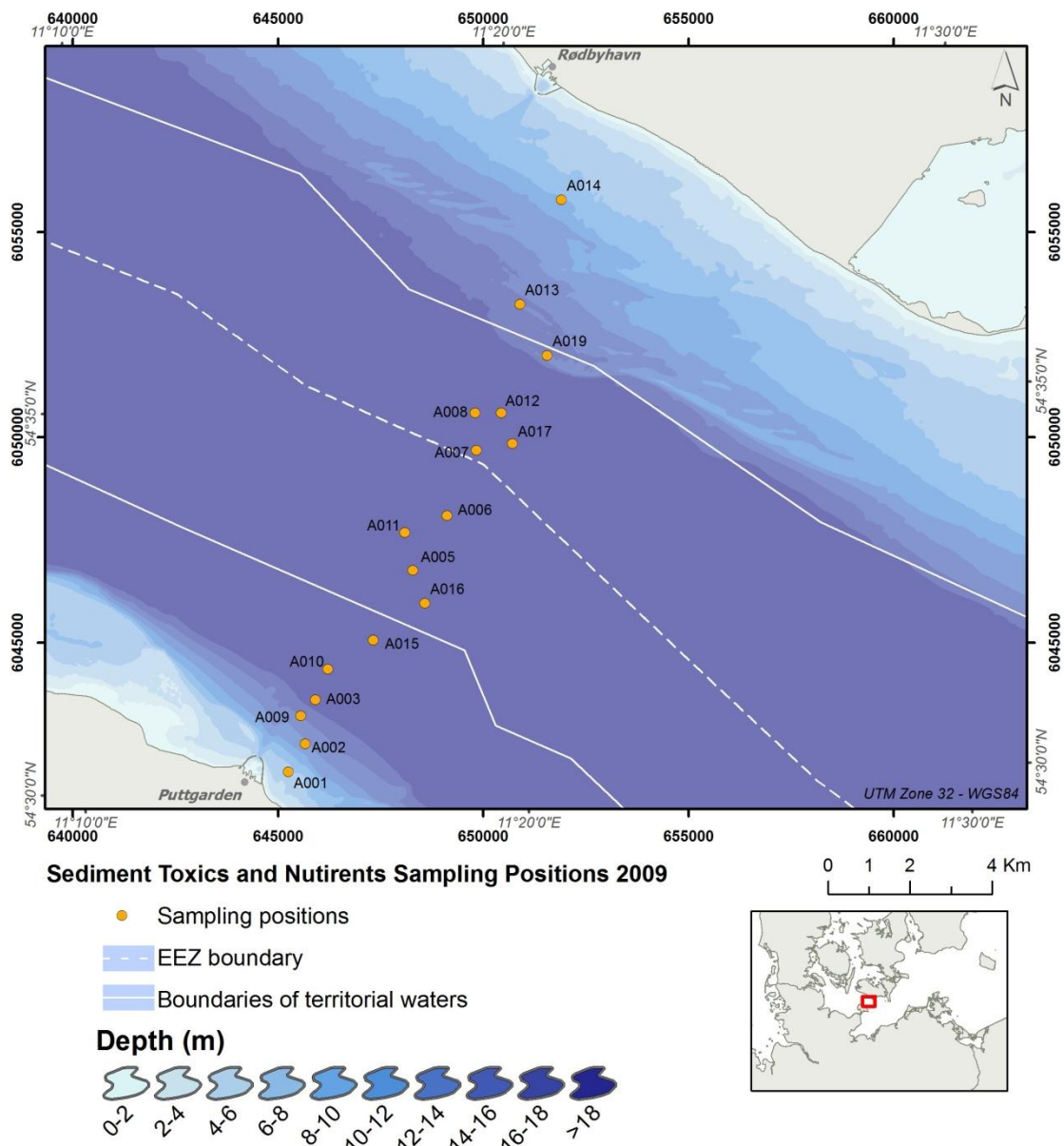


Figure 2-2 Position for sediment sampling carried out 11-12 November 2009 from JHC Miljø. Location of samples was similar to positions for geotechnical samplings carried out during spring and early summer 2009.

Table 2-1 Overview of analysis carried out on sediment core samples; C-organic carbon, LOI – loss on ignition, POP – persistent organic pollutants, POP-cm – POP depth profiles in cm increments, N – total nitrogen, P – total phosphorus, M – heavy metals, TBT – tributyltin, Rel – release of nutrients, OD – oxygen demands of sediments

Section	A001	A002	A003B	A005	A006	A007	A008	A011	A013	A0016	A0017	A019
A0xx-1 0-30cm	C,LOI,POP N,P,M Rel, OD	C,LOI,POP N,P,M,TBT Rel, OD	C,LOI,POP N,P,M Rel, OD	C,LOI,POP N,P,M,TBT Rel, OD	C,LOI,POP N,P,M,TBT Rel, OD	C,LOI,POP N,P,M,TBT Rel, OD	C,LOI,POP N,P,M Rel, OD	C,LOI,POP N,P,M,TBT Rel, OD	C,LOI,POP N,P,M Rel, OD	C,POP POP-cm	C,POP POP-cm	C,LOI,POP N,P,M Rel, OD
A0xx-2 30-60cm		LOI N,P,M Rel, OD		LOI N,P,M	C,LOI,POP N,P,M Rel, OD	LOI N,P,M Rel, OD	LOI N,P,M Rel, OD					LOI N,P,M Rel, OD
A0xx-3 70-100cm					LOI N,P Rel, OD		LOI N,P,M Rel, OD					



DHI and IOW (Institut für Ostseeforschung Warnemünde) were jointly responsible for the planning of the sediment sampling. Chemical analysis for persistent organic pollutants was under the responsibility of IOW, whereas DHI was responsible for the field work, for analysis for heavy metals, TBT-compounds, nutrient concentrations and their release from sediments, oxygen uptake of stirred sediments and light attenuation of suspended sediments.

Prior to chemical analysis and lab experiments the selected subsamples (e.g. 0-30 cm depth range) of sediments were thoroughly mixed in rinsed (1 N HNO<sub>3</sub>, 3 times MilliQ water) 10 L polycarbonate bowls. Subsamples for shipment to laboratories or brief storage were transferred to combusted (550°C) 500 ml alu trays (for analysis of persistent organic pollutants), or to Rilsan bags (for analysis of dry mass, LOI, TBT, heavy metals, nutrients, and for oxygen consumption experiments). Air was excluded from Rilsan bags and the bags were sealed. Subsamples were shipped cold in insulated containers or stored at 0-4°C.

### **2.1.2 Nutrients in sediments**

Determination of dry weight and loss on ignition (i.e. organic content) in sediment samples were carried out according to Danish Standard 204 (DS 204, 1980). The concentration of total nitrogen in sediments was analysed after Nordforsk (1975) and the concentration of total phosphorus was analysed after Danish Standard 259 (DS 259, 1982).

### **2.1.3 Release of nutrients**

Nutrient elutriation experiments were carried out in oxic water using a modified European sludge test (DS/EN 12457-2, 2003). Instead of using a liquid-to-solid (L/S) ratio of 10 L/kg as described in DS/EN 12457-2 (2003), an approximate ratio of 50L/kg was used due to the high sensitivity of the analytical method (see below). By using a higher L/S ratio, dilution of test water prior to analysis could be omitted.

A total of 45 experiments (flasks) including six controls were carried out. In the laboratory 2-5 g of wet sediment were transferred to 200 ml GFC-filtered 'artificial' seawater (20 ‰ NaCl; Pro Analyti). The flasks were placed on a shaking table in darkness. Subsamples were collected after 24h allowing the sediment to settle for 30 min before sampling. Subsamples were filtered (through capsules with 0.2 µm pore size filters) and collected in 25 ml polypropylene flasks, capped and stored at -20°C until analysis. When analysed, samples were thawed and subsequently analysed for NO<sub>2</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup> and PO<sub>4</sub><sup>3-</sup> using a Technicon autoanalyzer. Limits of detection were 0.5, 1.8, 4.2 and 1.9 µg/l, respectively. Six flasks without sediment added served as blanks.

### **2.1.4 Heavy metals**

The analytical procedure for heavy metals was based on a modified Danish Standard 259 (DS 259, 1982). Subsamples of homogenised sediment samples were weighed in cleaned glass flasks, 20 ml 7 M nitric acid was added and samples digested under pressure by heating in an autoclave to 120°C for 30 minutes. Similar operation was performed on blank samples and certified reference material at the same time. Digested samples were analysed by atomic absorption spectrometry with graphite furnace technique (ETAAS) for As, Cd, Cr, Cu, Ni, Pb and Zn with the use of background correction and the standard addition technique. For Hg, subsamples were analysed by atomic absorption with the cold vapour technique (CVAAS) after reduction, using sodium boric hydride (Danish Standard 2210). The analytical results were controlled by simultaneous analysis of 'reference' materials. The analytical uncertainty, described by the coefficient of variation CV<sub>Total</sub>, varies between 5 and 10%.



### **2.1.5 Persistent organic pollutants**

The analytical procedure for persistent organic pollutants (POPs) followed the instructions by the HELCOM monitoring programme, and was in line with the guidelines described in the HELCOM COMBINE manual (HELCOM 2008), in particular its Appendix B-14, Appendices 1 and 2. The 2 sediment cores were cut in 1-cm-slices down to 16 cm, and these slices were kept deep-frozen until they were analysed.

Before chemical analyses, all samples were freeze-dried for at least 36 hours at 0.160 mbar vacuum. After freeze-drying, the samples were carefully homogenized, avoiding any contamination. Sub-samples of the homogenates (1.0-2.0 g dry mass) were, after addition of a fixed amount of radio-labelled internal standard containing all compounds, extracted twice by n-hexane/acetone (60/40) in an accelerated solvent extractor (ASE) run at 100°C and 140 bar. The extracts were desulphurised by activated copper, followed by a clean-up through aluminium oxide + silica gel column chromatography and a pre-separation of organochlorines from PAHs by high-performance liquid chromatography (HPLC) using a LiChosphere Si 100 column. The final analysis for POPs was performed by an Automass III high-performance gas chromatography / mass spectrometry (GCMS) system using a DR-5 column and run in the selected ion mode (SIM).

The analytical quality is routinely controlled by parallel analyses of blanks, blanks added with internal standard, blanks added with internal and external standard, analysis of reference material and occasionally replicate analysis of real samples. The combined measuring uncertainty (uncertainty of the true value in a reference material combined with the standard deviation of the value measured from the assigned value) was for most POPs measured below 20%.

### **2.1.6 Oxygen consumption of sediments**

Typical oxygen demand estimates that involve sediment cores incubated in laboratory or *in situ* chambers placed on sediment surface do not account properly for the high oxygen demands associated with the reduced compounds, which can be present in sediments and which would exert a rapid oxygen demand if suspended in the water column. Therefore, to arrive at more representative estimates of oxygen demand relating to dredging we used an adaptation of a standard BOD test (DS/EN DS/EN 1899-1, 2003). Instead of determining the oxygen demand of 'wastewater' over a period of 5 days, artificial seawater was used along with added sediment to determine the rate of oxygen consumption by sediments (and pore water) under situations simulating dredging operations.

A total of 18 experiments were carried out comprising 10 experiments with surface sediments and 8 experiments with subsurface sediment/soils. In the laboratory 4 ml of wet sediment was sampled using a 10 ml syringe with a cut front end. This end was pushed through a small hole in the Rilsan bag till the syringe was filled (10 ml) with sediment from the middle of the bag where oxidation of sediments presumably was low. Using the piston, 4 ml sediment representing the sample in the 'middle' of the Rilsan bag was transferred to a flask containing 250 ml GFC-filtered 'artificial' seawater (20‰ NaCl; Pro Analysi) equilibrated with atmospheric air. After transfer of sediment the flask was topped up with 'artificial' seawater and sealed using a glass stopper taking care to exclude all air. The flasks were mounted on a 60 cm diameter plankton wheel rotating 2 rpm and placed in a 10°C constant temperature room in darkness. Flasks without sediment served as controls.

Oxygen concentration (mg O<sub>2</sub>/l) in the flasks was measured with a Radiometer oxygen probe (Clark type) after 5-6 h and 21-25 h incubation. After measurements at 5-6 h the water lost when inserting the electrode was replenished by oxygenated



water and the stopper inserted again. The oxygen consumption of the different sediment samples was calculated based on the sediment volume and dry weight after correcting for blank values and for added oxygen with replenishment water.



### 3 NUTRIENT CONCENTRATION IN SEDIMENTS AND RELEASE OF NUTRIENTS

Concentration of total nitrogen and total phosphorus in sediment samples along with corresponding loss on ignition, LOI (i.e. the organic content of sediments) is shown in Appendix B, and scatterplots of nutrient concentrations as function of LOI are shown in Figure 3.1. The concentration of total nitrogen and total phosphorus in particular is clearly related to the loss on ignition indicating that most of the nutrients in surface sediments and subsurface soil are bound in organic matter. One sample (A008-3) though, had higher phosphorus concentration than expected from the organic content, two samples had higher content of nitrogen (A007-1; A006-3) than expected from LOI content and phosphorus (A003-1B) and, one sample (A003-1) had lower concentration of both phosphorus and nitrogen than expected from the LOI content.

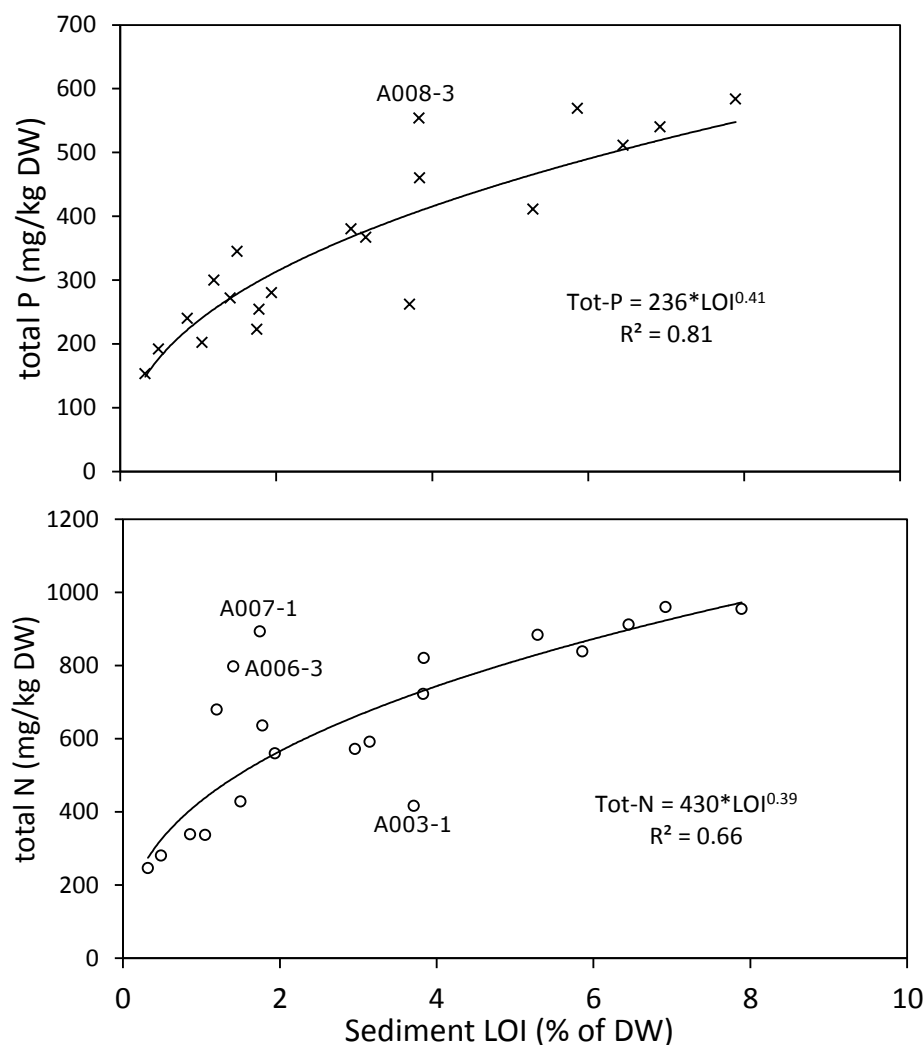
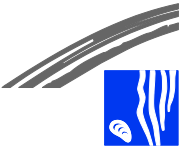


Figure 3-1 Scatterplot of concentration of total nitrogen (upper), total phosphorus (lower) as function of LOI (loss on ignition) in sediment. Power functions were fitted to data.





According to German regulation concentrations of nutrients (total phosphorus and total nitrogen) in sediments are to be considered in the approval procedure for disposal of dredged sediments, using 'Richtwerte' for phosphorus and nitrogen at 500 mg P and 1500 mg N per kg dry sediment (Anon 2009). Figure 3.2 show the distribution of phosphorus and nitrogen concentrations across samples (including surface and subsurface samples) along with the German Richtwerte. Concentration of phosphorus exceeds the 'Richtwerte' at 500 mg P/kg sediment in two samples, while all samples had concentrations much below the 'Richtwerte' for nitrogen at 1500 mg N/kg. Averaged over all samples concentration of phosphorus was 30% below the 'Richtwerte' and concentration of nitrogen was 63% below the 'Richtwerte'.

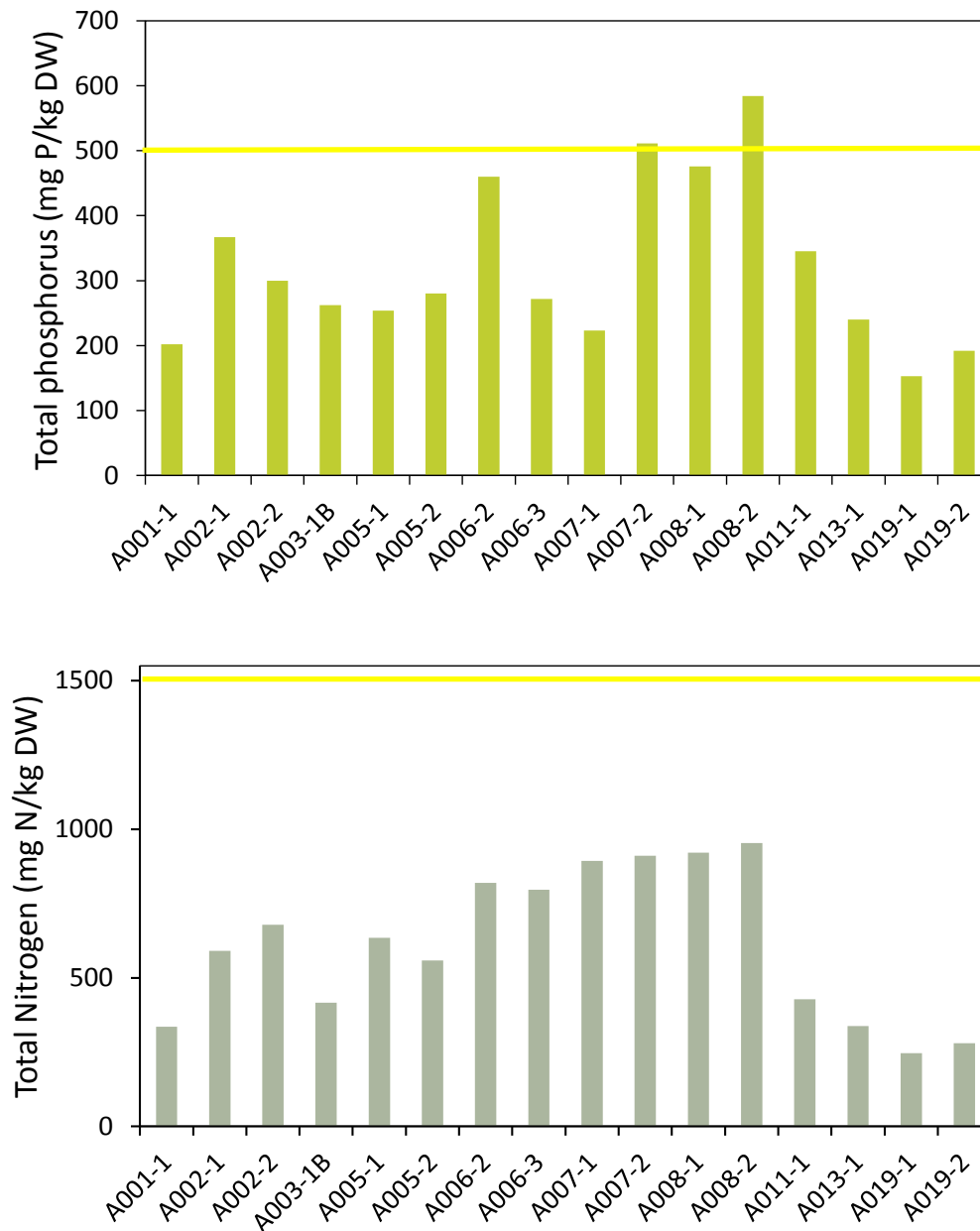


Figure 3-2 Concentration of total phosphorus (upper) and total nitrogen (lower) in surface and sub-surface sediments. The yellow lines indicate the level of SQG, i.e. 'Richtwerte' defined by the German authorities (Anon 2009) (see Table 4.4).



### 3.1 Release of nutrients

The elutriate tests were performed over 24 hours to assess the immediate release of nutrients. The test was run under oxic conditions as such conditions dominate in the Fehmarnbelt (DO in bottom water rarely falls below 2 mg O<sub>2</sub>/l, and if so only for 1-2 months in late summer-early autumn).

Figure 3.3 shows the release of dissolved inorganic nitrogen (DIN = sum of NO<sub>2</sub>, NO<sub>3</sub> and NH<sub>4</sub>) and phosphate expressed as a percentage of the content of total nitrogen and total phosphorus in sediments. Release of inorganic nitrogen was dominated by NH<sub>4</sub> on average amounting to 84% of the total DIN release (see Appendix C). Total DIN release across all samples averaged 0.43%, while P-release was higher at 0.95% (Appendix C). The percentage release was unrelated to depth strata and LOI content.

A key issue when dredging large volumes in coastal areas that are already classified as eutrophic is the risk of further stimulation of phytoplankton growth. In eutrophic lakes even natural resuspension events can lead to release of phosphorus from sediments (Søndergaard et al. 1992), but it is also seen that resuspension events can lead to lower phosphate concentrations probably due to adsorption onto oxidized iron and subsequent co-sedimentation (Møhlenberg 1995).

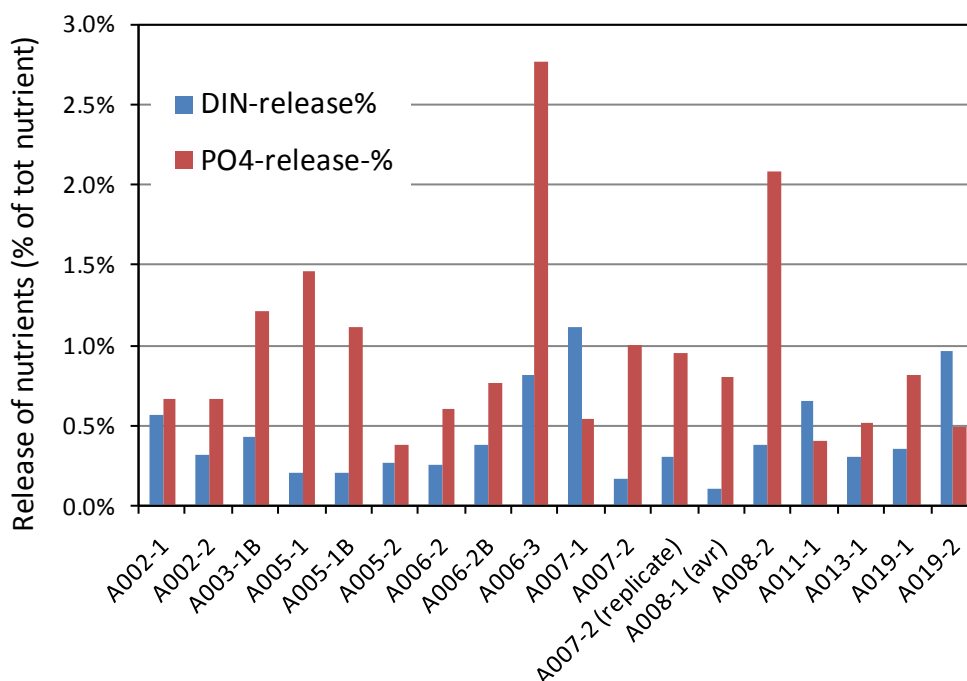


Figure 3-3 Release of nutrients from sediments (as % of sediment content) after elutriating in artificial seawater on a shaking table in darkness for 24 h. DIN represents the sum of NO<sub>2</sub>, NO<sub>3</sub> and NH<sub>4</sub> release.

An evaluation of the potential impacts of nutrient release from sediments during dredging operations is based on the following:

- Concentration of nutrients in surface and subsurface sediments as determined in this study (surface sediments 0-100 cm) and in the feasibility study (down to 3.6m; Lahmeyer/COWI 1998).



- Three different types of sediment were defined: 1) surface sediments present at water depths less than 13m mostly consisting of sand but clay till was also present, 2) surface sediments at water depth larger than 13m (organic rich, including mud, clay and sand) and 3) subsurface soil (1-12m) (organic rich till, clay and sand). For each type 25%, 50% and 75% percentiles were calculated to represent high, medium and low concentrations
- Release of nitrogen and phosphorus expressed as percentages of the total nutrient contents.
  - Initially, 25%, 50% and 75% percentiles were calculated for each sediment type to represent high, medium and low release. However, as release-% was unrelated to sediment type and organic content, 25%, 50% and 75% percentiles were finally calculated based on all experimental results and applied uniformly to all three sediment types.
- Knowledge on sediment density in order to convert nutrient release based on mass (dry weight) to release based on volume (m<sup>3</sup>). These data were obtained from the feasibility study (COWI/Lahmeyer 1998).
  - For data from the feasibility study, density of sediments and subsurface soil was obtained from COWI-Lahmeyer (1998). For the present study density was estimated from a power function established based on all data from the feasibility study (density, ton/m<sup>3</sup> = 0.1907\*DW(% of DW)<sup>0.565</sup>, R<sup>2</sup> = 0.996) (see Appendix G).
- A maximum sediment spill of 3% is assumed for tunnel dredging
- A daily maximal dredging intensity at 40,000 m<sup>3</sup> for tunnel dredging
- Dredging to 12m below seabed

Figures on dredging intensity and spill rates are provided by Femern A/S and published in (FEHY-2011).

Close to the German coast and within the tracé to be dredged for a tunnel solution a subsoil occurrence of peat with an organic content of about 50% and a very high concentration of nitrogen (15600 mg tot-N/kg DW at 3.5m below seabed) but low concentration of phosphorus was found under the feasibility study COWI-Lahmeyer (1998). During sampling of the sediment and soil for this study it was not possible to penetrate and obtain a sample from this layer. Accordingly, test of nutrient release could not be carried out, and as release data are not available from the feasibility study either, we cannot quantify the impacts when these layers are dredged. The peat layer attains a thickness of 5 m over a length of 2.5 km along the trace (preliminary map from the Geotechnical mapping, Rambøll – Arup Joint Venture), and if 0.33% of the nitrogen content is released (see Figure 3.2, Table 3.1) 18.7 gN/m<sup>3</sup> rather than 0.73 gN/m<sup>3</sup> would be released under laboratory conditions (see Table 3.1).

The expected daily nutrient release due to dredging was calculated by multiplying the content of nutrients in surface sediment with the release rates and summing the estimated releases over the dredging depth (12m) assuming a relative contribution of 1:11 of surface and subsurface concentrations (i.e. 1m surface sediments and 11m subsurface soil). Calculations were carried out using 50%, 25% and 75% percentiles to represent the most likely rate (50% percentile), and a minimum and a maximum rate of release of nitrogen (Table 3.1) and phosphorus (Table 3.2).



Table 3-1 Estimated release of inorganic nitrogen during dredging operation based on information on nitrogen concentrations in sediment, density of sediment/soil, release rates measured in laboratory and a sediment spill of 3% (a, b, c etc identifies release rates from different depth strata that are summed to calculate release rates for entire sediment column (see Table 3.3).

Depth (soil)	Depth (water) (type)	Percentile	N-conc	Density	Release laboratory		Release dredging	
			mgN/kg dw	ton/m <sup>3</sup>	%-N	gN/m <sup>3</sup>	gN/1000m <sup>3</sup>	gN/d
Surface (0-1m)	0-13m (sand)	25%	263	2,30	0,25%	1,26	38	126 a
		50%	280	2,35	0,33%	1,84	55	184 b
		75%	309	2,37	0,53%	3,36	101	336 c
Surface (0-1m)	13-30m (recent marine, clay till)	25%	428	1,70	0,25%	0,90	27	90 a1
		50%	657	1,75	0,33%	1,92	58	192 b1
		75%	838	1,85	0,53%	4,58	137	458 c1
Subsurface (1-12m)	0-30m	25%	107,5	2,05	0,25%	0,37	11	411 d
		50%	147	2,13	0,33%	0,73	22	808 e
		75%	221,5	2,35	0,53%	2,34	70	2574 f

Table 3-2 Estimated release of phosphorus (phosphate) during dredging operation based on information on nitrogen concentrations in sediment, density of sediment/soil, release rates measured in laboratory and a sediment spill of 3% (a, b, c etc identifies release rates from different depth strata that are summed to calculate release rates for entire sediment column (see Table 5.3).

Depth (soil)	Depth (water) (type)	Percentile	P-conc	Density	Release laboratory		Release simulated dredging	
			mgP/kg dw	ton/m <sup>3</sup>	%-P	gP/m <sup>3</sup>	gP/1000m <sup>3</sup>	gP/d
Surface (0-1m)	0-13m (sand)	25%	152	2,30	0,55%	1,59	48	159 a
		50%	190	2,35	0,78%	2,97	89	297 b
		75%	216	2,37	1,08%	4,82	145	482 c
Surface (0-1m)	13-30m (gyttje, recent marin, clay till)	25%	260	1,70	0,55%	1,19	36	119 a1
		50%	323	1,75	0,78%	2,24	67	224 b1
		75%	464	1,85	1,08%	5,19	156	519 c1
Subsurface (1-12m)	0-30m	25%	260	2,05	0,55%	1,96	59	2161 d
		50%	290	2,13	0,78%	3,45	103	3792 e
		75%	380	2,35	1,08%	8,23	247	9052 f

Summary data for daily release of nitrogen and phosphorus during dredging at shallow waters and deeper waters are shown in Table 3.3. With a daily maximum dredging intensity of 40,000 m<sup>3</sup>, the average release of nitrogen is approx 1 kg DIN/d and the average release of phosphorus is approximately 4 kg PO<sub>4</sub>-P/d; in both cases irrespective whether dredging takes place in shallow or in deep waters (Table 3.3). The lower and higher values (in brackets in Table 3.3) can be seen as the range in daily release taking place during the entire dredging operation. It must be stressed that the potential release of nitrogen when dredging the subsoil peat layer located north of Fehmarn is not included in the predictions.



Table 3-3 Depth integrated nutrient release during dredging at shallow waters (<13m depth) and deeper waters (>13m depth). Summary data calculated by adding data for release from surface (<1m) sediments (a-c) or (a1-c1) to data for release from subsurface sediments (d-f); see Tables 3.1 and 3.2. Values in bold represent the most likely release (based on medium values of sediment concentrations and release-%). The range (in brackets) represents the minimum estimates of release (based on 25% percentiles of sediment concentrations and 25% percentiles of release-%) and a maximum daily estimates of release (based on 75% percentiles of sediment concentrations and release-%)

	Nitrogen release g N/d	Phosphorus release g P/d
Shallow (<13m)	<b>992</b> (592-2910)	<b>4088</b> (2320-9534)
Deep (>13m)	<b>1000</b> (500-3032)	<b>4016</b> (2280-9572)

The estimated releases at 1 kg nitrogen per day and 4 kg phosphorus per day must be considered as very low; especially considering the large horizontal transports through the Fehmarnbelt.

If we assume that 0.33% of the nitrogen content in spilled peat is released then the estimated daily release of nitrogen will increase by a 10-factor. However, considering that nitrogen availability of partly degraded peat is low, because a major part is bound in humic compounds (Parent and Ilnicki 2003) we do not expect release of inorganic nitrogen that is readily available for phytoplankton. Therefore, nitrogen release probably will enrich the pool of dissolved organic nitrogen DON that already is large (> 200 mg DON/m<sup>3</sup>) in Baltic water but considered to be unavailable to phytoplankton.

For reference, the daily demand for nutrients by phytoplankton in the Fehmarnbelt within a 100m wide zone along the entire alignment (18 km) can be estimated from measured primary production (0.65 g C m<sup>-2</sup> d<sup>-1</sup>) averaged over the period where phytoplankton is nutrient limited (FEMA-FEHY 2011). Using a Redfield (molar) ratio of 106:16:1 for C:N:P content and demand in phytoplankton (Redfield 1958), and converting it to a weight ratio (41:7.2:1) a daily demand for (and assimilation of) nitrogen and phosphorus by phytoplankton within this zone can be calculated to 553 kg N and 35 kg P. For nitrogen, the daily uptake is 2.5 orders of magnitude higher than the estimated average release, while for phosphorus the demand is about 10 times higher than the average release and 7 times higher than the maximum release. Given these figures we can rule out broad scale effects of nitrogen release.

In the Fehmarnbelt phytoplankton production is potentially limited by nutrients from March through September (see FEMA-FEHY 2011) and evaluated on the ratio between inorganic nutrients nitrogen rather than phosphorus is the most limiting nutrient. Therefore, an additional small source of phosphate will most likely not lead to higher primary production, or stimulate blooms of cyanobacteria.



## 4 **POLLUTANTS IN SEDIMENTS**

Two of the most significant factors controlling the capacity of sediments for accumulating and retaining toxic pollutants are grain size (Horowitz 1991) and the organic content (Schorer 1997). For metals there is a strong correlation between decreasing grain size and increasing trace element concentrations, while persistent organic pollutants generally show tighter coupling to the organic content in sediments but weak correlation to grain size (Schorer 1997). Because of the intrinsic influence of organic content and grain size organic rich, silty-clayish sediments naturally will have higher concentrations of pollutants than nearby sandy sediments exposed to identical pollutant loads.

Based on local traditions different countries and international organisations use or recommend different normalization procedures. They include: 1) analyse heavy metals in the fine sediment fractions only ( $< 20 \mu\text{m}$ ,  $< 63 \mu\text{m}$ ), or 2) normalize concentration of metals (in whole samples) to concentration of organic matter, total organic carbon, concentration of lithium (Li), aluminium (Al), iron (Fe), cesium (Cs) and other elements (Smedes 2002). Herut and Sandler (2006) recently published a critical review of various normalisation methods for heavy metals. Others including Denmark (BLST 2008) do not specify normalization, when differentiating between problematic and unproblematic toxicant levels in sediments.

### 4.1 **Heavy metals in Fehmarnbelt sediments**

Heavy metals in sediments are primarily associated with the organic matter and/or adsorbed to fine particles because such particles dominate in terms of surface area. Due to methodological difficulties separating sediments in size fractions, and subsequent analysis for heavy metals in these size fractions are rarely carried out. Instead, concentration of heavy metals in sediments is routinely evaluated on the basis of the total organic content, e.g. quantified as loss on ignition, LOI.

Five of the eight heavy metals analysed in sediments were present in concentrations above the detection limits in all surface samples. In contrast, the concentrations As, Cd and Hg were below detection limits in all (As) or in 25-50% of surface samples. An overview of sample concentrations of 8 different heavy metals is shown in Appendix D. For those 5 heavy metals that were present in concentrations above the detection limits in all surface samples maps of their distribution along the alignment are shown in Figure 4.1 to Figure 4.5.

In general, the distribution of heavy metals followed the depth contour, with the highest concentration in the deepest central part of the Fehmarnbelt and lower concentrations in the shallower coastal waters. Besides, at similar depths there was a tendency to higher concentrations in the German EEZ than in the Danish EEZ waters. This trend could be explained by a higher organic content in the German coastal waters probably caused by a more protected coastline for the prevailing western-south-westerly winds.

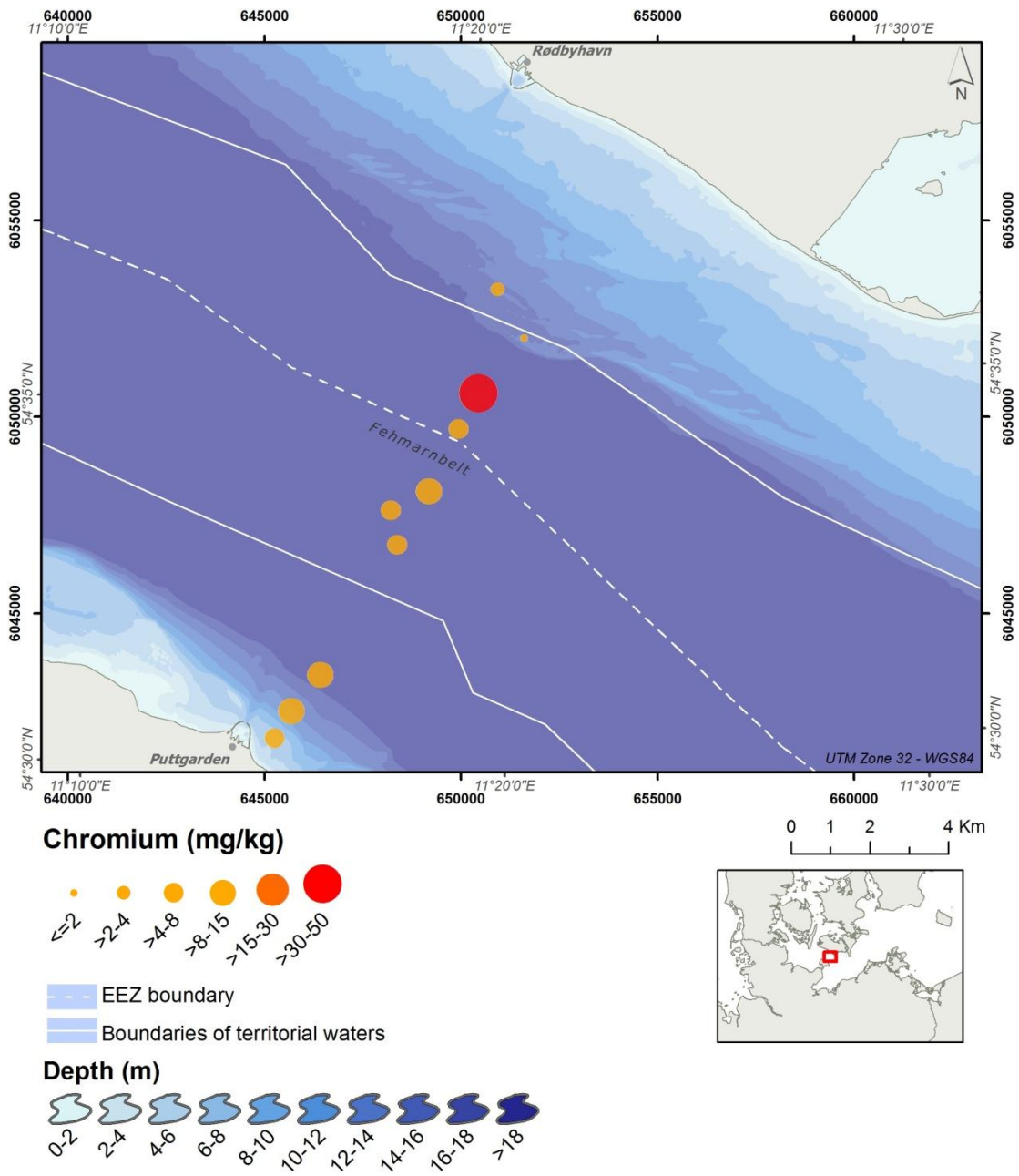


Figure 4-1 Concentration of chromium (Cr) in surface sediments (0-30cm) across the Fehmarnbelt.

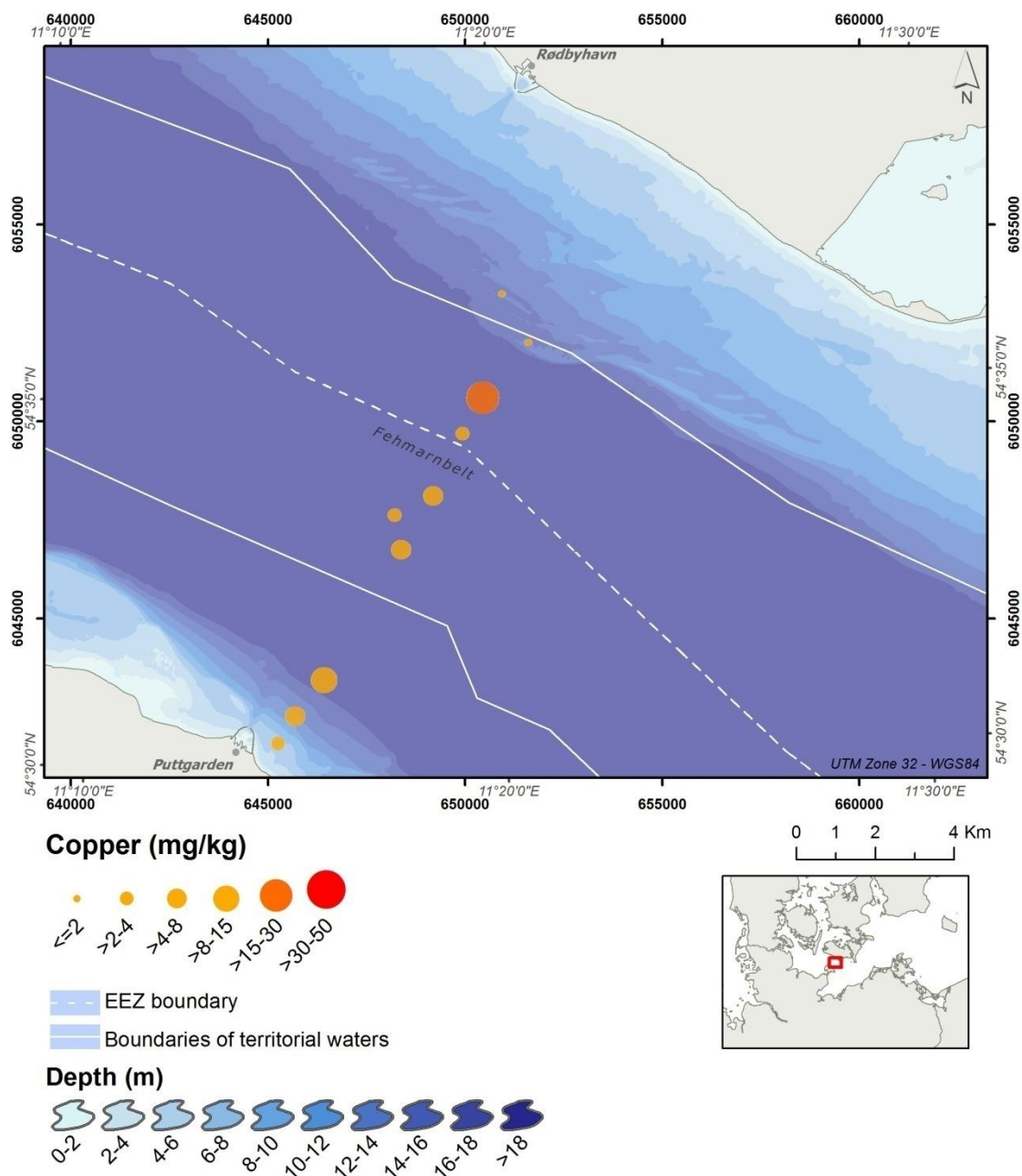


Figure 4-2 Concentration of copper (Cu) in surface sediments (0-30cm) across the Fehmarnbelt.



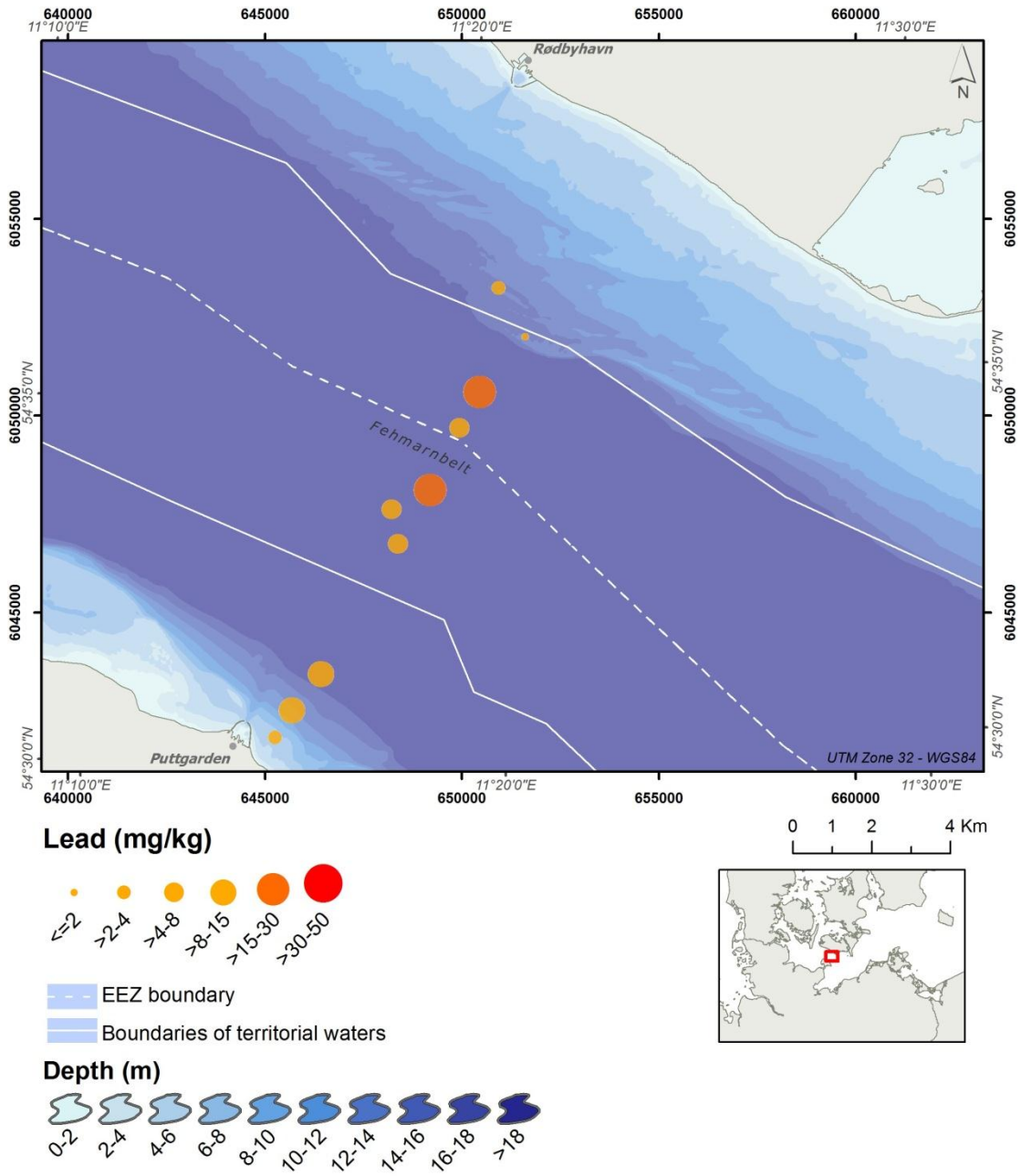
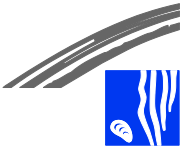


Figure 4-3 Concentration of lead (Pb) in surface sediments (0-30cm) across the Fehmarnbelt.

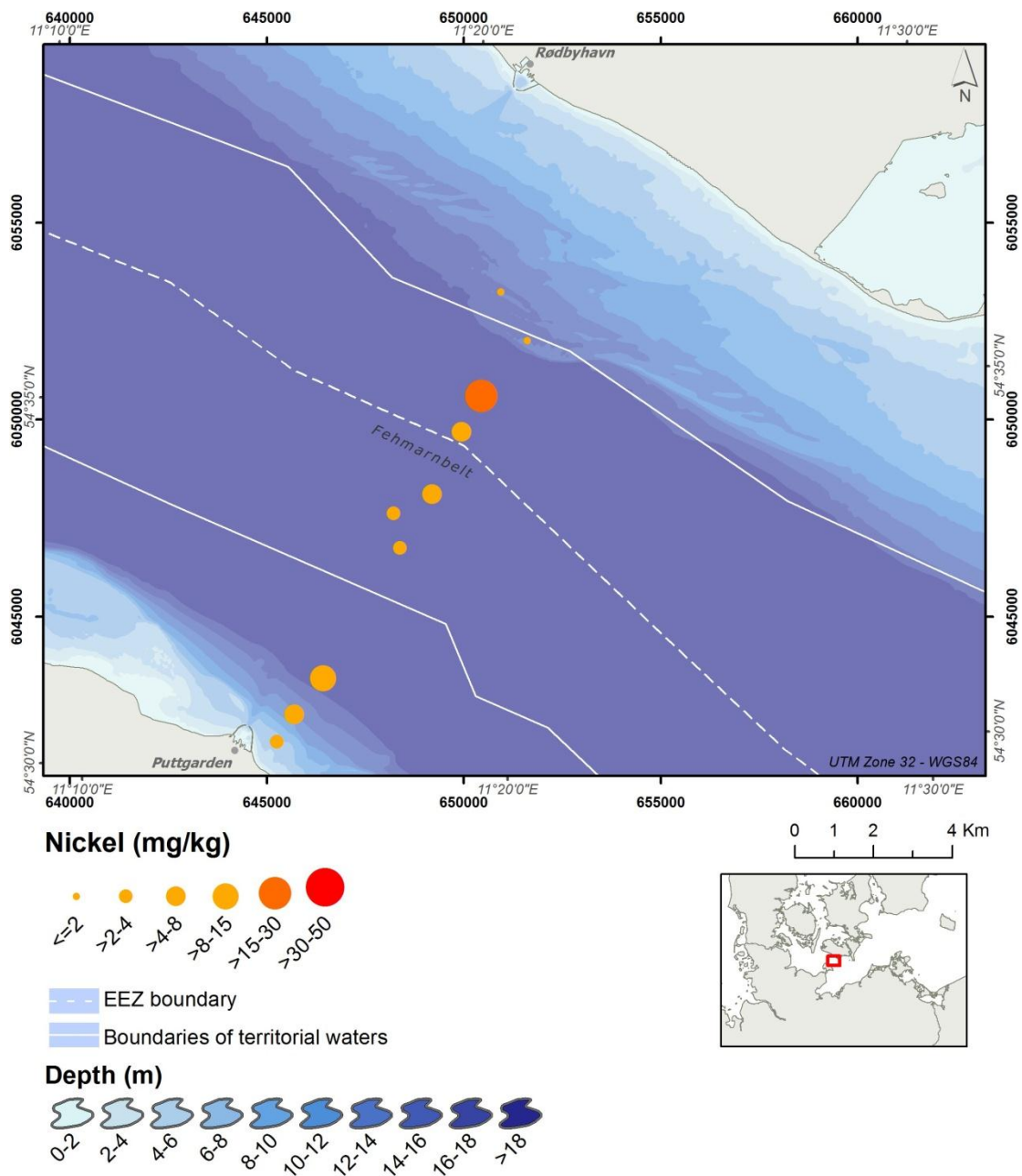


Figure 4-4 Concentration of nickel (Ni) in surface sediments (0-30cm) across the Fehmarnbelt.

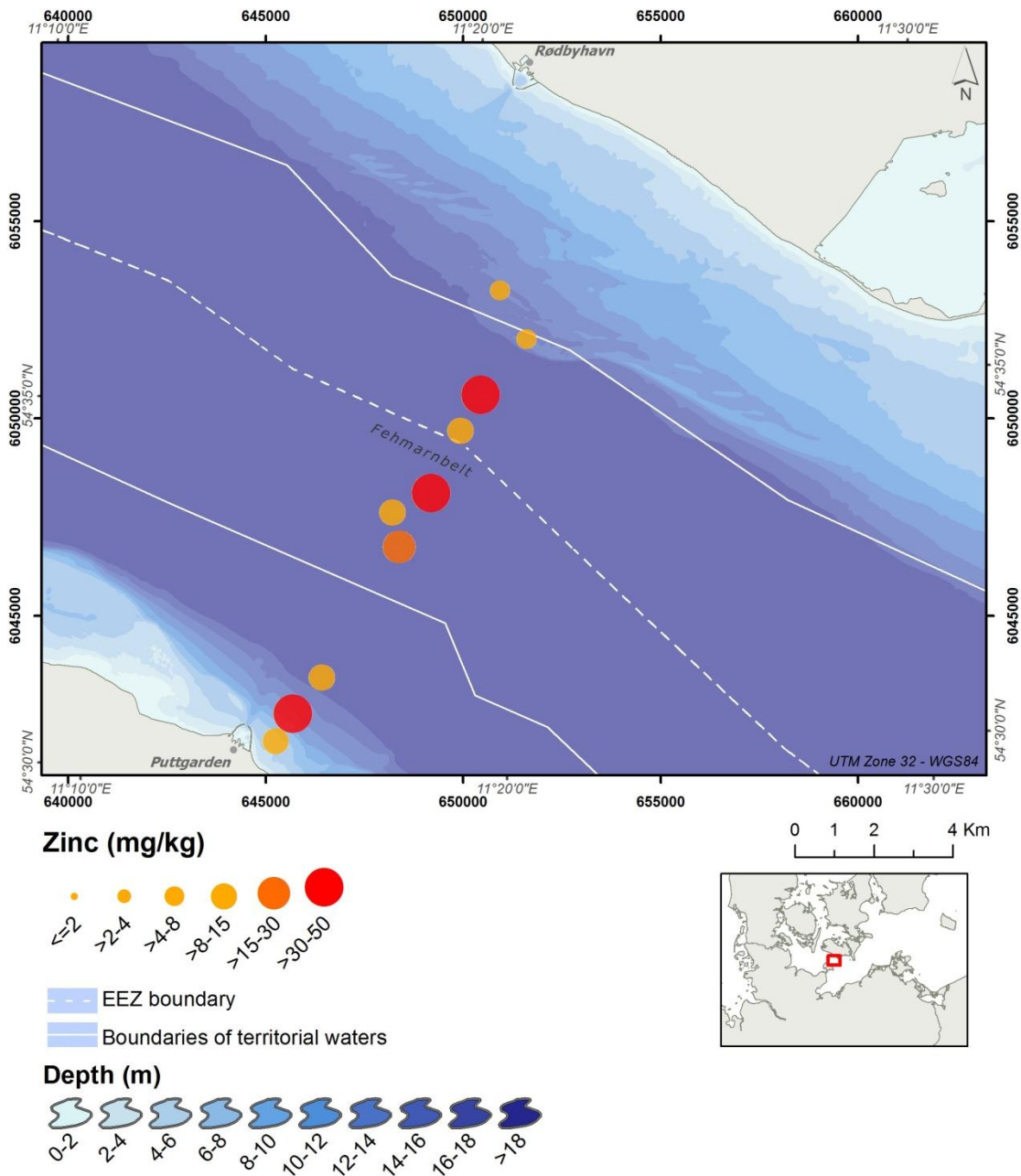


Figure 4-5 Concentration of zinc (Zn) in surface sediments (0-30cm) across the Fehmarnbelt.

A comparison of heavy metal concentrations from Fehmarnbelt sediments and concentrations in sediments from Danish coastal and estuarine waters not affected by point sources, such as wastewater outlets and harbours, is shown in Figures 4.6 – 4.9 as scatterplots showing the relation between metal concentrations and organic content in sediments.

Overall the Fehmarnbelt sediments followed the general pattern that the concentration of heavy metals is related to the organic content of sediments (Figure 4.8 to Figure 4.10). The plots showed that metal concentrations in the Fehmarnbelt sediments was comparable to diffusely polluted sediments (Cu, Pb, Zn), slightly higher than diffusely polluted sediments (Cr, Ni) or lower than diffusely polluted sediments (Cd, Hg) from other Danish waters. The concentration of arsenic was below the detection limit in all 19 samples analysed.

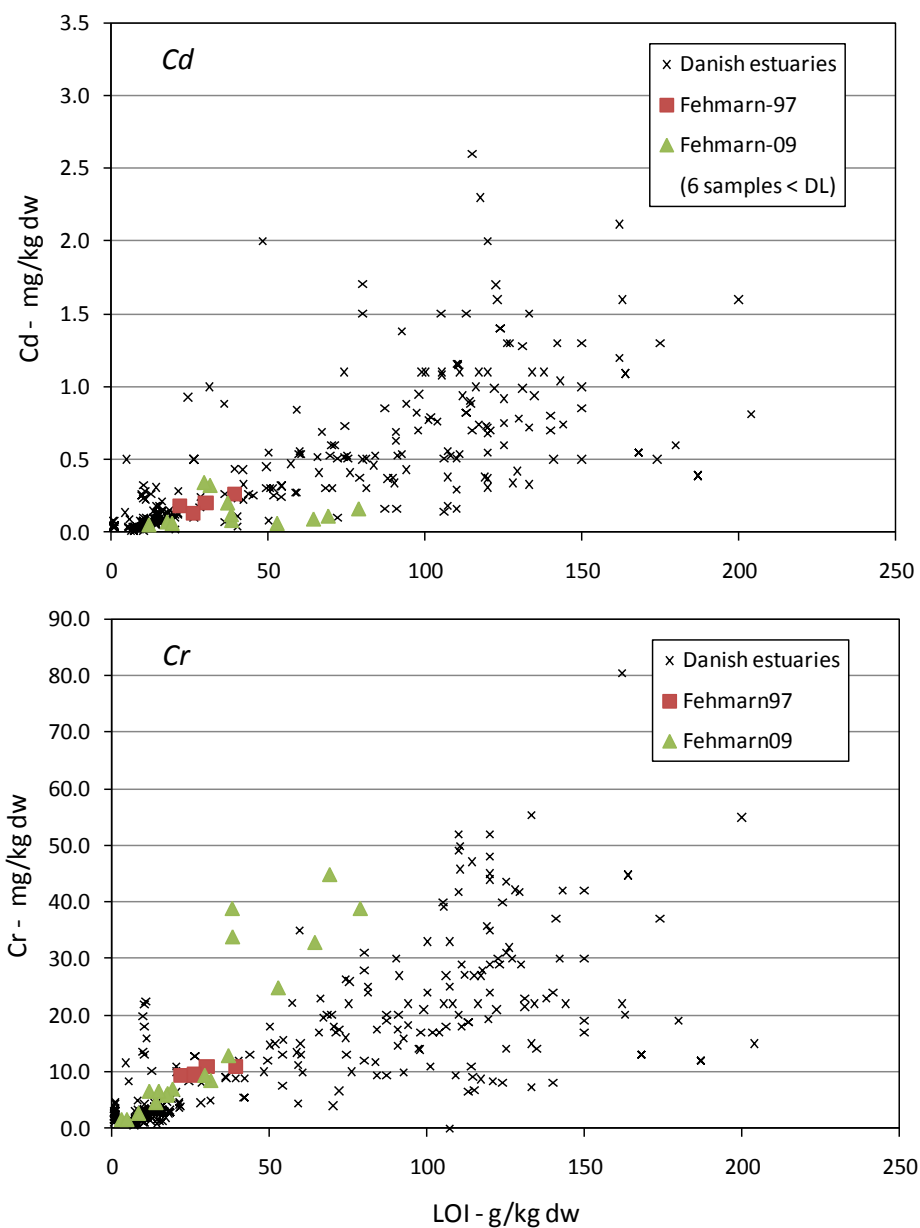


Figure 4-6 Scatter-plot of cadmium (Cd) and chromium (Cr) concentration in sediments with different content of LOI (six samples from the Fehmarnbelt had Cd concentration below detection limit of 0.05 mg/kg dw). Data from Fehmarnbelt sediment collected in November 2009. For comparison is shown data from the Fehmarnbelt Feasibility study (1997) and from diffusely polluted Danish estuaries and coastal waters (i.e. data from areas with known point sources not included).

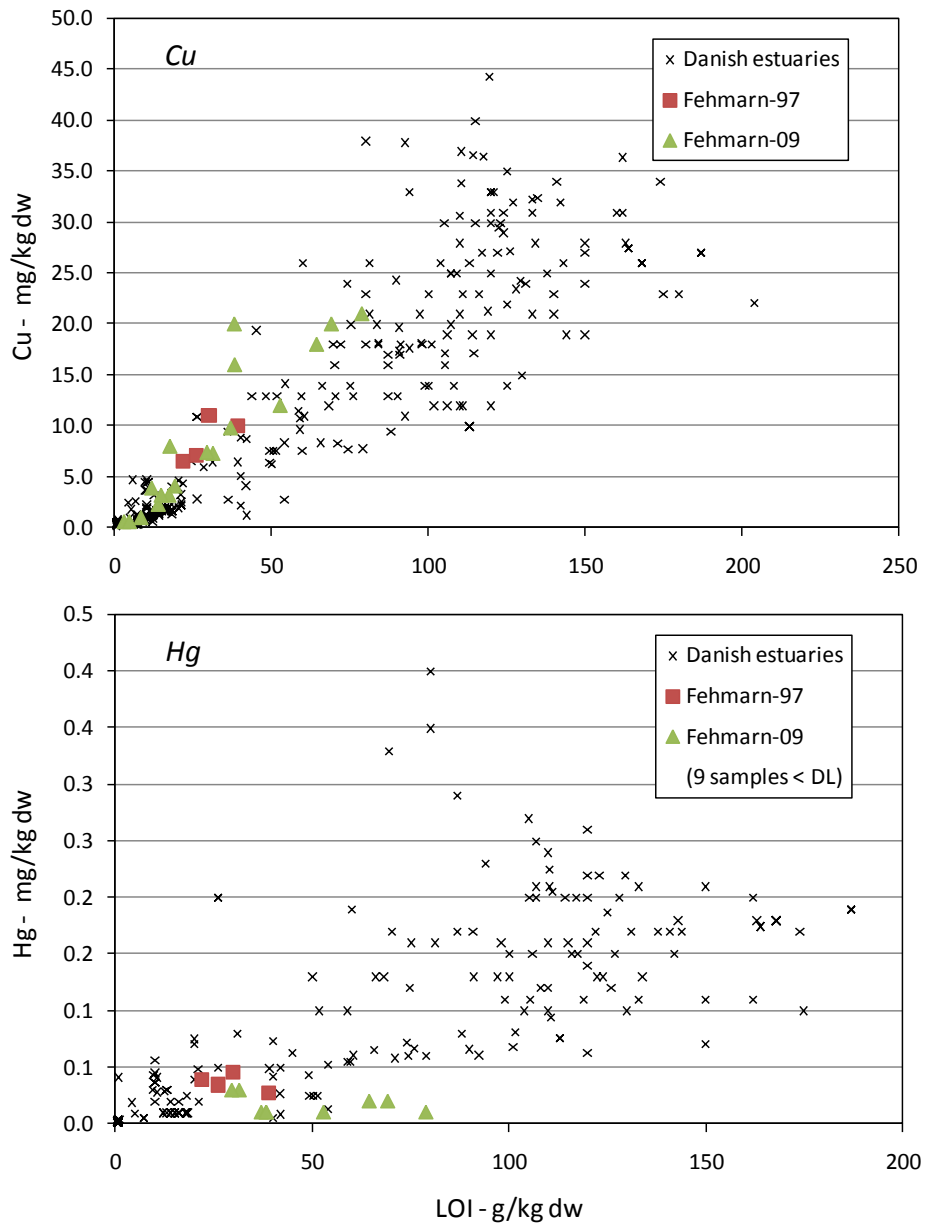


Figure 4-7

Scatter-plot of copper (Cu) and mercury (Hg) concentration in sediments with different content of LOI. Data from Fehmarnbelt sediment collected in November 2009 (nine samples from the Fehmarnbelt had Hg concentrations below detection limit of 0.01 m/kg dw). For comparison is shown data from the Fehmarnbelt Feasibility study (1997) and from diffusely polluted Danish estuaries and coastal waters (i.e. data from areas with known point sources not included).

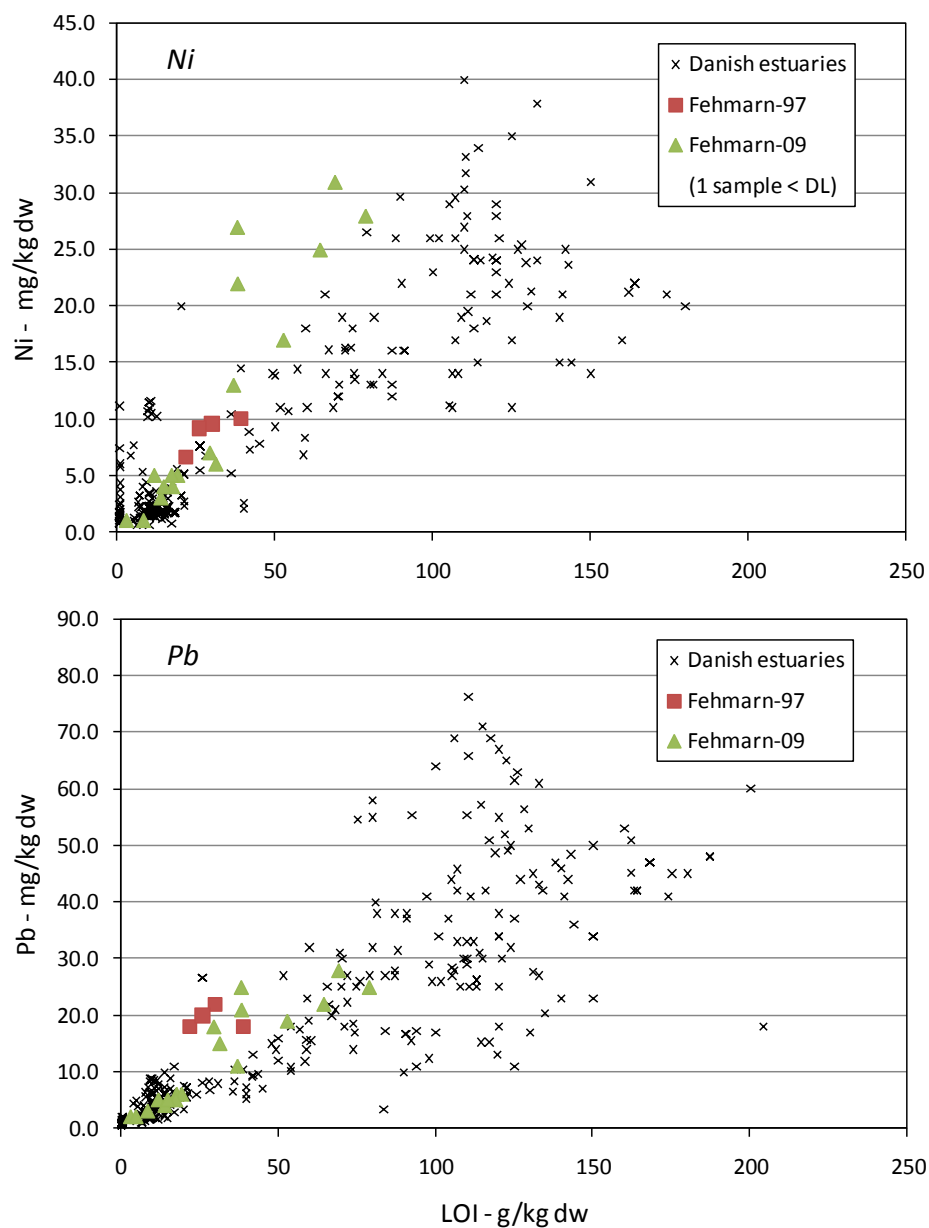


Figure 4-8 Scatter-plot of nickel (Ni) and lead (Pb) concentration in sediments with different content of LOI. Data from Fehmarnbelt sediment collected in November 2009 (one sample from the Fehmarnbelt had Ni concentration below detection limit of 1 mg/kg dw). For comparison is shown data from the Fehmarnbelt Feasibility study (1997) and from diffusely polluted Danish estuaries and coastal waters (i.e. data from areas with known point sources not included).

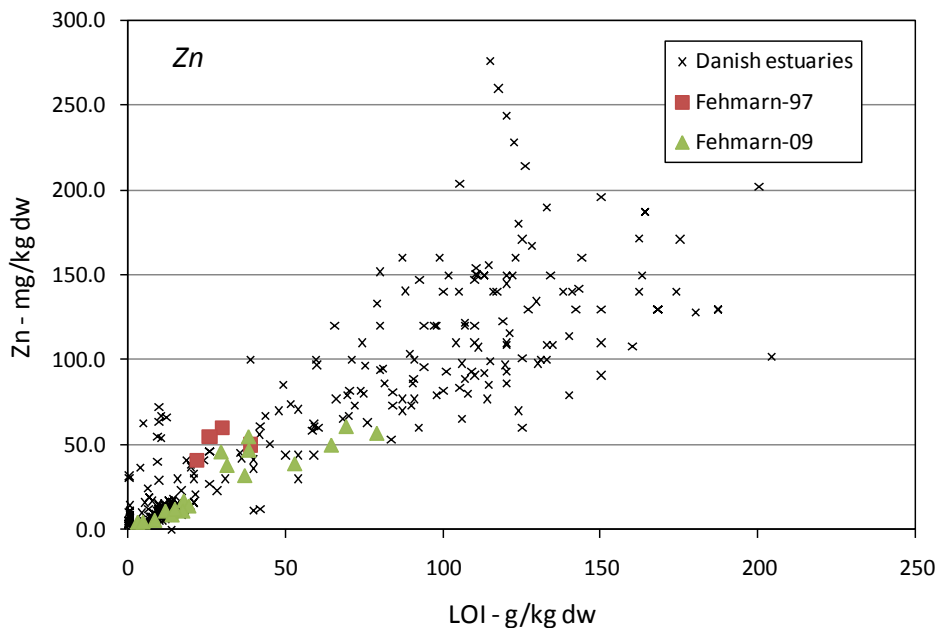


Figure 4-9 Scatter-plot of zinc (Zn) concentration in sediments with different content of LOI. Data from Fehmarnbelt sediment collected in November 2009. For comparison is shown data from the Fehmarnbelt Feasibility study (1997) and from diffusely polluted Danish estuaries and coastal waters (i.e. data from areas with known point sources not included).

## 4.2 Persistent organic pollutants in sediments

Persistent organic pollutants (POP's) analysed in Fehmarnbelt sediments include chlorinated biphenyls (seven PCB congeners: PCB-28/31, -52, -101, -118, -153, -138, -180), chlorinated pesticides (DDT and degradation products, HCB), polycyclic aromatic hydrocarbons, PAH's (16 compounds), and tributyltin (TBT and degradation products of TBT).

Summary data for PCB's, DDT's, Hexachlorobenzene and PAH's in surface sediments (0-30cm), are shown in Table 4.1 and data for TBT and degradation products are shown in Table 4.2. Detailed data including all compounds are shown in Appendix E.

The horizontal distribution of POP's in surface sediments is depicted in Figures 4.10 – 4.13. In contrast to the distribution of heavy metals the concentration of POP's did not follow the depth contours, but was highest inside the German territorial waters close to the Puttgarden harbour. Except for HCB, POP's did not correlate to the concentration of organic carbon in sediments.

Two sediment samples were analysed in replicate (A007-1, A008-1; see Table 4.1). Except for DDTs, replicate concentrations were very uniform with coefficients of variation (CV%) ranging between 7.2 and 11.6%. Differences in DDT concentrations in replicates were much higher primarily due to a sample with "0" concentration.

In general, compared to the sediment quality guidelines (see Section 4.3) the concentration of POP's was low with one exception for PCBs at Station A011 located in the middle of the Fehmarnbelt alignment (Figure 4.12). At this station the concentration of PCBs was approximately 100 times higher than the average concentration



for the other stations (Table 4.1). Evaluated on the basis of very low concentrations of PCBs at nearby stations we assume that the high concentration at Station A011 is probably related to pollution from an object either lost or dumped at sea.

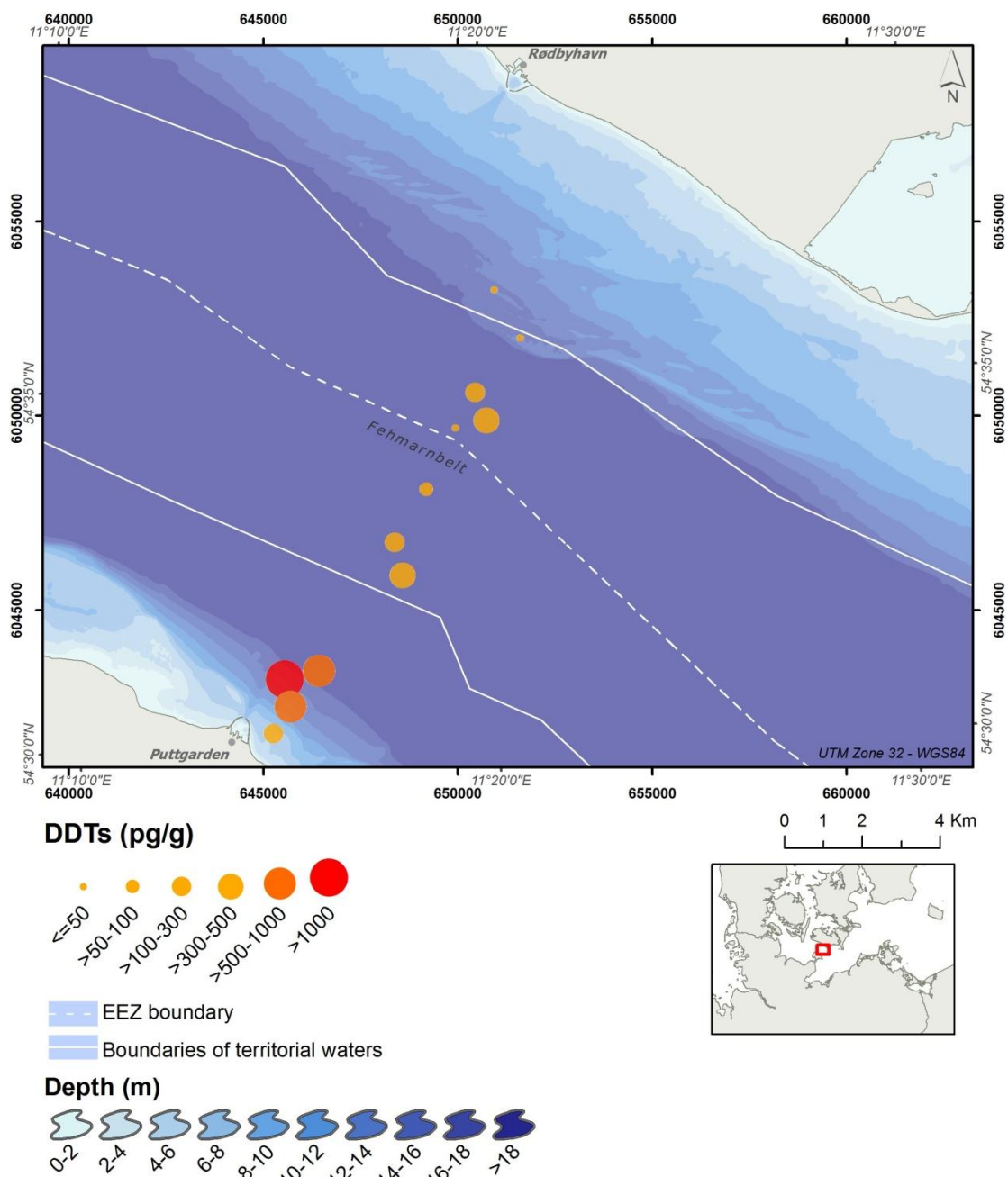


Figure 4-10 Concentration of DDTs (sum of *p,p'*-DDT, *o,p'*-DDT, *p,p'*-DDD, *p,p'*-DDE) in surface sediments (0-30 cm) across the Fehmarnbelt.



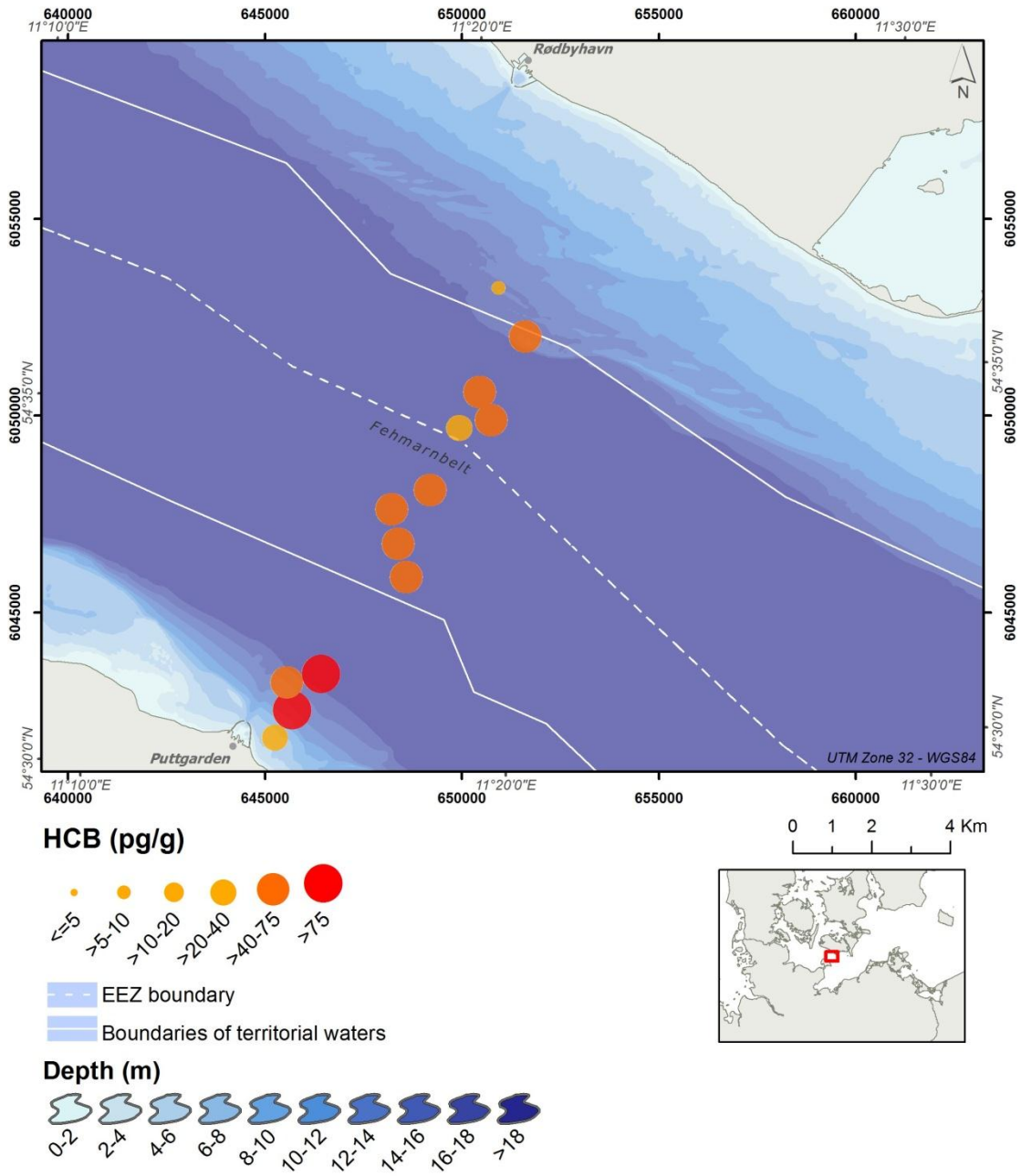
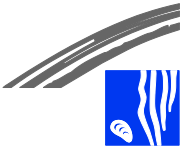


Figure 4-11 Concentration of HCB in surface sediments (0-30 cm) across the Fehmarnbelt.

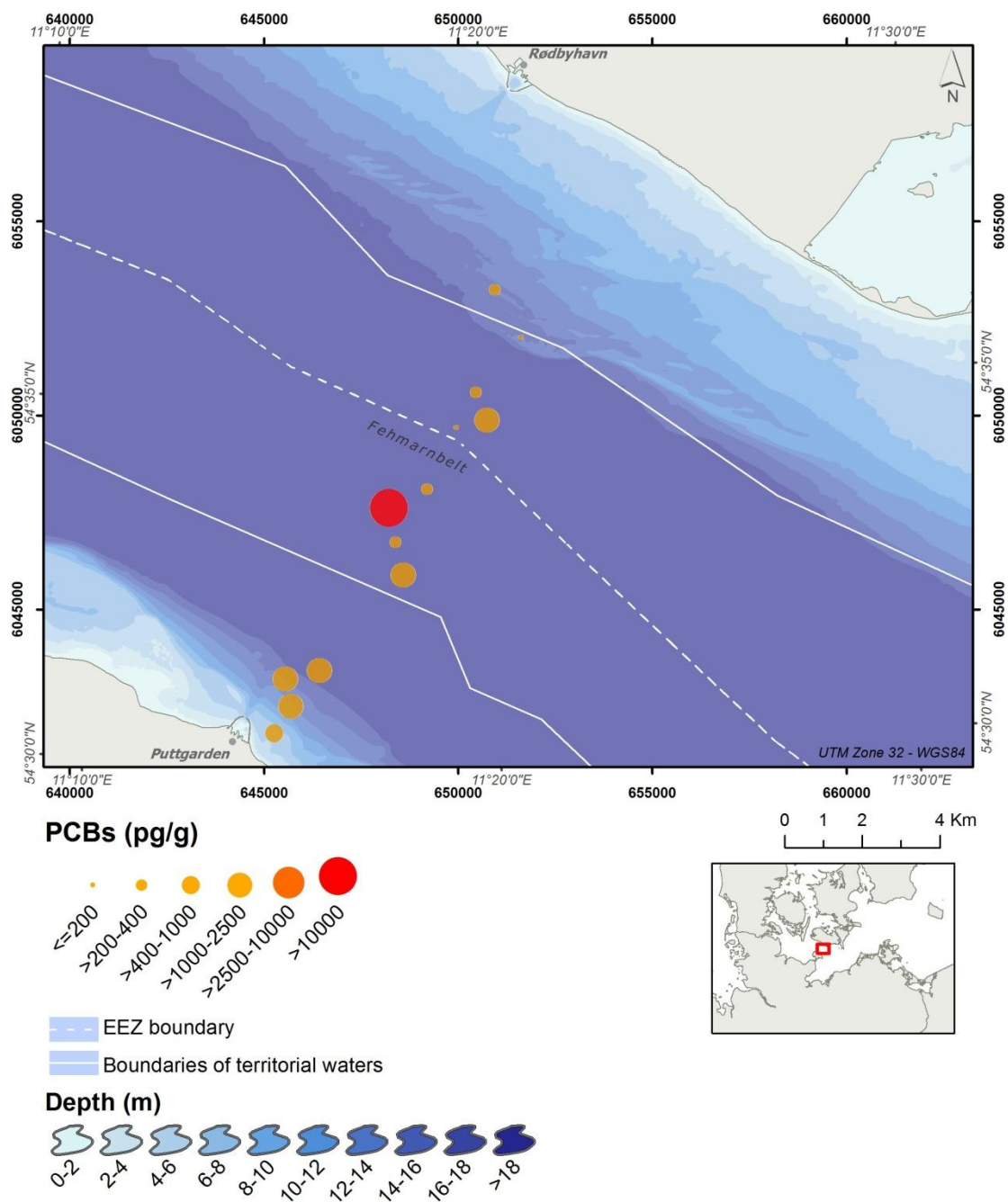


Figure 4-12 Concentration of PCBs (sum of PCB-28/31, PCB-52, PCB-101, PCB-118, PCB-153, PCB-138, PCB-180) in surface sediments (0-30 cm) across the Fehmarnbelt.

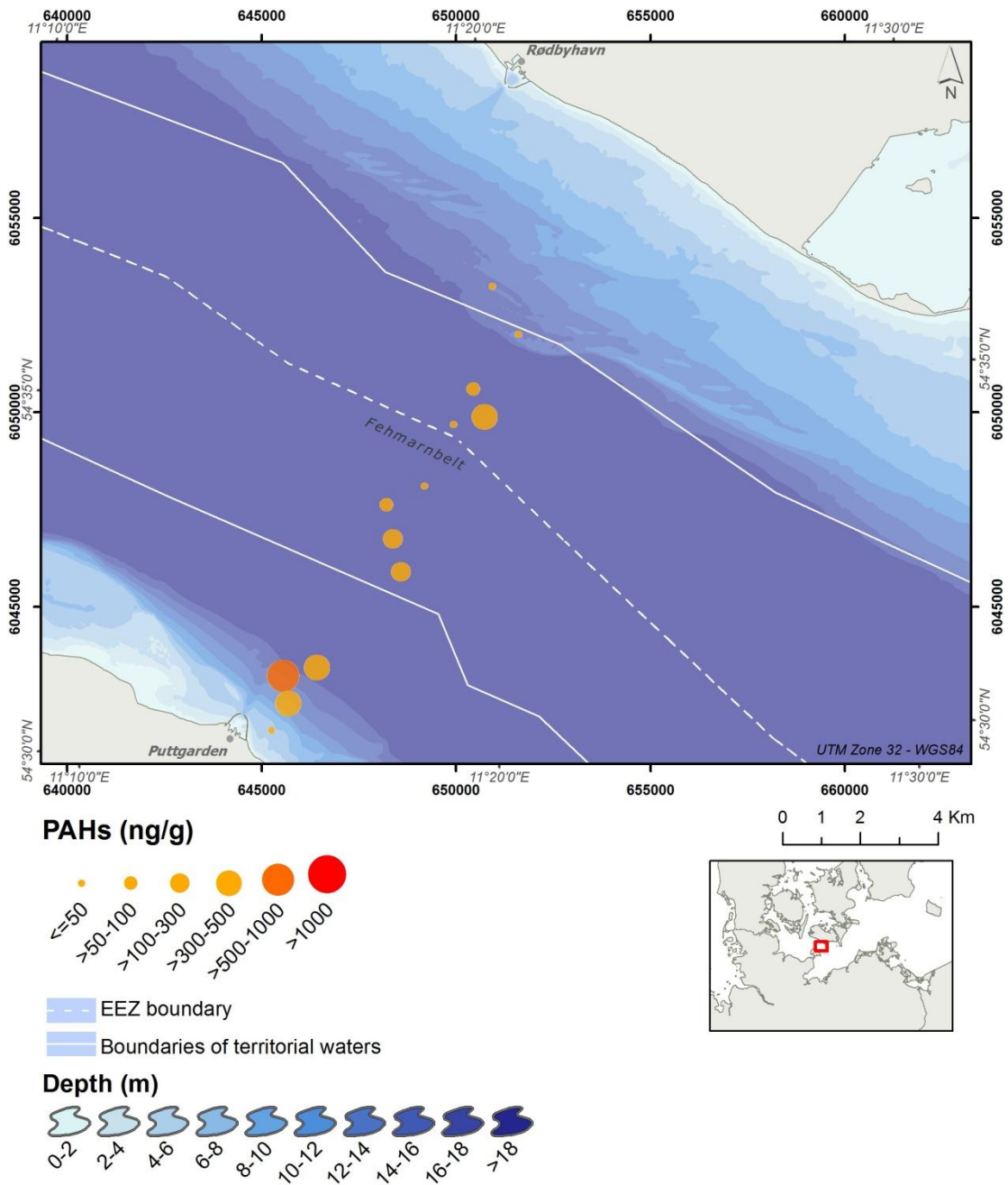


Figure 4-13 Concentration of PAH's (sum of 16 species) in surface sediments (0-30 cm) across the Fehmarnbelt.



Table 4-1 Concentration of organic carbon (% of dw), HCB, sum of 7 PCBs, sum DDTs and sum PAH (16 species) in surface sediment samples from the Fehmarnbelt fixed link alignment

Sample	C-org. % of dw	HCB (pg/g) ----- pg/g	Sum 7 PCBs ----- pg/g	Sum DDTs ----- ng/g	Sum 16 PAHs ----- ng/g
A001-1	0.21	40	444	119	36
A002-1	0.95	96	2304	920	468
A003-1B	1.07	78	2154	744	382
A009-1	1.09	75	2346	1126	644
A005-1	0.98	42	397	109	133
A006-1	1.07	41	277	79	48
A007-1 (A-replicate)	0.46	29	156	79	33
A007-1 (B-replicate)	0.49	27	175	0	28
A008-1 (A-replicate)	0.39	48	351	113	73
A008-1 (B-replicate)	0.81	38	391	216	68
A011-1	0.76	51	74208	0	85
A013-1	0.04	26	347	35	17
A019-1	0.07	67	158	37	17
A016 top 5 cm	0.85	65	1289	343	175
A017 top 5 cm	1.55	70	1329	457	370

Two sediment cores (A016, A017, see Figure 2.2) sampled in the central and deep part of Fehmarnbelt were selected for a detailed study on depth distribution of pollutants. These cores were sliced in 1 cm sections that were analysed for HCB, PCBs, PAHs and DDTs.

The results showed that the highest concentration of POPs was present in the upper 10cm of the sediment and that 5-10 times lower concentrations were approached at depths 10-12cm below the sediment surface (Figure 4.14; Figure 4.15). This pattern indicates that pre-industrial (>100 years old) levels of PAH's (< 50 ng/g sediment dw) are reached at a depth of 10-12cm (Ricking and Schulz 2002). This fact again indicates that Fehmarnbelt does not constitute a sedimentation area such as the Arkona basin further to the East.

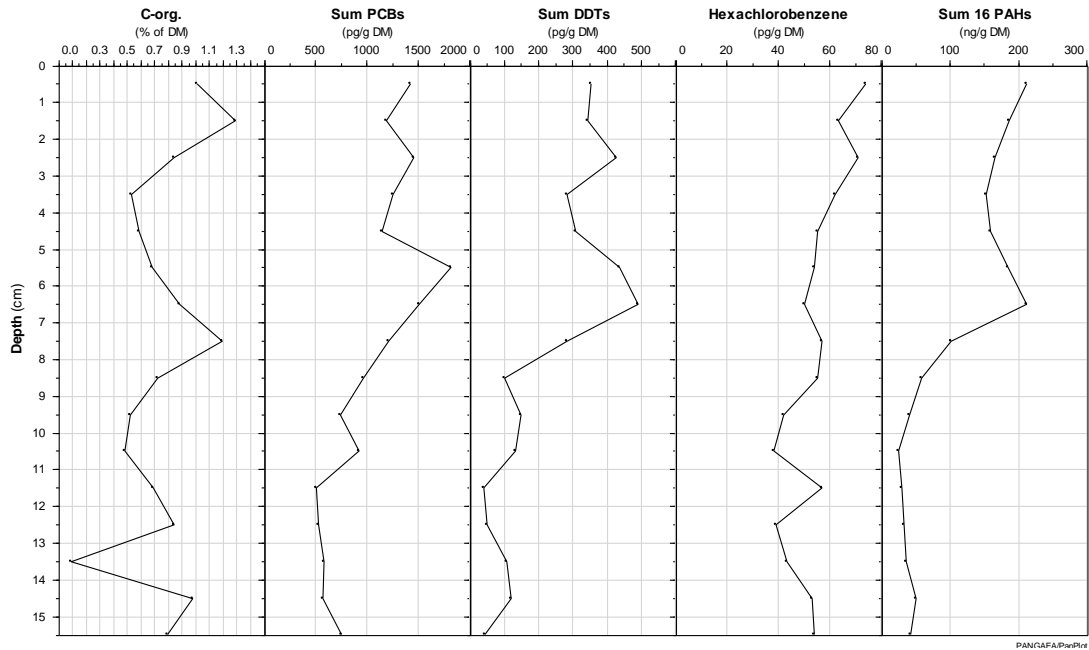
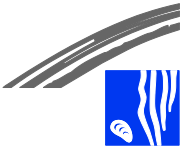


Figure 4-14 Depth profiles of organic carbon, sum PCBs, sum DDTs, sum PAHs and HCB in a sediment core taken at station A016. Analyses were carried out in 1 cm slices from surface till 16 cm below sediment surface.

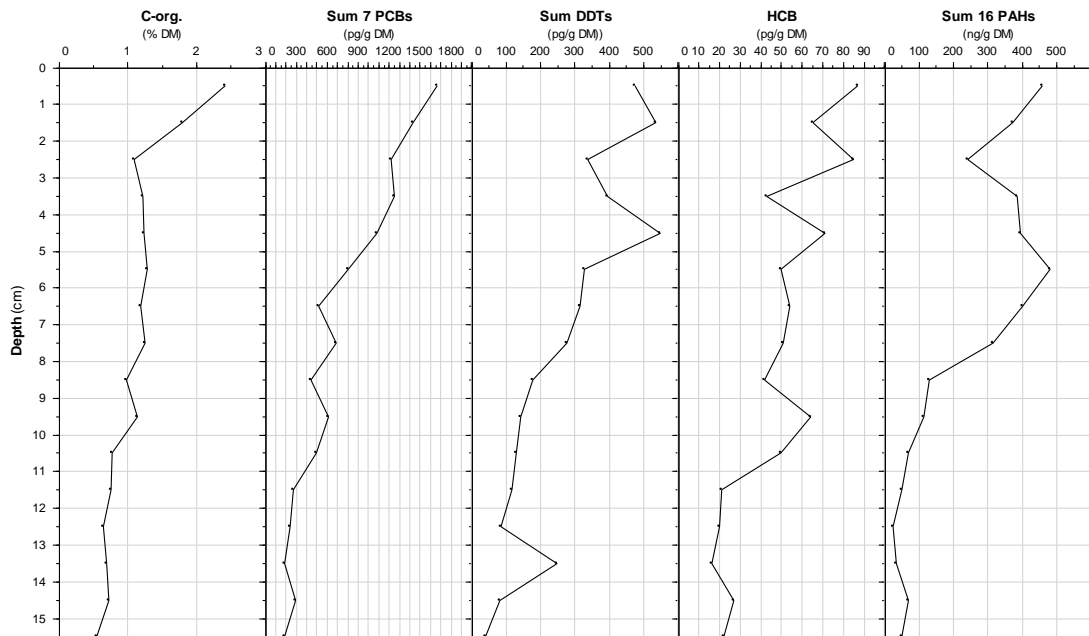


Figure 4-15 Depth profiles of organic carbon, sum PCBs, sum DDTs, sum PAHs and HCB in a sediment core taken at station A017. Analyses were carried out in 1 cm slices from surface till 16 cm below sediment surface.

The concentration of organotin compounds originating from antifouling paints was low and generally at or below detection limits (Table 4.2).



Table 4-2 Concentration of tributyltin (TBT), dibutyltin (DBT) and monobutyltin (MBT) in surface sediment (0-30cm) samples from the Fehmarnbelt fixed link alignment. nd = not detected; values in brackets = maximum concentrations, but below official method detection limit.

Sample	TBT	DBT	MBT
	----- $\mu\text{g Sn/kg dw}$ -----		
A002-1	2.2	<(0.6)	<(0.6)
A005-1	<(0.94)	<(0.4)	<(0.4)
A006-1	1.7	1.2	<(0.6)
A007-1	nd	<(0.4)	nd
A011-1	<(0.3)	<(0.4)	<(0.3)
<i>Uncertainty of measurement</i>	14%	15%	25%

### 4.3 Potential toxic effects of dredging

Depending on presence of local pollutant sources and the sedimentary conditions, marine sediments may contain a large number of pollutants that may be present in high concentrations. It is often presumed that such pollutants are released to the water column during dredging operations subsequently with a risk of adverse impact on aquatic life in the water. Other concerns relate to the dredged (and polluted) sediment if it is dumped in the marine environment. In such cases, pollutants can be released to the water column during dumping and can lead to 'enrichment' of the sea bed with pollutants when settled as bound to sediment particles. Settled sediments may thus affect benthic organisms, provided pollutant concentrations exceed certain limits and that pollutants are present in a bioavailable state.

#### 4.3.1 Sediment quality guidelines

Sediment dredging and disposal activities in Denmark and Germany are amongst other regulated according to the concentration of toxic substances in sediments and the the amount of sediment dredged. If concentrations of toxic substances are below certain low limits and/or the amount dredged is low the toxic content will not prevent dredging and disposal (BLST 2008, Manz et al. 2007). In contrast, if concentrations exceed certain limits set by the authorities' further evaluations and investigations may be required (Manz et al. 2007). Such investigations could include elutriation tests to quantify mobility of toxic substances and laboratory survival test with 'standard' organisms exposed to undisturbed sediments or porewater extracted from sediments.

When dredging extends to large depths in sediment/soil - which will be the case in the Fehmarnbelt - soil with different concentrations of pollutants (usually decreasing downwards) will come into contact with water due to spill (typically a few percentages of dredged volume (FEHY 2011). Based on basic mass balance arguments soil and sediments with the highest concentrations will have the largest risk for enriching the water with pollutants, while deep-laying soil with natural background levels (pre-industrial) of pollutants can be considered harmless and with a minimal release to the water.

In the Fehmarnbelt dredging can be expected to extend to 12 m below the seabed (FEHY 2011). In result, 10-15 cm thin surface sediments with enriched concentrations of persistent organic pollutants (Figures 4.16, 4.17) will be dredged, a few percentages lost as spill and depending on particle settling velocities these spilled sediments will be spread over large ( $>>\text{km}^2$ ) areas in very thin layers ( $< 1\text{mm}$ ) (FEHY 2011). When dredging extends to below 10-15 cm the concentration of per-



sistent organic pollutants will reach background concentrations that except for PAH compounds practically is zero. Assuming that settling velocities of sediments from surface layers and subsoil layers are comparable the sediments spread originating from subsoil will 'dilute' the sediment concentration upon settlement. Hence, for each m<sup>2</sup> dredged only 1% of the sediment volume will have concentrations that are enriched and 99% of the sediment volume will have background concentrations, and if these sediments are deposited in the same areas the resulting surface concentrations of pollutants will be markedly reduced compared to the sediments that are dredged, but also compared to the seabed where spilled sediments are deposited.

In the following the evaluation of potential impacts of pollutants is based on the concentrations measured in surface sediments, with the notion that if pollutant concentrations in the surface lies below the various sediment quality guidelines, including quality objectives set by national authorities or suggested by international fora then impacts related to these pollutants are considered not to be problematic.

The evaluation of pollutant levels in sediments is usually based on so called sediment quality guidelines (SQG) that generally are derived based on three different approaches: 1) definition of criteria from data sets from toxicity experiments with polluted sediment (toxicological criteria), 2) defining criteria based on data from unpolluted sediments (background levels) or 3) a combination of both approaches. In Table 4.3 is listed a selection of SQG that are accepted by environmental authorities and that includes some of the lowest criteria values available. The ERL (Effect Range Low, Buchman 2008) values are based on toxicological data and, sediment concentrations below these values are highly unlikely to affect sediment-living organisms. OSPAR (2009) and German (Anon 2009) values are based on background concentrations and accepted exceedence from background concentrations, while the Danish BLST (2008) values are based on both toxicological and background data. Danish authorities operate with two sets of criteria values, Lower Action level (L Ac) and Higher Action level (H Ac), where values below L Ac are considered unproblematic.

Table 4-3 Sediment quality guidelines (ERL values from Buchman 2008; OSPAR values from OSPAR (2009); Danish EPA values from BLST, 2008). German values from Anon 2009. Values in bold are used in the evaluation. n.a. = no criteria defined

Element / Compound	ERL	OSPAR	Danish EPA/BLST		German#	
			L Ac	H Ac	R1	R2
Arsenic (As) (mg/kg)	<b>8.2</b>	25	20	60	20	60
Cadmium (Cd) -	1.2	0.37	<b>0.4</b>	2.5	2	6
Chromium (Cr) -	81	81	<b>50</b>	270	90	270
Copper (Cu) -	34	27	<b>20</b>	90	70	210
Lead (Pb) -	46.7	38	<b>40</b>	200	100	300
Mercury (Hg) -	<b>0.15</b>	0.07	0.25	1	0.4	1.2
Nickel (Ni) -	<b>20.9</b>	36	30	60	70	210
Zinc (Zn) -	150	122	<b>130</b>	500	250	750
PAH sum -	<b>4*</b>	0.25	3**	30**	3*	9*
DDT sum (µg/kg)	<b>1.58</b>	n.a.	n.a.	n.a.	22	66
PCB sum -	23	1.09	<b>20</b>	200	40	120
HCB	n.a.	n.a.	n.a.	n.a.	<b>2</b>	6
TBT -	n.a.	0	<b>7</b>	200	20	300
Tot-P (mg/kg)	n.a.	n.a.	n.a.	n.a.	500	
Tot-N -	n.a.	n.a.	n.a.	n.a.	1500	

# heavy metals in <20 µm fraction, POPs in < 63 µm fraction, tot-N, Tot-P in bulk samples; \*sum of 16 compounds; \*\* sum of 9 compounds



German guidelines (Ostsee Richtwerte R1, R2, Anon 2009) are based on toxicant concentrations in various sediment size fractions (heavy metals: < 20 µm, POP's: < 63 µm).

As seen in Table 4.3 there is good agreement between those SQG that are based on toxicological criteria (ERL, Danish EPA/BLST), while the OSPAR data that are based on 'background' data are much lower for the anthropogenic TBT but also much lower for PCB and PAH, which do occur naturally although at much lower concentrations than in present day sediments.

The use of sediment fraction below 20 µm as base for setting the German "Richtwerte" excludes a direct comparison with other sediment quality guidelines that refer to bulk sediments. Numerous studies have examined the relation between grain size and heavy metal contents in sediments (e.g. Lakhan et al. 2003; Schorer 1997), but the influence of site-specific conditions on slopes between grain size and metal concentration and, potential bias due to flocculation during wet sieving in some studies preclude direct application of concentrations ratios (< 20 µm : bulk sediment) to other sediments. Instead the average metal concentrations in the 20 µm fraction was estimated by linear regressions between % volume of sediment < 20 µm and metal concentrations based on data from six surface samples where both grain size curves (laser diffraction) and heavy metal data were available (Table 4.4). Cumulative size distribution of sediments is shown in Appendix G. Average (over stations) metal concentration in the fine sediment fraction was calculated from regressions interting 100% in < 20 µm fraction.

Table 4-4 Corresponding physical and chemical data characterizing surface sediments from 6 stations (A001-A008). Coefficient of variation of linear regressions ( $R^2$ ) between organic content (LOI), percentage sediment volume below 20 µm and below 63 µm and, concentrations of lead (Pb) chromium (Cr), copper (Cu), nickel (Ni) and zinc (Zn).

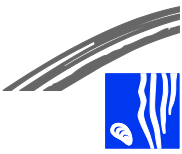
	A001	A002	A003	A005	A006	A008	$R^2$		
							LOI	<20µm	<63µm
Depth (m)	8	14	19.5	30.1	28.9	26			
LOI (% of DW)	1.05	3.15	3.71	1.78	2.96	6.11			
% of Vol. <20 µm	6%	14%	33%	12%	6%	98%			
% of Vol. <63 µm	11%	38%	49%	16%	8%	100%			
Pb (mg/kg DW)	4	15	11	6	18	28	0.84	0.60	0.58
Cr (mg/kg DW)	4.6	8.6	13	6.3	9.5	45	0.84	0.97	0.87
Cu (mg/kg DW)	2.5	7.3	9.8	8	7.4	20	0.89	0.91	0.85
Ni (mg/kg DW)	3	6	13	4	7	31	0.89	0.97	0.91
Zn (mg/kg DW)	9.4	38	32	17	46	61	0.83	0.50	0.51

The coefficient of variation ( $R^2$ ) were uniformly high (0.83-0.89) for regression lines between LOI and 5 heavy metals, but more variable ( $R^2 = 0.5-0.97$ ) for regressions lines between % sediment volume below <20 µm and heavy metals (Table 4.5). Two metals (Pb and Zn) showed poor relations to the fractions of fine sediment.

#### 4.3.2 Heavy metals in sediments

The concentrations of heavy metals were low and in all cases, except 1-2, below the lowest SQG, see Figure 4.16. Averaged over stations and heavy metals, concentrations were 68% below the lowest SQG in the sediment surface and 75% below SQG in the subsurface sediments (30-100cm). In two samples (both from station A008 located in the middle of the Fehmarnbelt alignment) the concentration of





copper was at level with SQG (19 and 20 mg Cu/kg) and the concentration of Ni (31 and 27 mg Ni/kg) exceeded lowest toxicologically derived SQG, but still were below the 'background level' (36 mg Ni/kg) calculated by OSPAR (see Table 4.3).

Below 0.5m from the seabed the sediment concentration of heavy metals reaches background levels (COWI-Lahmeyer 1998). Considering that dredged subsurface sediments with a background concentration exceeding the dredged surface sediments in volume by more than a 10 factor, and that the concentration of heavy metals averaged over the alignment stretch was way below the lowest SQG, the disposal of dredged sediments and settlement of dredge spill is highly unlikely to affect benthic organisms in relation to the concentration of heavy metals. Regarding release during dredging of sediments, previous studies with sediment from the Fehmarnbelt showed that release of heavy metals from sediments when suspended was low, typically 1% of the sediment concentration (COWI-Lahmeyer 1998).

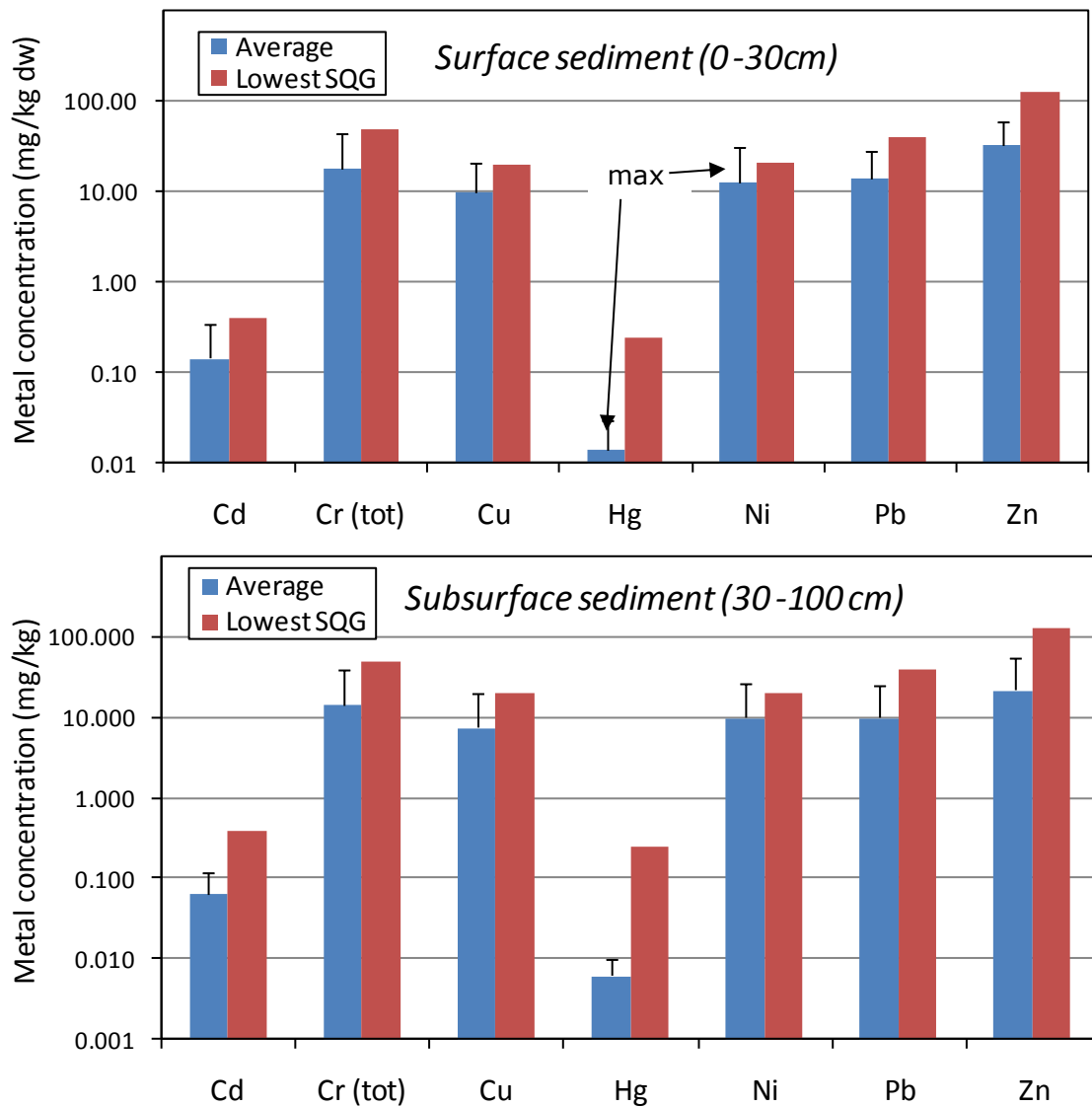


Figure 4-16 Average and max concentration (error bars) of 7 heavy metals in surface sediments (upper) and subsurface sediments. Red bars indicate lowest SQG-values (see Table 4.4). Notice that y-axis is logarithmic.

In a comprehensive assessment based on laboratory and field studies of about 100 contaminated sediments from across the United States, it was shown that net re-



lease of heavy metals was insignificant (Lee et al. 1975). The main reason was that during resuspension of sediments (i.e. spill), ferric hydroxide, which is formed in the water column due to oxidation of ferrous iron, acts as a very efficient adsorbant leading to a rapid scavenging of heavy metals in the precipitate. The scavenged metals are then re-deposited in the sediments. In effect, concentration of heavy metals in the water column will show no change or even a reduction; all dependent on the availability of reactive iron in sediments. Other lab-based studies confirmed a low mobilisation of heavy metals from contaminated sediments (Calmano et al. 1994, Shipley et al. 2011).

The compliance with the German SQG (Richtwerte) that refers to fine sediment (< 20 µm) was examined using calculated concentrations in the < 20 µm fraction (see section 4.3.1). Because the calculated values are based on several samples the metal concentrations represents the average for the surface sediment along the alignment. Concentration of As, Cd and Hg were below detection limits in all (As) or in several samples, hence concentration of these metals in the < 20 µm sediment fraction could not be calculated by regression. Also, because the calculated concentrations of Pb and Zn were based on 'poor' regressions ( $R^2 = 0.5-0.6$ ) the values for these elements shown in Table 4.6 could be somewhat flawed (about  $\pm 30\%$ ).

The calculated metal concentrations in the fine sediments constituted at most 50% of the corresponding German SQG for Cr, and were markedly lower for other metals (Table 4.5).

Table 4-5 *Estimated heavy metal concentration in surface sediments in fraction < 20 µm and German SQG for unproblematic sediments (Richtwerte R1). Brackets for Pb and Zn indicate that values could be somewhat flawed (see text).*

	Sediment concentration (mg/kg DW)	
	<i>FB &lt; 20µm</i>	<i>R1</i>
Pb	(28)	100
Cr	45	90
Cu	20	70
Ni	32	70
Zn	(61)	250

### 4.3.3 **Persistent organic pollutants in sediments**

#### *Tributyltin*

Five sediment samples from the central and deep parts of the Fehmarnbelt, where ships traffic is most intense, were selected for TBT analysis. Concentration of tributyltin and the degradation products was low at all stations (Fig. 4.17). Compared to the SQG set by the Danish BLST (2008) at 7µg Sn-TBT/kg, the concentration in sediments was 6-7 times lower. Being a recently introduced pollutant concentration, TBT reaches 0 (background) concentrations below 10 cm sediment depth (see Figure 4.14). It is therefore concluded that impacts of TBT related to spill or disposal of dredged sediment are highly unlikely.

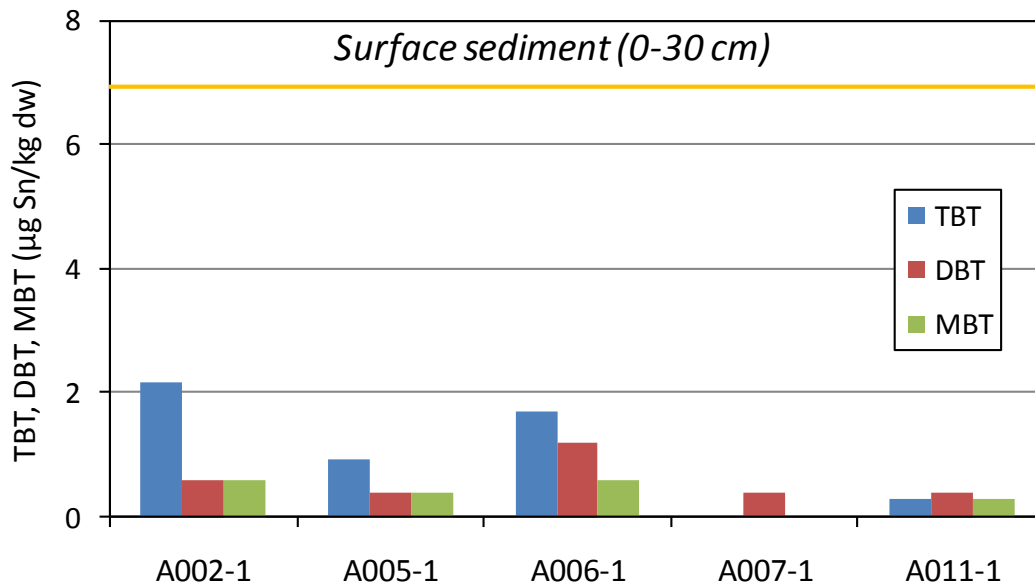


Figure 4-17 Concentration of tributyltin (TBT), dibutyltin (DBT) and monobutyltin (MBT) in surface sediments. The yellow line indicates the level of SQG defined by Danish BLST (2008) (see Table 4.4).

#### PCB

Except for one sample the concentration of PCBs in surface sediments was well below the lowest SQG at 20 µg PCB/kg. Averaged over stations the concentration of PCBs was 4 times lower than the lowest SQG. One surface sample (A011-1 in the middle of the Belt) differed from the other 14 samples by exceeding the lower SQG by a factor of 3.5 and showing a concentration that was 85 times higher than the other samples (Figure 4.18). As concentration of PCB was low at the nearby stations (see Figure 4.12) it is likely that the pollution is very localised and probably due to hydraulic fluid seeping from equipment lost from a vessel. The alternative, that the sample was contaminated during sample preparation or during analysis seems unlikely.

Overall, however, concentration of PCBs is low and confined to the upper 10-12 cm (Figures 4.14; 4.15). Considering that only 1/100 of sediment column to be dredged contain PCB concentrations above background concentrations, impacts related to release of PCB during dredging and subsequent settling of PCB on sediments is very unlikely.

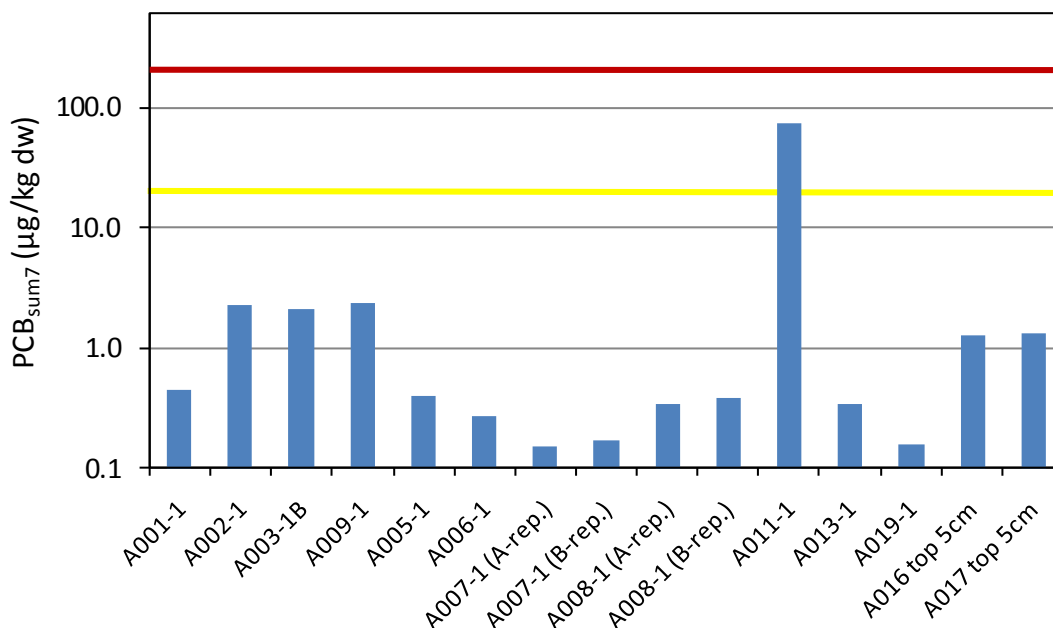


Figure 4-18 Concentration of PCBs (sum of seven congeners) in surface sediments. The yellow line indicates the level of SQG (20 µg/kg) defined by Danish BLST (2008) (see Table 4.4). The red line indicates the 'higher action level' set by the Danish BLST (2008). Notice that y-axis is logarithmic.

#### DDT

Concentration of DDT and degradation products was low and no samples exceeded the lowest SQG (ERL: 1.58 µg/kg) (Figure 4.21). Averaged over all samples, the concentration of DDTs was 5 times below SQG. Considering that DDTs only occur in the upper 10-15cm of sediments and that dredging is planned to extend to 12-14m depth, impacts of DDTs related to dredging activities including sediment spill, sediment dumping and settling of suspended sediments will be highly unlikely.

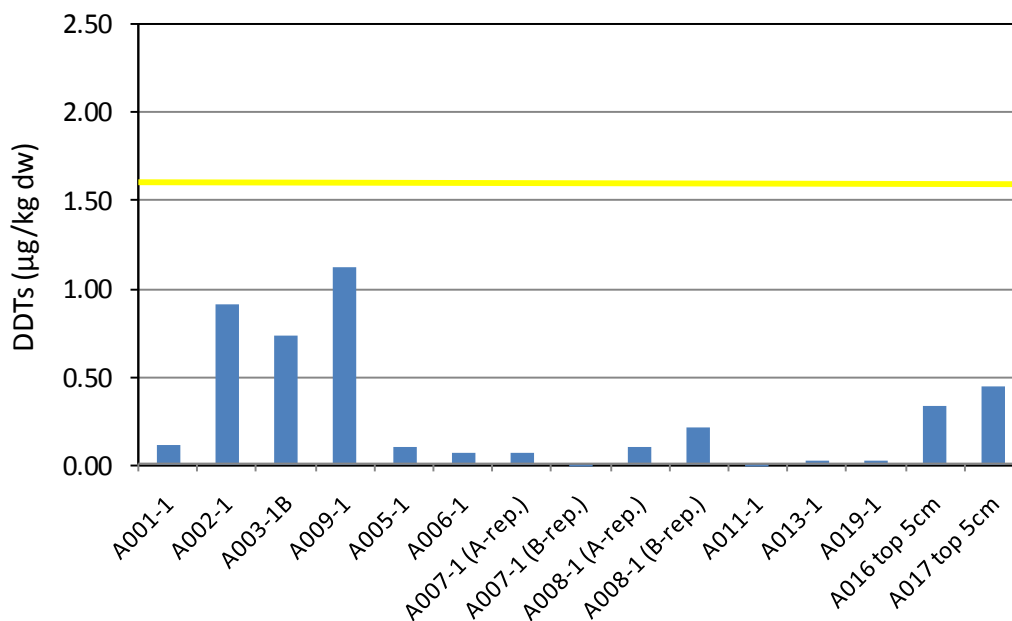


Figure 4-19 Concentration of DDTs (sum of p,p'-DDT, o,p'-DDT, p,p'-DDD, p,p'-DDE) in surface sediments. The yellow line indicates the lowest SQG (1.58 µg/kg) (see Table 4.3).



### PAH

Concentration of PAH compounds was low and no samples exceeded the lowest SQG (ERL based on a sum of 16 compounds) at 4 mg/kg (Figure 4.20). In the sample with the highest concentration (A009-1 in the coastal area near Puttgarden) the concentration is 6 times lower than SQG, and averaged over all samples the PAH concentration was 15 times lower than the most conservative SQG.

Below 10cm depth, PAHs reached a background concentration that on average was 10 times lower than the surface concentrations. Considering that the concentration of PAH averaged over the entire depth to be dredged (12-14m) is very close to the background concentrations, impacts of PAHs related to any dredging and disposal processes are highly unlikely.

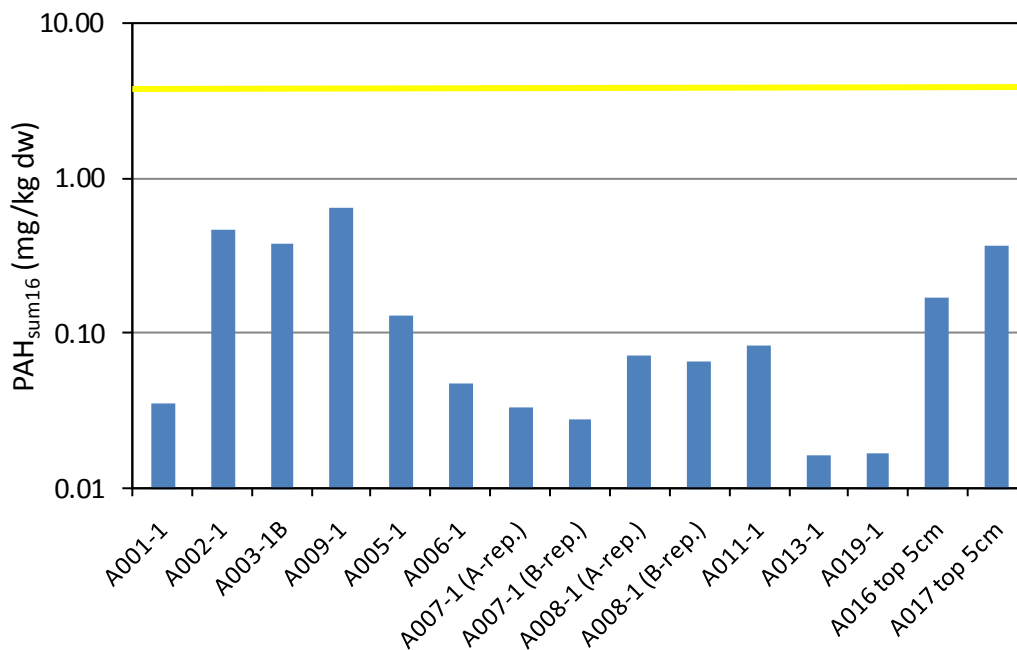


Figure 4-20 Concentration of PAHs (16 compounds) in surface sediments. The yellow line indicates the lowest SQG (4 mg/kg) (see Table 4.4).

#### 4.3.4 Persistent organic pollutants in water column

Upon dredging and disposal of dredged sediment at sea there is a risk of release of pollutants to the water column. Depending on spill rates and pollutant concentrations in sediments, high concentrations may develop in the water column potentially affecting pelagic organisms. However, based on numerous laboratory and field studies encompassing contaminated sediments from almost 100 sites across the USA, Jones-Lee and Lee (2005) concluded that organic pollutants only to a very limited extent are released from spilled sediments and remain in the water column after settlement of the spill. Considering that the concentration of POPs in the Jones-Lee and Lee study on average was 1-to-2 orders of magnitude higher than in the Fehmarnbelt sediments, and that dredging activities in their study also included disposal of sediment, it is highly unlikely that dredging will give rise to elevated concentrations of POPs in the water column.



## 5 OXYGEN CONSUMPTION OF SEDIMENTS

Oxygen consumption of sediments (surface and subsurface) was investigated using sediment from 18 samples of surface and subsurface sediments. Further information on incubations and raw data are shown in Appendix F.

The cumulated oxygen consumption varied between 0.02 and 0.35 mg O<sub>2</sub>/ml sediment (Figure 5.1). The cumulated oxygen consumption in general was higher after 22h than after 5h, but averaged over all 18 samples the increase was only 25%. Hence, oxygen consumption rates were much lower in the later part of incubation indicating that the initial and major part of oxygen uptake was due to oxidation of reduced substances such as sulphides within sediments. The later (5-22h) and much lower rate of oxygen consumption may be seen as an oxidation of organic matter in sediments.

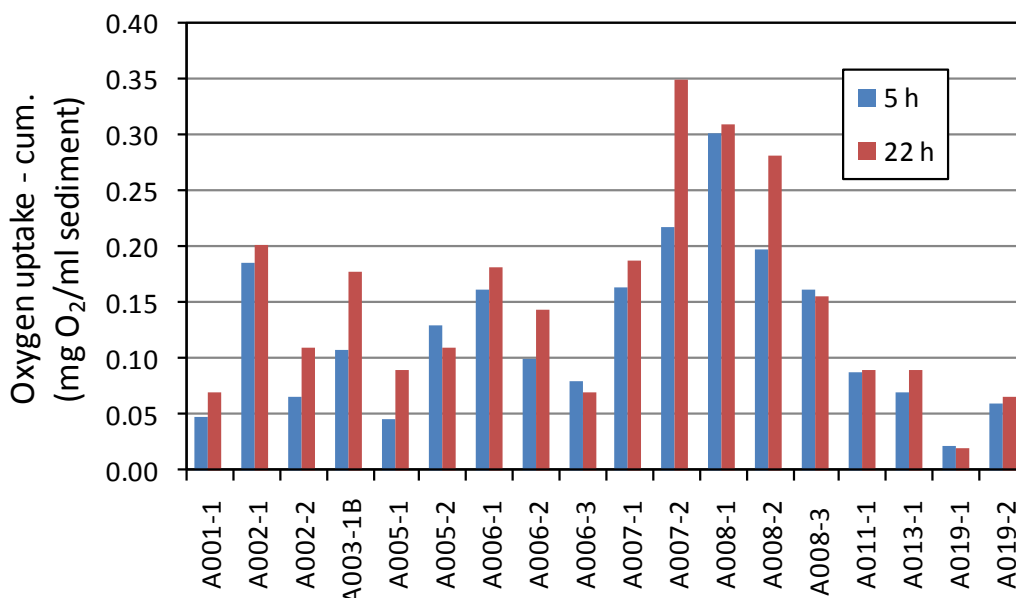


Figure 5-1 Oxygen uptake of sediments incubated in closed flasks mounted on a rotating plankton wheel. Values represent cumulated uptake over 5h and 22h.

The cumulated oxygen uptake increased with the organic content of sediments (Figure 5.2) and decreased with increasing dry weight percentage of sediments (Figure 5.3). These relations are probably due to a higher intrinsic oxygen demand of organic-rich sediments and that the ventilation of sediments with high water content is less intense than in (sandy) sediments with higher dry weights. Hence, organic rich sediments will tend to accumulate oxygen demand to a larger extent than sandy sediments. Upon resuspension e.g. during dredging activities organic rich sediments will have the largest impact on oxygen in the water column. In case that sediment spill is massive it may lead to measurable decrease in concentration of oxygen in the water column (Lee and Jones 1999).

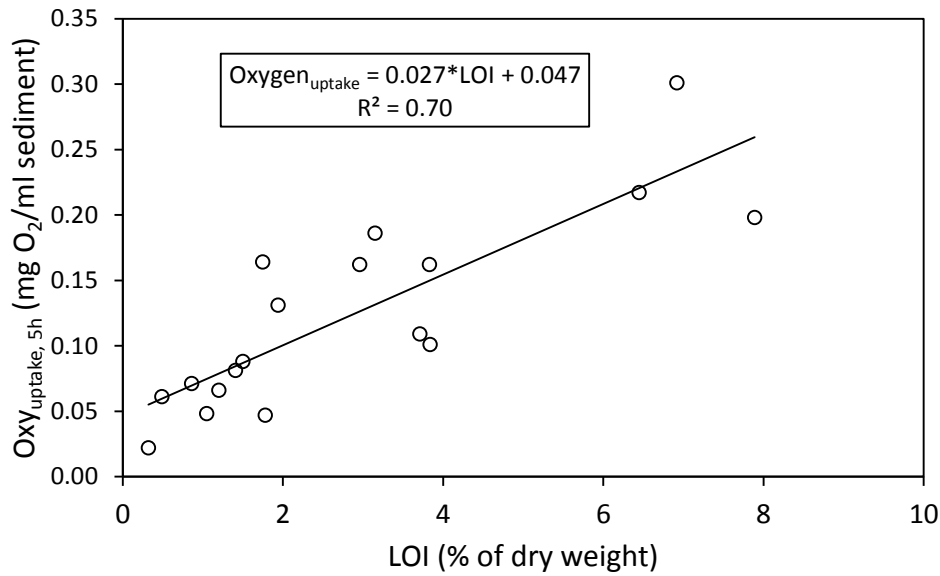


Figure 5-2 Cumulated oxygen uptake of sediments over 5h as function of organic content in sediments (LOI). Linear regression line and equation shown.

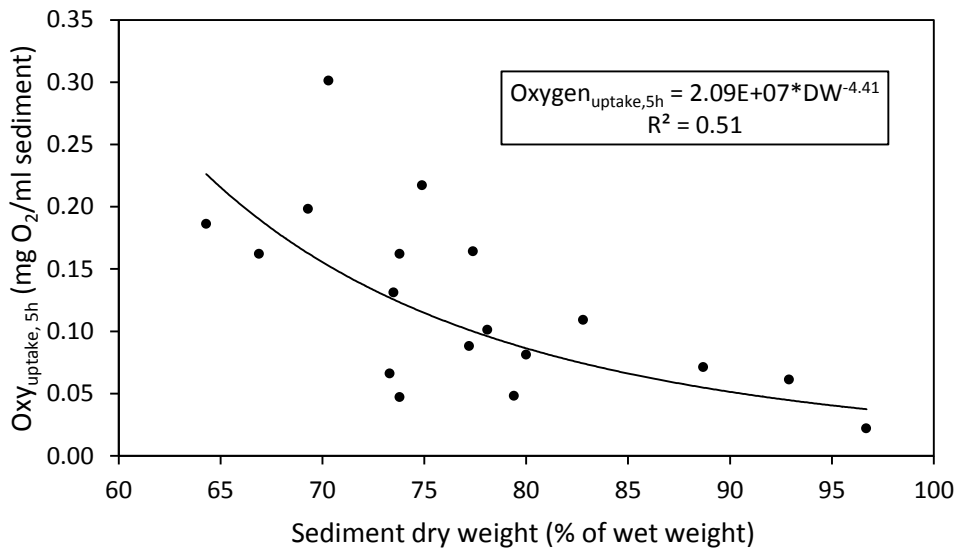


Figure 5-3 Cumulated oxygen uptake of sediments over 5h as function of dry weight percentage of sediments. Power function regression line and equation shown.

## 5.1 Oxygen demand of dredged sediments and impacts in water column

Generally, oxygen demand of sediments is associated with the relatively slow biotic reactions (degradation of organic carbon). However, during storms leading to re-suspension or during dredging operations various abiotic (inorganic) reactions (e.g. oxidation of accumulated sulphides and ferrous iron) often play a much larger role in the depletion of dissolved oxygen in the water column than the oxygen uptake of undisturbed sediments.

An evaluation of the potential impacts of oxygen uptake from suspended sediments under dredging operations is based on a calculated daily oxygen uptake following the same procedure as outlined for nutrient release (section 4.1).



The expected daily oxygen uptake due to dredging was calculated based on sediment LOI concentration and using the relation between LOI and oxygen demand (Figure 5.2) to calculate the oxygen demand for different sediment types, The calculated oxygen demand was multiplied with a spill rate of 3% and integrated over depth, by adding the oxygen demand of surface sediments (0-1 m) to the demand of subsurface sediments (1-12 m) (Table 5.1). Calculations were carried out using 50%, 25% and 75% percentiles for LOI in the different sediment types and strata to represent the most likely rate, a minimum and a maximum rate of oxygen uptake.

Table 5-1 *Estimated oxygen uptake in the water column during dredging operation based on information on oxygen demands in sediment, density of sediment/soil, oxygen demands measured in laboratory and a sediment spill rate of 3% of a daily maximal extraction of 40.000m<sup>3</sup>.*

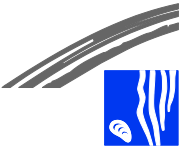
Depth (water) (type)	Percentile	LOI	Density	DO demand		DO uptake
		% of dw	ton/m <sup>3</sup>	laboratory mgO <sub>2</sub> /ml sed	gO <sub>2</sub> /m <sup>3</sup>	dredging kgO <sub>2</sub> /d
0-13m (sand)	25%	0,23	2,30	0,053	100	10,04 <sup>a</sup>
	50%	0,41	2,35	0,058	116	11,61 <sup>b</sup>
	75%	0,77	2,37	0,068	140	13,97 <sup>c</sup>
13-30m (recent marine, clay till)	25%	1,77	1,70	0,095	78	7,80 <sup>a1</sup>
	50%	3,15	1,75	0,132	118	11,80 <sup>b1</sup>
	75%	4,91	1,85	0,180	186	18,59 <sup>c1</sup>
0-30m	25%	1,40	2,05	0,085	116	127,41 <sup>d</sup>
	50%	2,13	2,13	0,104	159	175,26 <sup>e</sup>
	75%	4,02	2,35	0,156	312	342,80 <sup>f</sup>

Table 5-2 *Depth integrated oxygen uptake in water column during dredging at shallow waters (<13m depth) and deeper waters (>13m depth). Summary data calculated by adding data for oxygen uptake from surface (<1m) sediments (a-c) or (a1-c1) to data for uptake from subsurface sediments (d-f); see Table 6.5. Values in bold represent the most likely oxygen uptake (based on medium values of sediment LOI). The range (in brackets) represents the minimum estimates of oxygen uptake (based on 25% percentiles of sediment LOI) and a maximum daily estimate of oxygen uptake (based on 75% percentiles of sediment LOI)*

	Oxygen uptake kg O <sub>2</sub> /d
Shallow (<13m)	<b>186</b> (138-356)
Deep (>13m)	<b>186</b> (136-362)

Summary data for daily oxygen uptake during dredging at shallow and at deep waters are shown in Table 5.2. The average oxygen uptake is estimated to 186 kg O<sub>2</sub>/d and identical for dredging in shallow and deep waters. The lower and higher values (in brackets) can be seen as the range in the daily oxygen uptake taking place during the entire dredging operation.





A daily uptake of 136-362 kg O<sub>2</sub>/d during dredging, theoretically, can lead to lower concentrations of oxygen in the water column. Assuming an oxygen concentration in Fehmarnbelt waters of 7 g O<sub>2</sub>/m<sup>3</sup>, the daily demand from spilled sediment theoretically would consume the oxygen inventory in a volume of 25.000 to 50.000 m<sup>3</sup>. Hence, local depressions in oxygen cannot be ruled out, especially during calm periods. Different studies published in the literature are not conclusive. In a comparative study encompassing more than 20 field studies from the US waterways, a significant oxygen decrease in the water column during dredging operations was only observed in sediment plumes downstream hydraulic dredgers, while oxygen decrease could hardly be observed in connection with clamshell dredging where spill was low (Lee and Jones-Lee 1999).



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# *A P P E N D I C E S*



## ***A P P E N D I X   A***

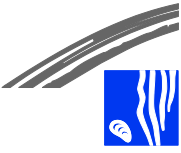
***Position, date of sampling, depth at station, sediment core length and comments related to sampling of sediments***





Table A 1. Positions (WGS84/ETRS89) and water depth at sampling stations. Length of sediment cores retrieved and brief description of surface sediments

Station	Date UTC	Position N decimal degrees	Position E decimal degrees	Depth m	Core length mm	Comments
A013	11/11/09 08:10	54.60407	11.33617	17.0	1000	Gravel
A019	11/11/09 09:10	54.59267	11.34583	17.5	1220	
A008	11/11/09 09:50	54.58050	11.32783	26.0	1530	
A012	11/11/09 10:30	54.58067	11.31800	25.0	1200	
A017	11/11/09 11:45	54.57367	11.33167	28.0	1030	
A007	11/11/09 12:20	54.57250	11.31800	28.5	1300	
A006	11/11/09 13:15	54.55833	11.30617	28.9	1550	
A006.2	11/11/09 13:45	54.55833	11.30617	28.9	1050	
A011	11/11/09 15:10	54.55500	11.29000	29.4	530	Short core/subsurface stone
A005	11/11/09 15:30	54.54667	11.29250	30.1	1620	
A014	11/11/09 16:40	54.62667	11.35320	10.5	<500	Short core/subsurface stone
A016	12/11/09 06:54	54.53933	11.29667	30.2	1830	
A010	12/11/09 08:08	54.52567	11.25933	24.3	1900	
A009	12/11/09 08:46	54.51567	11.24867	16.6	3200	Core sectioned in two: 2100 mm and 1100
A002	12/11/09 09:06	54.50950	11.25000	14.0	1750	
A005B	12/11/09 09:51	54.54700	11.29267	29.7	2420	
A015	12/11/09 10:27	54.53167	11.27677	28.4	2330	Station moved.
A003	12/11/09 11:47	54.51900	11.25433	19.5	< 400	Short core/subsurface stone; sample discarded. Core resampled at A003B
A001	12/11/09 12:14	54.50350	11.24333	8.0	<1000	Coarse sand
A003B	12/11/09 12:41	54.51900	11.25417	19.8	2410	New position



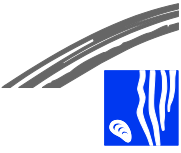
## **A P P E N D I X B**

***Dry weight, loss on ignition and concentration of  
total nitrogen and total phosphorus in sediments***



Table B 1. Dry weight, loss on ignition and concentration of total nitrogen and total phosphorus in surface and subsurface sediments along alignment

Sample	Dry Weight	LOI of DW	Total nitrogen	Total phosphorus
Method	DS 204	DS 204	Nordforsk 1975:6	DS 259+SM17udg.3120B
	% of wet weight	% of dry weight	mg/kg DW	mg/kg DW
A001-1	79.4	1.05	336	202
A002-1	64.3	3.15	591	367
A002-2	73.3	1.2	679	300
A003-1B	82.8	3.71	416	262
A005-1	73.8	1.78	635	254
A005-2	73.5	1.94	559	280
A006-1	66.9	2.96	571	380
A006-2	78.1	3.84	820	460
A006-3	80	1.41	797	272
A007-1	77.4	1.75	893	223
A007-2	74.9	6.45	911	511
A008-1	70.3	6.92	959	540
A008-1 (replicate)	72	5.29	883	411
A008-2	69.3	7.89	954	584
A008-3	73.8	3.83	722	554
A011-1	77.2	1.5	428	345
A013-1	88.7	0.86	338	240
A019-1	96.7	0.32	246	153
A019-2	92.9	0.49	280	192



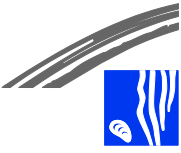
## ***A P P E N D I X C***

### ***Raw data from nutrient elutriate test***



Table C 1. Sediment wet weight added to 200 ml artificial seawater, and concentration of NO<sub>2</sub>, NH<sub>4</sub>, PO<sub>4</sub>, SiO<sub>2</sub> and NO<sub>3</sub> in water (filtered) after 24 h on a shaking table.

Station	Sample	Sediment g wet weight	NO <sub>2</sub>	NH <sub>4</sub>	PO <sub>4</sub>	SiO <sub>2</sub>	NO <sub>3</sub>
			----- μM -----				
Blank	DHI_1	0	0.02	2.97	0.15	17.5	0.93
Blank	DHI_2	0	0.02	3.31	0.08	4.40	1.06
Blank	DHI_3	0	0.02	1.35	0.06	2.94	0.44
A006-3	DHI_4	1.95	0.12	8.29	0.81	35.0	1.39
A006-3	DHI_5	2.2	0.17	7.60	0.57	17.5	0.56
A006-1	DHI_6	2.15	0.14	4.68	0.39	26.5	1.09
A006-1	DHI_7	2.14	0.23	3.67	0.24	25.6	0.48
A006-0	DHI_8	2.41	0.06	5.44	0.20	14.3	1.51
A006-0	DHI_9	1.92	0.04	2.32	0.15	7.08	0.43
A006-1B	DHI_10	3.3	0.30	7.56	0.53	27.4	2.18
A006-1B	DHI_11	2.7	0.23	4.13	0.47	20.0	0.71
A002-1	DHI_12	1.86	0.17	4.94	0.24	25.2	1.24
A002-1	DHI_13	1.77	0.17	5.23	0.35	24.2	1.17
A002-2	DHI_14	4.04	2.08	4.39	0.34	9.79	1.40
A002-2	DHI_15	2.98	1.44	3.64	0.39	6.11	0.65
A007-1	DHI_16	2.84	0.16	16.45	0.10	10.7	1.56
A007-1	DHI_17	2.32	0.12	11.24	0.29	8.09	0.64
A007-2	DHI_18	2.53	0.08	4.50	0.46	8.24	1.08
A007-2	DHI_19	1.52	0.08	2.99	0.50	8.20	0.60
A007-3	DHI_20	2.63	0.09	6.92	0.60	16.7	1.18
A007-3	DHI_21	2.44	0.09	4.33	0.60	37.2	0.27
A019-1	DHI_22	2.74	0.03	2.68	0.15	3.87	1.05
A019-1	DHI_23	3.07	0.04	3.53	0.24	6.59	0.77
A019-2	DHI_24	3.9	0.06	9.00	0.18	30.3	1.54
A019-2	DHI_25	3.42	0.06	2.89	0.21	64.9	0.64
A005-1	DHI_26	3.08	0.05	6.19	0.35	9.56	1.11
A005-1	DHI_27	2.27	0.03	2.43	0.60	9.66	0.37
A005-1B	DHI_28	3.16	0.05	5.38	0.43	7.71	1.42
A005-1B	DHI_29	2.96	0.03	2.87	0.47	7.16	0.43
A008-1	DHI_30	4.38	0.21	4.95	0.96	22.1	2.11
A008-1	DHI_31	4.82	0.16	2.22	0.76	14.9	0.73
A008-2	DHI_32	1.6	1.18	4.59	1.12	11.6	1.48
A008-2	DHI_33	2.23	1.33	3.06	1.05	15.9	0.90
A013-1	DHI_34	2.67	0.06	4.38	0.20	28.3	1.01
A013-1	DHI_35	4.11	0.06	2.39	0.24	18.1	0.45
A011-1	DHI_36	2.25	0.10	6.11	0.23	47.7	1.35
A011-1	DHI_37	3.94	0.16	4.78	0.25	18.2	0.49
A003-1B	DHI_38	2.63	0.08	5.26	0.35	24.7	1.28
A003-1B	DHI_39	1.9	0.05	2.87	0.34	14.9	0.57
Blank	DHI_40	0	0.04	4.44	0.05	5.41	1.19
Blank	DHI_41	0	1.54	0.04	7.78	0.49	0.21
Blank	DHI_42	0	0.66	0.05	6.25	0.23	0.66
<i>DL (μM)</i>		<i>0.04</i>	<i>0.3</i>	<i>0.06</i>	<i>0.2</i>	<i>0.1</i>	<i>0.12</i>
<i>Uncertainty RSD (%)</i>		<i>7</i>	<i>7</i>	<i>5</i>	<i>4</i>	<i>6</i>	<i>7</i>



## ***A P P E N D I X D***

### ***Concentration of heavy metals in sediments***



Table D 1. Concentration of LOI and heavy metals in surface and subsurface sediments

Sediment sample	LOI	As	Pb	Cd	Cr (total)	Cu	Hg	Ni	Zn
	%	----- mg/kg DW -----							
A001-1	1.05	<5	4	<0.05	4.6	2.5	<0.01	3	9.4
A002-1	3.15	<5	15	0.32	8.6	7.3	0.03	6	38
A002-2	1.2	<5	5	0.05	6.7	3.9	<0.01	5	11
A003-1B	3.71	<5	11	0.2	13	9.8	0.01	13	32
A005-1	1.78	<5	6	0.07	6.3	8	<0.01	4	17
A005-2	1.94	<5	6	0.06	7.1	4.1	<0.01	5	14
A006-1	2.96	<5	18	0.34	9.5	7.4	0.03	7	46
A006-2	3.84	<5	21	0.08	34	16	0.01	22	47
A006-3	1.41	<5	4	<0.05	4.7	2.3	<0.01	3	8.7
A007-1	1.75	<5	5	<0.05	6	3.2	<0.01	5	11
A007-2	6.45	<5	22	0.09	33	18	0.02	25	50
A008-1	6.92	<5	28	0.11	45	20	0.02	31	61
A008-1 (replicate)	5.29	<5	19	0.06	25	12	0.01	17	39
A008-2	7.89	<5	25	0.16	39	21	0.01	28	57
A008-3	3.83	<5	25	0.12	39	20	0.01	27	55
A011-1	1.5	<5	5	<0.05	6.7	3.2	<0.01	4	12
A013-1	0.86	<5	3	<0.05	2.8	1	<0.01	1	5.5
A019-1	0.32	<5	2	<0.05	1.7	0.6	<0.01	1	4.4
A019-2	0.49	<5	2	<0.05	1.7	0.6	<0.01	<1	4.5



## ***A P P E N D I X E***

### ***Concentration of persistent organic pollutants in sediments***





Table E 1. Concentration of organic carbon and PCB congeners in surface sediments; ; nd – below detection limit

Station	C-org	PCB_28/31	PCB_52	PCB_101	PCB_118	PCB_153	PCB_138	PCB_180
	% of DW	ng/kg dry weight						
A001-1	0.21	72	21	56	33	125	83	56
A002-1	0.95	154	111	295	248	643	554	299
A003-1B	1.07	122	93	268	220	643	445	363
A009-1	1.09	146	138	348	266	577	554	317
A005-1	0.98	49	nd	41	35	102	107	63
A006-1	1.07	39	10	28	14	77	64	46
A007-1 (rep. A)	0.46	31	nd	16	16	39	35	19
A007-1 (rep. B)	0.49	36	nd	17	21	39	33	29
A008-1 (rep. A)	0.39	58	nd	49	37	89	62	56
A008-1 (rep. B)	0.81	71	25	45	nd	105	87	57
A011-1	0.76	266	646	8228	2856	21693	19810	20708
A013-1	0.04	27	nd	59	29	101	78	54
A019-1	0.07	48	nd	13	7	35	30	24

Table E 2. Concentration of organic carbon and PCB congeners in 1 cm slices from Station A016; ; nd – below detection limit

Station / depth	C-org	PCB_28/31	PCB_52	PCB_101	PCB_118	PCB_153	PCB_138	PCB_180
	% of DW	ng/kg dry weight						
A016-1 0-1cm	1.01	144	126	124	113	381	298	159
A016-1 1-2cm	1.29	nd	99	102	104	331	276	207
A016-1 2-3cm	0.84	nd	99	116	109	405	286	367
A016-1 3-4cm (rep. A0)	0.53	109	118	103	85	343	280	211
A016-1 3-4cm (rep. B)	0.62	136	117	86	93	286	200	212
A016-1 4-5cm	0.59	nd	92	103	109	329	294	161
A016-1 5-6cm	0.68	172	146	228	115	509	342	248
A016-1 6-7cm	0.88	202	114	136	101	394	261	247
A016-1 7-8cm	1.19	107	78	90	74	284	258	260
A016-1 8-9cm	0.72	101	113	60	33	109	182	311
A016-1 9-10cm	0.52	69	81	71	31	160	122	161
A016-1 10-11cm	0.48	80	82	58	23	163	195	284
A016-1 11-12cm	0.69	63	95	33	nd	84	94	82
A016-1 12-13cm	0.84	57	79	34	nd	78	101	138
A016-1 13-14cm	0.09	77	91	28	10	64	112	160
A016-1 14-15cm	0.98	65	121	39	nd	106	101	82
A016-1 15-16cm	0.79	72	132	39	nd	91	159	204



Table E 3. Concentration of organic carbon and PCB congeners in 1 cm slices from Station A017 (\* = interference); nd – below detection limit

Station / depth	C-org	PCB_28/31	PCB_52	PCB_101	PCB_118	PCB_153	PCB_138	PCB_180
	% of DW	----- ng/kg dry weight -----						
A017 0-1cm	2.41	262	*	143	154	456	447	208
A017 1-2cm	1.79	146	*	142	159	444	378	168
A017 2-3cm	1.10	183	*	118	110	313	287	201
A017 3-4cm	1.22	110	*	131	116	384	337	171
A017 4-5cm	1.24	150	*	140	68	344	209	167
A017 5-6cm	1.28	154	*	92	46	220	192	101
A017 6-7cm	1.19	104	*	56	nd	126	148	82
A017 7-8cm	1.26	98	*	69	nd	188	204	127
A017 8-9cm	0.98	91	*	50	nd	98	108	90
A017 9-10cm	1.14	107	*	72	41	155	155	88
A017 10-11cm	0.77	78	*	51	27	120	119	99
A017 11-12cm	0.75	22	*	22	14	94	59	61
A017 12-13cm (rep. A0)	0.64	39	*	24	12	57	67	59
A017 12-13cm (rep. B)	0.52	23	*	23	11	72	49	47
A017 13-14cm	0.69	34	*	19	6	37	46	46
A017 14-15cm	0.72	29	*	24	16	91	64	69

Table E 4. Concentration of organic carbon, HCB, DDE's and DDT in surface sediments (nd – below detection limit); nd – below detection limit

Station	C-org.	HCB	p,p'-DDE	p,p'-DDD	p,p'-DDT
	% of dry weight	----- ng/kg dry weight -----			
A001-1	0.21	40	119	nd	nd
A002-1	0.95	96	573	347	nd
A003-1B	1.07	78	481	263	nd
A009-1	1.09	75	539	587	nd
A005-1	0.98	42	63	14	33
A006-1	1.07	41	40	nd	39
A007-1 (rep. A)	0.46	29	45	8	26
A007-1 (rep. B)	0.49	27	nd	nd	nd
A008-1 (rep. A)	0.39	48	84	29	nd
A008-1 (rep. B)	0.81	38	140	nd	76
A011-1	0.76	51	nd	nd	nd
A013-1	0.04	26	35	nd	nd
A019-1	0.07	67	37	nd	nd



Table E 5. Concentration of organic carbon, HCB, DDE's and DDT in 1 cm slices from Station A016; nd – below detection limit

Station	C-org. % of dry weight	HCB	p,p'-DDE ng/kg dry weight	p,p'-DDD	p,p'-DDT
A016-1 0-1cm	1.01	74	276	78	nd
A016-1 1-2cm	1.29	63	250	92	nd
A016-1 2-3cm	0.84	71	264	83	80
A016-1 3-4cm (rep. A)	0.53	57	216	68	nd
A016-1 3-4cm (rep. B)	0.62	66	211	71	nd
A016-1 4-5cm	0.59	55	224	84	nd
A016-1 5-6cm	0.68	54	189	76	170
A016-1 6-7cm	0.88	50	228	190	73
A016-1 7-8cm	1.19	57	146	73	63
A016-1 8-9cm	0.72	55	102	nd	nd
A016-1 9-10cm	0.52	42	86	nd	65
A016-1 10-11cm	0.48	38	84	nd	51
A016-1 11-12cm	0.69	57	nd	nd	41
A016-1 12-13cm	0.84	39	nd	nd	51
A016-1 13-14cm	0.09	43	55	nd	52
A016-1 14-15cm	0.98	53	55	nd	64
A016-1 15-16cm	0.79	54	nd	nd	43

Table E 6. Concentration of organic carbon, HCB, DDE's and DDT in 1 cm slices from Station A017; nd – below detection limit

Station	C-org. % of dry weight	HCB	p,p'-DDE ng/kg dry weight	p,p'-DDD	p,p'-DDT
A017 0-1cm	2.41	87	474	nd	nd
A017 1-2cm	1.79	65	371	162	nd
A017 2-3cm	1.10	85	336	nd	nd
A017 3-4cm	1.22	43	293	102	nd
A017 4-5cm	1.24	71	290	84	174
A017 5-6cm	1.28	50	135	71	120
A017 6-7cm	1.19	54	126	73	114
A017 7-8cm	1.26	51	133	46	98
A017 8-9cm	0.98	42	107	nd	69
A017 9-10cm	1.14	64	60	43	39
A017 10-11cm	0.77	50	53	26	49
A017 11-12cm	0.75	21	54	26	36
A017 12-13cm (rep. A)	0.64	20	123	32	64
A017 12-13cm (rep. B)	0.52	21	48	nd	nd
A017 13-14cm	0.69	16	117	45	85
A017 14-15cm	0.72	27	59	23	nd
A017 15-16cm	0.55	22	31	9	nd



Table E 7. Concentration of organic carbon and PAH's in surface sediments; nd – below detection limit

Station	C-org.  % of DW	----- $\mu\text{g}/\text{kg}$ dry weight -----															
		Naphtalene	Acenaphthylene	Acenaphthene	Fluorene	Phenathrene	Anthracene	Fluoranthene	Pyrene	Benz(a)anthracene	Chrysene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benz(g,h,i)perylene
A001-1	0,21	8,52	0,23	nd	1,54	4,00	0,52	3,38	3,83	1,00	1,06	4,36	nd	1,16	3,03	0,43	2,72
A002-1	0,95	29,77	1,54	1,04	4,34	19,82	5,73	49,00	47,10	27,85	23,46	84,28	28,46	32,60	54,95	9,95	48,33
A003-1B	1,07	12,30	1,10	1,53	4,08	22,35	4,27	37,39	38,28	17,51	15,94	79,60	22,10	24,88	49,60	8,36	43,12
A009-1	1,09	91,09	0,42	1,21	1,88	5,72	0,59	3,42	4,01	1,73	1,27	7,54	nd	2,24	5,81	0,81	5,18
A005-1	0,98	15,36	0,21	0,40	1,01	3,49	0,50	3,11	2,74	1,20	0,74	6,41	nd	1,57	5,65	0,67	4,70
A006-1	1,07	11,66	2,22	1,82	4,47	25,90	7,95	68,40	64,94	36,17	28,02	131,10	45,79	44,23	86,30	13,37	71,95
A007-1 (rep. A)	0,46	6,87	0,20	nd	0,89	3,23	0,30	2,27	2,29	1,09	0,84	5,27	nd	1,48	4,32	0,66	3,65
A007-1 (rep. B)	0,49	5,07	0,14	0,27	0,71	2,83	0,24	2,26	2,46	1,12	1,00	4,15	nd	1,41	3,34	0,47	2,83
A008-1 (rep. A)	0,39	7,38	0,38	0,47	1,47	7,03	0,66	6,99	6,63	2,83	3,44	12,25	nd	3,97	9,55	1,33	8,92
A008-1 (rep. B)	0,81	9,60	0,34	0,00	1,44	5,98	0,58	4,59	5,08	2,28	2,49	11,23	2,81	2,67	8,75	1,30	8,41
A011-1	0,76	7,91	0,49	0,98	1,48	6,99	1,21	6,97	9,01	2,82	3,74	13,42	4,46	4,42	10,53	1,45	9,02
A013-1	0,04	4,63	0,18	0,00	1,36	3,38	0,23	1,40	1,51	0,29	0,33	1,36	nd	0,39	0,76	0,12	0,81
A019-1	0,07	nd	2,19	5,10	1,81	5,86	nd	0,81	0,75	nd	0,16	nd	nd	0,08	nd	0,03	0,29



Table E 8. Concentration of organic carbon and PAH's in in 1 cm slices from Station A016; nd – below detection limit

Station	C-org. % of DW	µg/kg dry weight															
		Naphtalene	Acenaphtylene	Acenaphthene	Fluorene	Phenathrene	Anthracene	Fluoranthene	Pyrene	Benz(a)anthracene	Chrysene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benz(g,h,i)perylene
A016-1 0-1cm	1,01	8,48	0,85	0,60	2,23	10,62	1,96	17,60	15,87	8,92	9,19	40,08	14,04	14,36	33,03	5,28	27,99
A016-1 1-2cm	1,29	10,16	0,81	0,55	1,78	9,06	1,74	17,35	14,11	8,07	8,14	33,30	13,13	11,85	25,94	4,56	25,24
A016-1 2-3cm	0,84	14,09	0,86	nd	1,98	8,52	1,52	16,09	11,93	6,35	6,33	27,23	10,83	9,07	24,73	3,90	22,05
A016-1 3-4cm (rep. A0)	0,53	7,51	1,03	0,46	1,48	7,11	1,23	12,08	10,57	6,11	6,42	28,18	10,33	10,70	23,45	4,43	21,21
A016-1 3-4cm (rep. B)	0,62	9,81	0,85	0,66	1,98	8,21	1,32	12,79	12,18	6,73	6,30	26,15	9,39	10,05	21,66	3,96	18,72
A016-1 4-5cm	0,59	7,63	0,82	0,68	1,33	7,56	1,44	12,96	12,98	7,15	6,33	30,98	9,63	10,10	24,94	3,98	20,63
A016-1 5-6cm	0,68	11,84	0,88	0,84	4,85	21,74	3,56	15,94	15,11	8,82	7,90	27,76	9,71	10,76	21,08	3,61	19,76
A016-1 6-7cm	0,88	14,29	0,73	1,02	2,47	12,38	1,73	18,39	18,99	10,27	8,80	38,56	12,99	14,48	27,62	4,70	23,59
A016-1 7-8cm	1,19	7,79	0,57	0,62	1,71	6,81	0,79	7,63	7,94	4,02	3,19	18,40	6,16	5,21	15,27	2,21	12,59
A016-1 8-9cm	0,72	8,75	0,73	0,38	1,08	4,33	0,58	4,10	4,22	2,11	1,38	10,37	nd	2,76	8,59	1,30	7,30
A016-1 9-10cm	0,52	14,19	nd	nd	0,73	3,16	0,43	1,98	1,98	0,95	0,70	5,12	nd	1,30	4,68	0,60	4,03
A016-1 10-11cm	0,48	6,97	0,32	nd	0,65	2,87	0,23	1,64	1,56	0,67	0,64	3,44	nd	0,78	2,48	0,33	2,05
A016-1 11-12cm	0,69	12,00	0,30	nd	0,77	2,51	0,21	1,54	1,63	0,58	nd	3,74	nd	0,66	2,44	0,28	1,99
A016-1 12-13cm	0,84	9,87	0,24	nd	0,80	2,52	0,29	1,59	1,70	0,63	nd	3,72	4,02	0,79	3,17	0,35	2,50
A016-1 13-14cm	0,09	11,08	nd	nd	0,74	2,65	0,34	1,73	2,08	0,87	nd	5,65	1,67	1,11	4,17	0,45	3,65
A016-1 14-15cm	0,98	8,03	nd	0,29	0,85	2,91	0,32	2,90	2,72	1,44	1,01	7,96	7,95	2,07	6,33	0,87	5,81
A016-1 15-16cm	0,79	9,03	0,38	0,45	0,76	3,02	0,32	2,51	2,60	1,14	nd	6,09	6,40	1,58	4,70	0,61	3,89



Table E 9. Concentration of organic carbon and PAH's in 1 cm slices from Station A017; nd – below detection limit

Station	C-org. % of DW	$\mu\text{g}/\text{kg}$ dry weight															
		Naphtalene	Acenaphtylene	Acenaphthene	Fluorene	Phenathrene	Anthracene	Fluoranthene	Pyrene	Benz(a)anthracene	Chrysene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene
A017 0-1cm	2,41	13,06	1,65	1,03	4,81	20,37	3,42	35,84	31,15	16,82	15,09	102,95	29,17	25,38	91,49	10,13	55,85
A017 1-2cm	1,79	9,53	1,39	0,81	2,43	14,55	2,69	30,51	29,83	16,44	14,82	80,35	25,05	24,14	58,71	9,31	52,68
A017 2-3cm	1,10	9,15	1,39	0,78	2,08	12,46	2,26	24,44	19,76	11,09	9,70	46,05	14,88	13,86	36,32	5,67	30,04
A017 3-4cm	1,22	7,35	1,06	0,78	2,43	16,86	3,38	33,36	33,16	19,92	17,69	77,11	30,40	25,92	54,19	8,13	53,54
A017 4-5cm	1,24	11,96	1,59	0,80	2,37	14,62	2,69	29,01	31,44	16,93	12,13	84,09	27,27	24,38	66,64	10,08	56,88
A017 5-6cm	1,28	8,93	1,36	0,82	2,52	14,25	3,89	29,92	35,94	21,70	16,08	108,47	37,88	29,84	82,40	11,95	73,10
A017 6-7cm	1,19	11,34	1,60	0,76	2,14	11,88	2,49	23,16	30,95	16,87	9,52	92,23	30,88	24,11	69,79	9,84	61,00
A017 7-8cm	1,26	9,96	0,96	0,61	1,96	9,90	2,82	21,41	27,76	16,49	12,46	64,69	24,38	20,14	50,09	7,53	43,23
A017 8-9cm	0,98	9,06	0,88	0,37	1,08	5,16	0,84	6,89	10,83	5,16	nd	28,93	8,45	6,63	22,49	2,78	18,83
A017 9-10cm	1,14	3,79	0,42	0,22	0,83	4,02	0,83	6,17	8,51	5,00	3,13	25,91	8,41	6,24	20,07	2,99	16,59
A017 10-11cm	0,77	3,13	0,44	0,18	0,45	3,56	0,51	4,61	4,94	3,01	1,95	14,41	5,06	3,88	11,62	1,69	9,08
A017 11-12cm	0,75	3,04	0,17	0,17	0,44	2,04	0,35	2,08	2,49	1,51	nd	7,67	2,52	1,86	6,13	0,90	5,02
A017 12-13cm (rep. A)	0,64	24,56	nd	nd	0,46	2,06	0,27	2,40	2,71	1,65	nd	9,66	3,33	2,00	7,49	0,97	6,40
A017 12-13cm (rep. B)	0,52	4,92	nd	nd	0,45	1,78	0,20	1,42	1,47	0,74	nd	4,11	1,19	0,73	2,47	0,38	2,80
A017 13-14cm	0,69	10,54	0,43	0,43	0,82	3,52	0,42	2,40	2,67	nd	nd	4,20	nd	1,08	2,88	0,39	2,93
A017 14-15cm	0,72	42,77	nd	nd	0,53	2,03	0,32	1,50	1,81	1,09	0,74	5,75	1,77	1,19	4,28	0,64	3,92
A017 15-16cm	0,55	33,78	nd	nd	0,43	1,64	0,26	1,27	1,32	0,79	nd	3,99	1,13	0,82	2,53	0,41	2,70



## ***A P P E N D I X F***

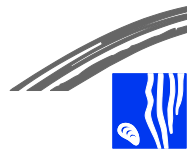
### ***Sediment oxygen consumption (raw data)***



Table F.1 Concentration of oxygen in 250 ml incubation flasks 5h and 22h after 4 ml sediment was added; calculated oxygen uptake of 4 ml sediment after 5h and 22h incubation. Blank 1-3 represents incubation flasks without sediment added

Sample	Oxygen concentration mg O <sub>2</sub> /l		Oxygen uptake mg O <sub>2</sub> /ml sediment	
	5 h	22 h	5 h	22 h
A001-1	8.04	7.54	0.048	0.0691
A002-1	7.49	7.01	0.186	0.201
A002-2	7.97	7.38	0.066	0.11
A003-1B	7.79	7.10	0.109	0.179
A005-1	8.04	7.46	0.047	0.0891
A005-2	7.71	7.38	0.131	0.11
A006-1	7.58	7.09	0.162	0.181
A006-2	7.83	7.24	0.101	0.144
A006-3	7.91	7.53	0.081	0.071
A007-1	7.57	7.06	0.164	0.189
A007-2	7.36	6.42	0.217	0.35
A008-1	7.03	6.58	0.301	0.31
A008-2	7.44	6.69	0.198	0.281
A008-3	7.58	7.19	0.162	0.1567
A011-1	7.88	7.45	0.088	0.091
A013-1	7.95	7.45	0.071	0.091
A019-1	8.14	7.73	0.022	0.021
A019-2	7.99	7.55	0.061	0.067
<i>Blank 1</i>	<i>8.21</i>	<i>7.87</i>		
<i>Blank 2</i>	<i>8.42</i>	<i>8.02</i>		
<i>Blank 3</i>	<i>8.06</i>	<i>7.56</i>		





## ***A P P E N D I X G***

### ***Relation between sediment dry weight and sediment density***



Table G1 Soil characteristics in samples from Feasibility study

Pos. No.	Depth m	Soil Type	DW (%) %	Density ton/m <sup>3</sup>
36	3.6 - 3.7	Gyttja (slope)	53	1,79
39	0 - 1	Gyttja (slope)	47,5	1,72
39	1.2 - 1.3	Gyttja (slope)	43,2	1,65
49	0 - 0.8	Gyttja (slope)	67	2,05
49	3.5 - 3.55	Peat	28,9	1,25
8	0.8 - 0.9	Late Glacial Clay	73,8	2,13
25	3.3 - 3.2	Late Glacial Clay Late Glacial Clay	69,1	2,08
21	0.5 - 0.55	(Sf)	87,4	2,38
39	2.4 - 2.5	Late Glacial Sand	82,7	2,31
7	2.5 - 2.6	Late Glacial Sand	85,5	2,35
28	3.7 - 3.8	Clay Till	88,7	2,41
28	0 - 0.1	Sand	85,9	2,37
41	0 - 0.25	Sand	76,3	2,21
50	0 - 0.1	Sand	83,2	2,33
32	0 - 0.1	Gyttja (basin)	67,6	2,05
24	0 - 0.1	Gyttja (basin)	73,7	2,15
49	0 - 0.8	Gyttja (slope)	67	2,05
38	0.25 - 0.3	Late Glacial Clay	76	2,19
40	0 - 0.1	Clay Till	91,1	2,44

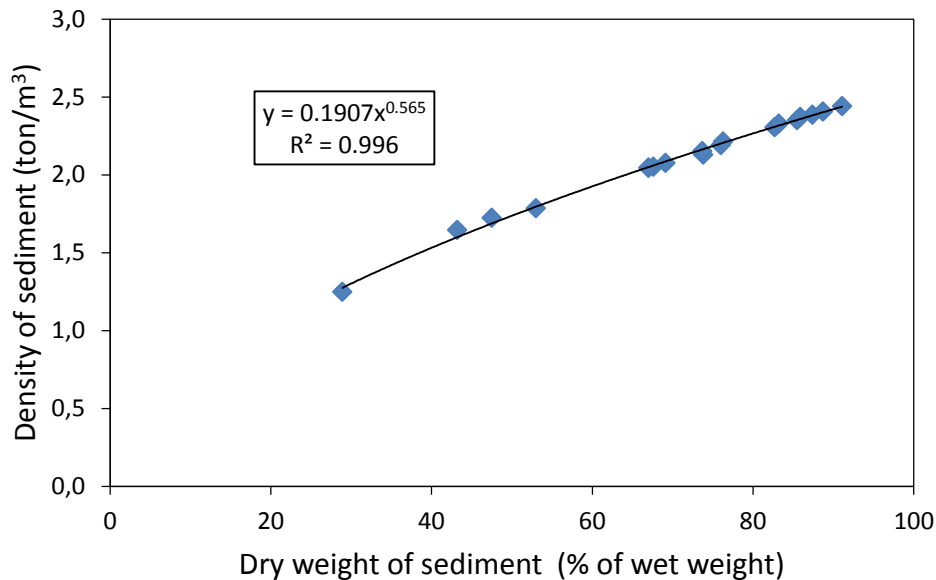


Figure G1. Relation between sediment dry weight percentage and sediment density



## ***A P P E N D I X H***

### ***Cumulative grain size distribution of surface sediments***



Data on grain size distribution of surface sediments are available from 6 samples where heavy metals were measured. Grain size distribution were determined wet by laser diffraction analysis carried out by University of Copenhagen, Department of Geography and Geology, Figure G1 shows cumulative volume distribution of samples from stations A001, A002, A003, A005, A006, A008.

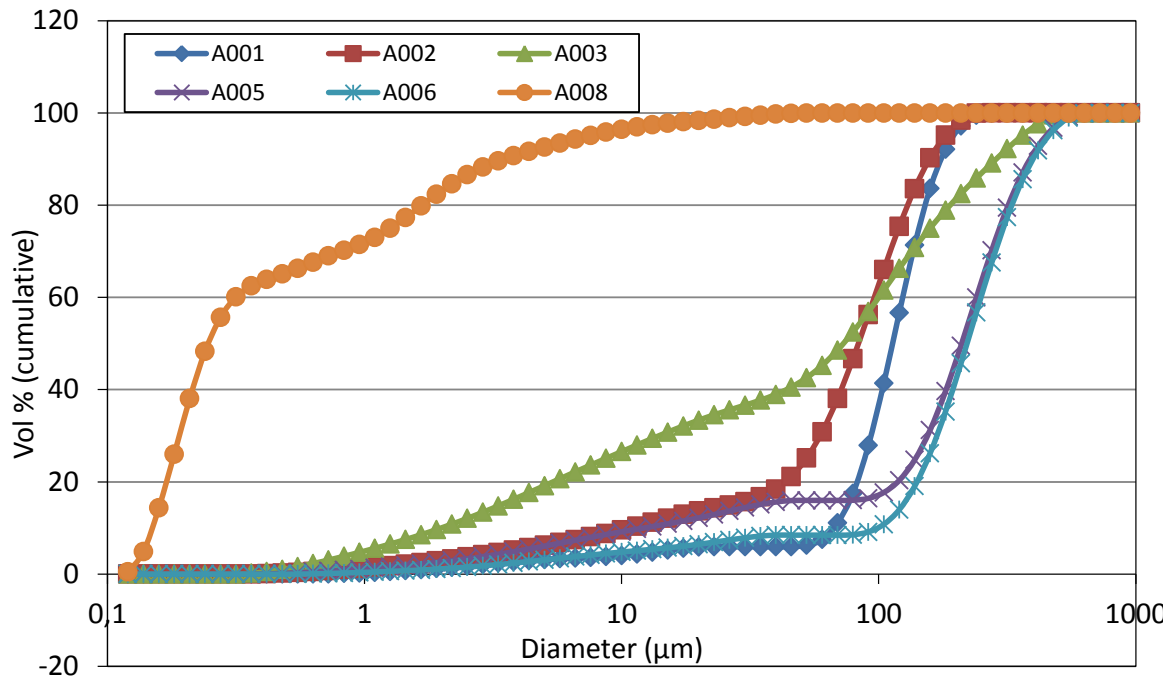


Figure H1. Grain size distribution from surface sediments from stations A001, A002, A003, A005, A006, A008).