Oil contaminated sediments in the North Sea: environmental effects 20 years after discharges of OBM drill cuttings

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SUMMARY AND CONCLUSIONS

In the period 1985 – 1995 the environmental effects of drill cutting discharges on the Dutch Continental Shelf have been extensively investigated. Particularly locations where oil based muds (OBM) had been used and discharged received attention. A general outcome of these studies was that 6 to 8 years after OBM cutting discharges elevated oil concentrations and associated biological effects still occurred within a few hundred meters from well sites. Although contamination levels generally seemed to have decreased compared to the situation shortly after drilling, it was argued that oil had not completely disappeared at any of the locations investigated, although there were clear signs of ecological recovery. Nevertheless it remained unclear to what extent recovery would continue at the longer term. Therefore the parties involved in the convenant between the Dutch government (represented by the Ministry of Transport and Public Works) and the oil companies (represented by NOGEPA) decided to continue monitoring sediment conditions at the long term.

In spring 2005 a renewed monitoring exercise was carried out including sediment sampling near four well sites in the Dutch sector, where OBM cuttings had been discharged 18 to 21 years ago. The locations were situated in the southern erosion area (1 location), the northern sedimentation area (2 locations) and the transition zone in between (1 location) respectively. At each location a compendious survey was carried out, during which sediments were sampled at 5 stations between 25 and 1000 m from the discharge site. At three locations a production platform was present, the fourth location has been abandoned immediately after an exploration drilling had been finished. This location could possibly give an indication of the impact of beamtrawl fishing, which is not allowed within 500 m from platforms, on the longterm distribution of discharged material. At all locations chemical analyses were performed to assess oil concentrations in the sediment. These analyses were carried out and reported by TNO. For the platform locations a complete fauna analysis was carried out to detect possible effects on the macrobenthic community. For the abandoned well site only the numbers of sea urchins *Echinocardium cordatum* (an OBM sensitive species) in the samples were counted. In this report the results of the biological analyses are presented, whereas the results of the chemical analyses are shortly summarized.

The results and conclusions of this study may be summarized as follows:

1. Platform L13-fe, erosion area: Slight contamination levels occurred up to at least 100 m, but to less than 250 m from the platform. Oil seems to have disappeared for the greater part after 18 years.

2. Platform L13-fe, erosion area: A clear effect on the benthic community could only be observed at the station nearest to the platform (40 m). Here the fauna was substantially impoverished.

3. Platform L13-fe, erosion area: The sea urchin *Echinocardium cordatum* seemed to be affected in its abundance up to 250 m from the platform.

4. Platform K12-a, transition zone: The sediment conditions seem to have considerably improved compared to the first 7 years after the discharges but slightly elevated oil concentrations occurred up to at least 100 m from the platform. Patchiness in the distribution of discharged material may have camouflaged the presence of local higher contamination levels.

5. Platform K12-a, transition zone: At 35 m from the platform the benthic fauna was clearly affected. The fauna composition at this station was different and substantially poorer than at stations further away from the platform.

6. Platform K12-a, transition zone: At 100 m the benthic community seemed to be only slightly affected.

7. Platform L4-a, sedimentation area: At stations 250 m and further away from the platform contamination seems to have decreased to values below background level.

8. Platform L4-a, sedimentation area: At 100 m oil concentrations in the superficial sediment layers (0 – 10 cm) had decreased to values just beyond background level. However in the deeper sediment layers no decrease was observed.

9. Platform L4-a, sedimentation area: At 100 m the fauna seemed to be not or hardly affected, in

spite of the presence of oil in the sediment.

10. Platform L4-a, sedimentation area: At 45 m from the platform the sediment was severely contaminated. The oil concentration (32 g per kg dry sediment) was higher than ever measured near L4-a. The chromatogram of the sediment sample was different from those usually found near old OBM locations and indicated that the oil was not or hardly weathered. This has led to the idea that the oil could be rather 'fresh'. However, no recent source of contamination is known. It is argued that most probably anaerobic conditions have inhibited bacterial degradation and weathering of the OBM base oil, that was discharged here 19 years ago.

11. Platform L4-a, sedimentation area: At 45 m from the platform the benthic fauna was severely impoverished. Most species that were common or even abundant further away from the platform were absent or occurred in very low densities.

12. Location G13-1, sedimentation area, abandoned well site: A measurable effect of beamtrawl fishing on the distribution of discharged material could not be demonstrated. As a consequence of the very patchy distribution of the discharged material, a much more extensive sampling program would be necessary to detect such an effect.

13. After 20 years, oil contaminated surface sediments (top 10 cm) generally occur up to somewhere between 100 m and 250 m from platforms. The concentrations measured are slightly beyond background level, but give an underestimation of the contamination present, since oil usually accumulates in the deeper sediment layers.

14. Measurable effects on the macrobenthic community are generally limited to an area within 100 m from platforms after 20 years.

15. At the species level effects may occur in an area within 100 m to maximally 250 m from well sites.

SAMENVATTING EN CONCLUSIES

In de periode 1985 – 1995 zijn de milieu-effecten van lozingen van boorgruis op het Nederlands Continentaal Plat (NCP) uitgebreid onderzocht. De aandacht ging vooral uit naar locaties waar oliehoudende boorspoeling (OBM) was gebruikt en samen met boorgruis geloosd. Een algemene conclusie die aan de resultaten van die studies werd verbonden was dat, 6 tot 8 jaar na lozing van OBM-houdend boorgruis, verhoogde olieconcentraties en daarmee gepaard gaande biologische effecten nog voorkwamen binnen enkele honderden meters van een lozingspunt. Hoewel de verontreinigingsniveaus in het algemeen leken te zijn afgenomen in vergelijking tot de situatie direkt na de lozing, werd beredeneerd dat de olie vermoedelijk op geen van de onderzochte lokaties geheel was verdwenen. Toch waren er duidelijke tekenen van ecologisch herstel. De vraag bleef echter of en in welke mate dit herstel zich op de langere termijn zou doorzetten. Daarom besloten de partijen die betrokken zijn in het convenant tussen de overheid (vertegenwoordigd door het ministerie van Verkeer en Waterstaat) en de oliemaatschappijen (vertegenwoordigd door NOGEPA) de bodemgesteldheid bij OBM lozingspunten te blijven monitoren op de langere termijn.

In de lente van 2005 werd een hernieuwde monitorings-actie gestart. Op het programma stond bemonstering van de zeebodem bij 4 locaties op het NCP, waar 18 tot 21 jaar eerder OBM-houdend boorgruis was geloosd. De locaties zijn gelegen in respectievelijk het zuidelijke erosiegebied (1 locatie), het noordelijke sedimentatiegebied (2 locaties) en het erosiegebied daartussenin (1 locatie). Op elke locatie werd een beknopte survey uitgevoerd waarbij het sediment werd bemonsterd op 5 stations op afstanden tussen de 25 en 1000 m van het lozingspunt. Op drie locaties staat een productieplatform, de vierde is een locatie die onmiddelijk nadat daar een exploratieboring was verricht is verlaten. Deze locatie zou mogelijk een aanwijzing kunnen geven over de lange-termijn invloed van boomkorvisserij op de verspreiding van geloosd materiaal (het is vissersboten niet toegestaan om binnen een afstand van 500 m van platforms te komen, maar vissen op verlaten boorlocaties is natuurlijk vrij). Op monsters van alle locaties werden chemische analyses verricht om olieconcentraties in het sediment vast te stellen. Deze analyses zijn uitgevoerd en gerapporteerd door TNO. Voor de platformlocaties werd een volledige fauna-analyse uitgevoerd teneinde eventuele effecten vast te stellen op de benthische gemeenschap. Op de verlaten locatie werden alleen de aantallen van de OBM-gevoelige ‘zeeklit’ (*Echinocardium cordatum*) in de monsters ter plaatse geteld. In dit rapport worden de resultaten van de biologische analyses gepresenteerd en besproken tegen de achtergrond van de resultaten van de chemische analyses.

De resultaten en conclusies van deze studie kunnen als volgt worden samengevat:

1. Platform L13-fe, erosiegebied: Licht verontreinigd sediment kwam voor tot op tenminste 100 m, maar minder dan 250 m van het platform. De olie in het sediment lijkt na 18 jaar voor het grootste deel verdwenen.

2. Platform L13-fe, erosiegebied: Een duidelijk effect op de benthische gemeenschap werd alleen waargenomen op het station dat het dichtst bij het platform was gelegen (40 m). Hier was de fauna aanmerkelijk verarmd.

3. Platform L13-fe, erosiegebied: Dichtheden van zeeklitten (*Echinocardium cordatum*) suggereren dat deze mogelijk nog effect ondervinden tot op 250 m van het platform.

4. Platform K12-a, overgangszone: De bodemkwaliteit lijkt aanzienlijk te zijn verbeterd vergeleken met die welke tot 7 jaar na de lozingen werd aangetroffen, maar licht verhoogde olieconcentraties kwamen nog voor tot op tenminste 100 m van het platform. Een sterk heterogene verdeling van olie in het sediment kan echter het lokaal voorkomen van hogere verontreinigingsniveaus hebben gemaskeerd.

5. Platform K12-a, overgangszone: Op 35 m van het platform was er een duidelijk effect waarneembaar op de benthische gemeenschap. De faunasamenstelling op dit station was anders en aanmerkelijk armer dan op stations verder weg van het platform.

6. Platform K12-a, overgangszone: Op 100 m van het platform leek de fauna nog slechts een gering effect te ondervinden van de voormalige lozingen.

7. Platform L4-a, sedimentatiegebied: Op stations

vanaf 250 m en verder weg van het platform lijkt verontreiniging te zijn afgenomen tot waarden beneden achtergrondniveau.

8. Platform L4-a, sedimentatiegebied: Op 100 m van het platform waren olieconcentraties in de oppervlakkige sedimentlaag (0 – 10 cm) gedaald tot een niveau even boven achtergrondniveau. In diepere lagen kon echter geen afname worden geconstateerd.

9. Platform L4-a, sedimentatiegebied: Op 100 m van het platform leek van een effect op de fauna niet of nauwelijks sprake, ondanks de aanwezigheid van olie in het sediment.

10. Platform L4-a, sedimentatiegebied: Op 45 m van het platform was de bodem zeer zwaar verontreinigd. De olieconcentratie (32 g per kg droog sediment) was hoger dan ooit eerder gemeten bij L4-a. Het chromatogram van het bodemmonster week af van de chromatograms die gewoonlijk rond oude OBM-lokaties worden gevonden en wees op niet of nauwelijks verweerde olie. Dit heeft geleid tot het idee dat de olie mogelijk wel eens ‘vers’ zou kunnen zijn. Er is echter geen recente bron van mogelijke verontreiniging bekend. Er zijn dan ook goede redenen om aan te nemen dat het hier toch om OBM-olie gaat die hier 19 jaar geleden is geloosd. Anaerobe omstandigheden in de bodem hebben vermoedelijk voorkomen dat bacteriële afbraak en verwering konden plaats vinden.

11. Platform L4-a, sedimentatiegebied: Op 45 m van het platform was de bodemfauna zeer sterk verarmd. De meeste soorten die verder weg van het platform algemeen of zelfs talrijk waren ontbraken op 45 m of waren er zeldzaam.

12. Locatie G13-1, sedimentatiegebied, verlaten locatie: Een meetbaar effect van boomkorvisserij op de verspreiding van geloosd materiaal kon niet worden aangetoond. Als gevolg van de zeer heterogene verspreiding van olie in het sediment zou een veel uitgebreider monsterprogramma moeten worden uitgevoerd teneinde zo’n effect te kunnen aantonen.

13. Meetbare olieverontreiniging van oppervlakkige (bovenste 10 cm) sedimenten komt na 20 jaar in het algemeen nog voor tot op een afstand ergens tussen 100 en 250 m van platforms. De gemeten concentraties, meestal licht boven achtergrondniveau, geven een onderschatting van de nog feitelijk aanwezige olie, omdat die zich doorgaans voornamelijk bevindt in diepere sedimentlagen.

14. Meetbare effecten op de benthische faunagemeenschap zijn na 20 jaar meestal beperkt tot een gebied binnen 100 m van een lozingspunt.

15. Op soortniveau kunnen effecten zich na 20 jaar manifesteren in een gebied binnen 100 m tot maximaal 250 m van een lozingspunt.

INTRODUCTION

In the period 1985 – 1995 extensive studies have been carried out on the environmental effects of drill cutting discharges on the Dutch Continental Shelf (DCS). The attention mainly focused on locations where oil based drilling muds had been used and discharged. Initially there were 5 locations that were investigated intensively. Most of these locations were visited more than once to assess effects immediately after drilling, but also at the longer term, *i.e.* up to 6 to 8 years after drilling. A general outcome of these studies was that, after a period of 6 to 8 years following the discharges of OBM cuttings, substantially elevated concentrations of oil in the sediment still occurred within a few hundred meters from platforms. Traces of oil could sometimes be found up to 500 – 1000 m (GROENEWOUD, 1995). Biological effects could be traced also within a few hundred meters from these OBM locations (DAAN & MULDER, 1993, 1994, 1995).

Although the 5 locations investigated were situated in areas with different hydrographic and sedimentological conditions, it was not known to what extent the results of the studies performed were representative for the major group of OBM locations in the Dutch sector. Most of the locations investigated were characterized by relatively large OBM discharges. Information on the extent of effects around locations were less OBM cuttings had been discharged was still scarce. To obtain more information about the extent of long-term effects around a variety of well sites where OBM cuttings had been discharged in the past, a 'DCS wide survey' was carried out in 1994 and 1995. This sampling programme covered 12 well sites, where OBM cuttings had been dumped 7 to 13 years before. At each of these locations a compendious survey was carried out. Surface sediments were sampled at 4 stations at distances between 100 and 2000 from the discharge site. The locations selected were proportionally divided over the silty sedimentation area, the sandy erosion area and the transition zone between these areas. Furthermore, the locations covered a wide range of amounts of discharged material and included production platforms as well as abandoned well sites.

Chemical analyses and visual inspection of the samples collected during the DCS wide survey showed that oil contaminated sediments occurred at at least 7 of the 12 locations investigated (Groenewoud, 1996). In most cases oil was found at the 100 m station only, but near one location oil was found also at 250 m from the well site. It was argued that it is unlikely that the oil had completely disappeared at any of the locations investigated (Daan & Mulder, 1996). The patchy distribution and/or accumulation of oil in deeper sediment layers may cause that the presence of oil is not always demonstrated by chemical analyses.

Biological effects of the former discharges were detected at most of the stations investigated. At 7 of the 10 locations where the sea urchin (*Echinocardium cordatum*) was found, this species showed depressed densities at the 100 m station. In two cases such depressed densities were found in the vicinity of well sites where no oil was detected. This indicated that the absence of oil in samples does not necessarily mean that sediment conditions have completely recovered. It was argued that oil still could be present in deep sediment layers or that oil is so patchily distributed that it can be missed in samples. Biological effects were also found in other components of the benthic fauna. The occurrence of such effects generally seemed to be limited to the 100 m station. It was suggested that the zone where persistent biological effects could be expected generally extended within a radius of about 200 m from well sites.

After the results of the DCS wide survey of 1994/'95 had been published (GROENEWOUD 1996, DAAN & MULDER, 1996), these have been extensively discussed within the workinggroup 'M4'. In this workinggroup the Dutch government is represented by the Ministry of Transport and Public Works and the oil companies by the Netherland Oil and Gas Exploration and Production Association (NOGEPA). The workinggroup concluded that oil concentrations in the area surrounding a discharge site had decreased after about 10 years and that there were clear signs of ecological recovery. However, it remained unclear to what extent recovery would continue at the longer term. Moreover, the sediment conditions immediately beneath the discharge site were unknown, since data on the situation within 50 to 100 m from well sites were still lacking. Therefore M4 advised the parties in the covenant between the Dutch government and the oil companies to continue monitoring of sediment conditions at the long term, including those at the discharge site itself. The parties in the covenant

Table 1
Synopsis of the locations investigated
res.cur. = residual current direction; year = last year of OBM discharge; oil(t) = tonnes of base oil discharged; time elapsed since last OBM discharge; platform present (+) or not (-).

area	location	res.cur.	year	oil(t)	time	platform
erosion	L13-fe	45°	1987	268	18	+
transition	K12-a	54°	1984	393	21	+
sedimentation	L4-a	45°	1986	178	19	+
sedimentation	G13-1	80°	1987	197	18	-

decided to adopt the advise of the workinggroup and, in 2005, took the initiative for a renewed monitoring exercise.

In 2005 the field programme included sampling of sediments near 4 well sites in the Dutch sector, where OBM cuttings had been discharged 18 to 21 years ago (Table 1). The locations were situated in the southern erosion area (1 location), the northern sedimentation area (2 locations) and the transition zone in between (1 location) respectively. At each location a compendious survey was carried out, during which surface sediments were sampled at 5 stations between 25 and 1000 m from the discharge site. At three locations a production platform was present, the fourth location has been abandoned immediately after an exploration drilling had been finished. This location could possibly give an indication of the impact of beamtrawl fishing, which is not allowed within 500 m from platforms, on the longterm distribution of discharged material and associated biological effects.

The chemical part of the programme was carried out and reported by TNO (Tamis et al., 2005). This report presents the biological results of the monitoring programme with reference to the results of the chemical analyses.

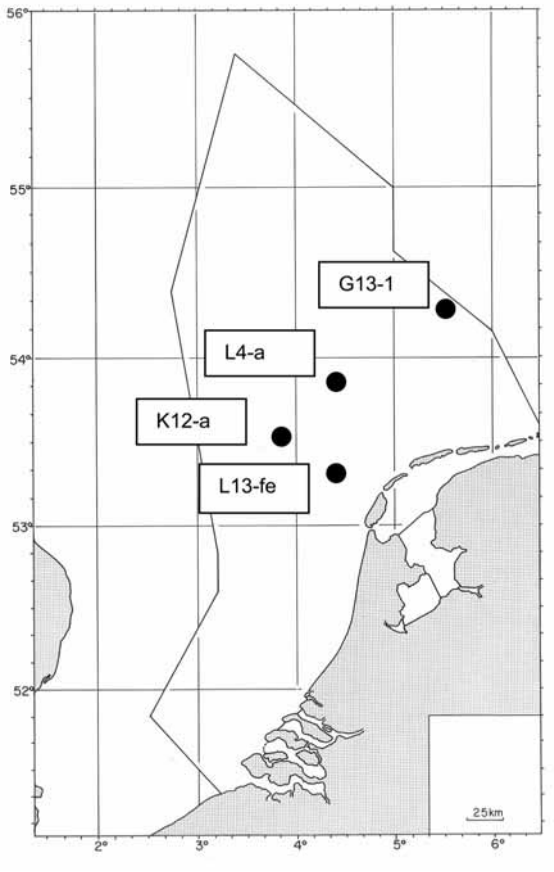

Fig. 1. Positions of the locations investigated.

ACKNOWLEDGEMENTS

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METHODS

Sampling

Sampling took place in March 2005 on board of the m.s. Arca. At each location a transect was chosen in the local residual current direction (see RUIJTER *et al.*, 1987). Along this transect 5 stations were sampled. The discharge site was ap-

proached as close as was possible from a safety point of view, i.e. at platform sites up to 35 to 45 m. At G13-1 the well was approached up to 25 m. The other stations were chosen at 100 m, 250 m, 500 m or 1000 m. The 1000-m station was assumed to represent a reference situation. At each station 10 samples were collected with a 0.18 m^2 Van Veen grab. From each sample small duplicate sediment cores (diameter 28 mm, depth 10 cm) were taken for chemical and grain size analysis. These samples were pooled by station, thoroughly homogenized and immediately frozen at –20 ^oC until later analysis in the laboratory. Then the contents of each grab were inspected for the presence of sea urchins (*Echinocardium cordatum*) and their numbers were counted on board. Four grab samples of each station were washed through a sieve (mesh size 1 mm) and the residual macrofauna was preserved in a 6% neutralized formaldehyde solution.

Oil analysis
Oil analyses of sediment samples were performed according to the gas chromatograph mass spectrometer technique. Concentrations of alkanes (C_{10} – C_{40}), unidentified complex matter (UCM) and 'other components' were quantified. The analytical procedures are described in detail by TAMIS *et al*. (2005).

Fauna analysis
Numbers of the OBM sensitive species *Echinocardium cordatum* were counted on board in all samples. A complete fauna analysis was performed for the three locations where a platform was present. In the laboratory the samples (4 per station) were stained with Bengal rose and sorted under a magnifier. Molluscs, crustaceans, echinoderms, polychaetes and sipunculids were identified to species level under a stereomicroscope and counted. Other taxa, e.g. nematods, nemertines and bryozoans, were not further identified.

Statistical procedures
Possible shifts in the macrofauna community along the transects sampled were tested by comparing the relative abundance of all identified species at each of the stations. For example, if at a certain station most species occur in low numbers compared to the other stations, the relative abundance at this station will be attributed a low value. The computation of relative abundance is based on a ranking procedure. For all of the individual species the mean density is considered at each of *n* investigated stations. Per species a rank is attributed to each of the stations: the rank is 1 for the station with the lowest abundance and n for the station with the highest abundance. When this procedure is completed for all species a mean rank can be calculated for each station. Differences in mean ranks between stations were tested for significance by applying analysis of variance. The method is described in more detail by DAAN *et al*., 1990.

Possible gradients in the distribution patterns of individual species were tested by logit regression (see *e.g*. JONGMAN *et al*., 1987). The regression was applied to those species of which at least 20 specimens were found. The method was used according to the improved procedure described by DAAN & MULDER (1994), i.e. the regression analysis was carried out with a correction for over-dispersion in the data.

Similarities in the fauna composition between stations were assessed on the basis of the Bray-Curtis index for percentage similarity (BRAY & CURTIS, 1957). Among a variety of indices that have been proposed, this index was found to reflect most accurately the actual similarity (BLOOM, 1981). The method was performed for squareroot transformed abundance data of the individual species to prevent that a few species would disproportionally dominate the between station similarities (see GRAY *et al*., 1988).

RESULTS AND DISCUSSION

LocationL13-fe
Erosion zone; 268 tonnes of oil discharged 18 yr ago, platform present

The sediment at this location consisted of medium coarse sand which looked visually clean. Some cuttings were found at the 100-m station and at the platform station (40 m). Oil was not ob-

Table 2. Oil concentrations ($mg.kg^{-1}$ dry sediment) at location L13-fe in 1995 and 2005. Values >10 are beyond natural background level.
Data from Tamis *et al.* (2005).

	1995	2005
40 m		120
100 m	200	26
250 m	5	2
500 m	5	2
1000 m	5	2

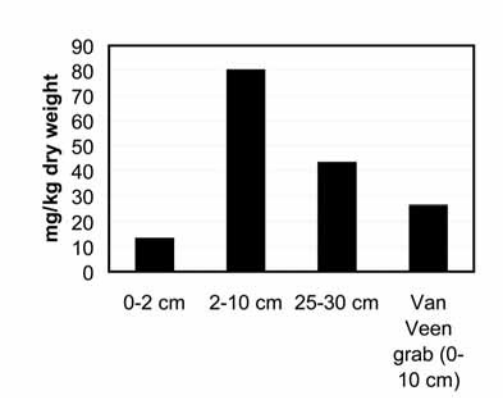

Fig. 2. Location L13-fe: vertical distribution of oil in the sediment at 100 m from the platform. Data from Tamis et al. (2005).

served, neither the smell of it. Nevertheless the chemical analyses revealed that elevated oil concentrations (compared to maximum background level) occurred at both the platform station and the 100-m station (Table 2). At the 100-m station the concentration measured was considerably lower than in 1995. A plot of oil concentrations in different sediment layers (Fig. 2) shows that most oil occurred in the deeper layers. The top layer (0 – 2 cm) was relatively clean. The difference in the values measured in one sediment sample from a boxcore and in a pooled sediment sample from 10 van Veen grabs illustrates the patchy distribution of oil in the sediment.

Table 3. Numbers of *Echinocardium cordatum* (specimens > 15 mm) in the Van Veen grab samples (10 per station) at L13fe.

40 m	100 m	250 m	500 m	1000 m
0	0	0	1	2
0	0	0	1	1
0	0	0	1	1
0	0	0	2	2
0	0	1	0	1
0	0	0	3	1
0	0	0	3	0
0	0	0	0	1
0	0	0	1	2
0	0	0	0	2

The results of the on-board countings of *Echinocardium cordatum* in the samples are given in Table 3. The species was found almost exclusively at the 500-m and 1000-m stations, where it occurred in most of the samples. At 40 m and 100 m *E. cordatum* was absent and at 250 m only one specimen was found, suggesting that

Table 4. The benthic fauna at L13-fe. Percentage occurrence of each species in the total number of samples.

POLYCHAETA		CRUSTACEA			
				Dosinia exoleta	5
Eteone foliosa	10	*Processa parva*	15	*Chamelea striatula*	30
Eteone longa	50	*Corystes cassivelaunus*	5	*Mactra corallina*	5
Hesionura augeneri	15	*Thia scutellata*	30	*Spisula spec. juv.*	5
Phyllodoce spec. juv.	15	*Pontophilus trispinosus*	5	*Spisula subtruncata*	15
Glycera spec. juv.	15	*Caprellidae spec.*	5	*Donax vittatus*	15
Glycinde nordmanni	30	*Megaluropus agilis*	5	*Gari fervensis juv.*	5
Goniada maculata	25	*Apherusa clevei*	5	*Tellina pygmea*	5
Streptosyllis websteri	5	*Apherusa ovalipes*	30	*Ensis ensis*	15
Exogone hebes	5	*Urothoe brevicornis*	5	*Corbula gibba*	5
Nephtys caeca	15	*Urothoe poseidonis*	55	*Thracia papyracea*	50
Nephtys cirrosa	75	*Leucothoe incisa*	15		
Nephtys hombergii	15	*Orchomene nana*	10	ECHINODERMATA	
Nephtys incisa	5	*Atylus swammerdami*	5		
Nephtys longosetosa	5	*Bathyporeia elegans*	35	*Ophiura albida*	60
Lumbrineris latreilli	10	*Bathyporeia guilliamsoniana*	5	*Echinocyamus pusillus*	55
Scoloplos armiger	75	*Pseudocuma longicornis*	10	*Echinocardium cordatum*	40
Aonides paucibranchiata	65	*Leptognathia spec.*	10		
Scolelepis bonnieri	30			OTHER TAXA	
Scolelepis foliosa	5	MOLLUSCA			
Spio filicornis	25			*Anthozoa spec.*	5
Magelona alleni	10	*Euspira nitida*	90	*Nemertini*	40
Magelona mirabilis	15	*Brachystomia eulimoides*	10	*Nematoda*	95
Chaetozone setosa	5	*Goodallia triangularis*	60	*Oligochaeta*	40
Ophelia limacina	45	*Tellimya ferruginosa*	15	*Tunicata indet. juv.*	25
Lanice conchilega	15	*Dosinia lupinus*	15	*Branchiostoma lanceolatum*	85

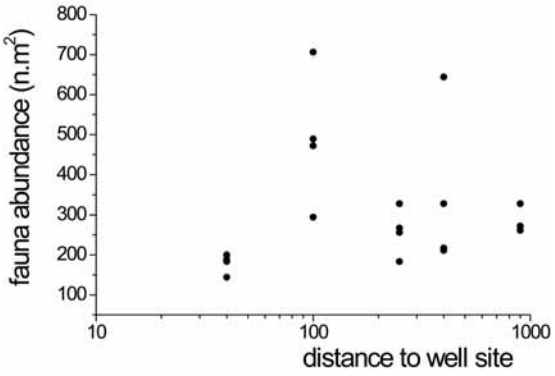

Fig. 3. Location L13-fe: Total fauna abundance along the residual current transect.

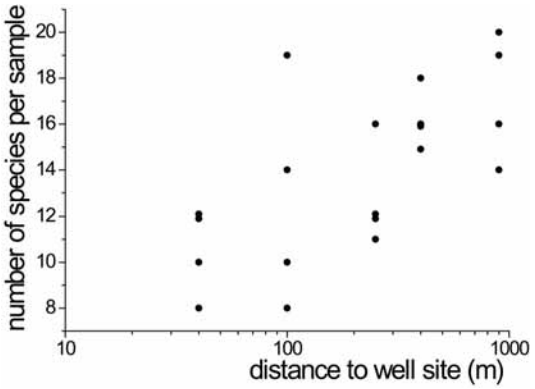

Fig. 4. Location L13-fe: Numbers of identified species per sample along the residual current transect.

there was still a negative effect of the former discharges on the density of the species in the vicinity of the platform. Logit regression was applied to the data and confirmed that there was a highly significant ($p< 0.1\%$) gradient in the abundance of the species along the transect sampled.

The fauna analyses yielded a total of 57 identified species. An overview of their percentual frequency of occurrence in the samples is given in Table 4. The quantitative data are listed in Table 22 (Appendix). Densities were more or less evenly distributed among the various species or, in other words, there were no species that dominated the fauna by number. The mean fauna densities fluctuated between 250 and 450 individuals per m^2 at the stations between 100 m and 1000 m (Fig. 3). However at 40 m the densities were clearly lower.

The total number of identified species found at each of the stations ranged between 24 (40 m) and 34 (1000 m). Per sample these numbers were between 8 and 20 (Fig. 4). Analysis of variance revealed that there were significant ($p< 5\%$) differences in the numbers of species per sample between the stations. These numbers were the lowest at 40 m and increased with increasing distance to the platform.

In terms of relative fauna abundance the 40-m station ranked lowest (Fig. 5). In other words, species occurred on average in the lowest densities at 40 m. However, the difference with the other stations was so small that analysis of variance did not reveal significant differences between the stations. This indicates that the relative abundance was not affected by the former discharges.

There were 11 species of which ≥ 20 specimens were found. These species were tested for possible gradients in their spatial frequency of occurrence by logit regression (Table 5). Spatial

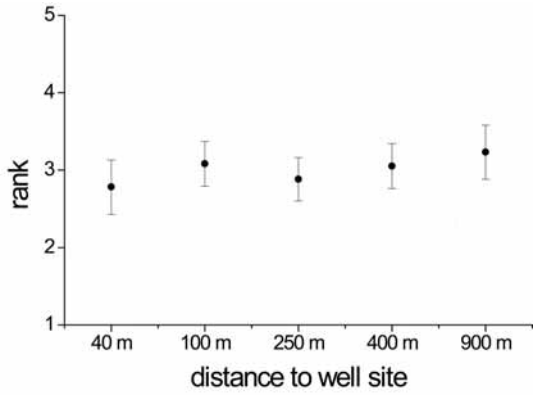

Fig. 5. Location L13-fe: relative macrofauna abundance along the residual current transect (mean ranks and 95% confidence limits).

Table 5. Location L13-fe. List of species for which density gradients were tested by logit regression. Sign of the gradient (+/-) and significance level are indicated. + = increasing frequency of occurrence away from the location; - = decreasing frequency away from the location; 0 = no gradient.

		sign. level (%)	
	sign	unc. test	corr. test
Eteone longa	0	-	-
Nephtys cirrosa	+	n.s.	n.s.
Scoloplos armiger	+	5	5
Aonides paucibranchiata	-	5	0.5
Urothoe poseidonis	+	0.1	1
Euspira nitida	+	1	0.1
Goodallia triangularis	0	-	-
Thracia papyracea	0	-	-
Ophiura albida	+	0.5	0.1
Echinocardium cordatum	+	0.1	0.1
Branchiostoma lanceolata	-	5	0.5

gradients appeared to be significant (p<5%) for 7 species, both in the uncorrected and corrected test. For 5 species the gradient was positive (increasing frequency of occurrence away from the platform), indicating that these species were still affected in their distribution by the former discharges. Of those species which in former surveys have shown to be sensitive to discharges of OBM cuttings (Daan *et al*., 1994), only the sea urchin (*Echinocardium cordatum*) showed such a gradient (Table 6). The other species did not occur in the area around L13fe, or occurred in too low numbers to discern any gradient.

In Table 7 the Bray-Curtis values for percentage similarity between stations are listed. The 40-m station appears to be clearly different from the other stations. The index values are lower when this station is compared with the other stations than for comparisons within the latter group of stations. The highest similarity exists among the stations between 100 m and 500 m.

Table 6. Location L13-fe: evaluation of the abundance patterns of 15 OBM-sensitive species. + = tendency for higher abundance away from the platform; - = tendency for lower abundance away from the platform; 0 = no tendency for a gradient. (?) = total number of specimens found <20. Note that the qualifications are based on the abundance patterns and not on presence-absence data as used in logit regression.

	tendency
Echinocardium cordatum	+
Tellimya ferruginosa	(?)
Harpinia antennaria	not found
Callianassa subterranea	not found
Owenia fusiformis	not found
Mysella bidentata	not found
Gattyana cirrosa	not found
Amphiura filiformis	not found
Cylichna cylindracea	not found
Nucula nitidosa	not found
Chaetozone setosa	(?)
Glycinde nordmanni	(?)
Nephtys hombergii	(?)
Pholoe minuta	not found
Scalibregma inflatum	not found

Table 7. Location L13-fe: Bray-Curtis percentage similarity between stations after squareroot transformation of species specific abundances.

	100 m	250 m	500 m	1000 m
40 m	47	43	38	36
100 m		61	61	45
250 m			65	54
500 m				54

The overall picture of the sediment conditions at L13-fe can be characterized by slight contamination levels up to at least 100 m, but less than 250 m from the platform. The contamination levels might have been underestimated to some degree since the highest oil concentrations were measured in deeper sediment layers that were not sampled routinely. Nevertheless, oil seems to have disappeared for the greater part after 18 years. Erosion of the sediment in this area, due to relatively strong bottom currents, may have promoted dispersion of discharged material. It may also have promoted aerobic sediment conditions necessary for oil degrading bacteria to do their work.

A clear effect on the benthic community could be observed only at the 40-m station where the fauna was clearly impoverished. Apparently the sediment conditions are still disturbed here to such an extent that the survival rate of settlers is suboptimal.

At the species level the distribution pattern of the sea urchin *Echinocardium cordatum* showed a clear gradient, which suggested that the species was still affected in its abundance up to 250 m from the platform. This seems surprising since no oil was found at this station. A possible explanation could be that traces of oil were still present in the sediment, but that these did not turn up in the (sub-)samples. The conditions could be still disturbed to such a degree that *E. cordatum* hardly can survive here. In the past, the species has shown to be very sensitive to OBM discharges (*e.g*. Daan et al., 1994). However, if the low abundance of *E. cordatum* at 250 m is indeed caused by the former discharges, it is not necessarily a persistent effect. It is also possible that the population, that was extincted in the contaminated area around the platform in the first years after the discharges, simply has not recovered yet.

Location K12-a

Transition zone; 393 tonnes of oil discharged 21 yr ago, platform present

The sediment at this location consisted of fine sand mixed up with some silt. At the stations 250

Table 8. Oil concentrations (mg.kg^{-1} dry sediment) at location K12-a in the period 1985 - 2005. Values >10 are beyond natural background level. Data from Tamis *et al*. (2005).

distance (m)	1985	1986	1987	1988	1990	1992	2005
10 m			35000				
35 m				120000			35
100 m	150	400	4000	400	20000	600	25
100 m					30000	1500	
100 m					17000		
250 m	600	400	300	30	9000	180	7
250 m					1000	30	
250 m					1700		
500 m		12	50	11		3	8
750 m		5		13		3	
1000 m		4		6		3	6
5000 m		6	15	7	180	3	
5000 m					50		

m to 1000 m almost all samples looked visually clean, except for one sample at 500 m in which oil particles were observed. At the 100-m station drill cuttings and oil particles were found in one sample, which also smelled of oil. At 35 m all samples slightly smelled of oil and did contain cuttings. Oil particles were found in 2 samples.

The chemical analyses revealed elevated oil concentrations at the 35-m and 100-m stations only (Table 8). The concentrations at these stations were only slightly beyond background level and much lower than during the first 7 years after the discharges. This might suggest that there has been a gradual decrease of oil in the sediment at the longer term. However, the data do not indicate a clear temporal trend. Particularly for the 100-m and 250-m stations a consistent data series is available, since these stations were visited during all surveys. At 100 m there was initially an increase in the concentrations measured up to 1987, followed by a dip in 1988 and an extremely high peak in 1990. At 250 m there was a decrease in concentrations measured during the first years after drilling, also followed by a high peak in 1990. These observations indicate that there is a high degree of patchiness in the distribution of oil near the platform which masks a temporal trend. Therefore, the low values in 2005 do not prove that the oil has almost completely disappeared. In contrast to preceding years oil was mainly found in the superficial sediment layer (top 10 cm). At 25-30 cm the concentration was below detection level.

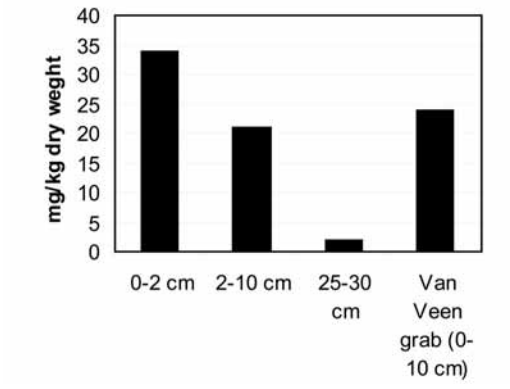

Fig. 6. Location K12-a: vertical distribution of oil in the sediment at 100 m from the platform. Data from Tamis et al. (2005).

The distribution of sea urchins (*Echinocardium cordatum*) along the transect sampled was extremely heterogeneous (Table 9). At 35 m the species was not found. At 100 m a dense population occurred with generally more than 10 specimens per grab sample. At the stations further away the numbers were clearly lower, but in most

Table 9. Numbers of *Echinocardium cordatum* (specimens > 15 mm) in the Van Veen grab samples (10 per station) at K12-a.

35 m	100 m	250 m	500 m	1000 m
0	20	4	3	2
0	13	3	3	5
0	11	4	2	3
0	12	0	0	0
0	10	2	2	2
0	24	4	3	3
0	13	0	2	1
0	10	0	2	5
0	1	0	0	3
0	8	1	5	1

Table 10. The benthic fauna at K12-a. Percentage occurrence of each species in the total number of samples.

POLYCHAETA		*Diplocirrus glaucus*	25	MOLLUSCA	
		Capitella capitata	5		
Polychaeta indet.	5	*Mediomastus fragilis*	70	*Hyala vitrea*	15
Harmothoe spec. juv.	40	*Notomastus latericeus*	100	*Euspira nitida*	100
Malmgreniella lunulata	75	*Ophelia limacina*	5	*Acteon tornatilis*	5
Pholoe minuta	60	*Myriochele oculata*	90	*Cylichna cylindracea*	10
Sigalion mathildae	5	*Owenia fusiformis*	10	*Tellimya ferruginosa*	70
Sthenelais limicola	75	*Pectinaria auricoma*	5	*Mysella bidentata*	60
Phyllodoce rosea	60	*Pectinaria koreni*	15	*Mactra corallina*	20
Phyllodoce maculata	5	*Sabellaria spinulosa*	5	*Spisula spec. juv.*	5
Eumida sanguinea	65	*Lanice conchilega*	80	*Spisula subtruncata*	40
Glycera spec. juv.	30			*Abra alba*	100
Glycera alba	15	CRUSTACEA		*Tellina fabula*	25
Glycinde nordmanni	10			*Phaxas pellucidus*	30
Goniada maculata	90	*Processa nouveli holthuisi*	5	*Corbula gibba*	35
Gyptis capensis	60	*Processa parva*	10	*Thracia papyracea*	100
Ophiodromus flexuosus	25	*Callianassa subterranea*	20	*Nucula nitidosa*	100
Nereis longissima	35	*Callianassa subterranea juv.*	65		
Nephtys spec. juv.	50	*Pinnotheres pisum*	5	ECHINODERMATA	
Nephtys caeca	20	*Liocarcinus marmoreus*	10		
Nephtys cirrosa	45	*Pagurus bernhardus juv.*	5	*Ophiura spec. juv.*	30
Nephtys hombergii	95	*Ione thoracica*	15	*Amphiura filiformis*	85
Nephtys incisa	5	*Caprellidae spec.*	25	*Acrocnida brachiata*	5
Nephtys longosetosa	5	*Apherusa ovalipes*	5	*Ophiura albida*	55
Nephtys assimilis	5	*Perioculodes longimanus*	25	*Ophiura texturata*	25
Lumbrineris latreilli	100	*Harpinia antennaria*	85	*Echinocardium cordatum*	70
Scoloplos armiger	40	*Leucothoe incisa*	90		
Poecilochaetus serpens	70	*Orchomene nana*	25	OTHER TAXA	
Spio filicornis	20	*Ampelisca tenuicornis*	10		
Spiophanes bombyx	100	*Bathyporeia elegans*	75	*Anthozoa spec.*	15
Spiophanes kroeyeri	10	*Bathyporeia guilliamsoniana*	40	*Nemertini*	100
Magelona alleni	5	*Iphinoe trispinosa*	10	*Oligochaeta*	40
Magelona mirabilis	30	*Eudorella truncatula*	20	*Turbellaria spec.*	5
Magelona johnstoni	65	*Eudorellopsis deformis*	10	*Phoronida*	20
Chaetozone setosa	25	*Pseudocuma longicornis*	10	Branchiostoma lanceolatum	5

samples a few specimens were found. As a result of overdispersion in the data logit regression did not reveal a significant gradient, but the difference between the 35-m station and 100-m station clearly indicates an adverse effect of the former discharges on the occurrence of *E. cordatum* in the close vicinity of the platform.

At the 5 stations a total number of 79 species were found. Their percentual frequency of occurrence in the samples is listed in Table 10 and a complete overview of species specific abundances is given in Table 23 (Appendix). The fauna was numerically dominated by the polychaetes *Lumbrineris latreilli, Spiophanes bombyx* and *Notomastus latericeus*, and by the mollusc *Abra alba*. The latter two species were especially abundant at the 35-m station. Their densities explain the high fauna abundance in the samples at 35 m (Fig. 7).

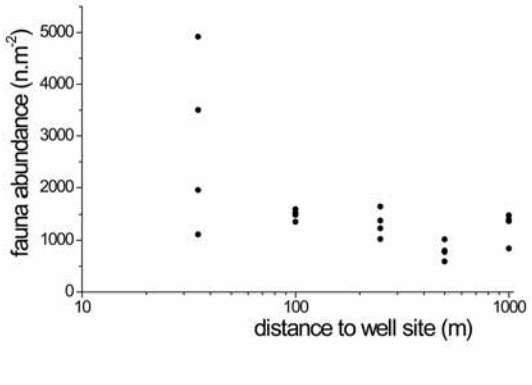

Fig. 7. Location K12-a: Total fauna abundance along the residual current transect

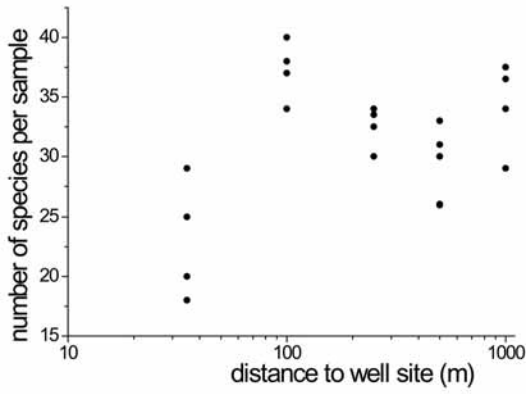

Fig. 8. Location K12-a: Numbers of identified species per sample along the residual current transect.

The total number of identified species at each of the stations ranged between 39 (35 m) and 52 (100 m and 1000 m). Per sample the numbers fluctuated between 18 and 40 (Fig.8). Analysis of variance revealed that there were highly significant ($p < 0.1\%$)differences in species richness between the stations. The 35-m station appeared to be significantly different from the other stations, whereas mutual differences among the other stations were statistically not significant.

On average, most species occurred in the lowest numbers at 35 m and in the highest numbers at 1000 m (Fig. 9). There appeared to be highly significant differences between the stations sampled (ANOVA, $p < 0.1\%$). The 35-m station was not the only one which differed from the 1000-m station. The 500-m station too had low relative abundance.

For 31 species of which at least 20 specimens were found each, possible gradients in frequency of occurrence were tested by logit regression (Table 11). In 6 species such a gradient appeared to be highly significant ($p < 0.1\%$) and in 2 species a gradient was significant ($p < 5\%$). In all cases the gradient was positive, i.e. frequency of occurrence increased away from the platfrom. In 23 species there was no (significant) gradient. An inspection of the abundance data of 15 known OBM-sensitive species (Daan *et al*., 1994) reveals that 5 of them show a tendency to increase abundance away from the platform (Table 12).

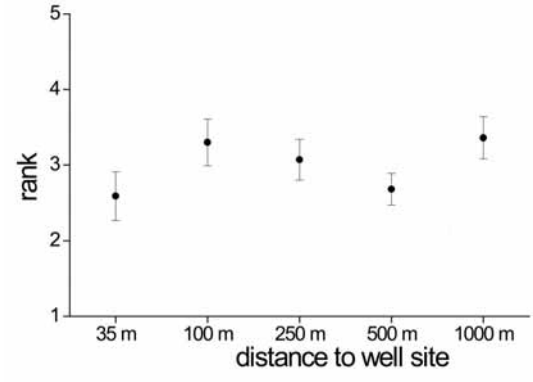

Fig. 9. Location K12-a: relative macrofauna abundance along the residual current transect (mean ranks and 95% confidence limits).

Table 11. Location K12-a. List of species for which density gradients were tested by logit regression. Sign of the gradient (+/-) and significance level are indicated. + = increasing frequency of occurrence away from the location; - = decreasing frequency away from the location; 0 = no gradient.

		sign. level (%)	
	sign	unc. test	corr. test
Malmgreniella lunulata	+	0.1	0.1
Pholoe minuta	0	-	-
Sthenelais limicola	0	-	-
Phyllodoce rosea	+	n.s.	n.s.
Goniada maculata	-	n.s.	n.s.
Gyptis capensis	0	-	-
Nephtys cirrosa	0	-	-
Nephtys hombergii	0	-	-
Lumbrineris latreilli	0	-	-
Scoloplos armiger	+	0.5	n.s.
Poecilochaetus serpens	+	5	5
Spiophanes bombyx	0	-	-
Magelona mirabilis	+	n.s.	n.s.
Magelona johnstoni	+	0.5	5
Mediomastus fragilis	+	n.s.	n.s.
Notomastus latericeus	0	-	-
Myriochele oculata	0	-	-
Lanice conchilega	+	0.1	0.1
Callianassa subterranea	0	-	-
Harpinia antennaria	+	0.1	0.1
Leucothoe incisa	+	1	0.1
Bathyporeia elegans	+	0.1	0.1
Euspira nitida	0	-	-
Tellimya ferruginosa	+	n.s.	n.s.
Mysella bidentata	0	-	-
Abra alba	0	-	-
Thracia papyracea	0	-	-
Nucula nitidosa	0	-	-
Amphiura filiformis	+	0.1	0.1
Ophiura albida	+	5	n.s.
Echinocardium cordatum	+	1	n.s.

Table 12. Location K12-a: evaluation of the abundance patterns of 15 OBM-sensitive species. + = tendency for higher abundance away from the platform; - = tendency for lower abundance away from the platform; 0 = no tendency for a gradient. (?) = total number of specimens found <20. Note that the qualifications are based on the abundance patterns and not on presence-absence data as used in logit regression.

	tendency
Echinocardium cordatum	+
Tellimya ferruginosa	+
Harpinia antennaria	+
Callianassa subterranea	+
Owenia fusiformis	(?)
Mysella bidentata	0
Gattyana cirrosa	not found
Amphiura filiformis	+
Cylichna cylindracea	(?)
Nucula nitidosa	0
Chaetozone setosa	(?)
Glycinde nordmanni	(?)
Nephtys hombergii	0
Pholoe minuta	0
Scalibregma inflatum	not found

Four species did not show any tendency for a gradient. The other species were too sparsely distributed to discern a spatial pattern in their density.

A comparison between stations based on the Bray-Curtis similarity index (Table 13) shows that the 35-m station has the lowest resemblance with the 1000-m reference station. The 100-m station clearly has more resemblance with the 1000-m station, but the highest similarity exists between the 250-m, 500-m and 1000-m stations. The values of the index indicate a spatial gradient in the fauna composition over the transect sampled.

A general impression of the sediment conditions near K12a is that these have considerably improved compared to the first 7 years after the discharges. Elevated oil concentrations were measured up to at least 100 m, but not as far as 250 m, as was always the case in the period 1985 – 1992. Moreover, the concentrations measured were only slightly beyond maximum background level. This suggests that a considerable amount of the oil has disappeared. However, patchiness in the distribution of the material discharged may have camouflaged the presence of locally higher contamination levels, which may still have significant impact on the functioning of the benthic community.

Table 13. Location K12-a: Bray-Curtis percentage similarity between stations after squareroot transformation of species specific abundances.

	100 m	250 m	500 m	1000 m
35 m	49	43	47	43
100 m		66	68	68
250 m			76	75
500 m				74

The presence of more contamination than actually has been measured is supported by the faunal characteristics of the 35-m station. The fauna composition at this station was clearly different from that at the other stations. In general, the fauna was poor here, although high total fauna densities occurred in some samples. This was caused by the abundance of two species, which apparently do not suffer from the disturbed sediment conditions and may locally thrive. However, the absence of a number of known OBM-sensitive species clearly indicates the presence of remnants of oil in the sediment. As a result, overall species richness and relative fauna abundance were obviously depressed.

At the species level, the high densities of *Echinocardium cordatum* at 100 m from the platform were remarkable. During the first 7 years after the discharges adult specimens of this species were invariably missing at this station. The numbers of *E. cordatum* at 100 m in 2005 strongly suggest that the species does no longer suffer here from disturbed sediment conditions. But why was its abundance so high compared to stations further away from the platform? Possibly the species has taken profit from the absence of beamtrawl fishing so close to the platform. In fact, beam trawlers are prohibited to enter the safety zone within 500 m from platforms. However, trawlers do not always comply to the rules and sometimes approach platforms closer than allowed, but, in view of safety reasons, it is unlikely that they come as close as 100 m from a platform.

Location L4-a

Sedimentation area, 178 tonnes of oil discharged 19 yr ago, platform present

The sediment at this location consists of fine to very fine sand mixed up with a substantial silt fraction. The sediment looked clean at 250 m and

Table 14. Oil concentrations (mg.kg^{-1} dry sediment) at location L4-a in the period 1986 - 2005. Values >10 are beyond natural background level. Data from Tamis *et al*. (2005).

distance (m)	1986	1987a	1987b	1994	2005
10 m			10000		
45 m	5300			140	32000
100 m	14	250	2200	140	25
250 m	5	4	30	18	9
500 m	11	3	10	16	8
750 m	2	2			
1000 m		2			6
2000 m	3				
5000 m	3		5	150*	

*no OBM base oil

further away from the platform. At 100 m drill cuttings and oil particles were observed in one sample, whereas three samples smelled of oil. At 45 m the sediment was heavily polluted. All samples contained oil and cuttings and had a strong smell of oil and H_2S.

The chemical analyses confirmed that at the stations at 250 m and further away from the platform oil concentrations were below detection level (Table 14). At 100 m oil could be detected, but the concentration was only slightly beyond the maximum background level. The concentration measured was clearly lower than in the period 1987 – 1994. At 45 m an extremely high value of 32000 mg/kg dry sediment was measured. This concentration was higher than measured ever before in the vicinity of L4a. However, surprisingly, the chromatogram was quite different from that at the other stations. Tamis et al. (2005) have argued that the chromatogram of the 45-m sample

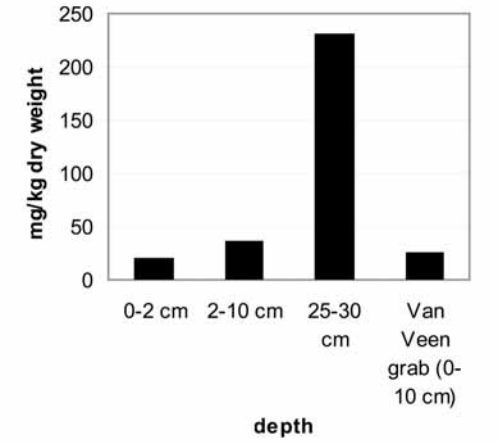

Fig. 10. Location L4-a: vertical distribution of oil in the sediment at 100 m from the platform. Data from Tamis et al. (2005).

was typical for OBM base oil that is not or hardly weathered. Therefore they suggested that the oil could originate from a more recent OBM contamination, but a recent source of such contamination could not be found since the last OBM drilling took place in 1986. Another possible explanation might be, therefore, that weathering of oil has not or hardly taken place during the 19 years following the discharges, due to anaerobic sediment conditions.

The vertical distribution of oil in the sediment at 100 m from the platform shows that the highest oil concentration was found in the deep layer at 25 – 30 cm below the sediment surface (Fig. 10). The concentration here was almost 10 times higher than in the upper 10 cm.

Numbers of the sea urchin *Echinocardium cordatum* were counted in all samples. The density of the species in the area was very low (Table 15). At 45 m the species was absent. At each of the other stations 1 or 2 specimens were found in only one sample. The numbers are too low to allow for a statistical analysis.

The fauna analyses yielded a total of 93 identi-

Table 15. Numbers of *Echinocardium cordatum* (specimens > 15 mm) in the Van Veen grab samples (10 per station) at L4-a.

45 m	100 m	250 m	500 m	1000 m
0	0	0	0	0
0	0	0	0	0
0	0	0	1	0
0	0	0	0	0
0	1	0	0	0
0	0	0	0	2
0	0	0	0	0
0	0	0	0	0
0	0	2	0	0
0	0	0	0	0

fied species. Their frequency of occurrence is summarized in Table 16. The quantitative data are listed in Table 24 (Appendix). The fauna in the area was numerically dominated by the brittle star *Amphiura filiformis* and (juveniles of the) crustacean *Callianassa subterranea*. Together these species accounted for almost 50% of the total fauna abundance in the area. The mean faunal densities at the stations at ? 100 m from the platform ranged between 700 and 1800 animals per m^2 (Fig. 11). The differences between these stations were largely due to differences in the abundance of the dominant species. For example, the high fauna density at the 250-m station was caused by the abundance of *A. filiformis* and *C. subterranea*. On the other hand, the mean fauna density was extremely low at 45 m. This was caused not only by the absence of the two dominant species, but also by the absence of most other species.

The total number of identified species was 14 at the 45-m station and ranged between 54 and 64 at the other stations. Per sample the numbers varied between 2 and 8 at 45 m and between 25

Table 16. The benthic fauna at L4-a. Percentage occurrence of each species in the total number of samples.

POLYCHAETA		*Mediomastus fragilis*	40	*Brachystomia eulimoides*	5
		Notomastus latericeus	45	*Semierycina nitida*	35
Polychaeta indet.	5	*Ophelia limacina*	25	*Lepton squamosum*	25
Gattyana cirrosa	5	*Ophelina acuminata*	15	*Devonia perrieri*	5
Harmothoe glabra	5	*Myriochele oculata*	5	*Mysella bidentata*	70
Malmgreniella lunulata	10	*Owenia fusiformis*	10	*Dosinia lupinus*	5
Pholoe minuta	75	*Pectinaria auricoma*	75	*Chamelea striatula*	5
Sthenelais limicola	60	*Pectinaria koreni*	10	*Mactra corallina*	5
Eteone longa	5	*Ampharete finmarchica*	5	*Spisula subtruncata*	5
Phyllodoce rosea	15	*Lysilla loveni*	5	*Spisula subtruncata juv.*	30
Phyllodoce maculata	5			*Abra alba*	45
Glycera spec. juv.	30	CRUSTACEA		*Abra spec. juv.*	5
Glycera alba	15			*Abra nitida*	20
Glycera lapidum	20	*Callianassa subterranea*	65	*Gari fervensis juv.*	10
Glycera rouxi	10	*Callianassa subterranea juv.*	70	*Phaxas pellucidus*	20
Glycinde nordmanni	25	*Upogebia deltaura*	70	*Corbula gibba*	70
Goniada maculata	70	*Upogebia deltaura juv.*	25	*Corbula gibba juv.*	5
Gyptis capensis	55	*Upogebia stellata*	25	*Thracia convexa*	5
Ophiodromus flexuosus	45	*Pinnotheres pisum*	5	*Thracia papyracea*	5
Exogone hebes	5	*Liocarcinus marmoreus*	15	*Nucula nitidosa*	75
Nereis longissima	20	*Pontophilus trispinosus*	5		
Nephtys spec. juv.	35	*Pagurus bernhardus juv.*	10	ECHINODERMATA	
Nephtys caeca	30	*Ione thoracica*	30		
Nephtys hombergii	75	*Eurydice spinigera*	10	*Amphiura filiformis*	80
Nephtys incisa	15	*Melita dentata*	5	*Ophiura albida*	20
Nephtys longosetosa	20	*Urothoe poseidonis*	15	*Echinocyamus pusillus*	60
Lumbrineris fragilis	35	*Harpinia antennaria*	65	*Echinocardium cordatum*	5
Lumbrineris latreilli	85	*Leucothoe incisa*	25	*Trachythyone elongata*	10
Orbinia sertulata	5	*Orchomene nana*	5	*Leptosynapta inhaerens*	15
Poecilochaetus serpens	75	*Ampelisca brevicornis*	10		
Prionospio cirrifera	10	*Ampelisca tenuicornis*	10	OTHER TAXA	
Polydora spec.	65	*Bathyporeia elegans*	10		
Prionospio steenstrupi	25	*Iphinoe trispinosa*	5	*Tunicata indet. juv.*	5
Spio filicornis	60	*Eudorella truncatula*	40	*Anthozoa spec.*	10
Spiophanes bombyx	55	*Diastylis bradyi*	20	*Nemertini*	75
Spiophanes kroeyeri	70			*Nematoda*	5
Magelona alleni	35	MOLLUSCA		*Oligochaeta*	5
Magelona johnstoni	5			*Turbellaria spec.*	5
Chaetopterus variopedatus	5	*Hyala vitrea*	60	*Golfingia elongata*	20
Aphelochaeta marioni	25	*Turritella communis*	5	*Golfingia vulgaris*	15
Diplocirrus glaucus	55	*Euspira nitida*	65	*Phoronida*	80
Capitella capitata	20	*Cylichna cylindracea*	15		

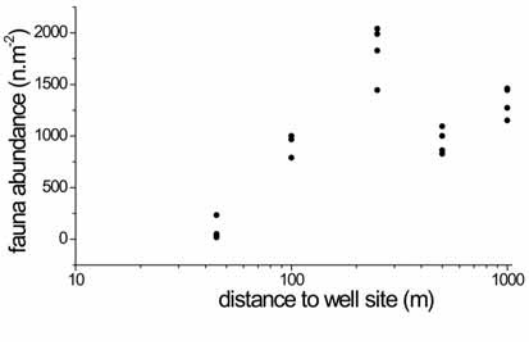

Fig. 11. Location L4-a: Total fauna abundance along the residual current transect

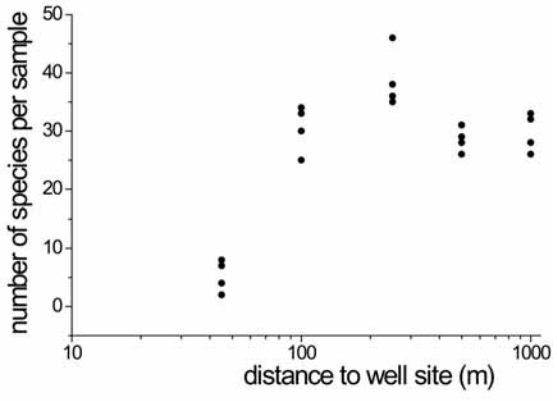

Fig. 12. Location L4-a: Numbers of identified species per sample along the residual current transect.

and 46 at the other stations (Fig. 12). Analysis of variance showed that there were highly significant ($p < 0.1\%$) differences between the stations. The 45-m station appeared to have significantly less species per sample than the other stations, whereas the 250-m station was slightly richer than the other ones.

As was the case for species richness, the relative fauna abundance was lowest at the 45-m station and highest at 250 m (Fig. 13). There appeared to be highly significant ($p < 0.1\%$) differences in the relative abundance of the stations sampled (ANOVA). Particularly the 45-m station was clearly different from the other stations, indicating that the fauna was strongly affected by the polluted sediment.

Possible gradients in the spatial abundance pattern were tested by logit regression for 22 species of which at least twenty specimens were found each (Table 17). In the uncorrected test a gradient appeared to be significant for 11 species. However, there appeared to be a high degree of dispersion in the data, so that gradients appeared to be significant for only 3 species in

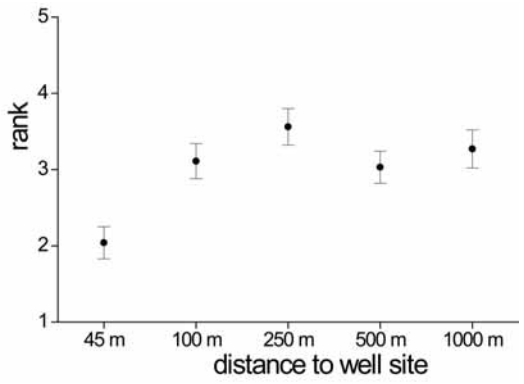

Fig. 13. Location L4-a: relative macrofauna abundance along the residual current transect (mean ranks and 95% confidence limits).

Table 17. Location L4-a. List of species for which density gradients were tested by logit regression. Sign of the gradient (+/-) and significance level are indicated. + = increasing frequency of occurrence away from the location; - = decreasing frequency away from the location; 0 = no gradient.

		sign. level (%)	
	sign	unc. test	corr. test
Pholoe minuta	+	5	n.s.
Goniada maculata	0	-	-
Gyptis capensis	0	-	-
Nephtys hombergii	+	n.s.	n.s.
Lumbrineris latreilli	+	0.1	0.1
Poecilochaetus serpens	+	0.5	n.s.
Spio filicornis	+	5	n.s.
Spiophanes bombyx	0	-	-
Spiophanes kroeyeri	+	5	n.s.
Diplocirrus glaucus	+	0.5	n.s.
Pectinaria auricoma	+	5	n.s.
Callianassa subterranea	+	0.1	0.1
Upogebia deltaura	+	n.s.	n.s.
Harpinia antennaria	+	5	n.s.
Hyala vitrea	+	n.s.	n.s.
Euspira nitida	+	n.s.	n.s.
Semierycina nitida	0	-	-
Mysella bidentata	+	n.s.	n.s.
Corbula gibba	+	n.s.	n.s.
Nucula nitidosa	+	0.5	n.s.
Amphiura filiformis	+	0.1	0.1
Echinocyamus pusillus	+	n.s.	n.s.

Table 18. Location L4-a: evaluation of the abundance patterns of 15 OBM-sensitive species. + = tendency for higher abundance away from the platform; - = tendency for lower abundance away from the platform; 0 = no tendency for a gradient. (?) = total number of specimens found <20. Note that the qualifications are based on the abundance patterns and not on presence-absence data as used in logit regression.

	tendency
Echinocardium cordatum	(?)
Tellimya ferruginosa	not found
Harpinia antennaria	+
Callianassa subterranea	+
Owenia fusiformis	(?)
Mysella bidentata	+
Gattyana cirrosa	(?)
Amphiura filiformis	+
Cylichna cylindracea	(?)
Nucula nitidosa	+
Chaetozone setosa	not found
Glycinde nordmanni	(?)
Nephtys hombergii	+
Pholoe minuta	+
Scalibregma inflatum	not found

the corrected test. In all cases the gradients were positive, i.e. increasing frequency of occurrence with increasing distance to the platform, indicating that the species were still negatively affected by the former discharges. An inspection of the abundance data of 15 species, which in the past have shown to be sensitive to OBM discharges (Daan *et al*., 1994), reveals that 7 of them showed a tendency for increasing abundance away from the platform (Table 18). The other species were not found in the area or in such low numbers that a possible pattern in their distribution could not be observed.

There were three species that were (almost) exclusively found at the 45-m station: the polychaete *Capitella capitata* and the crustaceans *Liocarcinus marmoreus* and *Pagurus bernhardus*. The first species is known as a typical opportunist, which thrives in disturbed sediment conditions (Eagle & Rees, 1973; Pearson & Rosenberg, 1978; Rygg, 1985, Daan et al., 1994). The two crustaceans are epifaunal species, which do not live in but on top of the sediment. Therefore, they are not directly exposed to the polluted sediment.

Table 19. Location L4-a: Bray-Curtis percentage simila between stations after squareroot transformation of spe specific abundances.

	100 m	50 m	n
45 m	9	7	
100 m		65	6
250 m			6
500 m			

A comparison of the stations on the basis of the Bray-Curtis index shows that there is hardly any similarity between the 45-m station and the other stations (Table 19), which confirms that the fauna at 45 m is strongly affected by the former discharges. Between the stations further away from the platform the similarity is fairly good.

The development of the sediment conditions at L4a is somewhat complicated. At the stations at 250m and 500 m contamination seems to have decreased to values below maximum background level. Up to 1994, when the last survey took place, elevated oil concentrations were found up to 500 m. At 100 m a measurable concentration of oil was found in the superficial sediment layer, but the concentration was only slightly beyond maximum background level. This suggested a decrease of oil at the long term. However, in the deeper sediment oil appeared to be present at a concentration level that was comparable to that in 1994. This suggests that oil has not disappeared from the deeper layers. It also indicates that the oil analyses of the regular sediment samples of the upper 10 cm give an underestimation of the oil that is still present in the bottom.

Most puzzling is the situation at the 45-m station. The degree of sediment contamination was higher than ever, but there can not have been an increase in the amount of oil in the sediment, since there have been no more discharges after 1986. As suggested by Tamis *et al*. (2005) it can be a local patch that has come to the sediment surface. But the question still remains why the chromatogram points at more or less 'unweathered' base oil. The most plausible explanation seems to be that weathering of oil has not or hardly taken place during the 19 years following the discharges. It is conceivable that the high oil concentration in combination with anaerobic sediment conditions have inhibited bacterial degradation of the oil. Further it is worth mentioning that, during fieldwork, a lot of oil particles were seen in the fauna samples. Such particles are usually

enveloped by a crust-like pellicle which may prevent the most volatile components that are inside to escape from the particles.

There is another interesting aspect concerning the origin of the contaminated material in the samples taken at the 45-m station. During sorting of the fauna samples in the laboratory, these appeared to contain a large number of (empty) shells, that are not known to occur in the North Sea. We found about 25 species we had never seen before. When these species were shown to two professional malacologists, they concluded that they are most probably native of the Indo-pacific, maybe somewhere in the south-east Asian seas.

Of course the question arose how these shells did end up here so close to platform L4a. The answer to this question appeared to be unambigious. The drillings that were performed in 1986, appeared to have been carried out from a rig, which, before it arrived at L4a, had been transported from a well site near Singapore to the North Sea. Apparently, a certain amount of bottom material must have been sticking to the legs of the rig after these were lifted for departure from Singapore. Subsequently, this material, including the shells, must have been brought down to L4a adhering to the legs of the rig.

The presence of the Asian shells in the samples at the 45-m station shows that the drill rig must have been standing at exactly this place in 1986. Hence, the fact that the high oil concentrations were found in the same samples in which the shells were found makes it most probable that the oil has reached the seabed at the same time as the shells did.

The high contamination level at the platform station was clearly reflected in the composition of the macrobenthic community. The fauna was severely impoverished. Most species that were common or even abundant further away from the platform were absent and of those species that did occur only a very few specimens were found. At 100 m, the fauna seemed to be not or hardly affected, in spite of the presence of oil in the sediment, particularly in the deeper sediment layers. During the preceding survey of 1994 a decrease in biological effects was already observed at this station. In that year an effect could be observed in 10 species that showed reduced abundance at 100 m. It is possible that an effect on a highly OBM-sensitive species like the sea urchin *Echinocardium cordatum* is still persistent, but the natural abundance of the species in the area was so low, that the presence of such an effect could not be statistically verified.

Table 20. Oil concentrations (mg.kg^{-1} dry sediment) at location G13-1 in 1995 and 2005. Values >10 are beyond natural background level. Data from Tamis *et al*. (2005).

	1995	2005
25 m	425	11
100 m	47	37
250 m	5	9
500 m	7	6
1000 m	5	5

Location G13-1
Sedimentation area, 197 tonnes of oil discharged 18 yr ago, no platform

The sediment at this location consists of fine to very fine sand and a substantial silt fraction. All samples looked clean, including those at 25 m from the well site. Some cuttings were found in a few samples at 25 m, 100 m and 250 m from the well site. One sample at 25 m had a smell of oil, but oil particles were not seen.

The chemical analyses revealed elevated oil concentrations at 25 m and 100 m, but the concentrations were only slightly beyond maximum background level (Table 20). Compared to the preceding measurement in 1995 the concentrations had decreased. Surprisingly, at 100 m the concentration measured was higher than at 25 m. A plot of the vertical distribution of oil in the sediment (Fig. 14) shows that oil was present in the deeper sediment layers. In the top layer (0 – cm)

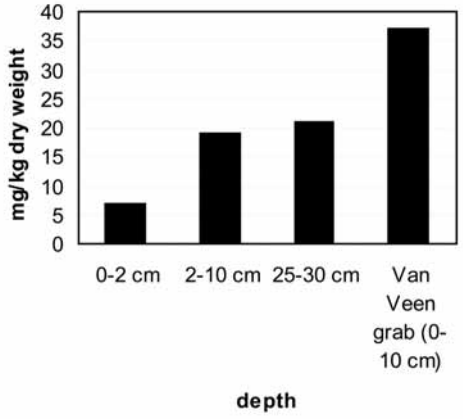

Fig. 14. Location G13-1: vertical distribution of oil in the sediment at 100 m from the wellsite. Data from Tamis et al. (2005).

Table 21. Numbers of *Echinocardium cordatum* (specimens > 15 mm) in the Van Veen grab samples (10 per station) at G13-1.

25 m	100m	250 m	500 m	1000 m
1	0	1	3	0
0	2	3	0	0
0	1	4	0	3
0	1	1	0	0
0	0	1	1	0
0	1	1	1	0
1	1	2	1	0
0	0	3	0	1
0	0	0	1	3
0	0	1	0	0

the concentration was below maximum background level. The difference between the values measured in a sediment sample from one box-core and the value measured in a pooled sediment sample from 10 Van Veen grabs illustrates the patchy distribution of oil in the sediment.
The numbers of sea urchins *Echinocardium cordatum* were counted on board in all samples (Table 21). The species was not particularly abundant in the area. Only at 250 m *E. cordatum* occurred in nearly all samples. At 25 m only 2 specimens were found, suggesting that there might be a long-term effect. However at the 1000-m reference station the species was also found in only 3 samples. It is not surprising, therefore, that logit regression did not reveal a significant gradient in the frequency of occurrence of *E. cordatum* along the transect sampled.

Location G13-1, where no platform is present, was visited to see whether beamtrawl fishing has a measurable effect on the distribution of discharged material and, indirectly, on the degradation of oil. The data do not unequivocally support this idea. The decrease of oil at the 25-m station between 1995 and 2005 indeed might have been promoted by beamtrawling, which could have spread the drill cuttings and have brought them in contact with aerobic conditions, which are beneficial for oil degradation. However, if beamtrawling had a significant effect, one should expect a similar strong decrease in oil concentrations at 100 m, but the decrease was only very slight at this station. At the 100-m stations of all other locations investigated the decrease was substantially stronger. We have to conclude, therefore, that a measurable effect of beamtrawl fishing can not be demonstrated. This does not mean that fishery does not have any effect. However, as a consequence of the very patchy distribution of the discharged material, a much more extensive sampling programme would be necessary to detect such an effect.

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Appendix

Table 22. Data platform L13-fe, survey March 2005.
Mean densities (n.m-2)
Number of samples ( ) in which species are present.
Tot. number of ind. per m2 per station.
Number of identified species.

Distance to platform (m)	40	100	250	500	1000
Number of analysed samples	4	4	4	4	4
POLYCHAETA					
Eteone foliosa			1.4 (1)		2.8 (1)
Eteone longa	1.4 (1)	20.8 (4)	5.6 (2)	5.6 (3)	
Hesionura augeneri		4.2 (1)		4.2 (2)	
Phyllodoce spec. juv.		2.8 2)	2.8 (1)		
Glycera spec. juv.		5.6 (3)			
Glycinde nordmanni	8.3 (2)	2.8 2)	1.4 (1)		1.4 (1)
Goniada maculata	6.9 (3)	1.4 (1)		1.4 (1)	
Streptosyllis websteri	1.4 (1)				
Exogone hebes				1.4 (1)	
Nephtys caeca	1.4 (1)	2.8 (1)		1.4 (1)	
Nephtys cirrosa	1.4 (1)	16.7 (4)	25.0 (4)	18.6 (3)	8.3 (3)
Nephtys hombergii		2.8 (1)	1.4 (1)	6.9 (1)	
Nephtys incisa		1.4 (1)			
Nephtys longosetosa	1.4 (1)				
Lumbrineris latreilli	1.4 (1)			1.4 (1)	
Scoloplos armiger	2.8 (2)	6.9 (3)	9.7 (2)	23.6 (4)	52.8 (4)
Aonides paucibranchiata	13.9 (4)	9.7 (3)	4.2 (3)	5.6 (2)	1.4 (1)
Scolelepis bonnieri		1.4 (1)	2.8 (2)	4.2 (3)	
Scolelepis foliosa		1.4 (1)			
Spio filicornis	2.8 (1)	1.4 (1)	2.8 (2)		1.4 (1)
Magelona alleni	1.4 (1)			1.4 (1)	
Magelona mirabilis			1.4 (1)	1.4 (1)	1.4 (1)
Chaetozone setosa					1.4 (1)
Ophelia limacina		1.4 (1)	1.4 (1)	8.3 (3)	9.7 (4)
Lanice conchilega			1.4 (1)	2.8 (2)	
CRUSTACEA					
Processa parva					4.2 (3)
Corystes cassivelaunus					1.4 (1)
Thia scutellata		2.8 (1)	6.9 (2)	6.9 (3)	
Pontophilus trispinosus	1.4 (1)				
Caprellidae spec.					1.4 (1)
Megaluropus agilis					1.4 (1)
Apherusa clevei					1.4 (1)
Apherusa ovalipes	2.8 (1)	4.2 2)		2.8 (2)	2.8 (1)
Urothoe brevicornis			1.4 (1)		
Urothoe poseidonis			18.6 (4)	5.6 (3)	2.8 (4)
Leucothoe incisa			1.4 (1)		2.8 (2)
Orchomene nana	2.8 (1)				1.4 (1)
Atylus swammerdami		1.4 (1)			
Bathyporeia elegans	18.6 (4)		2.8 (1)		5.6 (2)
Bathyporeia guilliamsoniana	2.8 (1)				
Pseudocuma longicornis		1.4 (1)			1.4 (1)
Leptognathia spec.		1.4 (1)			2.8 (1)

Table 22 (continued)

Distance to platform (m)	40	100	250	500	1000
Number of analysed samples	4	4	4	4	4
MOLLUSCA					
Euspira nitida	5.6 (2)	26.4 (4)	19.4 (4)	19.4 (4)	48.6 (4)
Brachystomia eulimoides	2.8 (2)				
Goodallia triangularis	9.7 (2)	77.8 2)	26.4 (2)	26.4 (3)	2.8 (3)
Tellimya ferruginosa				2.8 (2)	1.4 (1)
Dosinia lupinus		1.4 (1)		2.8 (1)	1.4 (1)
Dosinia exoleta			1.4 (1)		
Chamelea striatula		4.2 (1)	9.7 (2)	2.8 (1)	6.9 (2)
Mactra corallina	1.4 (1)				
Spisula spec. juv.			1.4 (1)		
Spisula subtruncata					5.6 (3)
Donax vittatus		6.9 2)		1.4 (1)	
Gari fervensis juv.					1.4 (1)
Tellina pygmea		1.4 (1)			
Ensis ensis		1.4 (1)	1.4 (1)		1.4 (1)
Corbula gibba			1.4 (1)		
Thracia papyracea	6.9 (3)	2.8 2)	1.4 (1)		18.6 (4)
ECHINODERMATA					
Ophiura albida	1.4 (1)	1.4 (1)	8.3 (2)	11.1 (4)	11.1 (4)
Echinocyamus pusillus		2.8 (1)	4.2 (3)	6.9 (4)	6.9 (3)
Echinocardium cordatum				6.9 (4)	8.3 (4)
OTHER TAXA					
Tunicata indet. juv.		13.9 (1)	43.6 (2)	84.7 (2)	
Branchiostoma lanceolatum	37.5 (4)	93.6 (4)	31.9 (4)	6.9 (3)	6.9 (2)
Anthozoa	1.4 (1)				
Nemertini	18.6 (4)	2.8 (1)		1.4 (1)	2.8 (2)
Nematoda	19.4 (4)	138.9 (4)	16.7 (4)	7.8 (3)	13.9 (4)
Turbellaria					
Oligochaeta	2.8 (2)	2.8 (4)		2.8 (2)	
Golfingia elongata					
Golfingia vulgaris					
Phoronida					
Total nr. of individuals (n/m2)	180	455	259	288	248
Nr. of identified species	24	32	29	28	34

Table 23. Data platform K12-a, survey March 2005.
Mean densities (n.m-2)
Number of samples ( ) in which species are present.
Tot. number of ind. per m2 per station
Number of identified species.

Distance to platform (m)	35	100	250	500	1000
Number of analysed samples	4	4	4	4	4
POLYCHAETA					
Polychaeta indet.	1.4 (1)				
Harmothoe spec. juv.			12.5 (4)	1.4 (1)	6.9 (3)
Malmgreniella lunulata		16.7 (3)	48.6 (4)	23.6 (4)	22.2 (4)
Pholoe minuta	1.4 (1)	22.2 (4)	5.6 (3)		8.3 (4)
Sigalion mathildae					1.4 (1)
Sthenelais limicola	5.6 (3)	8.3 (3)	5.6 (2)	8.3 (4)	8.3 (3)
Phyllodoce rosea	13.9 (4)	13.9 (4)	13.9 (4)	13.9 (4)	13.9 (4)
Phyllodoce maculata		1.4 (1)			
Eumida sanguinea	5.6 (2)	1.4 (1)	4.2 (2)	5.6 (4)	8.3 (4)
Glycera spec. juv.	2.8 (2)	5.6 (2)	1.4 (1)		2.8 (1)
Glycera alba	1.4 (1)	1.4 (1)			1.4 (1)
Glycinde nordmanni		1.4 (1)	1.4 (1)		
Goniada maculata	41.7 (4)	41.7 (4)	2.8 (4)	12.5 (3)	2.8 (3)
Ophiodromus flexuosus		6.9 (3)	1.4 (1)		1.4 (1)
Nereis longissima	6.9 (3)	2.8 (2)		1.4 (1)	2.8 (1)
Nephtys spec. juv.	4.2 (2)	6.9 (3)	8.3 (4)		1.4 (1)
Nephtys caeca	8.3 (3)		1.4 (1)		
Nephtys cirrosa	2.8 (4)	1.4 (1)		1.4 (1)	6.9 (3)
Nephtys hombergii	6.9 (4)	15.3 (4)	2.8 (4)	8.3 (3)	36.1 (4)
Nephtys incisa					1.4 (1)
Nephtys assimilis		2.8 (1)			
Lumbrineris latreilli	156.9 (4)	269.4 (4)	25.6 (4)	97.2 (4)	179.2 (4)
Scoloplos armiger			5.6 (3)	1.4 (1)	34.7 (4)
Poecilochaetus serpens	1.4 (1)	2.8 (2)	15.3 (4)	2.8 (3)	33.3 (4)
Spio filicornis	4.2 (3)	1.4 (1)			
Spiophanes bombyx	37.5 (4)	183.3 (4)	243.6 (4)	163.9 (4)	194.4 (4)
Spiophanes kroeyeri			1.4 (1)	1.4 (1)	
Magelona alleni	1.4 (1)				
Magelona mirabilis			16.7 (3)	1.4 (1)	15.3 (2)
Magelona johnstoni		5.6 (3)	8.3 (2)	11.1 (4)	34.7 (4)
Diplocirrus glaucus	1.4 (1)	4.2 (2)	1.4 (1)		2.8 (1)
Capitella capitata	1.4 (1)				
Mediomastus fragilis		45.8 (4)	15.3 (4)	11.1 (4)	5.6 (2)
Notomastus latericeus	483.3 (4)	18.3 (4)	34.7 (4)	38.9 (4)	33.3 (4)
Ophelia limacina				1.4 (1)	
Myriochele oculata	8.3 (3)	131.9 (4)	27.8 (4)	15.3 (3)	45.8 (4)
Owenia fusiformis		2.8 (2)			
Pectinaria koreni	1.4 (1)	5.6 (2)			
Sabellaria spinulosa	1.4 (1)				
Lanice conchilega		43.6 (4)	91.7 (4)	48.6 (4)	55.6 (4)
CRUSTACEA					
Processa nouveli holthuisi		1.4 (1)			
Processa parva					2.8 (2)
Callianassa subterranea	1.4 (1)	1.4 (1)	1.4 (1)		1.4 (1)

Table 23 (continued)

Distance to platform (m)	35	100	250	500	1000
Number of analysed samples	4	4	4	4	4
Callianassa subterranea juv.	1.4 (1)	12.5 (4)	8.3 (3)	11.1 (3)	6.9 (2)
Upogebia deltaura		4.2 (2)	5.6 (2)	2.8 (2)	2.8 (2)
Pinnotheres pisum			1.4 (1)		
Liocarcinus marmoreus	4.2 (2)				
Pagurus bernhardus juv.	1.4 (1)				
Ione thoracica		4.2 (1)		1.4 (1)	1.4 (1)
Eurydice spinigera	1.4 (1)				
Caprellidae spec.		2.8 (1)	1.4 (1)		15.3 (3)
Apherusa ovalipes				1.4 (1)	
Perioculodes longimanus	1.4 (1)	5.6 (3)	1.4 (1)		
Harpinia antennaria	1.4 (1)	6.9 (4)	11.4 (4)	19.4 (4)	98.6 (4)
Orchomene nana			12.5 (4)	1.4 (1)	6.9 (3)
Ampelisca brevicornis		16.7 (3)	48.6 (4)	23.6 (4)	22.2 (4)
Ampelisca tenuicornis	1.4 (1)	22.2 (4)	5.6 (3)		8.3 (4)
Bathyporeia elegans					1.4 (1)
Bathyporeia guilliamsoniana	5.6 (3)	8.3 (3)	5.6 (2)	8.3 (4)	8.3 (3)
Pseudocuma longicornis			12.5 (4)	1.4 (1)	6.9 (3)
MOLLUSCA					
Hyala vitrea		8.3 (3)			
Euspira nitida	63.9 (4)	34.7 (4)	63.9 (4)	52.8 (4)	59.7 (4)
Acteon tornatilis					1.4 (1)
Cylichna cylindracea	1.4 (1)				1.4 (1)
Tellimya ferruginosa		34.7 (4)	2.8 (4)	15.3 (3)	29.2 (3)
Mysella bidentata	2.8 (2)	19.4 (4)	4.2 (2)	6.9 (3)	2.8 (1)
Mactra corallina		5.6 (2)	2.8 (2)		
Spisula spec. juv.				2.8 (1)	
Spisula subtruncata		16.7 (3)	48.6 (4)	23.6 (4)	22.2 (4)
Abra alba	1893.6 (4)	125.0 (4)	34.7 (4)	12.5 (4)	3.6 (4)
Tellina fabula		1.4 (1)	4.2 (3)	1.4 (1)	
Phaxas pellucidus	1.4 (1)	22.2 (4)	5.6 (3)		8.3 (4)
Corbula gibba	6.9 (3)	4.2 (2)	1.4 (1)	1.4 (1)	
Thracia papyracea	11.1 (4)	33.3 (4)	58.3 (4)	3.6 (4)	54.2 (4)
Nucula nitidosa	22.2 (4)	2.8 (4)	34.7 (4)	13.9 (4)	15.3 (4)
ECHINODERMATA					
Amphiura filiformis	2.8 (1)	15.3 (4)	29.2 (4)	18.6 (4)	43.6 (4)
Acrocnida brachiata		1.4 (1)			
Ophiura spec. juv.	2.8 (2)	2.8 (1)	2.8 (1)	4.2 (1)	1.4 (1)
Ophiura albida	1.4 (1)	1.4 (1)	6.9 (2)	9.7 (4)	27.8 (3)
Ophiura texturata					1.4 (1)
Echinocardium cordatum		77.8 (4)	15.3 (3)	12.5 (4)	13.9 (3)

Table 23 (continued)

Distance to platform (m)	35	100	250	500	1000
Number of analysed samples	4	4	4	4	4
OTHER TAXA					
Branchiostoma lanceolatum					1.4 (1)
Anthozoa		1.4 (1)	1.4 (1)	1.4 (1)	
Nemertini	15.3 (4)	18.6 (4)	11.1 (4)	8.3 (4)	8.3 (4)
Turbellaria	5.6 (3)	8.3 (3)	5.6 (2)	8.3 (4)	8.3 (3)
Oligochaeta		4.2 (2)	5.6 (2)	2.8 (2)	2.8 (2)
Phoronida		2.8 (1)	1.4 (1)	2.8 (2)	
Total nr. of individuals	2851.9	1393.0	1052.9	744.4	1251.3
Nr. of identified species	39	52	49	42	52

Table 24.Data platform L4-a, survey March 2005.
Mean densities (n.m-2)
Number of samples ( ) in which species are present.
Tot. number of ind. per m2 per station.
Number of identified species.

Distance to platform (m)	45	100	250	500	1000
Number of analysed samples	4	4	4	4	4
POLYCHAETA					
Polychaeta indet.					2.8 (1)
Gattyana cirrosa			2.8 (1)		
Harmothoe glabra			2.8 (1)		
Malmgreniella lunulata			1.4 (1)		1.4 (1)
Pholoe minuta		12.5 (4)	26.4 (4)	8.3 (3)	23.6 (4)
Sthenelais limicola	1.4 (1)	9.7 (4)	6.9 (3)	2.8 (2)	4.2 (2)
Eteone longa	1.4 (1)				
Phyllodoce rosea		2.8 (2)		1.4 (1)	
Phyllodoce maculata				1.4 (1)	
Glycera spec. juv.		1.4 (1)	1.4 (1)	11.1 (4)	
Glycera alba			9.7 (3)		
Glycera lapidum			4.2 (2)	4.2 (2)	
Glycera rouxi				5.6 (2)	
Glycinde nordmanni		1.4 (1)	2.8 (2)	1.4 (1)	1.4 (1)
Goniada maculata	4.2 (3)	13.9 (3)	2.8 (2)	4.2 (2)	8.3 (4)
Gyptis capensis		13.9 (4)	4.2 (2)	9.7 (3)	5.6 (2)
Ophiodromus flexuosus		2.8 (1)	5.6 (3)	2.8 (2)	6.9 (3)
Exogone hebes				1.4 (1)	
Nereis longissima		2.8 (2)	2.8 (2)		
Nephtys spec. juv.	1.4 (1)	2.8 (2)		2.8 (2)	2.8 (2)
Nephtys caeca		2.8 (1)	4.2 (2)	4.2 (3)	
Nephtys hombergii	1.4 (1)	11.1 (4)	11.1 (4)	5.6 (2)	22.2 (4)
Nephtys incisa				1.4 (1)	5.6 (2)
Nephtys longosetosa		4.2 (2)	1.4 (1)		4.2 (1)
Lumbrineris fragilis		1.4 (1)	9.7 (3)	2.8 (1)	6.9 (2)
Lumbrineris latreilli	1.4 (1)	37.5 (4)	75.0 (4)	54.2 (4)	62.5 (4)
Orbinia sertulata			1.4 (1)		
Poecilochaetus serpens		33.3 (4)	11.1 (3)	12.5 (4)	15.3 (4)
Prionospio cirrifera			1.4 (1)		1.4 (1)
Polydora spec.		15.3 (2)	2.8 (4)	12.5 (3)	18.6 (4)
Prionospio steenstrupi			6.9 (3)	1.4 (1)	1.4 (1)
Spio filicornis		2.8 (1)	27.8 (4)	51.4 (4)	4.3 (3)
Spiophanes bombyx		13.9 (4)	13.9 (4)	4.2 (1)	6.9 (2)
Spiophanes kroeyeri		9.7 (4)	8.3 (3)	6.9 (3)	13.9 (4)
Magelona alleni		4.2 (3)	4.2 (2)	2.8 (2)	
Magelona johnstoni				1.4 (1)	
Chaetopterus variopedatus			1.4 (1)		
Aphelochaeta marioni		5.6 (3)	2.8 (2)		
Diplocirrus glaucus		1.4 (1)	13.9 (4)	4.2 (2)	16.7 (4)
Capitella capitata	9.7 (4)				
Mediomastus fragilis			12.5 (4)	6.9 (2)	4.2 (2)
Notomastus latericeus	1.4 (1)		11.1 (4)	5.6 (3)	2.8 (1)
Ophelia limacina		1.4 (1)	1.4 (1)	2.8 (2)	2.8 (1)
Ophelina acuminata		1.4 (1)	1.4 (1)	1.4 (1)	

Table 24.Data platform L4-a, survey March 2005.

Table 24 (continued)

Distance to platform (m)	45	100	250	500	1000
Number of analysed samples	4	4	4	4	4
Owenia fusiformis		4.2 (2)			
Pectinaria auricoma		13.9 (4)	41.7 (4)	13.9 (3)	9.7 (4)
Pectinaria koreni		2.8 (1)	1.4 (1)		
Ampharete finmarchica					1.4 (1)
Lysilla loveni					1.4 (1)
CRUSTACEA					
Callianassa subterranea		8.6 (4)	37.5 (4)	5.6 (2)	6.9 (3)
Callianassa subterranea juv.		59.7 (2)	225.0 (4)	158.3 (4)	163.9 (4)
Upogebia deltaura		13.9 (4)	23.6 (4)	11.1 (3)	2.8 (3)
Upogebia deltaura juv.			8.3 (3)	2.8 (2)	
Upogebia stellata			2.8 (2)	2.8 (2)	2.8 (1)
Pinnotheres pisum		1.4 (1)			
Liocarcinus marmoreus	4.2 (2)	1.4 (1)			
Pontophilus trispinosus	1.4 (1)				
Pagurus bernhardus juv.	47.2 (2)				
Ione thoracica		5.6 (2)	2.8 (2)	6.9 (2)	
Eurydice spinigera					4.2 (2)
Melita dentata					1.4 (1)
Urothoe poseidonis		2.8 (2)			1.4 (1)
Harpinia antennaria		6.9 (3)	23.6 (4)	2.8 (2)	25.0 (4)
Leucothoe incisa			4.2 (3)	1.4 (1)	1.4 (1)
Orchomene nana					1.4 (1)
Ampelisca brevicornis			1.4 (1)		1.4 (1)
Ampelisca tenuicornis		1.4 (1)	1.4 (1)		
Bathyporeia elegans					4.2 (2)
Iphinoe trispinosa	1.4 (1)				
Eudorella truncatula		1.4 (1)	5.6 (3)	5.6 (2)	5.6 (2)
Diastylis bradyi	1.4 (1)		1.4 (1)		2.8 (2)
MOLLUSCA					
Hyala vitrea		63.9 (2)	52.8 (4)	45.8 (4)	18.6 (2)
Turritella communis				1.4 (1)	
Euspira nitida		9.7 (3)	8.3 (3)	11.1 (4)	16.7 (3)
Cylichna cylindracea		2.8 (1)			5.6 (2)
Brachystomia eulimoides	1.4 (1)				
Semierycina nitida		30.6 (4)	8.3 (3)		
Lepton squamosum		4.2 (1)	4.2 (2)	5.6 (2)	
Devonia perrieri					1.4 (1)
Mysella bidentata		16.7 (4)	195.8 (4)	13.9 (3)	5.0 (3)
Dosinia lupinus		1.4 (1)			
Chamelea striatula					1.4 (1)
Mactra corallina					1.4 (1)
Spisula subtruncata		2.8 (1)			
Spisula subtruncata juv.			5.6 (3)	1.4 (1)	4.2 (2)
Abra alba		4.2 (2)	1.4 (1)	4.2 (2)	9.7 (4)
Abra spec. juv.		2.8 (1)			
Abra nitida		1.4 (1)	6.9 (2)	6.9 (1)	
Gari fervensis juv.		2.8 (2)			
Phaxas pellucidus		2.8 (1)	1.4 (1)	4.2 (2)	
Corbula gibba		18.6 (4)	26.4 (4)	25.0 (4)	6.9 (2)

Table 24 (continued)

Distance to platform (m)	45	100	250	500	1000
Number of analysed samples	4	4	4	4	4
Corbula gibba juv.			13.9 (1)		
Thracia convexa				2.8 (1)	
Thracia papyracea		1.4 (1)			
Nucula nitidosa		33.3 (4)	15.3 (3)	16.7 (4)	51.4 (4)
ECHINODERMATA					
Amphiura filiformis		145.8 (4)	712.5 (4)	27.8 (4)	543.6 (4)
Ophiura albida	1.4 (1)	1.4 (1)	1.4 (1)		2.8 (1)
Echinocyamus pusillus		15.3 (4)	5.6 (2)	5.6 (2)	11.1 (4)
Echinocardium cordatum				1.4 (1)	
Trachythyone elongata			2.8 (2)		
Leptosynapta inhaerens			4.2 (2)		1.4 (1)
OTHER TAXA					
Tunicata indet. juv.	1.4 (1)				
Anthozoa	1.4 (1)		1.4 (1)		
Nemertini		18.6 (4)	11.1 (4)	22.2 (4)	8.3 (3)
Nematoda					1.4 (1)
Turbellaria				1.4 (1)	
Oligochaeta					1.4 (1)
Golfingia elongata			5.6 (3)	2.8 (1)	
Golfingia vulgaris			4.2 (2)	1.4 (1)	
Phoronida		11.4 (4)	34.7 (4)	51.4 (4)	58.3 (4)
Total nr. of individuals	83.3	698.1	1807.0	702.8	1234.4
Nr. of identified species	14	54	64	54	54