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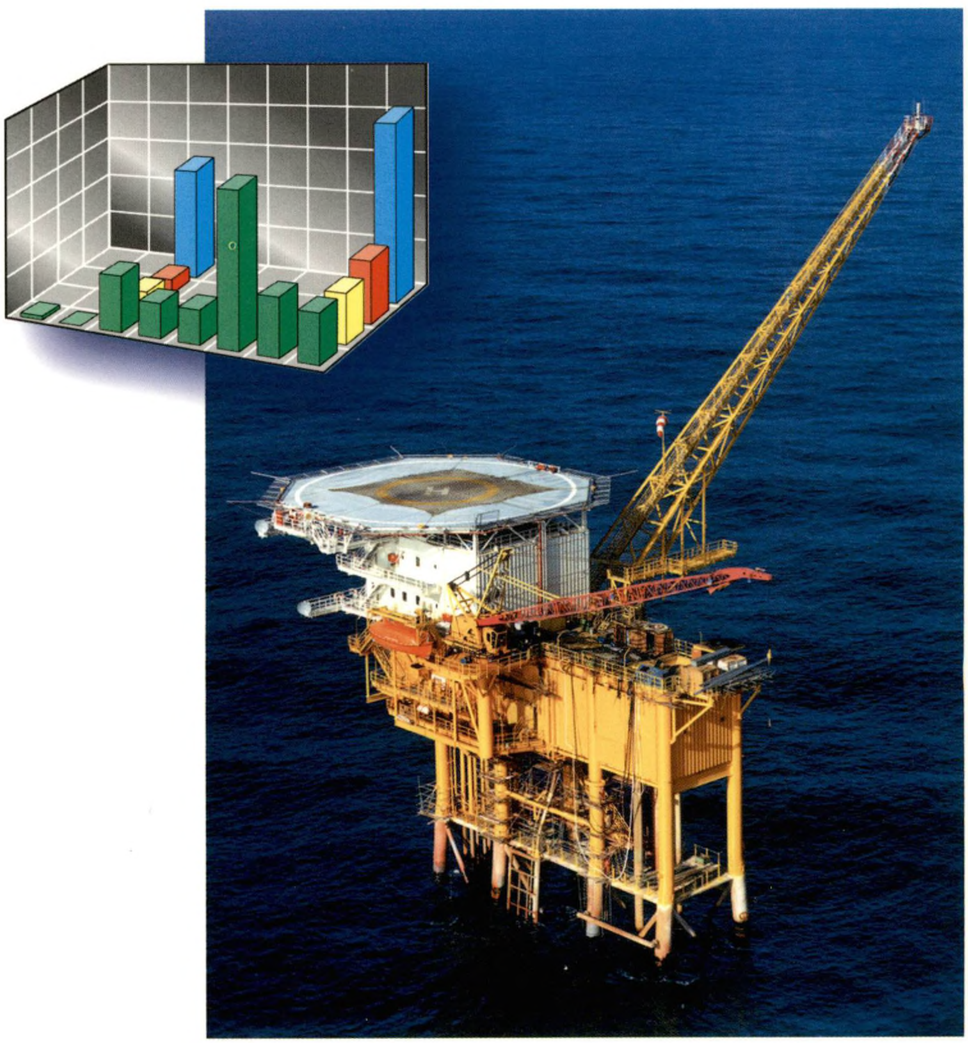

Nederlands Instituut voor Onderzoek der Zee

Netherlands Institute for Sea Research (NIOZ)
P.O. Box 59, 1790 AB Den Burg,
Texel, The Netherlands

North Sea Directorate
Ministry of Transport and Public Works
P.O.Box 5807, 2280 HV Rijswijk (Z-H)
The Netherlands

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R. DAAN, M. MULDER

This study was commissioned by the North Sea Directorate (RWS) and also carried out in the framework of the Dutch collaboration programme 'Policy Linked Ecological Research North Sea and Wadden Sea' (BEON)

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SUMMARY AND CONCLUSIONS

Field studies on the environmental effects of discharges of drill cuttings contaminated with oil based mud (OBM) have been carried out on the Dutch Continental Shelf since 1985. From 1993, when a ban was introduced on discharges of OBM contaminated drill cuttings, the research focuses on the long-term effects of former discharges. Surveys were carried out around the platforms K12a (transition zone between erosion and sedimentation) and P6b (erosion zone), 8 years and 6 years after termination of discharges of OBM cuttings at these locations respectively. The results of these surveys have been presented in previous reports. In 1994 a survey was carried out at location L4a in the sedimentation zone. This report presents the results of this study on the long-term effects of OBM cutting discharges at L4a, in this case 8 years after termination of the discharges.

At L4a a total of 6 wells have been drilled. The last two wells were drilled in 1986 using OBM. A baseline survey was carried out in May 1986 before drilling had started. Further three surveys were carried out to assess the short-term effects. The first took place in September 1986 when drilling of the wells was in progress, the second 4 months after drilling and the third 8 months after drilling. During these surveys there appeared to be a conspicuous gradient of decreasing oil concentrations in the sediment with increasing distance from the platform. A severely affected zone was identified extending to 100 - 250 m from the location. In this zone an accumulation of biological effects was observed and the fauna appeared to be substantially impoverished. There was, however, a larger area extending up to at least 500 m where more subtle effects on the benthic community could be detected by the absence or reduced abundance of a number of OBM sensitive species. The 1994 survey was undertaken to assess to what extent the short-term effects at L4a appeared to be persistent at the long-term, c.q. to detect possible recovery of the sediment conditions and the macrofauna community in the area.

Sediment sampling was mainly concentrated along a transect in the residual current direction of L4a. Sampling stations were chosen at distances ranging from 50 to 5000 m from the platform. Analyses included sediment grainsize characteristics, chemical analyses and faunistic descriptions. A few stations were also sampled in perpendicular directions, but only analysed for some physico-chemical characteristics and numbers of sea urchins (*Echinocardium cordatum*, specimens ≥15 mm).

In the residual current direction the chemical analyses revealed substantially elevated oil concentrations up to 100 m from the platform and slightly elevated concentrations up to 500 m. The concentrations at 100 m were lower than in June 1987, but at a similar level as in February 1987. The rate of degradation of oil in the sediment seems to be low, but can not reliably be quantified because of the patchy distribution of oil in the sediment. Clearly elevated concentrations of Barium were found up to 250 m. At 500 and 750 m the concentrations were slightly beyond background level, showing that residuals of the discharged material could be detected up to 750 m. At 100 m elevated concentrations of oil and Ba were found to a depth of at least 20 cm in the sediment. The highest concentrations were found in the deepest sediment layer analysed (15 - 20 cm), indicating that much of the material discharged is stored in the deeper sediment layers, where biodegradation is hardly possible.

Persistent biological effects were detected at distances ≤100 m from the platform. Within this zone a number of species, including the sensitive indicator species *Echinocardium cordatum*, *Montacuta ferruginosa* and *Harpinia antennaria*, were absent or occurred in reduced abundance compared to the stations at 750 - 5000 m. Nevertheless, on the community level the presence of such effects was only indicated by the relatively low similarity between the 100-m station and the remote stations. In terms of reduced species richness, total fauna abundance or relative fauna abundance, no effect could be demonstrated. Apparently, the fauna composition at 100 m was different from that at the remote station but not impoverished.

At 250 m from the platform the presence of biological effects could not be established with certainty. The major indication that the benthic community might still be affected at this station was that calculations of the Bray-Curtis similarity index for percentage similarity between stations showed that resemblance of the 250-m station with the stations at 750 - 5000 m was consistently lower than the mutual resemblance within these stations.

Compared to the situation during the first 8 months after termination of the discharges, there are clear signs of recovery of sediment conditions, particularly in the zone 250 - 500 m from the platform. Also at the 100-m station the extent of biological effects has decreased. Whereas in 1987 species richness and fauna abundance were substantially depressed at 100 m, the absence or reduced abundance of a few sensitive species as observed during the 1994 survey was not reflected in such adverse effects at the community level. On the contrary, the species richness at 100 m was even higher than at any of the stations sampled during the baseline survey.

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

1. Substantially elevated oil concentrations (up to 100 mg·kg^{-1} dry sediment) were found up to 100 m (residual current direction) from the platform. At 250 m and 500 m the concentrations were slightly beyond back-

ground level. Residuals of discharged material could be traced by elevated Ba concentrations up to 750 m from the platform.

2. Oil and Ba concentrations at 100 m were highest in the deepest sediment layer analysed, *i.e.* the layer at 15 - 20 cm depth, indicating that a substantial fraction of the discharged material is stored in the deeper sediment layers.

3. Qualitatively, the spatial distribution pattern of contaminants in the sediment around L4a is more or less the same as found in previous long-term studies at location P6b (erosion zone) and K12a (transition zone).

4. Clear evidence for persistent biological effects was obtained at the stations at ≤100 m from the platform by the significantly reduced abundances of 10 species, including those known as most sensitive to OBM contaminated sediment. The fauna composition at 100 m was different from that at remote stations (750 - 5000 m), but not impoverished.

5. At 250 m the fauna composition was also (but less) different from that at the remote stations.

6. Based on the above findings it is concluded that biological effects around an OBM platform in the sedimentation area of the Dutch Continental Shelf were still detectable 8 years after termination of the discharges of OBM contaminated drill cuttings. The extent of these effects was less than at location P6b (erosion zone, 6 years after discharge) and location K12a (transition zone, 8 years after discharge), which might be explained by the larger emissions at the latter locations.

SAMENVATTING EN CONCLUSIES

Sedert 1985 worden op het Nederlands Continentaal Plat veldstudies verricht naar de milieu-effekten van lozingen van boorgruis dat verontreinigd is met oliehoudende boorspoeling (OBM). Vanaf de invoering in 1993 van een verbod op lozingen van olie-houdend boorgruis is het onderzoek zich gaan concentreren op de lange-termijn effekten van voormalige lozingen. Veld-surveys werden uitgevoerd bij de platforms K12a (in de overgangszone tussen erosiegebied en sedimentatiegebied) en P6b (erosiegebied), respektievelijk 8 en 6 jaar nadat op deze lokaties voor het laatst OBM-houdend boorgruis was geloosd. De resultaten van deze surveys zijn in voorgaande rapporten gepubliceerd. In 1994 werd een survey uitgevoerd bij lokatie L4a in het sedimentatiegebied, waar 8 jaar geleden de laatste lozingen van oliehoudend boorgruis hadden plaatsgevonden. In dit rapport worden de resultaten van het lange-termijn onderzoek bij L4a gepresenteerd.

Op lokatie L4a zijn in totaal 6 boringen verricht, waarvan de laatste 2 (in 1986) met gebruikmaking van OBM. Vlak voordat deze boringen plaatsvonden is in mei 1986 een baseline survey uitgevoerd. Vervolgens zijn nog eens 3 surveys uitgevoerd teneinde de korte-termijn effekten van de lozingen op het bodemsysteem vast te stellen. De eerst vond plaats in september 1986 toen de boringen nog in volle gang waren, de tweede in februari 1987 (4 maanden na beëindiging van de boringen) en de derde in juni 1987 (8 maanden na de boringen). Tijdens deze surveys kon een zeer duidelijke gradient worden waargenomen van afnemende olie concentraties in het sediment met toenemende afstand tot het platform. Binnen een straal van 100 tot 250 m van de lokatie was het bodemsysteem in ernstige mate aangetast. Binnen deze zone werd een accumulatie van biologische effekten vastgesteld en de fauna bleek in aanzienlijke mate verarmd. Meer subtiele effekten echter konden tot op tenminste 500 m van het platform worden waargenomen. Deze effekten manifesteerden zich met name in het ontbreken of in verlaagde dichtheid voorkomen van enkele specifiek OBM-gevoelige soorten. De in 1994 uitgevoerde survey werd ondernomen om vast te stellen in hoeverre van dergelijke effekten bij L4a op de lange termijn nog sprake was en in hoeverre herstel van sedimentcondities en van de natuurlijke faunagemeenschap was opgetreden.

Bodembemonstering was hoofdzakelijk geconcentreerd op een aantal stations langs een raai in de reststroomrichting van L4a. De stations werden gekozen op afstanden varierend van 50 tot 5000 m van het platform. De bodemmonsters werden geanalyseerd op korrelgrootte-samenstelling, olie- en Bariumconcentraties en makrofaunasamenstelling. In dwarsstroomse en stroomopwaartse richting werden ook enkele stations bemonsterd. Van deze monsters vond slechts een beperkte fysisch-chemische analyse plaats en werden alleen de aantallen zeeëgels (*Echinocardium cordatum*, exemplaren ≥15 mm) in het veld geteld.

Uit de chemische analyses bleken in de reststroomrichting aanmerkelijk verhoogde olie-concentraties voor te komen tot op 100 m van het platform terwijl licht verhoogde concentraties werden gemeten tot op 500 m. De concentraties op 100 m waren lager dan in juni 1987, maar lagen op een vergelijkbaar niveau als in februari 1987. De degradatiesnelheid van olie in het sediment lijkt laag te zijn maar kan niet betrouwbaar gekwantificeerd worden als gevolg van de onregelmatige verspreiding van olie in het sediment. Duidelijk verhoogde Ba-concentraties werd gemeten tot op 250 m. Op 500 en 750 m afstand bleken de concentraties licht verhoogd t.o.v. natuurlijke achtergrondwaarden, waaruit kan worden afgeleid dat het voorkomen van restanten van het geloosde materiaal nog steeds aantoonbaar was tot op 750 m van de lokatie. Op 100 m werden verhoogde concentraties olie en Ba vastgesteld tot op tenminste 20 cm diep in het sediment. De hoogste concentraties werden gevonden in de diepste laag die geanalyseerd werd (15 - 20 cm), hetgeen erop wijst dat veel van het geloosde materiaal zich heeft opgehoopt in de diepere sedimentlagen, waar biodegradatie nauwelijks kan plaatsvinden.

Latente biologische effekten werden vastgesteld op afstanden ≤100 m van het platform. Een aantal soorten, waaronder de gevoelige indicatorsoorten *Echinocardium cordatum, Montacuta ferruginosa* en *Harpinia antennaria*, kwam binnen deze zone niet of ten opzichte van de stations op 750 - 5000 in significant lagere aantallen voor. Echter op community niveau wees slechts de geringe gelijkenis van de faunasamenstelling op het 100-m station met die op de verder afgelegen stations op de aanwezigheid van een effekt. Wat betreft soortenrijkdom, absolute fauna-abundantie en relatieve fauna-abundantie kon geen wezenlijk verschil met de overige stations worden gevonden. Blijkbaar was de faunasamenstelling op 100 m afwijkend van die op de verder afgelegen stations maar niet armer.

Op 250 m afstand kon de aanwezigheid van biologische effekten niet met zekerheid worden vastgesteld. De belangrijkste aanwijzing dat de benthische fauna hier nog steeds een effekt ondervond was dat de gelijkenis van de faunasamenstelling met die op de verder afgelegen stations (op basis van de Bray-Curtis similarity index) consekwent minder was dan de onderlinge gelijkenis binnen deze stations.

In vergelijking tot de situatie gedurende de eerste 8 maanden na beëindiging van de lozingen zijn er duidelijke tekenen van herstel van sedimentcondities, vooral in de zone 250 - 500 m van het platform. Ook op het 100-m station is de omvang van biologische effekten afgenomen. Waar in 1987 de soortenrijkdom en fauna-abundantie nog aanzienlijk verlaagd waren op 100 m, had de afwezigheid of het in verlaagde

dichtheden voorkomen van enkele gevoelige soorten niet een dergelijk op community niveau meetbaar effekt. De soortenrijkdom op 100 m was in 1994 zelfs hoger dan op enig station ten tijde van de baseline survey van 1986.

De resultaten en conclusies kunnen als volgt worden samengevat:

1. Aanzienlijk verhoogde olieconcentraties (tot 100 $mg \cdot kg^{-1}$ droog sediment) werden aangetroffen tot op 100 m (reststroomrichting) van het platform. Op 250 en 500 m waren de concentraties licht verhoogd ten opzichte van achtergrondniveau. Restanten van geloosd materiaal waren traceerbaar tot 750 m afstand op basis van verhoogde Ba-concentraties in het sediment.

2. Olie- en Ba-concentraties op 100 m waren het hoogst in de diepste sedimentlaag die geanalyseerd werd, *i.e.* de laag tussen 15 en 20 cm diep. Dit wijst erop dat een aanzienlijk deel van het geloosde materiaal nog aanwezig is in de diepere sedimentlagen.

3. In kwalitatieve zin was het ruimtelijke verspreidingspatroon van contaminanten in het sediment rond L4a min of meer gelijk aan wat eerder werd gevonden op de lokaties P6b (erosiezone) en K12a (overgangsgebied).

4. Het voorkomen van latente effekten kon met zekerheid worden vastgesteld tot op 100 m van het platform. Tien soorten, waaronder die welke bekend zijn als de meest gevoelige, kwamen binnen deze zone in signifikant verlaagde dichtheden voor. De faunasamenstelling op 100 m was afwijkend van die op veraf (750 - 5000 m) gelegen stations, maar niet verarmd.

5. Op 250 m was de fauna-samenstelling ook, maar minder afwijkend van die op de veraf gelegen stations.

6. Op basis van bovengenoemde resultaten kan geconcludeerd worden dat biologische effekten rond een platform in de sedimentatiezone van het Nederlands Continentaal Plat 8 jaar na de lozing van OBM-houdend boorgruis nog steeds konden worden aangetoond. De omvang van deze effekten was geringer dan op de lokaties P6b (erosiezone, 6 jaar na lozing) en K12a (overgangszone, 8 jaar na lozing), hetgeen in overeenstemming is met het feit dat op de laatste 2 lokaties zwaardere lozingen hadden plaatsgevonden.

1 INTRODUCTION

1.1 GENERAL PART

Oil based drilling mud's (OBM) have been extensively used during drilling activities in the North Sea in the 80's and the early 90's. Although drill cuttings from the wells bored generally passed one or more treatment facilities to separate mud from the cuttings before these were discharged, there were always substantial amounts of adhering residuals of base oil that reached the sea bed in this way. Concern about the environmental risk of these dumpings has led to benthic monitoring studies in all North Sea sectors. OBM are still in use but the extent of discharges has considerably decreased. Due to agreements between industry and national authorities or to national regulations, there are no longer discharges of OBM cuttings in the Norwegian, Danish, German and Dutch sectors since 1 January 1993 (ANONYMOUS, 1994). When wells are drilled with OBM at installations in these sectors, the drill cuttings are brought ashore for treatment and disposal. Only in the UK sector dumping of OBM cuttings is still going on, but various systems were developed to reduce the oil content of the material dumped. Cuttings are treated down to an oil content of 5-6% now before being discharged (ANONYMOUS, 1994).

With the termination of OBM cutting discharges, further investigations on the associated short-term effects have come to an end in the Dutch sector. However, in view of possible future clean-up measures for the seabed around abandoned well sites, the long-term effect of former OBM cutting discharges is still subject of interest.

Till now, studies on the long-term effects of OBM cutting discharges have been carried out at two locations on the Dutch Continental Shelf. At location K12a, in the transition zone between the sandy erosion area in the south and the sedimentation area in the north, a field survey was carried out in 1992, 8 years after dumping of OBM cuttings (DAAN & MULDER, 1993) and location P6b in the erosion area was investigated in 1993, 6 years after OBM cutting discharges at that site (DAAN & MULDER, 1994). Both studies indicated that there was a decrease in the spatial extent of pollution around the platforms and of associated biological effects. Clear signs of recovery were observed at 500 m from the platforms and beyond that distance. However, closer to the platforms oil concentrations were still elevated and particularly the deeper sediment layers (10-30 cm) appeared to be contaminated. Biological effects could still be detected up to 250 m and at both locations an accumulation of effects became manifest by a severely impoverished macrofauna. In other words, 6 to 8 years after discharges of OBM cuttings in the erosion zone and in the transition zone the persistent occurrence of environmental effects was established

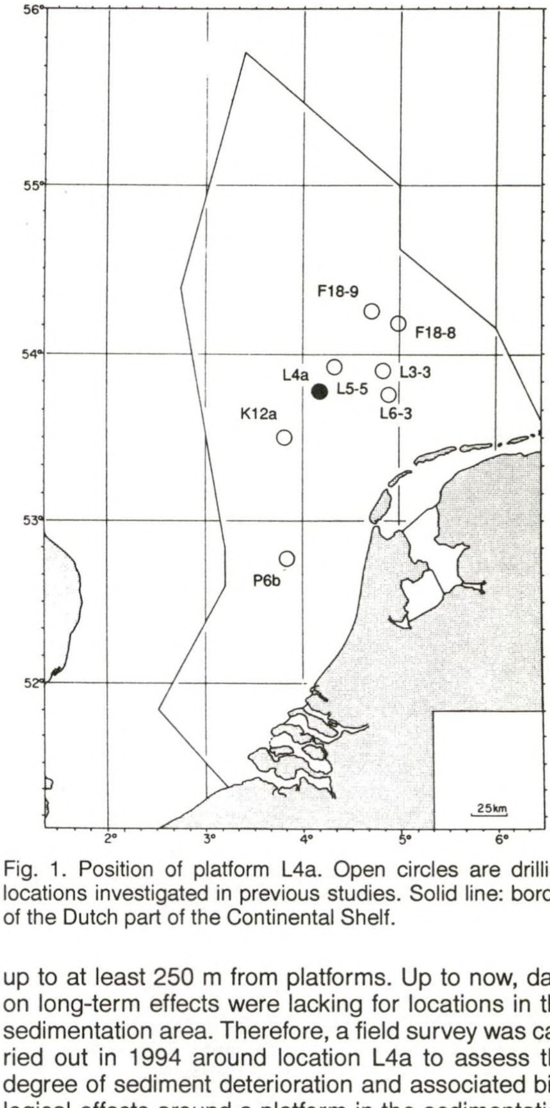

Fig. 1. Position of platform L4a. Open circles are drilling locations investigated in previous studies. Solid line: border of the Dutch part of the Continental Shelf.

up to at least 250 m from platforms. Up to now, data on long-term effects were lacking for locations in the sedimentation area. Therefore, a field survey was carried out in 1994 around location L4a to assess the degree of sediment deterioration and associated biological effects around a platform in the sedimentation area, in this case 8 years after OBM cuttings were dumped at this site. This report presents the results of this long-term effect study.

Platform L4a is situated in the Frisian Front area, in ± 40m waterdepth. The silt fraction (< 63 μm) of the sediment is about 15% (GROENEWOUD, 1991). At L4a 6 wells were drilled, 4 of them with WBM, but the last 2 wells were drilled with OBM based on low-tox oil (Table 1). These drillings took place during summer and autumn of 1986. All drill cuttings were discharged on the seabed.

Location L4a has already been subject of study in 1986 and 1987 to assess the short-term effects of the OBM cutting discharges. After a baseline survey in June 1986 (1 year after the last WBM drilling, but before OBM drilling started) the first survey took place in September 1986 when drilling of the 2 wells was

TABLE 1
Information on drilling location L4a.

position	53°43'31.5"N 04°05'56.2"E
area	transition zone; fine sand with silt (≈15%); depth 35 m
drilling activities	Jan. 1985-WBM drilling Aug.-Oct. 1986- OBM drilling
emission OBM drilling	178 tonnes of low-tox oil
platform	present

Former effect studies: Survey May 1986 (MULDER *et al.*, 1988; GROENEWOUD, 1991); Survey Sept. 1986 (MULDER *et al.*, 1988; GROENEWOUD, 1991); Survey Febr. 1987 (DAAN *et al.*, 1990; GROENEWOUD, 1991); Survey June 1987 DAAN *et al.*, 1990; GROENEWOUD, 1991).

still in progress (MULDER *et al.*, 1988). Another 2 surveys were carried out in February and June 1987, *i.e.* 4 and 8 months after completion of the wells respectively. The chemical analyses of these surveys revealed elevated oil concentrations in the sediment up to at least 500 m from the platform (residual current direction) with a conspicuous gradient in concentration levels (GROENEWOUD, 1991). The occurrence of biological effects appeared to correspond very well with this gradient in contamination levels (DAAN *et al.*, 1990). An accumulation of effects was detected up to 100 m from the location. However, the abundance patterns of a number of very sensitive species showed that subtle effects reached up to at least 500 m from the discharge site.

The present study, based on a field survey carried out in August 1994, aims to assess to what extent the short-term effects at L4a appeared to be persistent at the long-term, c.q. to detect possible recovery of the sediment conditions and the macrofauna community in the area.

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Ing. M. de Krieger (RWS, North Sea Directorate)
Ir. L. Henriquez (EZ, State Supervision of Mines)
Drs. P. Seeger (EZ)
Dr. D. Vethaak (RWS, RIKZ; from April 1994 onwards)
Drs. J.M. Marquenie (NOGEPA)
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Dr. R. Daan (NIOZ)

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TABLE 2
Schedule of analyses of the samples collected at L4a. Grainsize= analysis of grainsize distribution. Oil concentration= analysis of oil concentration in the sediment. Ba concentration= analysis of Ba concentration in the sediment. *E. cordatum*= on board countings of *Echinocardium cordatum*, specimens > 15 mm. Fauna analyses= complete fauna analysis (6 samples per station).

transect	*station distance*	*grainsize*	*oil concentration*	*Ba concentration*	*vert. profiles*	*E. cordatum*	*fauna analyses*
45°	50 m	X	X	X		X	
	100 m	2X	2X	2X	X	X	X
	250 m	2X	X	2X	X	X	X
	500 m	X	X	X		X	X
	750 m	X		X		X	X
	1000 m	X		X		X	X
	2000 m	X				X	X
	5000 m	X	X	X		X	X
135°	250 m	X		X		X	
	5000 m	X		X		X	
225°	250 m	X		X		X	
	5000 m	X		X		X	
315°	250 m	X		X		X	
	5000 m	X		X		X	

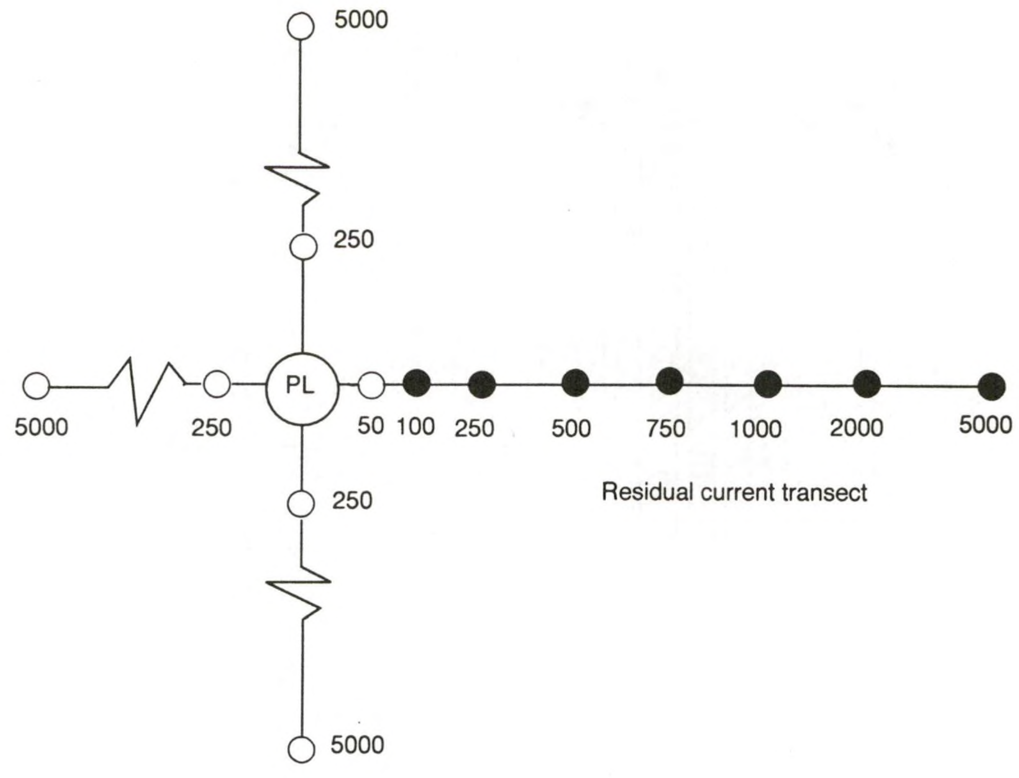

Fig. 2. Positions of the sampling stations along a cross-shaped transect. Solid circles: samples analysed for macrofauna.

ical and grainsize analyses were performed by IMW-TNO den Helder and are reported also separately (GROENEWOUD, 1995). J. van der Hoek sorted the samples. Thanks are also due to M. van Arkel for his organising helpfulness.

2 METHODS

2.1 SAMPLING

The survey at L4a was carried out in the 1st week of August 1994. Sampling stations were chosen along a cross-shaped transect, the main axis running parallel to the residual current direction (Fig. 2). The 100-m and 250-m stations in the residual current direction were approached twice and both times 5 grab samples (Van Veen grab, 0.2 m^2) were collected. At each of the other stations 10 samples were collected. From each sample small duplicate sediment cores (diameter 28 mm, depth 10 cm) were taken for chemical and grainsize analyses. The pooled sediment subsamples of each station were thoroughly homogenised and immediately frozen at -20° until later analysis in the laboratory. The contents of the grab were washed through a sieve (mesh size 1 mm). During sieving the numbers of *Echinocardium cordatum* (specimens ≥15 mm) were counted in 8 samples at each station. The remaining macrofauna was preserved in a 6% neutralized formaldehyde solution.

At the 100-m station an additional boxcore sample was collected to assess vertical profiles of oil and Ba concentrations in the sediment. Subsamples were taken from the sediment layers 0-2 cm, 2-10 cm and 15-20 cm and further treated in the same way as the routine sediment samples.

2.2. LABORATORY ANALYSES

In fact, field samples were collected in excess and not all samples were analysed. Table 2 gives an overview of the analyses that were applied to the samples of each station.

2.2.1 GRAINSIZE ANALYSIS

Grainsize analyses were performed to verify if the natural sediment composition is more or less homogeneous in the area investigated. The analytical procedures are described in detail by GROENEWOUD (1995).

2.2.2 BARIUM ANALYSIS

Barite is a substantial constituent of drilling muds. Because of its inertia Barite provides a good indicator for the dispersal of discharged material, in particular

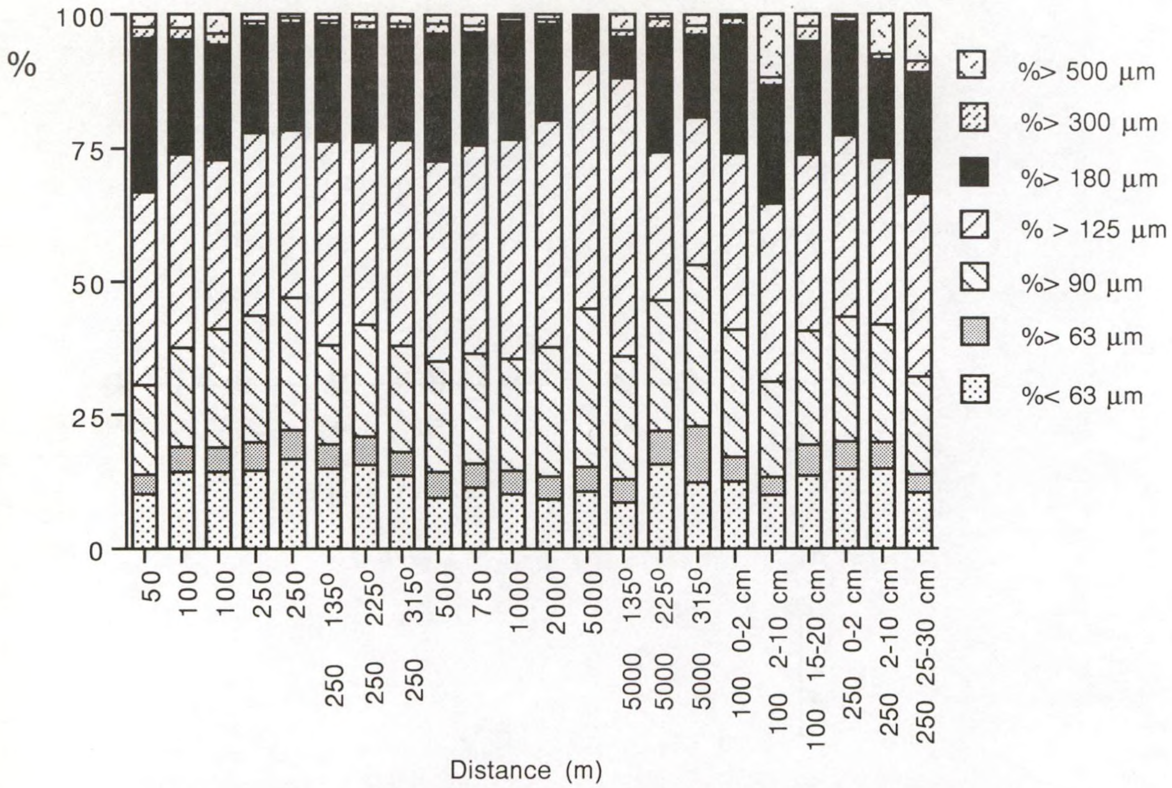

Fig. 3. Grainsize distribution along the different transects (data from GROENEWOUD, 1995).

of the smaller grain size fractions. The analytical procedure to measure Ba concentrations in the sediment are described in detail by GROENEWOUD (1995).

2.2.3 OIL ANALYSIS

Oil analyses of sediment samples were performed using the gas chromatograph mass spectrometer (GCMS) technique. Concentrations of alkanes (C_{10} - C_{30}), unidentified complex matter (UCM) and 'other components' were quantified. The analytical procedures are described in detail by GROENEWOUD (1995).

TABLE 3
Ba concentrations in the sediment around L4a, residual current transect (data from GROENEWOUD, 1994)

station	*Ba mg·kg^{-1} dry weight*
50 m	1800
100 m	1700
100 m	1300
250 m	285
250 m	310
500 m	110
750 m	95
1000 m	76
5000 m	50

2.2.4 FAUNA ANALYSIS

Macrofauna analyses were performed on 6 samples of each of 7 stations at the residual current transect. Routine methods of sorting and identification are described by MULDER *et al.* (1988).

2.2.5 STATISTICAL PROCEDURES

Possible shifts in the macrofauna community were tested by comparing the relative abundance of all identified species at each of the stations (ANOVA). This method is described in 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 also used in former studies and more details about its application are given in DAAN *et al.*, (1990). The method was used according to the improved procedure described by DAAN & MULDER (1994).

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

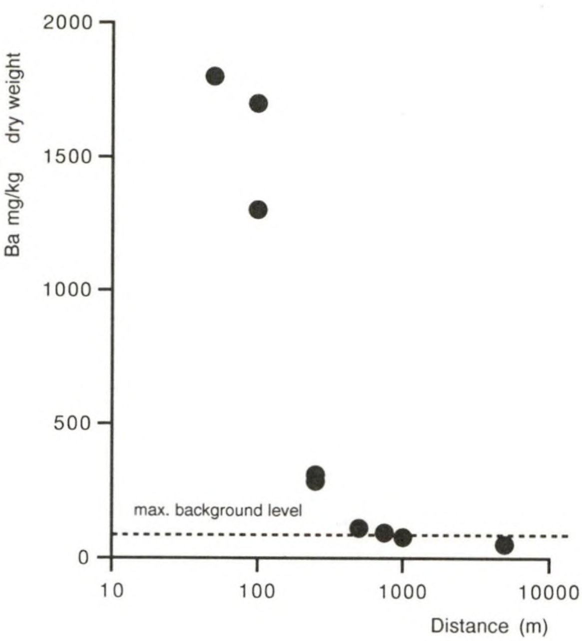

Fig. 4. Ba concentrations along the residual current transect at L4a (data from GROENEWOUD, 1994).

this index was found to reflect most accurately true similarity (BLOOM, 1981). The method was performed for squareroot transformed abundance data of the individual species to prevent that a few species would dominate the between station similarities (see GRAY *et al.*, 1988).

3 RESULTS

3.1 SEA BED CHARACTERISTICS

The sediment along the residual current transect consisted mainly of fine sand (fraction 63 -300 µm) mixed with 8 to 17% silt (fraction <63 µm, Fig. 3). The silt fraction at 100 m and 250 m was slightly higher than at the other stations, whereas the sand fraction tended to have a somewhat finer composition with increasing distance from the platform and particularly at 5000 m the fraction >180 µm was small. However, since the overall fine sand fraction (63 - 180 µm) varied within a narrow range (80 - 90%), the sediment composition seemed to be quite homogeneous in the area. Therefore, strong gradients in the natural fauna composition along the residual current transect should not be expected.

3.2 BARIUM CONCENTRATIONS IN THE SEDIMENT

The Ba concentrations in the sediment along the residual current transect are listed in Table 3. These concentrations are not corrected for natural background concentrations. GROENEWOUD & SCHOLTEN (1992) have shown that natural background concentrations are strongly related to the silt content of the sediment. According to the calibration line presented by DAAN & MULDER (1993) and taking into account that the silt fraction was 8 - 17% at L4a, natural background concentrations would be in the order of 30 - 80 mg·kg^{-1} dry sediment around the location. The table shows that at distances ≥1000 m the concentrations were at background level (see also Fig. 4). Clearly elevated concentrations occurred up to 250 m from the platform, whereas the concentrations were slightly beyond background level up to 750 m, which means that the presence of traces of the discharged material was still detectable up to this distance.

A vertical profile of Ba concentrations in the sediment at 100 m (Fig. 5) shows that the highest concentration was found in the deepest layer of the sediment core (15 - 20 cm), indicating that a substantial fraction of the discharged material is stored in the deeper sediment layers.

3.3 OIL CONCENTRATIONS IN THE SEDIMENT

Oil concentrations were determined at 5 stations along the residual current transect (Table 4, Fig. 6). Clearly elevated concentrations were found at 50 m and 100 m, but also at 250 m and 500 m the concentrations were still slightly elevated compared to usual background levels (≤3 mg·kg^{-1} dry sediment, see GROENEWOUD 1995). Surprisingly, the highest concentration was found at the 5000-m station. However, GROENEWOUD (1995) has argued that it is unlikely

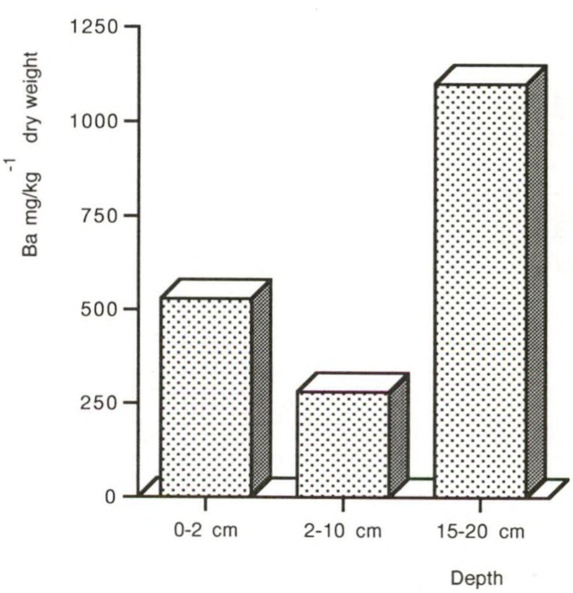

Fig. 5. Vertical profile of Ba concentrations in the sediment at 100 m (residual current transect, data from GROENEWOUD, 1995).

TABLE 4
Oil concentrations at some stations at the residual current transect (data from GROENEWOUD, 1994).

station		*oil conc. mg·kg^{-1} dry weight*
50 m		47.2
100 m		100.4
100 m		128.2
250 m		12.9
500 m		11.8
5000 m		198.4
	0-2 cm	10.3
100 m	2-10 cm	16.3
	15-20 cm	95.5

that the oil at this station originated from the OBM used at L4a because of the deviant composition. Particularly the fact that the chromatogram of the 5000-m sample showed an UCM hill ('UCM 2') at a different position than found in the usual oil fingerprint of the OBM used at L4a, supported the conclusion that the oil originated from another source of pollution. Traces of the oil type found at 5000-m, which was characterized by substantial fractions of higher alkanes and overall heavier components, also occurred in one of the 100-m samples. However, the chromatogram showed that oil from OBM contributed the major part of the total concentration in this sample.

A vertical profile of oil concentrations in a sediment core collected at the 100-m station shows that the highest concentration was found in the deepest layer

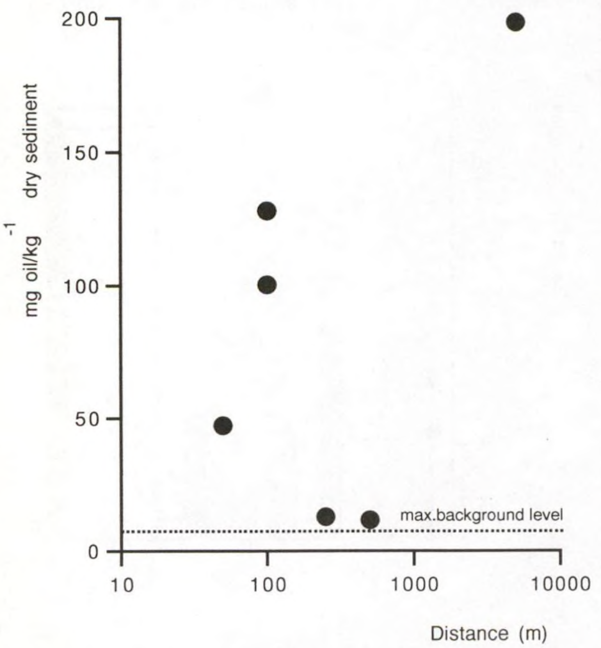

Fig. 6. Total oil concentrations along the residual current transect at L4a (data from GROENEWOUD, 1995).

of the core (15 - 20 cm, Fig. 7). The superficial sedimentlayer (0 - 10 cm) contained relatively low concentrations.

3.4 BIOLOGICAL FEATURES

3.4.1 FIELD OBSERVATIONS

The on board countings of *Echinocardium cordatum* revealed that large specimens (≥15 mm) were almost absent up to 100 m from the location, with the exception of 1 specimen at 50 m (Fig. 8). At all other stations, including those in upstream and perpendicular directions, the species occurred in 3 or more samples. Densities ranged between 2.8 and 28 ind·m^{-2}. Logit regression confirmed that there was a highly significant (0.1% level) relation between frequency of occurrence of *E. cordatum* in the samples and distance to the platform. The data suggest that the species was affected in its abundance up to at least 100 m, but not further than 250 m.

3.4.2 GENERAL FAUNA DESCRIPTION

The laboratory analyses yielded 116 identified species. In Table 5 their percentual occurrence in the samples is summarized. The original data are listed in Table 11 (Appendix). The fauna in the area was numerically dominated by the echinoderm *Amphiura filiformis* and the bivalve *Mysella bidentata*, which usually lives associated with *A. filiformis*. Together these species accounted for 64% of the total fauna abundance. Although both species have been identified as sensitive to OBM contamination of sediments (DAAN *et al.*, 1994), the abundance data do not suggest any tendency for decreasing densities on

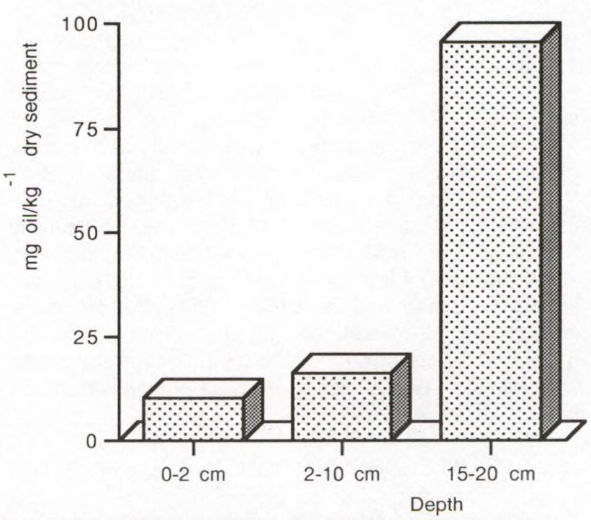

Fig. 7. Vertical profile of oil concentrations in the sediment at 100 m (residual current transect, data from GROENEWOUD, 1995).

TABLE 5

The benthic fauna at L4a, July 1994. Percentage of occurrence of each species in the total number of samples (42).

POLYCHAETA		*Mediomastus gracilis*	19	*Ebalia tuberosa*	2
		Notomastus latericeus	76	*Corystes cassivelaunus*	60
Aphrodita aculeata	10	*Owenia fusiformis*	50	*Macropodia rostrata*	2
Harmothoe lunulata	36	*Lanice conchilega*	38	*Upogebia stellata*	36
Harmothoe longisetis	19	*Polycirrus medusa*	2	*Upogebia deltaura*	64
Gattyana cirrosa	60	*Lagis koreni*	100	*Upogebia* spec. juv.	31
Sigalion mathildae	2	*Pectinaria auricoma*	57	*Callianassa subterranea*	100
Pholoe minuta	100	*Ampharete finmarchica*	2	*Decapoda larven*	50
Sthenelais limicola	60	*Sosane gracilis*	5	*Nebalia bipes*	10
Eteone longa	12	*Lysilla loveni*	2	*Mysiden larven*	5
Eteone lactea	5	*Terebellides stroemi*	17	*Eudorella truncatula*	10
Mysta picta	5			*Diastylis bradyi*	57
Mysta barbata	2	**MOLLUSCA**		*Eurydice spinigera*	2
Anaitides groenlandica	29			*Cirolana borealis*	64
Anaitides maculata	21	*Nucula turgida*	50	*Ione thoracica*	24
Anaitides spec. juv.	2	*Mytilus edulis*	7	*Melita obtusata*	2
Eumida sanguinea	10	*Thyasira flexuosa*	2	*Orchomenella nana*	14
Ophiodromus flexuosus	67	*Lepton squamosum*	12	*Leucothoe incisa*	29
Gyptis capensis	40	*Montacuta ferruginosa*	29	*Ampelisca brevicornis*	29
Synelmis klatti	21	*Mysella bidentata*	100	*Ampelisca tenuicornis*	60
Exogone hebes	10	*Acanthocardia echinata*	24	*Urothoe poseidonis*	50
Nereis longissima	43	*Dosinia lupinus*	26	*Bathyporeia elegans*	2
Nereis spec. juv.	2	*Venus striatula*	10	*Harpinia antennaria*	88
Nephtys hombergii	86	*Venus verrucosa*	12	*Harpinia pectinata*	2
Nephtys caeca	12	*Venus* spec. juv.	2	*Perioculodes longimanus*	36
Nephtys longosetosa	2	*Mysia undata*	5	*Synchelidium haplocheles*	2
Nephtys spec. juv.	45	*Tellina* spec. juv.	2	*Aora typica*	2
Glycera alba	5	*Abra alba*	7	*Lembos longipes*	7
Glycera spec. juv.	24	*Abra alba* juv.	74		
Glycinde nordmanni	12	*Gari fervensis*	36	**ECHINODERMATA**	
Goniada maculata	50	*Cultellus pellucidus*	33		
Lumbrineris latreilli	100	*Mya truncata*	5	*Astropecten irregularis*	5
Lumbrineris fragilis	45	*Corbula gibba*	24	*Amphiura filiformis*	100
Driloneris filum	5	*Thracia convexa*	26	*Amphiura chiajei*	71
Orbinia sertulata	24	*Thracia* spec. juv.	2	*Ophiura* spec. juv.	29
Paraonis fulgens	5	*Onoba vitrea*	79	*Echinocardium cordatum*	60
Poecilochaetus serpens	12	*Turritella communis*	43	*Echinocardium cordatum* juv.	52
Spio filicornis	98	*Natica catena*	2	*Cucumaria elongata*	38
Polydora pulchra	2	*Natica alderi*	7	*Cucumaria frondosa*	26
Polydora guillei	55	*Aporrhais pespelecari*	5		
Spiophanes kroyeri	21	*Cylichna cilindracea*	86	**OTHER TAXA**	
Spiophanes bombyx	95	*Philine catena*	2		
Magelona papillicornis	5			Nemertinea	100
Magelona alleni	21	**CRUSTACEA**		Turbellaria	60
Chaetopterus variopedatus	55			Phoroniden	95
Tharyx marioni	14	*Processa parva*	62	Harp. copepoda	5
Chaetozone setosa	36	*Pontophilus trispinosus*	2	Oligochaeta	5
Diplocirrus glaucus	40	*Pagurus bernhardus*	7	Echiurida	31
Scalibregma inflatum	93	*Macropipus holsatus*	2	Sipunculida	95
Ophelina acuminata	95	*Macropipus* spec. juv.	52	Anthozoa	14
Capitella capitata	21	*Ebalia cranchii*	2	Ascidiacea	2

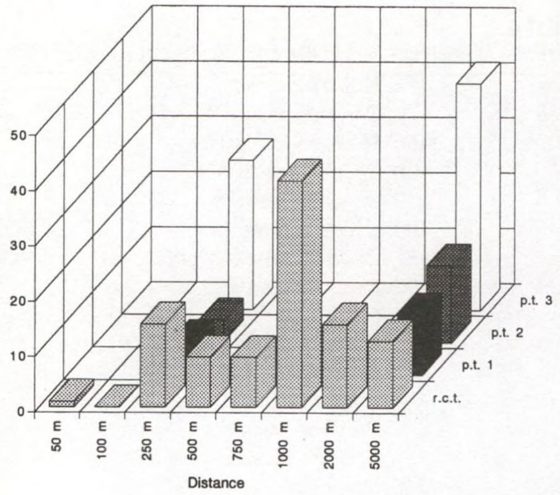

Fig. 8. Abundance of *Echinocardium cordatum* (specimens >15 mm) around L4a.

approach of the platform. In fact the highest numbers were found at 100 m and 250 m (Table 11). Nevertheless, during fieldwork the impression was that the abundance of *A. filiformis* was clearly depressed at 50 m from the platform (samples not analysed). Probably the species was affected in its abundance only in a very limited zone within 100 m from the platform.

There was considerable variation in the total fauna abundance between the stations investigated (Fig. 9). The highest numbers of individuals were found at 100 m and 250 m, the lowest numbers at 500 m and 2000 m. Although the variation is largely due to variable numbers of the dominant species *A. filiformis* and *M. bidentata* at the different stations, the fauna densities were still highest at 100 m and 250 m when these species are excluded from the calculation. Inspection of the data shows that a number of abundant (≥10 ind·m^{-2}) polychaetes (*Pholoe minuta, Lumbrineris latreilli, Spiophanes bombyx, Scalibregma inflatum, Notomastus latericeus* and *Pectinaria auricoma*) reached their highest densities particularly at these stations.

The numbers of species found at each of the stations ranged between 68 and 76 (Fig. 10). The mean number was 72, which is somewhat higher than during the baseline survey of 1986 when the mean number of species was 67 (in the same number of samples per station). The number of species per station does not show a spatial gradient that is related to distance from platform. Also the mean number of species per sample does not suggest the presence of an unequivocal trend (Fig. 11). Analysis of variance revealed that there were no significant differences in the numbers of species per sample between the different stations. At all stations the numbers were equal to or higher than in the baseline situation. In contrast, the survey of June 1987 (8 months after termination of the discharges) revealed numbers of species per sample that were equal to or higher than during the baseline only at distances ≥500 m, but lower at distances ≤250 m.

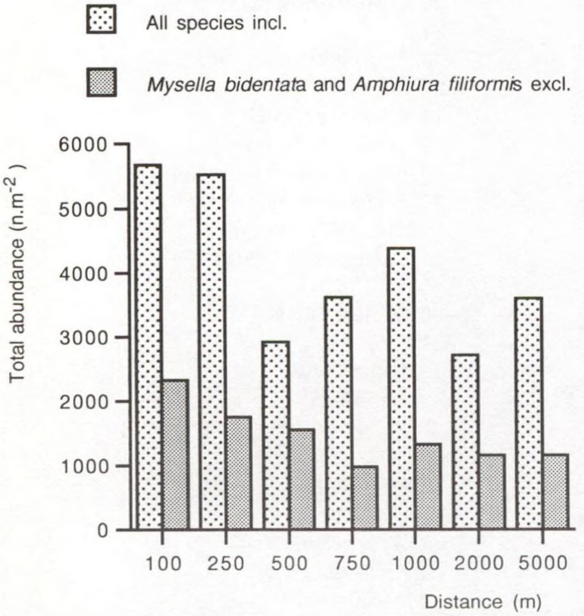

Fig. 9. Total macrofauna abundance at L4a (residual current transect).

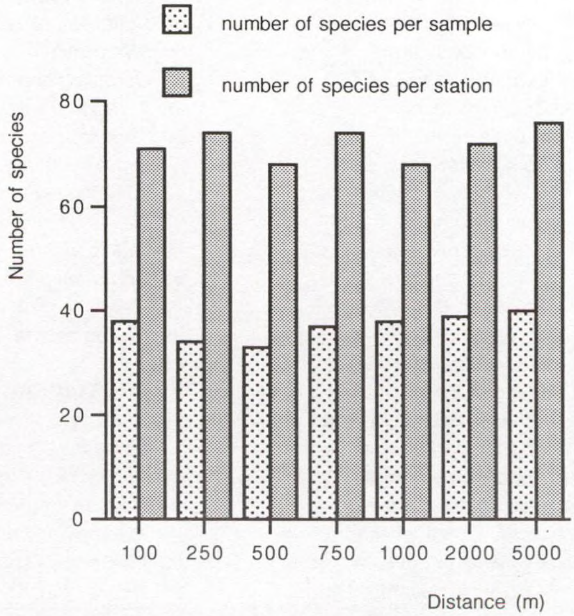

Fig. 10. Number of identified species per station and per sample along the residual current transect.

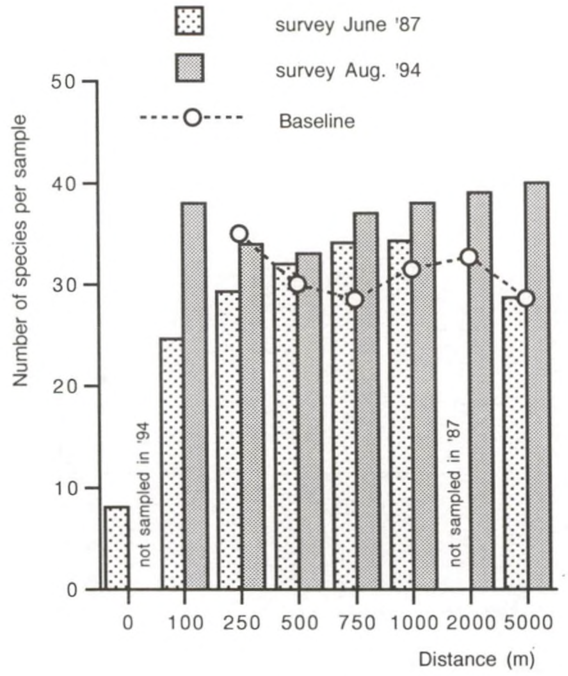

Fig. 11. Number of identified species per sample at L4a (residual current transect, post-drilling surveys 1987 and 1994 and baseline survey 1986).

3.4.3 PRESENCE-ABSENCE DATA: LOGIT REGRESSION

Possible gradients in the spatial abundance patterns of 46 individual species were tested by logit regression. Among these species there were 16 which showed a significant (5% level) gradient in their spatial frequency of occurrence, according to the uncorrected test (Table 6). The majority of these species occurred less frequently in the samples close to the platform than at the remote stations (slope of the gradient positive). In only 4 species the slope of the gradient was negative. After correction for overdispersion in the data, 10 species still showed a significant gradient. The slope of these gradients was positive for 9 species and negative for only one species. The number of rejections of H_0 (*i.e.* the frequency of occurrence is not dependent on distance to the platform) is higher than should expected if H_0 were true for all species. This implies that the probability that the 10 rejections of H_0 were all statistical Type-1 errors is less than 5%. The fact that most of the species listed occurred more frequently away from the location clearly indicates that these species still experience adverse effects of sediment contamination in the vicinity of the platform.

TABLE 6

List of species showing significant gradients in frequency of occurrence (logit regression). Sign of the gradient (+/-) and significance level are indicated:
+= increasing frequency of occurrence away from the location;
-= decreasing frequency of occurrence away from the location.

		sign. level (%)	
	sign	*uncorr. test*	*corr. test*
Sthenelais limicola	+	0.5	5
Ophiodromus flexuosus	+	5	1
Lumbrineris fragilis	-	5	n.s.
Diplocirrus glaucus	-	5	n.s.
Notomastus latericeus	-	0.1	0.1
Owenia fusiformis	+	5	5
Lanice conchilega	+	0.5	n.s.
Pectinaria auricoma	-	1	n.s.
Gari fervensis	+	1	5
Cylichna cilindracea	+	0.5	5
Corystes cassivelaunus	+	0.5	0.1
Upogebia deltaura	+	5	n.s.
Urothoe poseidonis	+	0.1	5
Harpinia antennaria	+	5	5
Amphiura chiajei	-	n.s	n.s.
Echinocardium cordatum adult	+	0.1	0.1.
Echinocardium cordatum juv.	+	0.1	n.s.

3.4.4 RELATIVE MACROFAUNA ABUNDANCE

In Fig. 12 a plot is given of the relative macrofauna abundance, calculated as the mean rank of each station for all identified species. The figure shows that the mean rank is close to 4 for all stations. Although at 500 m most species seemed to occur in somewhat lower numbers than at the other stations, there appeared to be no significant (5% level) difference in the relative abundance of the 7 stations (ANOVA).

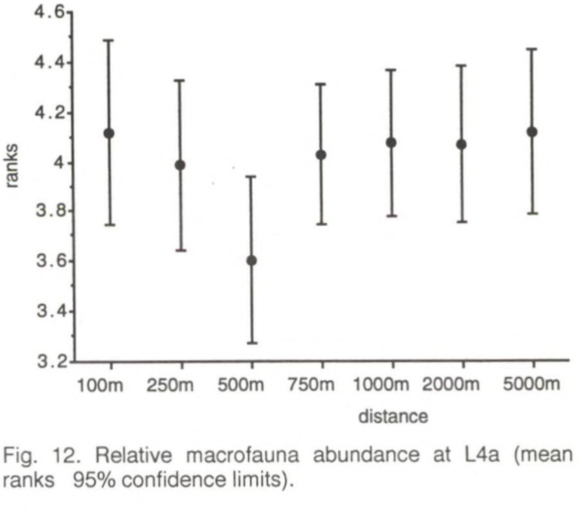

Fig. 12. Relative macrofauna abundance at L4a (mean ranks 95% confidence limits).

3.4.5 ABUNDANCE PATTERNS OF OBM-SENSITIVE SPECIES AND OPPORTUNISTIC SPECIES

The most sensitive indications for the persistent presence of biological affects may be obtained from the abundance patterns of species that in earlier studies have shown a consistent response to OBM cutting discharges. A list of 15 such species has been presented by DAAN *et al.* (1994). Table 7 shows to what extent the distribution patterns of these species showed abundance gradients that could be explained by gradients of stress. In the table the species are arranged according to decreasing evidence of sensitivity (or from 'very sensitive' to 'slightly sensitive'). There were 5 species that were absent or occurred in reduced abundance at 100 m. Among these species *Echinocardium cordatum, Montacuta ferruginosa* and *Harpinia antennaria* have been identified as the most sensitive indicators of environmental stress. It does not seem reasonable therefore, that their absence could be interpreted as a local minimum falling within the natural abundance variation of these species in the area. Moreover, since logit regression revealed significant gradients in the frequency of occurrence of these species in the samples (Table 6) and oil concentrations were still substantially elevated in the vicinity of the platform, their absence should be explained undoubtedly as a long-term effect of the former discharges. In the case of *E. cordatum,* the spatial gradient was not restricted to adults. Fig. 13

TABLE 7

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

	tendency
Echinocardium cordatum	+
Montacuta ferruginosa	+
Harpinia antennaria	+
Callianassa subterranea	0
Owenia fusiformis	0
Mysella bidentata	0
Gattyana cirrosa	+
Amphiura filiformis	0
Cylichna cilindracea	+
Nucula turgida	0
Chaetozone setosa	-
Glycinde nordmanni	0 (?)
Nephtys hombergii	0
Pholoe minuta	-
Scalibregma inflatum	-

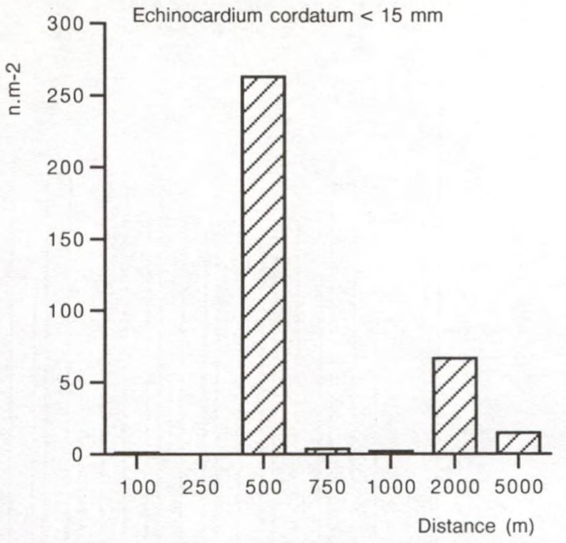

Fig. 13. Abundance pattern of juvenile *Echinocardium cordatum* along the residual current transect.

shows that also juveniles were almost absent at the 2 innermost stations, whereas juveniles did occur at all other stations albeit in highly variable numbers. Of the other species, only the polychaete *Gattyana cirrosa* and the bivalve *Cylichna cilindracea* showed abundance patterns that were more or less indicative of a persistent effect at the innermost station. On the other hand, there were 3 polychaete species, known as 'slightly sensitive', that were found in high numbers particularly at the 100-m station. Apparently these species did no longer experience adverse effects of the former discharges. However, a comparison with the survey of June 1987 learns that these species occurred already in unaffected densities at 100 m during that survey. In 1987 their abundance was only clearly reduced at a distance of ≈25 m from the platform, a station not sampled during the present survey.

A few specimens of the opportunistic species *Capitella capitata* were found at 4 stations between 100 m and 1000 m from the location. This may seem remarkable because, as yet, colonisation by this species around OBM locations was observed only at the short term, but around locations K12a and P6b the species was no longer found at the longer term (DAAN & MULDER, 1993, 1994). In view of the low numbers that were found and the absence of a clear gradient there seems to be no sufficient reason to explain the occurrence of *C. capitata* by the latent presence of oil in the sediment.

3.4.6 SIMILARITIES BETWEEN STATIONS

A triangular matrix was composed for between-station similarities on the basis of the Bray-Curtis index for percentage similarity (Table 8). There appeared to be very high (>80%) similarity on the one hand between the stations in the zone 750 - 5000 m and on the other hand between the 100-m and 250-m stations. On approach of the platform the differences in fauna composition with the 5000-m reference station increased and the 100-m station obviously had the lowest resemblance to the outermost stations.

TABLE 8

Bray-Curtis similarity between stations calculated after squareroot transformation of the data.

	250	*500*	*750*	*1000*	*2000*	*5000*
100	81	60	70	68	61	64
250		66	75	75	67	71
500			72	73	76	71
750				83	81	81
1000					80	81
2000						82

4 DISCUSSION

The presence of residuals of the discharged material could be traced by elevated Ba concentrations up to 750 m from the platform. The marked gradient in concentration levels (Fig. 4) suggests that the material can be found for the greater part within a radius of ≈250 m from the platform. Although the concentrations up to 500 m were lower than in June 1987 (GROENEWOUD, 1995), there is no convincing evidence that a substantial part of the material has spread out over a wider area. In fact the concentration at 100 m was at a similar level as in February 1987. It seems likely therefore that the between-survey differences in concentration levels should be largely explained by the patchy distribution of the material. The observation that the highest Ba concentrations at 100 m were determined in the deeper sediment layers also suggests that horizontal redistribution at the longer term is only of limited extent. Qualitatively the spatial distribution of oil concentrations was more or less similar to that of Ba, except for the relatively low concentration at 50 m. Like found for Ba, the oil concentrations at 100 m were substantially lower than in June 1987, but at a similar level as found in February 1987. The observation that the highest concentrations were observed also in the deepest sediment layer analysed (15 - 20 cm), where anaerobic conditions prevent bacterial degradation, also suggests that the rate of degradation of the oil at the longer term is very low. Although contamination levels seem to have decreased particularly in the superficial sediment layers (GROENEWOUD, 1995), a reliable estimate of the overall degradation rate can not be given quantitatively, because of the extremely patchy distribution of the material in the sediment and possible coverage of the material by new clean sediments.

A comparison of the spatial distribution of oil concentrations at L4a, 8 years after discharges, with the situation at K12a, also 8 years after discharges, and P6b, 6 years after discharges, learns that the overall pattern is more or less the same at the 3 locations: significantly elevated contamination levels within ≈250 m, whereas the concentrations drop to trace level between 250 and 500 m. Although at P6b (288 tonnes of oil discharged) the chemical analyses actually did not show elevated concentrations at 250 m, the presence of traces of oil was visually observed during the fieldwork at this station (DAAN & MULDER, 1994). At K12a the concentrations at 100 m were substantially higher than at L4a and P6b, which is easily explained by the larger amount of oil discharged at K12a (393 tonnes).

Clear evidence for the presence of persistent effects on the benthic community was only obtained at the 100-m station, where a number of species occurred in significantly reduced abundance compared to the stations at larger distance. Particularly the fact that among these species were those which have been identified as most sensitive to OBM contamination (*i.e.* adult *Echinocardium cordatum, Montacuta ferruginosa* and *Harpinia antennaria*, DAAN *et al.*, 1994) indicates that oil in the sediment was still a source of adverse effects on the benthos. Nevertheless, on the community level the presence of such effects was only indicated by the relatively low similarity between the 100-m station and the remote stations. In terms of reduced species richness, total fauna abundance or relative fauna abundance no effect could be demonstrated. Apparently the fauna composition at 100 m was different from that at the remote station but not impoverished.

For the 250-m station it is less clear whether the benthic community was still affected or not. On the one hand, 6 of the species for which significant gradients were detected seemed to occur in reduced abundance not only at 100 m but also at 250 m. On the other hand, these species were not particularly those known as most sensitive to OBM contamination. In this respect it is worth mentioning that, although juvenile *E. cordatum* were absent at 250 m, adults were found in reasonable numbers at this station. In view of the size of the animals in the samples (30 - 40 mm) and known growth rates of the species (DUINEVELD & JENNESS, 1984) this would imply that these individuals had managed to survive a period of ≈4 years preceding the moment of sampling, indicating that the slightly elevated contamination levels at 250 m did no longer substantially affect the species' local density. Still there was another slight indication of a persistent effect in the sense that the fauna composition at 250 m seemed to be somewhat different from the remote stations. Based on the between station Bray-Curtis similarities the 250-m station showed high similarity with the 100-m station, but resemblance with the stations at 750 - 5000 m was consistently lower than the mutual resemblance within these stations. This might indicate that the fauna composition at this station was still somewhat different from the natural one. Such a difference might be explained as a result of the former discharges, but a possible difference in the intensity of beamtrawling activities within a radius of 500 m and outside that zone can not be excluded as an additional factor. In principle, fishing boats are not allowed to enter the zone within 500 m from a platform. On the other hand this does not guarantee that fishing boats always comply to this rule. It is not clear therefore if fishing activities are in fact consistently less intensive in the vicinity of platforms.

Compared to the situation during the survey of June 1987, carried out 8 months after termination of the discharges, there are clear signs of recovery of sediment conditions, particularly in the zone 250 - 500 m from the platform. Although no drastic decrease of contamination levels was established, in 1987 at least 5 OBM sensitive species were found to be affected in their abundance up to 500 m from the location, whereas such clear evidence for reduced abundances was found only at 100 m in 1994. Also at the 100-m station the extent of biological effects has decreased. Whereas in 1987 more than 50% of the more or less abundant species occurred in reduced abundance at this station and species richness and total fauna abundance were substantially depressed, the absence or reduced abundance of a few sensitive species as observed during the 1994 survey was not reflected in such adverse effects at the community level. On the contrary, the species richness at 100 m was higher than at any of the stations sampled during the baseline survey.

A detailed comparison of the 1987 and 1994 data on species level is hampered by the relatively large year to year fluctuations that can naturally occur in the abundances of individual species and, therefore, in the composition of the benthic community (RACHOR & GERLACH, 1978; ZIEGELMEIER, 1978; DAAN & MULDER, 1994; DAAN *et al.*,1995). Since the majority of benthic infauna species have a life-span that is probably ≤ 1 year the differences between years should most likely be explained by differences in settlement and survival of new generations. However, it is remarkable that of the species tested on the basis of logit regression (uncorrected test) the percentage found to show a significant gradient was about the same in 1994 as in 1987 (35 and 34% respectively). Except for *Harpinia antennaria* and *Owenia fusiformis* the majority of species that displayed such a gradient in 1994 were others than those displaying a gradient in 1987. In other words, the number of species significantly affected in their abundance in the vicinity of the location was at the long term the same as at the short term, but the distance over which they were affected had substantially decreased at the longer term.

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Appendix

Table 9 . Grainsize distribution of the sediment at L4a (data from Groenewoud, 1994).

Distance (m)	%< 63 µm	%> 63µm	%> 90 µm	%> 125 µm	%> 180 µm	%> 300 µm	%> 500 µm
50	10.22	3.54	16.81	36.2	28.82	2.04	2.37
100	14.28	4.77	18.58	36.19	21.51	2.22	2.45
100	14.27	4.58	22.22	31.72	21.54	2.09	3.58
250	14.54	5.35	23.74	34.18	20.04	0.83	1.33
250	16.68	5.45	24.89	31.31	20.04	1	0.63
250 135°	14.89	4.55	18.58	38.22	21.7	0.95	1.11
250 225°	15.62	5.36	20.89	34.34	20.94	1.29	1.57
250 315°	13.58	4.43	19.94	38.55	20.82	0.9	1.78
500	9.44	4.87	20.7	37.52	23.9	1.86	1.7
750	11.41	4.42	20.63	39.13	21.07	1.27	2.06
1000	10.19	4.41	20.89	41.16	22.04	0.71	0.6
2000	9.29	4.15	24.3	42.5	18.05	0.75	0.97
5000	10.69	4.52	29.77	44.87	9.02	0.63	0.49
5000 135°	8.66	4.35	23.05	52.03	7.76	1.14	3.01
5000 225°	15.8	6.24	24.45	27.75	23.16	1.77	0.85
5000 315°	12.36	10.47	30.3	27.64	15.37	1.69	2.16
100 0-2 cm	12.47	4.6	23.94	33	23.97	1.39	0.62
100 2-10 cm	9.96	3.34	17.91	33.41	22.22	1.36	11.8
100 15-20 cm	13.58	5.83	21.28	33.01	21.28	2.83	2.19
250 0-2 cm	14.81	5.15	23.39	34.03	21.22	0.96	0.42
250 2-10 cm	14.94	4.87	22.05	31.28	18.51	0.92	7.43
250 25-30 cm	10.46	3.32	18.41	34.2	22.79	2.11	8.71

Table 10. Concentrations of oil components at L4a (mg/kg dry sedimemnt), data from Groenewoud, 1994).

Station	50 m	100 m	100 m	250 m	500 m	5000 m	100 m		
							0-2 cm	2-10 cm	15-20 cm
Component									
C10	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C11	0.03	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.05
Naphtalene	0.18	0.47	0.31	0.01	0.01	0.01	0.01	0.02	0.38
C12	0.18	0.38	0.24	0.06	0.01	0.02	0.02	0.06	0.33
C13	0.13	0.65	0.41	0.01	0.01	0.01	0.01	0.07	0.3
C14	0.16	0.31	0.22	0.13	0.02	0.03	0.01	0.03	0.27
C15	0.03	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02
C16	0.09	0.08	0.06	0.05	0.05	0.1	0.03	0.05	0.04
C17	0.13	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Pristane	0.01	0.01	0.07	0.01	0.15	0.01	0.01	0.01	0.01
C18	0.01	0.08	0.01	0.01	0.01	0.01	0.01	0.01	0.06
Phytane	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C19	0.51	0.73	0.55	0.48	0.43	0.68	0.55	0.87	0.59
C20	0.15	0.25	0.31	0.23	0.11	0.91	0.11	0.1	0.26
C21	0.11	0.35	0.31	0.56	0.09	0.62	0.22	0.16	0.4
C22	0.05	0.03	0.05	0.03	0.02	0.63	0.03	0.03	0.03
C23	0.02	0.01	0.05	0.07	0.05	0.01	0.04	0.07	0.08
C24	0.03	0.9	1.21	0.07	0.1	1.25	0.02	0.04	0.02
C26	0.04	0.16	5.58	0.11	0.03	2.41	0.03	0.11	0.04
C27	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04
C28	0.06	0.06	5.59	0.08	0.05	3.04	0.16	0.08	0.05
C29	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01
C30	0.07	0.01	1.64	0.06	0.01	0.25	0.19	0.01	0.02
C32	0.04	0.01	0.29	0.01	0.01	0.31	0.17	0.01	0.01
Sum C10-C32	2.11	4.62	16.99	2.05	1.23	10.4	1.7	1.8	3.04
Other	12.7	20.2	29.6	8.11	8.4	97.8	6.3	8.1	15.9
UCM 1	32.4	75.6	52.6	2.7	2.2	2.2	2.3	6.4	76.6
UCM 2	0	0	29	0	0	88	0	0	0
Total oil	47.21	100.4	128.2	12.68	11.83	198.4	10.3	16.3	95.54

Table 11. Data platform L4a, survey July 1994, residual current transect.
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)	100	250	500	750	1000	2000	5000
Number of analysed samples	6	6	6	6	6	6	6
POLYCHAETA							
Aphrodita aculeata		0.9 (1)	0.9 (1)		2.8 (2)		
Harmothoe lunulata	2.8 (2)	2.8 (2)	4.6 (3)	1.9 (2)	3.7 (2)	4.6 (4)	
Harmothoe longisetis	2.8 (3)	0.9 (1)	1.9 (1)	0.9 (1)		0.9 (1)	0.9 (1)
Gattyana cirrosa	0.9 (1)	5.6 (4)	2.8 (3)	11.1 (4)	10.2 (4)	12.0 (5)	8.3 (4)
Sigalion mathildae							0.9 (1)
Pholoe minuta	120.5 (6)	69.5 (6)	29.7 (6)	50.0 (6)	57.5 (6)	36.1 (6)	41.7 (6)
Sthenelais limicola		1.9 (2)	7.4 (4)	9.3 (5)	9.3 (5)	7.4 (5)	8.3 (4)
Eteone longa	0.9 (1)		6.5 (4)				
Eteone lactea	1.9 (2)						
Mysta picta							1.9 (2)
Mysta barbata		0.9 (1)					
Anaitides groenlandica		0.9 (1)	14.8 (5)	3.7 (3)	1.9 (2)	0.9 (1)	
Anaitides maculata					3.7 (4)	2.8 (3)	1.9 (2)
Anaitides spec. juv.							0.9 (1)
Eumida sanguinea	1.9 (2)	0.9 (1)		0.9 (1)			
Ophiodromus flexuosus	5.6 (3)	2.8 (2)	3.7 (3)	10.2 (5)	10.2 (5)	17.6 (5)	10.2 (5)
Gyptis capensis	2.8 (2)	1.9 (2)	0.9 (1)	1.9 (2)	1.9 (2)	4.6 (3)	5.6 (5)
Synelmis klatti	0.9 (1)	0.9 (1)	2.8 (3)	1.9 (1)	1.9 (2)		0.9 (1)
Exogone hebes	0.9 (1)	1.9 (1)			1.9 (1)	0.9 (1)	
Nereis longissima	5.6 (3)	3.7 (4)	10.2 (4)	2.8 (1)		2.8 (3)	2.8 (3)
Nereis spec. juv.				0.9 (1)			
Nephtys hombergii	11.1 (5)	7.4 (5)	12.0 (6)	2.8 (2)	17.6 (6)	12.0 (6)	10.2 (6)
Nephtys caeca	0.9 (1)	1.9 (2)	0.9 (1)	0.9 (1)			
Nephtys longosetosa		1.9 (1)					
Nephtys spec. juv.	3.7 (3)	5.6 (3)	2.8 (3)	7.4 (3)	2.8 (2)	5.6 (3)	7.4 (2)
Glycera alba		3.7 (1)			0.9 (1)		
Glycera spec. juv.	5.6 (3)	1.9 (2)		3.7 (3)		1.9 (2)	
Glycinde nordmanni	1.9 (1)	0.9 (1)	2.8 (2)		0.9 (1)		
Goniada maculata	19.5 (6)	7.4 (3)	0.9 (1)	5.6 (2)	4.6 (4)	1.9 (2)	3.7 (3)
Lumbrineris latreilli	810.8 (6)	310.4 (6)	108.4 (6)	91.7 (6)	147.3 (6)	127.0 (6)	160.3 (6)
Lumbrineris fragilis	10.2 (6)	11.1 (3)	1.9 (1)	8.3 (4)	2.8 (2)		3.7 (3)
Driloneris filum				0.9 (1)	0.9 (1)		
Orbinia sertulata	1.9 (2)	2.8 (3)	1.9 (2)	0.9 (1)		0.9 (1)	0.9 (1)
Paraonis fulgens				0.9 (1)	0.9 (1)		
Poecilochaetus serpens				0.9 (1)		3.7 (4)	
Spio filicornis	38.9 (6)	63.0 (6)	24.1 (6)	44.5 (6)	53.7 (6)	25.0 (5)	60.2 (6)
Polydora pulchra				0.9 (1)			
Polydora guillei	5.6 (2)	5.6 (2)	21.3 (5)	5.6 (3)	16.7 (3)	13.9 (4)	20.4 (4)
Spiophanes kroyeri	0.9 (1)	3.7 (4)		0.9 (1)		0.9 (1)	3.7 (2)

Table 11. continued.

Distance to platform (m)	100	250	500	750	1000	2000	5000
Number of analysed samples	6	6	6	6	6	6	6
Spiophanes bombyx	42.6 (6)	25.9 (6)	19.5 (6)	15.8 (6)	40.8 (6)	17.6 (5)	13.0 (5)
Magelona papillicornis						2.8 (2)	
Magelona alleni	11.1 (5)			0.9 (1)		1.9 (1)	1.9 (2)
Chaetopterus variopedatus	2.8 (2)	4.6 (3)	2.8 (2)	11.1 (4)	4.6 (4)	7.4 (3)	6.5 (5)
Tharyx marioni	12.0 (4)	1.9 (1)					0.9 (1)
Chaetozone setosa	22.2 (4)	6.5 (3)	1.9 (2)	0.9 (1)	4.6 (3)		1.9 (2)
Diplocirrus glaucus	25.0 (6)	5.6 (2)	1.9 (1)	0.9 (1)	5.6 (4)	0.9 (1)	1.9 (2)
Scalibregma inflatum	672.8 (6)	547.7 (6)	51.0 (6)	58.4 (6)	81.5 (5)	13.9 (4)	25.9 (6)
Ophelina acuminata	13.0 (4)	12.0 (6)	85.3 (6)	29.7 (6)	22.2 (6)	35.2 (6)	15.8 (6)
Capitella capitata	5.6 (4)		0.9 (1)	5.6 (3)	0.9 (1)		
Mediomastus gracilis	5.6 (4)	3.7 (2)	1.9 (1)				0.9 (1)
Notomastus latericeus	57.5 (6)	111.2 (6)	24.1 (6)	13.9 (5)	5.6 (4)	3.7 (3)	4.6 (2)
Owenia fusiformis	4.6 (2)	1.9 (1)	1.9 (2)	6.5 (4)	5.6 (4)	5.6 (3)	6.5 (5)
Lanice conchilega		0.9 (1)	13.0 (3)		9.3 (4)	10.2 (4)	9.3 (4)
Polycirrus medusa	0.9 (1)						
Lagis koreni	45.4 (6)	127.9 (6)	424.4 (6)	111.2 (6)	242.8 (6)	200.2 (6)	193.7 (6)
Pectinaria auricoma	45.4 (6)	36.1 (6)	1.9 (2)	5.6 (4)	1.9 (1)	1.9 (2)	6.5 (3)
Ampharete finmarchica		0.9 (1)					
Sosane gracilis	0.9 (1)	0.9 (1)					
Lysilla loveni							0.9 (1)
Terebellides stroemi	4.6 (4)		1.9 (2)				0.9 (1)
MOLLUSCA							
Nucula turgida	3.7 (3)	0.9 (1)	2.8 (3)	1.9 (2)	4.6 (4)	6.5 (3)	13.9 (5)
Mytilus edulis		0.9 (1)	0.9 (1)				0.9 (1)
Thyasira flexuosa							0.9 (1)
Lepton squamosum			0.9 (1)	2.8 (2)	0.9 (1)		3.7 (1)
Montacuta ferruginosa		0.9 (1)	1.9 (1)	4.6 (2)	9.3 (5)	2.8 (2)	0.9 (1)
Mysella bidentata	1247.3 (6)	1168.5 (6)	532.8 (6)	1101.8 (6)	1096.2 (6)	494.8 (6)	653.3 (6)
Acanthocardia echinata	0.9 (1)	0.9 (1)	4.6 (2)	3.7 (3)	0.9 (1)	1.9 (2)	
Dosinia lupinus	8.3 (5)	2.8 (3)		0.9 (1)		1.9 (2)	
Venus striatula				0.9 (1)	0.9 (1)	0.9 (1)	0.9 (1)
Venus verrucosa	1.9 (1)			1.9 (2)		0.9 (1)	0.9 (1)
Venus spec. juv.							0.9 (1)
Mysia undata							2.8 (2)
Tellina spec. juv.	1.9 (1)						
Abra alba	2.8 (2)	2.8 (1)					
Abra alba juv.		3.7 (3)	135.3 (5)	20.4 (5)	64.9 (6)	36.1 (6)	20.4 (6)
Gari fervensis			13.9 (3)	2.8 (3)	4.6 (2)	5.6 (4)	2.8 (3)
Cultellus pellucidus	0.9 (1)	0.9 (1)	1.9 (2)	3.7 (3)	3.7 (3)	4.6 (4)	
Mya truncata			0.9 (1)			0.9 (1)	
Corbula gibba	0.9 (1)		0.9 (1)	0.9 (1)	1.9 (2)	4.6 (4)	0.9 (1)
Thracia convexa	4.6 (4)	4.6 (4)		0.9 (1)	0.9 (1)	0.9 (1)	
Thracia spec. juv.							0.9 (1)

Table 11. continued.

Distance to platform (m)	100	250	500	750	1000	2000	5000
Number of analysed samples	6	6	6	6	6	6	6
Onoba vitrea	14.8 (6)	14.8 (4)	7.4 (4)	13.0 (5)	21.3 (5)	21.3 (5)	10.2 (4)
Turritella communis	18.5 (4)	0.9 (1)		6.5 (2)	15.8 (6)	11.1 (4)	0.9 (1)
Natica catena		0.9 (1)					
Natica alderi	0.9 (1)			1.9 (2)			
Aporrhais pespelecari						0.9 (1)	0.9 (1)
Cylichna cilindracea	2.8 (2)	8.3 (6)	9.3 (5)	22.2 (6)	14.8 (5)	23.2 (6)	47.3 (6)
Philine catena					0.9 (1)		
CRUSTACEA							
Processa parva	4.6 (3)	2.8 (3)	4.6 (3)	8.3 (4)	5.6 (3)	7.4 (4)	14.8 (6)
Pontophilus trispinosus	0.9 (1)						
Pagurus bernhardus	0.9 (1)	0.9 (1)	0.9 (1)				
Macropipus holsatus						0.9 (1)	
Macropipus spec. juv.		2.8 (2)	6.5 (4)	5.6 (5)	8.3 (4)	9.3 (4)	7.4 (3)
Ebalia cranchii							1.9 (1)
Ebalia tuberosa						1.9 (1)	
Corystes cassivelaunus	0.9 (1)	3.7 (3)	1.9 (2)	6.5 (4)	6.5 (5)	13.0 (5)	6.5 (5)
Macropodia rostrata							0.9 (1)
Upogebia stellata	2.8 (3)	4.6 (4)	1.9 (2)	4.6 (2)	0.9 (1)	2.8 (2)	0.9 (1)
Upogebia deltaura	4.6 (4)	1.9 (1)	2.8 (2)	13.0 (5)	9.3 (4)	8.3 (6)	16.7 (5)
Upogebia spec. juv.	2.8 (1)		1.9 (2)		1.9 (2)	6.5 (3)	9.3 (5)
Callianassa subterranea	107.5 (6)	96.4 (6)	61.2 (6)	81.5 (6)	71.4 (6)	72.3 (6)	76.9 (6)
Decapoda larven	15.8 (6)	11.1 (3)	3.7 (3)	3.7 (1)	6.5 (2)	8.3 (4)	2.8 (2)
Nebalia bipes				0.9 (1)		1.9 (2)	0.9 (1)
Mysiden larven				0.9 (1)		1.9 (1)	
Eudorella truncatula					0.9 (1)	1.9 (1)	1.9 (2)
Diastylis bradyi	2.8 (2)	4.6 (3)	2.8 (3)	7.4 (6)	4.6 (3)	3.7 (4)	2.8 (3)
Eurydice spinigera					1.9 (1)		
Cirolana borealis	8.3 (5)	6.5 (5)	4.6 (2)	5.6 (3)	4.6 (3)	4.6 (3)	9.3 (6)
Ione thoracica	1.9 (2)			2.8 (2)	0.9 (1)	6.5 (2)	4.6 (3)
Melita obtusata							0.9 (1)
Orchomenella nana	0.9 (1)	0.9 (1)	0.9 (1)			1.9 (1)	5.6 (2)
Leucothoe incisa	0.9 (1)	3.7 (2)	0.9 (1)	0.9 (1)	2.8 (3)	2.8 (3)	0.9 (1)
Ampelisca brevicornis	0.9 (1)	0.9 (1)	2.8 (2)	2.8 (3)	0.9 (1)	1.9 (2)	1.9 (2)
Ampelisca tenuicornis	14.8 (5)	3.7 (2)	23.2 (5)	4.6 (2)	4.6 (3)	11.1 (4)	3.7 (4)
Urothoe poseidonis		0.9 (1)	2.8 (2)	16.7 (6)	4.6 (4)	7.4 (3)	11.1 (5)
Bathyporeia elegans				0.9 (1)			
Harpinia antennaria	3.7 (3)	29.7 (5)	27.8 (6)	51.9 (6)	58.4 (6)	51.9 (5)	61.2 (6)
Harpinia pectinata		4.6 (1)					
Perioculodes longimanus	0.9 (1)		3.7 (4)	2.8 (2)	2.8 (2)	2.8 (3)	2.8 (3)
Synchelidium haplocheles							0.9 (1)
Aora typica			0.9 (1)				
Lembos longipes				0.9 (1)	1.9 (1)	0.9 (1)	

Table 11. continued.

Distance to platform (m)	100		250		500		750		1000		2000		5000	
Number of analysed samples	6		6		6		6		6		6		6	
ECHINODERMATA														
Astropecten irregularis					2.8	(2)								
Amphiura filiformis	2103.5	(6)	2601.2	(6)	840.5	(6)	1542.0	(6)	1968.2	(6)	1065.7	(6)	1787.5	(6)
Amphiura chiajei	7.4	(2)	33.4	(3)	11.1	(2)	55.6	(6)	114.9	(6)	49.1	(5)	70.4	(6)
Ophiura spec. juv.			0.9	(1)			8.3	(2)	8.3	(3)	23.2	(4)	12.0	(2)
Echinocardium cordatum			11.1	(3)	3.7	(2)	3.7	(2)	28.7	(6)	11.1	(6)	9.3	(6)
Echinocardium cordatum juv.	0.9	(1)			263.2	(6)	3.7	(3)	1.9	(1)	66.7	(6)	14.8	(5)
Cucumaria elongata	10.2	(6)	0.9	(1)			1.9	(2)	3.7	(3)	0.9	(1)	3.7	(3)
Cucumaria frondosa	2.8	(1)	2.8	(3)	1.9	(2)	0.9	(1)			2.8	(3)	0.9	(1)
OTHER TAXA														
Nemertinea	P	(6)	P	(6)	P	(6)	P	(6)	P	(6)	P	(6)	P	(6)
Turbellaria	6.5	(5)	3.7	(3)	5.6	(4)	4.6	(3)	2.8	(2)	3.7	(3)	9.3	(5)
Phoroniden	P	(4)	P	(6)	P	(6)	P	(6)	P	(6)	P	(6)	P	(6)
Harp. copepoda	0.9	(1)											0.9	(1)
Oligochaeta			2.8	(1)							0.9	(1)		
Echiurida			3.7	(2)	0.9	(1)	7.4	(3)	2.8	(1)	2.8	(3)	6.5	(3)
Sipunculida	25.0	(5)	53.7	(6)	28.7	(6)	45.4	(5)	33.4	(6)	55.6	(6)	28.7	(6)
Anthozoa	1.9	(1)	3.7	(2)			0.9	(1)	0.9	(1)	0.9	(1)		
Ascidiacea			3.7	(1)										
Total nr. of individuals	5676		5524		2923		3620		4386		2719		3600	
Nr. of identified species	71		74		68		74		68		72		76	
P= Present (not counted)														

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