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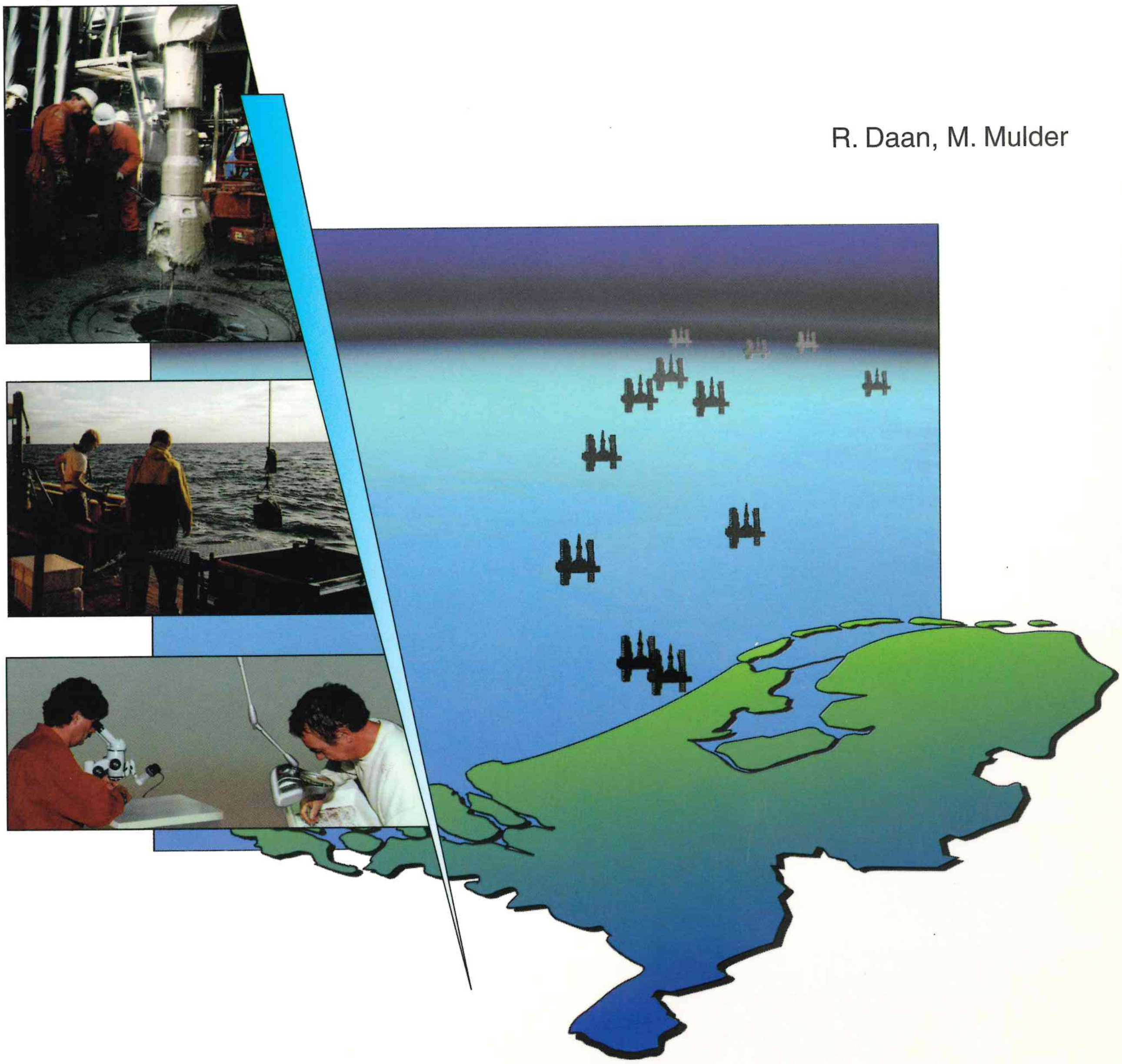

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LONG-TERM EFFECTS OF OBM CUTTING DISCHARGES AT 12 LOCATIONS ON THE DUTCH CONTINENTAL SHELF

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SUMMARY AND CONCLUSIONS

During drilling activities in the North Sea there has been an extensive use of oil based drilling muds (OBM) in the 80's and early 90's. Drill cuttings from wells drilled with OBM were discharged on the seabed and considerable amounts of OBM base oil adhering to drill cuttings have contaminated the seabed during those years. Field studies to assess the environmental effects of these discharges have been carried out on the Dutch Continental Shelf since 1985. Initially the attention focused on short-term effects. In the past 4 years the attention has shifted to the long-term environmental effects of the former discharges. Three locations received particular attention: L4-a (sedimentation area), K12-a (transition zone) and P6-b (erosion area). In summary, the outcome of these studies was that 6-8 years after the discharges substantially elevated oil concentrations and associated biological effects could be found within a few hundred metres from these locations. It was not known, however, whether the extent of environmental effects at these locations is representative of all locations where OBM cuttings have been discharged. In order to estimate the extent of this kind of pollution over the total Dutch Continental Shelf reliably, the need was felt to gather information from a larger number of OBM locations. Therefore, a sampling programme was carried out in 1994 and 1995 covering 12 well sites where OBM cuttings had been discharged 7 to 13 years ago. The locations were selected in areas with different sediment types. In terms of amounts of base oil discharged the discharge loads ranged from 13 to 298 tonnes. The locations included actual production platforms but also abandoned well sites. At each location compendious surveys were carried out, during which 4 stations were sampled at distances between 100 and 2000 m from the discharge site. Sediment samples for chemical analysis were collected at all stations and numbers of the OBM-sensitive species *Echinocardium cordatum* were counted in all samples. Additional macrofauna analyses were performed for 5 locations.
The chemical analyses revealed elevated oil concentrations at 5 of the 12 locations, but traces of oil were visually observed in a few samples at another 2 locations. Maximum concentrations, measured over the upper 10 cm layer, were generally in the order of 10-50 $mg \cdot kg^{-1}$ dry sediment, but at one location a concentration of 200 $mg \cdot kg^{-1}$ was found, which is comparable to the values found at the formerly investigated locations L4-a and P6-b, but considerably lower than at K12-a. This indicates that concentration levels at most locations are generally not as high as found at the locations formerly investigated. Except for one location where oil was found up to 250 m from the platform, elevated oil concentrations in surface sediments only occurred at 100-m stations.
Significant effects on the population densities of *E. cordatum* were found at 7 of the 12 locations. Further, at 2 locations the abundance pattern of the species was indicative of an effect but there was no statistical significance. Population densities of *E. cordatum* appeared to be depressed in the vicinity of two locations where no oil was detected. This indicates that the absence of oil in samples does not necessarily mean that sediment conditions have completely recovered. It can not be excluded that oil is still present in the deeper sediment layers that were not investigated. On the other hand, it is not clear whether remnants of the former discharges are still the actual cause of depressed population densities. Even when sediment conditions have completely recovered, it may take a long time before populations of long living species have recovered. Nevertheless, the consistent response of *E. cordatum* shows its particular value as a sensitive indicator of environmental effects caused by the former discharges.
At 3 of the 5 locations for which macrofauna analyses were carried out, effects were also found on other components of the benthic community. The occurrence of effects generally seemed to be limited to the 100-m station. Although a more extensive sampling programme could have revealed some more subtile effects also at a larger distance from a few locations, this suggests that the zone where persistent biological effects may be expected generally extends within a radius of ≈200 m from OBM discharge sites.

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

1. Oil contaminated surface sediment has been found at 7 of the 12 locations investigated. At one location the concentration was 200 $mg \cdot kg^{-1}$ dry sediment. At the other locations the maximum concentrations were in the order of 10-50 $mg \cdot kg^{-1}$ dry sediment.

2. Except for one location where oil was found up to 250 m from the platform, elevated oil concentrations were only found at stations at 100 m from discharge sites.

3. Elevated oil concentrations were observed near 1 of 3 locations in the sedimentation area, 4 of 5 locations in the transition zone and 2 of 4 locations in the erosion area.

4. Elevated oil concentrations were observed at 4 of 9 locations where a platform was present and at each of 3 abandoned well sites.

5. Elevated oil concentrations were detected at the location with the largest and relatively recent discharge (268 tonnes of base oil 8 years ago), but also at the location with the smallest and oldest discharge (13 tonnes of oil 13 years ago).

6. It is argued that it is unlikely that at any of the locations investigated the oil has completely disappeared. At locations where elevated oil concentrations do occur, the patchy distribution and/or accumulation of oil in deeper sediment layers may cause that the presence of oil in the sediment is not always demonstrated by the chemical analyses.

7. Visual inspection of complete grab samples may provide a more sensitive (although not quantitative) method to detect the presence of oil than chemical analyses of subsamples of surface sediments, due to the patchy distribution of oil in sediments.

8. At 7 of the 12 locations investigated a significant (adverse) effect could be detected on the population densities of the OBM sensitive species *Echinocardium cordatum.* At 2 other locations the abundance pattern of this species indicated such an effect, but there was no statistical significance.

9. Effects on *E. cordatum* were found at each of 3 locations in the sedimentation area, 2 of 5 locations in the transition zone and 2 of 4 locations in the erosion area.

10. Depressed population densities of *E. cordatum* were found near 6 of 9 production platforms and at 1 of 3 abandoned well sites.

11. Depressed population densities of *E. cordatum* were found near the location with the largest and relatively recent discharge (268 tonnes of base oil 8 years ago), but also at a location where only 26 tonnes of oil had been discharged 13 years ago.

12. Effects on *E. cordatum* were found not only at 5 of 7 locations were elevated oil concentrations were detected, but also at 2 locations where no oil was found over the sampled transect.

13. At 3 of the 5 locations for which complete macrofauna analyses were performed there appeared to be not only an effect on *E. cordatum* but also on other components of the macrobenthos. At 2 of these locations such effects could be detected at species level, but also at the community level. At one location there was only an effect at species level.

14. There were 3 locations where no oil and no effect were found on the macrofauna, indicating that the long-term effect of former OBM cutting discharges is clearly reduced compared to short-term effects as measured in the past.

15. For most locations investigated the area where effects on the macrobenthos do persistently occur is estimated to extend within a radius of ≈200 meter from the discharge site.

SAMENVATTING EN CONCLUSIES

Bij booraktiviteiten op de Noordzee is in de 80-er en begin 90-er jaren op uitgebreide schaal gebruik gemaakt van boorspoelingen op oliebasis (OBM). Gruis afkomstig uit de boorputten die geboord werden met OBM werd geloosd op de zeebodem en op die manier kwamen aanzienlijke hoeveelheden aanhangende boorspoeling op de zeebodem terecht. Sedert 1985 wordt op het Nederlands Continentaal Plat (NCP) veldonderzoek uitgevoerd naar de milieu-effekten van deze lozingen. Aanvankelijk ging het hierbij om onderzoek naar de korte-termijn effekten. In de 90-er jaren is de aandacht echter verschoven naar de lange-termijn effekten van voormalige lozingen. Met name de lokaties L4-a (sedimentatiegebied), K12-a (overgangsgebied) en P6-b (erosiegebied) zijn op lange-termijn effekten onderzocht. In het kort komen de resultaten van dat onderzoek erop neer dat 6 tot 8 jaar na de laatste lozingen nog duidelijk verhoogde olieconcentraties en daarmee samenhangende effekten op de bodemfauna konden worden aangetoond binnen enkele honderden meters van deze lokaties.

De vraag die echter bleef bestaan was in hoeverre de omvang van de effekten rond deze lokaties als representatief mag worden gezien voor al die lokaties waar in het verleden OBM-houdend boorgruis is geloosd. Teneinde een idee te krijgen van de omvang van deze vorm van verontreiniging op NCP-brede schaal, werd het noodzakelijk geacht over veldgegevens van een groter aantal OBM-lokaties te beschikken. Daarom is in 1994 en 1995 een bodembemonsterings-programma uitgevoerd waarbij 12 lokaties werden onderzocht waar 7 tot 13 jaar geleden lozingen van OBM-houdend boorgruis hadden plaats gehad. Het betreft lokaties in zowel het sedimentatiegebied, het erosiegebied als het overgangsgebied. De per lokatie geloosde hoeveelheden basis-olie lopen uiteen van 13 tot 298 ton. Voor het grootste deel betreft het lokaties waar een produktieplatform staat, maar ook de bodem bij enkele verlaten boorputten is onderzocht. Bij elke lokatie werd een beknopte survey uitgevoerd waarbij 4 stations werden bemonsterd op afstanden tussen 100 en 2000 m van het voormalige lozingspunt. Op al deze stations werden bodemmonsters genomen voor chemische analyse en verder werden ter plaatse tellingen uitgevoerd van de aantallen hartegels (*Echinocardium cordatum*) per monster. Daarnaast werd voor 5 lokaties een volledige fauna-analyse uitgevoerd.

Uit de chemische analyses bleken verhoogde olieconcentraties voor te komen bij 5 van de 12 lokaties, maar op nog 2 andere lokaties waren sporen van olie in de monsters met het oog waarneembaar. De maximale concentraties, gemeten over de bovenste 10 cm van het sediment, lagen in het algemeen in de orde van 10 tot 50 $mg \cdot kg^{-1}$ droog sediment maar op één lokatie werd een concentratie van 200 $mg \cdot kg^{-1}$ aangetroffen, een waarde die vergelijkbaar is met de concentraties die in vorig onderzoek zijn gevonden bij de lokaties L4-a en P6-b, maar beduidend lager dan bij lokatie K12-a. Dit wijst erop dat de olieconcentraties op de meeste lokaties minder hoog zijn dan op de drie vroeger onderzochte lokaties. Afgezien van één lokaties waar olie werd gevonden tot op 250 m van het platform kwamen verhoogde olieconcentraties in het oppervlakte-sediment uitsluitend voor op 100-m stations.

Op 7 van de 12 lokaties werd een signifikant effekt op de populatiedichtheid van *E. cordatum* gevonden. Op nog eens twee lokaties duidde het abundantiepatroon op een effekt, maar er was geen statistische signifikantie. Verlaagde populatie-dichtheden van *E. cordatum* kwamen onder meer voor rond twee lokaties waar geen olie werd gevonden. Dit illustreert dat afwezigheid van olie in de monsters nog niet betekent dat de sediment-condities volledig hersteld zijn. Het is bijvoorbeeld niet uitgesloten dat zich nog olie bevindt in de niet onderzochte diepere sedimentlagen. Aan de andere kant is het niet gezegd dat de aanwezigheid van restanten van de vroegere lozingen in het sediment nog steeds de aktuele oorzaak vormt van verlaagde populatie-dichtheden. Herstel van populaties van met name de lang levende soorten kan jaren duren, zelfs wanneer sediment-condities volledig hersteld zijn.

Niettemin bewijst de consekwente respons die *E. cordatum* vertoont bij OBM-lokaties de bijzondere waarde die deze soort heeft als gevoelige indikator voor het optreden van milieu-effekten van de voormalige lozingen.

Op 3 van de 5 lokaties waarvoor een volledige makrofauna-analyse werd uitgevoerd werden ook effekten gevonden op andere componenten van de benthische gemeenschap. Het voorkomen van effekten bleef in het algemeen beperkt tot de 100-m stations. Hoewel een uitgebreider monsterprogramma mogelijk meer (subtiele) effekten aan het licht zou hebben gebracht, ook op grotere afstand van enkele lokaties, wijst dit erop dat de zone waarin nog latente effekten voorkomen zich in het algemeen uitstrekt binnen een straal van ongeveer 200 m van OBM lozingspunten.

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

1. Met olie verontreinigd oppervlakte-sediment werd aangetroffen op 7 van de 12 onderzochte lokaties. Op één lokatie werd een concentratie van 200 $mg \cdot kg^{-1}$ droog sediment gemeten. Op de andere lokaties lagen de maximum concentraties in de orde van 10 tot 50 $mg \cdot kg^{-1}$ droog sediment.

2. Eén lokatie uitgezonderd, waar olie werd gevonden tot op 250 m van het platform, werden verhoogde

concentraties uitsluitend gevonden op stations op 100 m van een lozingspunt.

3. Verhoogde olieconcentraties werden waargenomen bij 1 van de 3 lokaties in het sedimentatiegebied, bij 4 van de 5 lokaties in het overgangsgebied en bij 2 van de 4 lokaties in het erosiegebied.

4. Verhoogde olieconcentraties werden waargenomen bij 4 van de 9 lokaties waar een produktieplatform stond en bij alle 3 verlaten lokaties.

5. Verhoogde olieconcentraties werden waargenomen bij de lokatie met de grootste en relatief recente lozing (268 ton basis-olie, 8 jaar geleden) maar ook bij de lokatie met de kleinste en oudste lozing (13 ton basis-olie, 13 jaar geleden).

6. In de discussie wordt beargumenteerd dat het onwaarschijnlijk is dat de olie op ook maar één van de onderzochte lokaties geheel verdwenen is. Op lokaties waar verhoogde olieconcentraties voorkomen kan de heterogene verspreiding en/of accumulatie van olie in diepere sedimentlagen er de oorzaak van zijn dat de aanwezigheid van olie niet altijd uit de chemische analyses blijkt.

7. In verband met de heterogene verspreiding van olie in sedimenten kan visuele inspectie van volledige bodemmonsters voor het vaststellen van de aanwezigheid (niet kwantitatief) van olie als methode gevoeliger zijn dan chemische analyse van submonsters van oppervlakte-sediment.

8. Op 7 van de 12 onderzochte lokaties kon een signifikant (negatief) effekt worden vastgesteld op populatie-dichtheden van de OBM-gevoelige soort *Echinocardium cordatum*. Op nog eens 2 lokaties wees het abundantiepatroon op een effekt, maar een ruimtelijke gradient bleek niet signifikant.

9. Van een effekt op *E. cordatum* was sprake op alle 3 lokaties in het sedimentatiegebied, op 2 van de 5 lokaties in het overgangsgebied en op 2 van de 4 lokaties in het erosiegebied.

10. Verlaagde populatiedichtheden van *E. cordatum* kwamen voor bij 6 van de 9 produktieplatforms en bij 1 van de 3 verlaten lokaties.

11. Verlaagde populatiedichtheden van *E. cordatum* kwamen voor bij de lokatie met de grootste en relatief recente lozing (268 ton basis-olie, 8 jaar geleden) maar ook bij een lokatie met een relatief kleine en oude lozing (26 ton basis-olie, 13 jaar geleden).

12. Effekten op *E. cordatum* werden niet alleen gevonden op 5 van de 7 lokaties waar verhoogde olieconcentraties zijn aangetroffen, maar ook op 2 lokaties waar geen olie is gevonden.

13. Op 3 van de 5 lokaties waarvoor een volledige makrofauna-analyse is uitgevoerd werden niet alleen effekten op de *E. cordatum* populatie gevonden maar ook op andere componenten van het makrobenthos. Op 2 van deze lokatie konden effekten niet alleen worden vastgesteld op soortniveau, maar ook op community niveau.

14. Op 3 lokaties werd noch olie, noch enig effekt op de makrofauna waargenomen. Dit wijst erop dat de lange-termijn effekten van lozingen van oliehoudend boorgruis duidelijk minder ver strekken dan de kortetermijn effekten zoals die in het verleden gemeten zijn.

15. Een schatting van de omvang van de zone waarin latente effekten op het makrobenthos voorkomen komt voor de meeste van de onderzochte lokaties neer op een gebied binnen een straal van ongeveer 200 m van het voormalige lozingspunt.

1 INTRODUCTION

1.1 GENERAL PART

During the past 10 years, extensive studies have been carried out on the environmental effects of drill cutting discharges on the Dutch Continental Shelf. The attention mainly focused on locations where oil based drilling muds (OBM) had been used and discharged. Combined chemical and biological research was carried out at the OBM locations F18.9, K12a, L4a, L5-5 and P6b. Most of these locations were visited more than once to assess effects immediately after drilling but also at the longer term. The location most extensively investigated is K12a. During a period of 8 years following the discharges of OBM cuttings 6 surveys were carried out around this platform. Long-term effects were also investigated at L4a (8 years after discharge) and P6b (6 years after discharge). A general outcome of these studies is 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 metres from these platforms, whereas traces of oil could sometimes be found up to 500 - 1000 m (DAAN & MULDER, 1993, 1994, 1995; GROENEWOUD 1995). In the vicinity of the platforms the concentrations seemed to be higher in the deeper sediment layers (10-30 cm) than in the superficial layer. Since oxygen hardly penetrates to these depths, it is supposed that biodegradation of the oil proceeds very slowly. Biological effects could be traced also within a few hundreds metres of these OBM locations. Although our knowledge about the extent of the sediment contamination and of the persistent biological effects around the platforms mentioned is quite detailed, there is still insufficient information available to reliably estimate the extent of this kind of pollution over the whole area covered by the Dutch Continental Shelf. One reason is that it is unknown whether the extent of the pollution and biological effects observed around the platforms investigated is representative for the major group of OBM sites in areas with similar hydrographic regime and sediment characteristics. Moreover, most of the locations investigated were characterized by relatively large OBM discharges. Information on the extent of effects around locations where less OBM has been discharged is still scarce. Further, redistribution processes may be different at abandoned well sites, compared to locations where a production platform has been placed. The reason is that beam trawlers, which in principle are not allowed to enter the zone within 500 m from platforms, may considerably affect the redistribution of discharged material at abandoned well sites. To obtain more basic information required to estimate the complete extent of effects of the former discharges in the Dutch sector, a sampling programme was carried out in 1994 and 1995 covering 12 well sites, where OBM cuttings had been discharged 7 years or longer ago. At each of these locations compendious surveys were carried out, during which surface sediments at 4 stations were sampled at distances between 100 m and 2000 m from the discharge site. The locations selected (Table 1, Fig. 1) are equally divided over the sedimentation area, the erosion area and the transition area, cover a wide range of amounts of discharged material and include production platforms as well as abandoned locations. In first instance surface sediment samples were collected at all locations for oil analyses (GROENEWOUD, 1996) and numbers of the OBM-sensitive species *Echinocardium cordatum*

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 = time elapsed since last OBM discharge; platform present (+) or not (-); fauna analysis = Complete fauna analysis performed (+)

Area	*location*	*res.cur.*	*year*	*oil (t)*	*time*	*platform*	*fauna analysis*
sedimentation	K7-fa	45°	1984	80	11 y	+	
sedimentation	K8-fa	45°	1984	108	11 y	+	+
sedimentation	G13-1	80°	1987	197	8 y	-	+
transition	L10-23	50°	1982	26	13 y	+	
transition	L11-7	35°	1981	13	13 y	-	
transition	K10-c	45°	1983	162	12 y	+	
transition	K12-6	50°	1987	205	8 y	+	+
transition	K11-10	45°	1986	198	8 y	-	
erosion	L14-s1	30°	1987	47	7 y	+	+
erosion	Q8-a2	10°	1985	107	10 y	+	
erosion	L13-10	45°	1987	268	8 y	+	+
erosion	Q8-5	10°	1984	145	11 y	+	

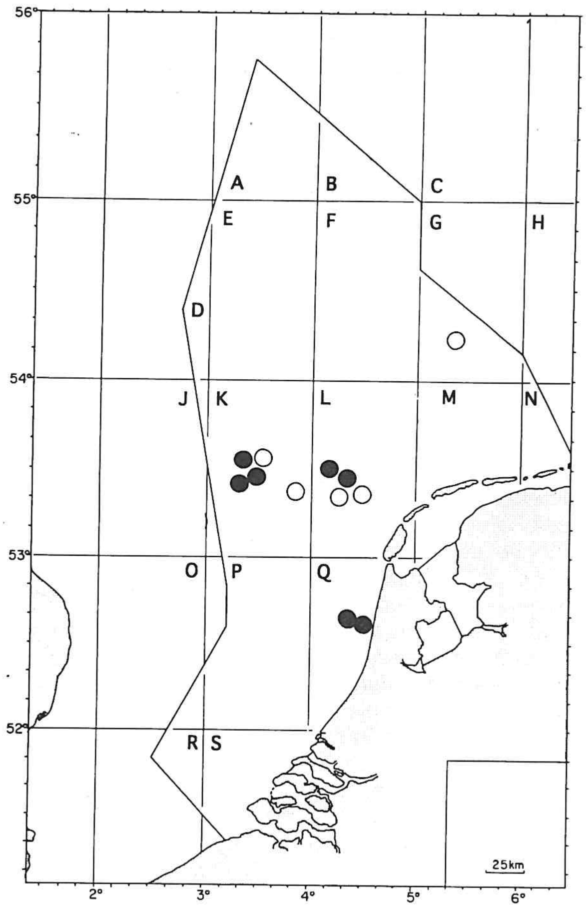

Fig. 1. Positions of the locations investigated in 1994 and 1995 in the Dutch sector of the North Sea.
open circles: locations for which a complete fauna analysis was performed.

(specimens >15 mm) were counted on board in all samples. Later on complete fauna analyses were performed for those locations where elevated oil concentrations were found. This report presents the results of this sampling programme.

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2 METHODS

2.1 SAMPLING

At each location a transect was chosen in the local residual current direction (see RUIJTER *et al.*, 1987). Sampling stations were chosen at 100 m, 250 m, 500 m and 1000 m (if less than 100 t oil had been discharged) or 2000 m (if more than 100 t had been discharged). The 1000-m and 2000-m stations were assumed to represent a local 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 grainsize analyses. These samples were pooled by station, thoroughly homogenised and immediately frozen at -20° until later analysis in the laboratory. Then the contents of each grab were inspected for the presence of *Echinocardium cordatum* and their numbers were counted on board. Four grabsamples of each station were washed through a sieve (mesh size 2 mm) and the residual macrofauna was preserved in a 6% neutralized formaldehyde solution.

2.2 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).

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

2.4 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).

2.5 FAUNA ANALYSIS

At all locations numbers of the OBM-sensitive species *Echinocardium cordatum* were counted in all samples. A complete fauna analysis was performed for 5 of the locations sampled. These locations are indicated in Table 1. Four of them were chosen because elevated oil concentrations in the surface sediment were observed. The fifth location (K8-fa) was selected because a conspicuous gradient was observed here in the abundance pattern of *Echinocardium cordatum*. Routine methods of sorting and identification are described by MULDER *et al.* (1988).

2.6 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).

TABLE 2

Total oil concentrations (mg·kg^{-1} dry sediment) at the locations investigated (data from GROENEWOUD, 1996). Values <8 are within the range of expected background concentrations.

Location	*station 100 m*	*station 250 m*	*station 500 m*	*station 1000 m*	*station 2000 m*
K7-fa	6	6	6	6	-
K8-fa	6	6	6	-	6
G13-1	48	5	7	-	5
L10-23	6	6	5	5	-
L11-7	9	6	5	7	-
K10-c	6	5	5	-	6
K12-6	36	17	6	-	6
K11-10	8	-	4	-	4
L14-s1	44	8	6	4	-
Q8-a2	6	6	6	-	5
L13-10	200	5	5	-	5
Q8-5	6	6	6	-	5

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), *i.e.* the regression analysis was carried out with a correction for over-dispersion.

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).

3 RESULTS

3.1 FIELD OBSERVATIONS AND OIL CONCENTRATIONS

Location K7-fa

sedimentation area, 80 tonnes of oil discharged 11 yr ago, platform present

The sediment at this location looked visually clean, except for some cuttings at the 100-m station. Oil was not observed and the chemical analyses showed that the total hydrocarbon concentrations did not exceed background level (Table 2). However, there was a conspicuous gradient in the occurrence of *Echinocardium cordatum* (Fig. 2). The species was absent at 100 m and occurred in increasing abundance as distance to the platform increased, up to 12 ind·m^{-2} at 1000 m. Logit regression confirmed that the gradient was highly significant ($p<0.001$).

Location K8-fa

sedimentation area, 108 tonnes of oil discharged 11 yr ago, platform present

The visual observations at this locations were quite similar to those at K7-fa. Although cuttings were found in all samples at the 100-m station, the sediment visually looked clean and oil concentrations did not exceed background levels. In spite of the absence of oil there again was a clear gradient in the occurrence of *E. cordatum* with densities increasing from 1 ind·m^{-2} at 100 m to 17 ind·m^{-2} at 2000 m (Fig. 2). Logit regression confirmed that the gradient in frequency of occurrence was significant ($p < 0.05$).

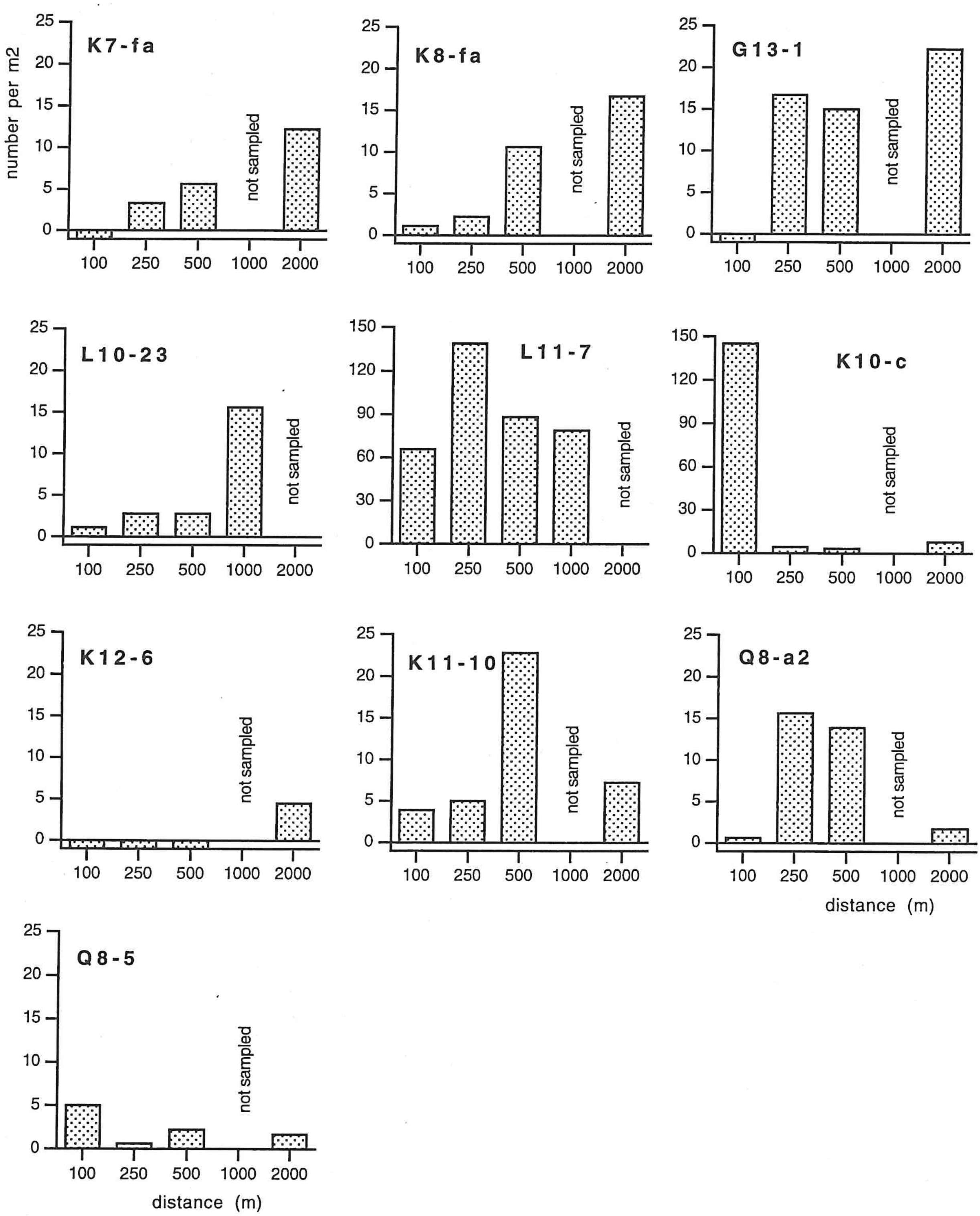

Fig. 2. Abundance patterns of *Echinocardium cordatum* at 10 locations investigated. (At L14-s1 and L13-10 the species was not found.)

Location G13-1
sedimentation area, 197 tonnes of oil discharged 8 yr ago, platform absent

At 100 m most samples contained drill cuttings and oil was observed in 4 samples. Cuttings were also found in most of the 250-m samples and a trace of oil was also observed in one of these samples. The chemical analyses revealed elevated oil concentrations at 100 m only (Table 2). Adult *E. cordatum* were not found at 100 m, whereas the species was found in nearly all samples at the other stations where mean densities fluctuated between 15 and 22 ind·m^{-2} (Fig. 2). A gradient in frequency was highly significant (logit regression, $p<0.05$).

Location L10-23
transition zone, 26 tonnes of oil discharged 13 yr ago, platform present

Some confusion existed about the position of this location since the formal coordinates of the well site did not correspond with the actual position of the production platform, which is located about 250 m away. It is not clear whether the given coordinates were wrong or that the production platform has been placed about 250 m away from the former drilling site. At the given position 3 grab samples were taken which contained a few cuttings and traces of oil. Three other samples collected at 100 m from the actual platform position all contained cuttings and oil. However, neither of these 6 samples has been analysed. At the stations along the regular sampling transect no trace of pollution could be visually observed and the analyses did not reveal oil concentrations exceeding background level (Table 2). Nevertheless there seemed to be a gradient in the abundance pattern of *E. cordatum*, which was found in mean densities of 1 ind·m^{-2} at 100 m increasing to 16 ind·m^{-2} at 1000 m. A gradient in frequency of occurrence was significant as revealed by logit regression ($p<0.05$).

Location L11-7
transition zone, 13 tonnes of oil discharged 13 yr ago, platform absent

A few cuttings and traces of oil were observed in some samples at 100 m. The chemical analyses showed that the oil concentration was slightly elevated compared to background level (Table 2) and the chromatogram fingerprint suggested that these traces could be identified as OBM base oil (GROENEWOUD, 1996). At the other stations no trace of oil was found.

E. cordatum was extremely abundant in the area around this location (Fig. 2). Mean densities fluctuated between 66 and 139 ind·m^{-2}. Although lowest at 100 m, the density of the species at this station was still so high that it hardly can be considered as affected by sediment contamination. Since *E. cordatum* appeared to occur in all samples, logit regression did not reveal a gradient in frequency of occurrence. Analysis of variance carried out *ad hoc* on the log-transformed abundance data revealed that the mean densities at 250 m were significantly higher than at the other stations. Between the other stations there were no significant differences. This indicates that the 100-m station was not affected and that the higher density at 250 m should be considered as a local maximum in an area where the species is abundant by nature.

Location K10-c
transition zone, 162 tonnes of oil discharged 12 yr ago, platform present

The grab samples collected at 100 m from the location nearly all contained drill cuttings, but oil was not observed. The chemical analyses too did not reveal concentrations beyond background level at this station, nor at any of the other stations (Table 2). *E. cordatum* occurred frequently in the samples and between 250 m and 2000 m mean densities ranged from 3 to 8 ind·m^{-2} (Fig. 2). However, at 100 m from the platform an extremely high density of *E. cordatum* appeared to occur. The mean density was 145 ind·m^{-2}, which indicates that the species does not experience any adverse effect of the former discharges at the long term. In spite of the abundance maximum at 100 m there was no significant gradient in the frequency of occurrence of the species along the transect sampled (logit regression, $p>0.05$).

Location K12-6
transition zone, 205 tonnes of oil discharged 8 yr ago, platform present

Up to 500 m from the platform nearly all samples contained remnants of drill cuttings and oil, albeit only a few small droplets at 500 m. The analyses revealed mean concentrations of 36 and 17 mg oil·kg^{-1} dry sediment at 100 m and 250 m respectively, but no concentrations beyond background level at 500 m (Table 2). *E. cordatum* did not occur within 500 m, but at 2000 m the species was found in 7 samples and the mean local density was 4 ind·m^{-2} (Fig. 2). Logit regression showed that there was a highly significant gradient in frequency of occurrence ($p<0.001$).

Location K11-10
transition zone, 198 tonnes of oil discharged 8 yr ago, platform absent

At 100 m remnants of drill cuttings and traces of oil were observed in 50% of the samples. However the chemical analyses did not reveal concentrations exceeding background level (Table 2). The highest

TABLE 3

The benthic fauna at K8-fa, Aug. 1995. Percentage of occurrence of each species in the total number of samples (16).

POLYCHAETA				CRUSTACEA	
		Notomastus latericeus	25		
Harmothoe lunulata	6	*Owenia fusiformis*	100	*Processa parva*	44
Harmothoe spec. juv.	6	*Myriochele oculata*	31	*Macropipus* spec. juv.	6
Polynoe kinbergi	6	*Lanice conchilega*	31	*Ebalia cranchii*	6
Sthenelais limicola	19	*Polycirrus medusa*	6	*Corystes cassivelaunus*	31
Anaitides groenlandica	6	*Lagis koreni*	6	*Callianassa subterranea*	94
Ophiodromus flexuosus	44	*Ampharete finmarchica*	6	*Ione thoracica*	19
Gyptis capensis	19			*Orchomenella nana*	6
Nereis longissima	25	MOLLUSCA		*Ampelisca tenuicornis*	13
Nephtys hombergii	94				
Nephtys caeca	56	*Montacuta ferruginosa*	44	ECHINODERMATA	
Glycinde nordmanni	13	*Mysella bidentata*	13		
Goniada maculata	19	*Acanthocardia echinata*	19	*Amphiura filiformis*	44
Lumbrineris latreilli	94	*Dosinia lupinus*	38	*Echinocardium cordatum*	63
Spiophanes bombyx	100	*Venus striatula*	13	*Echinocardium cordatum* juv.	6
Magelona papillicornis	6	*Spisula* spec. juv.	19		
Magelona alleni	44	*Abra alba*	25	OTHER TAXA	
Tharyx marioni	6	*Abra alba* juv.	94		
Diplocirrus glaucus	19	*Cultellus pellucidus*	50	Nemertinea	69
Scalibregma inflatum	31	*Thracia convexa*	6	Nematoda	6
Ophelia limacina	6	*Natica alderi*	31	Turbellaria	13
Ophelina acuminata	6	*Cylichna cilindracea*	13	Phoroniden	69
				Sipunculida	19
				Anthozoa	25

numbers of *E. cordatum* were found at the 500-m station and the lowest numbers at 100 m (Fig. 2). In first instance logit regression indicated a significant gradient, but after correction for overdispersion the gradient appeared to be no longer significant ($p > 0.05$), so there is no convincing evidence that the species was still affected at 100 m from the location.

Location L14-s1
erosion zone, 47 tonnes of oil discharged 7 yr ago, platform present

Most samples collected at the 100-m station appeared to contain some drill cuttings and traces of oil. At 250 m cuttings and oil were seen in only one sample. The analyses showed a substantial elevation of oil concentrations at 100 m and a slight elevation compared to background level at 250 m (Table 2). The chromatogram indicated that the oil could be identified as OBM base oil (GROENEWOUD, 1996). Adult *E. cordatum* were not observed in the samples, so the presence of a persistent biological effect can only be assessed on the basis of the results of the laboratory analyses of the fauna samples.

Location Q8-a2
erosion zone, 107 tonnes of oil discharged 10 yr ago, platform present

Drill cuttings were found in the samples up to 250 m from the platform, but oil was not observed. The sediment analyses also did not show any elevation of oil concentrations compared to background level (Table 2). At 100 m only 1 *E. cordatum* was found and it's local density seems low compared to the 250-m and 500-m stations where mean densities were about 14 ind·m^{-2} (Fig. 2). However, at 2000 m the density was low again (3 specimens found, which corresponds to about 2 ind·m^{-2}) and logit regression revealed no significant gradient in frequency of occurrence along the transect sampled ($p > 0.05$).

Location L13-10
erosion zone, 268 tonnes of oil discharged 8 yr ago, platform present

At 100 m drill cuttings occurred in all samples and oil was observed in 4 samples. At 250 m cuttings were not found, but oil was observed in 1 sample. The sediment analyses demonstrated strongly elevated oil concentrations at 100 m from the platform, but no elevation compared to background level at 250 m (Table 2). Adult *E. cordatum* were not observed in the samples, so the presence of a persistent biological effect can only be assessed on the basis of the results of the laboratory analyses of the fauna samples.

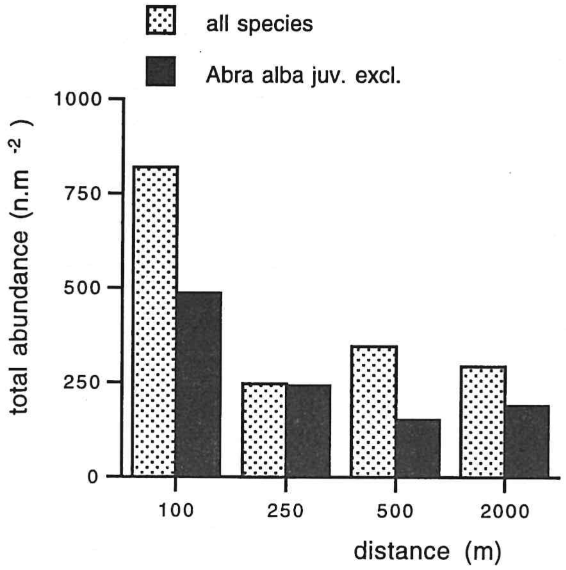

Fig. 3. Total macrofauna abundance at K8-fa (residual current transect).

Location Q8-5

erosion zone, 145 tonnes of oil discharged 11 yr ago, platform present

The sediment samples looked unpolluted at all stations and neither oil nor drill cuttings were observed. The chemical analyses confirmed the absence of oil in the samples (Table 2). *E. cordatum* occurred in moderate densities in the area. The highest number was found at 100 m, the lowest at 250 m (Fig. 2). There was no significant gradient in frequency of occurrence (logit regression, $p>0.05$). The abundance pattern of *E. cordatum* suggests that the species is not affected in it's distribution at distances ≥100 m.

The results of the on board counts of *Echinocardium cordatum* may be summarized as follows: An effect on the spatial abundance pattern of the species in terms of a significant gradient in frequency of occurrence was detected at each of the locations in the sedimentation area (K7-fa, K8-fa, G13-1) and at 2 locations in the transition zone (L10-23 and K12-6). In the erosion zone such a significant effect was not found, but at L14-s1 and L13-10 it was not possible to assess an effect because *E. cordatum* was not observed in the area around these locations. Further the remarkable low abundance of the species at the 100-m stations at K11-10 (transition zone) and Q8-a2 (erosion zone) might be indicative of an effect. Significant gradients were detected at locations where the presence of oil was assessed as well as at locations where no oil was found. Significant gradients were detected at locations where a large amount of oil was discharged relatively recently (K12-6) but also at a location where only a few tonnes were dumped relatively long ago (L10-23). Finally, significant gradients were mostly detected at locations where a production platform was present, but also at one abandoned location (G13-1).

3.2 MACROFAUNA COMPOSITION (LABORATORY ANALYSES)

Location K8-fa

sedimentation area, 108 tonnes of oil discharged 11 yr ago, platform present

The fauna analyses for this location yielded a total of 46 identified species. Their percentual occurrence in the samples is summarized in Table 3 and a complete overview of species specific abundances is given in Table 23 (Appendix). The fauna was numerically dominated by juveniles of the bivalve *Abra alba* and, to a lesser extent, by the crustacean *Callianassa subterranea.* These species accounted on average for 37% and 11% respectively of the total macrofauna. Particularly *A. alba* occurred in highly variable numbers, with a peak at 100 m (335 ind·m^{-2}) and a low at 250 m (4 ind·m^{-2}). Therefore, *A. alba* is largely responsible for the high fauna abundance at 100 m (Fig. 3). However, when *A. alba* is excluded the overall fauna abundance at 100 m is still high at 100 m.

The numbers of species per sample ranged from 10 to 24 (Fig. 4). On average the numbers were highest at the 100-m station. Analysis of variance revealed a significant difference between the mean number of species at 100 m and the numbers at the other stations ($p<0.05$). This is in contrast to what has been usually measured at locations where effects of discharged OBM cuttings on the macrofauna could be

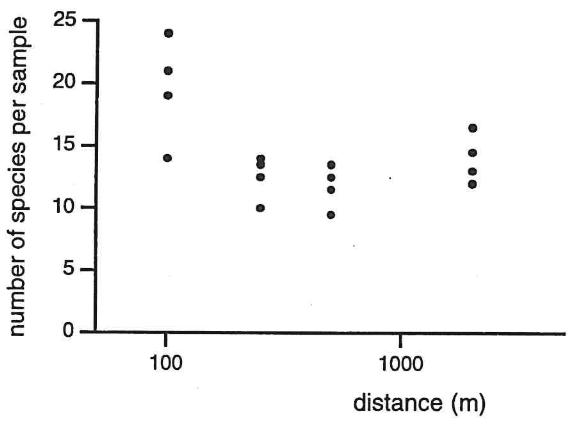

Fig. 4. Numbers of identified species per sample at K8-fa (residual current transect).

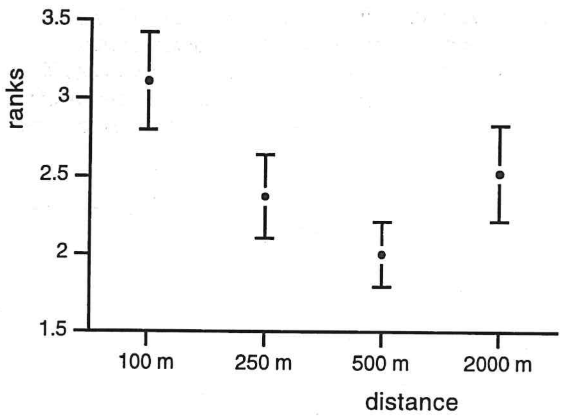

Fig. 5. Relative macrofauna abundance at K8-fa (mean ranks and 95% confidence limits).

assessed. Around those locations the numbers of species per surface unit tended to decrease on approach of the discharge site. It seems unlikely therefore that the relatively high species richness at 100 m could be explained as an effect of the former discharges.

On average, most species occurred in relatively high numbers at 100 m. Fig. 5 shows that the relative fauna abundance was obviously the highest at this station. Analysis of variance revealed that the mean rank of the100-m station was significantly higher than at all other stations ($p<0.05$). Further, the relative abundance at 500 m was significantly lower than at 2000 m. The spatial pattern of relative fauna abundance does not correspond to the usual pattern at locations, where an effect of discharged OBM cuttings can be detected. At those locations the lowest relative abundance has usually been found at the station closest to the discharge site.

For ten individual species possible gradients in frequency of occurrence were tested by logit regression (Table 4). Two species appeared to show a significant gradient. Of these species the polychaete *Myriochele oculata* occurred in abundance in the vicinity of the location and was hardly found at larger distances. Since *M. oculata* is not known as a typical opportunistic species, the peak at 100 m might be explained as a natural local high. *Echinocardium cordatum* occurred more frequently away from the location. The latter species was the only one of 15 known OBM-sensitive species showing a gradient in its abundance (Table 5). Most of the other species were too sparsely found to discover any spatial pattern.

Table 6, showing Bray-Curtis similarities between stations, reveals that there were only marginal differences in similarity for different pairs of stations. The values fluctuate between a narrow range of 57 - 66% similarity. Although the 100-m station seemed to have

TABLE 4

Location K8-fa. 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 of occurrence away from the location; 0 = no gradient.

		sign. level (%)	
	sign	*uncorr. test*	*corr. test*
Nephtys hombergii	+	n.s.	n.s.
Lumbrineris latreilli	-	n.s.	n.s.
Spiophanes bombyx	0	-	-
Owenia fusiformis	0	-	-
Myriochele oculata	-	0.1	0.1
Lanice conchilega	+	n.s.	n.s.
Montacuta ferruginosa	+	n.s.	n.s.
Cultellus pellucidus	+	n.s.	n.s.
Callianassa subterranea	+	n.s.	n.s.
Echinocardium cordatum	+	0.1	5

TABLE 5

Evaluation of the abundance patterns of 15 OBM-sensitive species at location K8-fa.
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	0(?)
Harpinia antennaria	not found
Callianassa subterranea	0
Owenia fusiformis	-
Mysella bidentata	0(?)
Gattyana cirrosa	not found
Amphiura filiformis	0(?)
Cylichna cilindracea	0(?)
Nucula turgida	not found
Chaetozone setosa	not found
Glycinde nordmanni	0(?)
Nephtys hombergii	0
Pholoe minuta	not found
Scalibregma inflatum	not found
Echinocardium cordatum juv.	0(?)

TABLE 6

K8-fa, 1995: Bray-Curtis percentage similarity between stations after squareroot transformation of species' abundances:

	250 m	*500 m*	*2000 m*
100 m	57	57	57
250 m		61	60
500 m			66

TABLE 7

The benthic fauna at G13-1, Aug. 1995. Percentage of occurrence of each species in the total number of samples (16).

POLYCHAETA		*Capitella capitata*	6	*Macropipus* spec. juv.	44
		Notomastus latericeus	6	*Ebalia cranchii*	13
Aphrodita aculeata	6	*Owenia fusiformis*	38	*Corystes cassivelaunus*	44
Harmothoe lunulata	13	*Lagis koreni*	38	*Callianassa subterranea*	63
Gattyana cirrosa	25			*Diastylis bradyi*	19
Sthenelais limicola	19	MOLLUSCA		*Ione thoracica*	6
Anaitides groenlandica	6			*Ampelisca brevicornis*	6
Ophiodromus flexuosus	31	*Nucula turgida*	56	*Ampelisca tenuicornis*	44
Nephtys hombergii	88	*Lepton squamosum*	6		
Nephtys incisa	13	*Kellia suborbicularis*	6	ECHINODERMATA	
Nephtys caeca	19	*Montacuta ferruginosa*	50		
Nephtys spec. juv.	13	*Dosinia exoleta*	6	*Amphiura filiformis*	100
Glycera alba	6	*Dosinia lupinus*	38	*Amphiura chiajei*	44
Glycinde nordmanni	25	*Venus striatula*	19	*Ophiura albida*	13
Goniada maculata	19	*Mysia undata*	6	*Ophiura* spec. juv.	6
Lumbrineris latreilli	75	*Abra alba*	13	*Echinocardium cordatum*	75
Poecilochaetus serpens	6	*Abra alba* juv.	13	*Echinocardium cordatum* juv.	75
Spiophanes kroyeri	13	*Cultellus pellucidus*	50	*Cucumaria elongata*	6
Spiophanes bombyx	63	*Corbula gibba*	88	*Cucumaria frondosa*	25
Scolelepis bonnieri	19	*Turritella communis*	25		
Magelona papillicornis	31	*Natica alderi*	88	OTHER TAXA	
Magelona alleni	19	*Cylichna cilindracea*	6		
Chaetopterus variopedatus	31			Nemertinea	50
Diplocirrus glaucus	6	CRUSTACEA		Turbellaria	6
Scalibregma inflatum	38			Phoroniden	81
Ophelina acuminata	19	*Processa parva*	75	Sipunculida	31

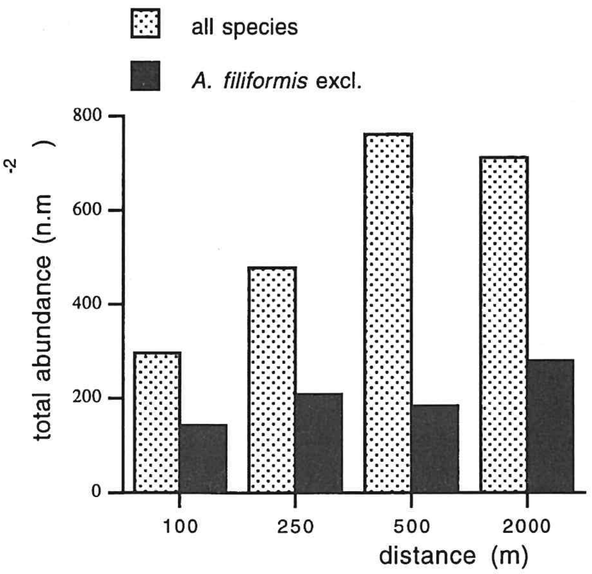

Fig. 6. Total macrofauna abundance at G13-1 (residual current transect).

the lowest similarity to the other stations, the index value is hardly lower than between the other stations. In summary, there is a persistent effect on *E. cordatum* at this location, but no detectable effect on other components of the community.

Location G13-1

sedimentation area, 197 tonnes of oil discharged 8 yr ago, platform absent

At the 4 stations a total number of 55 species were found. An overview of their percentual frequency of occurrence in the samples is given in Table 7. The quantitative data are listed in Table 24 (Appendix). The fauna was strongly dominated by the Echinoderm *Amphiura filiformis*, which accounted on average for 64% of the total fauna abundance. It was found in highest abundance at the remote stations 500-m and 2000-m. However, it was not only due to the high numbers of this species that the total fauna abundance was highest at these stations (Fig. 6). Also when *A. filiformis* is excluded the numerical fauna abundance seems to increase with increasing distance from the discharge site.

Table 24 shows that the total number of species at 100 m was the lowest (26) and at 2000 m the highest (37). Also when the number of species per sample is

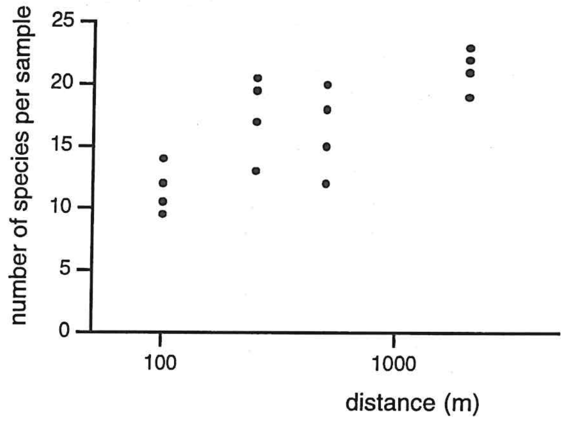

Fig. 7. Numbers of identified species per sample at G13-1 (residual current transect).

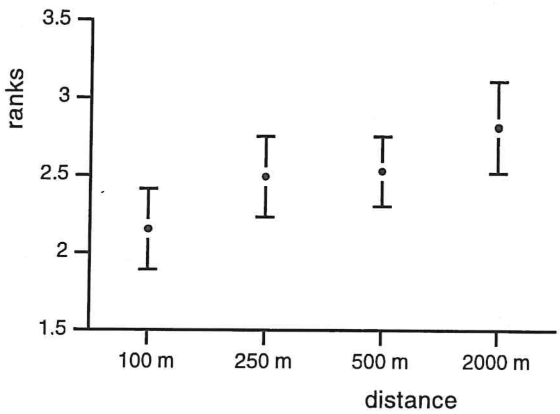

Fig. 8. Relative macrofauna abundance at G13-1 (mean ranks and 95% confidence limits).

considered, numbers seem to increase with increasing distance from the location (Fig. 7). Analysis of variance showed that the mean number at 100 m was significantly lower than at the other stations. Mutual differences between the other stations were non-significant. The low species richness at the station closest to the discharge site corresponds to the usual pattern at OBM-affected well sites.

As was the case for species richness, the relative fauna abundance was lowest at the 100-m station and increased with increasing distance to the platform (Fig. 8). There appeared to be significant differences in the relative abundance of the stations sampled ($p<0.05$, ANOVA). Particularly the difference between 100-m and 2000-m stations was significant (LSD-test). This implies that, on average, most species occurred in relatively low numbers at 100 m and in relatively high numbers at 2000 m.

There were 9 species of which ≥20 specimens were found. These species were tested for possible gradients in their spatial frequency of occurrence (Table 8). Spatial gradients appeared significant for the crustacean *Callianassa subterranea* and for *Echinocardium cordatum* ($p<0.05$). These species were absent at 100 m but occurred frequently at the sta-

TABLE 8

Location G13-1. 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 of occurrence away from the location; 0 = no gradient.

		sign. level (%)	
	sign	*uncorr. test*	*corr. test*
Nephtys hombergii	-	n.s.	n.s.
Lumbrineris latreilli	-	n.s.	n.s.
Spiophanes bombyx	-	n.s.	n.s.
Corbula gibba	+	n.s.	n.s.
Natica alderi	-	n.s.	n.s.
Processa parva	+	n.s.	n.s.
Callianassa subterranea	+	0.5	5
Amphiura filiformis	0	-	-
Echinocardium cordatum	+	0.1	5

TABLE 9

Evaluation of the abundance patterns of 15 OBM-sensitive species at location G13-1.
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	not found
Callianassa subterranea	+
Owenia fusiformis	(?)
Mysella bidentata	not found
Gattyana cirrosa	(?)
Amphiura filiformis	+
Cylichna cilindracea	(?)
Nucula turgida	(?)
Chaetozone setosa	not found
Glycinde nordmanni	(?)
Nephtys hombergii	0
Pholoe minuta	not found
Scalibregma inflatum	0(?)
Echinocardium cordatum juv.	+

TABLE 10

G13-1, 1995: Bray-Curtis percentage similarity between stations after squareroot transformation of species' abundances:

	250 m	*500 m*	*2000 m*
100 m	62	59	49
250 m		70	59
500 m			68

tions further away. Both species are known as sensitive to OBM contamination (DAAN *et al.*, 1994). An inspection of the abundance data of other known OBM sensitive species shows that also *Amphiura filiformis* occurred in relatively low numbers in the vicinity of the discharge site and in increasing abundance at larger distance. The other species were generally too sparsely distributed to discern a clear spatial pattern.

A comparison between stations based on the Bray-Curtis similarity index, shows that the 100-m station has the lowest resemblance with the 2000-m reference station (Table 10). The highest similarities were found between the 250-m and 500-m stations and between the 500-m and 2000-m stations. The values of the index clearly suggest a spatial gradient in the fauna composition of the sediment over the transect sampled.

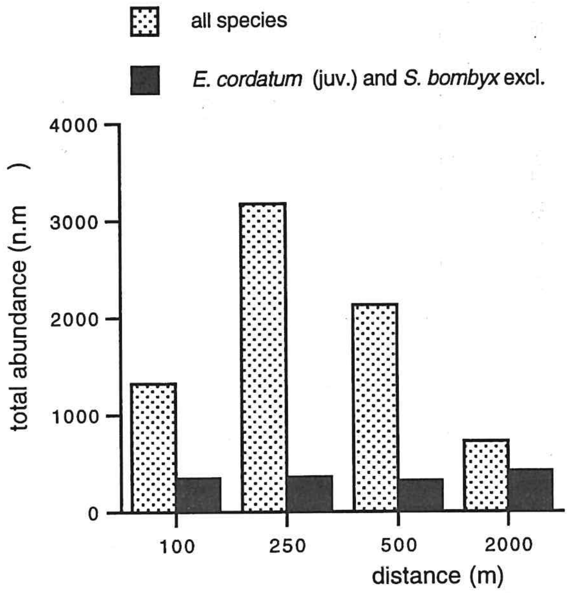

Fig. 9. Total macrofauna abundance at K12-6 (residual current transect).

TABLE 11

The benthic fauna at K12-6, Aug. 1995. Percentage of occurrence of each species in the total number of samples (16).

POLYCHAETA		MOLLUSCA		*Corystes cassivelaunus*	19
				Callianassa subterranea	13
Harmothoe lunulata	6	*Nucula turgida*	75	*Decapoda larven*	13
Sigalion mathildae	38	*Montacuta ferruginosa*	6	*Iphinoe trispinosa*	6
Sthenelais limicola	50	*Dosinia lupinus*	13	*Diastylis bradyi*	6
Eteone longa	13	*Venus striatula*	19	*Melita dentata*	6
Eteone lactea	6	*Venus* spec. juv.	6	*Hippomedon denticulatus*	19
Anaitides maculata	6	*Mactra corallina*	13	*Jassa falcata*	19
Anaitides subulifera	6	*Tellina fabula*	100	*Corophium insidiosum*	6
Nephtys hombergii	88	*Abra prismatica*	6		
Nephtys cirrosa	13	*Abra alba*	6	ECHINODERMATA	
Nephtys spec. juv.	13	*Abra alba* juv.	94		
Goniada maculata	75	*Ensis ensis*	6	*Astropecten irregularis*	31
Lumbrineris latreilli	50	*Ensis* spec. juv.	25	*Amphiura filiformis*	6
Scoloplos armiger	13	*Natica alderi*	81	*Ophiura* spec. juv.	81
Spio filicornis	13			*Echinocardium cordatum*	25
Spiophanes bombyx	94	CRUSTACEA		*Echinocardium cordatum* juv.	100
Scolelepis bonnieri	50			*Psammechinus miliaris*	6
Magelona papillicornis	69	*Processa parva*	19		
Chaetozone setosa	38	*Pontophilus bispinosus*	31	OTHER TAXA	
Notomastus latericeus	19	*Pagurus bernhardus*	13		
Owenia fusiformis	75	*Macropipus* spec. juv.	94	Nemertinea	25
Lanice conchilega	56	*Ebalia cranchii*	13	Nematoda	6
Lagis koreni	38	*Thia scutellata*	13	Anthozoa	25

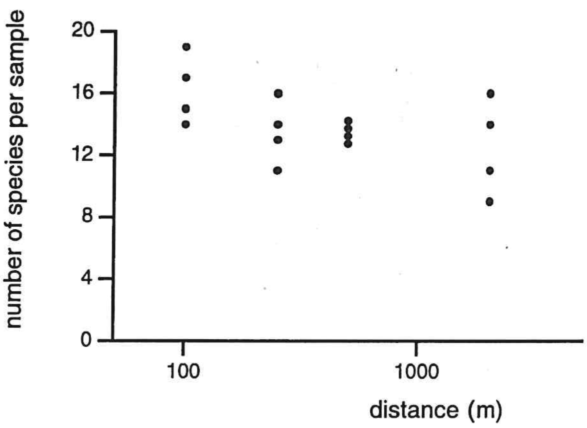

Fig. 10. Numbers of identified species per sample at K12-6 (residual current transect).

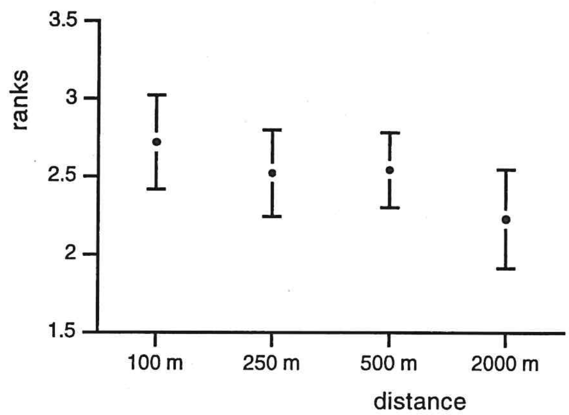

Fig. 11. Relative macrofauna abundance at K12-6 (mean ranks and 95% confidence limits).

Location K12-6

transition zone, 205 tonnes of oil discharged 8 yr ago, platform present

The laboratory analyses yielded 48 identified species. In Table 11 their percentual occurrence is summarized. The original data are listed in Table 25 (Appendix). The fauna in the area was numerically dominated by the polychaete *Spiophanes bombyx* and juvenile *Echinocardium cordatum*. Together these species accounted for 81% of the total fauna abundance. Both species were most abundant at the 250-m station. The large variation in total fauna abundance at the different stations (Fig. 9) is largely due to the variable numbers of these dominant species.

TABLE 12

Location K12-6. 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 of occurrence away from the location; 0 = no gradient.

		sign. level (%)	
	sign	*uncorr. test*	*corr. test*
Sthenelais limicola	-	n.s.	n.s.
Nephtys hombergii	-	n.s.	n.s.
Goniada maculata	-	1	0.5
Lumbrineris latreili	-	0.5	1
Spiophanes bombyx	+	n.s.	n.s.
Magelona papillicornis	+	5	0.5
Owenia fusiformis	-	n.s	n.s.
Lanice conchilega	+	n.s.	n.s.
Lagis koreni	+	n.s.	n.s.
Nucula turgida	-	n.s.	n.s.
Tellina fabula	0	-	-
Natica alderi	-	n.s.	n.s.

When these species are excluded, the total fauna abundance fluctuated within a narrow range of 320 - 420 ind·m^{-2}.

The numbers of species found at each of the stations ranged between 24 (2000 m) and 28 (100 m). Per sample these numbers were between 9 and 19 (Fig. 10). Analysis of variance revealed no significant differences in the numbers of species per sample between the stations ($p>0.05$).

In terms of relative fauna abundance the 100-m station ranked highest, whereas the relative abundance tended to decrease with increasing distance (Fig. 11). In other words, species occurred on average in the highest densities at 100 m and in the lowest densities at 2000 m. In spite of this seeming tendency, there appeared to be no significant differences in relative fauna abundance of the stations sampled (ANOVA, $p>0.05$). This indicates that the relative fauna abundance was not affected by the former discharges.

Possible gradients in the spatial abundance patterns of 12 species were tested by logit regression (Table 12). For 3 polychaete species a gradient appeared significant ($p<0.05$). For *Goniada maculata* and *Lumbrineris latreilli* the sign of the gradient was negative (decreasing frequency of occurrence with increasing distance to the platform) and for *Magelona papillicornis* the sign was positive. During former surveys the latter species has shown to be sensitive to discharges of OBM cuttings. Particularly at the nearby location K12-a the species showed similar abundance patterns during several surveys (Mulder *et al.*, 1987, 1988; Daan *et al.*, 1990; Daan & Mulder, 1993). Therefore the gradient may be considered indicative of a persistent effect.

In Table 14 the Bray-Curtis values for percentage similarity between stations are listed. The fauna compositions at the 250-m and 500-m stations appear to have the highest similarity to one another. However,

TABLE 13

Evaluation of the abundance patterns of 15 OBM-sensitive species at location K12-6.
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	0(?)
Montacuta ferruginosa	0(?)
Harpinia antennaria	not found
Callianassa subterranea	0(?)
Owenia fusiformis	0
Mysella bidentata	not found
Gattyana cirrosa	not found
Amphiura filiformis	0(?)
Cylichna cilindracea	not found
Nucula turgida	0
Chaetozone setosa	0(?)
Glycinde nordmanni	not found
Nephtys hombergii	0
Pholoe minuta	not found
Scalibregma inflatum	not found
Echinocardium cordatum juv.	0

the 100-m station is hardly different. The 2000-m station clearly differs from the other stations, indicating a gradient in fauna composition along the transect sampled. However, such a gradient might have a natural cause, *viz.* a change in the sediment texture along the transect. This is supported by the fact, that during fieldwork the Van Veen grab appeared to easily penetrate in the sediment up to 500 m, whereas at 2000 m the sediment seemed to be more hard-packed, because the sample volumes were clearly smaller at this station.

Location L14-s1

erosion zone, 47 tonnes of oil discharged 7 yr ago, platform present (subsea completion)

A total of 51 identified species were found at the 4 stations sampled. In Table 15 their percentual occurrence in the samples is summarized. The original data are listed in Table 26 (Appendix). The polychaetes *Spiophanes bombyx* and *Lanice conchilega* and juvenile specimens of *Echinocardium cordatum* dominated the fauna by number. On average these 3 species accounted for 65% of the faunal abundance in the area. Particularly the distribution pattern of the latter species was quite heterogeneous. Densities were lowest at the 100-m station (≈20 ind·m^{-2}), culminated at 250 m (250 ind·m^{-2}) and then gradually decreased beyond that distance to ≈100 ind·m^{-2} at 1000 m. In spite of the low densities at 100 m, logit regression did not reveal a significant gradient in frequency of occurrence. Also the other 2 species showed variable densities but no significant gradients were found.

TABLE 14

K12-6, 1995: Bray-Curtis percentage similarity between stations after squareroot transformation of species' abundances:

	250 m	*500 m*	*2000 m*
100 m	70	71	51
250 m		79	47
500 m			55

The total fauna abundance was highest at 250 m and 500 m, especially because of the high abundances of the three dominant species at these stations (Fig. 12). However, even when the dominant species are excluded, the faunal densities appeared to be highest at these stations. Densities at 100 m and 1000 m were lower, but similar to each other.

Fig. 13 shows that the mean number of species per sample was somewhat higher at 500 m than at the other stations. Analysis of variance revealed that the number of species at 500 m was significantly higher ($p<0.05$). Between the other stations there were no significant differences. There is no indication that the small peak in species richness at 500 m can be attributed to the spatial pattern of contamination around the location.

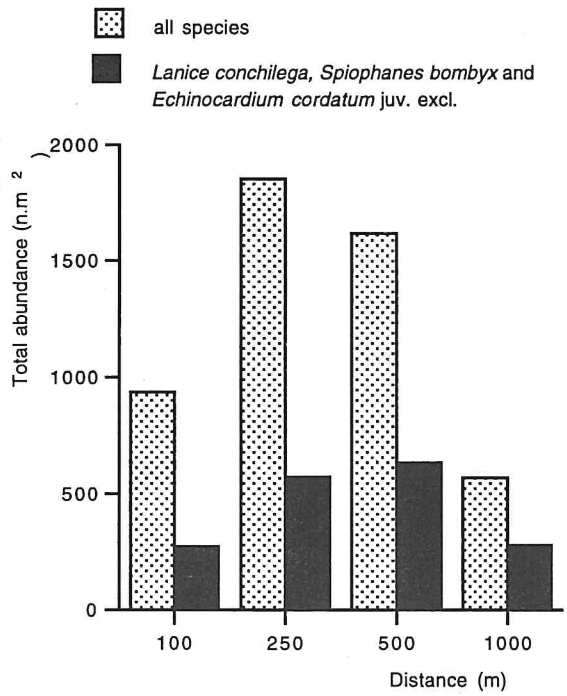

Fig. 12. Total macrofauna abundance at L14-s1 (residual current transect).

The relative fauna abundance appeared to be high

TABLE 15

The benthic fauna at location L14-s1, August 1994. Percentage of occurrence of each species in the total number of samples (16).

POLYCHAETA		*Owenia fusiformis*	25	*Diastylis bradyi*	69
		Lanice conchilega	100	*Atylus falcatus*	6
Harmothoe lunulata	13	*Lagis koreni*	75	*Hippomedon denticulatus*	31
Harmothoe longisetis	31			*Orchomenella nana*	6
Harmothoe spec. juv.	19	MOLLUSCA		*Bathyporeia guilliamsoniana*	13
Eteone longa	13			*Bathyporeia elegans*	6
Eteone lactea	50	*Donax vittatus*	6		
Anaitides groenlandica	25	*Laevicardium crassum*	13	ECHINODERMATA	
Anaitides maculata	31	*Dosinia lupinus*	69		
Eumida sanguinea	69	*Venus striatula*	19	*Astropecten irregularis*	13
Nereis longissima	6	*Venus verrucosa*	6	*Amphiura filiformis*	6
Nephtys cirrosa	94	*Spisula elliptica*	94	*Ophiura albida*	69
Nephtys caeca	6	*Tellina pygmaeus*	75	*Ophiura* spec. juv.	94
Nephtys spec. juv.	6	*Abra prismatica*	19	*Echinocardium cordatum* juv.	88
Glycera alba	19	*Ensis arcuatus*	81	*Echinocyamus pusillus*	56
Glycera spec. juv.	31	*Ensis* spec. juv.	13		
Goniada maculata	13	*Thracia phaseolina*	13	TUNICATA	
Scoloplos armiger	44	*Natica alderi*	44		
Paraonis fulgens	6			*Molgula oculata*	94
Spio filicornis	75	CRUSTACEA			
Spiophanes bombyx	88			OTHER TAXA	
Aonides paucibranchiata	6	*Processa parva*	19		
Scolelepis bonnieri	50	*Macropipus holsatus*	13	Nemertinea	94
Magelona papillicornis	6	*Macropipus* spec. juv.	100	Nematoda	50
Ophelia limacina	25	*Thia scutellata*	19	Amphioxus	25
Travisia forbesii	19	*Decapoda larven*	6		
Ophelina acuminata	6	*Gastrosaccus spinifer*	81		

at 500 m and low at 100 m and 1000 m (Fig. 14). Analysis of variance showed significant differences in relative fauna abundance between the stations sampled and it appeared from an LSD-test that the 100-m and 1000-m stations scored significantly lower than the 500-m station ($p<0.05$). The 250-m station did not differ significantly from any of the other stations.

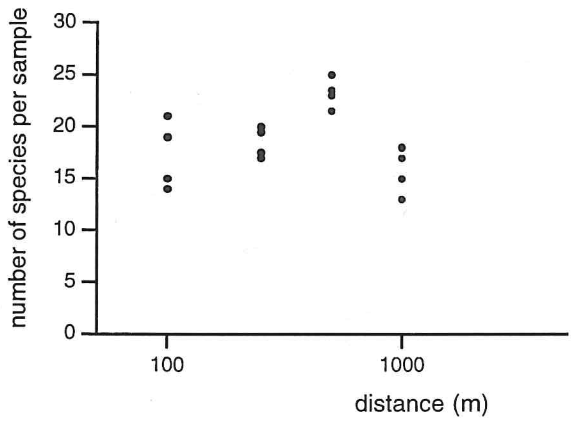

Fig. 13. Numbers of identified species per sample at L14-s1 (residual current transect).

The presence of significant gradients in frequency of occurrence was tested by logit regression for 14 species of which ≥20 specimens were found (Table 16). In not one of the species such a gradient was significant. An inspection of the abundance patterns of these species also showed that for most species there was no tendency for such a gradient, except for the polychaetes *Spio filicornis* and *Spiophanes bombyx* and for juvenile *E. cordatum* (Table 17). For *S. filicornis* and *S. bombyx* the apparent gradient did not correspond to their abundance patterns around OBM locations in previous surveys. *S. filicornis* was found in higher numbers at increasing distance from the location, whereas this species has never shown to be an OBM-sensitive species. On the other hand, *S. bombyx* has been identified as sensitive for OBM cutting discharges but occurred in increasing numbers on approach of the platform. Therefore, the seeming abundance gradients of these species can not be explained by their characteristic response to OBM contamination. A local natural gradient seems more plausible. Only for *E. cordatum* the abundance pat-

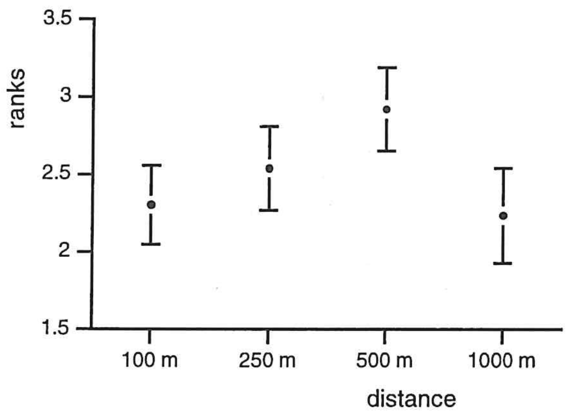

Fig. 14. Relative macrofauna abundance at L14-s1 (mean ranks and 95% confidence limits).

tern corresponds with its known high sensitivity to OBM. In fact the low density of *E. cordatum* in the vicinity of the platform is therefore the only indication that there is still an effect of the former discharges on the macrobenthos.

Bray-Curtis indices for percentage similarity between stations are listed in Table 18. The 250-m and 500-m stations appear to have the highest similarity, whereas the 1000-m station seemed to be slightly more different.

Location L13-10

Erosion zone, 268 tonnes of oil discharged 8 yr ago,

TABLE 16

Location L14-s1. 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 of occurrence away from the location; 0 = no gradient.

		sign. level (%)	
	sign	uncorr. test	corr. test
Eumida sanguinea	-	n.s.	n.s.
Nephtys cirrosa	+	n.s.	n.s.
Spio filicornis	+	n.s.	n.s.
Spiophanes bombyx	-	n.s.	n.s.
Lanice conchilega	0	-	-
Spisula elliptica	-	n.s.	n.s.
Tellina pygmaeus	+	n.s	n.s.
Ensis arcuatus	+	n.s.	n.s.
Macropipus spec. juv.	0	-	-
Gastrosaccus spinifer	+	n.s.	n.s.
Diastylis bradyi	+	n.s.	n.s.
Ophiura albida	-	n.s.	n.s.
Echinocyamus pusillus	+	n.s.	n.s.
Molgula oculata	-	n.s.	n.s.

TABLE 17

Evaluation of the abundance patterns of 15 OBM-sensitive species at location L14-s1.
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	not found
Montacuta ferruginosa	not found
Harpinia antennaria	not found
Callianassa subterranea	not found
Owenia fusiformis	0(?)
Mysella bidentata	not found
Gattyana cirrosa	not found
Amphiura filiformis	0(?)
Cylichna cilindracea	not found
Nucula turgida	not found
Chaetozone setosa	not found
Glycinde nordmanni	not found
Nephtys hombergii	not found
Pholoe minuta	not found
Scalibregma inflatum	not found
Echinocardium cordatum juv.	+

platform present

A total number of 60 species was found around this location. Their percentual occurrence in the samples is given in Table 19. The original data are listed in Table 27 (Appendix). The fauna was numerically dominated by two tube-building polychaetes, *Lanice conchilega* and *Spiophanes bombyx*. These species accounted for 41 and 15% of the total number of individuals respectively. *L. conchilega* was particularly abundant at the 250-m and 500-m stations, *S. bombyx* occurred in the highest numbers at 100-m. The two dominant species mainly determine the spatial pattern in fauna abundance along the transect sampled (Fig. 15). When these species are excluded the remaining numbers of individuals are lowest at the 100-m and 250-m stations and highest at the remote stations.

The total number of species was highest at the 500-m station (39). At the other stations the numbers

TABLE 18

L14-s1, 1994: Bray-Curtis percentage similarity between stations after squareroot transformation of species' abundances:

	250 m	500 m	1000 m
100 m	71	66	62
250 m		81	59
500 m			63

TABLE 19

The benthic fauna at L13-10, Aug. 1995. Percentage of occurrence of each species in the total number of samples (16).

POLYCHAETA		*Chaetozone setosa*	94	*Eualus pusiolus*	6
		Ophelia limacina	31	*Iphinoe trispinosa*	6
Harmothoe lunulata	6	*Owenia fusiformis*	50	*Diastylis bradyi*	38
Harmothoe longisetis	13	*Lanice conchilega*	100	*Melita dentata*	6
Harmothoe spec. juv.	6	*Lagis koreni*	56	*Hippomedon denticulatus*	25
Sigalion mathildae	6			*Leucothoe incisa*	13
Sthenelais limicola	13	MOLLUSCA		*Bathyporeia guilliamsoniana*	6
Eteone longa	19			*Bathyporeia elegans*	19
Eteone lactea	6	*Laevicardium crassum*	13	*Harpinia antennaria*	13
Mysta barbata	25	*Dosinia lupinus*	75	*Aora typica*	13
Anaitides groenlandica	13	*Venus* spec. juv.	38	*Caprella* spec.	6
Anaitides spec. juv.	6	*Mactra corallina*	6	*Corophium insidiosum*	31
Eumida sanguinea	44	*Spisula* spec. juv.	56		
Gyptis capensis	6	*Tellina pygmaeus*	38	ECHINODERMATA	
Proceraea cornuta	6	*Tellina fabula*	38		
Nephtys hombergii	6	*Abra prismatica*	6	*Amphiura filiformis*	6
Nephtys incisa	6	*Gari fervensis*	6	*Ophiura albida*	6
Nephtys cirrosa	69	*Ensis arcuatus*	100	*Ophiura* spec. juv.	69
Nephtys spec. juv.	69	*Thracia phaseolina*	75	*Echinocardium cordatum* juv.	75
Glycera spec. juv.	31	*Natica alderi*	44	*Echinocyamus pusillus*	38
Glycinde nordmanni	19			*Molgula oculata*	25
Goniada maculata	6	CRUSTACEA			
Scoloplos armiger	63			OTHER TAXA	
Paraonis fulgens	25	*Processa parva*	69		
Poecilochaetus serpens	6	*Pontophilus trispinosus*	6	Nemertinea	88
Spio filicornis	75	*Pagurus bernhardus*	19	Nematoda	31
Spiophanes bombyx	88	*Macropipus* spec. juv.	88	Amphioxus	50
Aonides paucibranchiata	13	*Thia scutellata*	38	Phoroniden	6
Scolelepis bonnieri	25	Decapoda larvae	6	Anthozoa	6
Magelona papillicornis	13	*Gastrosaccus spinifer*	19		

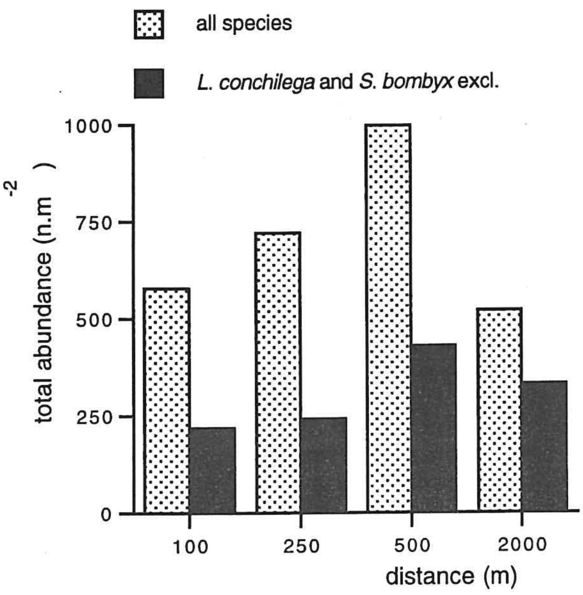

Fig. 15. Total macrofauna abundance at L13-10 (residual current transect).

were within a narrow range of 29 - 31 species per station. Per sample the numbers of species fluctuated from 12 to 24 (Fig. 16). On average the numbers were again highest at 500 m. However analysis of variance did not reveal significant differences between the stations.

The relative fauna abundance does not show any consistent spatial trend over the transect sampled (Fig. 17). There appeared to be no significant differences in the relative abundance of the different stations ($p>0.05$, ANOVA). This suggests that there was no station where the various species were generally more abundant (or less abundant) than at any of the other stations.

Logit regression was performed for 10 species of which ≥20 specimens were found (Table 20). Significant gradients were shown by 3 species, the mollusc *Dosinia lupinus*, the crustacean *Processa parva* and juvenile *Echinocardium cordatum*. All showed

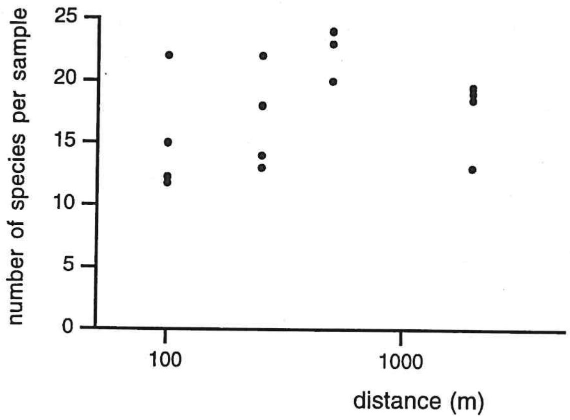

Fig. 16. Numbers of identified species per sample at L13-10 (residual current transect).

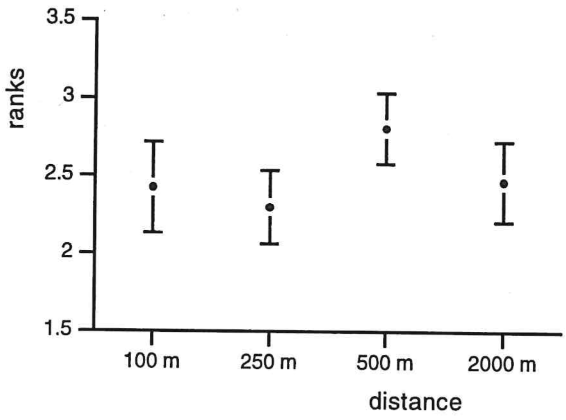

Fig. 17. Relative macrofauna abundance at L13-10 (mean ranks and 95% confidence limits).

increasing frequency of occurrence with increasing distance to the platform. In first instance the test also suggested a significant gradient in the polychaete *Nephtys cirrosa*, but after correction for overdispersion the gradient appeared to be no longer significant. Of those species which earlier have been identified as sensitive to OBM cutting discharges, *E. cordatum* (juveniles) was the only one which according to its abundance pattern still displayed the characteristic response (Table 21). However, nearly all other species were either not found or so sparsely distributed that it was impossible to discover any pattern that could suggest a spatial abundance gradient.

On the basis of the Bray-Curtis index for percentage similarity between stations the fauna composition at the 100-m station seems to be slightly different from the other stations (Table 22). The index value is consistently lower when this station is compared with the other stations than for comparisons within the latter group of stations. This may indicate that the sampling effort has been not extensive enough to detect all effects that occur at species level at the 100-m station, but adequate to detect a change in fauna composition at the community level.

TABLE 20

Location L13-10. 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 of occurrence away from the location; 0 = no gradient.

		sign. level (%)	
	sign	*uncorr. test*	*corr. test*
Nephtys cirrosa	+	1	n.s.
Spio filicornis	-	n.s.	n.s.
Spiophanes bombyx	-	n.s.	n.s.
Chaetozone setosa	-	n.s.	n.s.
Lanice conchilega	0	-	-
Dosinia lupinus	+	0.5	0.1
Ensis arcuatus	0	-	-
Thracia phaseolina	+	n.s.	n.s.
Processa parva	+	0.1	0.1
Echinocardium cordatum juv.	+	0.1	0.5

4 DISCUSSION

The present study has yielded a large amount of data

TABLE 21

Evaluation of the abundance patterns of 15 OBM-sensitive species location L13-10.
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	not found
Montacuta ferruginosa	not found
Harpinia antennaria	0 (?)
Callianassa subterranea	not found
Owenia fusiformis	0(?)
Mysella bidentata	not found
Gattyana cirrosa	not found
Amphiura filiformis	0(?)
Cylichna cilindracea	not found
Nucula turgida	not found
Chaetozone setosa	-
Glycinde nordmanni	0(?)
Nephtys hombergii	0(?)
Pholoe minuta	not found
Scalibregma inflatum	not found
Echinocardium cordatum juv.	+

TABLE 22

L13-10, 1995: Bray-Curtis percentage similarity between stations after squareroot transformation of species' abundances:

	250 m	*500 m*	*2000 m*
100 m	50	57	54
250 m		69	62
500 m			68

and because there are so many locations that were investigated, each with its specific characteristics (sediment structure, discharge load, time of discharge, presence or absence of a platform), it may be difficult to the reader of this report to obtain a general impression of the outcome of this study. Therefore the results are summarized in the table below to give a short overview.

The chemical sediment analyses have detected elevated oil concentrations at 5 locations. Except for L13-10 where a concentration of 200 mg oil·kg^{-1} dry sediment was found, the concentration levels were low (always less than 50 mg·kg^{-1} dry sediment). At each of these 5 locations the presence of oil had already been visually observed during the fieldwork. However, there was also one location (K11-10) where traces of oil were observed in several samples at 100 m, but analysis of the subsamples failed to detect elevated concentrations. Apparently, visual inspection of complete sediment samples may provide a more sensitive method to detect the presence of oil than advanced chemical analyses of subsamples. Also at location L10-23 oil has been visually observed, albeit not along the regular sampling transect, but in some additional samples that were not further analysed. Whether oil was detected or not did not depend on hydrographic regime, on the amount of oil discharged or the time elapsed since discharges were finished. In fact oil was detected at the location with the largest and relatively recent discharge (L13-10, 268 tonnes of oil 8 years ago), but also at the location with the smallest and oldest discharge (L11-7, 13 tonnes of oil 13 years ago). It is doubtful, therefore, whether at those locations where no oil was found in the sediment the oil has completely disappeared. In view of the very patchy distribution of oil in the sediment as visually observed in the samples at the contaminated locations, it seems more likely that such a patchy distribution also occurs at the locations where no oil was found. Moreover, it can not be excluded that higher concentrations may occur in deeper sediment layers that were not investigated. This means that a more extensive sampling programme could have revealed sites where elevated concentrations do still occur.

Significant gradients in the abundance pattern of *Echinocardium cordatum* were found at 7 of the 12 locations investigated. For 2 of these locations, L14-s1 and L13-10, the gradient was only detected on the basis of the abundance pattern of juveniles, since adults were not found around these locations. Further, at 2 locations (K11-10 and Q8-a2) the abundance pattern was indicative of an effect, but there was no statistical significance of a gradient. An effect on *E. cordatum* was detected at all locations in the sedimentation area, at 2 or 3 locations in the transition zone and at 2 or 3 locations in the erosion zone. Affected populations were found near production platforms but also at abandoned well sites (*e.g.* G13-1). Further, *E. cordatum* was not only affected in its abundance at locations where extensive discharges had taken place a relatively short time ago (L13-10)

Location	*area*	*oil disch. (tonnes)*	*how long ago (yr)*	*platform*	*oil vis. observed*	*oil analysis*	*effect on E.cordatum*	*other effects*
K7-fa	sed.	80	11	pres.	-	-	+	
K8-fa	sed.	108	11	pres.	-	-	+	-
G13-1	sed.	197	8	abs.	+	+	+	+
L10-23	trans.	26	13	pres.	-(*)	-	+	
L11-7	trans.	13	13	abs.	+	+	-	
K10-c	trans.	162	12	pres.	-	-	-	
K12-6	trans.	205	8	pres.	+	+	+	+
K11-10	trans.	198	8	abs.	+	-	?	
L14-s1	eros.	47	7	pres.	+	+	+ (juv.)	-
Q8-a2	eros.	107	10	pres.	-	-	?	
L13-10	eros.	268	8	pres.	+	+	+ (juv.)	+
Q8-5	eros.	145	11	pres.	-	-	-	

(*) oil not observed at regular stations, but some additional samples did contain oil

Locations earlier investigated:

L4-a	sed.	178	8	pres.	+	+	+	+
K12-a	trans.	288	6	pres.	+	+	+	+
P6-b	eros.	393	8	pres.	+	+	+	+

but also over the transect at L10-23, where a relatively small amount of OBM had been discharged 13 years ago, the species displayed a conspicuous gradient. This may seem surprising since no traces of oil were found along this transect. Although the local abundance gradient could have a natural cause it can not be excluded that the gradient should be explained as an effect of the former discharges. This is a warning that the results of the oil analyses should be carefully interpreted. In spite of the absence of any trace of oil in the samples, there may be a persistent effect of the former discharges. One reason is that the distribution of discharged material in the sediment is very patchy so that it is conceivable that such oil patches do not always turn up in the samples. On the other hand, elevated oil concentrations due to the former discharges are not necessarily the actual cause of depressed population densities. Recovery of initially exterminated adult populations may take several years and failing recruitment (by natural causes) may retard such a recovery. Indeed, the situation at L11-7 suggests that the presence of old base oil in the sediment does not necessarily have an adverse effect on *E. cordatum*. At this location traces of oil were observed at 100 m and detected by the chemical analyses (although the concentration was only slightly beyond background level), but population densities of *E. cordatum* were not depressed at this station.

The 5 locations for which further macrofauna analyses have been carried out, were all locations where an effect on *E. cordatum* has been assessed. At 3 of these location additional effects on the macrofauna could be detected. At G13-1 these effects were most pronounced and became manifest by clear gradients in *Callianassa subterranea* and *Amphiura filiformis*. Both species, which are characteristic of the sedimentation area (*e.g.* HOLTMANN *et al.*, 1995), have shown to be indicative of OBM contamination of sediments (DAAN *et al.*, 1994) and the latter species has been found to occur in reduced abundance within a radius of 2 - 6 km from multi-well sites in the Norwegian sector (OLSGARD & GRAY, 1995). Also at the community level effects were found. Species richness and relative fauna abundance were substantially lower at 100 m than at the remote stations and a comparison based on Bray-Curtis similarity suggested that the fauna composition at 100 m was different from the other stations. Less pronounced effects were observed at L13-10, where *Dosinia lupinus* and *Processa parva* displayed a gradient and the Bray-Curtis values indicated a slightly different fauna composition at 100 m. At K12-6 the gradient shown by *Magelona papillicornis* was the only indication of an additional effect. The consistent response of *E. cordatum* at all these locations shows that this species has the highest indicative value for the detection of biological effects of former OBM cutting discharges.

During this study, the occurrence of elevated oil concentrations in surface sediments and associated biological effects generally appeared to be limited to the 100-m station. Only at L13-10 the oil concentration at 100 m was at a similar level as measured during previous surveys at the locations L4-a and P6-b (≈100-200 $mg{\cdot}kg^{-1}$ dry sediment, GROENEWOUD (1995)), but considerably lower than at K12-a (≈500-1500 $mg{\cdot}kg^{-1}$ dry sediment, (DAAN & MULDER, 1993)). At all other locations the maximum concentrations in the surface sediment were consistently below 50 $mg{\cdot}kg^{-1}$ dry sediment and at 3 locations no oil and no effect were found at all. This indicates that the concentration levels as formerly measured at L4-a, K12-a and P6-b can not be considered as representative of the OBM locations on the Dutch Continental Shelf. Probably, the concentrations will generally be on a lower level at most locations (at least at the standard 100-m station; within 100 m higher concentrations can be expected). The latent presence of elevated oil concentrations confirms the low degradation rate of baseoil in North Sea sediments. During the long-term studies at L4-a, K12-a and P6-b the area where persistent biological effects occur was estimated to extend within a radius of a few hundred meters from these platforms. This estimate was based on the fact that the 100-m stations at these locations were substantially affected and that to a lesser extent effects were also found at the 250-m stations, whereas at 500 m biological effects were not detectable. The results of the present study indicate that the occurrence of biological effects was generally limited to the 100-m station. The 250-m stations seemed to be unaffected. Although a more extensive sampling programme might have revealed some more effects at a few locations, this suggests that the zone of persistent environmental stress generally extended within a radius of ≥100 m and <250 m from well sites or, in other words, within about 200 m from well sites.

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APPENDIX

Table 23. Data platform K8-fa, survey Aug. 1995, 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		2000	
Number of analysed samples	4		4		4		4	
POLYCHAETA								
Harmothoe lunulata							1.4	(1)
Harmothoe spec. juv.	1.4	(1)						
Polynoe kinbergi							2.8	(1)
Sthenelais limicola	5.6	(3)						
Anaitides groenlandica	1.4	(1)						
Ophiodromus flexuosus	1.4	(1)	5.6	(4)	2.8	(2)		
Gyptis capensis	1.4	(1)	1.4	(1)	1.4	(1)		
Nereis longissima	7.0	(3)	1.4	(1)				
Nephtys hombergii	19.5	(4)	20.9	(4)	19.5	(3)	15.3	(4)
Nephtys caeca	1.4	(1)	15.3	(4)	4.2	(2)	5.6	(2)
Glycinde nordmanni	4.2	(2)						
Goniada maculata	4.2	(2)					1.4	(1)
Lumbrineris latreilli	65.3	(4)	29.2	(4)	20.9	(4)	5.6	(3)
Spiophanes bombyx	68.1	(4)	25.0	(4)	18.1	(4)	26.4	(4)
Magelona papillicornis							1.4	(1)
Magelona alleni	13.9	(4)	1.4	(1)	4.2	(2)		
Tharyx marioni	1.4	(1)						
Diplocirrus glaucus	2.8	(2)					1.4	(1)
Scalibregma inflatum	1.4	(1)	2.8	(2)			2.8	(2)
Ophelia limacina	1.4	(1)						
Ophelina acuminata							1.4	(1)
Notomastus latericeus	2.8	(2)					2.8	(2)
Owenia fusiformis	114.0	(4)	16.7	(4)	22.2	(4)	33.4	(4)
Myriochele oculata	26.4	(4)	1.4	(1)				
Lanice conchilega	13.9	(1)	11.1	(1)			4.2	(3)
Polycirrus medusa							1.4	(1)
Lagis koreni	1.4	(1)						
Ampharete finmarchica	1.4	(1)						
MOLLUSCA								
Montacuta ferruginosa	1.4	(1)	2.8	(2)	4.2	(2)	4.2	(2)
Mysella bidentata	1.4	(1)					2.8	(1)
Acanthocardia echinata	2.8	(2)					1.4	(1)
Dosinia lupinus	9.7	(3)	4.2	(2)	1.4	(1)		
Venus striatula					1.4	(1)	1.4	(1)
Spisula spec. juv.					5.6	(3)		
Abra alba	1.4	(1)	1.4	(1)			2.8	(2)
Abra alba juv.	335.0	(4)	4.2	(3)	193.2	(4)	102.9	(4)

Table 23. continued.

Distance to platform (m)	100		250		500		2000	
Number of analysed samples	4		4		4		4	
Cultellus pellucidus	20.9	(3)	1.4	(1)	2.8	(1)	4.2	(3)
Thracia convexa	1.4	(1)						
Natica alderi	1.4	(1)	2.8	(2)	1.4	(1)	1.4	(1)
Cylichna cilindracea	1.4	(1)	1.4	(1)				
CRUSTACEA								
Processa parva	5.6	(3)	1.4	(1)			4.2	(3)
Macropipus spec. juv.	1.4	(1)						
Ebalia cranchii			1.4	(1)				
Corystes cassivelaunus	1.4	(1)	1.4	(1)	2.8	(1)	4.2	(2)
Callianassa subterranea	55.6	(4)	83.4	(4)	16.7	(3)	30.6	(4)
Ione thoracica	1.4	(1)	2.8	(1)			1.4	(1)
Orchomenella nana	1.4	(1)						
Ampelisca tenuicornis	1.4	(1)			1.4	(1)		
ECHINODERMATA								
Amphiura filiformis	7.0	(4)			4.2	(3)		
Echinocardium cordatum	1.4	(1)	2.8	(2)	15.3	(4)	18.1	(3)
Echinocardium cordatum juv.	1.4	(1)						
OTHER TAXA								
Nemertinea	P	(3)	P	(4)	P	(1)	P	(3)
Nematoda			1.4	(1)				
Turbellaria	2.8	(1)					1.4	(1)
Phoroniden	P	(4)	P	(3)	P	(1)	P	(3)
Sipunculida	1.4	(1)					2.8	(2)
Anthozoa	1.4	(1)	1.4	(1)	1.4	(1)	1.4	(1)
Total nr. of individuals	821		246		345		292	
Nr. of identified species	39		24		18		27	
P= present (not counted)								

Table 24. Data location G13-1, survey Aug. 1995, 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 well site (m)	100		250		500		2000	
Number of analysed samples	4		4		4		4	
POLYCHAETA								
Aphrodita aculeata	1.4	(1)						
Harmothoe lunulata					2.8	(2)		
Gattyana cirrosa							19.5	(4)
Sthenelais limicola	2.8	(1)	4.2	(2)				
Anaitides groenlandica							1.4	(1)
Ophiodromus flexuosus			2.8	(2)			4.2	(3)
Nephtys hombergii	7.0	(3)	13.9	(4)	9.7	(4)	4.2	(3)
Nephtys incisa							4.2	(2)
Nephtys caeca			1.4	(1)	1.4	(1)	1.4	(1)
Nephtys spec. juv.							2.8	(2)
Glycera alba	1.4	(1)						
Glycinde nordmanni	1.4	(1)			2.8	(2)	1.4	(1)
Goniada maculata	4.2	(2)	1.4	(1)				
Lumbrineris latreilli	8.3	(4)	9.7	(3)	11.1	(3)	4.2	(2)
Poecilochaetus serpens							1.4	(1)
Spiophanes kroyeri							2.8	(2)
Spiophanes bombyx	40.3	(3)	22.2	(3)	15.3	(3)	1.4	(1)
Scolelepis bonnieri	4.2	(2)	1.4	(1)				
Magelona papillicornis			5.6	(4)	4.2	(1)		
Magelona alleni					2.8	(1)	2.8	(2)
Chaetopterus variopedatus	1.4	(1)					23.6	(4)
Diplocirrus glaucus			1.4	(1)				
Scalibregma inflatum			2.8	(2)	1.4	(1)	11.1	(3)
Ophelina acuminata	1.4	(1)					2.8	(2)
Capitella capitata	1.4	(1)						
Notomastus latericeus			1.4	(1)				
Owenia fusiformis	4.2	(2)	1.4	(1)	5.6	(2)	2.8	(1)
Lagis koreni	1.4	(1)			2.8	(2)	11.1	(3)
MOLLUSCA								
Nucula turgida	1.4	(1)	8.3	(3)	4.2	(2)	9.7	(3)
Lepton squamosum					2.8	(1)		
Kellia suborbicularis	1.4	(1)						
Montacuta ferruginosa			2.8	(1)	4.2	(3)	9.7	(4)
Dosinia exoleta							7.0	(1)
Dosinia lupinus	1.4	(1)	4.2	(2)	11.1	(3)		
Venus striatula					2.8	(1)	2.8	(2)
Mysia undata			1.4	(1)				

Table 24. continued.

Distance to well site (m)	100		250		500		2000	
Number of analysed samples	4		4		4		4	
Abra alba							4.2	(2)
Abra alba juv.			1.4	(1)	2.8	(1)		
Cultellus pellucidus	1.4	(1)	7.0	(4)			5.6	(3)
Corbula gibba	7.0	(4)	8.3	(3)	9.7	(3)	23.6	(4)
Turritella communis			1.4	(1)	1.4	(1)	2.8	(2)
Natica alderi	18.1	(4)	8.3	(3)	9.7	(4)	11.1	(3)
Cylichna cilindracea							1.4	(1)
CRUSTACEA								
Processa parva	2.8	(2)	5.6	(3)	9.7	(3)	13.9	(4)
Macropipus spec. juv.	1.4	(1)	2.8	(1)	4.2	(3)	2.8	(2)
Ebalia cranchii			2.8	(2)				
Corystes cassivelaunus	5.6	(1)	2.8	(2)	5.6	(2)	2.8	(2)
Callianassa subterranea			4.2	(3)	12.5	(3)	16.7	(4)
Diastylis bradyi	1.4	(1)	1.4	(1)	1.4	(1)		
Ione thoracica							2.8	(1)
Ampelisca brevicornis			1.4	(1)				
Ampelisca tenuicornis	1.4	(1)	4.2	(3)	2.8	(2)	1.4	(1)
ECHINODERMATA								
Amphiura filiformis	154.3	(4)	269.7	(4)	578.2	(4)	433.7	(4)
Amphiura chiajei			1.4	(1)	5.6	(3)	4.2	(3)
Ophiura albida					1.4	(1)	1.4	(1)
Ophiura spec. juv.					1.4	(1)		
Echinocardium cordatum			16.7	(4)	11.1	(4)	26.4	(4)
Echinocardium cordatum juv.	13.9	(4)	51.4	(3)	13.9	(3)	18.1	(2)
Cucumaria elongata			1.4	(1)				
Cucumaria frondosa	1.4	(1)			4.2	(2)	1.4	(1)
OTHER TAXA								
Nemertinea	P	(2)	P	(3)	P	(2)	P	(1)
Turbellaria					1.4	(1)		
Phoroniden	P	(3)	P	(2)	P	(4)	P	(4)
Sipunculida	2.8	(2)					7.0	(3)
Total nr. of individuals	296.1		478.2		761.7		713	
Nr. of identified species	26		32		29		37	
P= present (not counted)								

Table 25. Data platform K12-6, survey Aug. 1995, 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		2000	
Number of analysed samples	4		4		4		4	
POLYCHAETA								
Harmothoe lunulata							1.4	(1)
Sigalion mathildae					7.0	(3)	12.5	(3)
Sthenelais limicola	19.5	(4)	4.2	(2)	1.4	(1)	1.4	(1)
Eteone longa					2.8	(2)		
Eteone lactea	1.4	(1)						
Anaitides maculata	1.4	(1)						
Anaitides subulifera			1.4	(1)				
Nephtys hombergii	16.7	(4)	11.1	(3)	16.7	(4)	11.1	(3)
Nephtys cirrosa	4.2	(2)						
Nephtys spec. juv.			2.8	(2)				
Goniada maculata	15.3	(4)	15.3	(4)	11.1	(3)	1.4	(1)
Lumbrineris latreilli	15.3	(4)	7.0	(2)	9.7	(2)		
Scoloplos armiger	2.8	(1)			1.4	(1)		
Spio filicornis			1.4	(1)	1.4	(1)		
Spiophanes bombyx	298.9	(4)	672.8	(4)	392.0	(3)	301.6	(4)
Scolelepis bonnieri	7.0	(3)	4.2	(2)	2.8	(2)	1.4	(1)
Magelona papillicornis	1.4	(1)	7.0	(3)	25.0	(3)	180.7	(4)
Chaetozone setosa	2.8	(2)	2.8	(2)	4.2	(1)	1.4	(1)
Notomastus latericeus			2.8	(2)			4.2	(1)
Owenia fusiformis	19.5	(4)	13.9	(3)	15.3	(3)	2.8	(2)
Lanice conchilega	11.1	(4)	1.4	(1)			27.8	(4)
Lagis koreni	8.3	(2)			1.4	(1)	16.7	(3)
MOLLUSCA								
Nucula turgida	5.6	(2)	16.7	(4)	16.7	(4)	4.2	(2)
Montacuta ferruginosa							2.8	(1)
Dosinia lupinus					4.2	(2)		
Venus striatula			2.8	(2)	1.4	(1)		
Venus spec. juv.							1.4	(1)
Mactra corallina							4.2	(2)
Tellina fabula	100.1	(4)	109.8	(4)	58.4	(4)	16.7	(4)
Abra prismatica					1.4	(1)		
Abra alba	1.4	(1)						
Abra alba juv.	11.1	(3)	54.2	(4)	82.0	(4)	65.3	(4)
Ensis ensis			1.4	(1)				
Ensis spec. juv.			1.4	(1)	7.0	(3)		
Natica alderi	19.5	(4)	20.9	(3)	15.3	(4)	5.6	(2)

Table 25. continued.								
Distance to platform (m)	100		250		500		2000	
Number of analysed samples	4		4		4		4	
CRUSTACEA								
Processa parva	1.4	(1)			2.8	(1)	1.4	(1)
Pontophilus bispinosus	7.0	(3)	2.8	(1)	2.8	(1)		
Pagurus bernhardus					1.4	(1)	1.4	(1)
Macropipus spec. juv.	30.6	(4)	41.7	(4)	8.3	(4)	5.6	(3)
Ebalia cranchii	1.4	(1)			1.4	(1)		
Thia scutellata	2.8	(2)						
Corystes cassivelaunus			4.2	(2)			1.4	(1)
Callianassa subterranea			1.4	(1)	1.4	(1)		
Decapoda larven	1.4	(1)	1.4	(1)				
Iphinoe trispinosa	1.4	(1)						
Diastylis bradyi	1.4	(1)						
Melita dentata							4.2	(1)
Hippomedon denticulatus	2.8	(2)			1.4	(1)		
Jassa falcata	1.4	(1)	4.2	(2)				
Corophium insidiosum			1.4	(1)				
ECHINODERMATA								
Astropecten irregularis			8.3	(3)	7.0	(2)		
Amphiura filiformis							1.4	(1)
Ophiura spec. juv.	22.2	(4)	9.7	(4)	8.3	(4)	1.4	(1)
Echinocardium cordatum							5.6	(4)
Echinocardium cordatum juv.	685.3	(4)	2142.0	(4)	1410.9	(4)	34.8	(4)
Psammechinus miliaris	1.4	(1)						
OTHER TAXA								
Nemertinea	P	(1)	P	(1)	P	(2)		
Nematoda	1.4	(1)						
Anthozoa	4.2	(2)			1.4	(1)	1.4	(1)
Total nr. of individuals	1328.8		3172		2125.3		722.8	
Nr. of identified species	28		24		27		24	
P= Present (not counted)								

Table 26. Data location L14-s1, survey August 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 well site (m)	100		250		500		1000	
Number of analysed samples	4		4		4		4	
POLYCHAETA								
Harmothoe lunulata			2.8	(1)	2.8	(1)		
Harmothoe longisetis			2.8	(2)	8.3	(3)		
Harmothoe spec. juv.	1.4	(1)			2.8	(2)		
Eteone longa			1.4	(1)	1.4	(1)		
Eteone lactea	4.2	(3)	8.3	(2)	8.3	(3)		
Anaitides groenlandica	1.4	(1)	1.4	(1)	2.8	(2)		
Anaitides maculata			4.2	(1)	15.3	(3)	1.4	(1)
Eumida sanguinea	4.2	(2)	27.8	(4)	30.6	(4)	2.8	(1)
Nereis longissima					1.4	(1)		
Nephtys cirrosa	13.9	(4)	57.0	(4)	38.9	(3)	22.2	(4)
Nephtys caeca							1.4	(1)
Nephtys spec. juv.					1.4	(1)		
Glycera alba					2.8	(2)	1.4	(1)
Glycera spec. juv.	2.8	(2)	1.4	(1)	2.8	(2)		
Goniada maculata	1.4	(1)			1.4	(1)		
Scoloplos armiger			1.4	(1)	8.3	(3)	5.6	(3)
Paraonis fulgens							1.4	(1)
Spio filicornis	2.8	(1)	16.7	(4)	20.9	(4)	41.7	(3)
Spiophanes bombyx	330.8	(4)	339.2	(4)	202.9	(3)	70.9	(3)
Aonides paucibranchiata			1.4	(1)				
Scolelepis bonnieri	4.2	(2)	5.6	(2)	2.8	(1)	5.6	(3)
Magelona papillicornis							1.4	(1)
Ophelia limacina					2.8	(2)	2.8	(2)
Travisia forbesii					11.1	(2)	2.8	(1)
Ophelina acuminata	1.4	(1)						
Owenia fusiformis					9.7	(4)		
Lanice conchilega	311.4	(4)	686.7	(4)	635.2	(4)	116.8	(4)
Lagis koreni	13.9	(3)	27.8	(4)	77.8	(4)	2.8	(1)
MOLLUSCA								
Donax vittatus	1.4	(1)						
Laevicardium crassum	1.4	(1)	1.4	(1)				
Dosinia lupinus	5.6	(3)	2.8	(2)	7.0	(3)	5.6	(3)
Venus striatula	1.4	(1)	1.4	(1)	1.4	(1)		
Venus verrucosa	1.4	(1)						
Spisula elliptica	41.7	(4)	29.2	(4)	48.7	(4)	26.4	(3)
Tellina pygmaeus	7.0	(3)	4.2	(1)	11.1	(4)	16.7	(4)
Abra prismatica	1.4	(1)	1.4	(1)	1.4	(1)		

Table 26. continued.

Distance to well site (m)	100		250		500		1000	
Number of analysed samples	4		4		4		4	
Ensis arcuatus	5.6	(3)	8.3	(3)	18.1	(4)	9.7	(3)
Ensis spec. juv.	1.4	(1)	1.4	(1)				
Thracia phaseolina	1.4	(1)	1.4	(1)				
Natica alderi	2.8	(2)	4.2	(2)	2.8	(2)	1.4	(1)
CRUSTACEA								
Processa parva			5.6	(1)	8.3	(2)		
Macropipus holsatus	1.4	(1)			1.4	(1)		
Macropipus spec. juv.	20.9	(4)	26.4	(4)	16.7	(4)	9.7	(4)
Thia scutellata					2.8	(2)	1.4	(1)
Decapoda larven							1.4	(1)
Gastrosaccus spinifer	16.7	(4)	4.2	(2)	7.0	(3)	34.8	(4)
Diastylis bradyi	4.2	(2)	11.1	(4)	4.2	(1)	20.9	(4)
Atylus falcatus			1.4	(1)				
Hippomedon denticulatus	1.4	(1)	1.4	(1)	1.4	(1)	4.2	(2)
Orchomenella nana	13.9	(1)						
Bathyporeia guilliamsoniana	1.4	(1)					1.4	(1)
Bathyporeia elegans							1.4	(1)
ECHINODERMATA								
Astropecten irregularis			1.4	(1)	1.4	(1)		
Amphiura filiformis	1.4	(1)						
Ophiura albida	15.3	(3)	30.6	(4)	5.6	(3)	1.4	(1)
Ophiura spec. juv.	15.3	(3)	159.9	(4)	150.1	(4)	33.4	(4)
Echinocardium cordatum juv.	19.5	(3)	255.8	(4)	146.0	(4)	101.5	(3)
Echinocyamus pusillus	4.2	(2)	1.4	(1)	33.4	(4)	4.2	(2)
TUNICATA								
Molgula oculata	25.0	(4)	90.4	(4)	45.9	(4)	12.5	(3)
OTHER TAXA								
Nemertinea	P	(4)	P	(4)	P	(4)	P	(3)
Nematoda	19.5	(4)	18.1	(3)	11.1	(1)		
Amphioxus	8.3	(2)	5.6	(2)				
Tot. nr. of individuals	934		1854		1618		569	
Nr. of identified species	33		34		37		29	
P=present (not counted)								

Table 27. Data platform L13-10, survey Aug. 1995, 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	2000
Number of analysed samples	4	4	4	4
POLYCHAETA				
Harmothoe lunulata		1.4 (1)		
Harmothoe longisetis		7.0 (2)		
Harmothoe spec. juv.			1.4 (1)	
Sigalion mathildae			1.4 (1)	
Sthenelais limicola			1.4 (1)	1.4 (1)
Eteone longa	1.4 (1)		2.8 (2)	
Eteone lactea			2.8 (1)	
Mysta barbata	5.6 (3)		1.4 (1)	
Anaitides groenlandica	1.4 (1)		1.4 (1)	
Anaitides spec. juv.	2.8 (1)			
Eumida sanguinea		11.1 (3)	9.7 (4)	
Gyptis capensis		1.4 (1)		
Proceraea cornuta	1.4 (1)			
Nephtys hombergii	1.4 (1)			
Nephtys incisa			1.4 (1)	
Nephtys cirrosa		9.7 (4)	11.1 (3)	27.8 (4)
Nephtys spec. juv.	16.7 (4)	2.8 (1)	12.5 (3)	8.3 (3)
Glycera spec. juv.	5.6 (3)		9.7 (2)	
Glycinde nordmanni	1.4 (1)	1.4 (1)	1.4 (1)	
Goniada maculata				1.4 (1)
Scoloplos armiger	1.4 (1)	4.2 (2)	7.0 (3)	12.5 (4)
Paraonis fulgens	5.6 (2)		1.4 (1)	1.4 (1)
Poecilochaetus serpens	1.4 (1)			
Spio filicornis	18.1 (3)	19.5 (3)	45.9 (4)	20.9 (2)
Spiophanes bombyx	207.1 (4)	26.4 (4)	98.7 (3)	102.9 (3)
Aonides paucibranchiata		4.2 (2)		
Scolelepis bonnieri	2.8 (2)		1.4 (1)	4.2 (1)
Magelona papillicornis			2.8 (2)	
Chaetozone setosa	33.4 (4)	18.1 (4)	12.5 (4)	5.6 (3)
Ophelia limacina		5.6 (2)	4.2 (2)	1.4 (1)
Owenia fusiformis	11.1 (3)		2.8 (2)	7.0 (3)
Lanice conchilega	151.5 (4)	453.1 (4)	469.8 (4)	86.2 (4)
Lagis koreni		2.8 (2)	8.3 (3)	12.5 (4)
MOLLUSCA				
Laevicardium crassum	1.4 (1)	1.4 (1)		
Dosinia lupinus	4.2 (1)	7.0 (3)	26.4 (4)	25.0 (4)
Venus spec. juv.		1.4 (1)	1.4 (1)	5.6 (4)

Table 27. continued.

Distance to platform (m)	100		250		500		2000	
Number of analysed samples	4		4		4		4	
Mactra corallina							1.4	(1)
Spisula spec. juv.	7.0	(3)	2.8	(1)	8.3	(4)	2.8	(1)
Tellina pygmaeus	1.4	(1)			12.5	(3)	5.6	(2)
Tellina fabula	7.0	(4)	1.4	(1)	1.4	(1)		
Abra prismatica			1.4	(1)				
Gari fervensis			1.4	(1)				
Ensis arcuatus	33.4	(4)	27.8	(4)	34.8	(4)	9.7	(4)
Thracia phaseolina	9.7	(4)	2.8	(2)	12.5	(4)	8.3	(2)
Natica alderi	1.4	(1)	2.8	(2)	8.3	(3)	2.8	(1)
CRUSTACEA								
Processa parva			8.3	(3)	9.7	(4)	12.5	(4)
Pontophilus trispinosus	1.4	(1)						
Pagurus bernhardus	2.8	(2)			1.4	(1)		
Macropipus spec. juv.	8.3	(3)	19.5	(4)	12.5	(3)	9.7	(4)
Thia scutellata			2.8	(2)	4.2	(2)	5.6	(2)
Decapoda larven					1.4	(1)		
Gastrosaccus spinifer	4.2	(2)			1.4	(1)		
Eualus pusiolus							1.4	(1)
Iphinoe trispinosa							1.4	(1)
Diastylis bradyi	1.4	(1)	2.8	(2)			5.6	(3)
Melita dentata					1.4	(1)		
Hippomedon denticulatus	1.4	(1)	2.8	(2)			2.8	(1)
Leucothoe incisa			1.4	(1)	2.8	(1)		
Bathyporeia guilliamsoniana	1.4	(1)						
Bathyporeia elegans	4.2	(2)					1.4	(1)
Harpinia antennaria	4.2	(2)						
Aora typica			1.4	(1)	1.4	(1)		
Caprella spec.			1.4	(1)				
Corophium insidiosum					1.4	(1)	12.5	(4)
ECHINODERMATA								
Amphiura filiformis	1.4	(1)						
Ophiura albida					1.4	(1)		
Ophiura spec. juv.	1.4	(1)	7.0	(3)	18.1	(3)	7.0	(4)
Echinocardium cordatum juv.			36.1	(4)	80.6	(4)	95.9	(4)
Echinocyamus pusillus			5.6	(2)	2.8	(2)	5.6	(2)
Molgula oculata					32.0	(4)		

Table 27. continued.

Distance to platform (m)	100		250		500		2000	
Number of analysed samples	4		4		4		4	
OTHER TAXA								
Nemertinea	P	(4)	P	(4)	P	(4)	P	(2)
Nematoda	2.8	(1)			4.2	(2)	2.8	(2)
Amphioxus	7.0	(3)	12.5	(4)			1.4	(1)
Phoroniden	P	(1)						
Anthozoa					1.4	(1)		
Total nr. of individuals	576.9		720		996.6		519.9	
Nr. of identified species	31		30		39		29	
P= present (not counted)								

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