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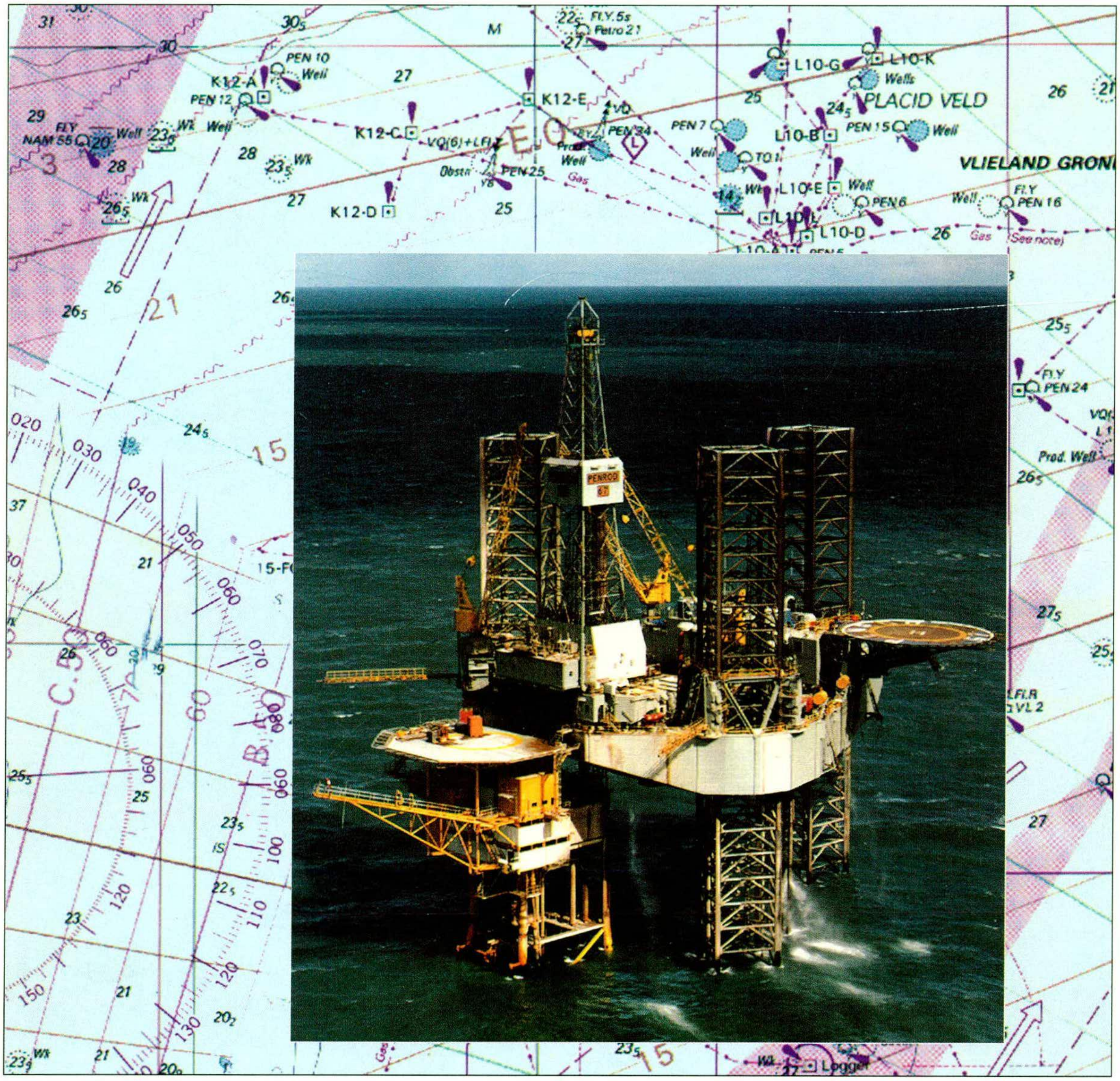

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This study was commissioned by the North Sea Directorate (RWS) and carried out in 1992

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SUMMARY AND CONCLUSIONS

During drilling activities in the North Sea in the 80's, there has been an extensive use of oil based drilling fluids or 'oil based muds' (OBM). The drilling fluids were largely regained from the formation solids at the drilling platform, but the material subsequently discharged was still substantially contaminated with base oil. Gradually there was growing concern about adverse environmental effects of these discharges, particularly about the effects on the benthic ecosystem. Hence, in the Dutch sector, a research programme was started in 1985 around some platforms where OBM-related discharges had taken place. In the following years this programme was continued by carrying out field surveys at several other locations, each with its specific degree of contamination. The results of these studies gradually gave rise to tightened regulations, which culminated in a complete ban on discharges of oil contaminated drill cuttings in the Dutch sector effective from January 1st 1993. With the introduction of the new legislation further research on the short-term effects of OBM related dumpings became less relevant. However, the long-term impact on the ecosystem is still subject of interest. Still little is known about degradation rates of oil in the sediment and to what extent disturbed benthic communities can recover at the longer term. Therefore, in 1992, a field survey was carried out near platform K12a, where, after drilling with OBM based on diesel and low-tox oil, extensive discharges took place 8 years before. Location K12a is already subject of study since 1985 and up to 1988 field surveys were carried out each year. In addition, an experimental study with sediment from this location was conducted in 1990. This report presents the results of the 1992 survey with a discussion on the effects observed over a period of 8 years.

Like in preceding years, bottom sampling was mainly concentrated along a transect in the residual current direction of K12a. Sampling stations were chosen at distances ranging from 100 to 7500 m from the platform. In a perpendicular direction only one station was sampled at 250 m from the platform. In the residual current direction substantially elevated concentrations of oil in the sediment were found up to 250 m. The impression, obtained during performance of the fieldwork, that especially the deeper sediment layers were severely contaminated was confirmed by the chemical analyses. The highest concentration was found at a depth of 25 - 30 cm in the sediment. It seems that the initially contaminated sediment layers are buried under a layer of freshly sedimentated material, but it is also possible that biodegradation of oil only occurred at and just below the sediment-water interface, while under the anaerobic conditions in the deeper layers degradation is hardly possible. After all there is no convincing evidence that, within 250 m from the platform, a substantial fraction of the oil is degraded since it was dumped in 1984. Particularly at 100 m the concentrations were still within the (broad) range of contamination levels observed between 1985 and 1990. It is concluded that, if there is any decrease of oil concentrations at all, such a decrease is masked by spatial patchiness, which largely explains the year to year differences in observed concentrations.

The chemical analyses of sediment samples collected at 500 m and further away from the platform did not reveal oil concentrations that exceeded background level, although, during fieldwork, traces of oil were visually observed at all stations up to 1000 m. A comparison with preceding years suggests that contamination levels have decreased in the area beyond 500 m. It is not clear whether this is the result of biodegradation or that remnants of oil are found again in the deeper sediment layers and therefore did not turn up in routine samples, which cover the upper 10 cm layer only.

In the benthic fauna composition an accumulation of effects could be detected at 100 m from the platform. At this station the fauna was substantially impoverished compared to the other stations. At 250 m only the absence (or reduced abundance) of some OBM-sensitive species, *e.g.* the absence of adult *Echinocardium cordatum* (only juveniles were found) indicated a persistent effect of the discharges. It was remarkable, however, that the indicator species *Montacuta ferruginosa*, a commensal of *E. cordatum*, was found at 250 m in fairly high numbers, which can be considered a sign of recovery of sediment conditions at this station. At 500 m and further away from the platform no significant effects could be detected. However, a complicating aspect in the interpretation of the data was that a reliable reference situation was lacking in this survey. From 2000 m and further away the sediment structure changed strongly and became so hard-packed that it was impossible to collect quantitative samples with the bottom grab. Consequently, the fauna numbers collected per sample were much lower than at the stations within 1000 m. Because of the absence of a reliable reference situation it is not justified to conclude that biological effects have disappeared between 500 and 1000 m and that sediment conditions have completely recovered. Nevertheless, there obviously are signs of recovery. Particularly the reappearance of adult *E. cordatum* in this area is indicative of such recovery.

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

1. The chemical analyses revealed substantially elevated concentrations of oil in the sediment out to 250 m from the platform. However, traces of oil were visually observed out to 1000 m.

2. There seems to be hardly any horizontal redistribution of discharged material at the longer term. Com-

ponents of the drilling muds used at K12a are stored mainly in the deeper sediment layers.

3. There is no convincing evidence for degradation of oil in the sediment, but the composition might have changed.

4. The oil-Barium ratio does not provide a useful parameter to estimate degradation rates of oil at K12a.

5. An accumulation of biological effects was assessed at 100 m from the platform (residual current direction). At this station the benthic fauna is still severely impoverished.

6. At 250 m from the platform (residual current direction) only the absence or reduced abundance of some OBM-sensitive species was indicative of environmental stress.

7. The absence of the opportunistic species *Capitella capitata* at the station nearest to the platform (100 m) points at stabilisation of sediment conditions.

8. From 250 m and further away from the platform the superficial sediment layers seem to allow settlement of juveniles of most species, including the sensitive indicator species *Montacuta ferruginosa* and *Echinocardium cordatum*. However, the size-frequency distribution of *E. cordatum* along the residual current transect suggests that new generations have low chance of growing up to adulthood within 500 m from the platform. An explanation for this low chance of survival could be that large animals burrow deeper in the sediment and thus come in contact with contaminated sediment layers.

9. Changes in the sediment structure along the residual current transect interfere with the interpretation of the faunistic data. Because of the compactness of the sediment from 2000 m and beyond that distance it was not possible to collect quantitative samples here. Hence, a reliable reference situation was lacking. With respect to future research the sampling of a perpendicular or an upstream transect might be considered. An alternative sampling method is also suggested, *e.g.* the use of a Hamon bottom grab.

SAMENVATTING EN CONCLUSIES

Gedurende de 80'er jaren is bij olie- en gasboringen op de Noordzee op uitgebreide schaal gebruik gemaakt van boorspoelingen op oliebasis (oil based muds = OBM). De spoeling, die onder meer tot doel heeft het gruis uit het boorgat in suspensie omhoog te brengen, werd op het platform voor een belangrijk deel teruggewonnen, maar niettemin was het vervolgens op de zeebodem geloosde materiaal nog steeds aanmerkelijk verontreinigd met restanten basisolie. Aanvankelijk bestonden er nauwelijks wettelijke restricties met betrekking tot de hoeveelheid en het type olie dat op deze manier in het mariene milieu terecht kwam. Geleidelijk aan echter is toenemende zorg ontstaan over de negatieve effekten die deze lozingen met name voor het benthische ecosysteem met zich meebrachten. In de Nederlandse sector is daarom in 1985 begonnen met onderzoek rond enkele platforms waar dergelijke lozingen hadden plaats gevonden en in de daarop volgende jaren is dit onderzoek voortgezet op diverse lokaties, ieder met zijn eigen graad van verontreiniging. Mede op basis van de resultaten van dit onderzoek is de regelgeving met betrekking tot het gebruik van OBM steeds stringenter geworden, culminerend in een totaal verbod op het lozen van oliehoudend boorgruis met ingang van 1 januari 1993. Met de invoering van dit verbod is de basis voor verder onderzoek naar effekten op de korte termijn in feite weggevallen, maar met name in het licht van eventuele toekomstige maatregelen tot bodemsanering blijft een relevante vraag in welke mate zich op de langere termijn nog effekten voordoen. Onduidelijk is nog in welke mate afbraak van olie in het sediment plaats vindt en in hoeverre, met name op sterk verontreinigde lokaties, de natuurlijke bodemfauna zich op de langere termijn herstelt. Daarom is in 1992 bij platform K12a, 8 jaar nadat daar voor het laatst met onder andere OBM op basis van dieselolie geboord was, een veldonderzoek uitgevoerd. De lokatie is al onderwerp van studie sedert 1985 en tot en met 1988 is er jaarlijks een veldsurvey uitgevoerd, terwijl in 1990 nog een experimentele studie met sediment van deze lokatie werd verricht. In dit rapport worden de resultaten van het in 1992 uitgevoerde onderzoek gepresenteerd en wordt het verloop van de waargenomen effekten over een periode van 8 jaar bediscussieerd.

Net als in voorgaande jaren werd de bodembemonstering in het veld voornamelijk geconcentreerd langs een transect in de reststroomrichting van K12a, met stations op afstanden variërend van 100 tot 7500 m van het platform. Dwarsstrooms werd alleen 1 station op 250 m van het platform bemonsterd. In de reststroomrichting werden aanmerkelijk verhoogde olieconcentraties aangetroffen tot op 250 m van het platform. De indruk, die tijdens het veldwerk verkregen werd, dat de olie voornamelijk in de wat diepere sedimentlagen terug te vinden was, werd later door de chemische analyses bevestigd. Kennelijk raken de aanvankelijk verontreinigde sedimentlagen op den duur begraven onder een laag van nieuw gesedimenteerd materiaal. Het is echter ook mogelijk dat biodegradatie van olie uitsluitend plaats vindt op en dicht onder het grensvlak van bodem en water en dat onder de anaerobe condities in het dieper gelegen sediment afbraak nauwelijks mogelijk is. Overigens is er geen overtuigende aanwijzing dat binnen 250 m een substantiële fractie van de geloosde olie is afgebroken. Met name op 100 m lagen de concentraties binnen de (wijde) range van waarden zoals die tussen 1985 en 1990 zijn aangetroffen. De conclusie lijkt gerechtvaardigd, dat, als er in de loop van de tijd al sprake is van een afname in olieconcentraties, deze in hoge mate gemaskeerd wordt door ruimtelijke patchiness, die in hoofdzaak de verschillen van jaar tot jaar in waargenomen concentraties verklaart.

Vanaf 500 m toonden de chemische analyses geen concentraties meer aan die boven achtergrondniveau uitkwamen, al konden in het veld nog sporen van olie in de vorm van teerbolletjes in het sediment tot op 1000 m worden waargenomen. Het lijkt er op dat vanaf 500 m de verontreiniging in vergelijking tot vorige jaren is afgenomen. Niet duidelijk is echter of dit het gevolg is van (bio-)degradatie of dat restanten van olie vooral in wat diepere sedimentlagen terecht zijn gekomen die niet in de routinematige sedimentbemonstering worden meegenomen, welke alleen de bovenste 10 cm van het sediment bestrijkt.

In de benthische faunasamenstelling kon een accumulatie van effekten worden waargenomen op 100 m van het platform, waar nog steeds sprake was van een aanzienlijk armere fauna dan op de overige stations langs het reststroomtransect. Op 250 m duidde slechts het ontbreken van enkele OBM-gevoelige soorten en de afwezigheid van volwassen *Echinocardium cordatum* (juvenielen werden wel aangetroffen) op een latent effekt van de lozingen. Opvallend was dat zich onder de hier ontbrekende soorten niet meer de met *E. cordatum* in symbiose levende indicatorsoort *Montacuta ferruginosa* bevond. De soort werd op 250 m zelfs in vrij grote aantallen gevonden, hetgeen een aanwijzing vormt voor optredend herstel van sedimentcondities op dit station. Vanaf 500 m kon geen significant effekt meer worden aangetoond. Een complicatie die zich echter voordeed was dat een betrouwbare referentie-situatie in deze survey ontbrak. Op de stations vanaf 2000 m en verder van het platform bleek namelijk de sedimentstruktuur sterk te veranderen en met name veel compacter te worden. Dit verhinderde dat met de Van Veen bodemhapper op dit deel van het transect nog kwantitatieve monsters genomen konden worden. Bijgevolg werd per equivalent bemonsterd oppervlak dan ook minder fauna aangetroffen dan op de stations binnen 1000 m. Door het ontbreken van een betrouwbare referentiesituatie is het niet mogelijk definitief te concluderen dat zich over het traject 500 - 1000 m geen biologische effekten meer voordoen en dat sedimentcondities hier volledig zijn hersteld. Tekenen dat zo'n herstel zich hier heeft voorgedaan zijn er echter wel. Met name het feit dat volwassen exemplaren van *E. cordatum* weer werden aangetroffen duidt hierop.

Samengevat leiden de resultaten van dit onderzoek tot de volgende conclusies:

1. De chemische analyses toonden aanmerkelijk verhoogde olieconcentraties in het sediment aan tot op 250 m van het platform. Visueel werden echter sporen van olie waargenomen tot op 1000 m.

2. Horizontale redistributie van geloosd materiaal lijkt nauwelijks meer plaats te vinden. Contaminanten afkomstig uit de op K12a gebruikte boorspoeling worden voornamelijk terug gevonden in de diepere sedimentlagen.

3. Er zijn geen overtuigende aanwijzingen voor afbraak van olie in het sediment, al kan de samenstelling geleidelijk veranderen.

4. De olie-Barium ratio is bij K12a geen bruikbare parameter voor het schatten van de afbraaksnelheid van olie in het sediment.

5. Een accumulatie van biologische effekten kon worden gedetecteerd op 100 m afstand (reststroomrichting) van het platform. Van 7 beschreven effekten werden er hier 5 vastgesteld. Op dit station wordt nog steeds een sterk verarmde bodemfauna aangetroffen.

6. Op 250 m van het platform was slechts het ontbreken (of in verlaagde dichtheden voorkomen) van een 5-tal gevoelige soorten indikatief voor 'environmental stress'.

7. Het ontbreken van de opportunistische soort *Capitella capitata* op het dichtst bij het platform gelegen monsterpunt (100 m) duidt op een stabilisatie van sedimentcondities.

8. Vanaf 250 m lijken de oppervlakkige sedimentlagen geschikt voor settlement van juvenielen van de meeste soorten, inclusief de gevoelige indicatorsoorten *Montacuta ferruginosa* en *Echinocardium cordatum*. Gezien de lengte-frequentie verdeling van *E. cordatum* langs het reststroomtransekt is het echter aannemelijk dat nieuwe generaties binnen 500 m van het platform nog steeds weinig kans maken tot wasdom uit te groeien. Een verminderde overlevingskans kan verklaard worden door aan te nemen dat grotere dieren zich dieper in het sediment ingraven en daardoor in contact komen met gecontamineerde lagen.

9. Veranderingen in sedimentstruktuur langs het reststroomtransect bemoeilijken de interpretatie van de faunistische gegevens. Door de compactheid van het sediment, vanaf 2000 m en verder, was het niet mogelijk hier kwantitatieve monsters te verzamelen, zodat een betrouwbare referentiesituatie voor de survey van 1992 ontbreekt. Voor een toekomstig onderzoek valt in overweging te nemen bemonstering van een dwarsstrooms of tegenstrooms transect in het veldprogramma op te nemen. Te denken valt ook aan een alternatieve monstermethode, bijvoorbeeld het gebruik van een Hamonhapper.

1 INTRODUCTION

1.1 GENERAL PART

Research on the environmental effects of drill cutting discharges in the Dutch sector of the North Sea is carried out since 1985. In the following years field surveys have been performed around several well sites in the erosion zone, the sedimentation zone and in the transition zone as well and included well sites where cuttings drilled with oil based muds (OBM) or water based muds (WBM) were discharged. Most attention has been paid to OBM related discharges and the adverse environmental effects of these dumpings have led to tightened regulations with respect to the use of OBM, which have resulted in a complete prohibition on discharges of OBM cuttings in the whole Dutch sector from 1993 onwards. With the termination of OBM cutting discharges further investigations on the associated short-term effects have become less relevant. However, in view of possible future clean-up measures for the seabed around abandoned well sites, the long-term effect of this environmental disturbance is still subject of interest. Little is known about the persistence of effects of former discharges at the longer term. Remaining questions are whether degradation of oil in the sediment occurs and if there is a decrease of toxic components. In this context the recovery rates of disturbed benthic communities are still subject of interest. This report describes the results of a survey at the production platform K12a carried out in 1992, 8 years after extensive OBM discharges were terminated at this location, and compares the biological and chemical features observed with those found in former surveys.

Platform K12a is situated near the southern border of the transition zone. The sediment at the seabed is characterized by fine sand and a small silt fraction. At this location 5 wells have been drilled in 1983 and 1984 with low-tox oil and diesel based OBM (see Table 1). The drill cuttings were discharged without previous washing. Between 1985 and 1988 combined biological and chemical surveys were carried out in September of each year. The biological data are reported by MULDER *et al.* (1987, 1988) and DAAN *et al.* (1990), the chemical data by KUIPER & GROENEWOUD (1986), GROENEWOUD *et al.* (1988) and GROENEWOUD (1991). The biological features observed around K12a are shortly outlined by DAAN *et al.* (1990):

1985: Effects measured up to 750-1000 m off the platform
1986: Clear effects measured up to 250 m off the platform
1987: Clear effects measured at the platform station
1988: Marginal effects measured within 100 m from the platform

The tendency shown by this overall picture is that of gradually decreasing biological effects during the 4 years following the drilling activities at K12a. This was quite surprising, since there was no consistent evidence for a substantial decrease in oil contamination levels of the sediment around the platform. Although, at 250 m in the residual current direction from the platform, the oil concentration was a factor 10 lower in 1988 than in the preceding years, such a tendency for decreasing contamination levels could not be observed within 100 m. It was suggested that a possible recovery of the benthic fauna could be explained by either a decrease in toxicity of the oil due to weathering or a decrease in availability of toxic compounds to the benthic fauna. However, it was stressed that patchiness in the spatial distribution of contaminated cuttings is of major importance with respect to the detection of biological effects and can mask the occurrence of such effects during field surveys.

In 1990, the environmental study of the area around K12a was continued with a boxcosm experiment, with sediment sections collected at 100 m, 250 m and 5000 m from the platform (DAAN *et al.*, 1992). That year, extremely high contamination levels were detected in the 100 m and 250 m sections, but also in the 5000 m sections the oil concentrations were significantly above background level. Particularly in the 100 m and 250 m sections fauna densities appeared to be very low and adult specimens of the test species *Echinocardium cordatum*, that were introduced in these boxcosms, displayed substantially elevated mortality and sublethal features in the sediments of 100 m and 250 m, which indicated disturbed sedi-

TABLE 1
Information on drilling location K12a.

Position:	53 °28'36.2" N 03° 47'19.4" E
Area:	Transition zone, fine sand with silt (5-10%); depth appr. 28 m;
Drilling activities:	5 wells drilled with diesel and low-tox OBM, Febr. 1983-Nov. 1984 cuttings not washed before discharge;
Emission:	Cuttings drilled with OBM: 1196 tonnes OBM: 1082 tonnes, including: oil: 393 tonnes;
Platform:	present

Former effect studies:
survey Sept. 1985 (MULDER *et al.*, 1987; KUIPER & GROENEWOUD, 1986)
survey Sept. 1986 (MULDER *et al.*, 1988; GROENEWOUD *et al.*, 1988)
survey Sept. 1987 (DAAN *et al.*, 1990; GROENEWOUD, 1991)
survey Sept. 1988 (DAAN *et al.*, 1990; GROENEWOUD, 1991)
boxcosms 1987 (pilot study, DAAN *et al.*, 1990)
boxcosms 1990 (DAAN *et al.*, 1992; GROENEWOUD & SCHOLTEN, 1992b)

ment conditions out to at least 250 m. Finally, on the basis of increased knowledge about species that respond very sensitive to discharges of OBM cuttings, it became clear that recovery of the macrobenthic community is not a matter of a few years. Subtle indications were obtained that environmental stress reached further than initially supposed. Particularly the spatial abundance patterns of *Montacuta ferruginosa* and large specimens of *Echinocardium cordatum* pointed at disturbed sediment conditions beyond 1000 m from the platform, even in 1988 (DAAN *et al.*, 1991; LEEUWEN, 1992).

For these reasons it was decided to continue the research programme around K12a and the survey conducted in 1992 will probably not have been the last one. Future surveys are planned every 2 years, but a reduced frequency of monitoring may be considered, depending on the rate of recovery of sediment conditions and of the macrobenthic community.

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Dr. W. Zevenboom (RWS, North Sea Directorate), chairwoman
Drs. S.A. de Jong (RWS, North Sea Directorate), secretary
Drs. J. Asjes (RWS, North Sea Directorate), secretary (from June 1993 onwards)
Ing. M. de Krieger (RWS, North Sea Directorate)
Drs. K. Meyer (VROM)
Ir. L. Henriquez (EZ, State Supervision of Mines)
Drs. P. Seeger (EZ)
Drs. W. Vonck (RWS, Tidal Waters Division)
Drs. J.M. Marquenie (Netherlands Oil and Gas Exploration and Production Association)
H.J. van het Groenewoud (TNO)
M. Mulder (NIOZ)
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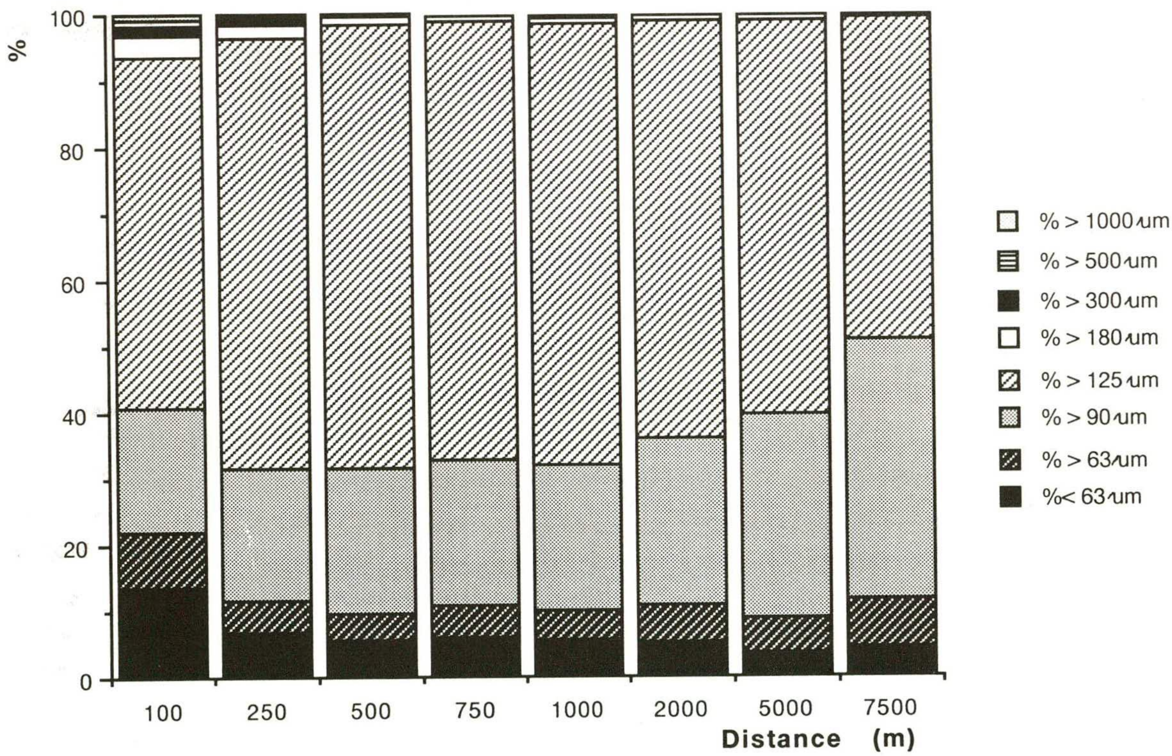

Fig. 1. Grainsize distribution of the sediment at K12a in 1992 (data from GROENEWOUD, 1993).

2 METHODS

2.1 SAMPLING

The survey at K12a was carried out in the second week of September 1992. Sampling stations were chosen in the residual current direction (54°), at 100, 250, 500, 750, 1000, 2000, 5000 and 7500 m from the platform. In a perpendicular direction (144°) another 250-m station was sampled. The 100-m and 250-m stations in the residual current direction were approached twice and both times 5 grab samples (Van Veen grab, 0.2 m^2) were collected. At each of the other stations 10 samples were collected. From each sample small duplicate sediment cores (diameter 28 mm, depth 10 cm) were taken for chemical and grainsize analyses. The pooled sediment samples of each station were thoroughly homogenised and immediately frozen at -20° until later analysis in the laboratory. The contents of the grab were washed through a sieve (mesh size 1 mm). During sieving the numbers of *Echinocardium cordatum* (specimens > 1 cm) were counted in all samples. The remaining 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 & SCHOLTEN (1992a).

2.3 BARIUM ANALYSIS

Barite was a substantial constituent of the drilling muds used at K12a and therefore provides a good indicator for the dispersal of discharged material, in particular of the smaller grain size fractions. Concentrations of Ba in the sediment were determined as follows:

About 10 grammes of sediment were dried for 2 hours at 105°C. Then 2 grammes were homogenized and destructed by means of sulphuric acid and hydrogen peroxide. After settling, the barium content of the destruate was determined using inductive coupled plasma atomic emission spectrometry (ICP-AES).

2.4 OIL ANALYSIS

Oil analyses of sediment samples were performed using the gas chromatograph mass spectrometer 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 & SCHOLTEN (1992a).

2.5 FAUNA ANALYSIS

In the laboratory macrofauna analyses were performed of the stations at 100, 250, 500, 750, 1000 and 5000 m in the residual current direction, 8 samples per station. Routine methods of sorting and identification are described by MULDER *et al.* (1988).

2.6 STATISTICAL PROCEDURES

Possible gradients in the distribution patterns of individual species were tested by logit regression (JONGMAN *et al.*, 1987). The regression was applied to those species of which at least 20 specimens were found. The method is described in more detail by DAAN *et al.* (1990).

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 also is described in detail by DAAN *et al.* (1990).

3 RESULTS

3.1 SEDIMENT CHARACTERISTICS

Grainsize analyses were performed for all stations at the residual current transect. Fig. 1 shows that the grainsize composition was quite homogeneous between 250 and 1000 m, but at 250 m the coarse fraction (> 300 μm) was elevated compared to the other stations, apparently due to the presence of drill cuttings. At 100 m the coarse fraction was even larger and, in fact, fine drill cuttings were observed at this station during the fieldwork. The very fine grainsize fractions (< 90 μm) too were large compared to the other stations. From 2000 m and further away from the platform the sediment composition changed. The fraction between 125 and 180 μm became gradually smaller, whereas the 90-125 μm fraction increased. Coinciding with this change in grainsize composition there was a shift in compactness of the sediment, which became manifest during sampling. Up to 1000 m from the platform the Van Veen grab penetrated easily in the sediment and was reasonably filled when it returned on deck. However, at the stations 2000-7500 m it was not possible to collect quantitative samples since the grab did hardly penetrate the hard-packed sediment. It was estimated by eye that the sample size was on average about a third or a fourth of that at the stations closer to the platform.

3.2 BARIUM CONCENTRATIONS IN THE SEDIMENT

Barium concentrations in the sediment around K12a have been assessed during all surveys carried out since 1986. Interpretation of the data has to take into account that small concentrations of Ba are always present in the sediment by nature. GROENEWOUD &

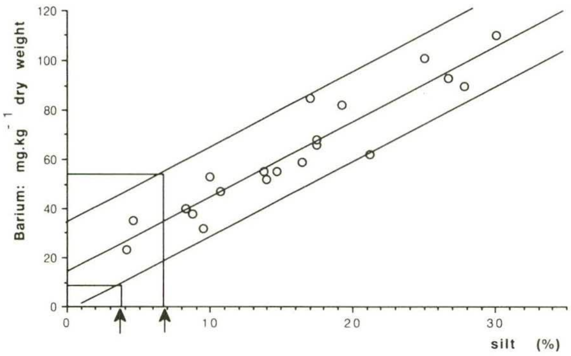

Fig. 2. Background concentrations of Ba in sediments with different silt (grainsize < 63 μm) fractions. The data are derived from the reference stations of all drilling locations in the Dutch sector investigated in previous studies (data in GROENEWOUD *et al.*, 1988; GROENEWOUD, 1991; GROENEWOUD & SCHOLTEN, 1992a; DAAN & MULDER, 1993). Arrows indicate min. and max. silt content of the sediment at K12a in 1992 (100-m station not included).

SCHOLTEN (1992a) have shown that the natural background concentrations are strongly related to the silt content of the sediment (fraction < 63 μm). To obtain an estimate of the range of natural background concentrations of Ba in sediments with different silt fractions a plot was made of the Ba concentrations at the reference stations of all drilling locations in the Dutch sector that were investigated before against silt fractions at those stations (Fig 2). For each location the data were used that were collected during the first survey around that location. Given the actual silt content of the sediment at the residual current transect of K12a in 1992 (3.8 - 6.8%), the plot shows that natural background concentrations should be expected in the range of 9 to 54 mg Ba·kg^{-1} dry sediment. Hence, the maximum background concentration to be expected

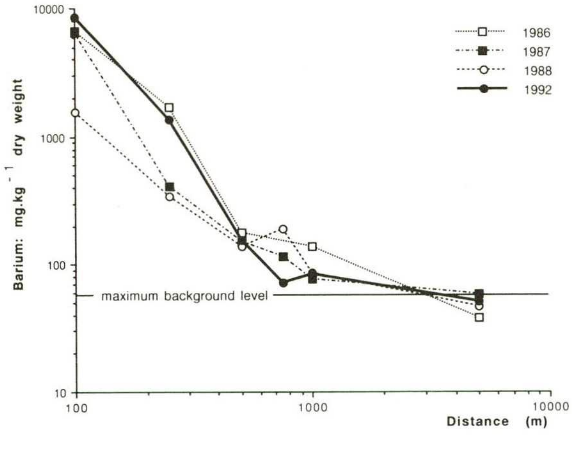

Fig. 3. Ba concentrations at K12a between 1986 and 1992.

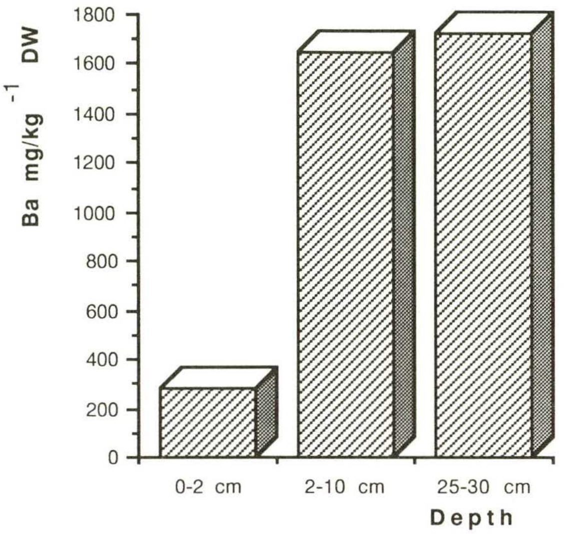

Fig. 4. Vertical profile of Ba concentrations in the sediment at 250 m (residual current transect) from K12a in 1992 (data from GROENEWOUD, 1993).

at K12a is 54 mg·kg^{-1} dry sediment. In Fig. 3 this level is indicated to show that Ba concentrations were beyond background level up to at least 1000 m from the platform. At 5000 m the concentration was at this maximum background level. Fig. 3 also shows that there is no consistent temporal change in the spatial distribution of Ba since 1986.

At 100 m and 250 m duplicate samples were collected (Table 2). The results confirm the observations of GROENEWOUD & SCHOLTEN (1992a, b), that there may be considerable local variation in Ba concentrations due to patchiness. Probably, this variation will largely explain the year to year differences between Ba concentrations at individual stations.

Fig. 4, showing a vertical profile of Ba concentrations in the sediment, suggests that much of the discharged material has settled deep in the sediment. The top layer of the sediment is relatively clean,

TABLE 2
Ba concentrations in the sediment at location K12a. (Data from GROENEWOUD,1993).

Distance		*mg/kg DW*
100 m		5700
100 m		11250
250 m		1620
250 m		1120
500 m		156
750 m		72
1000 m		85
5000 m		51
0-2 cm	250 m	280
2-10 cm	250 m	1650
25-30 cm	250 m	1720

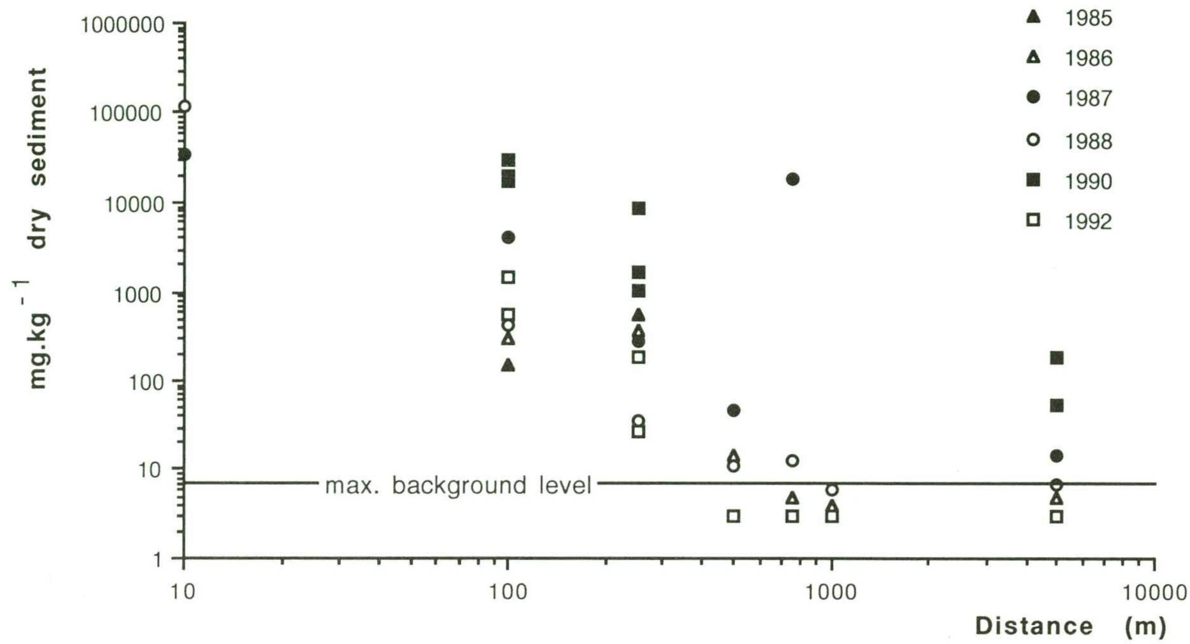

Fig. 5. Total oil concentrations at K12a between 1985 and 1992 (data from KUIPER & GROENEWOUD, 1986; GROENEWOUD *et al.*, 1988; GROENEWOUD, 1991; 1993; GROENEWOUD & SCHOLTEN, 1992b).

either due to sedimentation or to resuspension of Ba from the superficial sediment layers.

3.3 OIL CONCENTRATIONS IN THE SEDIMENT

Clearly elevated concentrations of oil in the sediment were found up to 250 m from the platform (Fig. 5). At 500 m and further away the concentrations did not exceed background level, although during the fieldwork tar droplets were seen in the samples out to 1000 m. A reason why these did not turn up in the subsamples, might be found in local patchiness but also in the vertical distribution of oil in the sediment: Fig. 6 shows that at 250 m the highest concentration was found at a depth of 25 - 30 cm in the sediment. Since 1987 the oil seems to have gradually accumulated in the deeper sediment layers. Because routine subsamples for oil analyses were collected only from the upper 10 cm layer, it is possible that tar droplets present in the deeper sediment layers were missed.
At 100 m and 250 m the concentrations were approximately at the same level as found in 1988 (Fig. 5). The differences between replicate samples illustrate the patchiness in the spatial distribution of the oil. Patchiness will also largely explain the year to year variation in the observed oil concentrations. There is no consistent trend that indicates a decrease in concentrations.

The chromatograms (Fig. 7) show that at those stations where significant oil concentrations were found a second UCM hill seems to appear after 15 - 20 minutes. Maybe this UCM hill is caused by degradation products, but it is also possible that the most volatile components have disappeared and that the longer chains are left.

GROENEWOUD & SCHOLTEN (1992a) have suggested that time series of oil/Ba ratios could give an indication for degradation of oil in the sediment. Fig. 8 shows the relation between oil and Ba concentrations between 1986 and 1992. This plot may illustrate that the 1992 ratios were low compared to those meas-

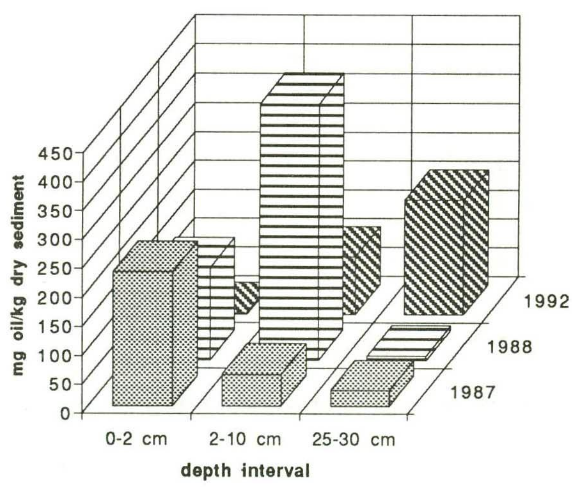

Fig. 6. Vertical profiles of oil concentrations in the sediment at 250 m (residual current transect) from K12a between 1987 and 1992 (data from GROENEWOUD, 1991; 1993).

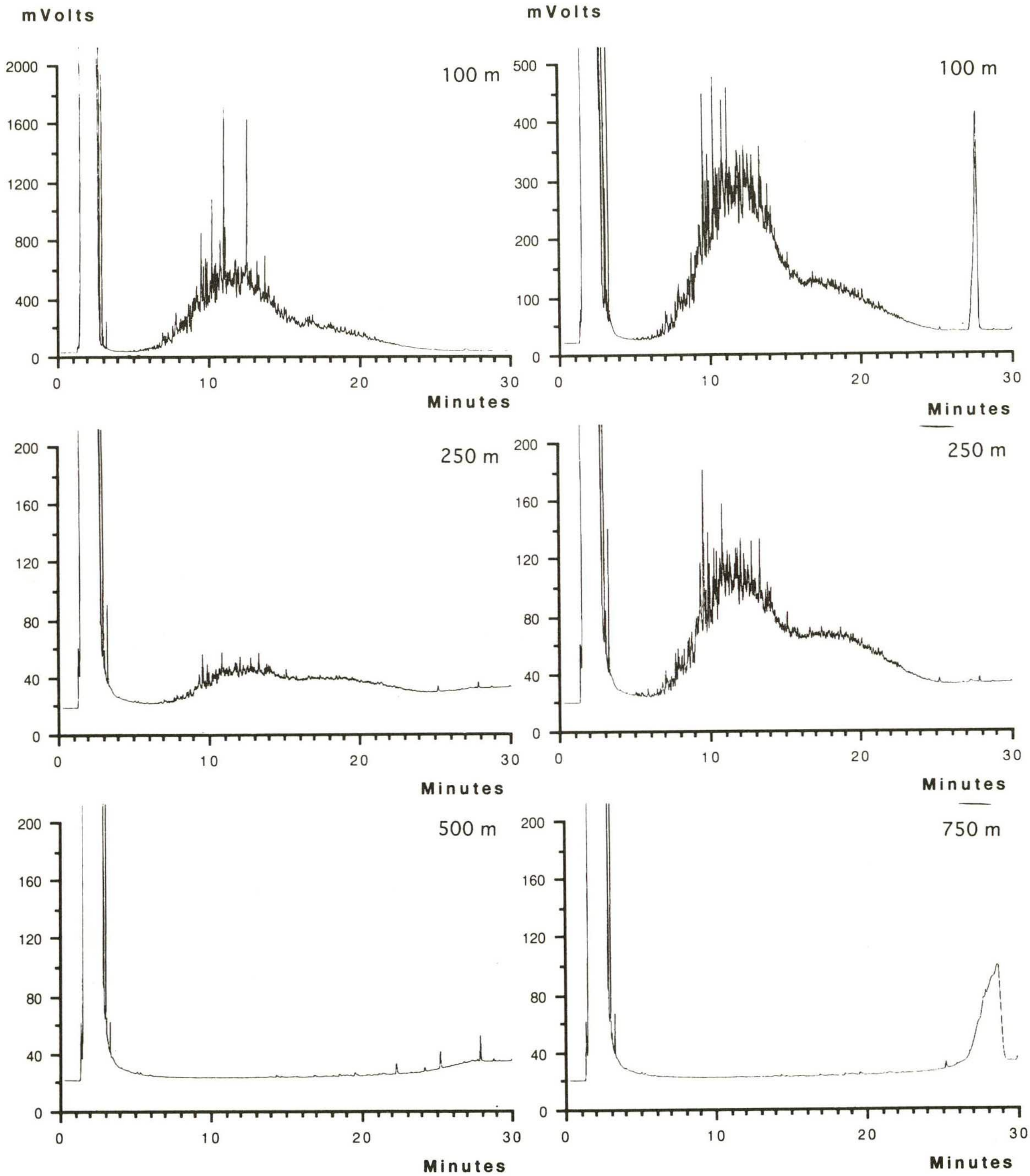

Fig. 7. GCMS chromatograms of sediment extracts collected at 100, 250, 500 and 750 m (residual current transect) from K12a in 1992 (figures from GROENEWOUD, 1993). Note different scales.

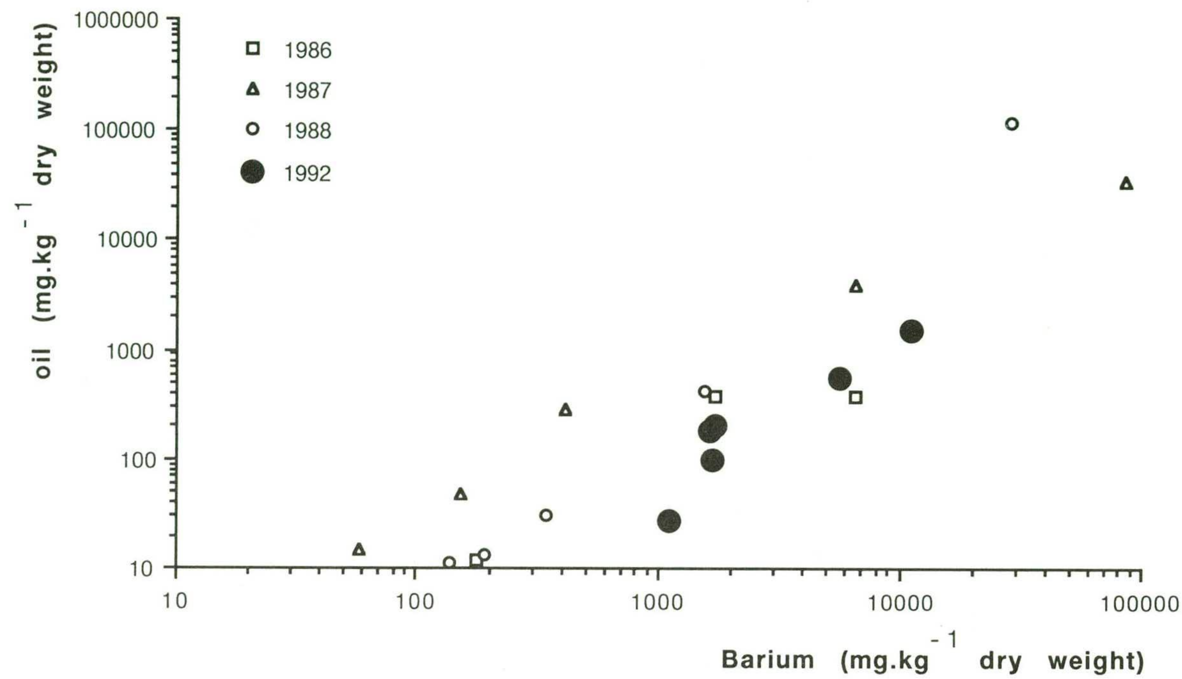

Fig. 8. Relation between oil and Ba concentrations at K12a between 1986 and 1992.

ured in 1987 and, if only from that year data had been available, one would conclude that degradation of oil had taken place in the intervening period. However, the 1992 ratios appear to be in a similar range of values as found in 1986 and 1988, indicating that degradation was negligible. A similar pattern is obtained when the UCM fraction is plotted against Ba concentrations (Fig. 9). For the same reason this pattern reveals no convincing evidence for degradation of the UCM fraction after 1986.

3.4 BIOLOGICAL FEATURES

3.4.1 GENERAL FAUNA DESCRIPTION

The on board countings of *Echinocardium cordatum* revealed that specimens >10 mm were absent exclusively at the 100-m station (Fig. 10). Specimens >15 mm occurred at 250 m but only along the perpendicular transect. Large specimens (>20 mm) were found only at 500 m and further away. It is remarkable that the highest numbers were found at and beyond 2000 m, in spite of the fact that the grab samples were far from quantitative at these stations (see chapter 3.1). In fact, the illustrated numbers per m^2 are underestimates and higher densities are to be expected at these stations. Logit regression revealed a significant (5% level) increase in frequency of occurrence of specimens >15 mm with increasing distance to the platform.

The laboratory analyses yielded 87 identified species. In Table 3 their percentual occurrence in the samples is summarized. The original data are listed in Table 9 (Appendix). The fauna in the area was dominated by (most juvenile) specimens of the crustacean *Callianassa subterranea* and the mollusc *Abra alba*, which both accounted for 16% of the total macrofauna, and by the polychaete *Spiophanes bombyx* (12%). *C. subterranea* and *S. bombyx* were obviously less abundant at 100 m than at the other stations. Table 9 suggests that these species were also less abundant at the 5000-m station, but the estimates of their abundance at this station are severe underestimates, because the samples at this station were not quantitative. Since this will hold for most of the other species, the results of the 5000-m station will be ignored from now on as representative of a reference situation. This decision was made also because the sediment structure at 5000 m was quite different from that at the stations within 1000 m (see Fig. 1), which implies that the fauna composition at 5000 m can not be considered as a reliable reference to the situation within 1000 m.

Most of the other abundant species (those which were present in mean densities of ≥10 individuals per m^2 between 250 m and 1000 m) showed a trend similar to that of *C. subterranea* and *S. bombyx*.: *Nephtys hombergi, Lumbrineris latreilli, Poecilochaetus serpens, Magelona papillicornis, Chaetozone setosa, Myriochele oculata, Nucula turgida, Mysella biden-*

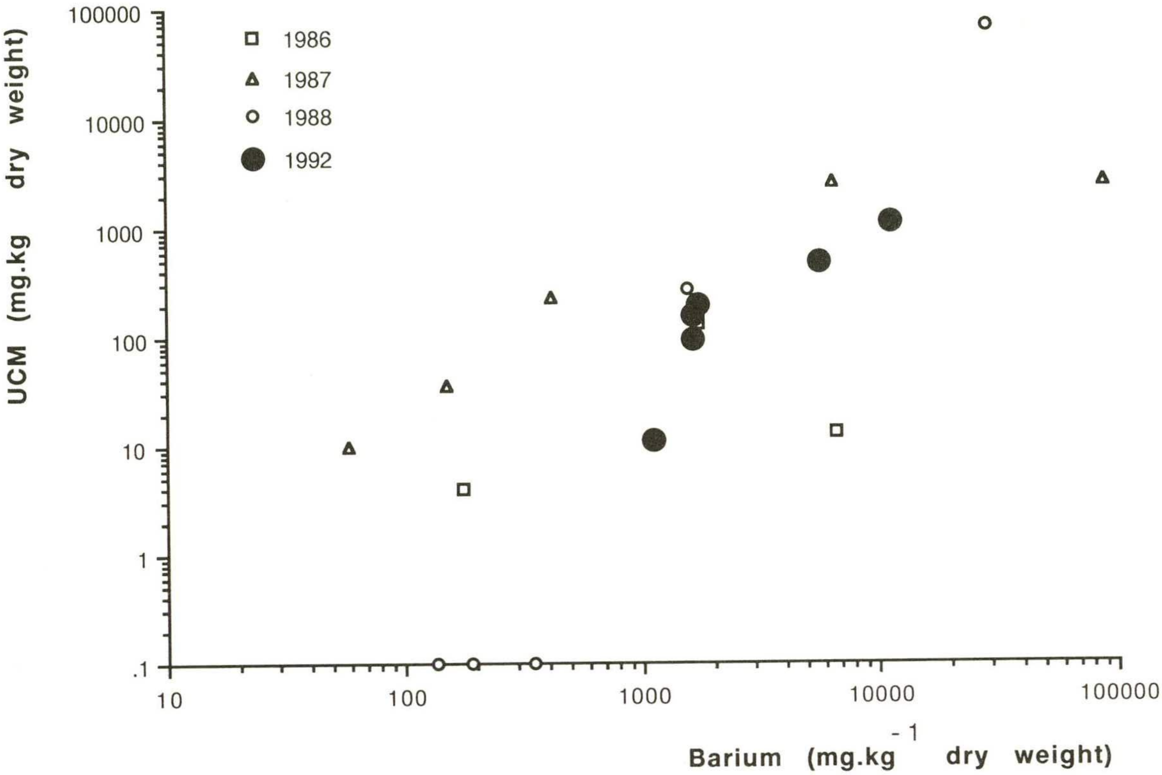

Fig. 9. Relation between UCM and Ba concentrations at K12a between 1986 and 1992.

tata, Venus striatula and (juvenile) *Echinocardium cordatum* all had their lowest density at the 100-m station. In 7 of them this density was less than 50% of the average density at the other stations.

As could be expected from the distribution patterns of the abundant species, the total macrofauna abundance was obviously the lowest at 100 m (711 ind·m^{-2}), whereas between 250 m and 1000 m the numbers fluctuated between 1070 and 1436 ind·m^{-2}. These numbers are low compared to total numbers found between 1985 and 1988, when mean fauna densities at these stations ranged between 1800 and 4500 ind·m^{-2} (see DAAN *et al.*, 1990). Note, however, that total numbers of individuals are always largely determined by the abundance of a few dominant species. Particularly the population densities of *Spiophanes bombyx* and juvenile *Lagis koreni* and *Echinocardium cordatum* around K12a show a very large year to year variation. The abundance of 1 or more of these species appears to fluctuate between several thousands of individuals per m^2 to nearly absence. In 1992 the mean densities of these 3 species were all relatively low and did not exceed 150 ind·m^{-2}. When the contribution of the dominant species is subtracted from the total fauna abundance, the numbers found in 1992 (635 ind·m^{-2})appear to be well within the range of fauna densities found in 1985

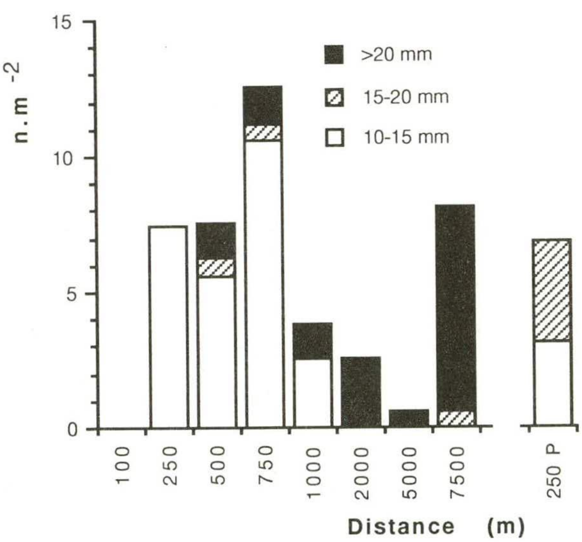

Fig. 10. Abundance and size distribution of *Echinocardium cordatum* at K12a in 1992.

TABLE 3
The benthic fauna at K12a, Sept. 1992.
Percentage of occurrence of each species in the total number of analysed samples (48).

POLYCHAETA		*Diplocirrus glaucus*	17	*Corystes cassivelaunus*	50
		Scalibregma inflatum	42	*Upogebia* spec. juv.	15
Harmothoe lunulata	15	*Ophelina acuminata*	4	*Callianassa subterranea*	98
Harmothoe spec. juv.	15	*Mediomastus gracilis*	4	*Decapoda larven*	23
Gattyana cirrosa	2	*Notomastus latericeus*	19	*Eudorella truncatula*	19
Sigalion mathildae	46	*Owenia fusiformis*	23	*Diastylis bradyi*	46
Pholoe minuta	27	*Myriochele oculata*	73	*Ione thoracica*	6
Sthenelais limicola	83	*Lanice conchilega*	63	*Melita obtusata*	6
Eteone longa	21	*Lagis koreni*	63	*Hippomedon denticulatus*	2
Eteone lactea	2	*Pectinaria auricoma*	4	*Orchomenella nana*	10
Eteone spec. juv.	2	*Eupolymnia nebulosa*	2	*Leucothoe incisa*	33
Mysta barbata	2			*Metopa alderi*	2
Anaitides groenlandica	6	**MOLLUSCA**		*Ampelisca brevicornis*	25
Anaitides mucosa	35			*Ampelisca tenuicornis*	25
Anaitides maculata	19	*Nucula turgida*	90	*Bathyporeia elegans*	2
Anaitides subulifera	25	*Montacuta ferruginosa*	60	*Bathyporeia tenuipes*	19
Anaitides spec. juv.	4	*Mysella bidentata*	71	*Harpinia antennaria*	19
Eumida sanguinea	13	*Acanthocardia echinata*	2	*Aora typica*	15
Ophiodromus flexuosus	44	*Dosinia lupinus*	6		
Gyptis capensis	15	*Venus striatula*	94	**ECHINODERMATA**	
Nereis longissima	15	*Venus verrucosa*	2		
Nereis spec. juv.	19	*Mactra corallina*	2	*Astropecten irregularis*	2
Nephtys hombergii	96	*Spisula subtruncata*	2	*Amphiura filiformis*	46
Nephtys cirrosa	8	*Spisula* spec. juv.	27	*Amphiura chiajei*	15
Nephtys spec. juv.	50	*Tellina fabula*	21	*Acronida brachiata*	4
Glycera alba	13	*Abra tenuis*	23	*Ophiura texturata*	4
Glycera spec. juv.	17	*Abra alba*	98	*Ophiura albida*	4
Glycinde nordmanni	8	*Ensis ensis*	2	*Ophiura* spec. juv.	29
Goniada maculata	73	*Cultellus pellucidus*	44	*Echinocardium cordatum*	40
Lumbrineris latreilli	98	*Corbula gibba*	2	*Echinocardium cordatum* juv.	79
Lumbrineris fragilis	4	*Thracia phaseolina*	2		
Scoloplos armiger	10	*Onoba vitrea*	2	**OTHER TAXA**	
Paraonis fulgens	2	*Natica alderi*	88		
Poecilochaetus serpens	83			Nemertinea	96
Spio filicornis	8	**CRUSTACEA**		Nematoda	4
Spiophanes bombyx	96			Turbellaria	10
Scolelepis bonnieri	6	*Processa parva*	19	Phoroniden	92
Magelona papillicornis	94	*Macropipus holsatus*	4	Harp. copepoda	2
Magelona alleni	4	*Macropipus* spec. juv.	2	Oligochaeta	31
Chaetozone setosa	83	*Ebalia cranchii*	8	Anthozoa	6
				Ascidiacea	2

- 1988 (500-1100 ind·m^{-2}).

The total number of identified species at each station fluctuated within a narrow range of 51 - 55 at the stations between 250 m and 1000 m, whereas the number at 100 m was hardly lower (49, Fig. 11). This may be explained by the fact that a relatively large number of samples (8) was analysed at each station: The larger the number of samples analysed, the larger the chance that some specimens of species, that were relatively rare at 100 m, will be found after all. When the average number of species per sample is considered, the difference between 100 m and the other stations becomes more evident (see Fig. 11) and appears to be significant at the 5% level (ANOVA).

3.4.2 PRESENCE-ABSENCE DATA: LOGIT REGRESSION

Possible gradients in the spatial abundance patterns of individual species, related to distance to the platform, were tested by logit regression. The procedure

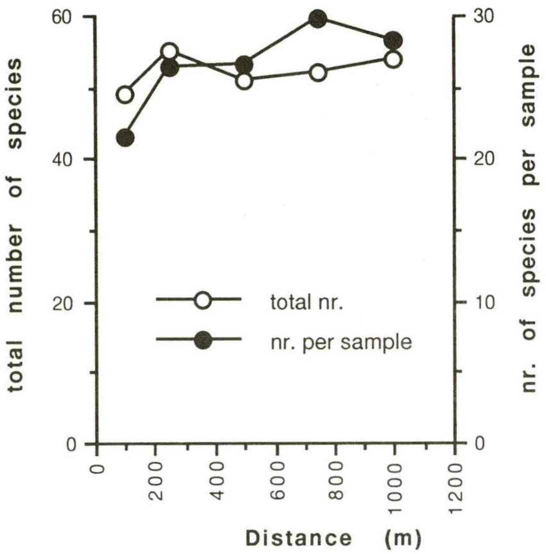

Fig. 11. Total number of species and mean number of species per sample at K12a in 1992.

was performed only for those species of which at least 20 specimens were found. The results, listed in Table 4, show that of 27 species tested, 13 species showed a significant (5% level) gradient in their spatial frequency of occurrence between 100 and 1000 m from the platform. In 4 species a gradient was even significant at the 0.1% level. The number of rejections of H_0 (*i.e.* frequency of occurrence is not dependent on distance to platform) is much higher than could be expected if H_0 were true for all species. Most species showed a significant increase in frequency of occurrence beyond 100 m from the platform. Two species, the polychaete *Lagis koreni* and the crustacean *Diastylis bradyi*, showed an opposite trend and were particularly abundant at the 100-m station. However, of *L. koreni*, a species which in former studies has appeared to be sensitive to OBM contamination of sediments (DAAN *et al.*, 1990), only juvenile specimens were found. Apparently, there has been settlement of spatfall of *L. koreni*, which accidentally found its way to the seabed close to the platform. It seems likely that these juveniles can survive in the thin clean top layer of the sediment, but it is questionable whether they can grow up to adults, which burrow deeper and may thus come in contact with contaminated sediment layers.

3.4.3 RELATIVE MACROFAUNA ABUNDANCE

A plot of the relative macrofauna abundance, calculated as the mean rank of all species at each station (Fig. 12), shows that the mean rank was lowest for the 100-m station, indicating that most species were less abundant here than at the other stations. However, analysis of variance revealed that the differences in relative abundance of the stations investigated were not significant.

3.4.4 ABUNDANCE PATTERNS OF OBM SENSITIVE AND OPPORTUNISTIC SPECIES

In Table 5 a number of species is listed, which in earlier studies have shown to be susceptible to OBM cutting discharges (see DAAN *et al.*, 1990). Also 4 opportunistic species are included. The abundance patterns of all these species were inspected for the presence of a possible spatial gradient at K12a in 1992. The table shows that 17 species occurred in too low numbers (<20 specimens found) to identify any gradient. Of those species of which at least 20 specimens were found, 13 species occurred in reduced abundance in the vicinity of the platform. In 8 species abundance was reduced only at the 100-m station, in 5 species abundance was reduced out to 250 m from the platform. One species, *Lagis koreni*,

TABLE 4

List of species for which gradients in frequency of occurrence 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; n.s = not significant.

	sign	*sign. level (%)*
Sigalion mathildae	+	0.1
Pholoe minuta	+	n.s.
Sthenelais limicola	+	n.s.
Ophiodromus flexuosus	+	0.1
Nephtys hombergii	0	-
Goniada maculata	-	n.s.
Lumbrineris latreilli	0	-
Poecilochaetus serpens	+	0.5
Spiophanes bombyx	+	5
Magelona papillicornis	+	n.s.
Chaetozone setosa	-	n.s.
Scalibregma inflatum	+	n.s.
Myriochele oculata	+	n.s.
Lanice conchilega	+	5
Lagis koreni	-	5
Nucula turgida	+	5
Montacuta ferruginosa	+	5
Mysella bidentata	+	0.1
Venus striatula	+	n.s.
Abra alba	0	-
Cultellus pellucidus	-	n.s.
Natica alderi	+	5
Corystes cassivelaunus	-	n.s.
Callianassa subterranea	0	-
Diastylis bradyi	-	1
Amphiura filiformis	+	0.1
Echinocardium cordatum	+	0.5

showed an opposite trend and high numbers of individuals were found particularly at 100 m and 250 m (see 3.4.2). 23 Species did not show any tendency or were too scarce to detect any gradient.

Opportunistic species all occurred in too low numbers to allow for a perceptible gradient, or were even absent (*Capitella capitata*).

3.4.5 EFFECTS IN RELATION TO OIL CONCENTRATIONS

Figure 13 illustrates which of 7 biological effects that have been described of former surveys (DAAN *et al.*, 1990) were observed at the stations investigated, in relation to the contamination level at each of these stations. Two effects were not observed at all in 1992: no increased abundance of opportunistic species at the most polluted stations could be identified and there was also no significant reduction in relative macrofauna abundance at these stations. All of the other 5 effects were detected at 100 m from the platform, at the highest concentration of 1028 mg oil·kg^{-1} dry sediment. It is remarkable that this number of effects was higher than in 1987 and 1988 (within 4 years after drilling ceased), when only 3 effects could be detected, although the oil concentration at this station was at a similar level those years. At 250 m, where a moderate contamination level of 104 mg oil·kg^{-1} was found, only some very sensitive species still showed reduced abundance and adult *Echinocardium cordatum* were still absent. Other effects that often have been observed at similar concentrations, like an overall reduction in macrofauna abundance, were not assessed. At the other stations the absence of adverse effects was in correspondence with the fact that oil concentrations in the upper 10 cm of the sediment were at background level.

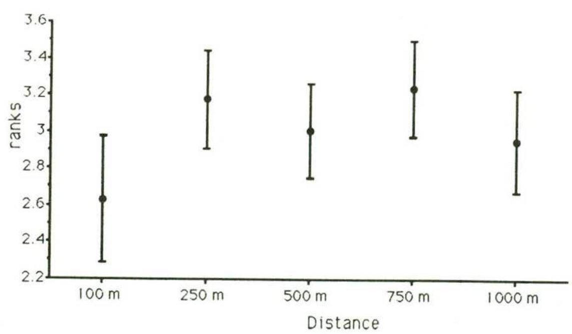

Fig.12. Relative macrofauna abundance at K12a (mean ranks and 95% confidence limits).

TABLE 5

Evaluation of the abundance patterns of 37 species sensitive to OBM contamination and 4 opportunistic species.
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
distance:radius of affected abundance
(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	*distance*
A. Species vulnerable to OBM contamination		
Montacuta ferruginosa	+	
Scalibregma inflatum	+100 m	100 m
Pholoe minuta	+	100 m
Amphiura filiformis	+	250 m
Echinocardium cordatum (≥15 mm)	+	250 m
Mysella bidentata	+	250 m
Nephtys hombergi	+	100 m
Lumbrineris latreilli	0	
Chaetozone setosa	0	
Owenia fusiformis	+	100 m
Nucula turgida	0	
Gattyana cirrosa	0 (?)	
Harpinia antennaria	0 (?)	
Lagis koreni	-	250 m
Glycinde nordmanni	0 (?)	
Cylichna cilindracea	species not found	
Harmothoe longisetis	species not found	
Callianassa subterranea	+	100 m
Magelona papillicornis	+	100 m
Tellina fabula	0 (?)	
Natica alderi	0	
Spiophanes bombyx	+	100 m
Ophiodromus flexuosus	+	250 m
Notomastus latericeus	0 (?)	
Lumbrineris fragilis	0 (?)	
Amphiura chiajei	0 (?)	
Leucothoe incisa	0 (?)	
Chaetopterus variopedatus	species not found	
Tharyx marioni	species not found	
Ophiura albida	0 (?)	
Gyptis capensis	0 (?)	
Lanice conchilega	+	250 m
Perioculodes longimanus	species not found	
Diplocirrus glaucus	0 (?)	
Abra alba	0	
Turritella communis	species not found	
Sthenelais limicola	0	
B. opportunistic species		
Nereis longissima	0 (?)	
Capitella capitata	species not found	
Spio filicornis	0 (?)	
Anaitides groenlandica	0 (?)	

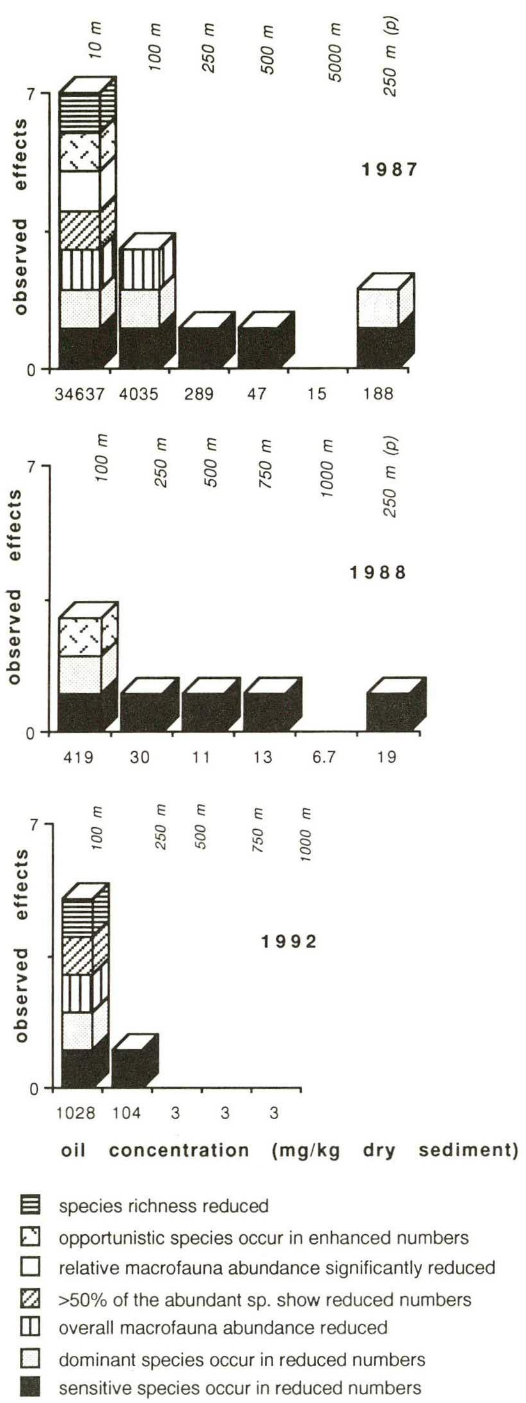

Fig. 13. Biological effects observed at the residual current transect of K12a between 1987 and 1992, at varying levels of sediment contamination. Station 250 m (p) is situated along a perpendicular transect.

4 DISCUSSION

The chemical analyses clearly indicate that there is hardly any horizontal redistribution of the discharged material at the longer term. The Ba concentrations as observed in 1992 still show a similar gradient as observed in the period 1986 - 1988 (Fig. 3). The absence of transport may be properly explained by the fact that the material is stored in the deeper sediment layers. The top layer showed low Ba concentrations and probably consists of recently sedimentated material. Burial of discharged material is also indicated by the vertical profile of oil concentrations at 250 m (r.c. direction), which showed high concentrations in the deeper layers, whereas in the upper 2 cm the concentration did not exceed background level.

At 500 m and further from the platform the oil analyses revealed no concentrations that exceeded background level, although traces of oil were visually observed at all stations up to1000 m, indicating that the oil has not completely disappeared. However there seems to be a decrease in contamination levels beyond 500 m in comparison with the period 1987 - 1990 when clearly elevated concentrations were frequently observed. There is an indication that such a decrease could be (partly) due to degradation in the aerobic top layer, since Ba levels were still significantly elevated out to at least 1000 m, which demonstrates that there are still traces of discharged material present in the sediment. It is also possible, however, that oil did not turn up in the subsamples due to patchiness in its distribution in the sediment or to the fact that oil was mainly present in deeper sediment layers.

Closer to the platform there is no convincing evidence for a decrease in oil concentrations. However, the chromatograms indicate that the oil seems to have undergone changes in chemical composition, which may influence its toxicity for benthic animals. The oil-Ba ratio, which could, in theory, provide a useful parameter to estimate the rate of breakdown of oil in the sediment (GROENEWOUD & SCHOLTEN, 1992a), did not point at substantial degradation, but we can not completely rely on this ratio. There is no doubt that during drilling of the wells at K12a drilling muds will have been employed with different compositions. Therefore, the ratio between oil and Ba can have been quite variable and the original ratio's in the material dumped will have been variable too. Hence, this may be considered a major cause of spatial and year to year differences in oil-Ba ratio's in the sediment. The presence of oil in the deeper sediment layers may still be an ecotoxicological risk, in particular to deep burrowing species.

Biological effects seemed to occur only within a few hundred meters from the platform. At 500 m and further away no significant effect could be detected anymore. In this respect, however, there is some uncertainty, since a reliable reference situation, to

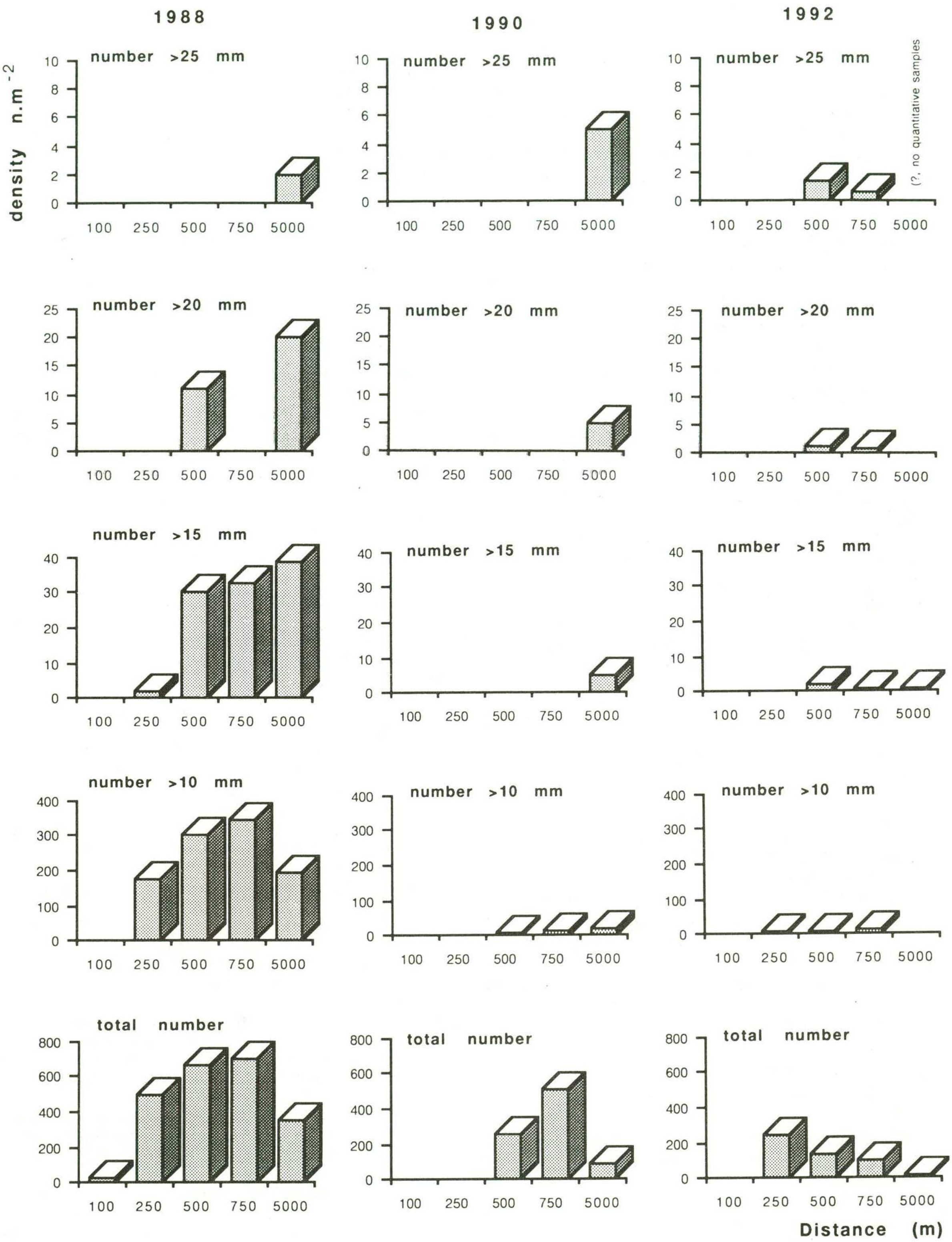

Fig. 14. Size distribution of *Echinocardium cordatum* at K12a in 1988, 1990 and 1992.

which the data could be related, was lacking. Nevertheless, most species which in earlier studies have shown a sensitive response to OBM cutting discharges, did not show any sign of a gradient between 500 and 1000 m. At 250 m only 5 sensitive species occurred in reduced abundance. Most other species were affected in their abundance only at the 100-m station. Even *Montacuta ferruginosa*, which is known as a very sensitive indicator species, seemed to be present at 250 m in unaffected densities, in spite of the fact that of its host species *Echinocardium cordatum* large specimens were still absent. Apparently, *M. ferruginosa* can settle and live in symbiosis also with smaller specimens. However, the question remains, whether these new generations are viable. A general impression obtained during the analysis of the samples was that a large proportion of the fauna consisted of small juvenile specimens. In this respect *E. cordatum* is a good example. Fig. 14 shows the abundance and size distribution of *E. cordatum* in 1988, 1990 and 1992 at those stations that were investigated each of these years. (The 1988 and 1990 data on size distribution are taken from VAN LEEUWEN (1992), who analysed the samples from 1988 (reported by DAAN *et al.*, 1990) in more detail and carried out an analysis of *M. ferruginosa* and *E. cordatum* in unused samples collected during a field survey in September 1990.) The figure shows that individuals >15 mm were present in all three years only at 500 m and beyond that distance. Smaller specimens were found, except for 1990, also at 250 m and, particularly in 1988, in high numbers. If individuals of this generation had grown up during the following 2 years, they would have reached a size of more than 15 mm (see growth curves presented by DUINEVELD & JENNESS, 1984). However, animals of that size were not found in 1990 out to 750 m. Apparently there were no surviving individuals of the 1988 generation. A new generation of juveniles was found in 1990 at 500 and 750 m, but not at 250 m. Of this generation a small fraction was recovered in 1990 in the size class >15 mm. These data suggest that there is still high mortality among juveniles that are growing up and that even at 500 and 750 m only a very few individuals will finally become adults. It is not clear, however, to what extent the low survival rates should be attributed to disturbed sediment conditions, since natural mortality among juvenile *E. cordatum* is always high. This can be deduced from the fact that juveniles are often found in densities of several thousands per m^2, whereas numbers of adults seldom exceed 10 $ind \cdot m^{-2}$.

When the results of the present survey are compared to those of previous studies, it is concluded that in the vicinity of the platform no recovery of the benthic community could be detected. In fact the number of measurable effects at 100 m was higher in 1992 than in 1987 and 1988. However, the absence of the opportunist *Capitella capitata* may indicate that sediment conditions have more or less stabilized. At stations that lie at 250 m or larger distance from the platform, there are signs of recovery of sediment conditions, particularly of the superficial sediment layer. This is mainly indicated by the reappearance of a number of sensitive species that probably have recolonized this superficial layer. Future surveys should show whether these new generations can develop successfully and generate vital populations of adults. Particularly for a deep burrowing species like *Callianassa subterranea*, of which high numbers of juveniles were found during the present survey, the answer to this question may provide improved insight into the recovery potential of the sediment around K12a.

Because of the spatial heterogeneity in sediment structure observed, the 5000 m station at the residual current transect can not longer be considered to represent a reliable reference situation. It is recommended therefore to look for other reference stations in future research. Remote stations along perpendicular transects or an upstream transect might be adequate. An alternative solution might be to use another sampler, *e.g.* a Hamon grab.

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APPENDIX

TABLE 6

Grainsize distribution of the sediment at K12a (data from GROENEWOUD, 1993).

Distance	*%>1000 µm*	*%>500 µm*	*%>300 µm*	*%>180 µm*	*%>125 µm*	*%>90 µm*	*%>63 µm*	*%<63 µm*
100	0.87	0.96	1.27	3.01	52.59	18.85	8.20	13.30
250	0.40	0.43	0.63	2.20	64.81	19.55	4.89	6.78
500	0.04	0.04	0.20	1.04	67.04	21.91	4.17	5.43
750	0.01	0.02	0.12	0.87	65.99	21.97	4.60	5.99
1000	0.01	0.01	0.12	0.87	66.53	21.95	4.55	5.49
2000	0.00	0.01	0.08	0.77	62.87	25.35	5.23	5.38
5000	0.13	0.03	0.07	0.74	59.23	30.84	5.05	3.76
7500	0.04	0.02	0.07	0.46	48.19	39.35	7.27	4.33
250								
0-2 cm	0.03	0.11	0.35	1.32	64.24	20.31	4.93	8.26
2-10 cm	0.57	0.33	0.67	1.82	67.66	20.30	4.32	3.96
25-30 cm	1.32	0.37	0.63	1.70	65.13	19.79	4.51	6.28

TABLE 7
Concentrations of oil components at K12a 1992 (mg/kg dry sediment), data from GROENEWOUD (1993).

Station	*100 m*	*100 m*	*250 m*	*250 m*	*500 m*	*750 m*	*1000 m*	*5000 m*	*250 m*		
									0-2 cm	*2-10 cm*	*25-30 cm*
Component											
C10	0.29	0.73	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C11	0.49	3.17	0.24	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Naphtalene	1.81	6.38	0.73	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.29
C12	2.75	7.78	1.10	0.19	0.01	0.01	0.01	0.01	0.01	0.50	0.39
C13	1.45	4.44	0.82	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.01
C14	1.02	6.24	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C15	0.23	3.10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C16	0.16	2.56	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C17	0.01	1.45	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Pristane	0.01	0.65	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C18	0.17	0.92	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Phytane	0.01	1.21	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C19	0.01	1.69	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C20	0.01	0.53	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C21	0.01	0.21	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C22	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C23	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C24	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C26	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C27	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C28	0.01	0.01	0.01	0.01	0.23	0.01	0.01	0.01	0.01	0.01	0.01
C29	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
C30	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Sum	8.63	41.22	3.20	0.53	0.57	0.35	0.35	0.35	0.36	0.88	0.99
other	72.45	343.59	15.79	15.68	1.36	1.35	1.36	1.34	1.37	4.48	6.00
UCM	471.87	1118.16	160.60	11.22	1.36	1.35	1.36	1.34	1.37	94.94	191.74
Total	552.95	1502.96	179.59	27.43	3.28	3.04	3.07	3.03	3.10	100.31	198.73

TABLE 8
Vertical profiles of total oil concentrations in the sediment (mg·kg dry^{-1} sediment) at 250 m (residual current transect) from K12a (data from GROENEWOUD, 1991; 1993).

	Sept. 1987	*Sept.1988*	*Sept. 1992*
0-2 cm	232	159	3
2-10 cm	55	444	100
25-30 cm	27	8	198

Table 9. Data platform K12a, survey Sept. 1992.
Mean densities (n.m-2)
Number of samples ( ) in which species are present.
Tot. number of ind. per m2 per station.
Number of identified species.

Distance to platform (m)	100	250	500	750	1000	5000
Number of analysed samples	8	8	8	8	8	8
POLYCHAETA						
Harmothoe lunulata		0.6 (1)			3.1 (4)	3.8 (2)
Harmothoe spec. juv.			1.9 (3)	1.3 (2)	1.3 (1)	0.6 (1)
Gattyana cirrosa						0.6 (1)
Sigalion mathildae			2.5 (2)	11.3 (7)	9.4 (8)	4.4 (5)
Pholoe minuta	0.6 (1)	5.0 (5)	3.8 (3)	0.6 (1)	3.1 (3)	
Sthenelais limicola	12.5 (7)	6.3 (6)	15.0 (7)	10.0 (7)	12.5 (7)	13.1 (6)
Eteone longa	1.9 (3)	1.9 (3)	0.6 (1)	0.6 (1)	0.6 (1)	0.6 (1)
Eteone lactea	0.6 (1)					
Eteone spec. juv.	0.6 (1)					
Mysta barbata		0.6 (1)				
Anaitides groenlandica			0.6 (1)			1.3 (2)
Anaitides mucosa		1.9 (2)	2.5 (4)	4.4 (5)	2.5 (4)	1.9 (2)
Anaitides maculata		3.1 (5)	2.5 (4)			
Anaitides subulifera	3.1 (3)		1.9 (2)	2.5 (3)	0.6 (1)	4.4 (3)
Anaitides spec. juv.			0.6 (1)			0.6 (1)
Eumida sanguinea				1.3 (1)	1.3 (2)	3.1 (3)
Ophiodromus flexuosus		1.3 (2)	10.6 (6)	10.0 (6)	6.3 (6)	0.6 (1)
Gyptis capensis		0.6 (1)	1.9 (3)	1.9 (3)		
Nereis longissima	1.3 (2)	2.5 (3)		0.6 (1)	0.6 (1)	
Nereis spec. juv.	1.3 (2)	3.1 (3)	1.9 (3)		0.6 (1)	
Nephtys hombergii	16.9 (8)	32.5 (8)	33.8 (8)	38.8 (8)	31.9 (8)	15.6 (6)
Nephtys cirrosa				1.9 (3)		0.6 (1)
Nephtys spec. juv.	13.1 (7)	3.8 (4)	6.3 (4)	5.6 (5)	1.3 (2)	1.9 (2)
Glycera alba	3.8 (4)	1.3 (1)	0.6 (1)			
Glycera spec. juv.	2.5 (3)	1.3 (2)	0.6 (1)		0.6 (1)	0.6 (1)
Glycinde nordmanni	0.6 (1)	1.9 (3)				
Goniada maculata	13.8 (7)	13.1 (6)	6.9 (6)	7.5 (6)	4.4 (5)	5.0 (5)
Lumbrineris latreilli	51.3 (8)	61.3 (8)	65.6 (8)	69.4 (8)	85.0 (8)	59.4 (7)
Lumbrineris fragilis	0.6 (1)	0.6 (1)				
Scoloplos armiger		0.6 (1)	1.3 (2)	1.3 (2)		
Paraonis fulgens						0.6 (1)
Poecilochaetus serpens	3.8 (4)	9.4 (8)	23.1 (8)	26.9 (8)	16.9 (7)	15.0 (5)
Spio filicornis		0.6 (1)		1.3 (2)	0.6 (1)	

Table 9. continued.

Distance to platform (m)	100	250	500	750	1000	5000
Number of analysed samples	8	8	8	8	8	8
Spiophanes bombyx	38.8 (7)	130.0 (8)	183.1 (8)	185.6 (8)	121.9 (8)	63.8 (7)
Scolelepis bonnieri				0.6 (1)	0.6 (1)	0.6 (1)
Magelona papillicornis	15.6 (7)	49.4 (7)	43.8 (8)	40.6 (8)	30.0 (8)	45.0 (7)
Magelona alleni			1.3 (2)			
Chaetozone setosa	19.4 (8)	23.8 (7)	37.5 (8)	36.9 (8)	20.0 (7)	2.5 (2)
Diplocirrus glaucus	0.6 (1)	1.9 (3)		1.3 (2)		1.3 (2)
Scalibregma inflatum	1.3 (2)	9.4 (6)	6.3 (4)	2.5 (3)	6.9 (5)	
Ophelina acuminata	0.6 (1)			0.6 (1)		
Mediomastus gracilis		0.6 (1)			0.6 (1)	
Notomastus latericeus	0.6 (1)	1.3 (2)	1.9 (2)	0.6 (1)	1.3 (2)	0.6 (1)
Owenia fusiformis	0.6 (1)	3.8 (3)	4.4 (4)	1.3 (2)	1.9 (1)	
Myriochele oculata	20.0 (7)	46.3 (6)	38.8 (7)	71.9 (7)	50.0 (8)	
Lanice conchilega	1.3 (2)	3.1 (4)	8.8 (8)	9.4 (7)	13.1 (5)	6.3 (4)
Lagis koreni	31.3 (8)	24.4 (7)	3.8 (4)	3.1 (5)	3.1 (4)	1.3 (2)
Pectinaria auricoma			0.6 (1)		1.3 (1)	
Eupolymnia nebulosa	0.6 (1)					
MOLLUSCA						
Nucula turgida	44.4 (7)	60.0 (8)	39.4 (8)	44.4 (8)	50.0 (8)	9.4 (4)
Montacuta ferruginosa		55.0 (8)	29.4 (8)	20.6 (8)	7.5 (5)	
Mysella bidentata	2.5 (2)	15.0 (7)	61.9 (8)	71.3 (8)	141.9 (8)	0.6 (1)
Acanthocardia echinata		0.6 (1)				
Dosinia lupinus	0.6 (1)	1.3 (1)	0.6 (1)			
Venus striatula	19.4 (7)	31.3 (8)	30.0 (7)	35.0 (8)	30.6 (8)	27.5 (7)
Venus verrucosa						0.6 (1)
Mactra corallina	0.6 (1)					
Spisula subtruncata						0.6 (1)
Spisula spec. juv.	3.1 (2)	2.5 (4)	1.3 (1)	2.5 (2)	1.9 (3)	0.6 (1)
Tellina fabula		1.3 (2)	1.9 (1)	1.9 (3)	1.3 (2)	2.5 (2)
Abra tenuis	0.6 (1)	1.9 (2)	1.9 (2)	2.5 (3)	1.3 (2)	0.6 (1)
Abra alba	228.8 (8)	306.3 (8)	161.9 (8)	125.6 (8)	85.0 (8)	71.3 (7)
Ensis ensis	0.6 (1)					
Cultellus pellucidus	8.8 (5)	6.9 (6)	3.1 (2)	4.4 (4)	3.1 (4)	
Corbula gibba					0.6 (1)	
Thracia phaseolina		0.6 (1)				
Onoba vitrea					0.6 (1)	
Natica alderi	14.4 (6)	21.3 (6)	23.1 (8)	17.5 (8)	13.1 (8)	6.9 (6)

Table 9. continued.

Distance to platform (m)	100	250	500	750	1000	5000
Number of analysed samples	8	8	8	8	8	8
CRUSTACEA						
Processa parva		0.6 (1)	1.9 (3)		4.4 (4)	0.6 (1)
Macropipus holsatus					0.6 (1)	0.6 (1)
Macropipus spec. juv.						0.6 (1)
Ebalia cranchii	1.9 (3)	0.6 (1)				
Corystes cassivelaunus	5.6 (6)	3.1 (3)	6.9 (4)	6.3 (6)	4.4 (4)	0.6 (1)
Upogebia spec. juv.	0.6 (1)	5.0 (4)		0.6 (1)	0.6 (1)	
Callianassa subterranea	93.1 (8)	207.5 (8)	240.0 (8)	215.6 (8)	203.8 (8)	31.9 (7)
Decapoda larven				1.3 (2)	3.1 (3)	9.4 (6)
Eudorella truncatula	0.6 (1)	2.5 (2)	1.3 (2)	1.3 (2)	1.3 (2)	
Diastylis bradyi	7.5 (7)	4.4 (5)	1.9 (3)	2.5 (3)	1.3 (2)	1.3 (2)
Ione thoracica		0.6 (1)		1.3 (1)	0.6 (1)	
Melita obtusata						3.8 (3)
Hippomedon denticulatus	0.6 (1)					
Orchomenella nana	3.1 (1)		0.6 (1)	0.6 (1)		4.4 (2)
Leucothoe incisa		0.6 (1)	0.6 (1)	3.1 (3)	7.5 (6)	5.0 (5)
Metopa alderi						0.6 (1)
Ampelisca brevicornis	2.5 (2)	1.3 (2)		2.5 (4)	1.3 (2)	1.3 (2)
Ampelisca tenuicornis	4.4 (5)	2.5 (3)		1.9 (3)	0.6 (1)	
Bathyporeia elegans			0.6 (1)			
Bathyporeia tenuipes			1.3 (2)	2.5 (4)	1.9 (2)	0.6 (1)
Harpinia antennaria		1.3 (2)	0.6 (1)	3.1 (5)	1.3 (1)	
Aora typica			0.6 (1)			25.0 (6)
ECHINODERMATA						
Astropecten irregularis						0.6 (1)
Amphiura filiformis	0.6 (1)	1.3 (1)	5.6 (5)	11.3 (4)	18.8 (8)	2.5 (3)
Amphiura chiajei			1.3 (1)	2.5 (3)	3.1 (3)	
Acronida brachiata	0.6 (1)				0.6 (1)	
Ophiura texturata	0.6 (1)					0.6 (1)
Ophiura albida	0.6 (1)					1.3 (1)
Ophiura spec. juv.		4.4 (4)	1.9 (2)	2.5 (4)	0.6 (1)	2.5 (3)
Echinocardium cordatum		7.5 (3)	7.5 (4)	12.5 (6)	3.8 (5)	0.6 (1)
Echinocardium cordatum juv.	1.9 (3)	235.6 (8)	129.4 (8)	83.1 (8)	36.9 (8)	7.5 (3)

Table 9. continued.

Distance to platform (m)	100	250	500	750	1000	5000
Number of analysed samples	8	8	8	8	8	8
OTHER TAXA						
Nemertinea	p (7)	p (8)	p (8)	p (8)	p (8)	p (7)
Nematoda	1.3 (2)					
Turbellaria	0.6 (1)	3.1 (3)		0.6 (1)		
Phoroniden	p (7)	p (8)	p (8)	p (7)	p (7)	p (7)
Harp. copepoda	0.6 (1)					
Oligochaeta	1.3 (1)	1.9 (3)	0.6 (1)	3.8 (3)	3.8 (3)	11.3 (4)
Anthozoa		1.3 (2)	0.6 (1)			
Ascidiacea				0.6 (1)		
Total nr. of individuals	711	1436	1272	1236	1070	488
Nr. of identified species	49	55	51	52	54	50

p=present (not counted)

CONTENTS