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Cover design: H. Hobbelink
(The illustration shows the spatial abundance pattern of
*Echinocardium cordatum* around drill site L5-5, Sept. 1991;
for details see Fig. 10 in this report)

# LONG-TERM EFFECTS OF DISCHARGES OF WASHED AND UNWASHED OBM DRILL CUTTINGS ON THE DUTCH CONTINENTAL SHELF

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This study was commissioned by the North Sea Directorate (RWS)
and carried out in 1990 and 1991

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## SUMMARY AND CONCLUSIONS


Biological research on the impact of discharges of oil contaminated drill cuttings at offshore installations on the Dutch Continental Shelf focussed in 1990 and 1991 on long-term effects. The investigations were carried out at two locations that were subject of study already in previous years.

At location L5-5 in the Frisian Front area, an explorative drilling took place in the autumn of 1988. During drilling oil based muds (OBM) were used and the drill cuttings contaminated with these muds were "washed" before they were dumped on the seabed. In May 1989 a first benthic survey was carried out around the location to study the initial biological effects of the discharges of these washed cuttings. The main conclusions arising from that study were (a) that the intensity of biological effects was less severe compared to OBM locations, where cuttings were not washed before discharge and (b) that the extent of the area subjected to environmental stress was not reduced. The question remained to what extent the short-term effects observed in 1989 would persist. Therefore follow-up surveys were performed in 1990 and 1991, of which the results are presented in this report.

In April 1990, one and a half year after drilling, a routine macrobenthos survey was carried out at L5-5. Starting at 25 m (in the residual current direction) from the discharge site, 7 stations were sampled at increasing distances, the last station being situated at 5000 m. The results show that the affected area was restricted to a few hundred metres from the discharge site. At distances ≥500 m oil concentrations were consistently at background level and no significant effects were observed. However, the distribution pattern of large *Echinocardium cordatum* suggested that initial effects were possibly still present up to a much larger distance.

In September 1991, 3 years after drilling, the area was investigated again. The number of stations sampled (18) was much higher than in 1990, but the laboratory analysis of the samples was confined to countings of 2 OBM sensitive species, *Echinocardium cordatum* and *Montacuta ferruginosa*. The main outcome of this study was that the distribution patterns of these species both showed reduced frequency of occurrence within 2000 m from the discharge site, when compared to the reference situation at 5000 m. It is argued that this is most likely a long-term consequence of an initial effect and should not be considered an actual effect of contamination at the long term.

The second location investigated was K12a, in the sandy erosion area south-west of the Frisian Front, where extensive drilling activities were terminated 6 years before. Cuttings were not washed before discharge. Between 1985 and 1988 combined biological and chemical monitoring took place in September of each year. The results of these field surveys indicated that, although a substantial decrease of contamination levels in the sediment was not observed, the biological effects seemed to gradually decrease. It was suggested that a possible recovery of the benthic fauna might be explained by either a decrease in toxicity of the oil or a decrease in bioavailability. In 1990 the toxicity of the sediment at K12a was tested in a boxcosm experiment, using intact sediment sections from 3 stations in the residual current direction of K12a. The boxcosms were incubated in an indoor basin under semi-natural conditions and stocked with the test species *Echinocardium cordatum*. Mortality and sublethal features among this species (deviant burrowing behaviour and loss of spines) were studied during 3 months. *Echinocardium* appeared to display a clear response to the severely contaminated sediment collected at 100 m and 250 m respectively. In the 5000-m sediment which also showed significantly elevated oil concentrations no response was observed. Although the experimental results may indicate that the toxicity of the oil (or bioavailability of toxic components) seems to decrease at the long term, it is stressed that, 6 years after drilling, the environmental conditions are still clearly affected up to at least 250 m from the discharge site.

The results and conclusions of the 1990 and 1991 studies may be summarized as follows:

1. L5-5. In 1990, one and a half year after the drilling, nearly all defined biological effects were detectable up to 100 m from the discharge site. Colonisation of the sediment by opportunistic species was observed only at a very limited scale.
2. L5-5. In the same year (1990), adverse effects were evident at 250 m by the absence of some very sensitive species (*e.g. Montacuta ferruginosa*). Moreover, overall low macrofauna abundance at one of the stations sampled at 250 m indicated environmental stress.
3. L5-5. Elevated oil concentrations in the sediment were found, in both years, up to 250 m from the discharge site. However, within this area there was no relationship between the extent of accumulation of biological effects and contamination level. Hence, it is suggested that oil is not the only factor responsible for environmental stress and that other substances in the discharged material may have significant impact.
4. L5-5. In terms of fauna composition, total macrofauna abundance or abundance of individual species, significant effects were not observed in 1990 at distances ≥500 m from the discharge site. However, large (≥20 mm) specimens of *Echinocardium cordatum* were found almost exclusively at ≥1000

m, indicating that this species was still affected up to a much larger distance.

5. L5-5. The more detailed spatial abundance pattern of *Echinocardium cordatum* (specimens ≥15 mm) as observed in 1991 confirmed that large specimens only frequently occurred at large distance from the discharge site. In the residual current direction the species was affected in its distribution up to 2 - 3 km from the discharge site. It is recommended to include size frequency distributions of *Echinocardium* in future surveys.
6. L5-5. Although in 1990 a few specimens of *Montacuta ferruginosa* were found at 500 - 1000 m from the discharge site, which suggested a possible recovery of environmental conditions in this zone, the spatial distribution pattern of this species in 1991 indicated that it still occurred in reduced abundance up to ≈2 km from the discharge site.
7. L5-5. The distribution pattern of *Montacuta ferruginosa* was, in both years, closely related to the distribution of larger specimens of its host species *Echinocardium cordatum*. This supports the hypothesis that the putative sensitivity of *Montacuta* to OBM contamination has likely to be explained by the sensitivity of its host, *Echinocardium*, and that the occurrence of *Montacuta* is restricted to those areas where *Echinocardium* can survive.
8. L5-5. Interpretation of long-term biological effects, as observed in field situations, should take into account the existence of two types of effects, *viz.* long-term consequences of initial effects (Type-A effects) and actual effects of contamination at the long term (Type-B effects). The absence (or reduced abundance) of *Montacuta* and large *Echinocardium* in the initially affected zone up to 2000 m from the discharge site should be considered a Type-A effect, *viz.* the long-term consequence of extermination of these species by the contamination that was initially present. The fact that the populations did not recover in 1990 and 1991 should largely be explained by the absence of a substantial spatfall, at least at ≥500 m from the discharge site, where oil concentrations did not exceed background level these years. Within 250 m the oil concentrations may have been still too high at all to allow for settlement of new generations (Type-B effect).
9. K12a. The fact that initial fauna densities were substantially lower in the severely contaminated sediment of 100 m and 250 m than in sediment of 5000 m demonstrated that, 6 years after drilling, contamination has still considerable impact on the benthic fauna at least up to 250 m. Both Type-A and Type-B effects may be involved.
10. K12a. Mortality among the natural infauna was high (on average ≈80% after 4 months) in all boxcosms, including those of 5000 m. This might be due to sediment contamination, since oil concentrations were also significantly elevated in the 5000-m sediment. However, temporary suboptimal experimental conditions should not be excluded as a possible explanation. Estimated mortality rates in the individual boxcosms were not correlated with total oil concentrations.
11. K12a. The test species *Echinocardium cordatum* showed increased frequency of sublethal effects and increased mortality in sediment of 100 m and 250 m. In the 5000-m sediment mortality was close to zero and sublethal effects were not observed.
12. K12a. The response of the test species *Echinocardium cordatum* was weak in view of the extremely high contamination levels in the sediment, ranging from 54 mg oil·kg$^{-1}$ dry sediment in the least contaminated 5000-m boxcosm to 30000 mg·kg$^{-1}$ in the most severely contaminated 100-m boxcosm. This indicates that at the long term the biological availability of toxic components decreases.

# SAMENVATTING EN CONCLUSIES

Sedert 1985 wordt in de Nederlandse sector van de Noordzee onderzoek uitgevoerd naar de biologische effekten van lozingen van oliehoudend boorgruis vanaf boorplatforms. In 1990 en 1991 ging de aandacht speciaal uit naar effekten op de langere termijn. Onderzoek werd uitgevoerd rond 2 lokaties die in voorgaande jaren ook al onderwerp van studie waren.

Lokatie L5-5, gelegen in het Friese Front gebied, is een lokatie waar in de herfst van 1988 één proefboring werd verricht. Tijdens bepaalde fases van de boring werd boorspoeling op olie-basis (OBM) toegepast. Het opgeboorde gruis (met aanhangende boorvloeistof) werd volgens een nieuw ontwikkelde methode 'gewassen' voor het op de zeebodem werd geloosd. In mei 1989 vond een eerste benthische survey rond de lokatie plaats, teneinde de biologische korte-termijn effekten van de lozingen van dit gewassen boorgruis vast te stellen. De belangrijkste conclusies van dat onderzoek waren (a) dat de biologische effekten minder sterk waren dan die welke zijn waargenomen op OBM-lokaties, waar het boorgruis voor de lozing geen wassing had ondergaan, maar (b) dat de omvang van het gebied dat als gevolg van de lozingen onderhevig bleek te zijn aan 'environmental stress' niet kleiner was dan op 'ongewassen-boorgruis' lokaties. De vraag bleef in hoeverre de in 1989 waargenomen korte-termijn effekten ook op langere termijn aantoonbaar zouden blijven. Om die reden werden in 1990 en 1991 vervolg-surveys uitgevoerd. In dit rapport wordt van de resultaten van deze surveys verslag gedaan.

In april 1990, anderhalf jaar na de boring, werd bij L5-5 een macrobenthos-survey uitgevoerd, volgens een inmiddels gebruikelijk concept. In de reststroomrichting werd, beginnend op 25 m en vervolgens op toenemende afstanden van het lozingspunt, een 7-tal stations bemonsterd. Het laatste station lag op 5000 m van het lozingspunt. Het optreden van biologische effekten werd afgeleid uit de makrofauna-samenstelling van de verschillende stations. De resultaten van deze survey laten zien dat aantoonbare effekten alleen voorkwamen tot op enkele honderden meters van het lozingspunt. Op afstanden ≥500 m werden in het sediment geen verhoogde olieconcentraties meer gevonden ten opzichte van natuurlijke achtergrondwaarden en ook geen significante biologische effekten. Het verspreidingspatroon van grotere *Echinocardium cordatum* vertoonde echter een indicatie, dat initiële effekten zich mogelijk nog steeds deden gelden tot op veel grotere afstand.

In september 1991, 3 jaar na de boring, werd het gebied nog eens bezocht. Dit keer werd een veel groter aantal stations (18) bemonsterd dan in 1990, maar beperkten de laboratorium-analyses zich tot tellingen van alleen 2 OBM-gevoelige soorten, namelijk *Echinocardium cordatum* en *Montacuta ferruginosa*. Het belangrijkste resultaat van deze studie is, dat beide soorten tot op 2000 m van het lozingspunt steeds minder frekwent bleken voor te komen dan daarbuiten. Wat *Echinocardium* betreft geldt dit met name voor de grotere (oudere) exemplaren. In de discussie wordt uiteengezet, dat dit effekt zeer waarschijnlijk gezien moet worden als het lange-termijn gevolg van een effekt dat op de korte termijn reeds moet hebben plaats gevonden, namelijk sterfte onder deze soorten in het aanvankelijk als gevolg van de lozingen verontreinigde gebied. Het effekt dient dus niet gezien te worden als een direkt gevolg van verontreiniging die op de lange termijn nog aanwezig zou zijn.

De tweede lokatie die in 1990 onderzocht werd was K12a, gelegen in het fijnzandige erosie-gebied ten zuid-westen van het Friese Front. Aan de uitgebreide booraktiviteiten die hier hebben plaats gevonden kwam in 1984, dus 6 jaar tevoren, een eind. Tijdens de boringen werd uitsluitend ongewassen boorgruis geloosd. In de periode 1985-1988 heeft ieder jaar, telkens in september, al een gecombineerde biologisch-chemische survey rond deze lokatie plaats gehad. De resultaten van deze veldstudies wezen erop, dat, hoewel van een aantoonbare afname van olieconcentraties in het sediment geen sprake was, biologische effekten wel geleidelijk leken af te nemen. Als mogelijke verklaring voor een eventueel herstel van de benthische fauna werd aangevoerd, dat ofwel de toxiciteit van de olie in het sediment zou kunnen zijn afgenomen, ofwel de biologische beschikbaarheid zou zijn verminderd. In 1990 werd de toxiciteit van het sediment rond K12a getest in een boxcosm-experiment. Hiertoe werden intakte sediment-kernen, afkomstig van een drietal stations in de reststroomrichting van K12a, in het laboratorium onder semi-natuurlijke omstandighden geïncubeerd. Op elk van de bodemkernen werd een 20-tal exemplaren van de hartegel (*Echinocardium cordatum*) als proefdier uitgezet. Gedurende 3 maanden werden bij deze soort vervolgens zowel mortaliteit als sublethale effekten (afwijkend ingraafgedrag en stekelverlies) gevolgd. *Echinocardium* bleek een duidelijke respons te vertonen op het ernstig verontreinigde sediment van zowel 100 als 250 m. In het sediment verzameld op 5000 m van het lozingspunt, waarin olieconcentraties veel lager, maar nog steeds significant verhoogd waren, kon geen respons worden waargenomen. Hoewel de resultaten er op wijzen dat de toxiciteit van de olie (of de biologische beschikbaarheid van toxische componenten) lijkt te zijn afgenomen, laat deze studie zien dat er rond K12a, 6 jaar na de boringen, nog steeds duidelijk sprake is van environmental stress tot op tenminste 250 m van het lozingspunt.

De resultaten en conclusies van de in 1990 en 1991 uitgevoerde studies kunnen als volgt worden samengevat:

1. L5-5. In 1990 konden anderhalf jaar na boring bijna alle eerder beschreven biologische effekten worden aangetoond tot op 100 m van het lozingspunt. Kolonisatie van het sediment door opportunistische soorten kon echter alleen in zeer geringe mate worden waargenomen.
2. L5-5. In hetzelfde jaar (1990) openbaarde op 250 m een negatief effekt zich slechts in het ontbreken van enkele zeer gevoelige soorten, zoals *Montacuta ferruginosa*. Bovendien duidde een geringe makrofauna-abundantie op één van de stations bemonsterd op 250 m op environmental stress.
3. L5-5. Verhoogde olieconcentraties in het sediment werden in beide jaren gevonden tot op 250 m van het lozingspunt. Binnen deze zone was er echter geen correlatie tussen de hoogte van olieconcentraties en de mate waarin een accumulatie van biologische effekten kon worden gevonden. Daarom moet er rekening mee worden gehouden dat andere componenten in het geloosde materiaal een rol van betekenis kunnen hebben gespeeld.
4. L5-5. Wat betreft fauna-samenstelling, totale fauna-abundantie of soort-specifieke dichtheden, konden in 1990 geen significante effekten worden aangetoond op afstanden ≥500 m van het lozingspunt. Opvallend was echter dat grotere exemplaren van *Echinocardium cordatum* alleen op grotere afstand (≥1000 m) werden gevonden. Dit wees erop dat deze soort in zijn verspreiding mogelijk nog steeds effekt ondervond tot op veel grotere afstand.
5. L5-5. Het meer gedetailleerde ruimtelijke verspreidingspatroon van *Echinocardium cordatum*, zoals dat verkregen werd uit de waarnemingen van 1991, bevestigde dat grotere exemplaren (≥15 mm) alleen frekwent voorkwamen op grote afstand van het lozingspunt. In de reststroomrichting bleek dat grote exemplaren van deze soort in relatief geringe dichtheden voorkwamen binnen een zone van 2 à 3 km van het lozingspunt. Het is aan te bevelen om ook bij toekomstige surveys voor *Echinocardium* niet alleen totale aantallen maar ook lengte-frekwentie verdelingen te bepalen.
6. L5-5. Hoewel in 1990 enkele exemplaren van *Montacuta ferruginosa* werden aangetroffen op afstanden van 500 tot 1000 m van het lozingspunt, hetgeen wees op een mogelijk herstel van de milieu- condities in deze zone, vertoonde het ruimtelijk verspreidingspatroon van deze soort in 1991 nog steeds verlaagde dichtheden tot op ≈2 km van het lozingspunt.
7. Het voorkomen van *Montacuta ferruginosa* was in beide jaren nauw gerelateerd aan het verspreidingspatroon van grotere exemplaren van zijn gastheer-soort, *Echinocardium cordatum*. Dit geeft steun aan de hypothese, dat de vermeende gevoeligheid van *Montacuta* voor OBM-verontreiniging waarschijnlijk verklaard moet worden uit de gevoeligheid van *Echinocardium* en dat de verspreiding van *Montacuta* beperkt is tot die gebieden waar *Echinocardium* kan overleven.
8. L5-5. Bij de interpretatie van biologische lange-termijn effekten, zoals die in het veld worden waargenomen, dient onderscheid gemaakt te worden tussen 2 soorten effekten, namelijk consekwenties op de langere termijn van effekten die op de korte termijn zijn gegenereerd (Type-A effect) en aktuele effekten van verontreiniging die op de lange termijn nog aanwezig is (Type-B effekt). De afwezigheid (of het minder frekwent voorkomen) van *Montacuta* en grotere exemplaren van *Echinocardium* in de aanvankelijk door de lozingen getroffen zone binnen 2000 m van het lozingspunt moet gezien worden als een type-A effekt. Er is hier namelijk sprake van een lange-termijn consekwentie van de sterfte die aanvankelijk als gevolg van de lozingen onder deze soorten is opgetreden. Het feit dat de populaties zich hier in 1990 en 1991 niet hersteld hebben moet voornamelijk geweten worden aan het ontbreken van een behoorlijke broedval in deze jaren. Dit geldt met name voor het gebied op ≥500 m van het lozingspunt, waar olieconcentraties in het sediment niet boven achtergrondniveau uitkwamen. Binnen 250 m waren de olieconcentraties wellicht nog te hoog voor een succesvolle rekolonisatie door eventuele nieuwe generaties (Type-B effekt).
9. K12a. Het feit, dat de aanvangsdichtheden van de fauna in het zwaar verontreinigde sediment van de 100-m en 250-m stations aanzienlijk lager waren dan die in het sediment van 5000 m, illustreert dat, 6 jaar na de lozingen, verontreiniging nog steeds effekt heeft op de benthische fauna tot op tenminste 250 m van het lozingspunt. Er kan hier zowel sprake zijn van Type-A effekten als van Type-B effekten.
10. K12a. Sterfte onder de nauurlijke infauna was hoog in alle boxcosms (ook in die van 5000 m) en bedroeg na 4 maanden gemiddeld ≈80%. Verontreiniging van het sediment (ook in de 5000-m boxcosms waren olieconcentraties aanmerkelijk verhoogd) kan hiertoe in belangrijke mate hebben bijgedragen. Het kan echter niet worden uitgesloten dat tijdelijk suboptimale experimentele omstandigheden ook een rol hebben gespeeld. De geschatte mortaliteit in de afzonderlijke boxcosms was niet gecorreleerd met totale olieconcentraties.
11. K12a. Bij de proefdier-soort *Echinocardium cordatum* trad verhoogde sterfte op in het sediment van 100 m en 250 m. Ook sublethale verschijnselen traden op. In het 5000-m sediment was sterfte vrij-

wel nihil en sublethale verschijnselen werden niet waargenomen.

12. K12a. De respons van *Echinocardium* was gering gezien de hoge mate van verontreiniging in het sediment (olieconcentraties varieerden van 54 $mg \cdot kg^{-1}$ droog sediment in de minst verontreinigde 5000-m box tot 30000 $mg \cdot kg^{-1}$ in de zwaarst verontreinigde 100-m box). Dit wijst er op dat op de langere termijn de biologische beschikbaarheid van toxische componenten afneemt.

# 1 INTRODUCTION

## 1.1 GENERAL PART

During drilling activities in the North Sea large amounts of drill cuttings with adhering drilling muds are dumped on the sea bed. These discharges are a source of concern with respect to their environmental impact, in particular when the cuttings are contaminated with oil based muds (OBM). Although in the late 1980's the amounts of toxic contaminants discharged per drilling were reduced due to tightened regulations with respect to the base oil employed and treatment ('washing') of oil contaminated cuttings before discharge, there is still a substantial emission of pollutants, that may affect the marine environment. In first instance the benthic fauna in the immediate vicinity of drilling locations is exposed to the material discharged.

Since 1985 a number of studies has been carried out on the biological effects of these discharges on the Dutch Continental Shelf. In general the attention was focussed on oil-contaminated cuttings. The research programme included several benthic surveys around, up to now, 6 locations (Fig. 1). Additionally, some experimental studies were performed in boxcosms. Both short-term (<1 year after discharge) and long-term effects were investigated. The research over the period 1985 - 1989 is reported by MULDER *et al.* (1987, 1988) and DAAN *et al.* (1990, 1991). All biological investigations were accompanied with chemical research on the distribution of contaminated material and actual oil concentrations in the sediment. The latter work was performed by TNO-den Helder and is reported by KUIPER & GROENEWOUD (1986), GROENEWOUD *et al.*, (1988), GROENEWOUD (1991) and GROENEWOUD & SCHOLTEN (1992).

In this report the results of the 1990 and 1991 programmes are presented, which included studies on long-term effects at two different locations with a different load of polluted material, *viz.* L5-5 and K 12-a (Table 1).

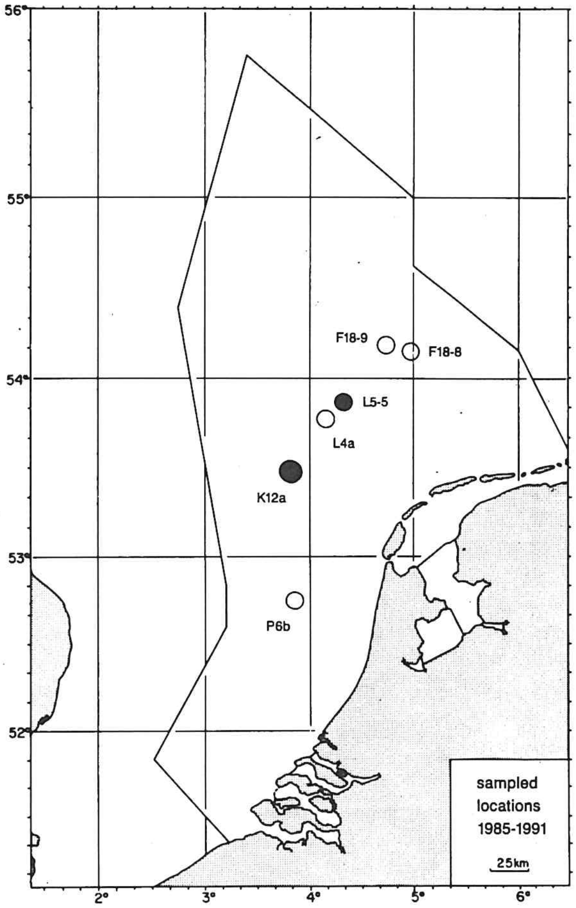


Fig. 1 Positions of drilling sites L5-5 and K12a. Open circles refer to drilling locations investigated in previous studies. Solid line: border of the Dutch part of the Continental Shelf.

## 1.2 LOCATION L5-5

Location L5-5 is situated in the Frisian Front area. The sediment at the location is characterized by a relatively large silt fraction. The natural grain size distribution is homogeneous in the area within a radius of 5 km from the discharge site (GROENEWOUD & SCHOLTEN, 1992). Drilling took place in summer and autumn of 1988. One hole was drilled and both WBM (water based muds) and OBM were utilized. WBM cuttings were discharged without any preceding treatment, but the OBM cuttings were washed before they were dumped. Washing of drill cuttings is a procedure introduced in 1988 and aimed to regain oil from the cuttings as much as possible and, thus, to minimize the concentration of contaminants in the material discharged. Discharge took place at a few metres above the sea floor. Data on the amount and composition of the material dumped are listed in Table 2. The amount of base oil discharged at L5-5 is low compared to other locations where oil based muds have been utilized. At other locations on the Dutch Continental Shelf that were investigated in earlier studies the amounts of oil discharged ranged from 178 tonnes (L4a, 89 tonnes per hole drilled), 283 tonnes (F 18.9, one hole drilled) to 393 tonnes (K12a, 79 tonnes per hole drilled, see Table 1 and 15).

In May 1989 (*i.e.* half a year after termination of the discharges) the first biological survey was carried out at the location (DAAN *et al.*, 1991). From the effects observed in that year it was concluded that the application of a washing procedure did not result in a reduction of the area around the discharge point, that was subjected to environmental stress. However, the intensity of the effects observed was generally less severe than at other OBM locations, where cuttings were not washed before discharge. An accumulation of effects connected with a substantially impoverished macrofauna was only assessed in the very close vicinity of the discharge site (at 25 m).

In April 1990 (one and a half year after drilling) a second survey was undertaken to investigate whether

TABLE1 1
Information on drilling locations L5-5 and K12a.

| | |
|---|---|
| *Location L5-5* | |
| Position: | 53°48'33.1" N<br>04°20'54.4" E |
| Area: | Transition zone between fine sand (South) and silty sediment (North); silt fraction (<63 mm) is ≈15%; depth ≈41 m |
| Drilling activities: | 1 well drilled with low-aromatic OBM, July-November 1988 OBM cuttings washed before discharge |
| Emission: | Dry rock: 336 m³ or 891 tonnes<br>WBM: 1241 m3 or 308 tonnes (excl. water)<br>OBM: 101 m³ or 148 tonnes<br>oil: 44 tonnes |
| Platform: | removed after drilling |
| Former effect studies:<br>survey May 1989 (DAAN *et al.*, 1991; GROENEWOUD & SCHOLTEN, 1992)<br>boxcosms autumn 1989 (DAAN *et al.*, 1991; GROENEWOUD & SCHOLTEN, 1992) | |
| *Location K12a* | |
| Position: | 53°28'36.2" N<br>03°47'19.4" E |
| Area: | Transition zone, fine sand with silt (5 -10%); depth ≈28 m; |
| Drilling activities: | 5 wells drilled with diesel and low-tox OBM,<br>Febr.1983 - Nov.1984;<br>cuttings not washed before discharge |
| Emission: | tot. emission: 2278 tonnes<br>OBM: 1082 tonnes<br>oil: 393 tonnes |
| Platform: | present |
| Former effect studies:<br>survey Sept. 1985 (MULDER *et al.*, 1987; KUIPER & GROENEWOUD, 1986)<br>survey Sept. 1986 (MULDER *et al.*, 1988; GROENEWOUD *et al.*, 1988)<br>survey Sept. 1987 (DAAN *et al.*, 1990, GROENEWOUD, 1991)<br>survey Sept. 1988 (DAAN *et al.*, 1990, GROENEWOUD, 1991)<br>boxcosms 1987-1988 (DAAN *et al.*, 1990, GROENEWOUD, 1991) | |

the effects observed initially were persistent, or to what extent a possible recovery could be observed by a change in macrofauna composition and distribution. The results of this survey are given in this report. Observed effects are qualified here as 'long-term' effects and will be compared to those observed in 1989, which are considered 'short-term` effects.

In September 1991, 3 years after drilling, location L5-5 was visited for the third time. This year an alternative field programme was carried out. In contrast to earlier surveys, where complete sample analyses were performed to get information on the distribution patterns of all macrofauna species, the attention now focussed on 2 OBM-sensitive species, *Montacuta ferruginosa* and *Echinocardium cordatum.* The choice for these species was based on the following considerations:

TABLE 2
Amounts and composition of mud and cuttings discharged during drilling of well L5-5. From a total of 6 drill section 3 were drilled with WBM and 3 with OBM. Data provided by the company concerned.

| | *m³* | *tonnes* |
|---|---|---|
| dry rock | 336 | 891 |
| WBM | 1241 | 308 (excl. water) |
| OBM | 101 | 148 |
| overboard chemicals: | | |
| baryte | | 249.6 |
| bentonite | | 39.4 |
| gypsum | | 9.4 |
| lime | | 1.7 |
| $CaCl_2$ | | 5.7 |
| KCl | | 76.8 |
| KOH | | 2.4 |
| NaOH | | 0.78 |
| bicarbonate | | 0.05 |
| base oil | 43.8 | |
| biopolymers | | 2.0 |
| starch derivatives | | 18.6 |
| foam inhibitor | 0.1 | |
| emulgator (10% low-tox oil10% methanol) | 2.5 | |
| emulgator (90% fatty acids10% methanol) | 2.2 | |
| viscosifier | | 0.8 |

In preceding studies *Montacuta* became manifest as a species extremely sensitive to OBM-contamination around platforms (DAAN *et al.*, 1991). At several OBM-locations, including L5-5, the species' abundance pattern showed reduced frequency of occurrence (or absence) within a radius of 1 to 2 km from the discharge site. A remarkable characteristic of *Montacuta* is that it lives as a commensal of *Echinocardium* (*e.g.* MORTON, 1962; GAGE, 1966). Hence, the question arose whether indeed *Montacuta* was as sensitive as it seemed to be, or that, in fact, its host (*Echinocardium*) was the primarily sensitive species. Although, till now, results of field research suggested that *Echinocardium* was less sensitive to OBM-contamination than *Montacuta*, it should be noted that this idea was merely based on numerical abundance patterns of *Echinocardium* around platforms. However, the spatial size distribution of *Echinocardium* has never been taken into account. It is conceivable that a more detailed study of this spatial size distribution might reveal a higher sensitivity of *Echinocardium*, especially of larger specimens, than was observed till now. Furthermore, it was hypothesised earlier that the presence of *Montacuta* might depend mainly on the occurrence of larger specimens of *Echinocardium* (DAAN *et al.*, 1991). The results of the 1990 study at L5-5 support this idea (see chapter 3.1.6).

Based on the above-mentioned considerations the following scenario is suggested. Pelagic larval stages (pluteus larvae) of *Echinocardium* may settle anywhere in the sediment around platforms. When the sediment is contaminated, the juvenile individuals may survive several months in a thin clean layer on top of the contaminated sediment. This could explain why the abundance pattern of the species does not always provide a clear indication of sensitivity. However, when growing up, the animals will burrow deeper, come in contact with contaminated sediment and die. As a result, the absence of animals that grow up to adulthood may explain the absence of *Montacuta*.

In view of this scenario, the spatial size distribution of *Echinocardium* was taken into account in the 1991 study. This approach might answer the question whether the absence of larger *Echinocardium*, which in laboratory experiments has shown to be very sensitive to OBM-contamination (ADEMA, 1991; DAAN *et al.*, 1990, 1991), could explain the absence of *Montacuta*.

## 1.3 LOCATION K12A

Location K12a, situated in the transition zone between the sandy southern area and the northern sedimentation area, has been monitored since 1985, one year after the last drilling was completed (Nov. 1984). At this location 5 wells were drilled 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 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 of 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. The effects observed became less severe and the affected area seemed to become smaller. This conclusion was quite surprising, since there was no consistent evidence for a substantial decrease in OBM contamination levels around the platform. Although, in the residual current direction, the oil concentration at 250 m from the discharge point 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. The fact, however, was stressed that patchiness in the spatial distribution of contaminated cuttings is of major importance in the detection of biological effects and could mask the occurrence of such effects during field surveys. It was concluded that the supposed recovery should be verified in a follow-up survey. Another approach could be to test sediment from K12a in an experimental boxcosm setup and to study the response of a test species at different contamination levels.

In 1990 a laboratory experiment was carried out in 6 boxcosms, with sediment sections originating from 3 stations at the residual current transect of K12a. The heart urchin *Echinocardium cordatum*, used as test species in this experiment, was introduced in the boxcosms and its lethal and sublethal responses were recorded during $3\frac{1}{2}$ months. The results of this experiment are reported here and will be compared to those of previous boxcosm experiments.

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# 2 METHODS

## 2.1 FIELD SURVEY AT L5-5, APRIL 1990

### 2.1.1 POSITIONING AND SAMPLING

In the third week of April 1990, the field survey at the abandoned location L5-5 was carried out on board of the R.V. 'Mitra'. The ship is provided with advanced apparatus like side scan, dynamic positioning and underwater video-cameras and therefore outstandingly equipped to accurately trace the discharge point.

Sampling stations were chosen along a cross-shaped transect. One axis of the transect ran parallel with the residual current direction, the other axis perpendicular to the first one (Fig. 2). At each station two sites were sampled. The outermost stations, at 5 km from the discharge point, were assumed to represent a reference situation to which possible spatial effects could be related.

Bottom samples were collected with a 0.2 $m^2$ Van Veen grab, 2 x 5 samples per station. From each sample small duplicate cores (diameter 28 mm, depth 10 cm) were taken for chemical and grainsize analyses (N.B. grainsize analyses are performed to confirm that the natural sediment composition is more or less homogeneous in the investigated area). The pooled sediment samples of a station were thoroughly homogenised and immediately frozen at -20°C until later analysis in the laboratory (see GROENEWOUD & SCHOLTEN, in prep.-a). Then the contents of the grab were washed through a sieve (mesh size 1 mm) and the residual macrofauna was preserved in a 6% neutralized formaldehyde solution.

### 2.1.2 LABORATORY ANALYSIS

In the laboratory the samples were stained with Bengal rose and sorted under a stereomicroscope. Then, molluscs, crustaceans, polychaetes and echinoderms were identified and counted on species level. Remaining taxa were not further identified and only recorded at higher taxonomic levels. When specimens were broken by handling, only heads were counted.

Not all samples were analysed. In Fig. 2 those stations are indicated of which a number of samples was analysed. Oil analyses were performed using the GCMS technique (gas chromatograph mass spectrometer). Concentrations of the fractions of alkanes ($C_9$-$C_{32}$), unidentified complex matter (UCM) and 'other components' were quantified. Methods and results are presented in detail by GROENEWOUD &

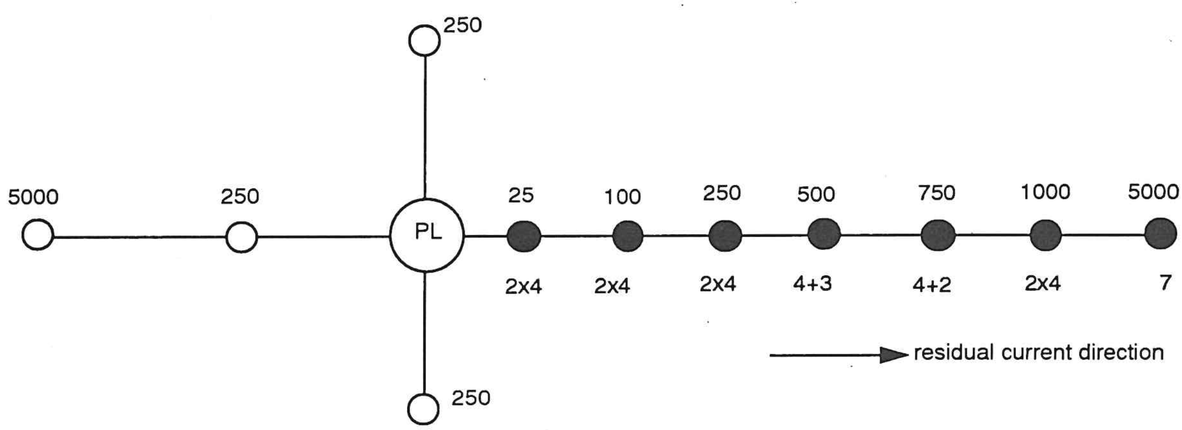


Fig. 2 Location L5-5. Positions of the sampling stations in 1990 (distance to platform in m). Solid circles: samples analysed (numbers are indicated); open circles: samples not analysed.

SCHOLTEN (in prep.-a). Data on oil concentrations are available for the stations at the residual current transect only.

2.1.3 STATISTICAL PROCEDURES

In samples collected over a gradient in pollution there is usually a gradual change in the abundance of individual species over the sampled transect. Statistical analyses of the data are required to obtain objective criteria to decide whether such changes in faunal abundance are significant or not. Such analyses have been performed on both species level and community level. The methods applied have been described in detail in an earlier report (DAAN *et al.*, 1990) and are summarized below.

2.1.3.1 INDIVIDUAL SPECIES (LOGIT REGRESSION)

Logit regression (JONGMAN *et al.*, 1987) is based on a mathematical model for presence-absence data of individual species in samples collected over a transect with a gradient in pollution. The basic idea is that, if the contaminant involved affects the chance of survival of a certain species, the frequency of occurrence of this species will increase or decrease along the transect. Thus, the probability ($p$) of a species being present in a sample will change along the transect. Logit regression provides a test to decide either that $p$ increases or decreases significantly with distance to the platform, or that $p$ just fluctuates at random. Logit regression was applied to those species of which at least 20 specimens were found. The fitted term in the analysis was the log-transformed distance to the platform.

2.1.3.2 MACROBENTHIC COMMUNITY (RELATIVE ABUNDANCE)

This method provides a measure of the mean relative abundance of all identified species at each station compared to the other stations around a location. If *e.g.* at a certain station most species occur in lower numbers than at other stations, the relative macrofauna abundance at this station will be attributed a low value. Computation of relative macrofauna abundance is based on a ranking procedure. For all of the individual species the mean density is considered at each of the (n) analysed stations. Per species a rank is attributed to each of the stations, *i.e.* the rank is 1

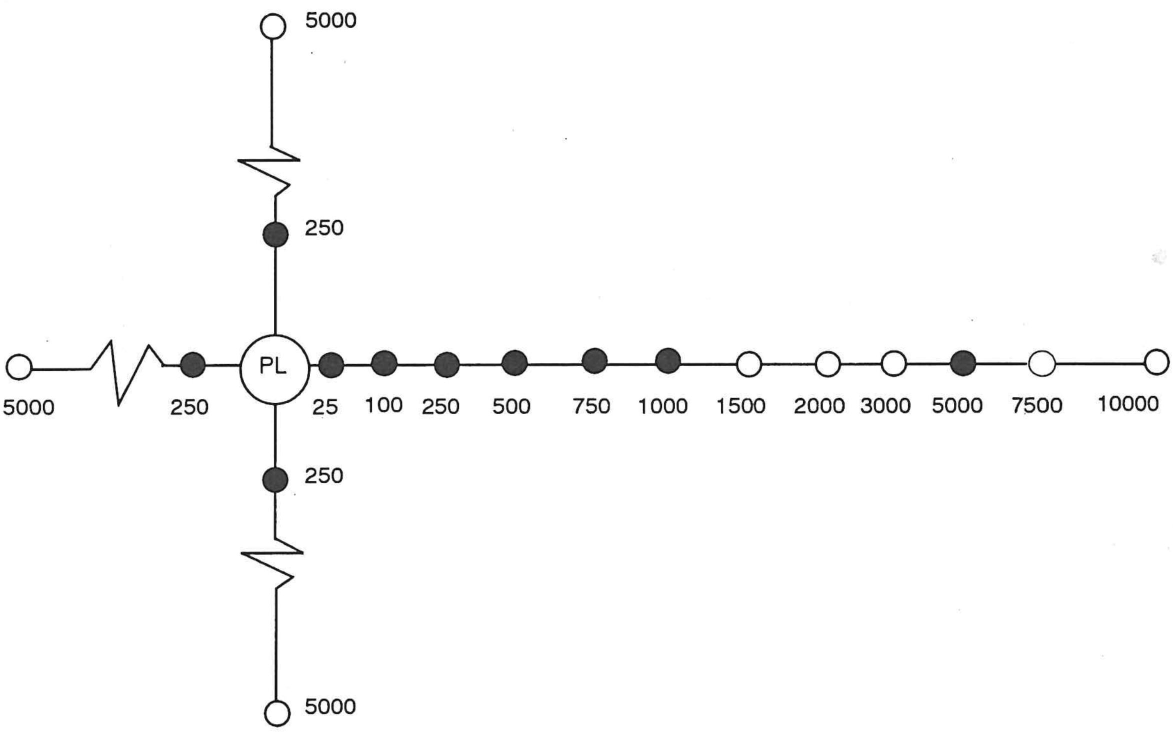


Fig. 3 Location L5-5. Positions of the sampling stations in 1991 (distance to platform in m). Solid circles: samples analysed in the laboratory for *Montacuta ferruginosa* and size distribution of *Echinocardium cordatum*. Open circles: Only field countings of *Echinocardium*.

for the station with the lowest density and n for the station with the highest density. When this procedure is completed for all species a mean rank can be computed for each station. Differences in mean ranks between stations can be tested for significance by applying analysis of variance and a least significant difference (LSD-) test (see SOKAL & ROHLF, 1981).

## 2.2 FIELD SURVEY AT L5-5, SEPTEMBER 1991

During fieldwork, in September 1991, a dense grid of sampling stations was chosen along the residual current transect (Fig. 3). In perpendicular directions 3x2 stations were sampled. Per station 8 Van Veen grab samples were taken, washed through a 1 mm sieve and treated as described in chapter 2.1.1.

While sieving the sediment samples on board, numbers of *Echinocardium* were counted in all samples of all stations. Only specimens ≥1cm were included, since smaller animals may easily be overlooked and, hence, can not reliably be quantified.

Not all samples were analysed in the laboratory. In Fig. 3 those 10 stations are indicated of which 6 samples each were analysed for the presence of *Montacuta* and *Echinocardium*. In addition to these species numbers of *Mysella bidentata* were counted (N.B. *Montacuta* and *Mysella* are small bivalve species, which look very similar and, therefore, can not be distinguished from each other during sorting; identification is only possible under the stereo-microscope). Specimens of *Echinocardium* were measured to the nearest mm.

## 2.3 BOXCOSM EXPERIMENTS K12A

The boxcosms employed were sediment cores collected in the second week of September 1990 on the residual current transect of location K12a. Three stations were chosen, at distances of 100 m, 250 m and 5000 m from the discharge point. All stations were first sampled with a Reineck boxcorer (round cores, diameter 30 cm, depth ≈40 cm), to determine the benthic fauna composition at the start of the experiment. Per station 10 cores were taken and sieved immediately on deck on a 1 mm mesh screen. The samples were preserved in 6% formalin for later analysis in the laboratory. Then the sediment sections to be used in the boxcosms were collected: 2 at each station. These intact boxcores were taken with a (modified) Scripps corer. The stainless steel boxes (50x50x60 cm) were furnished with a mica-teflon coating. The Scripps corer tended to dig about 40 cm deep, thus collecting the major sediment layers inhabited by the benthic infauna. On board the cores were placed in waterproof plywood cases with cooling water and fixed in sand. The water on top of the cores was regularly changed during the transport to the laboratory. After transport the complete cases were placed in an indoor basin and incubated at ≈16°C. During the period of incubation (4 months), the temperature was gradually lowered to ≈10°C, according to *in situ* temperatures. The water on the cores was continuously replaced with filtered and $O_2$-saturated water from the Wadden Sea, with salinity varying between 29 and 31‰. Apart from inspections, incubation always took place continuously in the dark. Some small crabs were removed to minimize mortality by predation.

The boxcosms were stocked with the test species *Echinocardium cordatum* on 24 September 1990. Per boxcosm 20 adult specimens (35 - 45 mm) were introduced and their burrowing times were measured from the moment the animals were placed on the sediment surface until only the apical tufts were visible. During the period of incubation the boxcosms were inspected daily for mortality and activity of test animals and natural infauna. At termination of the experiment (at 10 January 1991) from all boxcosms 10 small sediment samples were collected for oil analyses (see GROENEWOUD & SCHOLTEN, in prep.-a). Then the sediment of the boxcosms was washed through a 1 mm sieve to collect the macrofauna, including the introduced test animals.

# 3 RESULTS

## 3.1 FIELD SURVEY L5-5, APRIL 1990

### 3.1.1 GENERAL DESCRIPTION

The analysis of altogether 52 samples yielded 96 identified species. In Table 3 their frequency of occurrence in the samples is summarized. The abundance data, presented in Table 10 (Appendix), show that the fauna in the area was numerically dominated by the Echinoderm *Amphiura filiformis*, which accounted for 41% of the total macrofauna, the polychaete *Lumbrineris latreilli* (22%) and the bivalve *Mysella bidentata* (12%). *Amphiura* numbers fluctuated between 220 and 1540 ind·m$^{-2}$ at stations ≥250 m from the platform, but were considerably lower at 25 m and 100 m (15 - 21 ind·m$^{-2}$). Here *Amphiura* covered only 6% of the fauna. A similar pattern was observed in *Mysella*, which showed a decrease from 80 - 480 ind·m$^{-2}$ at stations ≥250 m to 1 - 8 ind·m$^{-2}$ within 100 m, where it represented only 1% of the macrofauna. A tendency for decreasing numerical abundance within 100 m was also found in *Lumbrineris*, but less pronounced (from 160 - 700 ind·m$^{-2}$ at ≥250 m to 80 - 270 ind·m$^{-2}$ within 100 m). Since the total fauna abundance was considerably reduced within 100 m (see below), the percentual contribution of *Lumbrineris* to the total fauna abundance was relatively high (43%) here compared to stations at ≥250 m (on average 21%).

TABLE 3

The benthic fauna at L5-5, April 1990. Percentage of occurrence of each species in the total number of analysed samples (52).

| | | | | | |
|---|---|---|---|---|---|
| **POLYCHAETA** | | *Diplocirrus glaucus* | 30.8 | *Upogebia deltaura* | 15.4 |
| *Aphrodita aculeata* | 17.3 | *Ophelina acuminata* | 17.3 | *Callianassa subterranea* | 80.8 |
| *Harmothoe lunulata* | 7.7 | *Capitella capitata* | 3.9 | *Nebalia bipes* | 5.8 |
| *Harmothoe longisetis* | 17.3 | *Notomastus latericeus* | 21.2 | *Eudorella truncatula* | 15.4 |
| *Gattyana cirrosa* | 51.9 | *Heteromastus filiformis* | 21.2 | *Diastylis bradyi* | 34.6 |
| *Polynoe kinbergi* | 3.9 | *Owenia fusiformis* | 40.4 | *Cirolana borealis* | 3.9 |
| *Pholoe minuta* | 80.8 | *Lagis koreni* | 7.7 | *Ione thoracica* | 3.9 |
| *Sthenelais limicola* | 40.4 | *Pectinaria auricoma* | 34.6 | *Hippomedon denticulatus* | 1.9 |
| *Eteone longa* | 3.9 | *Amphicteis sundevalli* | 1.9 | *Orchomenella nana* | 9.6 |
| *Eteone lactea* | 3.9 | *Sosane gracilis* | 3.9 | *Leucothoe incisa* | 1.9 |
| *Eumida sanguinea* | 3.9 | *Terebellides stroemi* | 1.9 | *Ampelisca brevicornis* | 34.6 |
| *Ophiodromus flexuosus* | 38.5 | *Lysilla loveni* | 3.9 | *Ampelisca tenuicornis* | 63.5 |
| *Gyptis capensis* | 46.2 | **MOLLUSCA** | | *Ampelisca* spec. juv. | 25.0 |
| *Synelmis klatti* | 25.0 | *Nucula turgida* | 26.9 | *Cheirocratus sundevalli* | 3.9 |
| *Exogone hebes* | 17.3 | *Thyasira flexuosa* | 21.2 | *Bathyporeia elegans* | 5.8 |
| *Nereis longissima* | 5.8 | *Lepton squamosum* | 1.9 | *Bathyporeia tenuipes* | 5.8 |
| *Nereis* spec. juv. | 3.9 | *Montacuta ferruginosa* | 21.2 | *Harpinia antennaria* | 7.7 |
| *Nephtys hombergii* | 46.2 | *Mysella bidentata* | 86.5 | *Perioculodes longimanus* | 26.9 |
| *Nephtys incisa* | 19.2 | *Arctica islandica* | 5.8 | *Aora typica* | 5.8 |
| *Nephtys cirrosa* | 7.7 | *Acanthocardia echinata* | 1.9 | *Caprella* spec. | 5.8 |
| *Nephtys caeca* | 3.9 | *Dosinia lupinus* | 25.0 | **ECHINODERMATA** | |
| *Nephtys* spec. juv. | 75.0 | *Venus striatula* | 59.6 | *Amphiura filiformis* | 94.2 |
| *Glycera rouxii* | 53.9 | *Mysia undata* | 11.5 | *Amphiura chiajei* | 25.0 |
| *Glycera alba* | 5.8 | *Spisula elliptica* | 7.7 | *Ophiura texturata* | 1.9 |
| *Glycera* spec. juv. | 59.6 | *Abra tenuis* | 1.9 | *Ophiura albida* | 7.7 |
| *Glycinde nordmanni* | 59.6 | *Abra alba* | 11.5 | *Ophiura* spec. juv. | 44.2 |
| *Goniada maculata* | 69.2 | *Cultellus pellucidus* | 17.3 | *Echinocardium cordatum* | 32.7 |
| *Lumbrineris latreilli* | 100.0 | *Mya* spec. juv. | 1.9 | **OTHER TAXA** | |
| *Lumbrineris fragilis* | 53.9 | *Corbula gibba* | 86.5 | Nemertinea | 88.5 |
| *Driloneris filum* | 1.9 | *Thracia convexa* | 32.7 | Nematoda | 1.9 |
| *Orbinia sertulata* | 3.9 | *Cingula nitida* | 23.1 | Turbellaria | 55.8 |
| *Paraonis* spec. | 3.9 | *Turritella communis* | 53.9 | Phoroniden | 19.2 |
| *Poecilochaetus serpens* | 9.6 | *Natica alderi* | 67.3 | Harp. copepoda | |
| *Spio filicornis* | 38.5 | *Buccinum undatum* | 5.8 | Parasitaire copepoda | 17.3 |
| *Polydora guillei* | 3.9 | *Cylichna cilindracea* | 53.9 | Holothuroidea | 26.9 |
| *Spiophanes bombyx* | 7.7 | *Philine scabra* | 9.6 | *Sagitta* spec. | 1.9 |
| *Scolelepis foliosa* | 3.9 | **CRUSTACEA** | | Echiurida | 26.9 |
| *Magelona alleni* | 61.5 | *Processa parva* | 9.6 | Sipunculida | 88.5 |
| *Chaetopterus variopedatus* | 73.1 | *Ebalia cranchii* | 23.1 | Anthozoa | 7.7 |
| *Tharyx marioni* | 21.2 | *Corystes cassivelaunus* | 3.9 | Ascidiacea | 1.9 |
| *Chaetozone setosa* | 15.4 | *Upogebia stellata* | 9.6 | Foraminiferida | 3.9 |

The other relatively abundant species (those, which occurred in natural densities of ≥10 ind·m$^{-2}$) showed a trend similar to that of the dominant species: *Pholoe minuta, Chaetopterus variopedatus, Corbula gibba* and *Callianassa subterranea* all occurred in reduced abundance within 100 m from the discharge point.

The spatial pattern of the total macrofauna abundance was the same as described above for the abundant species. The total numbers of individuals were low within 100 m (280 - 420 ind·m$^{-2}$) compared to the area at ≥250 m (750 - 3100 ind·m$^{-2}$). Remarkably, the 2 sites sampled at 250 m represented the stations with the lowest and highest fauna abundance respectively. At the first station the fauna densities were intermediate between those within 100 m and those found at ≥250 m.

The last row of Table 10 suggests that the species richness was also relatively low in the vicinity of the platform. However, the number of species found at a station depends on the number of samples taken. Since the number of samples was not the same at all stations, the data cannot be straight off compared. It is possible, however, to compare species richness at different stations by considering the mean number of (identified) species per Van Veen grab sample at each station. The mean number of species per sample was consistently lower at the stations within 100 m (14 - 19 species per sample) than at the stations at ≥250 m (22 -36 species per sample).

TABLE 4

L5-5, April 1990: List of species for which density gradients were tested by logit regression. Sign of the gradient (+/-) and significance level are indicated: += increasing densities off the location; -= decreasing densities off the location.

| | *sign* | *signif. level (%)* |
|---|---|---|
| *Gattyana cirrosa* | + | n.s. |
| *Pholoe minuta* | + | 0.1 |
| *Sthenelais limicola* | + | n.s. |
| *Ophiodromus flexuosus* | - | n.s. |
| *Gyptis capensis* | + | n.s. |
| *Nephtys hombergii* | + | n.s. |
| *Nephtys incisa* | - | n.s. |
| *Glycera rouxii* | + | 0.01 |
| *Glycinde nordmanni* | + | 0.05 |
| *Goniada maculata* | - | n.s. |
| *Lumbrineris latreilli* | + | n.s. |
| *Lumbrineris fragilis* | + | n.s. |
| *Spio filicornis* | + | n.s. |
| *Magelona alleni* | - | n.s. |
| *Chaetopterus variopedatus* | + | n.s. |
| *Diplocirrus glaucus* | + | n.s. |
| *Owenia fusiformis* | + | 0.5 |
| *Pectinaria auricoma* | + | 0.01 |
| *Nucula turgida* | + | n.s. |
| *Montacuta ferruginosa* | + | 0.05 |
| *Mysella bidentata* | + | 0.5 |
| *Venus striatula* | - | n.s. |
| *Corbula gibba* | + | 0.1 |
| *Thracia convexa* | + | 0.5 |
| *Turritella communis* | + | n.s. |
| *Natica alderi* | + | n.s. |
| *Cylichna cilindracea* | + | 0.1 |
| *Callianassa subterranea* | + | 0.01 |
| *Diastylis bradyi* | - | 0.05 |
| *Ampelisca brevicornis* | + | 0.01 |
| *Ampelisca tenuicornis* | + | n.s. |
| *Amphiura filiformis* | + | n.s. |
| *Amphiura chiajei* | + | n.s. |
| *Echinocardium cordatum* | + | 0.01 |

### 3.1.2 PRESENCE-ABSENCE DATA: LOGIT REGRESSION

Logit regression was applied to those species of which at least 20 specimens were found. The results are listed in Table 4. The hypothesis $H_0$, that the frequency of occurrence in the samples was not dependent on the distance of the sampling station to the discharge site, was rejected at the 5% level in 14 species. In other words, these species showed significant density gradients. There was only one species (the crustacean *Diastylis bradyi*) showing a negative gradient, *i.e.* decreasing abundance at increasing distance to the platform. The species was frequently found especially in the 25-m and 100-m samples. The other species all occurred frequently at the stations ≥500 m, whereas their numbers were low within 250 m. Table 4 shows that the regression coefficients, significant or not, were generally positive, indicating that most species occurred in reduced numbers in the vicinity of the platform.

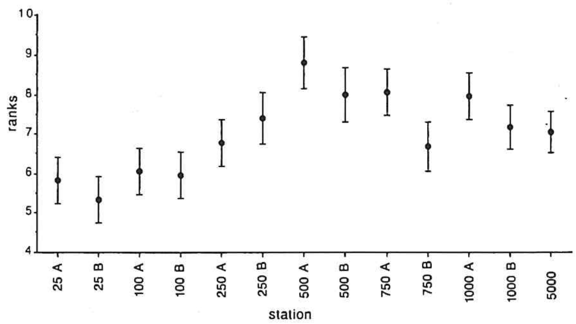


Fig. 4 Relative macrofauna abundance at L5-5, April 1990 (mean ranks and 95% confidence limits).

### 3.1.3 RELATIVE MACROFAUNA ABUNDANCE

The relative macrofauna abundance was low at both 25-m stations and gradually increased with distance to the platform (Fig. 4). Analysis of variance revealed highly significant (0.1% level) differences in mean ranks of the different stations. An LSD-test, additionally applied to test the significance of differences between individual stations (Table 5), revealed that the lower relative abundance at 25 m and 100 m was highly significant. The small differences within these stations were not significant. Beyond 250 m the relative abundance became rather variable, even within 2 stations at the same distance. *E.g.*, the difference between mean ranks of the two 750-m stations was significant at the 0.5% level. This may illustrate how variable the natural fauna composition of the sediment may be, even at a very small spatial scale. On the other hand, since the performance of the LSD-test involved a high number of comparisons (78), only individual differences significant at the 0.1% level are in fact decisive, when an overall significance level of ≈5% is considered acceptable. When this more stringent level of significance is employed, the conclusion that most species occur in reduced numbers at the

TABLE 5

L5-5, April 1990: Statistical significance (LSD-test) of differences in relative abundance between sampled stations at the residual current transect.

| | 25 A | 25 B | 100 A | 100 B | 250 A | 250 B | 500 A | 500 B | 750 A | 750 B | 1000 A | 1000 B | 5000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 A | . | | | | | | | | | | | | |
| 25 B | n.s. | . | | | | | | | | | | | |
| 100 A | n.s. | n.s. | . | | | | | | | | | | |
| 100 B | n.s. | n.s. | n.s. | . | | | | | | | | | |
| 250 A | 5 | 0.5 | n.s. | n.s. | . | | | | | | | | |
| 250 B | 0.1 | 0.1 | 0.5 | 0.5 | n.s. | . | | | | | | | |
| 500 A | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | . | | | | | | |
| 500 B | 0.1 | 0.1 | 0.1 | 0.1 | 1 | n.s. | n.s. | . | | | | | |
| 750 A | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | n.s. | n.s. | n.s. | . | | | | |
| 750 B | n.s. | 0.5 | n.s. | n.s. | n.s. | n.s. | 0.1 | 0.5 | 0.5 | . | | | |
| 1000 A | 0.1 | 0.1 | 0.1 | 0.1 | 1 | n.s. | n.s. | n.s. | n.s. | 0.5 | . | | |
| 1000 B | 0.5 | 0.1 | 5 | 1 | n.s. | n.s. | 0.1 | n.s. | 5 | n.s. | n.s. | . | |
| 5000 | 1 | 0.1 | 5 | 5 | n.s. | n.s. | 0.1 | 5 | 5 | n.s. | 5 | n.s. | . |

stations up to 100 m from the discharge point still remains in force.

### 3.1.4 ABUNDANCE PATTERNS OF SENSITIVE AND OPPORTUNISTIC SPECIES

In Table 6 a number of sensitive and opportunistic species (see DAAN *et al.*, 1990) is listed and the response shown by their spatial abundance pattern at location L5-5 in 1990. This table shows to what extent the listed species revealed a gradient in their distribution pattern indicative of OBM contamination of the sediment at L5-5. Seventeen species occurred in too low densities (< 20 specimens found) to identify such a gradient. Seven species did not display any gradient and 16 sensitive species showed reduced densities generally up to 100 m from the discharge site, but some species (*Montacuta ferruginosa*, *Echinocardium cordatum* and *Owenia fusiformis*, see Fig. 5) occurred in reduced densities up to 250 m. Some species occurred in reduced densities only at the first of two sites sampled at 250 m, *e.g. Callianassa subterranea*, an abundant species at larger distance (Fig. 6). Increased abundance of opportunistic species in the vicinity of the discharge site was only observed in *Capitella capitata*. Nine specimens of this species were found at one of the 25-m sites.

### 3.1.5 DOSE-EFFECT RELATIONSHIPS

Fig. 7 illustrates to what extent an accumulation of biological effects was observed at a number of sta-

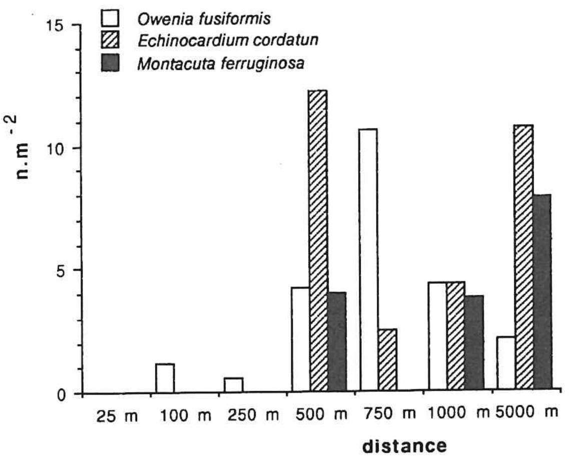


Fig. 5 L5-5, April 1990: abundance patterns of 3 OBM-sensitive species.

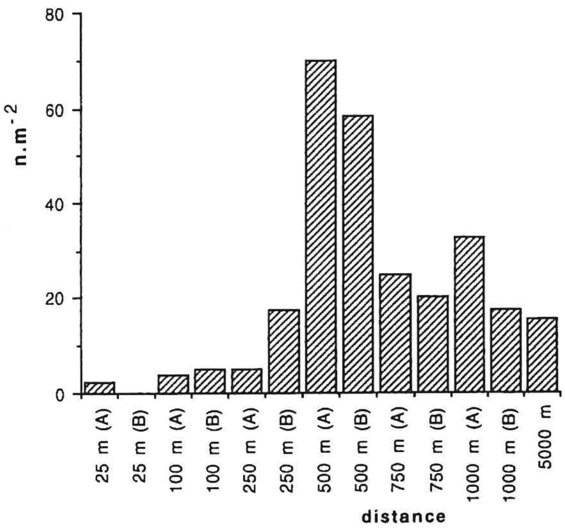


Fig. 6 L5-5, April 1990: abundance pattern of *Callianassa subterranea*.

tions along the residual current transect of L5-5. Here only those stations are included, where oil concentrations in the sediment were assessed (see GROENEWOUD & SCHOLTEN, in prep.-a). The figure demonstrates that the number of effects observed consistently decreased with increasing distance to the discharge site. On the other hand, a relationship between actual contamination levels and accumulation of effects is not clear. At station 100-m (a), where the oil concentration in the sediment did not exceed background level (and where the for base oil characteristic UCM fraction was relatively low, see GROENEWOUD & SCHOLTEN in prep.-a), nearly all biological effects were observed, except for the presence of opportunistic species. In contrast, the 250-m (b) station, where the highest oil concentration (64.5 $mg \cdot kg^{-1}$ dry sediment) was found, seemed to be hardly affected in its fauna composition. Only a few very sensitive species were absent here.

TABLE 6

L5-5, April 1990: Evaluation of the abundance patterns of 41 species, which earlier have been described as either "sensitive" or "opportunistic".
+: abundance pattern is indicative of a sensitive species
-:abundance pattern is indicative of an opportunist
=: abundance pattern does not indicate a response
?: numbers found too low to be indicative.
(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).

| | | *affected up to* |
|---|---|---|
| **A. Sensitive species** | | |
| *Montacuta ferruginosa* | + | 250 m |
| *Scalibregma inflatum* | ? | |
| *Pholoe minuta* | + | 100 m |
| *Amphiura filiformis* | + | 100 m |
| *Echinocardium cordatum* | + | 250 m |
| *Mysella bidentata* | + | 100 m |
| *Nephtys hombergii* | + | 100 m |
| *Lumbrineris latreilli* | + | 100 m |
| *Chaetozone setosa* | ? | |
| *Owenia fusiformis* | + | 250 m |
| *Nucula turgida* | + | 250 m |
| *Gattyana cirrosa* | + | 100 m |
| *Harpinia antennaria* | ? | |
| *Lagis koreni* | ? | |
| *Glycinde nordmanni* | + | 100 m |
| *Cylichna cilindracea* | + | 250 m |
| *Harmothoe longisetis* | ? | |
| *Callianassa subterranea* | + | 250 m |
| *Magelona papillicornis* | ? | |
| *Tellina fabula* | ? | |
| *Natica alderi* | = | |
| *Spiophanes bombyx* | ? | |
| *Ophiodromus flexuosus* | = | |
| *Notomastus latericeus* | ? | |
| *Lumbrineris fragilis* | = | |
| *Amphiura chiajei* | + | 100 m |
| *Leucothoe incisa* | ? | |
| *Chaetopterus variopedatus* | + | 100 m |
| *Tharyx marioni* | ? | |
| *Ophiura albida* | ? | |
| *Gyptis capensis* | = | |
| *Lanice conchilega* | ? | |
| *Perioculodes longimanus* | ? | |
| *Diplocirrus glaucus* | + | 250 m |
| *Abra alba* | ? | |
| *Turritella communis* | = | |
| *Sthenelais limicola* | = | |
| **B. Opportunistic species** | | |
| *Nereis longissima* | ? | |
| *Čapitella capitata* | - | 25 m |
| *Spio filicornis* | = | |
| *Anaitides groenlandica* | ? | |

3.1.6 LONG-TERM *VS* SHORT-TERM EFFECTS

The biological effects observed at the residual current transect of L5-5 in 1990 can be compared with short-

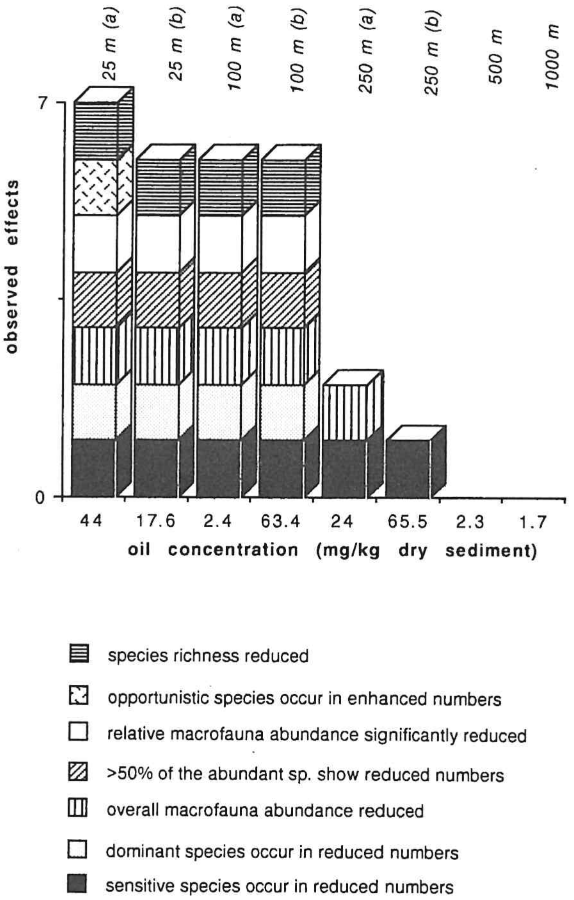


Fig. 7 L5-5, April 1990: effects observed at the residual current transect at varying levels of sediment contamination.

term effects observed in 1989, half a year after termination of the discharges of washed cuttings (see DAAN *et al.*, 1991). The comparison is based on stations that were sampled during both surveys (25 m, 250 m, 500 m, 750 m, 1000 m and 5000 m).

In 1989 a total number of 36 samples yielded 86 identified species at these stations whereas the 1990 survey included 44 samples, resulting in 96 species. Since the higher number of species in 1990 may easily be explained by the higher number of samples, there seems to be no difference in overall species richness of the area between both years. An inspection of the listed species shows that the fauna composition was also more or less the same. Moreover, the following data show that the total fauna abundance does not seem to have changed between 1989 and 1990:

Total fauna abundance (ind·m$^{-2}$)

| | *1989* | *1990* |
|---|---|---|
| 25 m | 470 | 354 |
| 250 m | 1381 | 1925 |
| 500 m | 1585 | 2665 |
| 750 m | 1893 | 1400 |
| 1000 m | 844 | 1251 |
| 5000 m | 1121 | 811 |

In 1989 an accumulation of all defined effects was only observed at 25 m. In 1990 this situation was still met, but also the 100-m station (not sampled in 1989) showed nearly all effects, except for the presence of opportunistic species. Also at 250 m the situation was quite similar both years. The absence (*Montacuta ferruginosa* and *Echinocardium cordatum*) or reduced abundance (*Callianassa subterranea*) of some sensitive species was still indicative of sediment contamination. A few specimens of the opportunist *Capitella capitata* were only found in 1989, whereas in 1990 the total fauna abundance seemed to be slightly reduced at one of the 250-m sites. Apparently the lower oil concentrations in the sediment within 250 m in 1990 (≥65 mg·kg$^{-1}$ dry sediment) compared to 1989 (190 - 237 mg·kg$^{-1}$ dry sediment) were not reflected by a reduction of biological effects.

In the area between 500 - 1000 m the comparison between short-term and long-term effects is complicated. In 1989 this area showed elevated oil concentrations (±30 mg·kg$^{-1}$ dry sediment), which could explain the absence of *Montacuta* and *Echinocardium*. In 1990 the concentrations were at background level (2 mg·kg$^{-1}$ dry sediment) and both species were present in several samples, albeit in low numbers. At first sight, this might indicate a recovery of this area to conditions in which *Montacuta* and *Echinocardium* may survive. However, the size class distribution of *Echinocardium* at the different stations (Fig. 8) shows that larger (>20 mm) specimens were almost exclusively found at 1000 m and 5000 m. At 500 m and 750 m only small specimens were present. The size class 11-15 mm, which presumably settled in the past year (see DUINEVELD & JENNESS, 1984), was most frequently present. It is conceivable that these animals may thrive in the clean top layer of the sediment. It is however not clear whether they will be able to grow

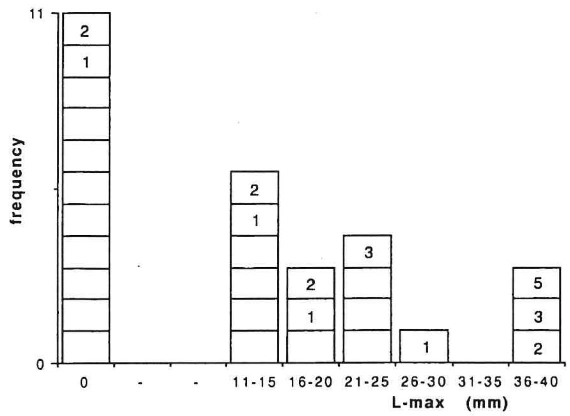


Fig. 9 L5-5, April 1990: frequency distribution of the maximum test- length class (L-max) of *Echinocardium cordatum* in individual samples at stations between 500 m and 5000 m from the discharge site. L-max = "0 mm" means that *Echinocardium* was not present. The figures in the boxes represent the numbers of *Montacuta ferruginosa* in the corresponding sample.

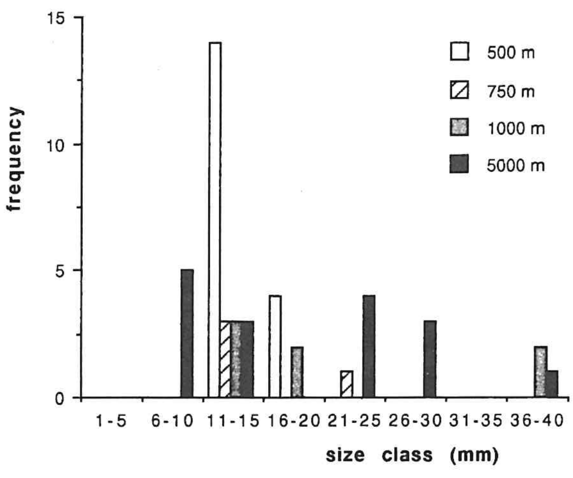


Fig. 8 L5-5, April 1990: frequency distribution of different test- length classes of *Echinocardium cordatum* at 4 stations on the residual current transect.

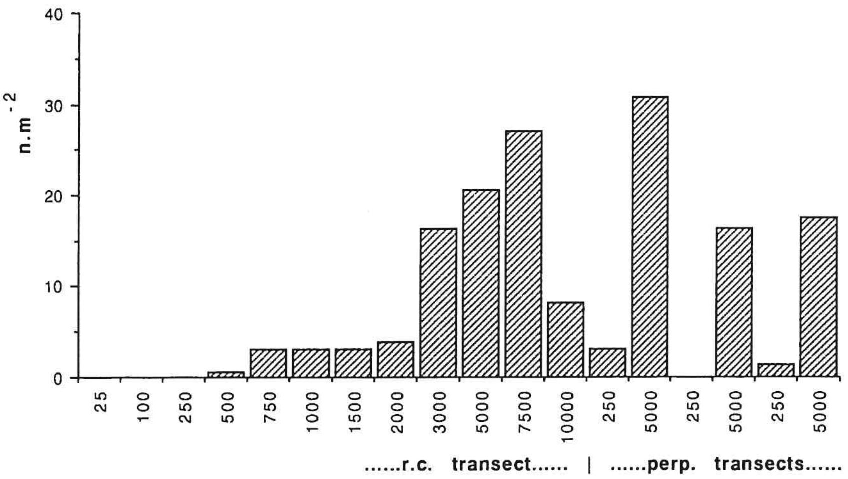


Fig. 10 L5-5, Sept. 1991: Abundance pattern of *Echinocardium cordatum* (specimens > 1 cm). Distance to discharge site in m.

up to larger, deeper burrowing animals. This may, in turn, determine the survival rate of *Montacuta*, which lives as a commensal of *Echinocardium* (*e.g.* GAGE, 1966). As Fig. 9 shows the occurrence of *Montacuta* seems to be associated in particular to the occurrence of larger *Echinocardium*. The exact nature of this relationship is unknown. It is possible that larvae of *Montacuta* selectively settle on larger specimens of *Echinocardium*, but another explanation could be that older *Echinocardium* are more frequently accompanied by *Montacuta* merely because they have been exposed to settling of the latter species for a longer time. Summarizing it is concluded that species that are very sensitive to oil contamination of the sediment, could resettle in the area between 500 and 1000 m. However, it is still questionable to what extent these new populations are viable.

## 3.2 FIELD SURVEY AT L5-5, SEPTEMBER 1991

### 3.2.1 SPATIAL ABUNDANCE PATTERNS

The results of the on board countings of *Echinocardium* (Table 11 and Fig. 10) revealed a clear gradient in its density pattern in all directions. As mentioned in chapter 2.2 only larger specimens (≥1 cm) were counted, but small specimens were hardly observed. Logit regression confirmed that there was a significant (P<0.1%) relation between frequency of occurrence and distance to the discharge site. At stations ≥3000 m from the discharge site the densities generally fluctuated between 15 and 30 ind·m$^{-2}$. Only the 10,000-m station was somewhat lower (8 ind·m$^{-2}$). At stations ≤2000 m the numbers were consistently below 4 ind·m$^{-2}$. The data suggest that *Echinocardium* is affected in its distribution up to 2000 - 3000 m.

The laboratory analyses confirmed that small *Echinocardium* were scarce in the area (Table 12). A few specimens of 2 - 4 mm, which have to be considered as offspring from the current years spatfall (see DUINEVELD & JENNESS, 1984) were only found at two 250-m stations. At the other stations all animals were larger than 15 mm.

Table 12 shows that there is a clear relationship between the occurrence of *Echinocardium* and *Montacuta ferruginosa*. The latter species was only found in samples where older *Echinocardium* (≥25 mm or ≥2 years old) were present. *Montacuta* was less abundant than *Echinocardium*, but its distribution pattern was quite similar with absence or reduced abundance up to 2000 m in the residual current direction. Along the perpendicular transects the species was almost absent at the 250-m stations.

Much more abundant than *Montacuta* was the allied species *Mysella bidentata* (Table 12). It was present in all samples, generally in high numbers. However, *Mysella* was extremely heterogeneously distributed. Mean densities (Table 13) were highest at the 250-m station at the 167, perpendicular transect and lowest at the 100-m station in the residual current direction. Statistical analysis (KRUSKAL-WALLIS test) showed highly significant (P<0.1%) differences in densities between stations, but there was no trend related to distance to the discharge site (Table 13).

### 3.2.2 EFFECTS IN RELATION TO OIL CONCENTRATIONS

The spatial distribution pattern of *Echinocardium* and *Montacuta*, which suggested that their abundances were affected up to 2000 m from the discharge site, is remarkable in view of the actual contamination level of the sediment at the sampled stations (Fig. 11). Elevated oil concentrations were only found at 25 m, 100 m and 250 m in the residual current direction. At the other stations where oil concentrations were measured (500 m and 5000 m in residual current direction and 3 x 250 m on perpendicular transects), the concentrations were about 3 mg·kg$^{-1}$ dry sediment, i.e. not exceeding background level. This implies that the absence of *Echinocardium* at 500 m (r.c. direction) and at the 250-m stations (perp. directions) can not be explained by actual contamination. In 1990 a similar situation was met, in the sense that larger *Echinocardium* were absent at 500 m though the oil concentration was at background level (see chapter 3.1.6). Only in April 1989, half a year after the drilling activities were terminated, the absence of *Echinocardium* at this station could be related to a significantly elevated concentration of 30 mg oil·kg$^{-1}$ dry sediment. This indicates that a recovery from the 1989 situation at 500 m did not occur in the two following years. Although, during the fieldwork, cuttings were found in the sediment at this station, it seems questionable that such a recovery was prevented as a long term effect of cutting discharges, since oil concentrations were at background level these years. A more realistic explanation seems to be that settlement of new generations in the area was accidentally low these years and, since natural mortality among newly settled generations may be high, it is likely that a come-back of natural population densities of adults was not possible. Moreover, the period elapsed since the initial effects occurred is probably too short for new spatfall to develop into individuals larger than 2 cm. It is concluded therefore that the absence, c.q. reduced abundance of *Echinocardium* in the area 500 - 2000

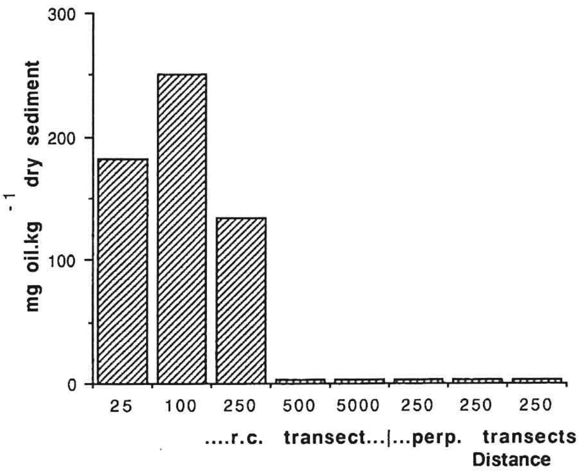


Fig. 11 L5-5, Sept. 1991: Oil concentrations in the sediment. Distance to discharge site in m. (Data from GROENEWOUD & SCHOLTEN, in prep.-b).

m (r.c. direction) and at the 250-m stations (perp. transects) should be considered a long-term consequence of an initial effect rather than a long-term effect of actual disturbance.

The strongly related effect observed in the commensal *Montacuta* should be interpreted in the same way. However, the elevated concentrations of oil in the sediment within 250 m at the r.c. transect may still be a barrier, preventing resettlement of new populations. Experimental work has shown that these concentrations are high enough to produce sublethal or even lethal effects in *Echinocardium* (ADEMA, 1991; DAAN *et al.*, 1990,1991).

### 3.3 BOXCOSM EXPERIMENT WITH SEDIMENT FROM K12A

#### 3.3.1 GENERAL REMARKS

Differences between the sediment sections of the 3 stations could be visually observed. At the sediment surface of the 100-m and 250-m boxcosms contamination was manifest by the presence of black oil patches. These patches were largest in the 100-m boxcosms. Moreover, the sediment of 100 m showed less relief (indicative of sub-surface biological activity) compared to the sediment of the other stations. During the experimental period large colonies of an orange-yellow sulphur bacterium (*Beggiatoa* spec.) developed in the 100-m and 250-m boxes. A few small colonies also appeared on the 5000-m sediment.

Oil analyses performed after termination of the experiment (GROENEWOUD & SCHOLTEN, in prep.-a) revealed that the boxcosms represented a clear gradient in sediment contamination levels.

| *Boxcosm* | *(mg·kg$^{-1}$ dry sediment)* |
|---|---|
| 5000 m (A) | 180 |
| 5000 m (B) | 54 |
| 250 m (A) | 1044 |
| 250 m (B) | 1715 |
| 100 m (A) | 29859 |
| 100 m (B) | 16946 |

The data tabulated above show extremely high oil concentrations in the sediment of 100 m. Even more remarkable is the fact that the sediment of the 5000-m station showed substantially elevated concentrations. These concentrations were much higher than found during field surveys in preceding years. The highest value found ever before at the 5000-m station of K12a was 15 mg·kg$^{-1}$ dry sediment in September 1987 (GROENEWOUD, 1991). The concentrations found at 100 m and 250 m were also considerably higher than in preceding years.

TABLE 7

Boxcosm experiment K12a. Initial fauna abundance of the sediment used in the boxcosms. Numbers of identified species and individuals in 10 Reineck samples per station.

| | *number of species* | *total number of individuals* |
|---|---|---|
| 5000 m | 46 | 2143 |
| 250 m | 35 | 705 |
| 100 m | 34 | 524 |

### 3.3.2 SURVIVAL OF THE NATURAL INFAUNA

An estimate of the survival rate of the natural infauna in the boxcosms can be obtained by comparing the abundance of living fauna present at the end of the experiment with estimates of the initial macrofauna abundance. Estimates of the initial abundance are based on the Reineck samples taken simultaneously, when the sediment sections for the boxcosms were collected. As Table 7 shows, the number of identified species and the total fauna abundance were by far the highest at the 5000-m station and the lowest at the 100-m station. The 250-m and 100-m station did not differ too much. The high fauna density at 5000 m was mainly due to large numbers of juvenile *Echinocardium cordatum*, which comprised ≈60% of the fauna by number (see Table 14). This species was absent at the other stations. Other species that were particularly abundant at 5000 m (compared to the stations closer to the platform) were *Lanice conchilega*, *Montacuta ferruginosa*, *Callianassa subterranea* and *Amphiura filiformis*. The bivalve *Nucula turgida* was especially abundant at the 250-m station.

A comparative estimate of mortality in the different boxcosms is hampered by the fact that the overall mortality was unexpectedly high in all boxcosms. As Table 8 shows, the mortality among the total infauna varied between 75% (250-m boxcosms) and 97% (5000-m boxcosms). The high percentual mortality in the 5000-m sediment was mainly due to the complete mortality among the juvenile *Echinocardium*. When this species, initially not present in the other boxcosms, is excluded, the overall mortality in the 5000-m sediment was similar to that in the 100-m sediment (83%). The high overall mortality implies that the duration of the experiment probably has been too long to reliably assess substantial differences in mortality rates of the natural infauna in the different sediment sections. Therefore, differences in mortality rates of individual species (Table 8) should be interpreted very cautiously. Moreover, the number of experiments (6) was too low to make the application of a statistical test worthwhile. The values for estimated percentages mortality listed in Table 8 show that mortality was high (90-99%) in all boxcosms for *Spiophanes bombyx* and "other polychaetes". Similar high mortalities were observed in *Poecilochaetus serpens, Magelona papillicornis*, *Abra alba*, "other crustaceans", *Amphiura filiformis* and *Echinocardium cordatum*, but only in sediment of those stations where these species were initially abundant enough to detect any mortality. Only two species that were initially abundant (≥2 specimens per Reineck box) seemed to display different mortality rates in the boxcosms of the 3 stations: In *Lumbrineris latreilli* the estimated mortality was highest in the 5000-m sedi-

TABLE 8

Boxcosm experiment K12a. Densities ($n \cdot m^{-2}$) of 15 abundant species or taxonomic groups before and after incubation. Estimated percentual mortalities are indicated. Oil concentrations in parentheses ($mg \cdot kg^{-1}$ dry sediment).

| | *5000 m (54-180)* | | | *250 m (1044-1715)* | | | *100 m (16946-29859)* | | |
|---|---|---|---|---|---|---|---|---|---|
| | *start* | *end* | *% mort* | *start* | *end* | *% mort* | *start* | *end* | *% mort* |
| *Nephtys hombergi* | 56 | 12 | 89 | 51 | 22 | 57 | <27 | | |
| *Lumbrineris latreilli* | 158 | 2 | 99 | 168 | 50 | 70 | 168 | 74 | 56 |
| *Poecilochaetus serpens* | 38 | 0 | 100 | <27 | | | <27 | | |
| *Spiophanes bombyx* | 147 | 2 | 99 | 170 | 2 | 99 | 152 | 0 | 100 |
| *Magelona papillicornis* | 30 | 2 | 93 | <27 | | | 38 | 0 | 100 |
| *Lanice conchilega* | 79 | 20 | 75 | <27 | | | <27 | | |
| other polychaetes | 118 | 10 | 92 | 129 | 14 | 89 | 125 | 12 | 90 |
| *Nucula turgida* | 59 | 52 | 12 | 263 | 128 | 51 | 79 | 24 | 30 |
| *Montacuta ferruginosa* | 45 | 14 | 69 | <27 | | | <27 | | |
| *Abra alba* | 63 | 0 | 100 | <27 | | | <27 | | |
| *Natica alderi* | 30 | 26 | 13 | 32 | 14 | 56 | <27 | | |
| *Callianassa subterranea* | 203 | 38 | 81 | 70 | 18 | 74 | <27 | | |
| other crustaceans | 39 | 2 | 95 | <27 | | | 34 | 2 | 94 |
| *Amphiura filiformis* | 37 | 2 | 95 | <27 | | | <27 | | |
| *Echinocardium cordatum* | 1869 | 4 | 99 | <27 | | | <27 | | |
| *total infauna* | 3032 | 200 | 97 | 997 | 254 | 75 | 742 | 124 | 83 |

ment and in *Nucula turgida* the opposite was true. In none of both species, however, a consistent relationship (positive or negative) with oil contamination levels could be observed.

### 3.3.3 RESPONSES BY TEST ANIMALS

After *Echinocardium* was introduced to the sediment in the boxcosms all animals immediately started burrowing. There were no differences in activity between higher and lower contaminated boxes. Most of the animals (>50%) burrowed under the sediment within 10 minutes and after 15 minutes all had disappeared. However, daily inspections in the course of the incubation period revealed differences in burrowing behaviour (Table 9). In the 5000-m boxes and in one of the 250-m boxes the animals remained under the sediment for almost the whole period. In the other 250-m box and in the 100-m boxes a significant fraction (on average 10-20%) of the animals could always be observed at the sediment surface. An increasing number reappeared completely on top of the sediment and finally did not burrow anymore. Most frequently this was observed in the 100-m box with the highest oil concentration. The frequent reappearance of *Echinocardium* at the sediment surface may unmistakably be considered deviant behaviour due to sediment contamination. In the natural situation animals on top of the sediment will be an easy prey for epifaunal predators.

Loss of spines at the ventral side was observed in most animals that died during the experimental period, but it also frequently occurred in surviving specimens in the sediment section with the highest oil concentration.

In the 5000-m sediment only 1 animal died. Slightly elevated mortality occurred in the 250-m sediment and mortality was high (45%) in one of the 100-m boxes.

## 4 DISCUSSION

### 4.1 FIELDSURVEY AT L5-5, APRIL 1990

A remarkable outcome of the field study on long-term effects at L5-5 was the poor relationship between the appearance of effects and actual oil concentrations in the sediment. Although oil concentrations were implicitly considered a measure for the contamination level, which could primarily explain a deviant fauna composition, and distance to platform is in the sense of an explanatory variable in fact a derivative of oil concentration, the observed effects relate better to distance than to oil concentrations. *E.g.*, at 100 m, where 2 stations were sampled of which only one showed sediment contamination, both sites were equally affected. On the other hand, the station with the highest contamination level (one of the 250-m sites) seemed to be hardly affected in its fauna composition. Redistribution of discharged material, resulting in the disappearance of contaminants at sites where the macrofauna was affected by pollution in an earlier phase, might partly explain why at one of the 100-m stations clear effects were observed in the absence of oil in the sediment. However, the question remains why at 250 m at an oil concentration of 60 mg·kg$^{-1}$ dry sediment the biological effects were so weak. This paradox suggests that oil is not the only factor responsible for environmental stress. It is conceivable that other substances in the discharged material may have considerable impact. It is not clear which of the substances listed in Table 2 might be expected to occur at 100 m in concentrations high enough to cause significant adverse effects on the benthic community. A possible suggestion may be the occurrence of a salinity shock during discharge of mud and cuttings. During the WBM phase of drilling 76 tonnes KCl were discharged and during the OBM phase deep salt layers may have been drilled. Hence, the discharges could possibly have resulted in temporary elevated salinities in the water close to the sea floor. Particularly in the vicinity of the discharge point such a salinity shock could have exterminated a substantial part of the macrofauna. If this is a realistic explanation, the effects observed up to 100 m in 1990 should be regarded as “a long term consequence of initial effects” (or “Type-A effect”), since the enhanced salinity is not to be expected to persist for long time. This implies that the low fauna abundance within 100 m should not necessarily be considered as “an actual effect of contamination at long term” (or “Type-B effect”).

TABLE 9

Boxcosm experiment K12a. Burrowing behaviour, loss of spines and mortality in *Echinocardium cordatum* (all values in %). *: the fraction of living animals that were, averaged over the whole incubation period visible (a) or on top of the sediment (b).

| | *5000 m* | | *250 m* | | *100 m* | |
|---|---|---|---|---|---|---|
| *box* | *A* | *B* | *A* | *B* | *A* | *B* |
| *mg oil·kg$^{-1}$dry sedim.* | *180* | *54* | *1044* | *1715* | *29859* | *16946* |
| animals visible at the sediment surface (*a) | 0.2 | 0.2 | 0.1 | 11.7 | 22.7 | 9.3 |
| animals on top of the sediment (*b) | 0 | 0 | 0 | 3.1 | 12.1 | 1.7 |
| loss of spines in dead animals | 0 | - | 80 | 0 | 70 | - |
| loss of spines in surviving animals | 0 | 0 | 5 | 2 | 25 | 2 |
| mortality | 5 | 0 | 10 | 15 | 45 | 0 |

In fact, we have to consider long-term effects always in the sense of the 2 categories described above. The distribution pattern shown by *Echinocardium cordatum* seems to display both a Type-A and a Type-B effect. During the first survey in 1989 the species appeared to be almost completely exterminated in the area within 1000 m and maybe in an even larger area, but between 1000 m and 5000 m no stations were sampled. The period of 1 year expired since the former survey is too short for newly settled individuals to grow up to animals larger than 20 mm (see DUINEVELD & JENNESS, 1984). Therefore the absence (or reduced abundance) of larger specimens of *Echinocardium* at 500 m and 750 m should be definitely explained as a Type-A effect. The recolonisation of the sediment at these stations by young specimens may indicate a possible recovery of environmental conditions. This is supported by the low oil concentrations at these stations (not exceeding background level) and the reappearance of *Montacuta ferruginosa* at 500 m and 750 m, but it remains questionable to what extent the newly settled populations will be viable. On the other hand, the absence of small specimens of *Echinocardium* at stations at ≤250 m from the discharge site suggests a Type-B effect, indicating unfavourable conditions for settlement of new generations.

## 4.2 FIELD SURVEY AT L5-5, SEPTEMBER 1991

The presence-absence data for *Montacuta ferruginosa* in the samples of September 1991 support the idea that its occurrence depends in particular on the presence of larger specimens of *Echinocardium cordatum*. In view of this close relationship, that has been found also in the distribution patterns of both species at drilling site K12a (unpubl. data), and the fact that *Montacuta* is considered a sensitive indicator for the environmental impact of OBM-cutting discharges, this implies that the distribution pattern of large *Echinocardium* may provide an indication of similar sensitivity. Moreover, it seems likely that, in fact, *Echinocardium* is the primarily sensitive species. A main reason to suppose this is that the species has shown its susceptibility to sediment contamination with OBM in bioassays (ADEMA, 1991) and boxcosm experiments (DAAN *et al.*, 1990, 1991).

In principle, the availability of a large indicator species like *Echinocardium* enables a simple method to detect the spatial extent of the environmental impact of discharges of OBM cuttings. Time-consuming laboratory analyses seem to be no longer necessary and a spatial abundance pattern can be quickly assessed by on board countings of *Echinocardium* in sediment samples collected over a dense sampling grid, provided that the species is more or less abundant by nature in the area to be investigated. The survey of 1991, when large *Echinocardium* were sampled over a much more detailed sampling grid than in 1990, clearly showed that a biological effect could be detected in this way up to ≈2000 m from the discharge site of L5-5. However, when the aim is to detect to what extent conditions recover in process of time, the method is not *a priori* valid. In the first place there should be spatfall, in order to be able to verify whether recolonisation of new generations leads to viable populations of adults. Moreover this spatfall should be extensive, since natural mortality among juvenile generations is probably high and only a few animals will grow up to adulthood. The fact that there was apparently no substantial spatfall around L5-5 in the period after the discharges were terminated must have prevented, at least partly, a comeback of *Echinocardium* in the initially affected area within ≈2000 m from the discharge site. This may illustrate that a complete biological recovery of an initially affected area may take several years, even when the abiotic environmental conditions recover within short time.

## 4.3 BOXCOSM EXPERIMENT K12A

The overall mortality among the natural infauna in the boxcosms of K12a (≈80%) was high compared to the average mortality in sediment of L5-5 (65%), that was tested in another boxcosm experiment simultaneously with the K12a series (see DAAN *et al.*, 1992). This may indicate that the high contamination levels found in all boxcosms decreased the chance of survival for most of the individual species. *E.g.* the complete mortality among the juvenile *Echinocardium* in the 5000-m sediment might be possibly explained by oil contamination. This is supported by earlier boxcosm observations, which showed that 23% of juvenile *Echinocardium* could survive in unpolluted sediment from the K12a area, even over a longer incubation period of 5 months (see DAAN *et al.*, 1990). The boxcosm experiment referred to was a pilot study carried out in 1987 with 2 "unpolluted" and 2 "heavily polluted" (data on oil concentrations are lacking) sediment sections collected at 5000 m and 100 m from the platform. The survival rates then observed among other species than *Echinocardium* in the 5000-m boxes were much higher (70% after 5 months) than in the present experiment (20% after 4 months). It should be noted, however, that the initial fauna abundance (juvenile *Echinocardium* excluded) was much lower in the 1987 experiment (684 ind·m$^{-2}$) and that the fauna was dominated by *Nucula turgida*, which showed 100% survival in both the polluted and unpolluted sediment. The present experiment affirmed the relatively high survival of *Nucula* even in severely contaminated sediment. A second explanation for the high mortality among the infauna is that the experimental conditions may have been suboptimal, particularly in the first two weeks of the experiment, due to problems with replacement of the overlaying water. These problems were solved before the test animals were introduced to the boxcosms.

The complicated interpretation of boxcosm data on survival of natural infauna should be regarded as largely due to the variability in initial densities. In individual boxcosms with different oil concentrations the initial fauna abundance may largely depend on the level of contamination. Not only the quantitative variability can be a source of mis-interpretation of comparative mortality estimates, but also the variation in species composition. The low number of species that were initially abundant at all of the three stations hampers a thorough statistically based comparison. Moreover, sediment colonised by large numbers of newly settled individuals of some species may reveal much higher overall mortality rates than sediment mainly inhabited by older individuals. It is concluded therefore that estimation of survival of natural infauna in boxcosms does not provide a reliable tool to study effects of sediment pollution.

In accordance with earlier boxcosm experiments (DAAN *et al.*, 1990, 1991) the test species *Echinocardium cordatum* displayed a consistent response to contamination of the sediment. Increased frequency in the occurrence of sublethal features (burrowing behaviour and loss of spines) as well as mortality were related to a gradient in oil concentrations in the sediment. However, compared to earlier experimental results the response was weak in view of the extremely high concentrations found in the sediment sections of K12a. Clearly elevated concentrations of oil in the sediment of the 5000-m station (54 - 180 $mg \cdot kg^{-1}$ dry sediment) did not generate any response. Similar concentrations (29 - 215 $mg \cdot kg^{-1}$) in sediment originating from location L5-5 generated in 1989 (1 year after drilling) a significant response in *Echinocardium*, which showed extensive loss of spines, whereas mortality ranged from 15 - 100% within 3 months. Also in the 250-m sediment of K12a, though severely contaminated, lethal effects occurred only at a moderate scale and high mortality (45%) was observed in only one 100-m sediment core at the extremely high concentration of $\approx$30 000 mg $oil \cdot kg^{-1}$ dry sediment. This high dose - low response ratio indicates that at the long term the biological availability of toxic components decreases. However, it should be stressed that, 6 years after drilling, the environmental conditions are still strongly affected up to at least 250 m from the discharge site.

## 5 REFERENCES


ADEMA, D.M.M., 1991. Development of an ecotoxicological test with the sediment reworking species *Echinocardium cordatum*. TNO-report R 90/473.

DAAN, R., W.E. LEWIS & M. MULDER, 1990. Biological effects of discharged oil-contaminated drill cuttings in the North Sea. Boorspoeling III-IV, NIOZ-rapport 1990-5. NIOZ, Texel, The Netherlands: 1-77.

—, 1991. Biological effects of washed OBM drill cuttings discharged on the Dutch Continental Shelf. Boorspoeling V, NIOZ-rapport 1991-8. NIOZ, Texel, The Netherlands: 1- 33

DAAN, R., W.E. LEWIS, M. MULDER & S.A. DE JONG, 1992. The assessment of a no-effect concentration of oil in thermally treated OBM drill cuttings for marine benthos: Ecotoxicity. NIOZ-rapport 1992-7. NIOZ, Texel, The Netherlands.

DUINEVELD, G.C.A. & M.I. JENNESS, 1984. Differences in growth rates of the sea urchin *Echinocardium cordatum* as estimated by the parameter w of the von Bertalanffy equation applied to skeletal rings. Mar. Ecol. Prog. Ser. **19:** 65-72.

GAGE, J., 1966. The life histories of the bivalves *Montacuta substriata* and *Montacuta ferruginosa*, 'commensals' with spatangoids. J. Mar. Biol. Ass. U.K. **46:** 499-511.

GROENEWOUD, H. VAN HET, L. VAN DER VLIES, G. HOORNSMAN & T. BOWMER, 1988. A comparative study of monitoring techniques to establish distribution and biological effects of drilling muds around off-shore installations on the Dutch Continental Shelf (1986). TNO-rep. nr. R 88/ 405: 1-53

GROENEWOUD, H. VAN HET, 1991. Monitoring offshore installations on the Dutch continental shelf; a study of monitoring techniques for the assessment of chemical and biological effects of the discharges of drilling muds (1987-1988). TNO-rep. nr. R 90/380: 1-96.

GROENEWOUD, H. VAN HET & M. SCHOLTEN, 1992. Monitoring environmental impacts of washed OBM drill cuttings discharged on the Dutch Continental Shelf, 1989: Sediment analysis and bioaccumulation. TNO-rep. nr. R92/ 056.

—, in prep.-a. Monitoring the recovery from environmental impacts of washed and unwashed OBM cuttings discharges on the Dutch Continental Shelf, 1990: Sediment analysis and Bioaccumulation. TNO-rep.

—, in prep.-b. Monitoring the recovery from environmental impacts of washed OBM cuttings discharges on the Dutch Continental Shelf, 1991: Sediment analysis. TNO-rep.

JONGMAN, R.H.G., C.J.F. TER BRAAK & O.F.R. VAN TONGEREN, 1987. Data analysis in community and landscape ecology. Pudoc, Wageningen, The Netherlands: 1-299.

KUIPER, J. & H. VAN HET GROENEWOUD, 1986. Monitoren van de verspreiding en de biologische effecten van olie rond platforms op de Noordzee. TNO-rep. nr. R85/350a: 1-51.

MORTON, J.E., 1962. Habit and orientation in the small commensal bivalve mollusc, *Montacuta ferruginosa*. Anim. Behav. **10:** 126-133.

MULDER, M., W.E. LEWIS & M.A. VAN ARKEL, 1987. Effecten van oliehoudend boorgruis op de benthische fauna rond mijnbouwinstallaties op het Nederlands Continentaal Plat. Boorspoeling I, NIOZ-rapport 1987-3. NIOZ, Texel, The Netherlands: 1-60.

—, 1988. Biological effects of the discharges of contaminated drill-cuttings and water-based drilling fluids in the North Sea. Boorspoeling II, NIOZ-rapport 1988-3: 1-126. NIOZ, Texel, The Netherlands: 1-126.

SOKAL, R.R. & F.J. ROHLF, 1981. Biometry. W.H. Freeman & Co, San Francisco: 1-859.

# APPENDIX

Table 10. Data location L5-5 (abandoned), survey April 1990, residual current transect (77°).
Number of identified species.
Mean densities (n.m-²).
Tot. number of ind. per m² per station.
Number of samples ( ) in which species are present.

| Distance to platform (m) | 25 | 25 | 100 | 100 | 250 | 250 | 500 |
|---|---|---|---|---|---|---|---|
| Number of analysed samples | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| POLYCHAETA | | | | | | | |
| Aphrodita aculeata | -- | 2.5 (2) | 1.2 (1) | 1.2 (1) | 1.2 (1) | 2.5 (2) | 1.2 (1) |
| Harmothoe lunulata | 1.2 (1) | -- | -- | -- | -- | -- | -- |
| Harmothoe longisetis | -- | -- | -- | -- | 1.2 (1) | 5.0 (3) | -- |
| Gattyana cirrosa | 3.8 (2) | -- | 1.2 (1) | -- | 11.2 (3) | 15.0 (4) | 20.0 (4) |
| Polynoe kinbergi | -- | -- | -- | -- | -- | -- | 1.2 (1) |
| Pholoe minuta | 2.5 (2) | 3.8 (3) | 1.2 (1) | 2.5 (2) | 21.2 (3) | 68.8 (4) | 12.5 (4) |
| Sthenelais limicola | 1.2 (1) | 2.5 (2) | 1.2 (1) | 3.8 (2) | 2.5 (1) | -- | 2.5 (2) |
| Eteone longa | 1.2 (1) | -- | -- | -- | -- | 1.2 (1) | -- |
| Eteone lactea | -- | -- | -- | -- | -- | -- | -- |
| Eumida sanguinea | -- | -- | -- | -- | 1.2 (1) | -- | -- |
| Ophiodromus flexuosus | 3.8 (1) | 1.2 (1) | 5.0 (2) | 3.8 (3) | 6.3 (3) | -- | 6.3 (3) |
| Gyptis capensis | 2.5 (2) | 1.2 (1) | 1.2 (1) | 8.8 (3) | 3.8 (1) | 2.5 (2) | 6.3 (3) |
| Synelmis klatti | 3.8 (3) | -- | 2.5 (1) | 6.3 (3) | -- | 2.5 (2) | 2.5 (1) |
| Exogone hebes | 1.2 (1) | -- | -- | -- | 1.2 (1) | -- | -- |
| Nereis longissima | -- | -- | -- | 1.2 (1) | -- | -- | 3.8 (2) |
| Nereis spec. juv. | -- | -- | -- | -- | -- | -- | 2.5 (1) |
| Nephtys hombergii | 2.5 (2) | 5.0 (2) | -- | -- | 2.5 (1) | 6.3 (3) | 6.3 (3) |
| Nephtys incisa | -- | -- | 1.2 (1) | 1.2 (1) | -- | 6.3 (2) | 8.8 (3) |
| Nephtys cirrosa | -- | -- | -- | -- | -- | 6.3 (2) | 2.5 (1) |
| Nephtys caeca | -- | 2.5 (2) | -- | -- | -- | -- | -- |
| Nephtys spec. juv. | 8.8 (3) | 21.2 (3) | 7.5 (4) | 11.2 (4) | 12.5 (3) | 3.8 (2) | 8.8 (4) |
| Glycera rouxii | -- | -- | 2.5 (2) | 1.2 (1) | 1.2 (1) | 3.8 (2) | 7.5 (3) |
| Glycera alba | -- | -- | -- | -- | 2.5 (2) | 1.2 (1) | -- |
| Glycera spec. juv. | 22.5 (4) | 11.2 (4) | 7.5 (3) | 10.0 (3) | 5.0 (2) | 8.8 (3) | 5.0 (3) |
| Glycinde nordmanni | -- | 1.2 (1) | 1.2 (1) | 3.8 (3) | 2.5 (2) | 3.8 (3) | 7.5 (4) |
| Goniada maculata | 5.0 (2) | 6.3 (4) | 3.8 (2) | 10.0 (4) | 3.8 (2) | 3.8 (2) | 5.0 (3) |
| Lumbrineris latreilli | 111.2 (4) | 268.7 (4) | 97.5 (4) | 85.0 (4) | 162.5 (4) | 698.8 (4) | 628.7 (4) |
| Lumbrineris fragilis | 5.0 (3) | 1.2 (1) | 1.2 (1) | 2.5 (2) | 2.5 (2) | 3.8 (1) | 2.5 (2) |
| Driloneris filum | -- | -- | -- | -- | -- | -- | -- |
| Orbinia sertulata | -- | -- | -- | -- | -- | -- | 1.2 (1) |
| Paraonis spec. | -- | -- | -- | -- | -- | -- | -- |
| Poecilochaetus serpens | -- | -- | -- | -- | 1.2 (1) | -- | -- |
| Spio filicornis | -- | 5.0 (2) | 1.2 (1) | -- | 1.2 (1) | 1.2 (1) | 3.8 (3) |
| Polydora guillei | -- | -- | -- | -- | 1.2 (1) | 5.0 (1) | -- |
| Spiophanes kroyeri | -- | -- | -- | -- | -- | -- | -- |
| Spiophanes bombyx | -- | -- | -- | -- | -- | -- | -- |
| Scolelepis foliosa | -- | -- | -- | -- | -- | -- | -- |
| Magelona alleni | 3.8 (2) | 2.5 (2) | 13.7 (3) | 1.2 (1) | 7.5 (3) | 13.7 (4) | 11.2 (4) |
| Chaetopterus variopedatus | 5.0 (3) | -- | 2.5 (2) | 6.3 (4) | 20.0 (4) | 30.0 (4) | 40.0 (4) |
| Tharyx marioni | -- | -- | -- | -- | 1.2 (1) | -- | 3.8 (2) |
| Chaetozone setosa | -- | -- | 1.2 (1) | -- | 1.2 (1) | -- | 6.3 (3) |
| Diplocirrus glaucus | -- | -- | -- | -- | -- | 3.8 (3) | 7.5 (3) |
| Scalibregma inflatum | -- | -- | -- | -- | -- | -- | -- |
| Ophelina acuminata | 1.2 (1) | -- | -- | -- | 1.2 (1) | -- | 1.2 (1) |
| Capitella capitata | 11.2 (2) | -- | -- | -- | -- | -- | -- |
| Notomastus latericeus | 1.2 (1) | -- | 1.2 (1) | 2.5 (2) | -- | 2.5 (1) | 6.3 (3) |
| Heteromastus filiformis | 1.2 (1) | -- | 1.2 (1) | 1.2 (1) | 1.2 (1) | 3.8 (3) | 1.2 (1) |
| Owenia fusiformis | -- | -- | 1.2 (1) | 1.2 (1) | -- | 1.2 (1) | 5.0 (3) |
| Lanice conchilega | -- | -- | -- | -- | -- | -- | -- |
| Lagis koreni | -- | -- | -- | -- | -- | -- | 3.8 (2) |
| Pectinaria auricoma | -- | -- | -- | -- | -- | -- | 38.7 (4) |
| Amphicteis sundevalli | -- | -- | -- | -- | -- | -- | 2.5 (1) |
| Sosane gracilis | -- | -- | -- | -- | -- | -- | -- |
| Lysilla loveni | -- | -- | -- | -- | -- | -- | 2.5 (1) |
| Terebellides stroemi | -- | -- | -- | -- | -- | -- | -- |

Table 10. Data location L5-5 (abandoned), survey April 1990, residual current transect (77°).
Number of identified species.
Mean densities ($n.m^{-2}$).
Tot. number of ind. per $m^2$ per station.
Number of samples ( ) in which species are present.

| Distance to platform (m) | 500 | 750 | 750 | 1000 | 1000 | 5000 |
|---|---|---|---|---|---|---|
| Number of analysed samples | 3 | 4 | 2 | 4 | 4 | 7 |
| POLYCHAETA | | | | | | |
| Aphrodita aculeata | 1.7 (1) | -- | -- | -- | -- | -- |
| Harmothoe lunulata | 1.7 (1) | 1.2 (1) | -- | -- | 1.2 (1) | -- |
| Harmothoe longisetis | 3.3 (2) | -- | 2.5 (1) | -- | -- | 1.4 (2) |
| Gattyana cirrosa | 5.0 (2) | 2.5 (2) | 5.0 (1) | 3.8 (2) | 5.0 (2) | 4.3 (4) |
| Polynoe kinbergi | -- | 1.2 (1) | -- | -- | -- | -- |
| Pholoe minuta | 41.7 (3) | 21.2 (4) | 15.0 (2) | 25.0 (4) | 15.0 (4) | 22.9 (6) |
| Sthenelais limicola | 1.7 (1) | 7.5 (2) | 5.0 (2) | 2.5 (2) | 2.5 (2) | 2.1 (3) |
| Eteone longa | -- | -- | -- | -- | -- | -- |
| Eteone lactea | -- | 1.2 (1) | -- | 1.2 (1) | -- | -- |
| Eumida sanguinea | -- | -- | 2.5 (1) | -- | -- | -- |
| Ophiodromus flexuosus | 1.7 (1) | 2.5 (1) | 2.5 (1) | -- | 2.5 (2) | 1.4 (2) |
| Gyptis capensis | 1.7 (1) | 1.2 (1) | 2.5 (1) | 3.8 (2) | 3.8 (2) | 4.3 (4) |
| Synelmis klatti | 1.7 (1) | 1.2 (1) | -- | 1.2 (1) | -- | -- |
| Exogone hebes | -- | 1.2 (1) | -- | 5.0 (4) | 1.2 (1) | .7 (1) |
| Nereis longissima | -- | -- | -- | -- | -- | -- |
| Nereis spec. juv. | -- | -- | -- | -- | 1.2 (1) | -- |
| Nephtys hombergii | 20.0 (3) | 6.3 (3) | 2.5 (1) | 6.3 (2) | 7.5 (4) | -- |
| Nephtys incisa | 8.3 (3) | -- | -- | -- | -- | -- |
| Nephtys cirrosa | -- | -- | -- | 1.2 (1) | -- | -- |
| Nephtys caeca | -- | -- | -- | -- | -- | -- |
| Nephtys spec. juv. | 5.0 (1) | 12.5 (4) | 2.5 (1) | 11.2 (3) | 8.8 (4) | 5.0 (3) |
| Glycera rouxii | 5.0 (2) | 5.0 (3) | 5.0 (2) | 11.2 (3) | 6.3 (3) | 7.9 (6) |
| Glycera alba | -- | -- | -- | -- | -- | -- |
| Glycera spec. juv. | 10.0 (2) | 5.0 (2) | 2.5 (1) | 6.3 (2) | -- | 3.6 (2) |
| Glycinde nordmanni | 1.7 (1) | 6.3 (3) | 2.5 (1) | 6.3 (3) | 3.8 (3) | 5.7 (6) |
| Goniada maculata | 5.0 (2) | 6.3 (3) | 5.0 (2) | 10.0 (4) | 5.0 (2) | 4.3 (4) |
| Lumbrineris latreilli | 413.3 (3) | 247.5 (4) | 232.5 (2) | 321.2 (4) | 268.7 (4) | 186.4 (7) |
| Lumbrineris fragilis | 10.0 (3) | 8.8 (3) | 2.5 (1) | 6.3 (3) | 5.0 (2) | 5.0 (4) |
| Driloneris filum | -- | -- | -- | -- | 1.2 (1) | -- |
| Orbinia sertulata | -- | -- | -- | -- | -- | .7 (1) |
| Paraonis spec. | -- | -- | -- | -- | -- | 2.1 (2) |
| Poecilochaetus serpens | -- | 1.2 (1) | -- | 1.2 (1) | -- | 2.1 (2) |
| Spio filicornis | 10.0 (3) | 3.8 (1) | 2.5 (1) | 2.5 (2) | 1.2 (1) | 3.6 (4) |
| Polydora guillei | -- | -- | -- | -- | -- | -- |
| Spiophanes kroyeri | -- | -- | -- | -- | -- | -- |
| Spiophanes bombyx | -- | 1.2 (1) | 2.5 (1) | -- | 1.2 (1) | .7 (1) |
| Scolelepis foliosa | -- | 1.2 (1) | -- | -- | 1.2 (1) | -- |
| Magelona alleni | 3.3 (1) | 3.8 (2) | -- | 11.2 (4) | 7.5 (3) | 2.1 (3) |
| Chaetopterus variopedatus | 16.7 (2) | 11.2 (3) | 7.5 (2) | 8.8 (3) | 3.8 (2) | 6.4 (5) |
| Tharyx marioni | 6.7 (3) | 2.5 (2) | -- | 2.5 (2) | -- | .7 (1) |
| Chaetozone setosa | 3.3 (1) | -- | -- | -- | 1.2 (1) | .7 (1) |
| Diplocirrus glaucus | 8.3 (2) | 2.5 (2) | 10.0 (2) | 7.5 (3) | 2.5 (1) | -- |
| Scalibregma inflatum | -- | -- | -- | -- | -- | -- |
| Ophelina acuminata | 1.7 (1) | -- | 10.0 (2) | -- | 1.2 (1) | 1.4 (2) |
| Capitella capitata | -- | -- | -- | -- | -- | -- |
| Notomastus latericeus | 3.3 (1) | 2.5 (1) | -- | 1.2 (1) | -- | -- |
| Heteromastus filiformis | -- | 1.2 (1) | -- | 1.2 (1) | 1.2 (1) | -- |
| Owenia fusiformis | 3.3 (2) | 11.2 (4) | 10.0 (2) | 5.0 (3) | 3.8 (2) | 2.1 (2) |
| Lanice conchilega | -- | -- | -- | -- | -- | -- |
| Lagis koreni | 1.7 (1) | -- | -- | 1.2 (1) | -- | -- |
| Pectinaria auricoma | 21.7 (3) | 5.0 (2) | -- | 5.0 (3) | 5.0 (3) | 3.6 (3) |
| Amphicteis sundevalli | -- | -- | -- | -- | -- | -- |
| Sosane gracilis | 1.7 (1) | -- | -- | 1.2 (1) | -- | -- |
| Lysilla loveni | -- | -- | -- | -- | -- | .7 (1) |
| Terebellides stroemi | -- | 1.2 (1) | -- | -- | -- | -- |

Table 10 continued.

| Distance to platform (m) | 25 | 25 | 100 | 100 | 250 | 250 | 500 |
|---|---|---|---|---|---|---|---|
| Number of analysed samples | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| MOLLUSCA | | | | | | | |
| Nucula turgida | -- | -- | -- | -- | -- | 7.5 (3) | 1.2 (1) |
| Thyasira flexuosa | 2.5 (1) | -- | 1.2 (1) | -- | -- | 2.5 (2) | 5.0 (3) |
| Lepton squamosum | -- | -- | -- | -- | -- | -- | 1.2 (1) |
| Montacuta ferruginosa | -- | -- | -- | -- | -- | -- | 6.3 (3) |
| Mysella bidentata | 7.5 (4) | 1.2 (1) | 3.8 (3) | 5.0 (2) | 120.0 (4) | 456.2 (4) | 293.7 (4) |
| Arctica islandica | -- | -- | -- | -- | -- | 1.2 (1) | -- |
| Acanthocardia echinata | -- | -- | -- | -- | -- | -- | -- |
| Dosinia lupinus | -- | -- | 2.5 (2) | -- | 3.8 (3) | 3.8 (2) | 1.2 (1) |
| Venus striatula | 1.2 (1) | 13.7 (4) | 3.8 (2) | 5.0 (4) | 5.0 (3) | 5.0 (2) | 1.2 (1) |
| Mysia undata | -- | 1.2 (1) | -- | -- | -- | 1.2 (1) | 3.8 (2) |
| Spisula elliptica | -- | -- | -- | -- | -- | -- | -- |
| Abra tenuis | -- | -- | -- | -- | 2.5 (1) | -- | -- |
| Abra alba | -- | -- | 1.2 (1) | -- | -- | -- | 2.5 (2) |
| Gari fervensis | -- | -- | -- | -- | -- | -- | -- |
| Cultellus pellucidus | -- | -- | 1.2 (1) | 1.2 (1) | -- | 1.2 (1) | 3.8 (3) |
| Mya spec. juv. | -- | -- | 1.2 (1) | -- | -- | -- | -- |
| Corbula gibba | 5.0 (1) | 8.8 (3) | 5.0 (3) | 7.5 (3) | 16.2 (4) | 13.7 (4) | 17.5 (4) |
| Thracia convexa | -- | -- | 1.2 (1) | 1.2 (1) | 2.5 (2) | -- | 3.8 (2) |
| Cingula nitida | 3.8 (1) | -- | 10.0 (2) | 17.5 (2) | 1.2 (1) | -- | 1.2 (1) |
| Turritella communis | -- | 7.5 (3) | 5.0 (2) | 2.5 (2) | 23.7 (4) | 5.0 (3) | 5.0 (2) |
| Natica alderi | 2.5 (1) | 3.8 (2) | 1.2 (1) | 5.0 (2) | 13.7 (4) | 11.2 (3) | 15.0 (3) |
| Retusa truncatula | -- | -- | -- | -- | -- | -- | -- |
| Retusa umbilicata | -- | -- | -- | -- | -- | -- | -- |
| Buccinum undatum | 5.0 (3) | -- | -- | -- | -- | -- | -- |
| Cylichna cilindracea | -- | 2.5 (2) | 1.2 (1) | 1.2 (1) | 3.8 (1) | 6.3 (3) | 10.0 (3) |
| Philine scabra | -- | 2.5 (2) | 1.2 (1) | -- | -- | -- | 1.2 (1) |
| CRUSTACEA | | | | | | | |
| Processa parva | -- | -- | 2.5 (2) | 2.5 (2) | -- | -- | -- |
| Pagurus bernhardus | -- | -- | -- | -- | -- | -- | -- |
| Porcellana longicornis | -- | -- | -- | -- | -- | -- | -- |
| Porcellana spec. juv. | -- | -- | -- | -- | -- | -- | -- |
| Macropipus spec. juv. | -- | -- | -- | -- | -- | -- | -- |
| Pinnotheres pisum | -- | -- | -- | -- | -- | -- | -- |
| Ebalia cranchii | 2.5 (2) | -- | -- | -- | -- | -- | 2.5 (2) |
| Cancer pagurus | -- | -- | -- | -- | -- | -- | -- |
| Corystes cassivelaunus | -- | -- | -- | -- | -- | -- | -- |
| Upogebia stellata | 1.2 (1) | -- | -- | -- | 1.2 (1) | 2.5 (2) | -- |
| Upogebia deltaura | -- | -- | -- | -- | -- | 2.5 (2) | 1.2 (1) |
| Callianassa subterranea | 2.5 (2) | -- | 3.8 (2) | 5.0 (3) | 5.0 (3) | 17.5 (4) | 70.0 (4) |
| Nebalia bipes | -- | -- | 1.2 (1) | 1.2 (1) | -- | -- | -- |
| Eudorella truncatula | 2.5 (2) | -- | 1.2 (1) | -- | 5.0 (2) | -- | -- |
| Iphinoe trispinosa | -- | -- | -- | -- | -- | -- | -- |
| Diastylis bradyi | 5.0 (3) | 5.0 (4) | 1.2 (1) | 3.8 (2) | 3.8 (2) | -- | 3.8 (2) |
| Cirolana borealis | -- | -- | -- | -- | -- | 1.2 (1) | -- |
| Ione thoracica | -- | -- | -- | -- | -- | -- | 3.8 (1) |
| Melita obtusata | -- | -- | -- | -- | -- | -- | -- |
| Hippomedon denticulatus | -- | -- | -- | -- | -- | -- | -- |
| Orchomenella nana | 1.2 (1) | -- | -- | -- | -- | -- | -- |
| Leucothoe incisa | -- | -- | -- | -- | -- | -- | -- |
| Ampelisca brevicornis | -- | -- | 1.2 (1) | -- | 1.2 (1) | 1.2 (1) | 1.2 (1) |
| Ampelisca tenuicornis | 15.0 (3) | -- | 11.2 (4) | 6.3 (2) | 3.8 (2) | 8.8 (2) | 21.2 (4) |
| Ampelisca spec. juv. | 2.5 (2) | 3.8 (2) | -- | 3.8 (2) | 3.8 (2) | -- | -- |
| Amphilochus spec. | -- | -- | -- | -- | -- | -- | -- |
| Cheirocratus sundevalli | -- | -- | 1.2 (1) | -- | -- | -- | -- |
| Bathyporeia guilliamsoniana | -- | -- | -- | -- | -- | -- | -- |

Table 10 continued.

| Distance to platform (m) | 500 | 750 | 750 | 1000 | 1000 | 5000 |
|---|---|---|---|---|---|---|
| Number of analysed samples | 3 | 4 | 2 | 4 | 4 | 7 |
| MOLLUSCA | | | | | | |
| Nucula turgida | 6.7 (2) | 3.8 (2) | 5.0 (1) | 2.5 (2) | 1.2 (1) | 1.4 (2) |
| Thyasira flexuosa | 1.7 (1) | 1.2 (1) | -- | 1.2 (1) | -- | .7 (1) |
| Lepton squamosum | -- | -- | -- | -- | -- | -- |
| Montacuta ferruginosa | 1.7 (1) | -- | -- | 7.5 (3) | -- | 7.9 (4) |
| Mysella bidentata | 480.0 (3) | 160.0 (4) | 122.5 (2) | 133.8 (4) | 78.8 (4) | 80.0 (6) |
| Arctica islandica | -- | -- | 2.5 (1) | 1.2 (1) | -- | -- |
| Acanthocardia echinata | -- | -- | -- | -- | -- | .7 (1) |
| Dosinia lupinus | -- | 2.5 (2) | -- | 1.2 (1) | 2.5 (1) | .7 (1) |
| Venus striatula | 3.3 (1) | 5.0 (2) | 5.0 (1) | 6.3 (4) | 7.5 (3) | 2.9 (3) |
| Mysia undata | -- | 1.2 (1) | -- | -- | -- | .7 (1) |
| Spisula elliptica | -- | 1.2 (1) | -- | 2.5 (2) | -- | .7 (1) |
| Abra tenuis | -- | -- | -- | -- | -- | -- |
| Abra alba | -- | -- | 2.5 (1) | -- | 1.2 (1) | .7 (1) |
| Gari fervensis | -- | -- | -- | -- | -- | -- |
| Cultellus pellucidus | -- | -- | -- | 3.8 (2) | 1.2 (1) | -- |
| Mya spec. juv. | -- | -- | -- | -- | -- | -- |
| Corbula gibba | 8.3 (3) | 20.0 (4) | 15.0 (2) | 26.2 (4) | 11.2 (4) | 13.6 (6) |
| Thracia convexa | 3.3 (2) | 2.5 (2) | 5.0 (2) | -- | 6.3 (3) | 1.4 (2) |
| Cingula nitida | 1.7 (1) | 1.2 (1) | -- | -- | 1.2 (1) | 1.4 (2) |
| Turritella communis | 3.3 (2) | 1.2 (1) | 7.5 (1) | 5.0 (2) | 100.0 (3) | 4.3 (3) |
| Natica alderi | 5.0 (3) | 15.0 (4) | 2.5 (1) | 12.5 (4) | 6.3 (4) | 5.7 (3) |
| Retusa truncatula | -- | -- | -- | -- | -- | -- |
| Retusa umbilicata | -- | -- | -- | -- | -- | -- |
| Buccinum undatum | -- | -- | -- | -- | -- | -- |
| Cylichna cilindracea | 11.7 (2) | 8.8 (3) | 15.0 (2) | 10.0 (3) | 8.8 (2) | 5.7 (5) |
| Philine scabra | 3.3 (1) | -- | -- | -- | -- | -- |
| CRUSTACEA | | | | | | |
| Processa parva | -- | -- | -- | -- | -- | .7 (1) |
| Pagurus bernhardus | -- | -- | -- | -- | -- | -- |
| Porcellana longicornis | -- | -- | -- | -- | -- | -- |
| Porcellana spec. juv. | -- | -- | -- | -- | -- | -- |
| Macropipus spec. juv. | -- | -- | -- | -- | -- | -- |
| Pinnotheres pisum | -- | -- | -- | -- | -- | -- |
| Ebalia cranchii | -- | 2.5 (1) | 10.0 (2) | 1.2 (1) | 1.2 (1) | 2.9 (3) |
| Cancer pagurus | -- | -- | -- | -- | -- | -- |
| Corystes cassivelaunus | 1.7 (1) | 1.2 (1) | -- | -- | -- | -- |
| Upogebia stellata | 1.7 (1) | -- | -- | -- | -- | -- |
| Upogebia deltaura | -- | 2.5 (2) | 2.5 (1) | 1.2 (1) | -- | 1.4 (1) |
| Callianassa subterranea | 58.3 (3) | 25.0 (4) | 20.0 (2) | 32.5 (4) | 17.5 (4) | 15.7 (7) |
| Nebalia bipes | 5.0 (1) | -- | -- | -- | -- | -- |
| Eudorella truncatula | -- | 1.2 (1) | -- | -- | 1.2 (1) | .7 (1) |
| Iphinoe trispinosa | -- | -- | -- | -- | -- | -- |
| Diastylis bradyi | -- | 1.2 (1) | -- | 1.2 (1) | -- | 1.4 (2) |
| Cirolana borealis | -- | -- | -- | -- | 1.2 (1) | -- |
| Ione thoracica | -- | -- | -- | 1.2 (1) | -- | -- |
| Melita obtusata | -- | -- | -- | -- | -- | -- |
| Hippomedon denticulatus | -- | -- | -- | -- | 1.2 (1) | -- |
| Orchomenella nana | -- | -- | -- | 20.0 (3) | 1.2 (1) | -- |
| Leucothoe incisa | 1.7 (1) | -- | -- | -- | -- | -- |
| Ampelisca brevicornis | 5.0 (3) | 1.2 (1) | -- | 6.3 (3) | 5.0 (3) | 5.7 (4) |
| Ampelisca tenuicornis | 18.3 (3) | 8.8 (3) | 5.0 (2) | 5.0 (2) | 5.0 (2) | 6.4 (4) |
| Ampelisca spec. juv. | -- | 1.2 (1) | -- | 2.5 (1) | 1.2 (1) | 3.6 (2) |
| Amphilochus spec. | -- | -- | -- | -- | -- | -- |
| Cheirocratus sundevalli | -- | -- | 2.5 (1) | -- | -- | -- |
| Bathyporeia guilliamsoniana | -- | -- | -- | -- | -- | -- |

Table 10 continued.

| Distance to platform (m) | 25 | 25 | 100 | 100 | 250 | 250 | 500 |
|---|---|---|---|---|---|---|---|
| Number of analysed samples | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Bathyporeia elegans | -- | 2.5 (2) | 1.2 (1) | -- | -- | -- | -- |
| Bathyporeia tenuipes | -- | -- | 1.2 (1) | 1.2 (1) | -- | -- | -- |
| Harpinia antennaria | -- | -- | -- | -- | -- | -- | -- |
| Apherusa spec. | -- | -- | -- | -- | -- | -- | -- |
| Perioculodes longimanus | 3.8 (3) | -- | 3.8 (3) | 3.8 (3) | -- | -- | -- |
| Aora typica | -- | -- | -- | -- | 1.2 (1) | -- | 1.2 (1) |
| Caprella spec. | 1.2 (1) | -- | 1.2 (1) | -- | -- | -- | -- |
| ECHINODERMATA | | | | | | | |
| Amphiura filiformis | 15.0 (3) | 20.0 (4) | 28.7 (4) | 21.2 (3) | 221.3 (4) | 1541.2 (4) | 1253.7 (4) |
| Amphiura chiajei | -- | -- | -- | -- | -- | 6.3 (2) | 1.2 (1) |
| Ophiura texturata | -- | -- | -- | -- | -- | -- | -- |
| Ophiura albida | -- | -- | -- | -- | 3.8 (1) | -- | -- |
| Ophiura spec. juv. | 2.5 (2) | 6.3 (3) | 2.5 (1) | 1.2 (1) | -- | 1.2 (1) | 7.5 (3) |
| Echinocardium cordatum | -- | -- | -- | -- | -- | -- | 16.2 (4) |
| OTHER TAXA | | | | | | | |
| Nemertinea | -- | P (4) | P (4) | P (2) | P (4) | P (4) | P (4) |
| Nematoda | 1.2 (1) | -- | -- | -- | -- | -- | -- |
| Turbellaria | 3.8 (3) | 2.5 (2) | -- | 3.8 (2) | 6.3 (4) | 3.8 (3) | 3.8 (2) |
| Phoroniden | -- | -- | P (1) | -- | P (1) | -- | -- |
| Harp. copepoda | -- | -- | -- | -- | -- | 1.2 (1) | 1.2 (1) |
| Parasitaire copepoda | -- | -- | -- | -- | 1.2 (1) | 3.8 (2) | 3.8 (2) |
| Holothuroidea | -- | 1.2 (1) | 2.5 (1) | 2.5 (2) | 1.2 (1) | 3.8 (2) | 3.8 (1) |
| Sagitta spec. | -- | 1.2 (1) | -- | -- | -- | -- | -- |
| Echiurida | -- | -- | 2.5 (1) | 2.5 (1) | -- | 7.5 (2) | 8.8 (3) |
| Sipunculida | 5.0 (2) | -- | 38.7 (4) | 33.7 (4) | 23.7 (4) | 72.5 (4) | 97.5 (4) |
| Anthozoa | -- | -- | 1.2 (1) | 1.2 (1) | -- | -- | -- |
| Ascidiacea | -- | -- | -- | -- | -- | -- | -- |
| Foraminiferida | -- | 1.2 (1) | -- | -- | -- | -- | -- |
| Tot. nr. of individuals | 287.2 | 420.9 | 304.8 | 304.7 | 755.6 | 3095.2 | 2752.4 |
| Nr. of identified species | 34 | 24 | 45 | 35 | 44 | 44 | 60 |

P= present, not counted

Table 10 continued.

| Distance to platform (m) | 500 | 750 | 750 | 1000 | 1000 | 5000 |
|---|---|---|---|---|---|---|
| Number of analysed samples | 3 | 4 | 2 | 4 | 4 | 7 |
| Bathyporeia elegans | -- | -- | -- | -- | -- | -- |
| Bathyporeia tenuipes | -- | 1.2 (1) | -- | -- | -- | -- |
| Harpinia antennaria | -- | 1.2 (1) | 5.0 (1) | 2.5 (2) | -- | -- |
| Apherusa spec. | -- | -- | -- | -- | -- | -- |
| Perioculodes longimanus | 3.3 (1) | 2.5 (2) | -- | 1.2 (1) | -- | .7 (1) |
| Aora typica | -- | 2.5 (1) | -- | -- | -- | -- |
| Caprella spec. | 1.7 (1) | -- | -- | -- | -- | -- |
| ECHINODERMATA | | | | | | |
| Amphiura filiformis | 1148.3 (3) | 763.8 (4) | 655.0 (2) | 566.2 (4) | 326.2 (3) | 277.9 (7) |
| Amphiura chiajei | 13.3 (3) | 2.5 (2) | -- | 6.3 (3) | 6.3 (2) | -- |
| Ophiura texturata | 1.7 (1) | -- | -- | -- | -- | -- |
| Ophiura albida | -- | 2.5 (1) | -- | 2.5 (1) | -- | .7 (1) |
| Ophiura spec. juv. | 6.7 (2) | 8.8 (4) | 5.0 (2) | 2.5 (1) | 8.8 (3) | -- |
| Echinocardium cordatum | 8.3 (3) | 5.0 (2) | -- | 8.8 (3) | -- | 10.7 (5) |
| OTHER TAXA | | | | | | |
| Nemertinea | P (3) | P (4) | P (2) | P (4) | P (4) | P (7) |
| Nematoda | -- | -- | -- | -- | -- | -- |
| Turbellaria | 6.7 (2) | 6.3 (2) | 5.0 (2) | 7.5 (3) | 5.0 (2) | 1.4 (2) |
| Phoroniden | P (2) | P (1) | P (1) | -- | P (2) | P (2) |
| Harp. copepoda | -- | 2.5 (2) | -- | 5.0 (3) | 5.0 (2) | 3.6 (3) |
| Parasitaire copepoda | -- | 1.2 (1) | 2.5 (1) | 2.5 (2) | -- | -- |
| Holothuroidea | -- | 2.5 (2) | 2.5 (1) | 1.2 (1) | 1.2 (1) | .7 (1) |
| Sagitta spec. | -- | -- | -- | -- | -- | -- |
| Echiurida | 5.0 (2) | 2.5 (2) | -- | -- | -- | 3.6 (3) |
| Sipunculida | 135.0 (3) | 72.5 (4) | 37.5 (2) | 93.8 (4) | 63.7 (4) | 62.1 (7) |
| Anthozoa | 1.7 (1) | -- | -- | -- | -- | .7 (1) |
| Ascidiacea | 1.7 (1) | -- | -- | -- | -- | -- |
| Foraminiferida | 1.7 (1) | -- | -- | -- | -- | -- |
| Tot. nr. of individuals | 2577.0 | 1533.0 | 1267.5 | 1455.8 | 1045.6 | 811.0 |
| Nr. of identified species | 52 | 58 | 36 | 53 | 47 | 52 |

P= present, not counted

Table 11. Data L5-5, survey September 1991.
<u>Echinocardium</u> <u>cordatum</u>: Number of individuals (specimens > 1cm) in each sample (field counts)
r.c. = residual current transect ($77^0$)
p.t. = perpendicular transect

| r.c. | 25 m | 100 m | 250 m | 500 m | 750 m | 1000 m | 1500 m | 2000 m | 3000 m | 5000 m | 7500 m | 10000 m |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sample 1 | -- | -- | -- | -- | 1 | 1 | 2 | -- | 5 | 3 | 2 | -- |
| 2 | -- | -- | -- | -- | -- | -- | -- | -- | 1 | 5 | 4 | 3 |
| 3 | -- | -- | -- | -- | -- | -- | -- | -- | 5 | 5 | 3 | 3 |
| 4 | -- | -- | -- | -- | 1 | 1 | -- | -- | 2 | 5 | 8 | 3 |
| 5 | -- | -- | -- | -- | 2 | 2 | 2 | 1 | 5 | 3 | 7 | 2 |
| 6 | -- | -- | -- | -- | -- | 1 | -- | 1 | 4 | 6 | 7 | -- |
| 7 | -- | -- | -- | -- | 1 | -- | -- | 4 | -- | 2 | 8 | -- |
| 8 | -- | -- | -- | 1 | -- | -- | 1 | -- | 4 | 4 | 4 | 2 |
| p.t. 167° | | | | | | | | | | | | |
| sample 1 | | | 1 | | | | | | | 11 | | |
| 2 | | | 2 | | | | | | | 5 | | |
| 3 | | | -- | | | | | | | 6 | | |
| 4 | | | -- | | | | | | | 3 | | |
| 5 | | | -- | | | | | | | 7 | | |
| 6 | | | -- | | | | | | | 11 | | |
| 7 | | | -- | | | | | | | 1 | | |
| 8 | | | 2 | | | | | | | 5 | | |
| p.t. 257° | | | | | | | | | | | | |
| sample 1 | | | -- | | | | | | | 3 | | |
| 2 | | | -- | | | | | | | 6 | | |
| 3 | | | -- | | | | | | | 4 | | |
| 4 | | | -- | | | | | | | 3 | | |
| 5 | | | -- | | | | | | | 2 | | |
| 6 | | | -- | | | | | | | 4 | | |
| 7 | | | -- | | | | | | | 1 | | |
| 8 | | | -- | | | | | | | 3 | | |
| p.t. 347° | | | | | | | | | | | | |
| sample 1 | | | -- | | | | | | | 5 | | |
| 2 | | | -- | | | | | | | 1 | | |
| 3 | | | -- | | | | | | | 1 | | |
| 4 | | | 1 | | | | | | | 3 | | |
| 5 | | | -- | | | | | | | 1 | | |
| 6 | | | -- | | | | | | | 8 | | |
| 7 | | | 1 | | | | | | | 3 | | |
| 8 | | | -- | | | | | | | 6 | | |

Tabel 12. Data L5-5, survey September 1991
Numbers of individuals per sample (laboratory analyses)
residual current transect

| | Mysella bidentata | Montacuta ferruginosa | Echinocardium cordatum | (size in mm) |
|---|---|---|---|---|
| 25 m | | | | |
| sample 1 | 116 | -- | -- | |
| 2 | 22 | -- | -- | |
| 3 | 23 | -- | -- | |
| 4 | 33 | -- | -- | |
| 5 | 13 | -- | -- | |
| 6 | 285 | -- | -- | |
| 100 m | | | | |
| sample 1 | 20 | -- | -- | |
| 2 | 20 | -- | -- | |
| 3 | 3 | -- | -- | |
| 4 | 31 | -- | -- | |
| 5 | 11 | -- | -- | |
| 6 | 18 | -- | -- | |
| 250 m | | | | |
| sample 1 | 148 | -- | -- | |
| 2 | 48 | -- | -- | |
| 3 | 51 | -- | -- | |
| 4 | 60 | -- | 3 | (4,2,3) |
| 5 | 94 | -- | -- | |
| 6 | 52 | -- | -- | |
| 500 m | | | | |
| sample 1 | 61 | -- | -- | |
| 2 | 59 | -- | -- | |
| 3 | 54 | -- | -- | |
| 4 | 213 | -- | -- | |
| 5 | 350 | -- | -- | |
| 6 | 257 | -- | -- | |
| 1000 m | | | | |
| sample 1 | 140 | -- | (+ fragments) | |
| 2 | 150 | -- | -- | |
| 3 | 73 | -- | -- | |
| 4 | 70 | -- | 1 | (38) |
| 5 | 199 | 2 | 2 | (33,35) |
| 6 | 85 | 1 | 1 | (34) |
| 2000 m | | | | |
| sample 1 | 23 | -- | -- | |
| 2 | 18 | -- | -- | |
| 3 | 45 | -- | -- | |
| 4 | 26 | -- | -- | |
| 5 | 73 | -- | (+ fragments) | |
| 6 | 31 | 1 | 1 (+ fragm.) | (34) |
| 5000 m | | | | |
| sample 1 | 66 | 1 | 3 | (38,34,27) |
| 2 | 59 | 1 | 5 | (18,30,28,25,30) |
| 3 | 43 | -- | 5 | (35,29,40,20,18) |
| 4 | 42 | 1 | 3 | (25,25,16) |
| 5 | 104 | -- | 3 | (34,18,17) |
| 6 | 79 | 3 | 4 | (35,26,25,24) |

Table 12 (continued)
Data L5-5,survey September 1991
Numbers of individuals per sample (laboratory analyses)
perpendicular transects

| | Mysella bidentata | Montacuta ferruginosa | Echinocardium cordatum (size in mm) | |
|---|---|---|---|---|
| 250 m 167° | | | | |
| sample 1 | 302 | -- | 1 | (30) |
| 2 | 272 | -- | 2 | (30,28) |
| 3 | 136 | -- | -- | |
| 4 | 138 | -- | -- | |
| 5 | 116 | -- | -- | |
| 6 | 212 | -- | -- | |
| 250 m 257° | | | | |
| sample 1 | 42 | -- | -- | |
| 2 | 23 | -- | -- | |
| 3 | 30 | -- | -- | |
| 4 | 28 | -- | -- | |
| 5 | 34 | -- | -- | |
| 6 | 10 | -- | -- | |
| 250 m 347° | | | | |
| sample 1 | 68 | -- | -- | |
| 2 | 78 | -- | -- | |
| 3 | 87 | -- | -- | |
| 4 | 134 | 1 | 2 | (4,34) |
| 5 | 133 | -- | -- | |
| 6 | 107 | -- | -- | |

Table 13. Data L5-5, survey September 1991
Numbers per m² at each station (laboratory analyses)

| | residual current transect | | | | | | | perpend. transects | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 167° | 257° | 347° |
| station: | 25m | 100m | 250m | 500m | 1000m | 2000m | 5000m | 250m | 250m | 250m |
| Montacuta ferruginosa | -- | -- | -- | -- | 2.5 | .8 | 5.0 | -- | -- | .8 |
| Mysella bidentata | 410.0 | 85.5 | 377.5 | 828.3 | 597.5 | 180.0 | 327.5 | 980.0 | 139.2 | 505.8 |
| Echinocardium cordatum | -- | -- | 2.5 | 0.6 | 3.1 | 3.8 | 20.6 | 3.1 | -- | 1.3 |

Table 14. Boxcosms K12a , natural infauna.
Mean densities ($n.m^{-2}$) at the start of the incubation period (11.9.1990) and at the end (10.1.1991).

| | 5000 m | | 250 m | | 100 m | |
|---|---|---|---|---|---|---|
| | start | end | start | end | start | end |
| POLYCHAETA | | | | | | |
| Harmothoe lunulata | 18.3 | 8.0 | 1.4 | -- | -- | -- |
| Harmothoe longisetis | 1.4 | -- | -- | -- | -- | -- |
| Harmothoe spec. juv. | 2.8 | -- | 2.8 | -- | -- | -- |
| Sigalion mathildae | 4.2 | -- | -- | -- | -- | -- |
| Pholoe minuta | 4.2 | -- | -- | -- | -- | -- |
| Sthenelais limicola | 12.7 | -- | 5.6 | 4.0 | 1.4 | -- |
| Eteone longa | 1.4 | -- | 2.8 | -- | -- | -- |
| Anaitides groenlandica | 5.6 | -- | -- | -- | 2.8 | -- |
| Anaitides mucosa | 1.4 | -- | 1.4 | -- | -- | -- |
| Anaitides maculata | -- | -- | 1.4 | -- | 1.4 | -- |
| Anaitides spec. juv. | -- | -- | -- | -- | 1.4 | -- |
| Eumida sanguinea | 9.9 | -- | -- | -- | -- | -- |
| Ophiodromus flexuosus | 8.5 | -- | 9.9 | 4.0 | 1.4 | -- |
| Gyptis capensis | 4.2 | 2.0 | 4.2 | -- | -- | -- |
| Nereis longissima | -- | -- | 5.6 | 2.0 | 1.4 | 2.0 |
| Nereis spec. juv. | 1.4 | -- | 1.4 | -- | 7.0 | -- |
| Nephtys hombergii | 56.3 | 12.0 | 50.7 | 22.0 | 25.4 | 8.0 |
| Nephtys cirrosa | 15.5 | -- | 2.8 | 2.0 | 12.7 | -- |
| Nephtys spec. juv. | 1.4 | -- | -- | -- | 7.0 | -- |
| Glycera alba | -- | -- | -- | -- | 1.4 | -- |
| Glycera spec. juv. | -- | -- | 1.4 | -- | 2.8 | -- |
| Glycinde nordmanni | -- | -- | 1.4 | -- | 8.5 | -- |
| Goniada maculata | 7.0 | -- | 16.9 | -- | 11.3 | 2.0 |
| Lumbrineris latreilli | 157.7 | 2.0 | 167.6 | 50.0 | 167.6 | 74.0 |
| Poecilochaetus serpens | 38.0 | -- | 15.5 | -- | 22.5 | -- |
| Spio filicornis | 4.2 | -- | 4.2 | -- | 21.1 | -- |
| Spiophanes bombyx | 146.5 | 2.0 | 170.4 | 2.0 | 152.1 | -- |
| Scolelepis bonnieri | -- | -- | 1.4 | 2.0 | 4.2 | -- |
| Magelona papillicornis | 29.6 | 2.0 | 22.5 | -- | 38.0 | -- |
| Magelona alleni | 1.4 | -- | -- | -- | -- | -- |
| Chaetozone setosa | 14.1 | -- | 22.5 | -- | 5.6 | -- |
| Diplocirrus glaucus | 1.4 | -- | 1.4 | -- | 1.4 | -- |
| Notomastus latericeus | 1.4 | -- | -- | -- | 1.4 | -- |
| Lanice conchilega | 78.9 | 20.0 | 5.6 | -- | 1.4 | -- |
| Lagis koreni | 1.4 | -- | -- | -- | -- | -- |
| MOLLUSCA | | | | | | |
| Nucula turgida | 59.2 | 52.0 | 263.4 | 128.0 | 78.9 | 24.0 |
| Montacuta ferruginosa | 45.1 | 14.0 | -- | 2.0 | -- | -- |
| Dosinia lupinus | 2.8 | 4.0 | 7.0 | 4.0 | -- | 2.0 |
| Venus striatula | 2.8 | -- | 11.3 | 2.0 | 1.4 | 2.0 |
| Mactra corallina | 4.2 | 2.0 | -- | -- | 2.8 | -- |
| Spisula spec. juv. | 4.2 | -- | -- | -- | -- | -- |
| Tellina fabula | 1.4 | -- | 5.6 | -- | -- | -- |
| Abra alba | 63.4 | -- | 21.1 | -- | 4.2 | -- |
| Cultellus pellucidus | 2.8 | -- | 4.2 | -- | 2.8 | -- |
| Natica alderi | 29.6 | 26.0 | 32.4 | 14.0 | 1.4 | 8.0 |
| CRUSTACEA | | | | | | |
| Corystes cassivelaunus | -- | 2.0 | 7.0 | 4.0 | 4.2 | 2.0 |
| Upogebia spec. juv. | 1.4 | -- | 1.4 | -- | -- | -- |
| Callianassa subterranea | 202.8 | 38.0 | 70.4 | 18.0 | 25.4 | -- |
| Decapoda larven | -- | -- | -- | -- | 1.4 | -- |
| Diastylis bradyi | 2.8 | -- | 7.0 | -- | -- | -- |
| Melita obtusata | -- | -- | -- | -- | 21.1 | -- |
| Orchomenella nana | 1.4 | -- | -- | -- | 1.4 | -- |

Table 14 continued.

| | 5000 m | | 250 m | | 100 m | |
|---|---|---|---|---|---|---|
| | start | end | start | end | start | end |
| Leucothoe incisa | 21.1 | -- | 4.2 | 2.0 | -- | -- |
| Ampelisca brevicornis | 5.6 | -- | -- | -- | -- | -- |
| Ampelisca tenuicornis | 2.8 | -- | -- | -- | -- | -- |
| Ampelisca spec. juv. | 4.2 | -- | -- | -- | -- | -- |
| Bathyporeia tenuipes | 1.4 | -- | 2.8 | -- | 4.2 | -- |
| Aora typica | 4.2 | -- | -- | -- | 2.8 | -- |
| ECHINODERMATA | | | | | | |
| Amphiura filiformis | 36.6 | 2.0 | 8.5 | -- | -- | -- |
| Ophiura texturata | 2.8 | -- | -- | -- | -- | -- |
| Ophiura albida | 2.8 | -- | 2.8 | -- | 2.8 | -- |
| Ophiura spec. juv. | 8.5 | -- | 14.1 | -- | 4.2 | 4.0 |
| Echinocardium cordatum | 1869.0 | 4.0 | -- | -- | -- | -- |
| Psammechinus miliaris | -- | -- | -- | -- | 1.4 | -- |
| OTHER TAXA | | | | | | |
| Nemertinea | P | P | P | P | P | P |
| Nematoda | 1.4 | -- | -- | -- | -- | -- |
| Turbellaria | 8.5 | -- | -- | -- | 2.8 | -- |
| Phoroniden | P | P | -- | P | -- | -- |
| Harp. copepoda | 2.8 | -- | 8.5 | -- | 71.8 | -- |
| Parasitaire copepoda | 2.8 | -- | -- | -- | -- | -- |
| Oligochaeta | -- | -- | P | -- | -- | -- |
| Holothuroidea | 2.8 | -- | -- | -- | -- | -- |
| Sagitta spec. | -- | -- | 4.2 | -- | 8.5 | -- |
| Anthozoa | -- | 8.0 | -- | -- | -- | -- |
| Tot. number of ind. | 3032.0 | 200.0 | 996.7 | 254.0 | 741.9 | 124.0 |
| Nr. of identified species | 46 | 23 | 35 | 21 | 34 | 10 |

P= present, not counted

Table 15. Locations investigated between 1985 and 1991.

| Location | Position | Drilling activities | Area | Survey | Remarks | Report |
|---|---|---|---|---|---|---|
| P6b | 52°42'?''N 03°50'?''E | 1 well, drilled with low-tox OBM with high aromatic content; drilled in April-June'85 | Erosion zone, sand silt fraction (<63 μm) < 1% | Sept.'85 | | Mulder et al., 1987 |
| F18/8 | 54°05'30''N 04°59'15''E | 1 Well drilled with WBM in April 1986 | Sedimentation area, silt fr. 10 - 20% depth 40 m. Deserted location | May/June '86 | | Mulder et al., 1987 |
| L4a | 53°43'40''N 04°06'15''E | Previous drilling with WBM in Jan.'85; drilling of 2 wells in Aug.-Oct. 1986 with low-aromatic OBM; tot. emission: 912 tonnes. OBM: 555 tonnes; oil:178 tonnes | Transition zone, fine sand with silt (≈ 15%) depth 35 m. Platform present | May '86 | 'Baseline' (only WBMs discharged) | Mulder et al., 1988 |
| | | | | Sept.'86 | Drilling not yet finished | Mulder et al., 1988 |
| | | | | Febr.'87 | | Daan et al., 1990 |
| | | | | June'87 | Additional photo-survey (Sept.'87) | Daan et al., 1990 |
| K12a | 53°28'36.2''N 03°47'19.4''E | 5 Wells drilled diesel and low-tox OBM, between Febr.'83 and Nov.'84: tot. emission: 2278 tonnes. OBM: 1082 tonnes; oil: 393 tonnes | Transition zone, fine sand with silt (5 - 10%) depth 28 m. Platform present | Sept.'85 | | Mulder et al., 1987 |
| | | | | Sept.'86 | | Mulder et al., 1988 |
| | | | | Sept.'87 | Additional photo-survey 4 boxcosms | Daan et al., 1990 |
| | | | | Sept.'88 | | Daan et al., 1990 |
| | | | | Sept.'90 | 6 boxcosms | This report |
| F18/9 | 54°06'09.8''N 04°45'25.1''E | 1 Well drilled with OBM in May'87; tot. emission: 1912 tonnes; OBM: 819 tonnes; oil: 283 tonnes | Sedimentation area, silt (10 - 20%); depth 42 m. Deserted location | June'88 | 17 boxcosms (collected Sept.'88) | Daan et al., 1990 |
| L5-5 | 53°48'33.1''N 04°20'54.4''E | 1 Well drilled with low-aromatic OBM, July-Nov. 1988; tot. emission: 1347 tonnes. WBM: 308 tonnes; OBM: 148 tonnes; oil: 44 tonnes | Transition zone, fine sand and silt (≈15 %), depth ≈41 m), Deserted location | May '89 | 14 boxcosms (collected Sept.'89) | Daan et al., 1991 |
| | | | | April '90 | | This report |
| | | | | Sept. '91 | | This report |

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