EFFECTS OF BEAMTRAWL FISHERY ON THE BOTTOM FAUNA IN THE NORTH SEA

II - THE 1990 STUDIES

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TABLE OF CONTENTS

TABLE OF CONTENTS

page

SUMMARY/CONCLUSIONS/RECOMMENDATIONS
SAMENVATTING/CONCLUSIES/AANBEVELINGEN

SUMMARY

In 1989, BEON carried out a study of the direct effects of beam trawling on the benthic system of the southern North Sea. Results of the study were published in BEON report no. 8 (1990). In August 1990 research into the effects of beam trawling was continued by the following members of BEON: the North Sea Directorate (DNZ) of the Ministry of Transport and Public Works, the Netherlands Institute For Fisheries Investigations (RIVO), the Marine Geology Department of the National Geological Service (RGD), the Delta Institute for Hydrobiological Research (DIHO) and the Netherlands Institute for Sea Research (NIOZ). Three studies were carried out to answer the following questions:

Study no. 1: To what depth does commercial beam trawling disturb the sediment (penetration depth of the fishing gear)?

Study no. 2: What is the survival rate for benthos and fish after being caught in a beam trawl or after escaping through the meshes?

Study no. 3: Have years of beam trawling had a significant effect on the benthic system?

Studies nos. 1 and 2 were a continuation of the research carried out in 1989; study no. 3 concerned a new subject.

Study no. 1 (penetration depth of the beam trawl) was performed a few hundred metres southwest of the site selected for the 1989 study in ICES quadrant 36F5, some 45 km north of Ameland (central position 53°51'28" N, 5°48'29" E). In this area, where the seaflor consists of fine sandy sediment, a commercial beamtrawler (length: 41 m, 1600 kW) made a single haul with its beam trawls lowered to either side, passing between two buoys located close together. The precise location of the path of the trawl was verified using side-scan sonar. Subsequently, bottom samples were taken by the research vessel Mitra within a few hours after trawling, eight samples from within the tracks of the trawl and five samples from a transect 100 m south of it.
A number of side-scan images of the seafloor were also made before the passage of the trawl and some time afterwards. The r.v. "Mitra" was equipped with a very precise position-finding device combined with a computer-controlled dynamic positioning system. The bottom samples were processed and preserved on board. The penetration depth of the beam trawls was determined by comparing sediment structures, chemical and physical parameters and the vertical distribution of the benthic organisms in the samples taken from the sediment inside and outside the trawl tracks.

Study no. 2 (survival rate of benthos and fish in the beam trawl) was carried out in the hard sandy area where the corresponding study had been carried out in 1989: in ICES quadrants 36F5 (northern half) and 37F5 (southern half), 45 to 90 km north of Ameland. Catches from a commercial beam trawler, equipped for sole fishing north of 53° N, were sorted and the species identified. The condition of the various species of benthos and fish was determined. Live animals were used to perform survival studies on board to ascertain what percentage survived for 24 or 48 hours.
The species composition and the condition of the animals caught with a normal sole net, with ten tickler chains, were compared with those from a net without tickler chains. In order to establish the survival rate of benthos and fish escaping through the meshes, a fine mesh outer net was placed around the commercial beam trawl. The survival of animals that had escaped through the meshes of the trawl and were found still alive inside the outer net was estimated over a period of 24 to 48 hours.

Study no. 3 (long-term effects of beam trawling) was carried out in and around "Borkum Reef", in ICES quadrant 37F5, about 60 km north of Ameland. Borkum Reef, which covers a surface area of several hundred square kilometres, is an end moraine from the Saalian ice age. In this sandy area, the presence of rocks hampers beam trawling, and therefore the area is less intensively fished. The area in and around the Borkum Reef is regarded as one of the few areas in the North Sea where research can be carried out into possible long-term effects of beam trawling. Before the actual study started, side-scan sonar images of part of Borkum Reef were taken from r.v. Mitra. In the scanned area, a transect was sampled close to the gravel and rock deposits which had been observed. Transects to the north and south of the Reef, situated in areas which are more frequently fished, were also sampled. Ten samples were taken from each transect to enable the composition of the benthic communities (meiofauna, macrofauna and fish) on the less fished Reef to be compared with those in the two fished areas. The effectiveness of a newly developed benthos dredge in sampling large-sized macrobenthos species, often occurring in low densities, was also tested.

CONCLUSIONS

-The side-scan sonar is very suitable for detecting and mapping trawl tracks. The tracks remain visible in the hard-sand sediment for up to 12 hours after trawling under windforce conditions of less than 4 Bf.

-Very high-quality position-finding equipment (such as Hyperfix) linked to a computer-controlled positioning device is indispensable for research of the kind carried out in Studies no. 1 and 3.

-The Towed Underwater Camera (ROV) makes it possible to take underwater pictures of fishing gear in action at relatively low fishing speeds (9-12 km.h^{-1}). The shoes and the first two tickler chains are clearly visible. The third and fourth tickler chain are only partially visible on hard sediment. The other chains are hidden by the sediment thrown up by previous chains.

-In spite of the very good position-finding and positioning equipment, it appeared to be impossible to sample with certainty inside the trawl track. The parallel stratification which was clearly visible in some of the profiles indicated that 3 of the 8 samples must have been taken from outside the trawl track. In future studies, the position of the bottom sampler will need to be determined with even greater accuracy.

-On account of the almost complete absence of visible structures on the X-ray photographs due to the use of a liner with too great a diameter (7 cm), it was impossible to draw conclusions about the effectiveness of x-ray photography to determine the penetration depth of the beam trawl.

-Differences in the distribution of the median grain size inside and outside the trawl track indicate disturbance of the sediment by fishing gear.

-The results of analysis of sediment structures, such as parallel stratification, particle size distribution, reciprocal formation factor, porosity and vertical distribution of foraminifers and meiofauna, indicate that the beam trawl disturbs the hard-sand sediment to a depth of at least 4-8 cm.

-The methods which were applied during this project, are not suitable for determination of the exact penetration depth, due to a lack of knowledge about the sediment at one and the same location before and after trawling and/or the absence of a reference stratum in the sediment.

-In studies of the composition of catches, it is necessary to distinguish between biomass (weight) and numbers of animals. In terms of biomass, the catches from the sole net with tickler chains consisted of 65% fish and 35% benthos; in terms of numbers they consisted of 35% fish and 65% benthos. Most (80-90%) of the benthos were echinoderms (starfish).

-In terms of weight, 60-70% of the fish were undersized; in terms of numbers, 85-90%. Most of the undersized fish (90%) were dab or plaice.

- The net with tickler chains caught about twice as much fish and benthos as the net without them. The catch of sole was four times higher in the net with tickler chains.

- Fish escaping through the meshes have a high chance of survival: at least 80-90%. Smaller species (such as dragonet, solenette and lesser weever) may consequently have become relatively more abundant as a result of intensive fishing.

- Fish in commercial catches have a very low chance to survive. For most species, the survival chance of discards thrown back into the sea is 0%. Literature indicates that the chance to survive for one or two stronger species (sole and plaice) could be at best 10%; most of the survivors are presumably specimens which have entered the net shortly before it is hauled in.

- The chance to survive for benthos which is returned to the sea after the catch have been processed, can be summarized as follows: for molluscs and crabs 40% at best, for starfish at least 70-80%, and for whelks and hermit crabs approximately 100%.

- Sole fishing produce quite a lot of dead organic material (mainly dead fish and a small proportion of dead benthos): approx. 0.1-0.2 g ash-free dry weight per m^2 per haul. Seabirds and starfish may derive some benefit from this food source.

- The "CANOCO" analysis was found to be a suitable method for determining the contribution of particular environmental factors to the species composition of the benthic fauna (macrofauna and fish).

- Sediment characteristics such as grain size and silt content are the dominant factors in determining the species composition of the macrobenthic infauna in and around Borkum Reef; to a lesser extent this also applies to the species composition of macrobenthic epifauna and fish.

- In this project, it was not possible to demonstrate that any significant differences in species composition existed in the meiofauna, macrobenthos, (infauna and epifauna) or fish which could clearly be attributed to long-term beam trawling.

- The differences in species composition which were found - albeit not significant - point to lower densities of molluscs (Corbula gibba, Natica alderi, Ensis spec., Tellina fabula), crustaceans (Corystes, Thia) and worms (e.g. Pectinaria) in the areas which had been fished more intensively.

- The sediment sampler and the 2.80 m beam trawl are not suitable for obtaining quantitatively reliable samples of the larger molluscs, crustaceans and echinoderms, which tend to occur in lower densities. The benthos dredge seems a more suitable instrument to measure the distribution of these species.

RECOMMENDATIONS

- The techniques for measuring the penetration depth of fishing gear described here yield relevant information, but in order to determine exact depths other methods (e.g. the use of divers) are needed.

- In the follow-up research, survival studies should also be carried out at lower water temperatures and with beam trawls equipped for plaice fishing.

- Because of the smaller grain size and the higher silt content in the area to the south of Borkum Reef, this area should be excluded from follow-up research into long-term effects of beam trawling on the benthic system in and around Borkum Reef.

- A benthos dredge seems more effective than a sediment sampler or a 2.80 m beam trawl for the purpose of sampling larger benthic species, which are sensitive to beam trawling.

- In order to avoid the areas inside Borkum Reef (and inside similar rocky areas) which are still fished, more information is needed about the exact position of large rocks which hamper commercial beam trawling .

- Uncertainty remains regarding the fishing intensity, both in such rocky areas and in the surrounding normally fished areas. The long-term effects of beam trawling on the North Sea ecosystem can only be definitely determined if fishing is prevented in a large area, representative for beam trawling areas. The development of the benthic system (sediment characteristics, meiofauna, macrofauna and fish) in such an area, closed to fishing, and in a comparable area where fishing still takes place, should be studied for between ten and twenty years.

SAMENVATTING

In 1989 is door het BEON onderzoek uitgevoerd naar de directe effecten van boomkorvisserij op het benthische systeem van de zuidelijke Noordzee. De resultaten van deze studie zijn gepubliceerd in BEON-rapport 8 (1990). In augustus 1990 hebben de BEON-leden Ministerie van Verkeer en Waterstaat/Directie Noordzee (DNZ), Rijks instituut voor Visserij Onderzoek (RIVO), Rijks Geologische Dienst/Afdeling Mariene Geologie (RGD), Delta Instituut voor Hydrobiologisch Onderzoek (DIHO) en het Nederlands Instituut voor Onderzoek der Zee (NIOZ) het onderzoek naar de effecten van de boomkorvisserij gecontinueerd. Binnen dit project is een drietal studies uitgevoerd met de volgende vraagstellingen:

Studie 1: Tot welke diepte omwoelt de commerciële boomkor het bodemsediment (penetratie diepte van het vistuig).

Studie 2: Hoe groot zijn de kansen van benthos en vis om te overleven na de vangst in de boomkor of na de ontsnapping via de mazen.

Studie 3: Zijn effecten van jarenlange boomkorvisserij op het benthische systeem aantoonbaar.

Studie 1 en 2 zijn uitbreidingen van het in 1989 uitgevoerde onderzoek; de derde studie is in 1990 voor het eerst uitgevoerd.

Studie 1 (penetratie diepte van de boomkor) werd uitgevoerd enkele honderden meters ten zuidwesten van het in 1989 gekozen onderzoeksgebied in ICES quadrant 36F5, ca. 45 km ten noorden van Ameland (centrale positie 53°51'28" N en 5°48' 29" E). In dit gebied met fijnzandig sediment werd door een commerciële boomkorkotter (lengte 41 m - 1600 kW) varend tussen twee dicht bijeenliggende boeien een dubbel visspoor getrokken.
Na verifiëring van de precieze lokatie van het visspoor m.b.v. side-scan sonar werden, binnen enkele uren na de bevissing, in het visspoor en 100 m ten zuiden van het spoor 8 resp. 5 bodemhappen genomen vanaf O.V. "Mitra". Ook vooraf-gaand aan en enige tijd na de bevissing werden nog enkele side-scan opnamen gemaakt. De O.V. "Mitra" was uitgerust met zeer nauwkeurige plaatsbepalingsapparatuur, in combinatie met een computergestuurd dynamisch positioneringssysteem. De bodemhappen werden aan boord verder bewerkt en geconserveerd. De penetratiediepte van de boomkor werd in het laboratorium vastgesteld door vergelijking van sedimentstructuren, chemisch/fysische parameters en verticale *verspreiding van de bodemorganismen in de* bodemhappen genomen binnen en buiten het visspoor.

Studie 2 (overlevingskansen van benthos en vis in de boomkor) werd uitgevoerd in het hardzandige gebied waar deze studie in 1989 ook werd uitgevoerd: in ICES quadranten 36F5 (noordelijke helft) en 37F5 (zuidelijke helft), 45 tot 90 km ten noorden van Ameland. De vangsten van een commerciële boomkorkotter, uitgerust voor de tongvisserij benoorden 53°, N, werden uitgezocht en op soort gebracht. Van de aangetroffen soorten benthos en vis werd de konditie vastgesteld. Levende dieren werden aan boord in overlevingsexperimenten ingezet, zodat de overleving na 1 à 2 etmalen kon worden bepaald. Tevens werd de samenstelling en de konditie van de vangsten vergeleken in boomkorren uitgerust met verschillende aantallen wekkerkettingen. Om ook de overlevingskansen van via de mazen ontsnapte benthos en vis te bepalen werd gevist met een fijnmazige omhullingskuil rondom het net van de commerciële boomkor.
De overleving van de via de mazen van de boomkor ontsnapte en levend in de omhullingskuil aangetroffen soorten benthos en vis werd aan boord bepaald in overlevingsexperimenten met een duur van 1 à 2 etmalen.

Studie 3 (lange termijn effecten van boomkorvisserij) werd uitgevoerd in en rond "Borkum Rif" in ICES quadrant 37F5, ca. 60 km ten noorden van Ameland. Borkum Rif met een totaal oppervlak van enkele 100^den^ km² is een eindmorene van de Saalien ijstijd. In dit zandige gebied wordt de boomkorvisserij gehinderd door de aanwezigheid van stenen en daarom wordt dit gebied minder intensief bevist dan de omliggende gebieden. Het gebied in en rond Borkum Rif wordt beschouwd als een van de weinige gebieden op de Noordzee waar onderzoek naar mogelijke lange termijn effecten van boomkorvisserij uitgevoerd kan worden. Voorafgaand aan het onderzoek werden van een deel van Borkum Rif opnamen m.b.v. side-scan sonar gemaakt vanaf O.V. Mitra. In dit gescande gebied werd een raai uitgezet nabij de waargenomen grind- en stenenafzettingen. Ten noorden en ten zuiden van het Rif in het normaal beviste gebied werd eveneens een raai gelegd.
Op iedere raai werden 10 bemonsteringen uitgevoerd om de samenstelling van de bodemgemeenschappen (meio-, macro- en visfauna) in het onbeviste Rif te kunnen vergelijken met de soortensamenstelling in de beviste gebieden ten noorden en ten zuiden van het Rif. Tevens werd de bruikbaarheid van een nieuw ontwikkelde bodemschaaf als bemonsteringsapparaat van groter en schaarser voorkomend macro benthos getest.

CONCLUSIES

- De side-scan sonar is zeer geschikt voor het opsporen en in kaart brengen van vissporen; tot 12 uur na de bevissing blijven de sporen in het hardzandige sediment herkenbaar (bij niet te veel wind, minder dan 4 Bf).

- Plaatsbepalingsapparatuur van zeer hoge kwaliteit (bijv. Hyperfix) gekoppeld aan computergestuurde positioneringsapparatuur is onmisbaar voor onderzoek zoals in studies 1 en 3 is beschreven.

- De gesleepte onderwater camera (ROV) maakt het bij vissnelheden van 9-11 $km.h^{-1}$ mogelijk onderwateropnamen van vistuigen in aktie te maken. De sloffen en eerste twee wekkerkettingen van de boomkor zijn duidelijk zichtbaar. De derde en vierde wekkerketting zijn alleen op harde bodem gedeeltelijk waarneembaar. De andere kettingen zijn door het opgewervelde sediment aan het oog onttrokken.

- Ondanks de zeer goede plaatsbepalings- en positioneringsapparatuur blijkt het onmogelijk met zekerheid in een visspoor te monsteren. De aanwezigheid van parallelle gelaagdheid, die goed zichtbaar was in een aantal lakprofielen, gaf aan dat 3 van de 8 monsters naast het visspoor moeten zijn genomen. Bij volgend onderzoek zal de bepaling van de plaats waar de bodemhapper terecht komt nog nauwkeuriger moeten zijn.

- Door het nagenoeg ontbreken van zichtbare structuren op de röntgenfoto's door het gebruik van een te brede (ϕ 7 cm) liner bleek het niet mogelijk conclusies te trekken over de bruikbaarheid van röntgenfotografie bij de bepaling van de penetratiediepte van de boomkor.

- Verschil in spreiding in mediane korrelgrootte binnen en buiten het visspoor wijst op omwoeling van het sediment door vistuigen.

- De resultaten t.a.v. de bepaling van parallelle gelaagdheid, korrelgrootte verdeling, reciproke formatie factor, porositeit en verticale verdeling van foraminiferen en meiofauna geven aan, dat de boomkor het hardzandige sediment tot op een diepte van tenminste 4-8 cm verstoort.

- Exacte penetratiediepten zijn met de tijdens dit onderzoek gebruikte methoden niet vast te stellen door het ontbreken van kennis omtrent het sediment op exact dezelfde plaats vóór het vissen en/of het ontbreken van een referentie laag in het sediment.

- Bij de bepaling van de samenstelling van de vangsten dient onderscheid gemaakt te worden tussen *biomassa's* (*gewichten*) *en aantallen* dieren. In biomassa bestonden de vangsten van het tongennet met wekkers uit 65% vis en 35% benthos, in aantallen bestond de vangst uit 35% vis en 65% benthos. Het benthos bestaat grotendeels (80-90%) uit echinodermen (zeesterren, kamsterren, slangsterren).

- In gewicht was 60-70% van de vis ondermaats, in aantal 85-90%. De ondermaatse vis bestond voor 90% uit schar en schol.

- Het net met wekkers ving ongeveer dubbel zoveel vis en benthos als het net zonder wekkers. In het net met wekkers was de vangst van tong verviervoudigd.

- Vissen die door de mazen van het net ontsnappen hebben een grote overlevingskans, tenminste 80-90%. Kleinere vissoorten (zoals pitvis, dwergtong en kleine pieterman) kunnen door de intensieve visserij daardoor relatief talrijker zijn geworden.

- De vissen in de commerciële vangsten hebben een zeer lage overlevingskans. Voor de meeste soorten is de overlevingskans van discards die terug gaan in zee 0%. Uit de literatuur blijkt dat voor enkele sterkere soorten (tong en schol) de overlevingskans ongeveer 10% kan zijn, vermoedelijk betreft het dan vooral vissen die pas kort voor het "halen" in het net gekomen zijn.

- De overlevingskans van gevangen benthos, dat na de vangstverwerking wordt teruggezet in zee, kan globaal omschreven worden als: voor schelpdieren en krabben hoogstens 40%, voor zeesterren en kamsterren tenminste 70-80% en voor wulken en heremieten ongeveer 100%.

- De tongvisserij produceert vrij veel dood organisch materiaal (voornamelijk dode vis en een gering deel dood benthos): ongeveer 0.1-0.2 g asvrij drooggewicht per m^2 per trek. In ieder geval zullen zeevogels en zeesterren (mogelijk ook kamsterren en slangsterren) hiervan kunnen profiteren.

- De "CANOCO"-analyse blijkt een geschikte methode om de bijdrage van bepaalde omgevings factoren aan de soortensamenstelling van de bodem fauna (macro- en visfauna) te bepalen.

- Sedimentkarakteristieken als korrelgrootte en slibgehalte blijken in en rond Borkum Rif de dominante factor te zijn m.b.t. de soortensamenstelling van de macrobenthische infauna; in mindere mate geldt dit ook voor de soortensamenstelling van macrobenthische epifauna en vis.

- In dit onderzoek konden geen significante verschillen in *soortensamenstelling* van *meiofauna*, van macrobenthische in- en epifauna en van vis worden aangetoond, die aan langdurige boomkorbevissing moeten worden toegeschreven.

- De in dit onderzoek aangetoonde, overigens niet significante verschillen in soortensamenstelling wijzen op geringere dichtheden mollusken (Corbula gibba, Natica alderi, Ensis spec., Tellina fabula), crustaceeën (Corystes, Thia) en wormen (bijv. Pectinaria) in de meer intensief beviste gebieden.

- De bodemhapper en de 2.80 m boomkor zijn niet geschikt om kwantitatief betrouwbaar de veelal in geringere dichtheden voorkomende, grotere mollusken, crustaceeën en stekelhuidigen te bemonsteren. De bodemschaaf lijkt beter geschikt om de verspreiding van deze mogelijk voor boomkorvisserij gevoelige soorten te bepalen.

AANBEVELINGEN

- De hier gebruikte technieken om de penetratie diepte van vistuigen te meten geeft relevante informatie, voor het vaststellen van exacte diepen zijn echter andere methodieken (bijv. het gebruik van duikers) noodzakelijk.

- In het vervolgonderzoek zullen de overlevingsstudies ook bij lagere watertemperaturen en met boomkorren uitgerust voor de scholvisserij moeten worden uitgevoerd.

- Vanwege de geringere korrelgrootte en het hogere slibgehalte moet het gebied ten zuiden van Borkum Rif niet betrokken worden bij vervolg onderzoek naar lange termijn effecten van boomkorvisserij op het benthisch systeem in en rond Borkum Rif.

- Een bodemschaaf lijkt beter bruikbaar bij de bemonstering van voor de boomkorvisserij gevoelige grotere benthossoorten dan een bodemhapper of een 2.80 m boomkor.

- Meer informatie over de exacte ligging van grote stenen, die de commerciële boomkorvisserij verhinderen, is noodzakelijk om de wel beviste deelgebieden in Borkum Rif en soortgelijke stenengebieden met grotere zekerheid te vermijden.

- Onzekerheid over de mate van bevissing zowel van dergelijke stenengebieden als de omringende normaal beviste gebieden blijft echter bestaan. De lange termijn effecten van boomkorvisserij op het Noordzee ecosysteem kunnen alleen met zekerheid worden vastgesteld, wanneer visserij in een groot voor boomkorvisserij representatief gebied wordt uitgesloten. De ontwikkeling van het benthisch systeem (*sedimentkarakteristieken, meio-*, macro- en visfauna) in dit voor de visserij gesloten gebied en in een vergelijkbaar bevist gebied zal gedurende 10 à 20 jaar bestudeerd moeten worden.

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The projectgroup as a whole is responsible for the summary, conclusions and recommendations.

1. INTRODUCTION (ed. S.J. de Groot)

In 1989 a concerted action was initiated by researchers of the Netherlands Institute for Fisheries Research (RIVO-DLO), the Ministry of Transport and Public Works - North Sea Directorate (RWS-DNZ) and Directorate Tidal Waters (RWS-DGW) and the Netherlands Institute for Sea Research (NIOZ). Institutes that co-operate in the BEON-programme (policy linked ecological research in the North Sea and Wadden Sea). The first results of the action were reported in 1990 in the BEON-report nr. 8 (1989-programme). Since then two other institutes joined the programme, the Netherlands Geological Survey - Marine Geology Division (RGD/EZ) and the Delta Institute for Hydrobiological Research of the Academy of Sciences (DIHO). The underlying thought of the present concerted action is that since ICES (International Council for the Exploration of the Sea) reported in the mid-seventies on the effect of trawling on the seabed and benthic life, much has changed in the Dutch fishery fleet in relation to number of vessels, size of vessels and weight of gears. It was assumed that the increase in weight of bottomgears would result in a same increase in effects not withstanding the actual pressure of the gear towed along the bottom hardly increased due to the increase of fishing speed. A literature study, initiated by RWS-DNZ and RIVO-DLO, preceded the present investigations- "Literature study into the effects of demersal fishery on the bottom and benthic life" (in Dutch), by H.C. Welleman (RIVO-DLO report MO 89-201). The present investigations limit themselves to the effects of the heavy Dutch flatfishbeamtrawl. It is fully understood that the smaller beamtrawl (e.g. used by the Belgian fleet) and shrimp-beamtrawl, the ottertrawl, bottom pairtrawl and clam, cockle and mussel-dredges, all have their specific effects and are omitted from our programme. This is due to lack of funding and manpower. Funding by the EC (DG14-FAR-programme) will partly overcome this problem. The ottertrawl will also be studied, as well as the smaller beamtrawl. Also other institutes, of other countries will participate in the programme (Belgium, Germany, U.K.). The 1990-studies were carried out from 20-31 August near the Borkum Riff with a commercial beamtrawler (1600 kW/2200 HP) chartered for RIVO-DLO by the Ministry of Agriculture, Nature Management and Fishery - Fisheries Directorate and R.V. "Mitra" (RWS-DNZ). The report constitutes of a technical description and the reporting on the 3 main studies, dealing with the question of how a gear penetrates into the bottom (study 1), the survival of benthos, fish and fish-bycatch during their stay in the codend during trawling (study 2) and the longterm effects of trawling on the benthic ecosystem respectively (study 3). The members of the BEON-Working Group "Effects of Fishing on Benthos" are fully aware that several others contributed substantially to the present results. Those not mentioned are herewith acknowledged, but also by name the following :
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2. GENERAL INFORMATION AND METHODS (ed. J.S. Sydow)

As mentioned in the introduction three studies were carried out in the period 20-31 August 1990.

2.1. Study 1: Penetration depth

Study on penetration of beamtrawls into the bottom was carried out on a location very near to the location of 1989 in the ICES-quadrant 36F5, 45 km north of Ameland with the geographical co-ordinates:

53° 51' 28" N, 5° 48' 29" E (Fig. 0.1)

Two ships were involved in this experiment: r.v. "Mitra" (Fig. 0.2) which carried out bottom surveys and bottom sampling and a commercial beamtrawler of 1600 kW (2200 HP) for fishing. R.V. "Mitra" was equipped with apparatus as mentioned in Fig. 0.2, the commercial beamtrawler with two standard beamtrawls for sole-fishing. The study was carried out in the period 20-24 August 1990.

2.1.1 Mitra-report

Monday and Tuesday (20 -21 August) wind was too strong (W-NW, 7-8 Bf) for working. On Wednesday (22 August) wind slacked to force 6-4 Bf and r.v. "Mitra" departed in the afternoon (16.00 hr) to the experimental area with 5 scientists of the Netherlands Institute for Sea Research (NIOZ) on board and 2 scientists of the Netherlands Geological Survey (RGD). Weather conditions on Thursday (23 August) were: wind direction north, force 3-4 Bf, wave-height of ca 125 cm and NW swell. Under these circumstances the study started with a check of accuracy of the Hyperfix-position at the TE5 Lt-buoy. At 6.30 hr two reference-buoys were dropped near the position 53°51'29.56" N and 5°48'31.55" E, with a distance between the buoys of 100 m in N/S-direction. R.V. "Mitra" started with 3 side scan sonar surveys of the seabottom over a distance of 450 m and a range of 100 m (situation before trawl fishing, Fig. 0.3). At ca 8.00 hr the commercial trawler fished between the two reference buoys. Immediately after trawling r.v. "Mitra" made a side scan sonar survey of the trawl marks on a Sonagram (Fig. 0.4 and 0.5), followed by some limited investigations with the Remote Operated Hoisted Platform (ROHP, an underwater inspection system), in order to ensure that the position of r.v. "Mitra" was in the trawl tracks. Video images, taken by video camera mounted on the ROHP, were very poor due to an electronic interference. However, the trawl marks could be seen pretty good on MESOTECH-sonar mounted on the ROHP. A photograph taken from the MESOTECH-sonar recording is shown in Fig. 0.8. After these observations of bottom structure 8 samples were taken with a boxcorer in the trawl marks. These boxcore samples were investigated by scientists of NIOZ and RGD. Seven hours after trawling side scan sonar surveys were carried out again by r.v. "Mitra" (Fig. 0.6). Afterwards 5 boxcore samples were taken on an undisturbed site 100 m south of the fishing area. Fig. 0.9 shows the sample positions in- and outside the trawl mark. After 12 hours a final side scan sonar survey was carried out parallel to the trawl marks to see what was left of the bottom surface disturbances (Fig. 0.7).

Side scan sonar recordings (SMS)

The Seafloor Mapping System (SMS) uses a high frequency 100 KHz sound beam to create a picture of the seafloor. An underwater towed fish emits short high frequency "sound bursts" which are sharply beamed on either side of the fish in a direction perpendicular to the direction of travel. On board r.v. "Mitra" a dry graphic/digital recorder converts the incoming data from both channels, after several automatic corrections such as for slant range, speed, depth, etc., into an acoustic picture of the seabed. The SMS-fish operates about 50 m behind the r.v. "Mitra" and was towed approximately 12-18 meters above the seabed, a distance necessary for obtaining good sonar recordings. Longitudinal transects were sailed along the "cable route" using ranges of 100 m per channel. Sonar recordings were continuously evaluated at the recorder and data were stored on tape, to be used for onshore processing and scaling to obtain compositions of sonar of the seabed (mosaics). Unfortunately rough weather conditions (increase of swell) influenced the recording quality.
The side scan sonar surveys of the situation before, immediately after, 7 hours after and 12 hours after beamtrawling were carried out with a swell of ca 125 cm. Fig. 0.3 presents a sonar picture of the sea-floor before trawl fishing. Figures 0.4 and 0.5 show the situation immediately after fishing. Fig. 0.6 shows the situation 7 hours after trawling and Fig. 0.7 the situation 12 hours after trawling. In the side scan sonar-image of the situation immediately after beam trawling the trawl marks can be seen clearly, especially in the more detailed image in Fig. 0.5. From the picture made 7 hours after trawl fishing appears that the marks begin to fade, while in the picture taken 12 hours after trawling the marks had nearly disappeared.

2.1.2 Commercial trawler-report

Monday and Tuesday (20-21 August), with bad weather, were used for installation and testing of the underwater video camera. Wednesday (22 August) was used for some measurements of resistance-experiments of the gear over the bottom for different linelength ratios. On Thursday (23 August) the trawler fished for the penetration depth-study mentioned above under normal fishing conditions (ratio warp-depth: 5:1, speed 7 knots, low tidal current (neaptide)).
The standard gear of the vessel (double beam) was used, total weight (in air) of each gear = 7 tonnes. The tickler chain array was already used for half of its lifespan (about 85% of its original weight). The weight per gear was about 5400 kg in water. Due to the vertical component of pullforces by the warp this resulted in a true weight of each gear on the bottom of 3200 kg. The subdivision for this figure was 750 kg for groundrope and light tickler chains, 1300 kg for the tickler chains (0.11 kg/cm^2) and 1150 kg for two trawl shoes (0.17 kg/cm^2). Photographs of the fishtrawl, shoes, towed vehicle, tickler chains and transportbelt are shown in Fig. 0.10.
An underwatercamera mounted on a remote operated vehicle (ROV) was used to observe the fishing gear performance. The camera is mounted on a vehicle which is manoeuverable by magnusrotors in the horizontal and vertical plain. The vehicle was towed, via the derrick, by the fishing vessel with a maximum operation speed of 5 knots, in fact too low compared with *normal fishing speeds of 7 knots. The trawl shoe, the first tickler chain and the clouds of stirred* sediments (dust clouds) could clearly be observed (Fig. 0.10). The third and fourth tickler chain could only be seen partially, and only on hard bottom. It was observed that the first chain touches the bottom lightly. Good pictures were obtained with the low light-camera 1.5 hour after sunrise at a depth of 30 m without illumination and a full cloud cover.

2.2. Study 2: Survival of fish and benthos

Survival experiments, in combination with discard investigations, were carried out in the same hard sandy area as in 1989: ICES quadrants 36F5 (northern half) and 37F5 (southern half), 45-90 km north of Ameland. The measurements were carried out on board of the commercial beamtrawler, which was equipped with the standard fishtrawl, transportbelt and sorting table. In the week of 27-31 August 1990 survival experiments were carried out in combination with investigations of discard fish. The starboard gear was fully rigged while the port gear was used without tickler chains.

2.3. Study 3: Long term effects

The study of the longterm effects of trawling in the benthic ecosystem was carried out in and around an area known as Borkum Riff in ICES-quadrant 37F5, 60 km north of Ameland (Fig. 0.1). The seabottom in the Riff contains a lot of stones varying in sizes from some millimeters up to blocks of some tonnes. The selected side scanned area (triangle) has the following geographical coördinates:

54° 0' 45.46" N, 5° 58' 22.40" E
54° 2' 54.91" N, 5° 58' 31.63" E
54° 3' 03.20" N, 5° 52' 51.46" E

The geographical co-ordinates of the transects (Fig. 0.1) are:

Riff:

start	54° 01' 13"	N, 5° 58' 36"	E
end	54° 03' 27"	N, 5° 54' 60"	E

North of Riff:

start	54° 06' 46"	N, 5° 58' 13"	E
end	54° 08' 15"	N, 5° 54' 04"	E

South of Riff:

start	54° 00' 24"	N, 5° 56' 49"	E
end	54° 01' 57"	N, 5° 52' 41"	E

In the area no (known) wrecks, obstacles and pipelines could be found. Only an abandoned telephone cable crosses the southern part of the triangle. This study was carried out by r.v. "Mitra" which was equipped with the apparatus as mentioned in Fig. 0.2. Some weeks before the start of this experiment r.v. "Mitra" carried out a side scan sonar survey of this part of Borkum Riff. The result of the scanning is shown in Fig. 0.11.
The study was carried out in the period 27-30 August 1990. On Monday (27 August) r.v. "Mitra" departed from Scheveningen harbour at 12.00 hr, after preparation of a benthos dredge (an experimental system to collect slice samples of the bottom while the gear was towed by r.v. "Mitra"), a 3 m-beamtrawl and the REINECK-boxcore of NIOZ. North of Vlieland the benthos dredge was tested and seemed to operate reasonably well. In the morning of Tuesday (28 August) the Hyperfix positioning was checked at the wave-measuring station in the Wierumer grounds. At 8.30 hr r.v. "Mitra" arrived at the area of investigations to make the first surveys in an area without stones on the southwest side of the Borkum Riff-border, at a distance of about 1500 m in the direction 300°-120° and a length of 5000 m (transect nr. 100, Fig. 0.12). During the morning the benthos dredge was tested and this time the dredge did not function well. After consultation, the 3 m-beamtrawl was used instead of the benthos dredge, in tows of 300 m. After fishing 10 hauls of the transect South of the Riff boxcore samples were taken in the middle of each haul (Figures 0.12 and 0.13). In the afternoon the Hyperfix became unreliable and it was decided to use the Autocarta and direct positioning (Dp). On Wednesday (29 August) transect nr. 200 (inside the Riff) was checked by means of side scan sonar. Then 10 hauls of about 300 m were carried out with the 3 meter beamtrawl and 10 boxcore samples were collected, again in the middle of the fishing transects (Fig. 0.14 and 0.15). After finishing transect nr 200 another transect (without stones) was selected north of the Borkumer Stones. This area was investigated with side scan sonar on the occurrence of stones and trawl marks of commercial trawlers. The transect (nr. 300) had the same direction and the same length as the other 2 transects (Figures 0.16 and 0.17). On Wednesday five times was fished with the 3 m-beamtrawl in transect nr. 300. Next day 5 hauls were made with the 3 m-beamtrawl and again 10 boxcore samples were collected in the middle of the hauls. Finally the modified benthos dredge was used again to collect samples of the bottom in 2 sampling locations of the transects 200 and 300. A total number of 30 boxcore samples and 9 benthos dredge samples were collected. Table 0.1-0.3 gives a complete review of the sailed transects and the collected samples (positions, length, direction, start positions etc.).

Table 0.1: Review of data of the sailed transect South of the Riff and positions of the hauls and stations during the study on long term effects on the Borkum Riff.

FISH-HAULS

Date of survey: 28-08-1990
Survey Vessel : r.v. "Mitra"
Transect specifications:

- transect	: 100 (south of the riff)
- start x	: 688670.00 (UTM) end x: 693000.00 (UTM)
- start y	: 5991000.00(UTM) end y: 5988500.00(UTM)
- length	: 4999.89 m
- direction	: 120°

In transect 100 10 fishhauls are made with the 3 m fish trawl. The length of these hauls is ca 300 m. The direction of transect Z 1V - Z 7V is 300°. The direction of transect Z 8V - Z 10V is 120°. The waterdepth is ca. 34 m. (N=North Z=South R=Riff B=Boxcore S=Benthos dredge V=Beamtrawl T=(summer)Time)

Haul:	Time:	N:	E:
Z 1V start	10:53	54 00 24.17	05 56 49.32
end		54 00 29.37	05 56 35.46
Z 2V start	11:24	54 00 33.57	05 56 23.99
end		54 00 38.75	05 56 10.13
Z 3V start	11:50	54 00 44.75	05 55 52.74
end		54 00 49.94	05 55 38.88
Z 4V start	12:11	54 01 01.62	05 55 09.85
end		54 01 06.81	05 54 55.98
Z 5V start	12:30	54 01 11.71	05 54 43.68
end		54 01 16.89	05 54 29.81
Z 6V start	12:50	54 01 29.22	05 53 56.42
end		54 01 34.42	05 53 42.54
Z 7V start	13:15	54 01 52.13	05 52 55.34
end		54 01 57.31	05 52 41.46
Z 8V start	20:15	54 00 39.06	05 56 36.14
end		54 00 33.86	05 56 50.01
Z 9V start	19:55	54 00 48.41	05 56 10.81
end		54 00 43.23	05 56 24.86
Z10Vstart	19:35	54 00 59.54	05 55 39.55
end		54 00 54.34	05 55 53.42

BOXCORE-SAMPLES

In the fishhauls of transect nr. 100 10 boxcore-samples are collected.

Sample nr:	Time:	N:	E:
Z 1B	17:10	54 00 26.77	05 56 42.36
Z 2B	17:00	54 00 36.16	05 56 17.03
Z 3B	16:50	54 00 47.34	05 55 45.78
Z 4B	15:55	54 01 04.22	05 55 02.89

continue Table 0.1

Sample nr:	Time:	N:	E:
Z 5B	15:35	54 01 14.30	05 54 36.72
Z 6B	14:50	54 01 31.83	05 53 49.45
Z 7B	15:00	54 01 54.72	05 52 48.37
Z 8B	20:15	54 00 36.47	05 56 43.05
Z 9B	19:00	54 00 45.82	05 56 17.71
Z 10B	19:30	54 00 56.95	05 55 46.46

"BENTHOS DREDGE"-SAMPLES

In the fishhauls of transect nr. 100 4 dredge-hauls are made in a direction of ca 300°.

Sample nr:	Time:	N:	E:
Z 1S start	09:11	54 00 30.00	05 56 31.99
end		54 00 30.34	05 56 31.13
Z 2S start	09:23	54 00 43.50	05 55 56.23
end		54 00 44.08	05 55 54.68
Z 3S start	09:33	54 00 52.93	05 55 30.51
end		54 00 54.14	05 55 27.30
Z 4S start	09:48	54 01 06.27	05 54 56.98
end		54 01 07.45	05 54 53.83

The length of the hauls is resp. 19, 33, 69 and 68 m.

Table 0.2: Review of data of the sailed transect in the Riff and positions of the hauls and stations during the study on long term effects on the Borkum Riff.

FISH-HAULS

Date of survey : 29-08-1990
Survey Vessel : r.v. "Mitra"
Transect specifications:
- transect : 200 (Riff)
- start x : 691401.00 (UTM) end x : 694000.00 (UTM)
- start y : 5993500.00(UTM) end y : 5991000.00(UTM)
- length : 3606.22 m
- direction : 134°

In transect 200 10 fishhauls are made with the 3 m fish trawl. The lenght of these hauls is ca 300 m. The direction 140°. The waterdepth is ca. 34 m. (N=North Z=South R=Riff B=Boxcore S=Benthos dredge V=Beamtrawl T=(summer)Time)

Haul:	Time:	N:	E:
R 1V start	09:30	54 03 27.23	05 54 59.99
end		54 03 19.59	05 55 10.01
R 2V start	09:00	54 03 15.13	05 55 21.86
end		54 03 07.51	05 55 31.88
R 3V start	10:15	54 03 00.65	05 55 43.89
end		54 02 53.02	05 55 53.91
R 4V start	10:35	54 02 48.89	05 56 02.70
end		54 02 41.27	05 56 12.72
R 5V start	11:00	54 02 13.81	05 56 59.61
end		54 02 06.18	05 57 09.63
R 6V start	11:15	54 01 57.24	05 57 25.82
end		54 01 49.61	05 57 35.83
R 7V start	11:35	54 01 39.98	05 57 58.84
end		54 01 32.36	05 58 08.86
R 8V start	11:50	54 01 20.92	05 58 26.45
end		54 01 13.29	05 58 36.46
R 9V start	13:25	54 02 29.41	05 56 33.16
end		54 02 21.79	05 56 43.18
R10V start	13:45	54 02 45.91	05 56 15.08
end		54 02 38.29	05 56 25.10

BOXCORE-SAMPLES

In the fishhauls of transect nr. 200 10 boxcore-samples are collected.

Sample nr:	Time:	N:	E:
R 1B	14:05	54 03 23.41	05 55 05.00
R 2B	14:45	54 03 11.33	05 55 26.87
R 3B	15:00	54 02 56.84	05 55 48.90
R 4B	15:12	54 02 45.09	05 56 07.71
R 5B	15:55	54 02 10.00	05 57 04.62
R 6B	16:00	54 01 53.43	05 57 30.83
R 7B	16:20	54 01 36.16	05 58 03.85
R 8B	16:30	54 01 17.10	05 58 31.46
R 9B	15:25	54 02 25.59	05 56 38.17
R 10B	15:40	54 02 42.09	05 56 20.09

"BENTHOS DREDGE"-SAMPLES

Date of survey: 30-08-1990
In the fishhauls of transect nr. 200 2 dredge-hauls are made in a direction of ca 300°. The length of the hauls is ca 50 m.

Haul:	Time:	N:	E:
R 1S start	14:20	54 03 23.41	05 55 05.00
end		54 03 24.28	05 55 02.69
R 2S start	14:35	54 03 11.33	05 55 26.87
end		54 03 12.19	05 55 24.57

Table 0.3: Review of data of the sailed transect North of the Riff and positions of hauls and stations during the study on long term effects on the Borkum Riff.

FISH-HAULS

Date of survey : 29-08-1990/30-08-1990
Survey Vessel : r.v. "Mitra"
Transect specifications:
- transect : 300 (north of the riff)
- start x : 690170.00 (UTM) end x: 694500.00 (UTM)
- start y : 6002500.00 (UTM) end y: 6000000.00(UTM)
- length : 4999.89 m
- direction : 120°

In transect 300 10 fishhauls are made with the 3 m fish trawl. The length of these hauls is ca 300 m. The direction of transect N 1V-N 7V is ca 120° and transect N 8V-N 10V ca 300°. The waterdepth (N 1V-N 10V) is resp. 36, 36.2, 36.5, 36.5, 34.3, 34.5, 32.2, 32.6, 36.7 and 36.4 m.
(N=North Z=South R=Riff B=Boxcore S=Benthos dredge V=Beamtrawl T=(summer)Time)

Haul:	Time:	N:	E:
29-08-1990			
N 1V start	18:35	54 08 15.97	05 54 03.66
end		54 08 10.79	05 54 17.63
N 2V start	18:55	54 08 02.38	05 54 41.13
end		54 07 57.20	05 54 55.09
N 3V start	19:07	54 07 48.57	05 55 18.40
end		54 07 43.37	05 55 32.37
N 4V start	20:15	54 07 22.49	05 56 28.09
end		54 07 17.30	05 56 42.05
N 5V start	20:30	54 07 10.31	05 57 00.51
end		54 07 05.11	05 57 14.46
30-08-1990			
N 6V start	09:00	54 07 05.55	05 57 20.39
end		54 07 00.35	05 57 34.34
N 7V start	09:15	54 06 51.25	05 57 59.48
end		54 06 46.05	05 58 13.43
N 8V start	09:30	54 06 47.02	05 58 13.55
end		54 06 52.22	05 57 59.60
N 9V start	09:45	54 07 23.45	05 56 35.49
end		54 07 28.65	05 56 21.53
N10V start	10:05	54 07 41.83	05 55 47.69
end		54 07 47.03	05 55 33.73

BOXCORE-SAMPLES

Date of survey: 30-08-1990
In the fishhauls of transect nr. 300 10 boxcore-samples are collected.

Sample nr:	Time:	N:	E:
N 1B	10:45	54 08 13.38	05 54 10.65
N 2B	11:00	54 07 59.79	05 54 48.11
N 3B	11:10	54 07 45.97	05 55 25.39
N 4B	11:20	54 07 19.90	05 56 35.07
N 5B	11:35	54 07 44.44	05 55 40.71
N 6B	11:45	54 07 26.05	05 56 28.51
N 7B	11:50	54 07 07.71	05 57 07.48
N 8B	12:00	54 07 02.96	05 57 27.37
N 9B	12:05	54 06 48.84	05 57 59.30
N 10B	12:15	54 06 49.62	05 58 06.58

"BENTHOS DREDGE"-SAMPLES

Date of survey: 30-08-1990
In the fishhauls of transect nr. 300 2 dredge-hauls are made in a direction of ca 120° and 246°. The length of the hauls is ca 50 and 62 m.

Haul:	Time:	N:	E:
N 1S start	15:40	54 08 13.38	05 54 10.65
end		54 08 12.52	05 54 12.95
N 2S start	16:00	54 07 59.79	05 54 43.11
end		54 07 59.06	05 54 44.92

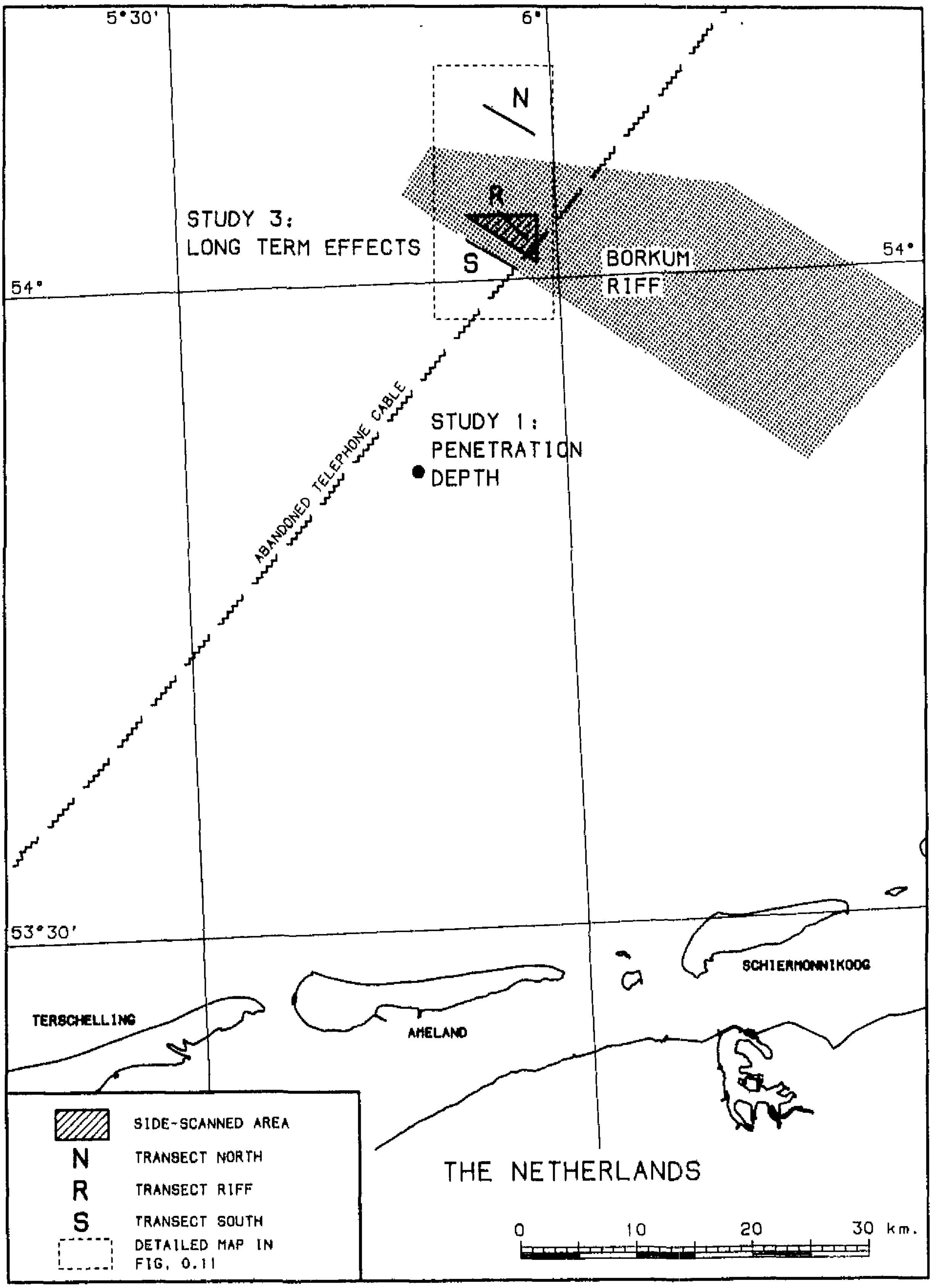
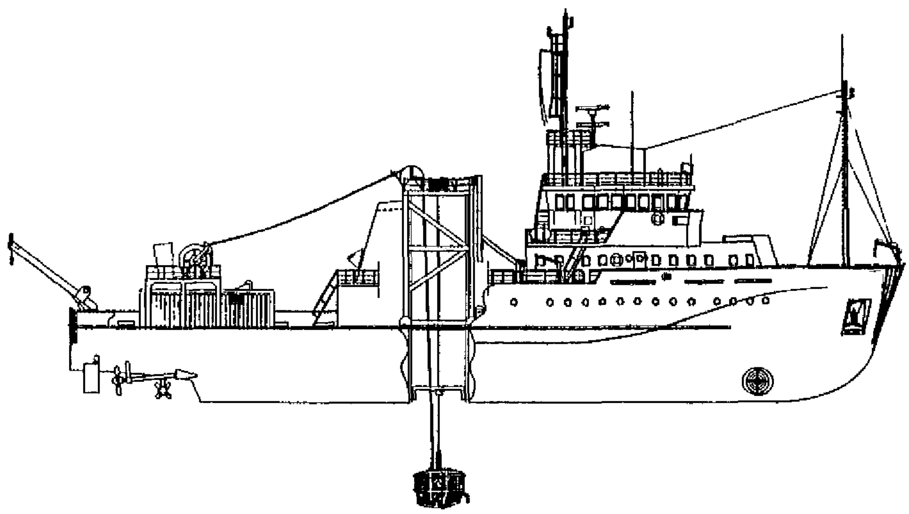


FIG. 0.1 EXPERIMENTAL AREAS



Survey vessel: r.v. "Mitra"
- length o.a. : 56.25 m.
- beam moulded : 11.50 m.

Standard equipment used in studies 1 and 2

Positioning system	: Hyper Fix Terschelling chain -pattern combination 2-1 4-1 4-2
Data acquisition and processing system	: Racal Autocarta II -survey data stored on disk
Echo sounding system	: Atlas Deso 20 -frequency 210 kHz. Datawell Hippy 120 heave compensator
Side scan sonar (S.M.S.)	: E.G. & G. Seafloor Mapping System type 960 - frequency: 100 kHz. - range : 50/100 m. (each side)
Dynamic Positioning System (D.P.)	: Kongsberg DP-311
Underwater Inspection (R.O.H.P.)	: Remote Operated Hoisted Platform developed by: - Rijkswaterstaat North Sea Directorate - Seatec Underwater Systems

Temporary equipment

Used in:

Study 1,3:	Bottomsampling equipment	: Reineck Boxcore (NIOZ)
Study 3:	Bottom trawl	: 3 m-beamtrawl (NIOZ)
Study 3:	Bottom dredge	: Bottom dredge equipment developed by NIOZ

FIG. 0.2 SURVEY VESSEL AND SURVEY EQUIPMENT

North Sea Directorate, MTZM

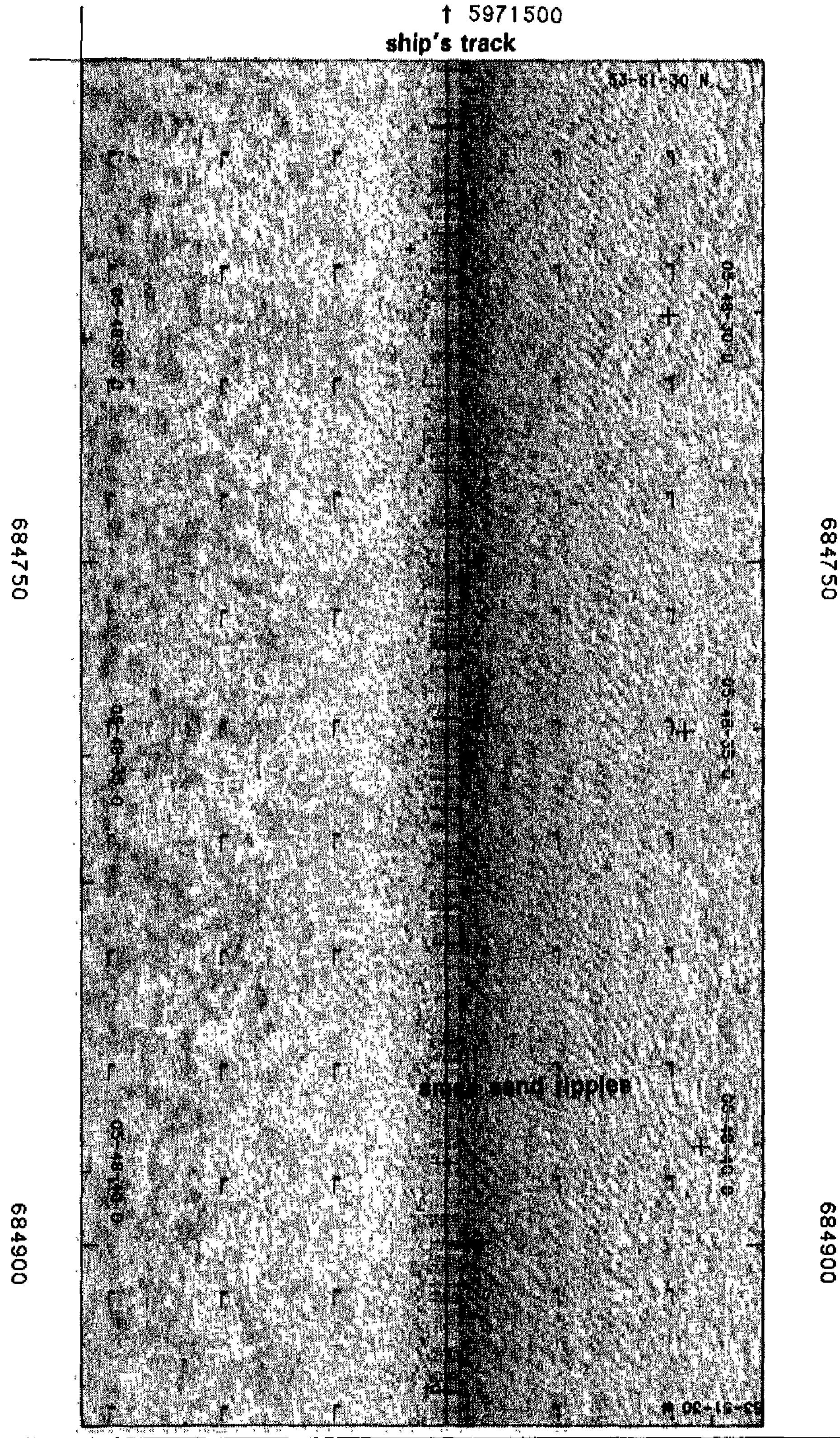


FIG. 0.3 SIDE SCAN SONAR RECORD OF THE SEABOTTOM DURING THE PENETRATION STUDY BEFORE TRAWL FISHING.

- survey date : 23-08-1990
- survey vessel : Mitra
- side scan sonar: E.G. & G. 960 Seafloor Mapping System
- sonar frequency: 100 kHz.
- sonar range : 100 m. (each side)
- ships heading : 270°
- wind : N 3-4 Bf.
- waveheight : ± 125 cm.
- swell : NW

- U.T.M (3°)
- Geographs

0 15 30 45 m

North Sea Directorate, MTZM

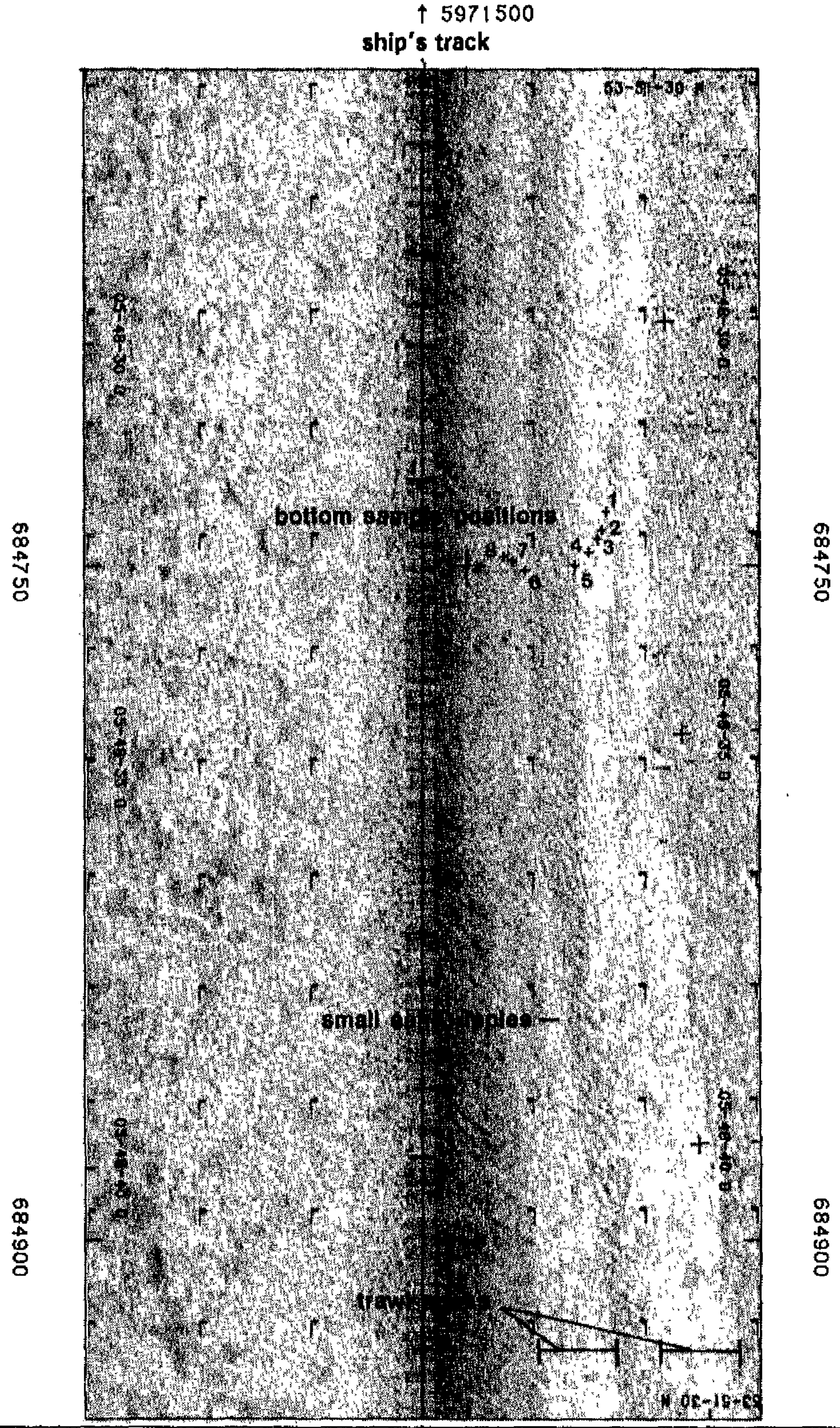


FIG. 0.4 SIDE SCAN SONAR RECORD OF THE SEABOTTOM DURING THE PENETRATION STUDY IMMEDIATELY AFTER TRAWL FISHING.

- survey date : 23-08-1990
- survey vessel : Mitra
- side scan sonar: E.G. & G. 960 Seafloor Mapping System
- sonar frequency: 100 kHz.
- sonar range : 100 m. (each side)
- ships heading : 270°
- wind : N 3-4 Bf.
- waveheight : ± 125 cm.
- swell : NW

- U.T.M (3°)
- Geographs

0 15 30 45 m

North Sea Directorate, MTZM

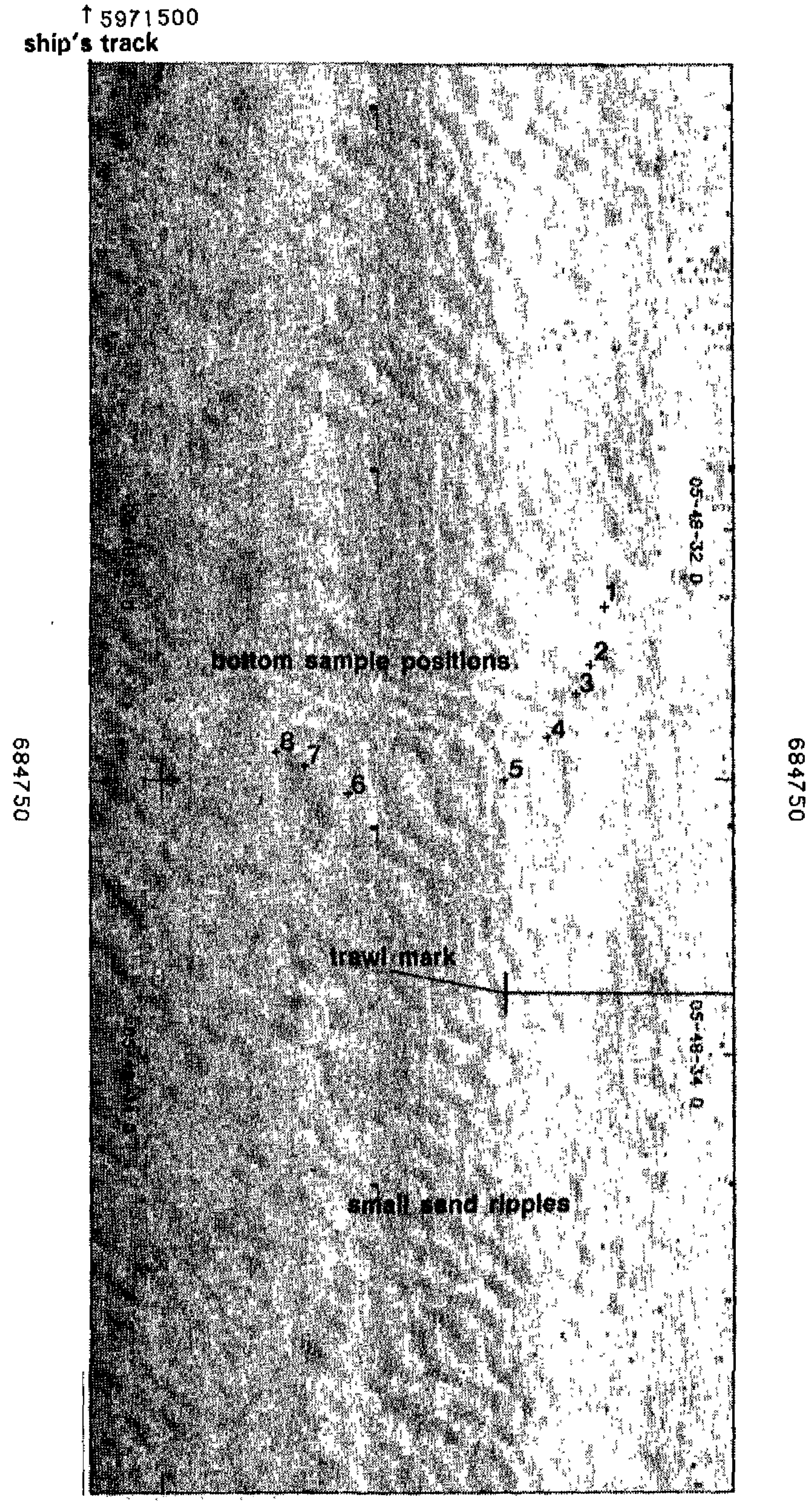


FIG. 0.5 MORE DETAILED SIDE SCAN SONAR RECORD OF THE SEABOTTOM DURING THE PENETRATION STUDY IMMEDIATELY AFTER TRAWL FISHING.

- survey date : 23-08-1990
- survey vessel : Mitra
- side scan sonar: E.G. & G. 960 Seafloor Mapping System
- sonar frequency: 100 kHz.
- sonar range : 100 m. (each side)
- ships heading : 270°
- wind : N 3-4 Bf.
- waveheight : ± 125 cm.
- swell : NW

- U.T.M (3°)
- Geographs

0 5 10 15 m

North Sea Directorate, MTZM

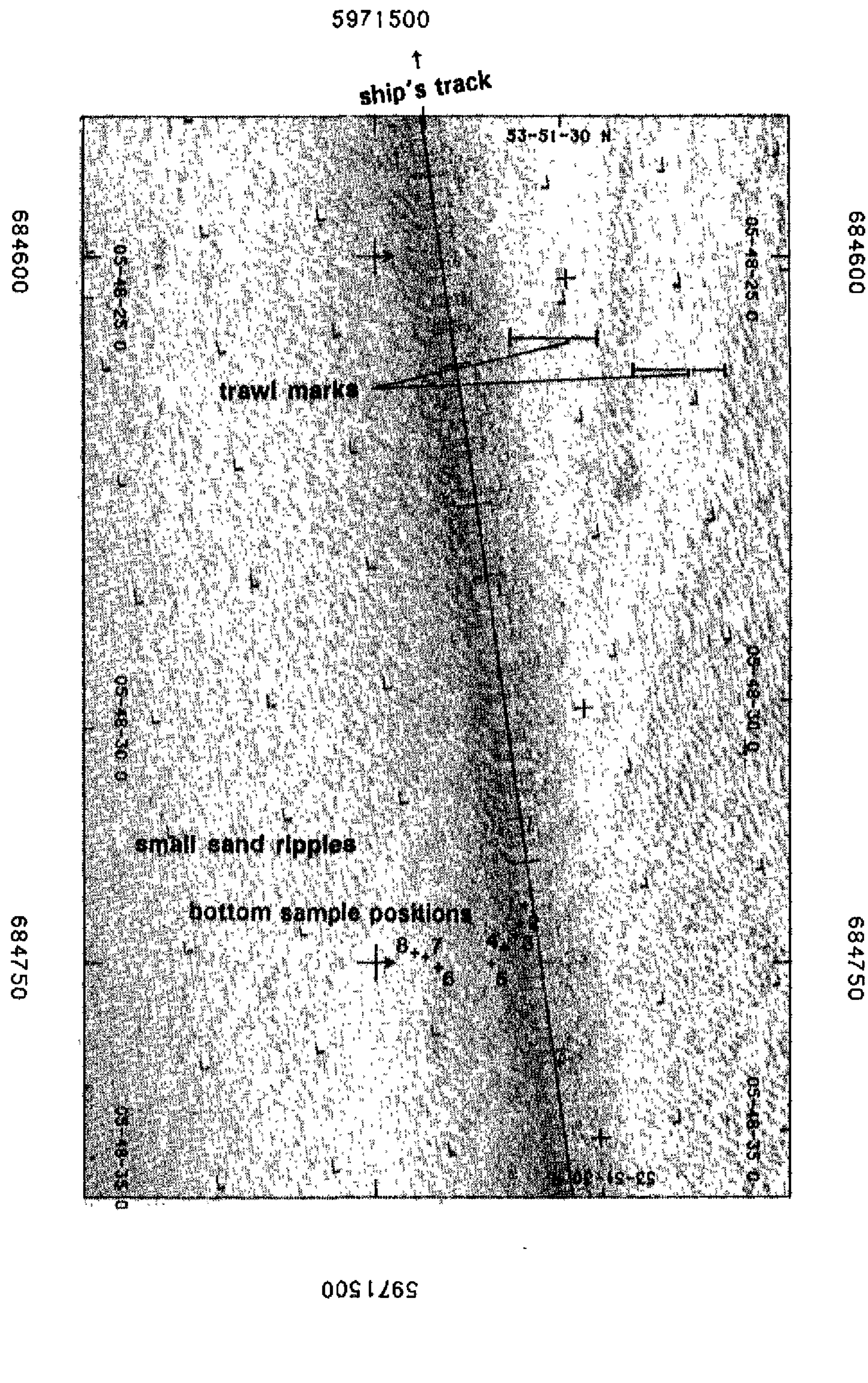


FIG. 0.6 SIDE SCAN SONAR RECORD OF THE SEABOTTOM DURING THE PENETRATION STUDY ABOUT 7 HOURS AFTER TRAWL FISHING.

- survey date : 23-08-1990
- survey vessel : Mitra
- side scan sonar: E.G. & G. 960 Seafloor Mapping System
- sonar frequency: 100 kHz.
- sonar range : 100 m. (each side)
- ships heading : 270°
- wind : N 3-4 Bf.
- waveheight : ± 125 cm.
- swell : NW

- U.T.M (3°)
- Geographs

0 15 30 45 m

North Sea Directorate, MTZM

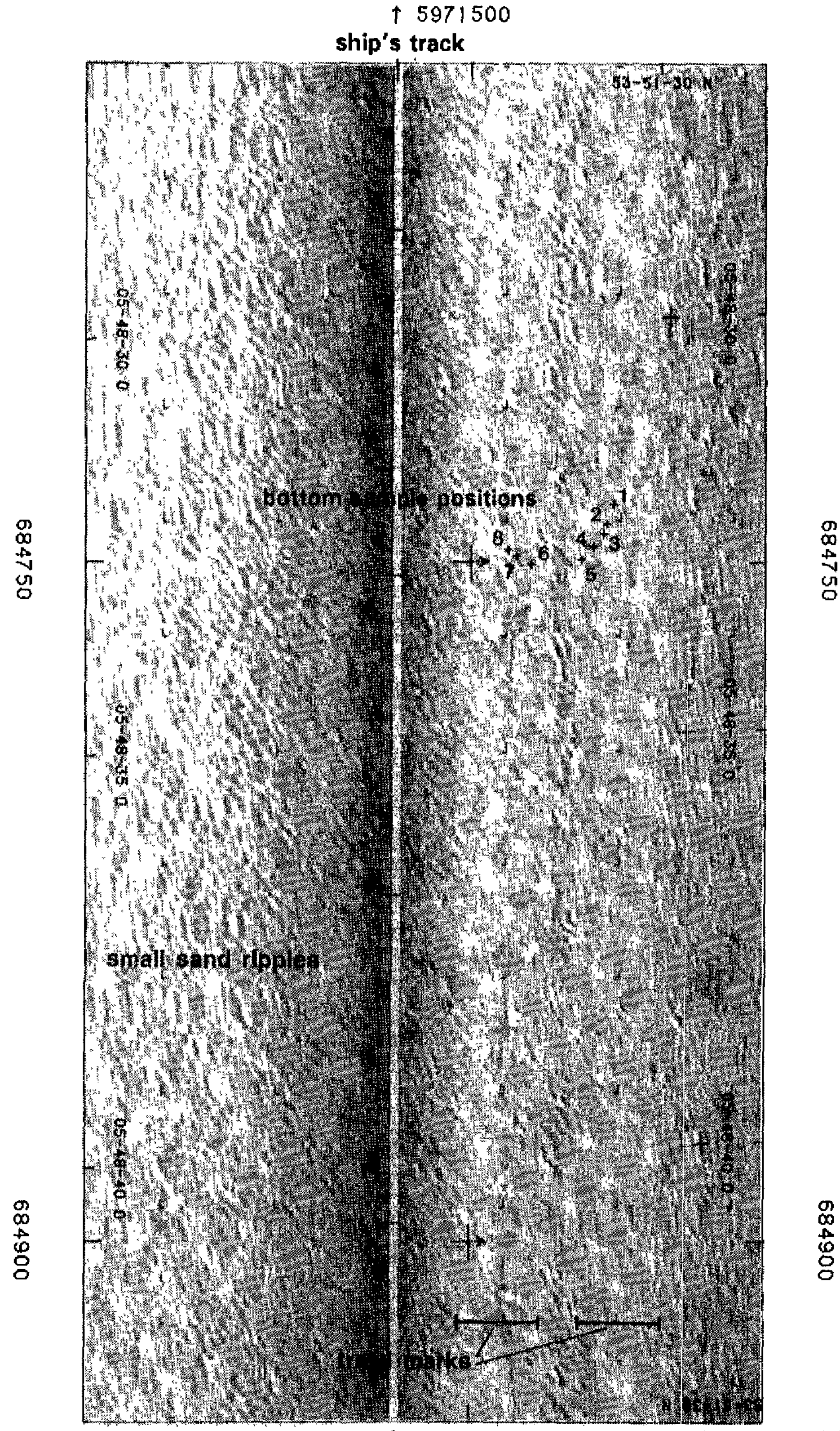


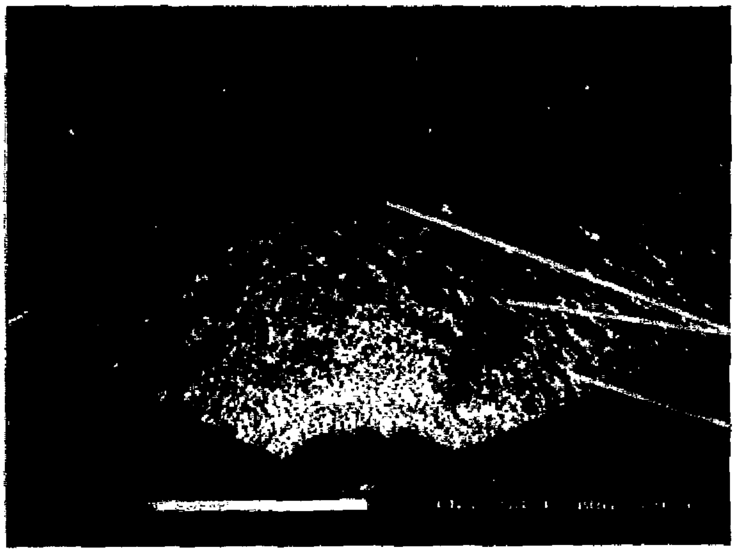
FIG. 0.7 SIDE SCAN SONAR RECORD OF THE SEABOTTOM DURING THE PENETRATION STUDY ABOUT 12 HOURS AFTER TRAWL FISHING.

- survey date : 23-08-1990
- survey vessel : Mitra
- side scan sonar: E.G. & G. 960 Seafloor Mapping System
- sonar frequency: 100 kHz.
- sonar range : 100 m. (each side)
- ships heading : 270°
- wind : N 3-4 Bf.
- waveheight : ± 125 cm.
- swell : NW

- U.T.M (3°)
- Geographs

0 15 30 45 m

North Sea Directorate, MTZM



sonar range 58 m.

FIG. 0.8 SEABOTTOM IMAGE OF THE SITUATION IMMEDIATELY AFTER BEAMTRAWLING.
The image was made by a Mesotech obstacle avoidance sonar, mounted on the R.O.H.P (Remote Operated Hoisted Platform).

North Sea Directorate, MTZM

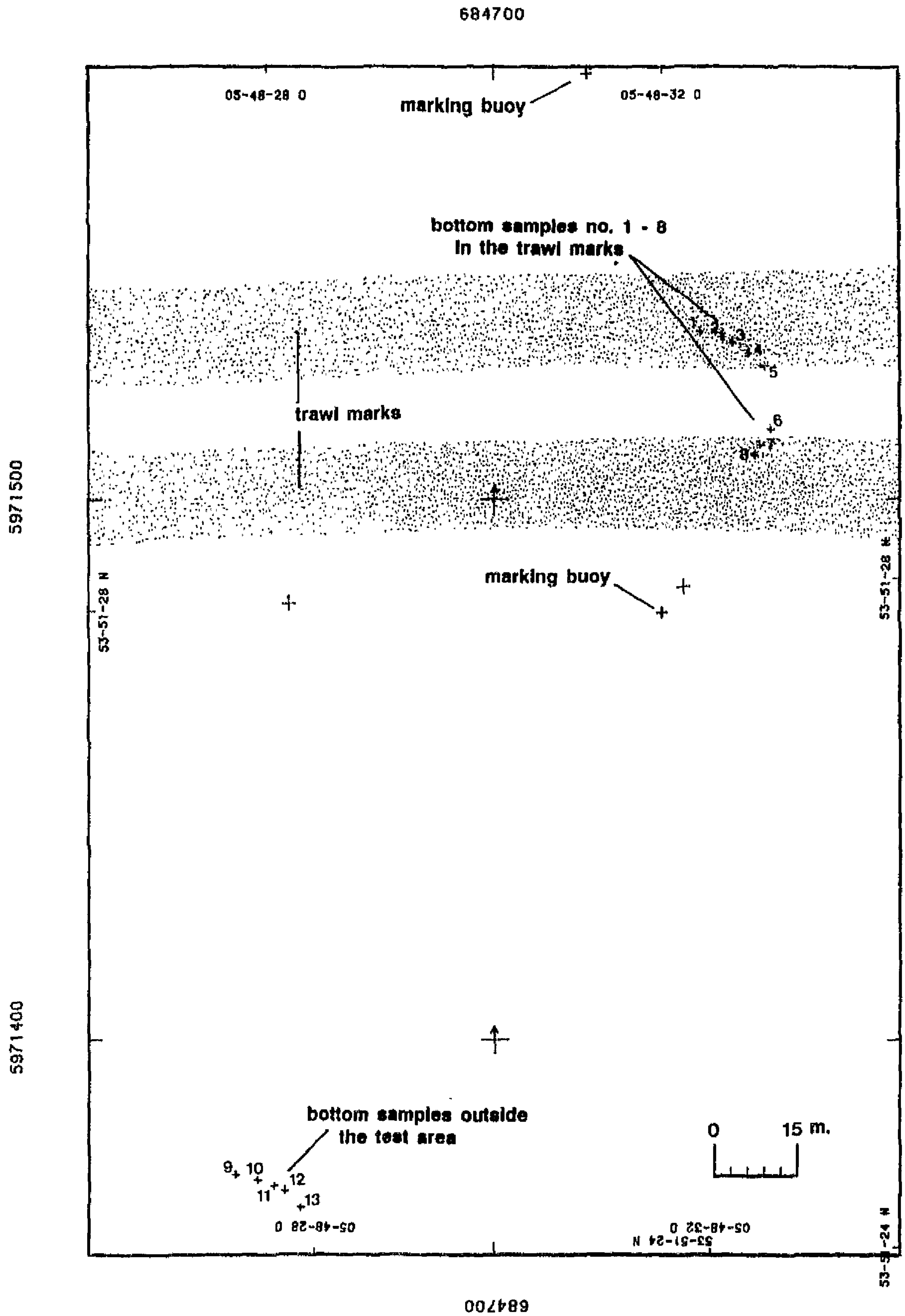
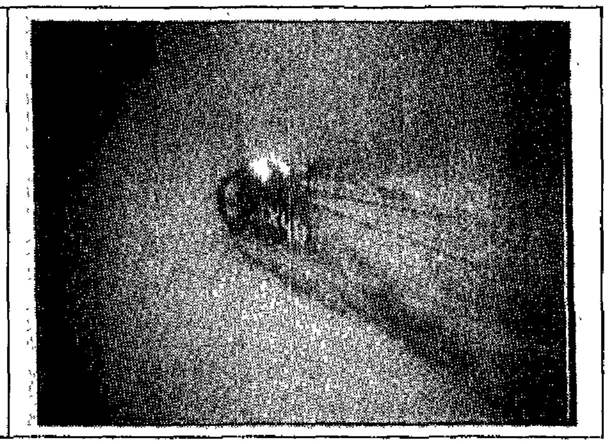


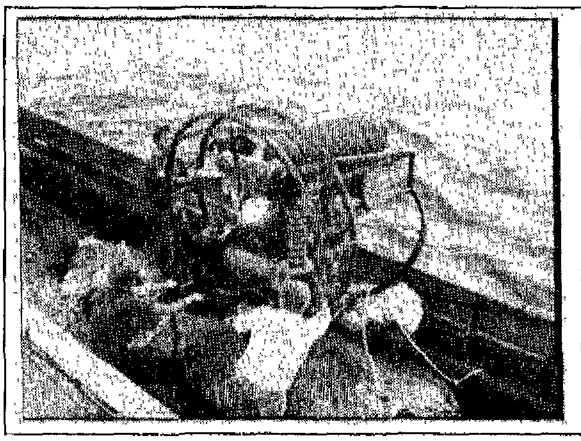
FIG. 0.9 POSITIONS OF BOTTOM SAMPLES IN AND OUTSIDE THE TRAWL MARKS DURING THE PENETRATION STUDY.

North Sea Directorate, MTZM

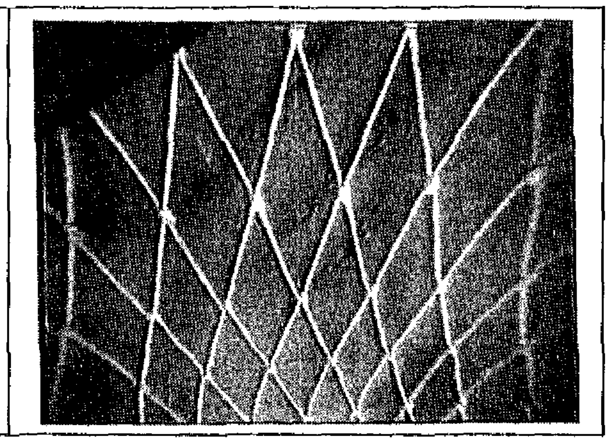
Net with groundrope
and light ticklers



Dust clouds
from shoe



Vehicle over board



First tickler chains
lightly over the bottom

Transportbelt and
and sorting table

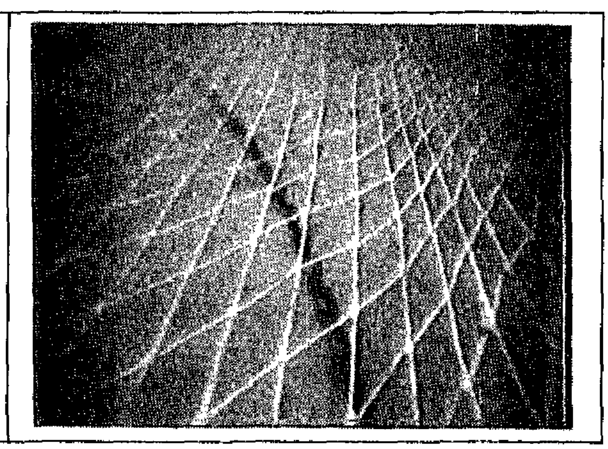


FIG. 0.10 PHOTOGRAPHS FROM VIDEO MADE ON BOARD BEAMER/ROV
Netherlands Institute for
Fishery Investigations, RIVO-DLO

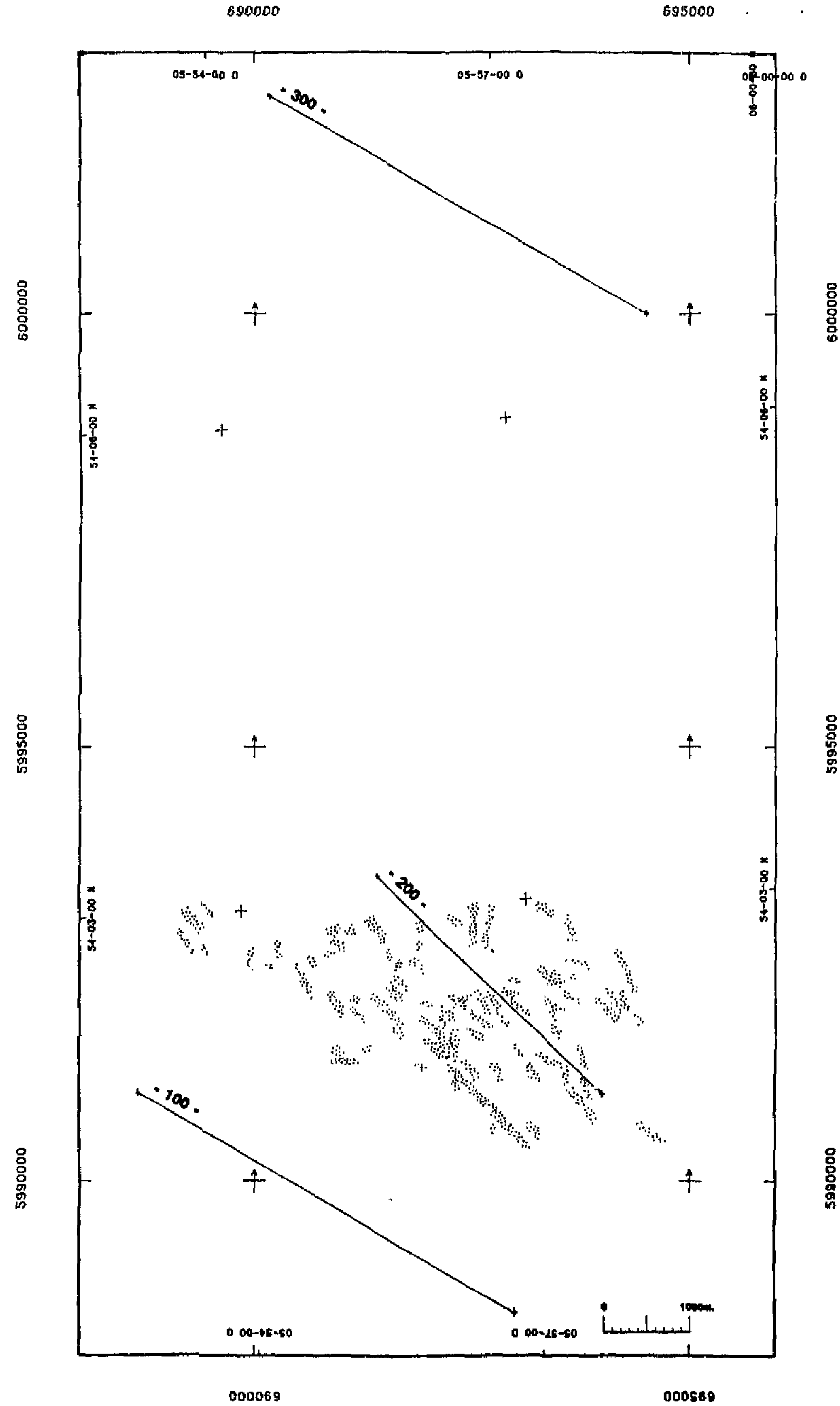


FIG. 0.11 POSITIONS OF STONES (RIFF) IN THE EXPERIMENTAL AREA OF STUDY 3.

The experiments were carried out in the transects 100 (South of the Riff), 200 (Riff), 300 (North of the Riff).

▓▓: stones in Riff.

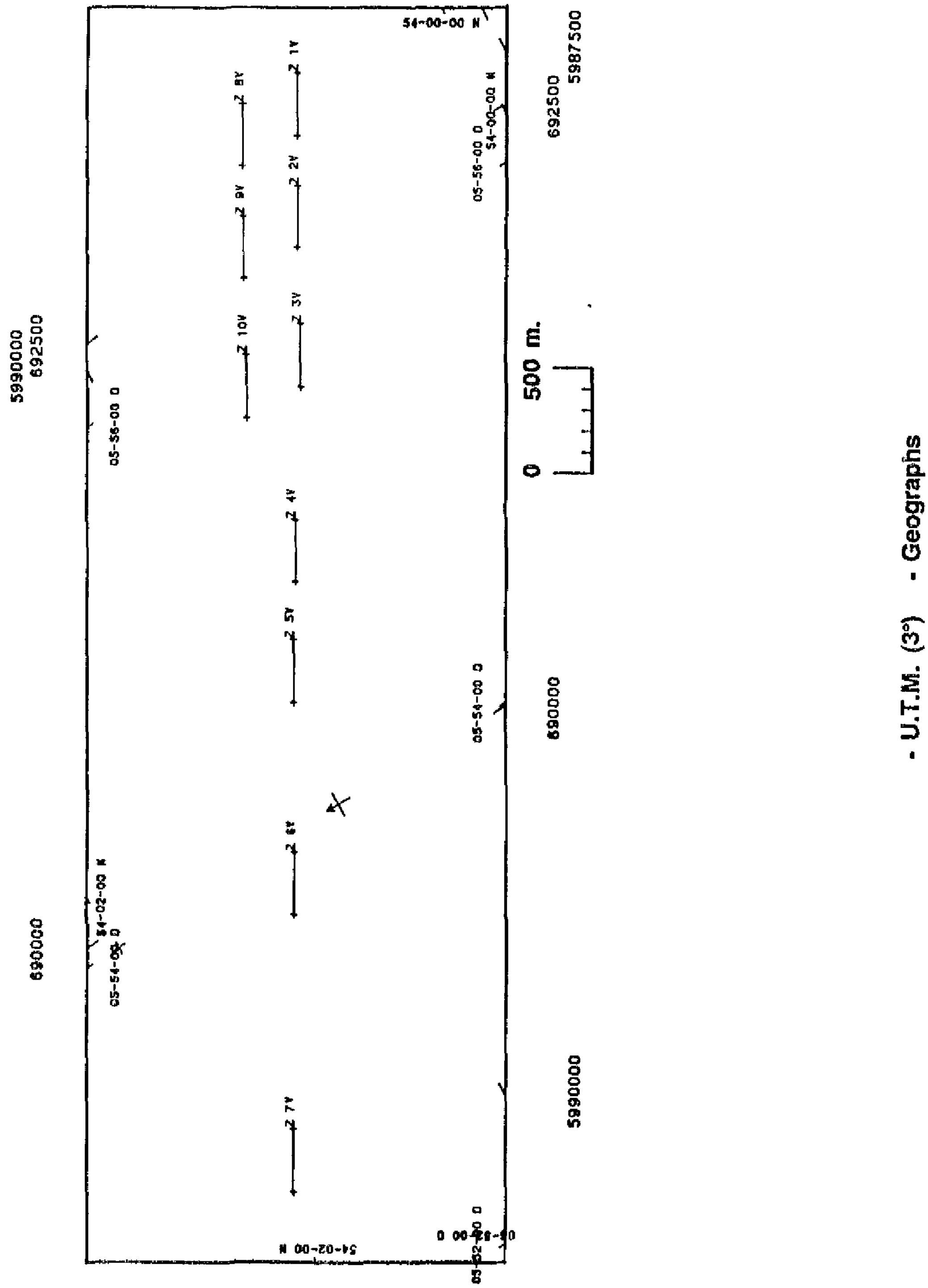


FIG. 0.12 FISH HAULS 1-10 CARRIED OUT IN TRANSECT 100 (SOUTH OF RIFF).

Z1V:
- length of the haul
Z - South of Riff
1 - number of the haul
V - beamtrawl
date: 28-08-1990 ; research vessel: r.v."Mitra"

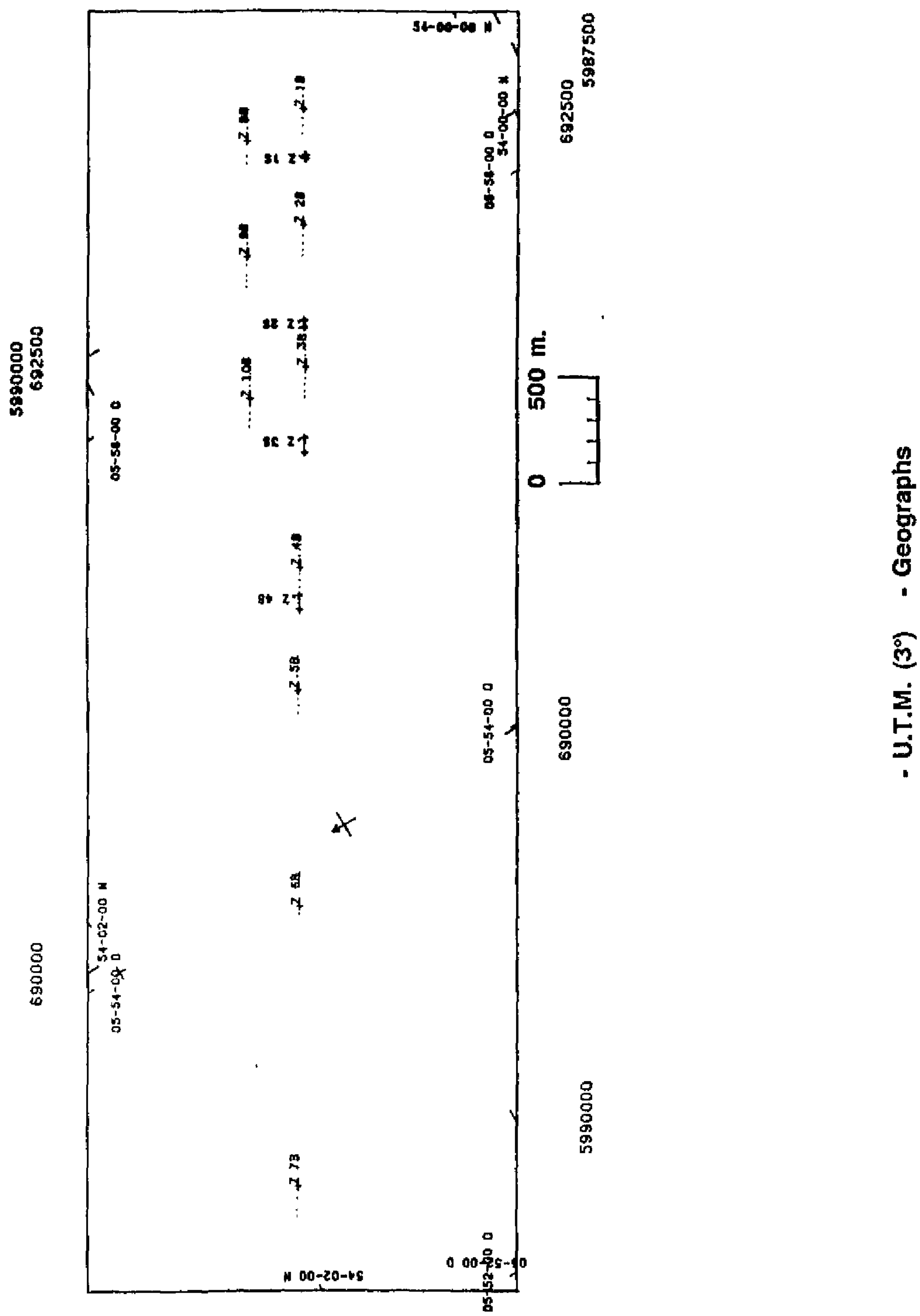


FIG. 0.13 BOXCORE AND BENTHOS DREDGE SAMPLES CARRIED OUT IN THE FISHHAULS 1-10 OF TRANSECT 100 (SOUTH OF RIFF).

+Z1B:
+: position of the boxcore sample
Z: South of Riff
1: number of the boxcore sample
B: boxcore
......: fishhaul

Z4S:
:length of the haul
Z : South of Riff
4 : number of the haul
S : benthosdredge

date: 28-08-1990 ; research vessel: r.v. "Mitra"

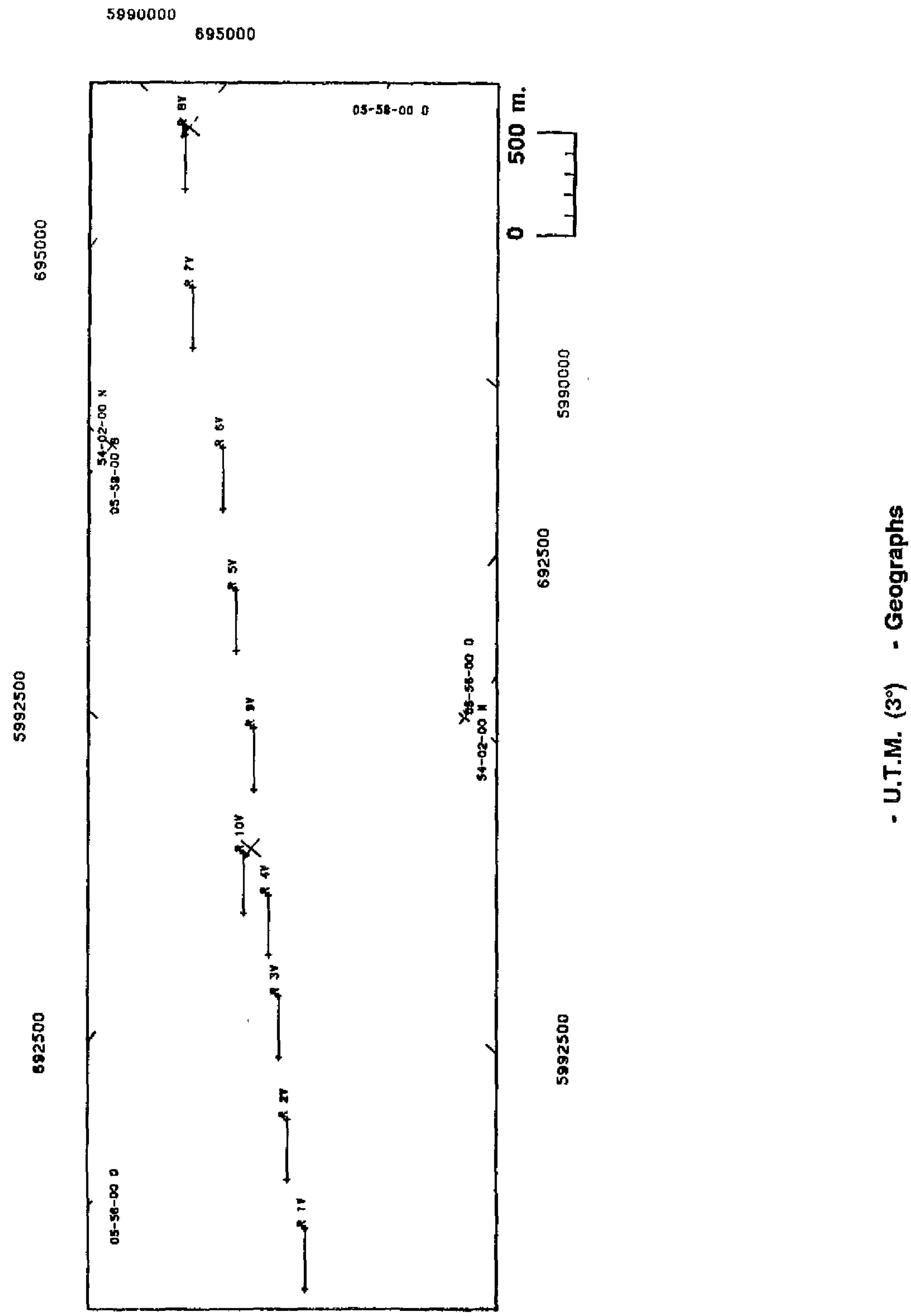


FIG. 0.14 FISH HAULS 1-10 CARRIED OUT IN TRANSECT 200 (RIFF).

R1V:
- length of the haul
R - Riff
1 - number of the haul
V - beamtrawl
date: 29-08-1990 ; research vessel: r.v."Mitra"

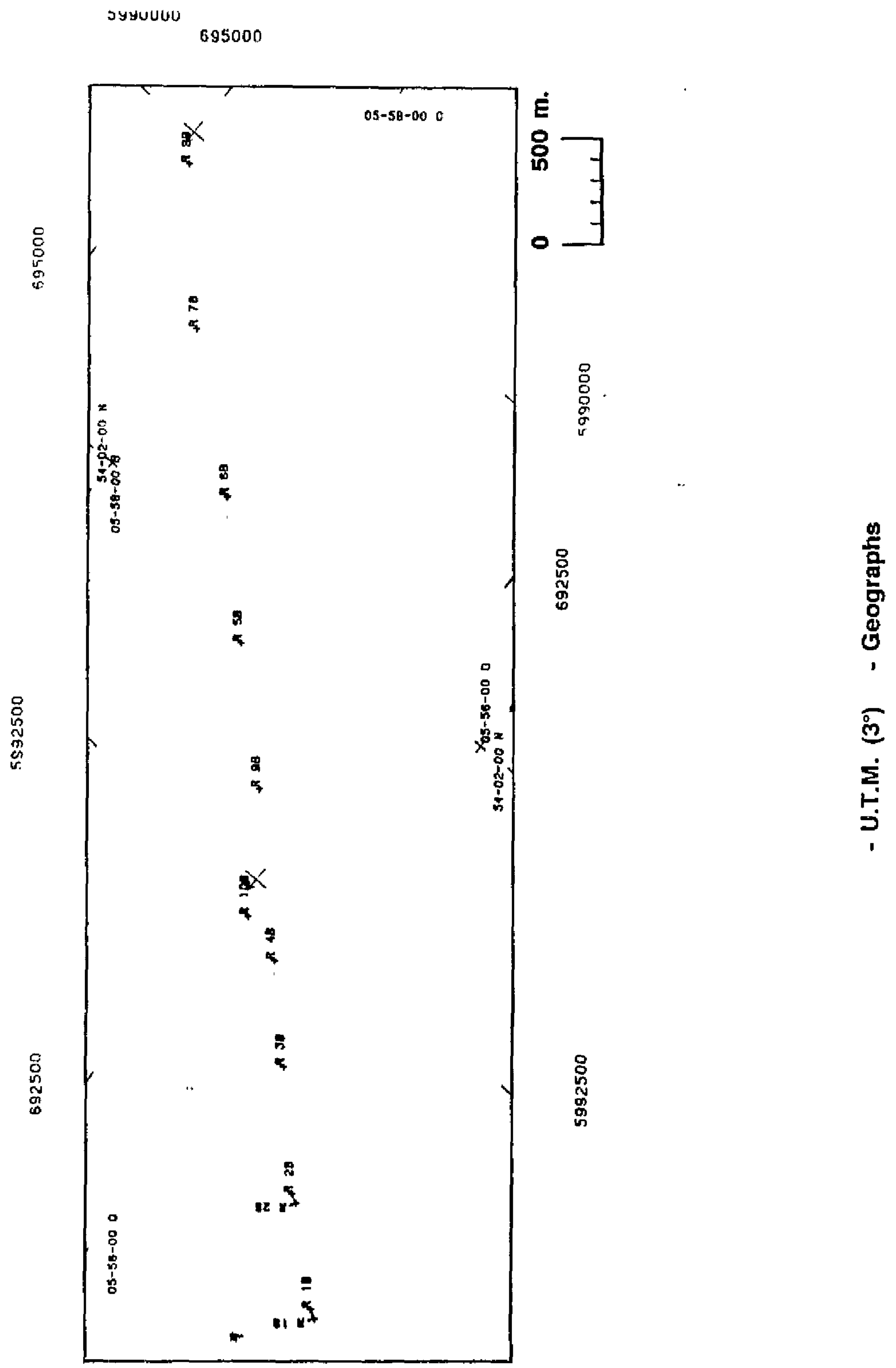


FIG. 0.15 BOXCORE AND BENTHOS DREDGE SAMPLES CARRIED OUT IN THE FISHHAULS 1-10 OF TRANSECT 200 (RIFF).

+R1B:
+: position of the boxcore sample
R: Riff
1: number of the boxcore sample
B: boxcore
......: fishhaul

R4S:
: length of the haul
R: Riff
4: number of the haul
S: benthosdredge

date: 30-08-1990 ; research vessel: r.v. "Mitra"

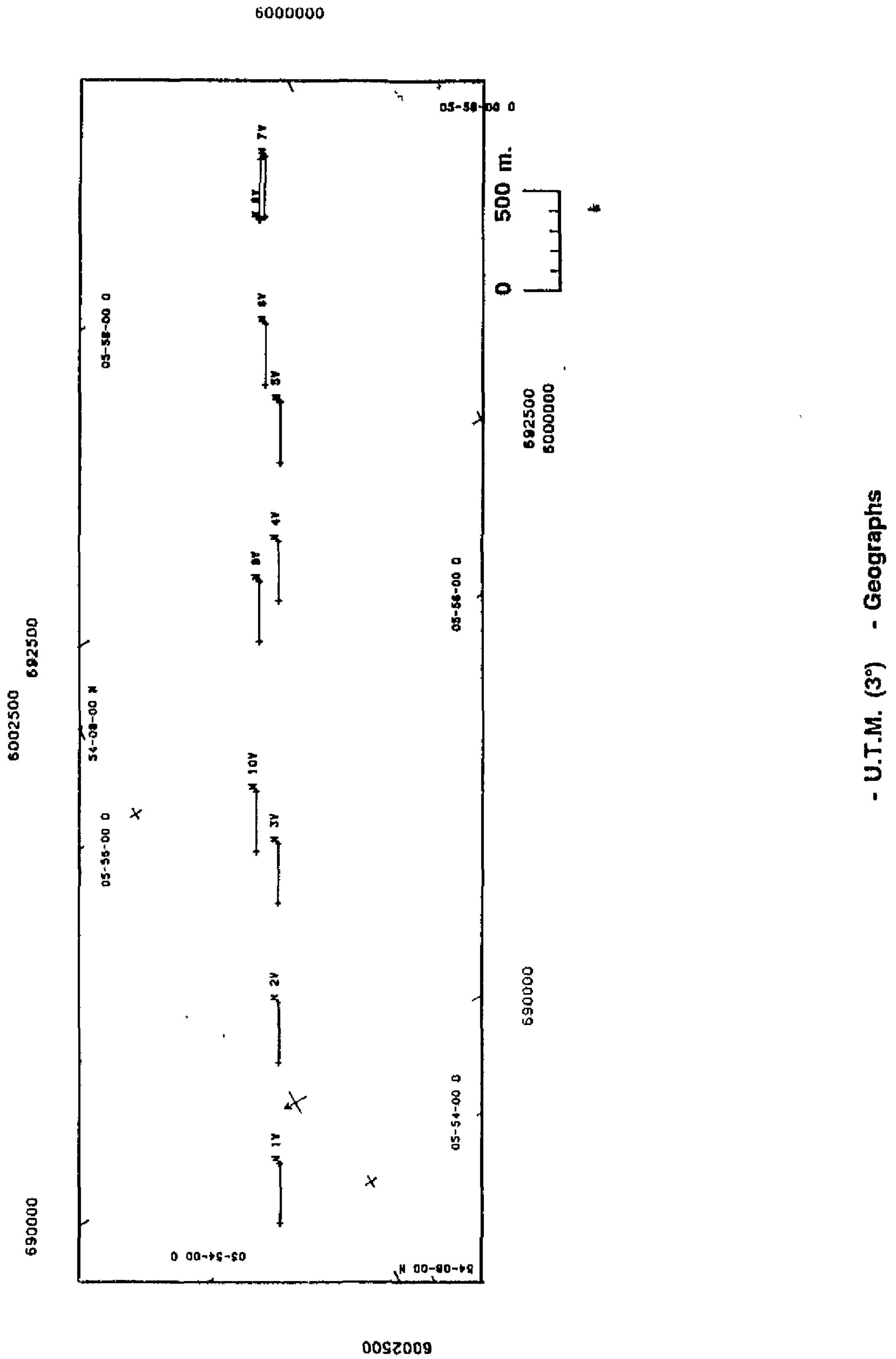


FIG. 0.16 FISH HAULS 1-10 CARRIED OUT IN TRANSECT 300 (NORTH OF THE RIFF).

N1V:
- length of the haul
N - North of Riff
1 - number of the haul
V - beamtrawl
date: 30-08-1990 ; research vessel: r.v."Mitra"

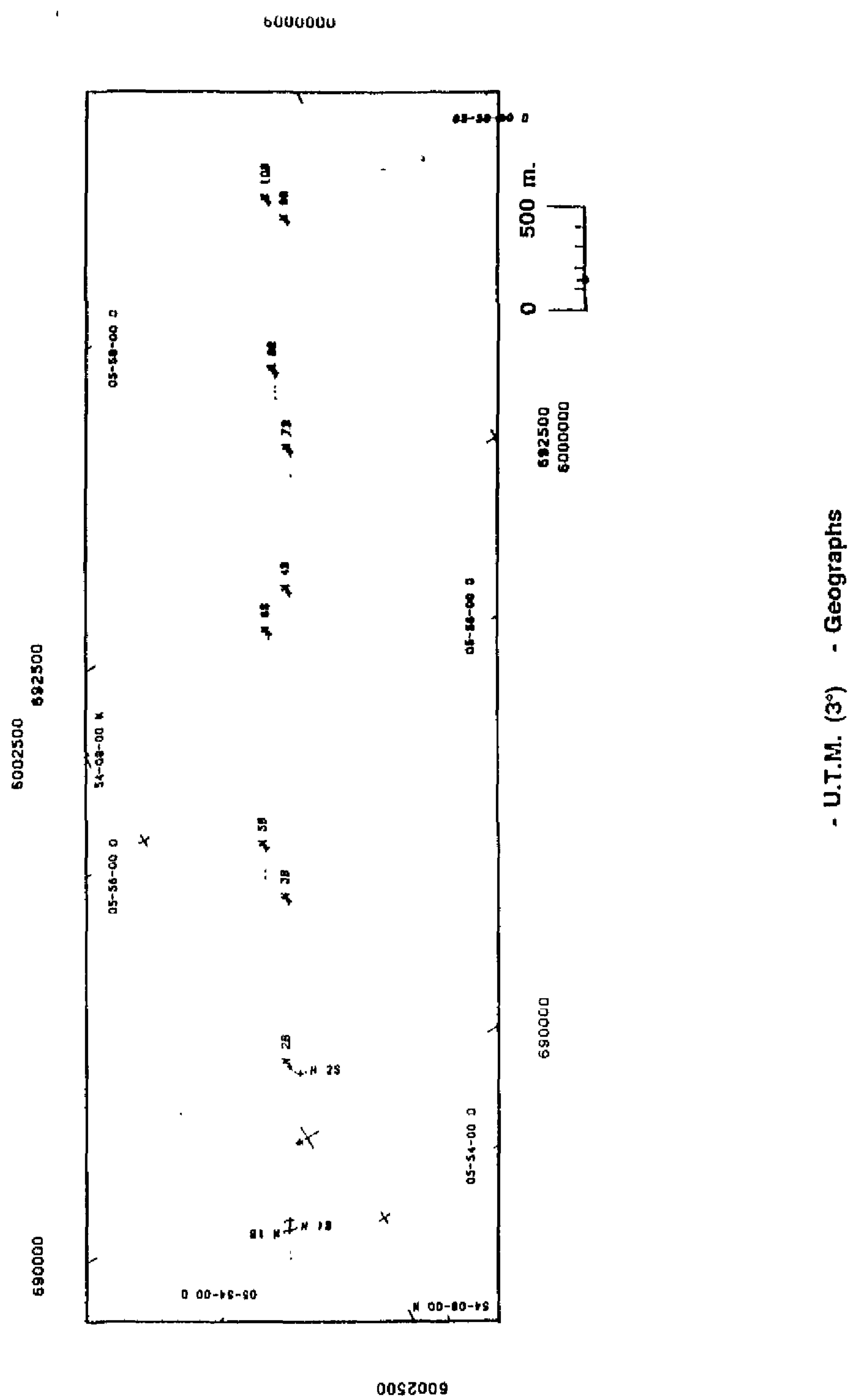


FIG. 0.17 BOXCORE AND BENTHOS DREDGE SAMPLES CARRIED OUT IN THE FISHHAULS 1-10 OF TRANSECT 300 (NORTH OF RIFF).

+N1B:
+: position of the boxcore sample
N: North of Riff
1: number of the boxcore sample
B: boxcore
......: fishhaul

N4S:
: length of the haul
N: North of Riff
4: number of the haul
S: benthosdredge

date: 30-08-1990 ; research vessel: r.v. "Mitra"

3. STUDY 1: PENETRATION DEPTH OF BEAMTRAWL GEAR.
(eds. C. Laban & H. Lindeboom)

3.1 INTRODUCTION

If fishing gear disturbs the sediment and the sediment resettles after passage of the gear it may be expected that sediment characteristics will be changed as deep as the penetration depth of the beamtrawl. A method to determine the penetration depth is the measurement of sediment characteristics which show a distinctive depth profile. Such a profile may be measured before and after fishing whereby changes in the profiles may indicate the depth at which the gear has influenced the sediments. One of these characteristics is the reciprocal formation factor, which in general shows a distinctive profile into the sediment (Helder, 1989). Another closely related characteristic is the pore water content. Also lacker peels, X-ray photographs or mud contents may be used to yield insight into the penetration depth. Furthermore, the meiofauna distribution into the sediment often shows a distinctive pattern.

3.2 MATERIAL AND METHODS

After making side scan sonar records of the study area 13 boxcore samples were taken. Eight boxcore samples were taken in the trawl tracks, five (S1-S5) in one track and three (S6-S8) in the other. Another five boxcore samples (B9-B13) were taken approx. 100 m outside the trawl tracks (see table 1.1). In order to obtain sedimentary structures of each boxcore sample a lacker peel has been made of approx. 15 x 30 cm. Additional subsamples were taken in plastic liners in order to take X-ray photographs and to study the benthic foraminifera (S1-S5 and B9-B13). For determination of changes in the very fine sand fractions and the silt content, subsamples were taken at three depth intervals; 0-3 cm, 9-14 cm and 19-24 cm respectively. Profiles of reciprocal formation factors were measured by means of a resistivity probe made at the NIOZ workshop. This probe measures the electrical resistance inside the sediment. From each boxcore sample two subsamples were taken, each with a diameter of 10 cm and a length of 13-15 cm. In these subsamples the probe was driven into the sediment at 1 cm intervals and the resistivity at each depth was recorded. The reciprocal formation factor F^{-1} was calculated from:

$$F^{-1} = Ro/Rz$$

in which Rz and Ro are the electrical resistivity in sediment and overlying water,respectively. Porosity profiles were constructed by way of measurements of water content of the sediment. In each boxcore sample one core with a diameter of 3.5 cm and a length of 9-10 cm was taken. Starting at the sediment surface this sample was subdivided into 9 to 10 slices of 1 cm each and water content of these slices was determined by weight measurement before and after drying till constant weight at a temperature of 80°C. The porosity (vol%) was then calculated from:

$$\text{por.(vol/vol)} = 100 * (\text{vol.water/vol.total})$$

giving:

$$\frac{M_{water}/R_w}{(M_{water})/R_w + (M_{dry})/R_{dry}}$$

in which:

M_{water} = mass water (g)
M_{dry} = mass dry sediment (g)
R_w = 1 kg/litre
R_{dry} = 2.65 kg/litre

From each boxcore a subsample with a surface area of 10 cm^2 was taken and divided in slices of 1 cm each. These slices were stored in 4% formaldehyde in plastic jars. The meiofauna content of the slices was determined by washing the slices for 15 minutes in a washing-gutter with a length of 100 cm and a width of 2.5 cm. The total number of organisms, caught on a 50 μm sieve, was counted on counting trays of 50x50 mm with a 5x5 mm grid size.

3.3 RESULTS AND DISCUSSIONS

3.3.1 GEOMORPHOLOGY AND GEOLOGY OF THE AREA OF INVESTIGATION

The area of investigation (Fig. 0.1) lies Southwest of the Borkum Riff, an area with medium sand (250 to 500 micron) with gravel. The Borkum Riff is regarded as a remnant of a moraine of the Saalian glaciation. The area southwest of the Borkum Riffgrund consists of fine sand (<250 micron) (Figge, 1981), belonging to the Terschellingbank Member of the Nieuw Zeelandgronden Formation (Harrison et al, 1987). This formation consists mainly of during the Holocene transgression reworked glacial sand. According to the side scan sonar records the area has a flat bottom covered with current ripples with a height of 4 to 6 cm and a mean wavelength of 2 m (Allen, 1984).

3.3.2 SEDIMENTOLOGICAL DESCRIPTIONS OF THE CORES

Cores S1 to S8 in the trawl track

The cores S1 - S5 were most likely taken from a trawl track immediately after passing of the trawl. On the side scan sonar record the bottom shows a clear track of the trawl in which most of the sand ripples were destroyed by the net (Fig. 1.1 and 1.2). The uppermost 5 to 7 cm of those cores are without structures. Parallel horizontal lamination is present in core S1 at 5 to 12 cm below the surface and in core S3 from 7 cm below the surface down to the end of the core. In core S2 (top layers dipping, core disturbance?) a horizontal silty layer occurs at 4 cm below the top . In core S4 a distinct transition into finer sand with bioturbation underneath occurs at 4 cm. In core S5 a transition into more dense and finer sand at 2 cm depth is observed.

In the cores S6 to S8, (supposed to be taken from the second trawl track) (Fig. 0.7 and 1.1), parallel lamination is present from the top down to respectively 3 and 7.5 cm. This clearly indicates, that these samples were not taken from a trawl track. In core S8 cross bedding structures have been found pointing to deposition by current ripples. The laminated layers are overlying structureless beddings. The absence of structures in the deeper layers is possibly due to bioturbation. Near and at the base of cores S7 and S8 slightly dipping silty layers are present.

Cores B9 to B13 ± 100 m outside the trawl track

The cores B9, B10, B11, B12 and B13 taken at a distance of ± 100 m outside the trawl track show a parallel laminated bedding at the top down to respectively 4.5, 4.5, 1.5, 4 and 1 cm. In core B10 cross bedded structures are present. There is a strong similarity between the cores S6 - S8 and these cores. This once again indicates that the cores S6 - S8 were taken outside the track. Below the bedded layer a structureless layer occurs. The absence of sedimentary structures is possibly due to bioturbation. Below the structureless layer parallel lamination occurs towards the base. In core B13 at the base a layer of 5 cm with cross bedded structures is found (Fig. 1.1).

3.3.3 X-RAY PHOTOGRAPHS

From each boxcore additional cores (ϕ = 9 cm) have been taken for X-ray photographs. The cores were split and of both parts X-ray photographs were taken (L) + (R). In only one core (B10) clear sedimentary structures are visible. In core S7 at ± 5 cm some lamination is present. At the base of core S8 a laminated bedding occurs in silty sediments. The lacking of sedimentary structures in the X-ray photographs is probably due to the large diameter of the cores used.

3.3.4 GRAINSIZE ANALYSES

Subsamples for grainsize analyses were taken in all boxcores at a depth between 0 to 3 cm; 9 to 14 cm and 17 to 24 cm. It was expected that in the trawl track in the top few centimetres the grainsize should be coarser because of the whirling up and deposition by currents fine sand grains and mud, resulting in loss of part of the finer fraction. According to this assumption, finer grained sediments with a higher mud content were expected in the subsamples below the top .
From the cores taken in the trawl track (S1 to S5) only core S2 shows a difference between the mud content of the superficial sediments at 2 cm (2.1%) and the sediment at 14 cm. (6.0%). The d50 of the superficial sediments ranges from 193.7 (S1) to 240.8 (S5) micron. The d50 of the second subsample however is ranging from 215.0 to 254.2 micron (Fig. 1.2). The skewness of the cumulative curves of all subsamples does not vary much with the exception of the subsample of B1 at 24 cm which contains 26.3% of mud. The sediments were all very well sorted.
The d50 of the superficial sediments in the cores taken just outside the trawl track (S6 to S8) are ranging from 214.2 to 232.3 micron. The d50 of the second subsample ranges from 224.3 to 230.8 micron. The skewness was identical in all of the curves. The variation of the d50 is only 18.1 micron, except for the subsample at 24 cm depth of core S8 which contains 51.9% mud. The sediments are very well sorted.
The cores taken at ± 100 m outside the trawl track show an almost identical cummulative curve with a d50 of the superficial sediments ranging from 221.9 to 230.5 micron.
The sediments below the superficial layer are varying from 217.3 to 256.3 micron. The deepest subsamples are ranging from 217.9 to 242.9 micron. The sediments from this area are also very well sorted.

3.3.5 RECIPROCAL FORMATION FACTOR AND POROSITY PROFILES

Duplicate profiles of the reciprocal formation factor F^{-1} measured in 8 samples collected inside the trawl track (see Fig. 0.7 and 1.1) and in 5 samples collected outside the track are shown in figure 1.3. Porosity profiles measured in 5 samples collected in the trawl track and in 5 samples collected outside the track are shown in figure 1.4a and 1.4b, respectively. The mean values of these porosity profiles in and outside the trawl track are shown in Fig. 1.5a and 1.5b. At first there seems to be no statistically significant difference between the samples from the trawl track and the samples collected outside the track. The problem lies in the fact that not all samples which were supposed to be taken from a trawl track have indeed been taken there. As stated before the geological features indicate that samples S6-S8 were not taken inside a track. Apparently the very accurate positioning system of the survey vessel, including the sampling gear, does not guarantee that the samples come from inside a track. This seriously hampers comparative research, and in future research this needs to be taken into account. However, since there are clear indications that samples S1 - S5 come from inside the track we will treat those accordingly. Although there are remarkable differences between different profiles, these differences can be found both inside and outside the tracks. The lack of a fixed horizon or a reference depth inside the samples hampers possible general calculations and the drawing of general conclusions from all profiles together. A reference depth is needed not only because a part of the sediment stirred up by the passage of the beam trawl will resettle outside the fish track, but also because the depth of the disturbed bottom layer will depend on the position of the bottom sample (on top of the ripples or between them). Therefore, these techniques cannot accurately indicate the penetration depth of the fishing gear into the sediment. Only if natural

markers, e.g. shell layers or anaerobic colour change, are present at a fixed depth, or if divers introduce a marker in the sediment before the fishing takes place the actual penetration depth of the fishing gear may be established by measuring profiles in the sediment.
However, a closer look at the different profiles yields some interesting information. The F^{-1}-gradient in sample S1 (Fig.1.3a) is the only gradient showing a distinct increase of the reciprocal formation factor at 4-5 cm depth. This sample possibly was taken from the centre of the trawl track (Fig. 0.7) and apparently the sediment in this centre is less dense than the other sediments measured. This could indicate that after the passing of the net the resuspended sediment is partly collected at the spot where the cod-end of the net just passed. Apparently the net shape causes some turbulent flow behind the net which deposits part of the sediment in the centre of the trawl track. This would explain the relatively loosely packed sediment (high F^{-1}) at this spot. The side scan sonar record of the track (Fig. 0.7) showing a shade in the middle of the track supports this hypothesis. Furthermore, it is striking that none of the profiles taken inside the track show a dip in the reciprocal formation factor in the first few centimetres as was found in samples B10A and B13B. The fact that only the straight profiles were found in the samples from the track could indicate that the top 4 cm of the sediment was removed by the fishing gear. Some of the samples show higher reciprocal formation factors deeper in the sediment. This is related to the relatively high values measured in the overlying water, and could be a measure of disturbance of the boxcorer sample. The mean porosity profile in the trawl track (Fig. 1.5*) points to a sediment which is less dense in the uppermost 4 cm. This could be an indication of resuspended and redeposited layers. Analysis of the mean porosity profile in the trawl track, showing decreased porosity in the sediment deeper than 4 cm, (Fig. 1.5*), points to a removed upperlayer, forcing the sediment-water boundary towards the deeper more compact layers. Due to the lack of a reference depth the thickness of the removed or disturbed layer cannot be estimated. One possible reason could be that beam trawling compresses the sediment resulting in decreased porosity values. Sample B11 has relatively high F^{-1} values in the uppermost 4 cm and high porosity values in the top 6 cm. This is due to the muddy nature of this sediment. Assuming that samples S1 - S5 were taken inside the tracks and the other samples outside the tracks the reciprocal formation factor and the porosity both indicate that the uppermost 4-5 cm of the sediment within the track were disturbed by the trawling.

3.3.6 FORAMINIFERAL ASSEMBLAGES

Of two samples (SF1 and BF9) of the upper 10 cm of respectively the boxcores S1 (in the trawl track) and B9 (100 m outside the trawl track) foraminiferal analysis has been done at each centimetre. In order to recognise the living foraminifera Rose Bengal was used to stain the protoplasm. The samples contained a poor to very poor foraminiferal fauna. Only five specimens showed a red colour, indicating that they were possibly alive during the sampling. No living specimens were found in the top layer. Because of the lack of living specimen all foraminera were used. In Fig. 1.6 two curves are shown in which the percentages of the total number of foraminifera are given against the depth. In BF9 (100 m outside the trawl track) two peaks are present at respectively 2 cm and at 4 - 6 cm depth. In the curve of SF1 (in the middle of the trawl track) also two peaks occur at respectively 2 and 8 cm depth. Between those two peaks a layer of about 4 cm thick with a low percentage of foraminifera is present (Neele, 1990). A possible expla- nation is that the uppermost layer was disturbed by trawling down to a depth of 6.5 cm. This could explain the layers with low percentages of foraminifera. The peak in SF1 at 8 cm is probably similar to the peak at 4 - 6 cm in the curve of BF9. The peak in the top layer in curve SF1 was probably formed by redeposition after whirling up of sediments by the trawl. The sand fraction drops faster than the relative light foraminifera which will accumulate in the top layers.
This could point to a penetration of the trawl of ± 6.5 cm.

3.3.7 MEIOFAUNA

Of the different meiofauna organisms only the nematodes were present in sufficient numbers in all samples to draw conclusions. The results (Fig. 1.7) clearly indicate a difference between the samples taken inside the track and the samples taken outside the track. The typical profile with a distinctive maximum in the top centimeters and the relatively high numbers of nematodes which are found outside the track are completely missing inside the track. These results are influenced by different factors. The location where the shoes, or the cod-end of the net of the beamtrawl passed may cause different sediment movements leading to different profiles. Because of the high mobility of some of the species of the meiofauna the time lapse between trawling and sampling may have influenced the profiles. Nevertheless, the meiofauna distribution after passing of a trawl clearly indicates that the meiofauna is influenced till a depth of 7-8 cm in the sediment.

3.4 CONCLUSIONS

-- The absence of parallel lamination in the top few cm of the cores S1 to S5 is probably due to the trawling activities. This can be concluded from the cores S6 to S8 which must have been taken close to the trawl track and the cores B9 tot B13 taken ± 100 m from the trawl track. The parallel lamination in the top of the last mentioned cores is absent in the cores taken in the trawl track. The thickness of the laminated beds is mainly 3 to 7 cm, so the disturbance caused by the trawl is minimal 7 cm.

-- In the X-ray photographs the sedimentary structures as described from the lacker peels are not visible. The photographs mainly show fine sediments without sedimentary structures. At the top hardly no shells occur. Near the base the sediments become more shelly.

-- The grainsize analyses did not show the coarsening of the superficial sediments in the uppermost cm in the trawl track caused by trawling. The superficial sediments in the trawl track however show a wider ranges (47.1 micron) in the d50 than the cores taken outside of the track 18.1 (close to the trawl track) and 8.6 micron (± 100 metres from the trawl track). This difference in d50 in and outside of the trawl track probably points to the reworking due to the trawling.

-- *Measuring profiles of sediment characteristics in trawl tracks,* without knowledge of the original profile at the same spot, or without the presence of a fixed reference depth can not give an accurate measure for the penetration depth of fishing gear.

-- The passage of a beamtrawl passing disturbed the sediment at depths between at least 4 and 8 cm.

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Table 1.1 List of sampling stations

STATION	Sample	Date	Time	Latitude	Longitude	Depth (m)
90BC1	S1	23/8/90	10.00-13.00	53°51'29.5"	5°48'32.3"	29.5
90BC2	S2	"	"	"	"	"
90BC3	S3	"	"	"	"	"
90BC4	S4	"	"	"	"	"
90BC5	S5	"	"	53°51'29.3"	5°48'32.9	"
90BC6	S6	"	"	"	"	"
90BC7	S7	"	"	53°51'28.9"	5°48'33.21"	"
90BC8	S8	"	"	53°51'28.8"	5°48'33.2"	"
90BC9	B9	"	16.00-18.00	53°51'24.5"	5°48'26.6"	28.8
90BC10	B10	"	"	"	"	"
90BC11	B11	"	"	"	"	"
90BC12	B12	"	"	"	"	"
90BC13	B13	"	"	"	"	"

S= trawl track
B= blanc, outside trawl track

Explanation of used code: 90BC1= 1990 BOXCORE 1; S1= CORE 1 supposed to be taken in the trawl track; B9= core 9 taken outside the trawl track.

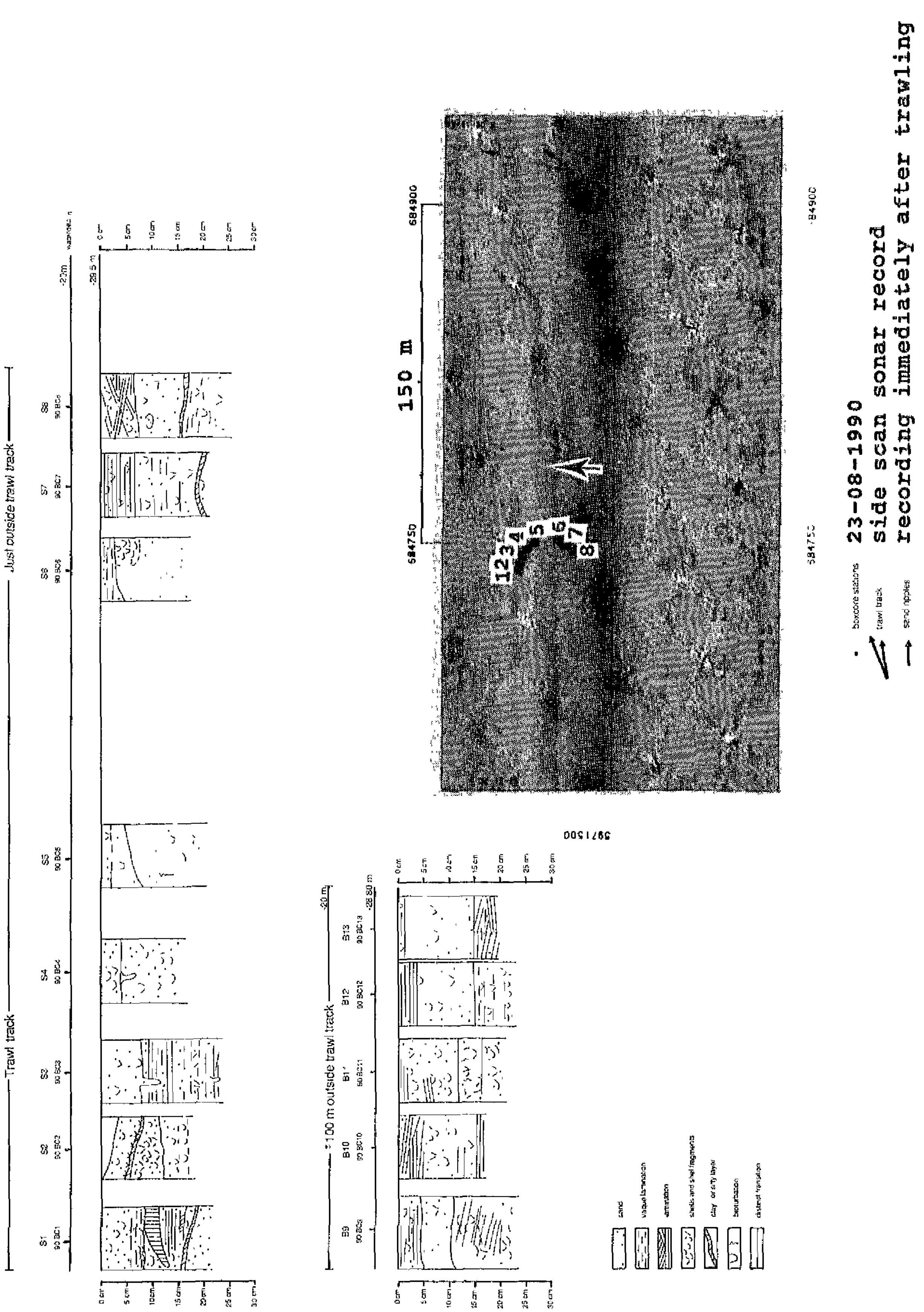

FIG. 1.1: Sedimentary stuctures as described from the lacker peels. In the uppermost cm of the cores S1 to S5 no sedimentary structures occur. In the cores taken just outside and at ± 100 m outside the trawl track in the uppermost cm of each core to a certain depth sedimentary structures occur. The lack of sedimentary structures in the first 5 cores points to a disturbance by the fishing gear to at least a depht of 7 cm.

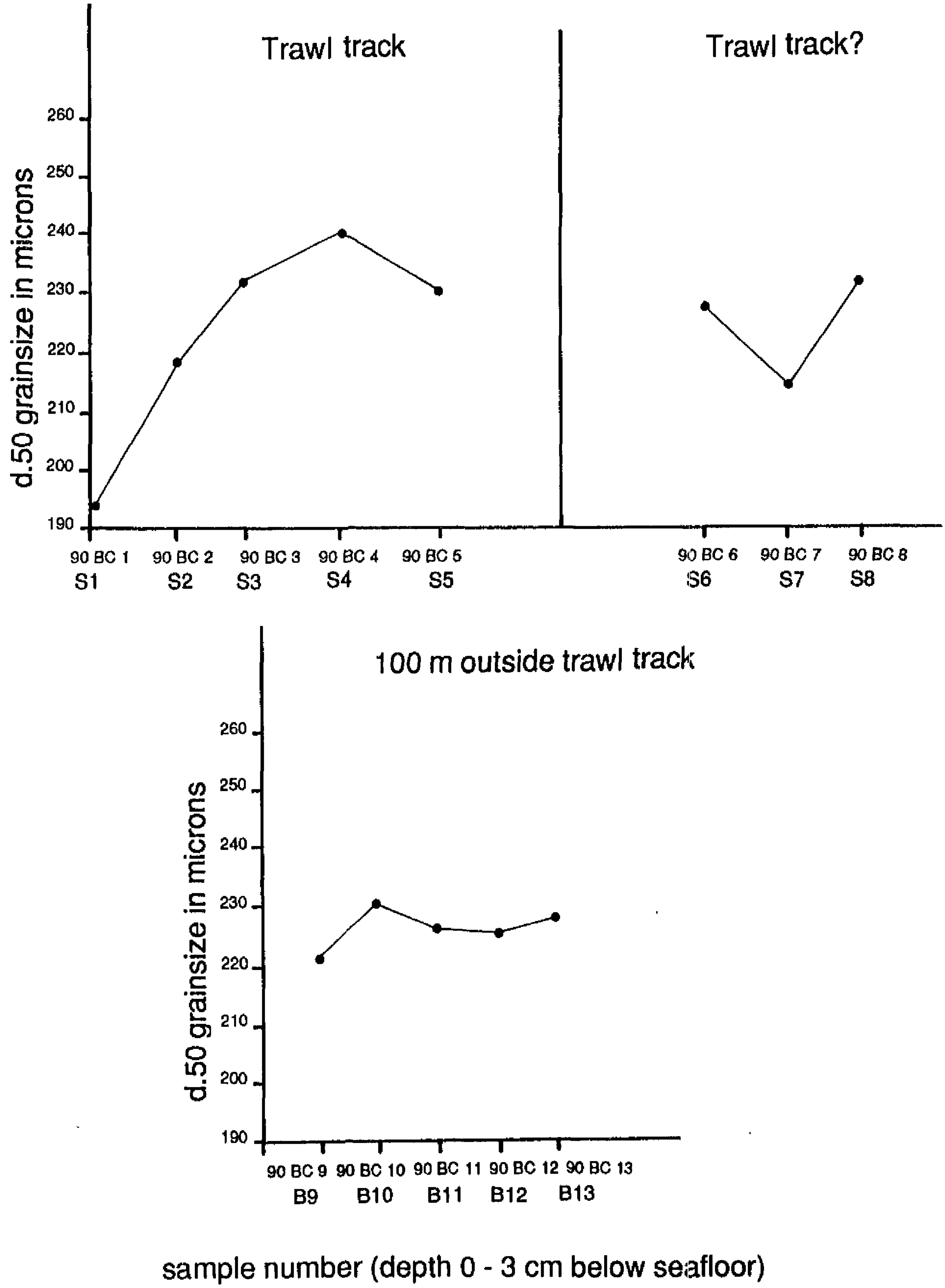

FIG. 1.2: The d50 of the sandfraction from 0 to 3 cm in the trawl track, just outside the trawl track and at 100 m outside the trawl track shows a range of respectively 47.1, 18.1 and 8.6 micron. The differences point to the reworking of the upper laminated beds by trawling.

Geological Survey of the Netherlands, RGD

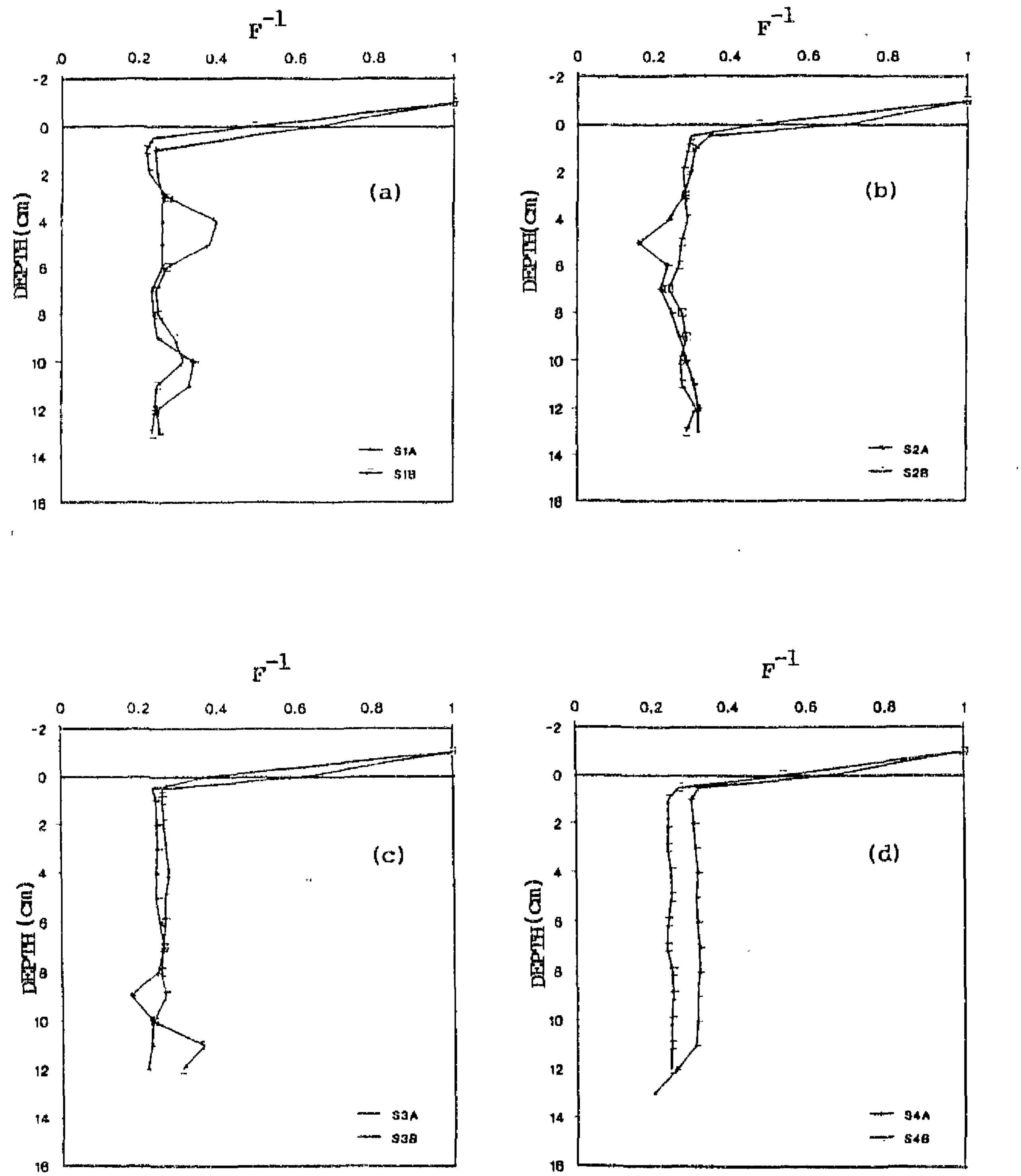

FIG. 1.3[a]: Depth profiles of the reciprocal formation factor in sediments collected in the trawl track (a-h) and outside the trawl track (i-m).

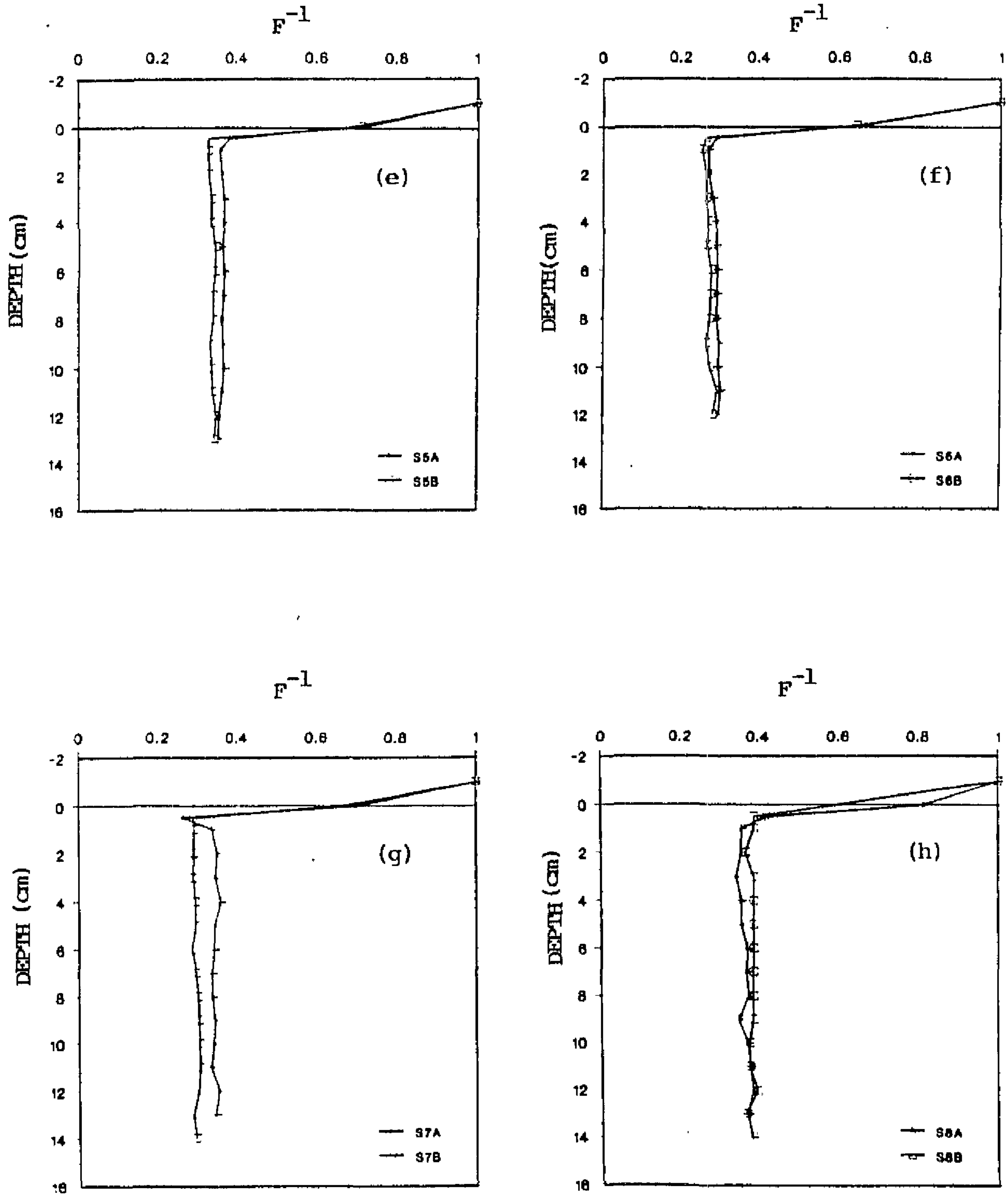

FIG. 1.3[b]: Depth profiles of the reciprocal formation factor in sediments collected in the trawl track (a-h) and outside the trawl track (i-m).

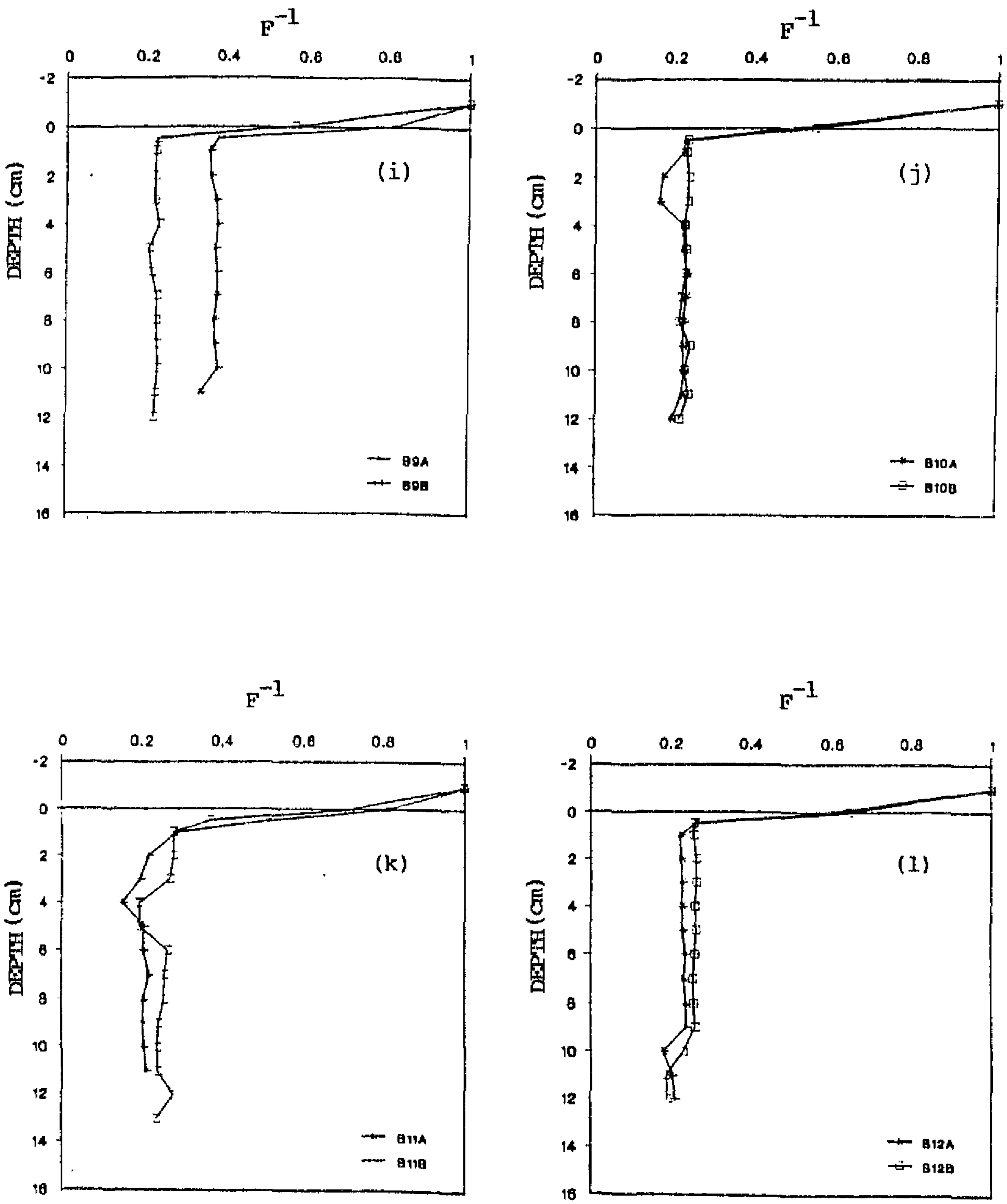

FIG. 1.3c: Depth profiles of the reciprocal formation factor in sediments collected in the trawl track (a-h) and outside the trawl track (i-m).

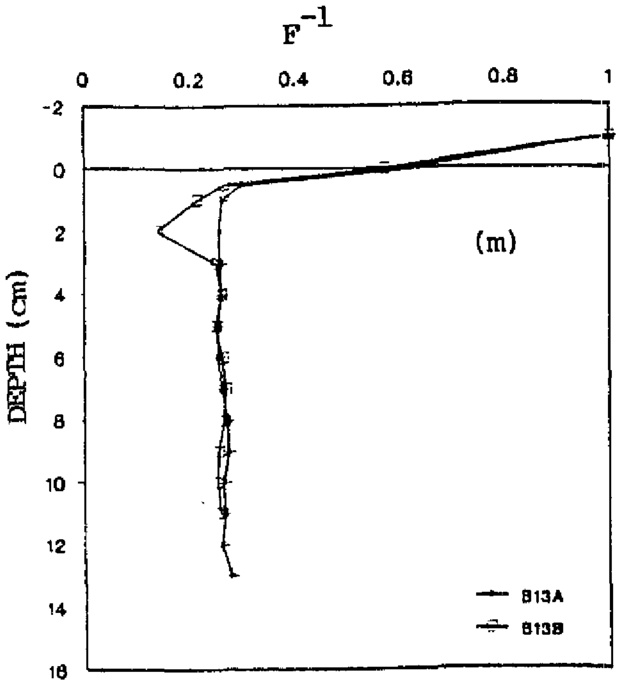

FIG. 1.3[d]: Depth profiles of the reciprocal formation factor in sediments collected in the trawl track (a-h) and outside the trawl track (i-m).

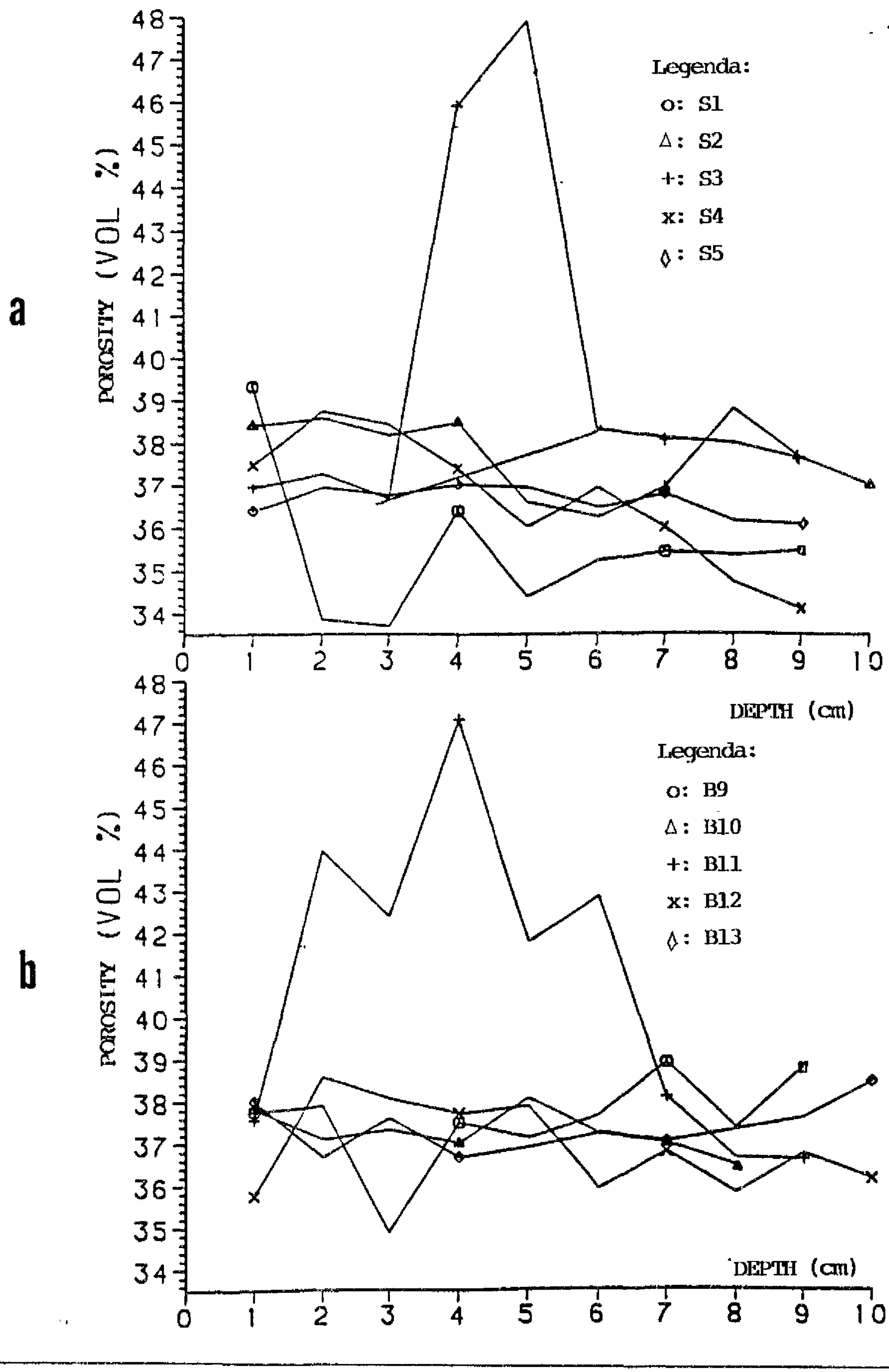

FIG. 1.4: Porosity profiles of the cores S1-S5 which are supposed to be taken in the trawl track (a) and B9-B13 which are taken outside the trawl track (b). The peak in core S3 is due to a shell fragment, the peak in the profile of core B11 is due to the high mudpercentage.

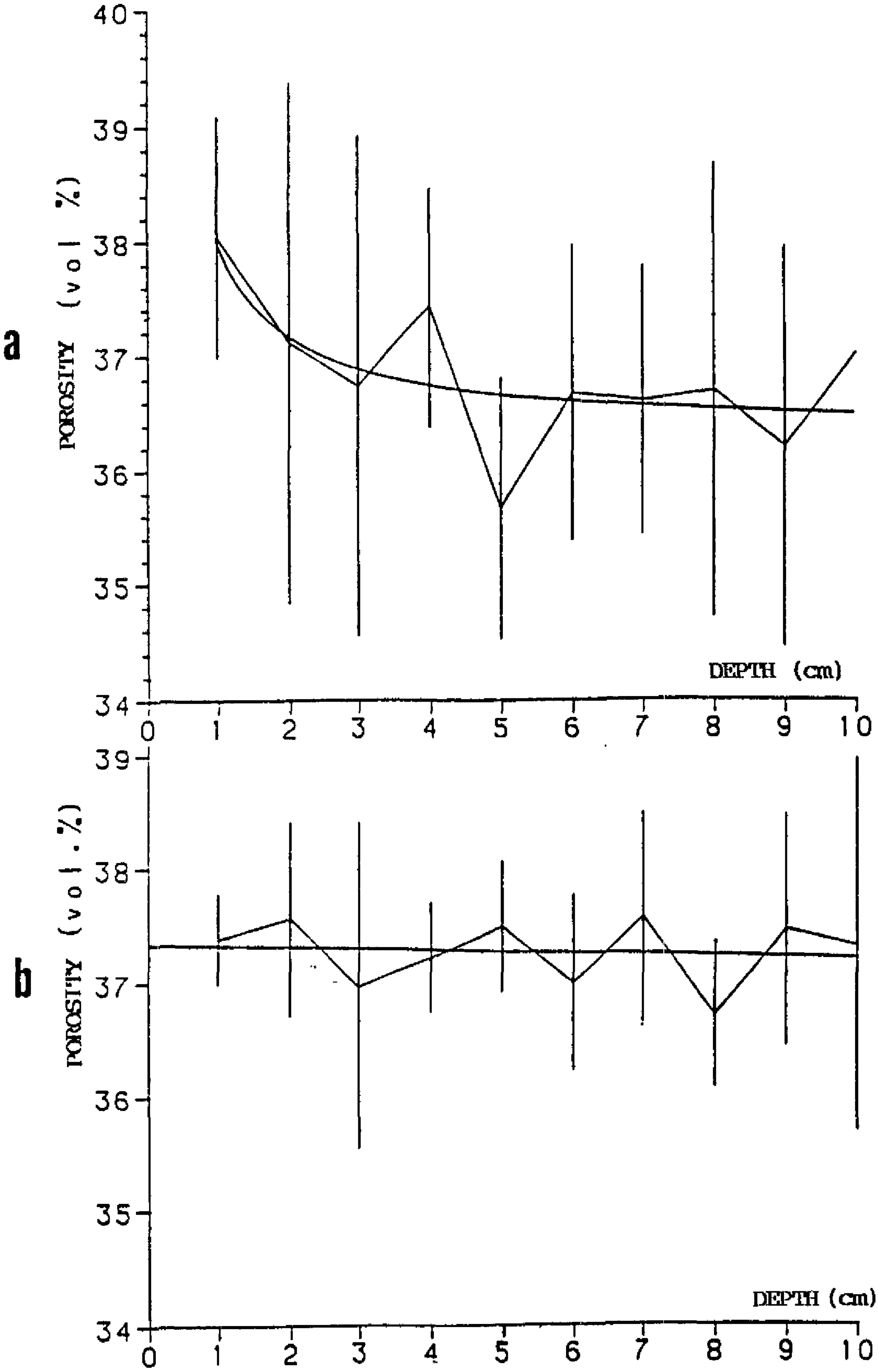

FIG. 1.5: Mean porosity profiles of the cores S1-S4 and B9-B13. S5 has been deleted because of the position at the edge of the trawl track and B11 because of high mud percentage.

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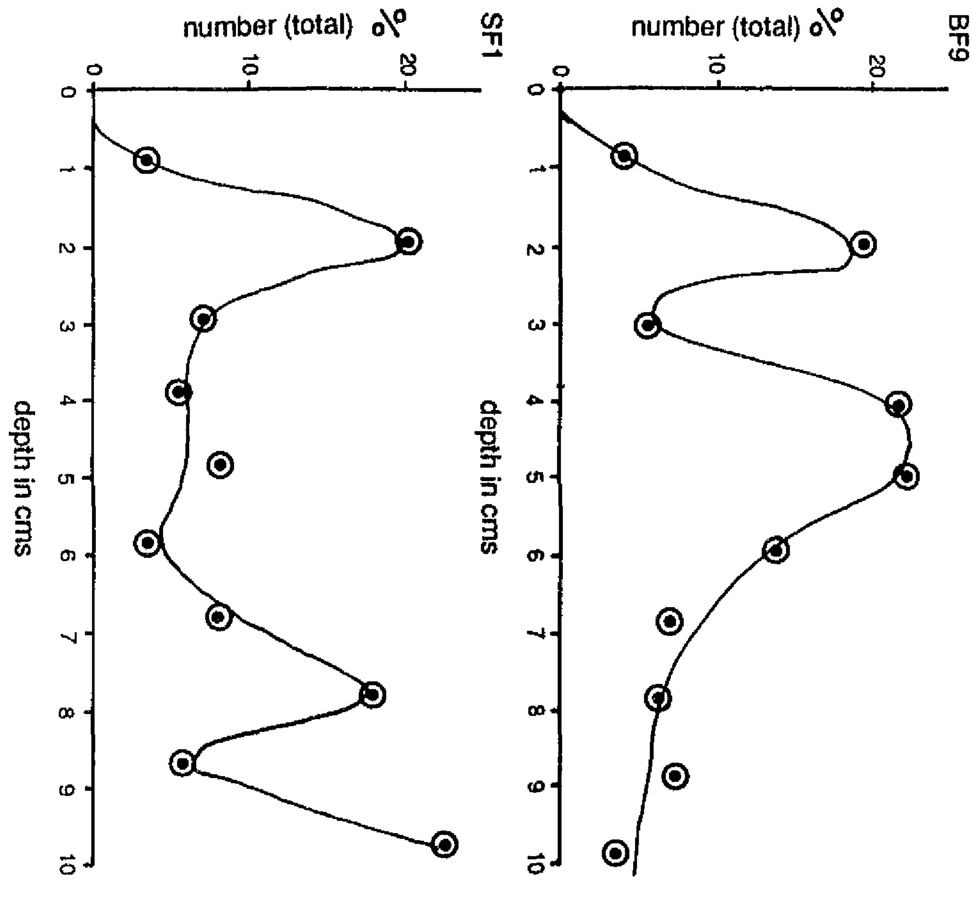
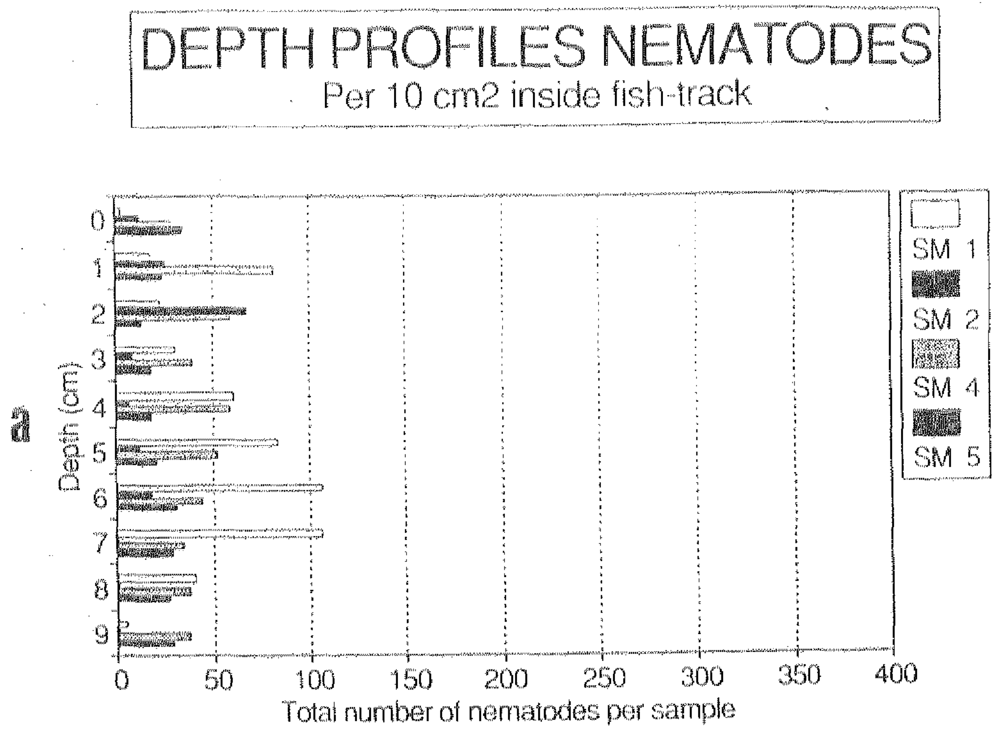


FIG. 1.6: Foraminifera in percentages of the total number in the middle of the trawl track (SF1) and 100 m outside the trawl track (BF9). The foraminifera are dominated by 2 species Ammonia beccari and Cribonium excavatum f selseyense. The lack of specimen in the curve at the left is probably due to trawling. The lower peak corresponds with the lower peak at the curve at the right. During the trawling the sediments are wirled up and the relative light foraminifera are deposited after the sandgrains which explains the second peak in SF1. The maximum reworking by trawling as read from the curves is ± 6.5 cm.



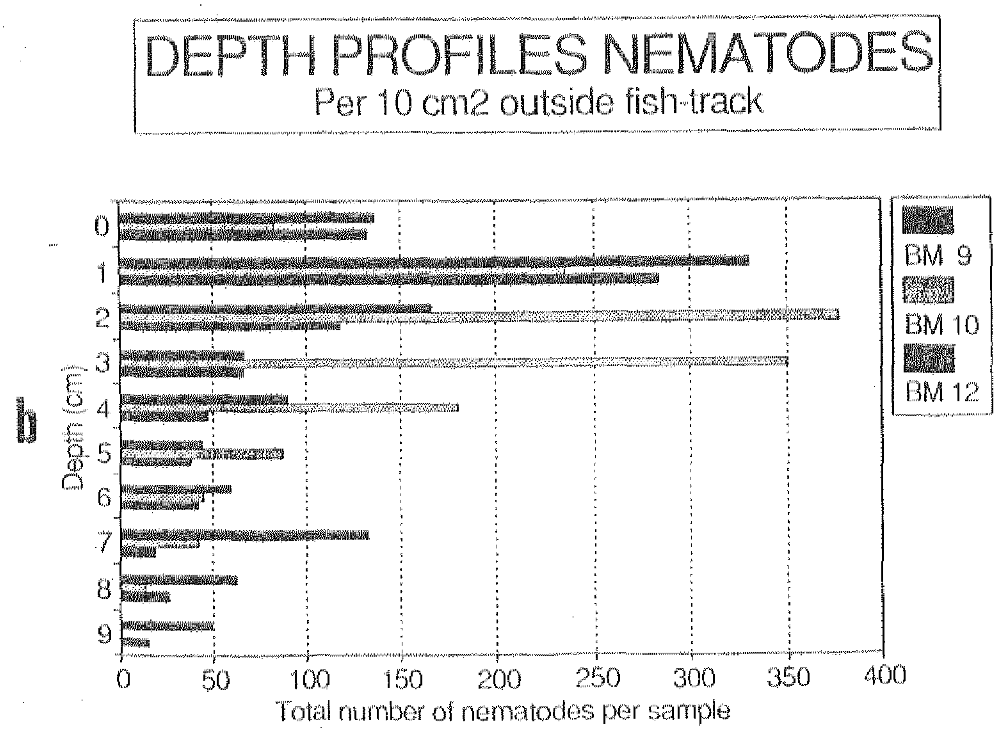


FIG. 1.7: Depth profiles with the numbers of nematodes in- and outside the trawl track, fig. 1.7[a] and fig. 1.7[b] respectively, clearly indicate a difference between the samples taken inside the track and the samples taken outside the track. The typical profile with a distinctive maximum in the top centimetres and the relatively high numbers of nematods which are found outside the track are completely missing inside the track.

DIHO

4. STUDY 2: MEASUREMENTS OF CATCH COMPOSITION AND SURVIVAL OF BENTHIC ANIMALS IN BEAM TRAWL FISHERY FOR SOLE IN THE SOUTHERN NORTH SEA.

(ed. M. Fonds)

4.1. INTRODUCTION

From 29 to 31 August 1990 the catch composition and survival chances of benthos were investigated on board of a commercial beam-trawler, fishing for sole (Solea solea) with two 12 meter beamtrawls and 8 cm meshsize nets with 10 tickler chains in front of the ground chain. The investigations concerned :

1. Composition of the catch in marketable fish - discard fish - benthos rest (invertebrates).
2. Mortality of invertebrates in the catches during sorting on deck.
3. Survival chances of invertebrates that are thrown back alive into the sea after sorting of the catches.
4. Survival chances of undersized flatfish and other small fish that pass through the 8 cm meshes of commercial sole nets.

Mortality and survival were investigated particularly in relation to the effect of tickler chains. Therefore the tickler chains were removed from the port-side net whereas the starboard net was fully rigged with 10 tickler chains. Catch composition and the survival chances of benthic animals were compared for the two nets.

4.2. METHODS

1. The total catch of starboard net (A) and portside net (B) were estimated by the crew in numbers of baskets, one basket was 33 kg. From each haul one basket was randomly filled from the belt lifting the catch to the sorting table. All fish and invertebrates in this sample were counted and weighed with a hand-held string balance.

2. One random (unsorted) sample of 10 litre of benthos rest (without fish) was collected from each catch on the sorting table. The sample was immediately stored in a 100 litre tank with running sea water and the numbers of dead and living benthic invertebrates were counted. The living specimens were used in survival trials. Most of the benthos rest consisted of starfish (Asterias rubens). In order to get sufficient numbers of other species for the survival tests, another 10 litre sample of benthic evertebrates without starfish was stored similarly in a 100 litre tub with sea water.

3. Survival of living specimens of different species was estimated over a period of 2-3 days in survival tanks with running sea water. The tanks were designed by the Fisheries Institute IJmuiden (R.I.V.O.) and described in the I.C.E.S. paper of VAN BEEK et al.1989. Survival of larger animals, such as edible crabs (Cancer pagurus) and starfish (Asterias rubens), was estimated in 100 litre sea water tanks. The survival tanks for some species (Astropecten, Ophiura, Arctica, Aphrodyte) were provided with a layer of sand, dredged with a VAN VEEN sampler, in order to give the animals the possibility to dig into sediment. The surface sea water temperature was 17.8 °C, temperature of running sea water (from deckwash) in the survival tanks was 18.2 °C.

4. Some very short hauls of 2 minutes were made with the starboard net (net A with ground chains) covered with a fine-mesh outer net (2 cm meshes). Fish that escaped through the 8 cm meshes of the commercial sole net were collected in the covering fine-mesh cod-end. After 2 minutes fishing at full speed the net was hauled and both the fine-mesh cod-end as well as the large-mesh cod-end were hoisted on board rapidly and carefully put into two 100 litre sea water tanks. The nets were opened in the water and fish were collected for survival experiments. The whole operation took about 5-10 minutes, the cod-end of the larger net was hanging in the air several minutes because the small-mesh cod-end had to be put aside and opened first.

4.3. RESULTS

Position of hauls, speed of the ship during fishing and the bottom area covered by each tow, are presented in Table 2.1. Total catch in kg per ha (10000 m^2) was calculated from the number of baskets multiplied by 33 kg. The hauls 1, 2, 4 and 5 were situated inside I.C.E.S. quadrant 36 F5, on the verge of the "Plaice Box", an area north of the Frisian islands where commercial fishing is limited. During hauls 4, 5 and 6 only the starboard net (A, with ground chains) was used because on the port-side an underwater vehicle with video camera was towed for observation of the fishing net. Fishing speed in these hauls was therefore lower (5 mph = 9 km/hr) as compared to the other hauls (7 mph = 12.6 km/hr).

4.3.1. Catch composition.

The general composition in marketable fish - discard fish - benthos rest in the catches is presented in Table 2.2, both in numbers (n) and in weight (kg) per hectare (10000 m2). Numbers of echinoderms and crabs are presented, because they dominated in the benthos rest.
The % catch composition of fish and benthos is presented in Table 2.3. Benthic invertebrates dominated in numbers (70 % of total catch), fish were more important in weight (64 % of total catch). Most of the fish were undersized discards (80-90 % in numbers, 60-80 % in weight), the benthos rest consisted mainly of echinoderms (80-90 % : Asterias, Astropecten, Ophiura, Echinocardium). The % composition per basket of the three most abundant fish species, plaice (P.platessa), dab (L.limanda) and sole (S.solea), is presented in Tables 2.4 and 2.5. For comparison the first three catches are summed for starboard net (A, with chains) and port-side net (B, without chains) because they were taken at the same time and the same position. The sum of all 6 catches with starboard net (net A) is also presented, indicating the catch composition for normal gear in different areas. Differences in % composition between A-net (with chains) and B-net (without chains) were small and not significant.
Most of the fish in the catches were flatfish, other commercal species (approx. 5-7 % of total catch) concerned mainly : young turbot (Scophthalmus maximus), brill (Rhombus laevis), gurnards (Trigla sp) and whiting (Merlangius merlangus). The % distribution in numbers and weight of the three most abundant flatfish (Sole, Plaice and Dab) is presented in Table 2.5. For the normal gear (A) the amount of discard fish in the catches was estimated at appoximately 60 % (in weight) to 80 % (in numbers). For soles only 5-10 % were discard, for plaice 55-85 % and for dabs 95-100 % . Catches of the net without chains contained less undersized plaice (56-86 %) as compared to the net with chains (80-90 %). The net with chains caught about two times more commercial fish (Table 2.2). When the value of plaice is set at dfl. 4/kg and sole dfl. 20/kg, the net with chains (A) caught about four times the money value of catches without chains (B), explaining why commercial beam trawling is carried out with 10 tickler chains.
Numbers per basket of the most common invertebrates in the different catches are presented in Table 2.6. Numbers and % dead or damaged individuals, counted in 10 litre samples taken from the sorting table, are presented in Table 2.7. Numbers of large and rare animals collected from the whole catch are presented in Table 2.8. It was not possible to ascertain whether starfish collected from the sorting table were actually dead, therefore only the number of damaged individuals is presented, survival % follows from Table 2.9.

4.3.2. Survival experiments.

The survival tests were always started with living animals, collected from the sorting table and stored immediately in seawater. The observations therefore refer particularly to the survival chances of benthic animals that are thrown back alive into the sea during sorting of the catch. Survival in the tanks was checked every day over a period of two to three days. Total numbers of invertebrates used in the survival tests, numbers of dead animals after 1-3 days and the % survival in our experiments are presented in Table 2.9 (net A, with chains) and Table 2.10 (net B, without chains). In general, survival chances were higher for invertebrates collected from the net without chains. The total % survival chance, estimated as % survival in the net observed during sorting on deck and % survival chance of living animals thrown back into the sea, is presented in Table 2.11 together with total survival chances estimated a year before (BEON report 1989). In the net with chains (A) survival was lower for edible crab (73 %), masked crab (39 %) and in one haul also sea stars (55 %). Survival of Ophiura was relatively low in both nets (60-70 %). Edible crabs (Cancer pagurus) collected from night time catches were often undamaged (Table 2.8 , hauls 1 & 2 at 20-22 hr : 37 crabs undamaged and 5 damaged), whereas crabs in day time catches were more often damaged (14 undamaged and 26 damaged). Edible crabs have a nocturnal way of life, digging into the sand bottom during the day. They are possibly scooped up by the net more or less undamaged when they crawl around at night, whereas crabs buried in the sand during the day are often decarapitated by the ground chains. The shellfish Arctica islandica was often already damaged in the net. However, many of these large black shells also broke when they dropped over a distance of 80 cm from the carry up belt onto the sorting table. This was tested twice, by putting 10 undamaged living animals on the belt : the first time 5 of the shells broke, the second time all ten shells broke when they dropped on the sorting table.

4.3.3. Survival of fish.

Figure 2.1 shows the length distribution of the three most abundant flatfish in the normal sole net (net A). Results of survival experiments with fish collected in the fine-mesh covering net after short hauls are presented in Table 2.12. In general, survival was high (75-100 %), only dab (L.limanda) showed a low survival : 67 % for dab from the outer covering net and 38 % for dab collected from the 8 cm-mesh large net. Fish in the large net had been out of the water longer (about 5 minutes) as compared to fish from the covering net, which may explain the difference. Still it is obvious that dab is more vulnerable than other flatfish and probably suffers more from beamtrawl fishery.

4.3.4. Benthos through the meshes.

The fine-mesh covering net also contained benthic invertebrates that passed through the 8 cm meshes of the large net : particularly many small sea urchins (Echinocardium cordatum, 2.5-3 cm diameter, Figure 2.2) and starfish (Asterias rubens, 6-10 cm diameter). Echinocardiums and starfish with diameters less than 2 cm probably went through the 2 x 2 cm meshes of the covering net. The small Echinocardiums in the covering net were densely packed and so severely damaged as to make survival experiments useless. Catches with the large net often contained fairly large numbers of large Echinocardium of 4-4.5 cm diameter (Fig.2.2).

4.4. DISCUSSION

4.4.1.Catch composition.

Commercial beamtrawlers catch about 3-20 kg fish and 3-7 kg benthic invertebrates per ha (10000 m2). When we take a percentage ash-free dry weight (% AFDW) of 15 % for fish and 10 % for invertebrates, this leads to a catch of 0.05 - 0.3 g AFDW / m^2 in fish and 0.05 - 0.1 g AFDW / m^2 in benthos. From the fish about 67 % is discarded with no survival chance, while all benthic evertebrates are discarded and about 40 % will die. This means that in ash-free dry weight (= dead organic material) a fishing beam trawler produces at least about 0.05 - 0.25 g AFDW / m^2. During other trawling surveys in the southern bight, with small nets and short hauls, dead fish were regularly found. Those dead fish are probably discards from commercial fishing. The question rises what kind of animals can or will eat this dead material? Birds can consume floating dead fish (Gadoids), while large predatory fish such as cod (Gadus morhua) or scavengers such as dab (L.limanda) may also consume part of the dead material. Echinoderms from the catches showed a high survival chance and they were discarded together with dead fish and dead benthos. Asterias rubens was the most abundant species and it is a well known scavenger that certainly eats dead fish. Hence, it is possible that the fishery is "feeding" the

starfish. Other species of starfish, such as Astropecten and Ophiura, are more specialized feeders (Astropecten in our survival experiments often released young whole Natica's, many still alive). It is also possible that other carnivores, such as the abundant worm Nephthys, may play some role.
Can we estimate the total annual production of dead material by the beamtrawl fishery ?
From Table 2.2 it follows that a commercial beamtrawler fishing for sole catches about 34.5 kg market fish - 45.7 kg discard fish - 43.2 kg benthos. Hence, the production of discard fish is about 1.3 times the landing of marketable fish. However, this applies only to sole fishery in Summer, beamtrawlers fishing for plaice use nets with wider meshes (12-13 cm mesh size). Therefore it is better to estimate production of dead fish by the sole fishery only from the landings of sole on the fish market. From Tables 2.2, 2.3, and 2.4 we can estimate that sole fishery catches the following relative amounts of fish :

13.4 kg total fish, 5.8 kg marketable fish.
1.7 kg marketable sole
7.6 kg discard fish
7.2 kg benthos rest, resulting in 2 kg dead benthos.

According to our estimates, based on a limited number of hauls in a limited area, the production of dead discard fish by sole fishery in summer is about 4-5 times the total landings of sole, the amount of dead benthos produced is about equal to the sole landings.

4.4.2. Effect of the ticklerchains on discards and benthos.

Notable is the effect of the ticklerchains on the amount of discards and benthic animals (see table 2.0). The use of ticklerchains results in nearly two times larger fishcatches than without ticklerchains, but less than a doubling of the amount of discarded fish. Marketable fish are caught about three to four times more with ticklers than without, the money value of the catches with tickler chains is about four times the value of catches without chains.

4.4.3. Survival of benthos.

The density of benthic invertebrates in the survival tanks was very high (50-100 animals per tank). Animals that go through the meshes or pass directly after sorting of the catch back into the sea will probably have a higher survival chance. Besides, in our survival experiments the water temperature was relatively high for North Sea species (18 °C), survival may be higher in other seasons when temperatures are lower. Survival chances measured in our experiments can be considered as minimum estimates, the actual survival will probably be higher.

4.4.4. Survival of fish.

Fish in commercial catches are packed in the codend together with sharp and hard sea stars, and their survival chances can be considered as practically zero. Fish that went through the meshes in the short test hauls of two minutes, however, showed a survival chance of 75-100 % . This indicates that fish are not severely damaged by the ground chains when they enter the net. VAN BEEK et al.(1989) estimated survival of plaice and sole in beamtrawl catches in relation to duration of the haul (hauls from 15 to 120 minutes). According to their report the % survival chance of flatfish shows an inverse linear relationship with tow length, indicating that mortality at time 0 (when the fish enter the net) would be 40 % . This is not in agreement with our observations on survival in very short hauls. However, when the data of VAN BEEK et al. are plotted together with our data (Figure 2.3), a semi logarithmic relationship can be calculated between % survival (S%) and time or duration of the tow (t, minutes):

ln S% = ln a - b.t or	: $S\% = a \cdot e^{-bt}$	
Sole through the meshes	: $S\% = 90\ e^{-0.018t}$	(r= -0.95, n= 13)
Sole discards from net	: $S\% = 80\ e^{-0.018t}$	(r= -0.91, n= 12)
Plaice discards from net	: $S\% = 94\ e^{-0.015t}$	(r= -0.94, n= 10)

This indicates rates of survival at t=0 of 90, 80 and 94 % respectively. A mortality of 10-20 % may be due to the 10 tickler chains in front of the net. Small fish species that pass throug the nets, such as dragonet (Callionymus lyra) or solenette (Buglossidium luteum), showed a high survival chance in our experiments. This suggests that these species may take advantage of the heavy bottom trawling and may have become more abundant in the southern North Sea.

LITERATURE.

BEON - Report 8, 1990. Effects of beamtrawl fishery on the bottom fauna in the North Sea. (57 pp.).

VAN BEEK,F.A., P.I.VAN LEEUWEN & A.D.RIJNSDORP, 1989. On the survival of plaice and sole discards in the otter trawl and beamtrawl fisheries in the North Sea. (I.C.E.S., Dem.Fish Comm., C.M.1989 / G46).

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TABLE 2.0.

Dead benthos, discards and fishcaught with- and without ticklerchains. Comparison of mean catches from haul 1, 2 and 3 (week 2).

	A net -with ticklerchains	B net -without ticklerchains
Steel over the bottom (net+ticklerchains)	2050 kg	750 kg
dead benthos	1.7 kg	0.9 kg
fish discards	7.8 kg	4.7 kg
market allowed fish	3.4 kg 1)	1.0 kg 2)
market value 3)	dfl 24.80 3)	dfl 4.80 3)

1) 2.7 kg plaice + 0.7 kg sole
2) 0.95 kg plaice + 0.05 kg sole
3) plaice dfl 4.00 /kg; sole dfl 20.00/kg

TABLE 2.1.

Position of hauls, speed of the ship during fishing and the total area covered by each net in ha (10000 m2). Estimates of total catch in kg for starboard net A (with 10 ground chains) and port-side net B (without ground chains).

Haul no	Date 1990	Time	Position	Depth m	Speed mph	Time haul min.	Length haul m	Surface area ha	Catch kg
1A	27-8	20.00	53.47-5.40	34	7	30	6300	7.6	200
1B	,,	,,	,,	,,	,,	,,	,,	,,	100
2A	,,	22.00	,,	34	7	75	15750	18.9	330
2B	,,	,,	,,	,,	,,	,,	,,	,,	170
3A	28-8	11.00	54.19-5.24	47	7	90	18900	22.7	170
3B	,,	,,	,,	,,	,,	,,	,,	,,	100
4A	29-8	14.00	53.49-5.43	29	5	115	17250	20.7	730
5A	,,	19.00	53.47-5.20	32	5	115	17250	20.7	660
6A	30-8	10.00	52.55-3.50	25	5	150	22500	27.0	100

TABLE 2.2.

The general catch composition in fish and benthos, in numbers (n) and in weight (kg) per hectare (10000 m2).

Haul	Market fish n - kg	Discard fish n - kg	Total fish n - kg	Benthos n - kg	Numbers of Echin.	Crabs
1A	22 - 6.7	205 - 15.6	227 - 22.3	257 - 7.1	208	47
1B	3 - 0.6	95 - 6.9	98 - 7.5	213 - 4.1	187	26
2A	11 - 2.5	68 - 5.8	79 - 8.3	- - 6.8	-	-
2B	8 - 1.6	56 - 5.2	64 - 6.8	216 - 3.3	201	15
3A	5 - 1.0	41 - 1.9	46 - 2.9	147 - 3.2	127	8
3B	4 - 0.7	37 - 2.1	41 - 2.8	67 - 1.6	57	7
4A	35 - 9.6	129 - 10.2	164 - 19.8	631 - 16.3	576	51
5A	55 - 13.5	152 - 10.6	207 - 24.1	507 - 8.9	454	46
6A	5 - 1.2	23 - 1.6	28 - 2.8	53 - 0.9	30	22

A : Net with chains, B : Net without chains.

TABLE 2.3.

Percentage catch composition in fish and benthos, and the numbers of starfish (Asterias) as % of total number of benthic invertebrates.

	Percentage of total catch Numbers Fish - %	Benthos %	Weight Fish - %	Benthos %	Discard fish as % of total fish. Numbers - %	Weight %	Sea stars, % of total n of invertebr. %
1A	47 -	53	76 -	24	90 -	70	81
1B	32 -	68	65 -	35	97 -	92	88
2A	(24) -	(76)	55 -	45	86 -	70	-
2B	23 -	77	67 -	23	88 -	77	93
3A	24 -	76	48 -	52	89 -	66	86
3B	38 -	62	64 -	36	90 -	75	85
4A	21 -	79	55 -	45	79 -	52	91
5A	29 -	71	73 -	27	73 -	44	90
6A	35 -	65	76 -	24	84 -	60	57
Mean :	30	70	64	35	86	67	84
St.dev.	9	9	10	11	7	14	11
A :	30	70	64	36	84	60	81
B :	31	69	65	35	92	82	89

A : Net with chains , B : Net without chains.

TABLE 2.4.

Relative numbers and weight of the three most abundant flatfish in the catches, estimated in one basket per catch.

	Common sole Solea solea n - kg	Plaice Pl.platessa n - kg	Dab Lim.limanda n - kg	All fish n - kg
Sum of first three catches with starboard net with chains (1A,2A,3A):				
Total :	41 - 6.9	222 - 30.7	353 - 16.3	641 - 56.9
Discards:	3 - 0.3	191 - 21.6	349 - 15.7	562 - 39.3
Discard %	7 - 4	86 - 70	99 - 96	88 - 69
Sum of three catches with port-side net without chains(1B, 2B, 3B) :				
Total :	21 - 3.2	282 - 35.1	371 - 20.7	729 - 64.6
Discards:	1 - 0.1	254 - 28.6	350 - 18.9	664 - 51.8
Dicard %	5 - 3	90 - 81	94 - 91	91 - 80
Sum of all 6 catches with starboard net with chains (A) :				
Total :	98 -16.7	436 - 68.6	646 -33.1	1257 -124.9
Discards:	11 - 1.0	339 - 38.7	630 -30.3	1047 - 74.6
Discard %	11 - 6	78 - 56	97 - 92	83 - 60

TABLE 2.5.

Percentage composition in numbers and weight of sole, plaice and dab in catches of A net (with chains) and B net (without chains).

	A net, with chains				B net, without chains			
	Sole -	Plaice -	Dab	Total	Sole -	Plaice -	Dab	Total
In numbers,								
% of flatfish	8	37	55	100	3	42	55	100
% of discards	1	29	53	83	0.1	38	52	90
% of marketable	7	8	2	17	3	4	3	10
In weight,								
% of flatfish	13	57	30	100	5	60	35	100
% of discards	0.5	40	29	70	0.1	48	32	80
% of marketable	12.5	17	1	30	5	12	3	20

TABLE 2.6.

Numbers of invertebrates in one basket for each catch.

Species Catch:	1A	1B	2A	2B	3A	3B	4A	5A	6a
ECHINODERMS:									
Asterias rubens	200	320	500	600	58	60	200	290	100
Astropecten irreg.	42	50	-	40	400	350	80	130	40
Ophiura spp.	-	100	-	120	-	-	90	50	130
Echinocardium cord.	70	-	-	-	120	20	180		
CRABS:									
Liocarcinus holsatus	24	62	-	48	9	20	26	40	90
Eupagurus bernhardus	33	7	-	4	24	24	20	8	94
Corystes cassivel.	2	3	-	4	5	10			4
Cancer pagurus		1	2				2		
MOLLUSCS:									
Arctica islandica	2		4		10	4		6	
Cardium echinatum					9	5			
Buccinum undatum					20	5			
POLYCHAETS:									
Aphrodite aculeata					10	10			

- : not measured.

TABLE 2.7.

Primary mortality of benthos in the net. Numbers of living and dead invertebrates in one 10 litre sample from each catch. Numbers in brackets indicate "damaged" starfish.

Catch :	1 A		2 A		3 A		Total		Dead or damaged
	n	dead	n	dead	n	dead	n	dead	%
ECHINODERMS:									
Asterias rubens	370		230		150		750		-
Astropecten irr.	28	(3)	16	(7)	284	(139)	328	(149)	(45)
Ophiura spp.	21	(21)	17	(17)	13	(13)	51	(51)	(100)
CRABS:									
Liocarcinus hols.	29	11	8	2	29	22	66	35	53
Eupagurus bernh.	13	2	2		71		86	2	2
Corystes cassivel.	2	2	-		10	8	12	10	83

TABLE 2.8.
Total numbers of large and rare invertebrates collected from the whole catches with A net (with chains) and B net (without chains).

	Cancer pagurus			Arctica isl.			Cardium echin.			Buccinum
	Total	damaged		Total	damaged		Total	damaged		all undam.
1 A :	8	1		13	7		-	-		-
1 B :	2	0		0	0		-	-		-
2 A :	20	4		15	10		-	-		-
2 B :	12	0		0	0		-	-		-
3 A :	3	2		88	70		12	8		20
3 B :	0	0		15	4		4	0		7
(4 A):	8	5		31	22		88	36		-
4 A :	9	7		20	16		-	-		-
5 A :	12	7		43	31		-	-		-
6 A :	8	5		21	15		-	-		-
Total A :	68	31	46%	231	171	74%	104	44	42%	27
,, B :	14	0	0	15	4	27%	-	-	-	-

TABEL 2.9.
Secondary mortality of benthos after sorting of the catch. Results of survival experiments with benthic invertebrates, collected alive from the starboard net (A, with chains). Numbers of dead animals removed from the survival tanks after 1, 2 and 3 days and the total % survival. Some experiments (started on Tuesday) lasted only 2 days.

Species		Numbers alive at start	Numbers dead after day 1	2	3	Total number dead	alive	Total surv. %
Asterias rubens	(Mo)	209	8	14	23	45	164	79
,, ,,	(Tu)	102	26	11	10	47	56	55
Astropecten irregularis		135	0	1	5	6	129	96
,, (damaged)	(Mo)	46	7	2	2	11	35	76
,, ,, ,,	(Tu)	52	2	1		3	49	94
Ophiura texturata & albida		112	0	8	18	26	79	71
Liocarcinus holsatus		61	2	6	2	10	51	84
Eupagurus bernhardus		112	1	5	4	10	102	91
Corystes cassivelaunus		13	5	3		8	5	39
Cancer pagurus		26	1	4	2	7	19	73
Arctica islandica		54	0	0	0	0	54	100
Cardium echinatum		58	2	0		2	56	97
Buccinum undatum		20	0	0		0	20	100
Aphrodyte aculeata		13	2	1		3	10	77

TABLE 2.10.

Secondary mortality and % survival of benthic invertebrates collected alive from the port-side net B without chains.

Species		Numbers at start	Numbers of dead 1	2	3	Tot.	Numbers alive	Surv. %
Asteria rubens	(Mo)	101	0	2	1	3	98	97
,,	(Tu)	100	4	9		13	87	87
Astropecten irregularis		101	0	0	1	1	100	99
,,		52	2	3		5	47	90
Ophiura texturata & albida		103	0	24	15	39	64	62
Liocarcinus holsatus		70	3	0	3	6	64	91
Eupagurus bernhardus		62	0	2	0	2	60	97
Corystes cassivelaunus		5	0	0		0	5	100
Cancer pagurus		12	1	0		1	11	92
Cardium echinatum		13	0	0		0	13	100
Buccinum undatum		7	0	1		1	6	86
Aphrodyte aculeata		12	0	2		2	10	83

TABLE 2.11.

Estimated total % survival chance of benthic invertebrates in commercial beamtrawl catches in sole fishery. *() = percentage damaged

Species	Percentage mortality On deck	Afterwards	Total	% survival estimated in 1990	1989
Asterias rubens	?	29	29	71	80
Astropecten irregularis	*(45)	4-14	9	91	70
Ophiura texturata & albida	*(100)	29	29	71	60
Liocarcinus holsatus	53	16	61	39	60
Eupagurus bernhardus	2	9	11	89	100
Corystes cassivelaunus	83	62	93	7	70
Cancer pagurus	46	27	61	39	60
Arctica islandica	74	0	74	26	<10
Cardium echinatum	42	3	44	56	-
Buccinum undatum	0	0	0	100	-
Aphrodyte aculeata	?	23	23	77	-

TABLE 2.12.

Results of survival experiments with fish from very short tows of two minutes. Fish collected from the large net compared with fish that went through the meshes and were collected from a fine-mesh covering net. Numbers of dead fish after 1 and 2 days in the survival tanks.

Species	Numbers alive at start	Numbers dead after day 1	Numbers dead after day 2	Total numbers dead	Total numbers alive	Total survival %
Fish from fine-mesh covering net :						
Pleuronectes platessa	8	1	1	2	6	75
Limanda limanda	24	3	5	8	17	67
Solea solea	5	0	0	0	5	100
Buglossidium luteum	74	0	0	0	74	100
Callionymus lyra	11	0	1	1	10	91
Fish from the large (8 cm mesh) net :						
Pleuronectes platessa	56	1	5	6	50	89
Limanda limanda	32	9	11	20	12	38
Solea solea	24	4	1	5	19	79
All fish from both nets together :						
Pleuronectes platessa	64	2	6	8	56	88
Limanda limanda	56	12	16	28	28	50
Solea solea	29	4	1	5	24	83

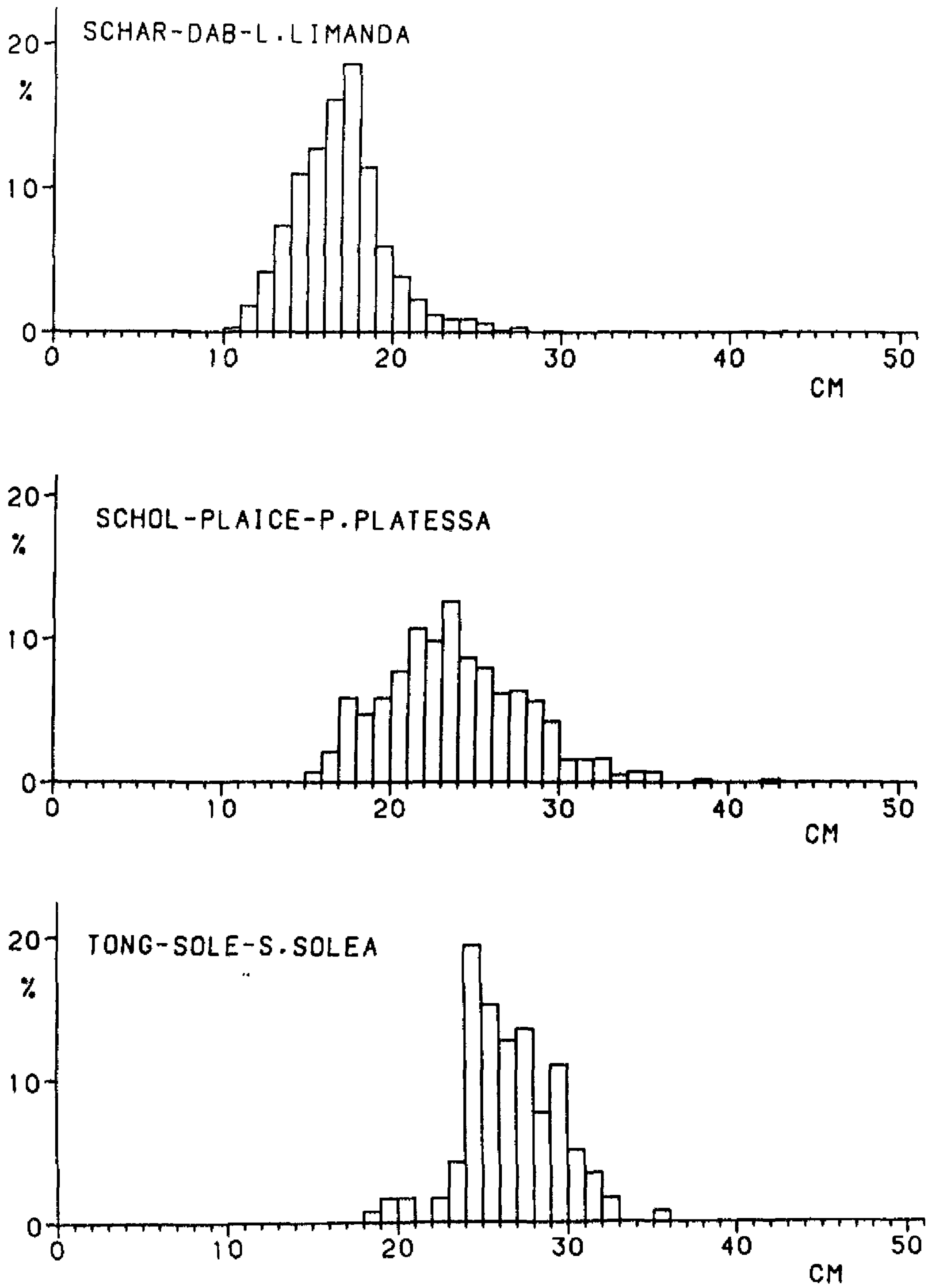


FIGURE 2.1. Length frequency distribution of dab, plaice and sole in catches of a commercial beamtrawler fishing for sole.

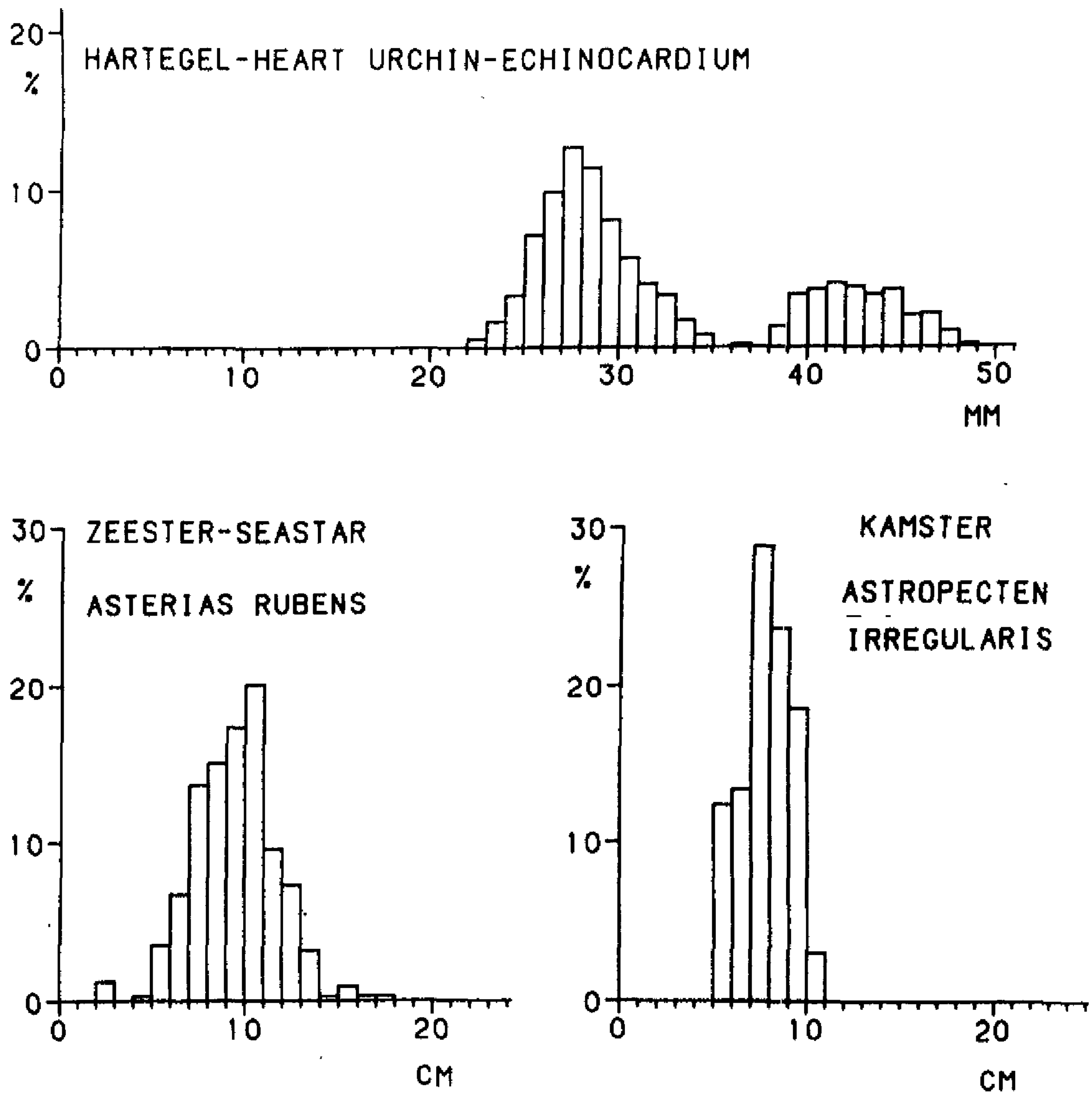
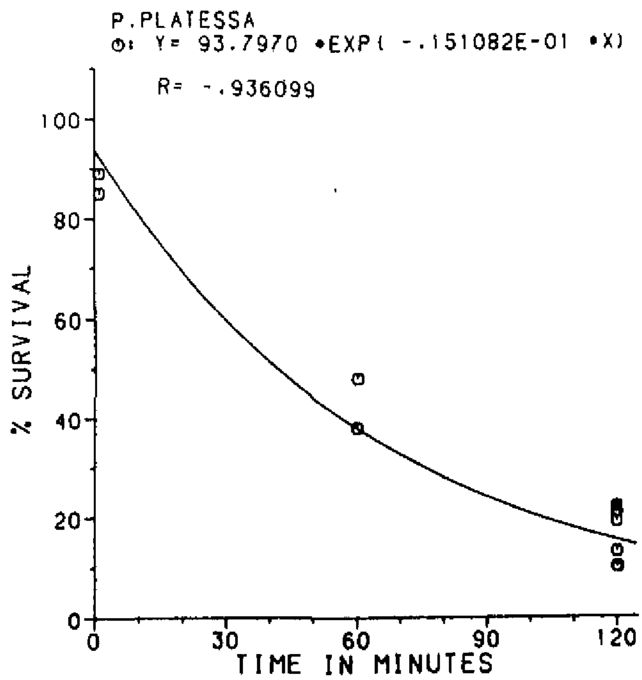


FIGURE 2.2. Diameters of Echinocardium cordatum in the fine-mesh net (25-35 mm diam.) and in the large net (40-50 mm diam.).



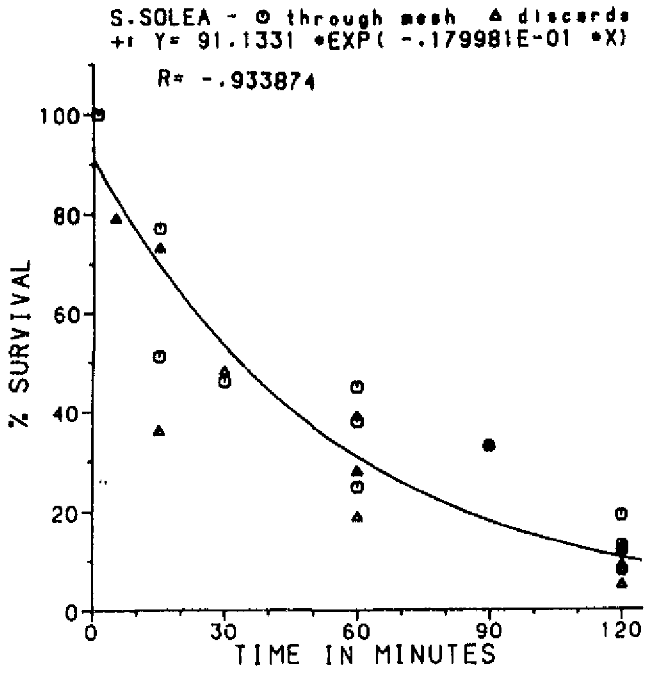


FIGURE 2.3. A non-linear reationship calculated for % survival of discard flatfish in relation to duration of hauls in minutes.
Data from F.VAN BEEK et al.(R.I.V.O.1989) and this study

5. STUDY 3: LONG TERM EFFECTS OF BEAMTRAWL FISHING ON THE BENTHIC ECOSYSTEM IN THE NORTH SEA

(ed. M. Bergman)

5.1. INTRODUCTION

During the last 20 years not only numbers and sizes of vessels engaged in beamtrawling have increased considerably, but also the size, weight and towing speed of the fishing gear used (ICES, 1988). According to the data on trawl intensity (Welleman, 1989) it can be calculated that in 1982 on average each m^2 of the bottom in almost half the Dutch sector of the North Sea has been beamtrawled once a year; in areas with the highest trawl intensity on average each m^2 has been trawled even 7 times a year.

Direct effects of beamtrawls were studied in the seventies. The penetration into the seabed of the tickler chains of these relatively light gears towed with relatively low speed was restricted to 1 à 3 cm (Bridger, 1972). Studies on the penetration of heavier modern gears revealed that the twenty tickler chains most likely scraped off successive layers of the sediment to a depth of more than 6 cm, at least in part of the trawled area (Bergman et al., 1990; see also study 1 in this report). Evidence is present of direct effects of beamtrawling on coelenterates, annelid worms, molluscs, echinoderms, crustaceans and discard fish (Graham, 1955; Bridger, 1970; Margetts & Bridger, 1971; de Groot, 1973; Bergman et al., 1990).

Based on the high frequency of commercial beamtrawling and the direct effects on benthic fauna it may be supposed, that beamtrawling has contributed to changes in the benthic system of the North Sea. However, direct effects cannot be extrapolated to long-term effects on benthic communities. These long-term effects most probably are expressed in changes in species composition. Therefore, the comparison of the benthic fauna in an untrawled area with that of an adjacent trawled area may yield valuable information on possible long-term effects. However, such untrawled locations appear to be rather uncommon in the dutch sector of the North Sea and uncertainty will always exist about the actual degree of trawling in a particular area during the last 10 years. The area in and around "Borkum Riff" is one of the few suitable locations in the southern North Sea, where a scarcely trawled area is enclosed by an area which is trawled relatively often.

5.2. MATERIALS AND METHODS

5.2.1. Area of investigation

Long-term effects of beamtrawling on the benthic system were studied in August 1990 in and around the "Borkum Riff", an area with fine to medium grained sand and a waterdepth of about 34 m, situated in ICES quadrant 37F5, 60 km north of Ameland (Fig. 0.1).

In the "Riff" the fishing effort, especially by beamtrawlers, has been relatively low because of the risk of substantial damage to the gear due to the occurrence of many large boulders, relics of the Saalien glacial period. Some trawling with smaller beam- and otter trawlers, however, may occur in limited stretches between the stones. To avoid such fished stretches a part of the Riff has been screened by side-scan sonar for the presence of stones. Then the transect in the Riff (length 3.6 km) was chosen between the recorded stones in such a way that trawling in the past was most unlikely (Fig. 0.1; Fig. 0.11). On the recordings with the side-scan sonar gravel and larger stones have not been distinguished.

During the last 10 years the area around the Riff has been beam trawled with an intensity more or less representative for the mean trawling intensity on the dutch sector of the North Sea (data 1982 in Welleman,1989; data 1990 pers. comm. de Groot, RIVO). In this trawled area two transects (length 5 km) were situated: transect "North" (8 km north of the transect in the Riff) and transect "South" (3 km south of transect Riff) (Fig. 0.1; Fig. 0.11). During the investigations all positions were verified with high accuracy navigational equipment (Hyperfix). On each transect (North, Riff, South) 10 bottom samples were collected to determine grainsize distribution and silt content of the sediment. These samples were analysed by the RGD.

5.2.2. Sampling demersal fish and macrobenthic epifauna

Demersal fish and macrobenthic epifauna on the transects (North, Riff and South) were sampled by way of 10 hauls (length 300 m) on each transect with a 2.80 m beamtrawl rigged with 2 tickler chains and a ground chain. The stretched mesh size of the gear was 2 cm, in the cod-end 1 cm. The trawlcatches were sieved on board over 1 cm mesh size. The fish was sorted out and measured to the nearest 0.5 cm below. The epifauna samples were preserved in 8% neutralized formalin seawater solution. The epifauna was sorted out and identified in the laboratory within 6 months of sampling.

5.2.3. Sampling macrobenthic infauna

Macrobenthic infauna on the transects North, Riff and South was sampled by way of 10 bottom grabs with a 0.071 m^2 Reineck boxcorer on each transect. Samples were sieved over 1 mm mesh size and preserved in 8% neutralized formalin-seawater solution stained with Bengal rose. The infauna was sorted out and identified in the laboratory within 6 months.

5.2.4. Sampling epifauna and infauna with a benthos dredge

Epifauna and macrobenthic infauna living in the upper sediment layer, were sampled with a special benthosdredge (0.5 m width). The dredge planes off a layer of sediment to a depth of 10 cm. The sediment is collected in a net with a stretched mesh size of 2 cm. The dredge was only used in two hauls (length 50 m) on transect North and transect Riff. The samples were sieved over 1 cm mesh size and preserved in neutralized formalin-seawater solution. The fauna was sorted out and identified in the laboratory within 6 months.

5.2.5. Sampling meiofauna

Meiofauna was collected on the transects North, Riff and South by taking one core (10 cm^2) of each of the 10 bottom grabs (Reineck boxcorer). The cores were divided in three slices (0-1 cm, 1-5 cm and 5-10 cm) and preserved on 4% formalin coloured with Bengal rose. In the laboratory the samples were washed in a washing-gutter (100 x 2.5 cm) during 15 minutes and sieved over 50 mm. Three samples of each transect were analysed by DIHO.

5.2.6. Statistical methods

The computer program CANOCO (ter Braak, 1988) has been used to analyse the species composition of fish, epifauna and infauna on the transects and to estimate the effects of some environmental variables (including fishery). Canonical community ordination (CANOCO) is a combination of ordination and multiple regression. In this study the contribution of three supplied environmental variables has been assessed to the sum of the "eigen-values", using partial canonical correspondence analysis. Grainsize and siltcontent (together indicated as "sediment") and "fishing" (untrawled area in Riff versus trawled area North and South) were selected as supplied environmental variables. An eigen-value ($0 \leq \lambda \leq 1$) is a measure of an ordination axis. An eigen-value of 0.3 is in general considered as a proper value for a clear ecological relation. The program is suited to test the statistical significance of relations between species composition and supplied environmental variables (Monte Carlo permutation test).

5.3. RESULTS

5.3.1. Sediment parameters

The relation between grainsize and siltcontent of the bottomsamples on transect North, Riff and

South is given in Fig. 3.1. Sediment composition on transect South shows a marked difference as compared to the other two transects. Nearly all bottomsamples of transect South seem to combine a smaller grainsize with a higher siltcontent (see also Table 3.1). The grainsize distribution of transect Riff and North are comparable, except for the larger variation in values of the samples of transect Riff. The mean siltcontent in the samples of transect Riff is higher with more variation than the siltcontent in the samples of transect North.

5.3.2. Demersal fish

Mean densities of demersal fishspecies on the three different transects in the studied area are given in Table 3.2, indicating increasing densities of solenette (Buglossidum luteum) and dab (Limanda limanda) on the more southerly transects. Of other common species (mean density more than 10 per 840 m2), the dragonet (Callionymus lyra) shows increasing numbers from north to south in the area. Only the scaldfish (Arnoglossus laterna) was found in the highest densities on the transect in the Riff.
Using ordination as a method to search for major gradients in the species composition of demersal fish on the transects irrespective of any environmental variable, a plot of the species composition can be given as determined by two ordination axes of unknown environmental variables (Fig. 3.2). The plot shows a certain clustering of the samples of each transect, as a consequence of their species composition in relation to both ordination axes. In Fig. 3.3 these gradients have been analysed using partial canonical correspondence analysis. As can be seen from this figure, the contribution of the sediment parameters to the sum of the eigen-values (l = 0.26) is about 0.07 (26%), the contribution of the fishing-factor is 0.03 (12%), whereas 0.15 (56% of the sum of the eigen-values) cannot be explained by correlation with sedimenttype or fishing-factor and is correlated with unknown (environmental) factors. The relative low contribution of the factors "sediment" and "fishing" to the sum of the eigen-values, which is also relatively low, indicates no clear relation between the occurrence of fish species and the supplied environmental variables.

5.3.3. Macrobenthic epifauna

Mean densities of macrobenthic epifauna living on the bottom or in the top centimeters of the sediment, are listed in Table 3.3. The echinoderms Asterias rubens, Astropecten, Echinocardium and Ophiura albida are found in the highest densities on transect North. Ophiura texturata shows highest abundancies on transect South. The crustaceans Eupagurus and Liocarcinus did not show differences in densities on the three transects. Abundancies of other epifauna species on the transects were too low to establish possible trends in distribution. In Fig. 3.4 an ordination plot of the species composition is given in relation to the two ordination axes of unknown environmental variables. In relation to both axes the plot indicates a slight clustering of the samples of each transect. In Fig. 3.5 the major gradients are analysed, using partial canonical correspondence analysis. The contributions of the supplied variables, sedimenttype and fishing-factor, to the sum of the first three eigen-values (l = 0.32) are 0.12 (39%) resp. 0.02 (6%); 54% of the sum of the eigen values cannot be explained by correlation with known environmental variables as sedimenttype and fishing-factor. An explicit relation between the presence of epifauna species and the supplied environmental variables is not found.

Table 3.4 summarises the mean percentages of starfish (Asterias rubens) (> 2 cm) on the transects with one or more regenerating arms due to damage in the past. The percentage of individuals with regenerating arms does not seem to be a suitable measure for the trawl intensity on the investigated transects, since this percentage on the transect Riff which is supposed to be trawled less frequently is not lower than on the well-trawled transects North and South.

5.3.4. Macrobenthic infauna

Mean densities of macrobenthic infauna are listed in Table 3.5. In search for major gradients in the species composition of the infauna on the transects, ordination can be used irrespective of any known environmental variable (Fig. 3.6). The plot indicates a marked clustering of the samples of transect South in relation to both ordination axes. Analysis of these gradients, using partial canonical correspondence analysis (Fig. 3.7) reveales the contribution of the supplied environmental variables sedimenttype and fishing factor to the high sum of the eigen-values (l= 0.72) as 0.38 (54%) resp. 0.09 (11%). Only 33% of the sum of the eigen-values seems to be correlated with unknown environmental variables. The correlation between species composition and sedimenttype proved to be significant. The relative high value given to sedimenttype (l= 0.38) clearly points to a normal ecological relationship; in this case 54% of the total eigen-value can be explained by the relation between species composition and sediment type. This is also illustrated in Fig. 3.8, where a linear relationship is demonstrated between the unknown first axis and grainsize, with respect to the species composition of macrobenthic infauna on all tran sects. The value estimated for the fishing-factor is 0.09 and it contributes 11% to the high sum of the eigen-values (0.72). This relationship however was not significant. Analysis with the "CANOCO" method shows for a number of infauna species (e.g. Ensis, Tellina, Corystes, Thia, Pectinaria) a lower abundance in the more intensively beamtrawled area outside the Riff (Table 3.6). These species can be indicated as potentially sensitive to the long-term effects of beam- trawling.

5.3.5. Epifauna and infauna caught with the benthosdredge

Mean densities of epifauna and infauna, based on two hauls with the benthosdredge on transect North resp. transect Riff, are listed in Table 3.7. The catches may illustrate the potential capacities of this newly developed dredge, which basically will collect epifauna as well as infauna inhabiting the uppermost 10 cm of the sediments. Remarkable are the relative high numbers of e.g. larger molluscs (Arctica, Venus, Ensis, Dosinia, Spisula, Gari and Thracia), larger crustaceans (Corystes, Thia) and the echinoderm Echinocardium collected with the dredge, as compared to catches of the 2.80 m beamtrawl (see Table 3.8). The catches of the benthos dredge and the catches of the Reineck boxcorer are not comparable because of the large differences in mesh size of gears and sieves used.

5.3.6. Meiofauna

Mean densities of nematodes and harpacticoid copepods (small crustaceans) at different depth in the sediment are listed in Table 3.9. Mean densities of nematodes and harpacticoids in the upper 10 cm of the sediment are similar on the three transects. The absence of harpacticoids in the deeper sedimentlayer on transect South can be ascribed to the smaller grainseze and the higher siltcontent of this area.

5.4. DISCUSSION

5.4.1. Long-term effects on the benthic fauna

The results of the canonical analyses dealing with the relationship between environmental variables and species composition of fish, epifauna and infauna, are summarized in Table 3.10. The sum of the eigen-values is low for the species composition of both fish and epifauna (0.26 resp. 0.32) and more than 50% of the sum remains unexplained. The supplied environmental variables contribute only 26% resp. 39% (sedimenttype) and 12% resp. 6% (fishing-factor) to the sum of the eigen-values. Long-term effects of beamtrawling on species composition of fish and epifauna can not be demonstrated by this study. With respect to fish fauna, the mobility of the species may explain the low correlation. The low correlation between beamtrawling and epifauna-composition may have been partly due to the mobility of the species, but also to the fact that some species (e.g. crustaceans) dig into the sediment during daytime and were out of

reach of the sampling gear (2.80 m beamtrawl), which did not penetrate deep enough into the sediment.
The sum of the eigen-values is high (I=0.72) for the species composition of infauna and only 32% of the sum of the eigen-values is related to unexplained environmental variables; the supplied environmental variables, sedimenttype and fishing-factor, account for 53% resp. 13% of the sum of the eigen-values. Sedimenttype appear to be the dominant factor for the species composition of infauna. Evidence of this dominance is also presented in literature (e.g. Jones, 1950; Glémarec, 1973; Duineveld et al., 1990). According to the contribution to the sum of the eigen-values, beamtrawling has also, although to a lower degree, a relation with species composition of infauna. Based on the short-term effects of beamtrawling on infauna (de Groot, 1973, 1984; BEON, 1990) long-term effects might be expected especially in echinoderms (Echinocardium), tube-dwelling worms (Lanice, Spiophanes), molluscs (Tellina, Ensis, Arctica), and crustaceans (Liocarcinus, Cancer pagurus, Corystes). Indeed, some of these (Corystes, Ensis, Tellina) are indicated by the "CANOCO"-analysis as potential vulnerable species. Densities of infauna were estimated with a boxcorer (0.071 m2), which mainly samples the more abundant, often small-sized, species on a quantitative reliable way. For establishing long-term effects on more scarcely occurring, larger and longliving species (e.g. Arctica, Cancer) the boxcorer is less suitable. For estimation of the densities of these species the 2.80 m beamtrawl is also inadequate, because of its low penetration into the sediments. Especially for the populations of these species (larger molluscs and crustaceans), however, we may expect long-term effects of beamtrawling (Bergman et al., 1990; see also study 2).
In the present study indications of long-term effects of beam trawling on meiofauna (nematodes and harpacticoids) were not found. The vertical distribution of harpacticoids seems to be determined by sediment characteristics. Due to the absence of sufficient interstitial spaces in the finer-grained sediments of transect South, harpacticoids are probably not able to penetrate into the deeper sedimentlayers.

5.4.2. Future research

Discussing the results of the study 1990, two major problems become clear. Firstly it is likely that a number of vulnerable benthic species have not been sampled very efficiently. Especially the less abundant, larger molluscs, crustaceans and echinoderms have been sampled quite inadequately with both the boxcorer and the 2.80 m beamtrawl. Preliminary data indicate that the benthosdredge could be a more suitable sampling gear to catch these species.
The second problem is the uncertainty about the degree of beamtrawl intensity both in the "untrawled" area in the Riff and in the "trawled" area surrounding the Riff. Reliable information on trawl intensity in the different areas is not available. If the Riff is trawled less intensively, the percentage of regenerating arms in starfish (Asterias rubens) seems not to offer a reliable measure for the degree of trawl-intensity on this geographical scale, in contrast with the conclusions of De Graaf & de Veen (1973). Nevertheless, the Borkum Riff area is known as the most suitable area on the dutch sector of the North Sea for investigation of long-term effects of trawling.
Future studies on long-term effects with the benthosdredge in the area of Borkum Riff should not longer include the finer-grained and more silty transect South, because of the marked effects of sediment type on species composition of benthic fauna. To avoid benthic sampling in trawled stretches inside the Riff, more information about the exact locations of large boulders is very important.
Because of the uncertainty about the trawl-intensity, a detailed study of long-term effects of beamtrawling on the North Sea ecosystem seems only possible when trawling is completely banned in a representative trawling area. The development of the benthic system in such a closed area and a comparable trawled area will provide information on the actual long-term impact of beamtrawling.

5.5. CONCLUSIONS

* "CANOCO"-analysis showed to be a valuable method to determine the contribution of environmental variables to the species composition of macrofauna and fish.
* Sediment characteristics (grainsize and siltcontent) appeared to be the dominant factors related with differences in species composition of infauna; the species composition of fish and epifauna is, to a lesser extent, also determined by sediment characteristics.
* Comparing the species composition of meiofauna, infauna, epifauna and fish of an less trawled area with a surrounding moderately trawled area in and around Borkum Riff, no significant differences due to long-term effects of beamtrawling could be demonstrated.
* Differences in species composition, although not significant, indicate lower abundances of molluscs (Corbula gibba, Natica alderi, Ensis spec., Tellina fabula), crustaceans (Corystes, Thia) and worms (e.g. Pectinaria) in the more intensively trawled area, possibly as a consequence of (long-term) beamtrawling.
* To establish the long-term effects of beamtrawling on less abundant, larger molluscs, crustaceans and echinoderms the sampling gears used (boxcorer and 2,80 m beamtrawl) appeared to be not very suitable.
* The benthosdredge, which collects relative high numbers of larger molluscs, crustaceans and echinoderms as compared to catches with other gears, seems to be more adequate for sampling these species living on and in the upper layer (ca. 10 cm) of the bottom.
* The area south of Borkum Riff has finer-grained sediment with a higher siltcontent than the area inside and north of the Riff. Since the benthic system seems to be largely determined by sediment characteristics, the area south of the Borkum Riff should not be involved in future research on effects of beamtrawling in this part of the North Sea.
* Uncertainty remains about the degree of trawling in and around Borkum Riff as well as in similar locations in the dutch sector of the North Sea. Percentages of regenerating arms of starfish Asterias rubens appeared not to be usefull as a measure for the degree of beamtrawling in the studied area. To avoid the commercially trawled stretches in the Riff with more certainty, information on the exact location of large boulders is very important.
* A detailed study on long-term effects of beamtrawling on the North Sea ecosystem seems only possible when trawling is banned in a representative trawling area. Research on the development of the benthic system in such a closed area in comparison with a normally trawled area will provide information about the actual long-term impact of beamtrawling.

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TABLE 3.1

Mean grainsize (mm) and siltcontent (% ≤ 63 mm) of the transects in and around Borkum Riff (Analysed by RGD).

	North		Riff		South	
	mean (n=10)	sd	mean (n=10)	sd	mean (n=10)	sd
Silt (%)	1.2	.5	2.1	1.7	3.4	1.9
Grainsize (mm)	322.7	68.8	320.4	86.6	220.1	8.2

TABLE 3.2

Mean densities of dermersal fish (numbers per 840 m2) on the transects in and around Borkum Riff. On each transect 10 hauls were made with the 2,80 m beamtrawl.

Densities (numbers per 840 m^2)

	North		Riff		South	
	mean (n=10)	sd	mean (n=10)	sd	mean (n=10)	sd
Buglossidium luteum	38.6	25.4	76.9	29.6	91.2	43.6
Limanda limanda	11.4	3.1	21.7	15.2	40.3	8.6
Trachurus vipera	2.8	3.9	1.0	1.7	.0	.0
Pleuronectes platessa	3.2	2.2	1.5	1.7	2.4	1.3
Callionymus lyra	14.8	10.2	10.1	5.3	6.7	3.9
Arnoglossus laterna	5.7	4.1	10.4	5.2	4.6	2.8
Trigla lucerna	2.7	1.4	.5	.9	.5	1.0
Solea solea	1.3	2.2	.9	1.6	1.0	1.3
Enchelyopus cimbrius	.2	.4	.0	.0	.0	.0
Hyperoplus lanceolatus	.0	.0	.2	.4	.0	.0
Agonus cataphractus	.0	.0	1.2	1.6	1.7	2.0
Syngnathus rostellatus	.0	.0	.1	.3	.0	.0
Scophthalmus rhombus	.0	.0	.1	.3	.0	.0

TABLE 3.3

Mean densities of epifauna (numbers per 840 m^2) on the transects in and around Borkum Riff. On each transect 10 hauls were made with the 2.80 m beamtrawl.

Densities (numbers per 840 m^2)

	North		Riff		South	
	mean (n=10)	sd	mean (n=10)	sd	mean (n=10)	sd
MOLLUSCS						
Buccinum undatum	.6	1.0	.6	.8	.0	.0
Aphorrhais pespelicana	4.9	7.6	.7	1.6	.0	.0
Ensis spec.	.0	.0	.2	.6	.0	.0
Arctica islandica	.1	.3	.0	.0	.0	.0
Sepia spec.	.4	.8	.8	2.5	.0	.0
ECHINODERMS						
Asterias rubens	2317.2	1909.9	809.3	402.1	694.6	308.4
Astropecten irregularis	22.8	18.0	12.5	8.4	.8	1.9
Echinocardium cordatum	39.2	54.6	21.3	20.9	6.0	8.9
Echinus esculetus	3.5	3.7	5.3	3.8	.3	.9
Ophiura albida	412.2	626.3	86.8	128.1	72.2	90.9
Ophiura texturata	.9	2.5	5.6	8.4	66.3	108.0
CRUSTACEANS						
Hyas araneus	.4	.7	.3	.7	.0	.0
Eupagurus bernhardus	35.9	31.2	32.8	17.5	29.2	11.6
Corystes cassivelaunus	2.1	2.9	1.1	1.9	.6	1.0
Liocarsinus holsatus	50.5	36.2	30.8	12.6	39.4	24.4
Thia polita	.4	1.3	.0	.0	.0	.0
PORIFERA						
Alcyonium digitatum	.1	.3	.0	.0	.0	.0
ANNELID WORMS						
Aphrodite aculeata	.5	.9	.4	.5	.2	.4

TABLE 3.4

Percentage damaged starfish (Asterias rubens) (≥ 2 cm) with regenerating arms on the transects in and around Borkum Riff.

Densities (numbers per 840 m^2)

	North		Riff		South	
	mean (n=10)	sd	mean (n=10)	sd	mean (n=10)	sd
Damaged	163.0	80.2	105.3	59.2	107.8	34.5
Total	1261.5	498.8	576.4	252.2	683.5	310.0
Damaged (%)	12.9		18.2		15.7	

TABLE 3.5

Mean densities of infauna (numbers . 0.071 m2) on the transects in and around Borkum Riff. On each transect 10 grab samples were made with the Reineck boxcorer.

	Densities (numbers . 0.071 m^2)					
	North		Riff		South	
	mean (n=10)	sd	mean (n=10)	sd	mean (n=10)	sd
ANNELID WORMS						
Harmothoe tunalata	.5	1.0	.2	.6	.0	.0
Sthenelais limicola	.3	.5	.0	.0	.1	.3
Sigalion mathildae	.1	.3	.3	.7	.7	.9
Eteone spec.	.0	.0	.1	.3	.0	.0
Anaitides maculata	.1	.3	.2	.4	.0	.0
Anaitides spec.	.0	.0	.0	.0	.1	.3
Eumida sanguinea	1.1	2.2	.1	.3	.0	.0
Gyptis capensis	.0	.0	.0	.0	.1	.3
Nereis longisima	.3	.7	.2	.4	.1	.3
Nephtys caeca	.0	.0	.1	.3	.3	.7
Nephtys hombergi	.8	.8	.3	.5	.7	.8
Nephtys spec. juv.	.1	.3	.5	.7	.3	.5
Glycera spec. juv.	.1	.3	.1	.3	.0	.0
Glycinde nordmanni	.3	.9	.2	.4	.3	.7
Goniada maculata	.7	.8	1.1	1.0	.7	.9
Lumbrinerus latreilli	.0	.0	.0	.0	.1	.3
Scoloplos armiger	1.0	1.1	1.1	1.4	.1	.3
Poecilochaetus serpens	.7	.8	.4	.7	.3	.5
Spio filicornis	1.4	1.6	.4	.5	.5	.9
Polydora pulcha	.4	1.3	.0	.0	.2	.4
Spiophanus bombyx	3.0	2.2	1.3	1.6	1.9	1.5
Aonides paucibranchiata	.0	.0	.9	1.6	.0	.0
Scolelepis bonnieri	1.4	1.6	.2	.4	.5	.7
Magelona papillicornis	22.3	37.2	10.4	14.6	96.5	76.8
Magelona alleni	.0	.0	.3	.9	.5	1.0
Chaetozone setosa	.1	.3	.3	.7	.1	.3
Ophelia limacina	.2	.4	.0	.0	.0	.0
Notomastus latericeus	.0	.0	.1	.3	.0	.0
Owenia fusiformis	.3	.7	.3	.7	.6	.5
Pectinaria auricoma	.0	.0	.2	.6	.0	.0
Lanice conchilega	3.0	3.0	1.2	1.4	.4	.7
Nemertinae indet.	2.2	1.4	1.6	1.1	1.4	1.4
Phoronide indet	5.0	8.9	4.7	8.9	6.3	4.8
MOLLUSCS						
Montacuta ferruginosa	.4	.7	.2	.6	.2	.4
Mysella bidentata	.0	.0	.0	.0	.5	1.6
Dosinia lupinus	.5	.9	.0	.0	.0	.0
Spisula subtruncata	.0	.0	.6	.7	3.0	2.8
Tellina fabula	.4	.7	.8	1.0	.7	.8
Abra prismatica	.3	.5	.2	.4	.0	.0
Cultelus spec.	.3	.7	.2	.4	.3	.7
Corbula gibba	.0	.0	.2	.4	.0	.0
Thracia spec.	.1	.3	.0	.0	.0	.0
Thracia spec. juv.(<5mm)	.0	.0	.1	.3	.2	.6
Natica alderi	.4	.7	.2	.4	.0	.0
Ensis spec.	.1	.3	.3	.7	.0	.0
ECHINODERMS						
Asterias rubens juv.	2.2	6.3	.3	.9	.1	.3
Amphiura filiformis (<3mm)	.5	1.0	.6	1.0	.8	1.1
Echinocardium cordatum(>2cm)	.8	.9	.9	.7	.7	.5
Echinocyamus pusillus	2.9	3.9	2.2	2.9	.0	.0
Ophiura spec. juv. (<3mm)	1.4	1.9	.2	.4	.4	.5
CRUSTACEANS						
Thia polita	.1	.3	.2	.4	.0	.0
Liocarcinus holsatus juv.	.2	.6	.1	.3	.0	.0
Calianassa subteranea	.0	.0	.5	1.6	.7	.8
Crustaceen klein	8.5	5.4	7.6	6.1	3.3	2.6
Natantia	.4	.7	.2	.6	.4	1.3
Corystes cassivelaunus	.0	.0	.1	.3	.1	.3
CHORDATES						
Amphioxus spec.	.1	.3	.1	.3	.0	.0
COELENTERATES						
Actinaria	.2	.4	.7	1.3	.4	.5

TABLE 3.6

Infauna species, showing higher densities in the Riff, and indicated as potentially sensitive to long-term effects of beamtrawling (CCA-method).

MOLLUSCS
Corbula gibba
Natica alderi
Ensis spec.
Tellina fabula
CRUSTACEANS
Corystes cassivelaunus
Thia polita
WORMS
Notomastus latericeus
Aonides paucibranchiata
Eteone spec.
Pectinaria auricoma
Nepthys spec. juv.

TABLE 3.7

Mean densities (n.25 m^{-2}) of epifauna and infauna species caught with the benthosdredge. Two hauls were made on transect North as well as on transect Riff.

	Densities (numbers per 25 m^2)	
	North mean (n=2)	Riff mean (n=2)
MOLLUSCS		
Arctica islandica	3.0	2.5
Venus striatula	2.5	2.0
Ensis spec.	14.5	9.5
Dosinia lupinus	14.0	31.0
Spisula subtruncata	-	4.0
Gari fervensis	1.0	-
Thracia papyracea	1.5	-
CRUSTACEANS		
Corystes cassivelaunus	1.0	1.0
Thia polita	8.0	60.5
Liocarcinus holsatus	0.5	1.5
ECHINODERMS		
Echinocardium cordatum	1.5	9.5
Astropecten spec.	-	1.0
Ophiura albida	1.5	15.5
ANNELID WORMS		
Aphrodite aculeata	-	1.0
COELENTERATES		
Anthozoa	2.5	1.0

TABLE 3.8

Mean densities of epifauna and infauna (numbers per 25 m^2) collected with the benthosdredge and the 2.80 m beamtrawl.

	Densities (numbers per 25 m^2)			
	Dredge		2.80 m beamtrawl	
	North (n=2)	Riff (n=2)	North (n=10)	Riff (n=10)
MOLLUSCS				
Arctica islandica	3.0	2.5	0.003	-
Venus striatula	2.5	2.0	-	-
Ensis spec.	14.5	9.5	-	0.006
Dosinia lupinus	14.0	31.0	-	-
Spisula subtruncata	-	4.0	-	-
Gari fervensis	1.0	-	-	-
Thracia papyracea	1.5	-	-	-
Buccinum undatum	-	-	0.02	0.02
Aphorrhais pespelicana	-	-	0.15	0.02
CRUSTACEANS				
Corystes cassivelaunus	1.0	1.0	0.06	0.03
Thia polita	8.0	60.5	0.01	0
Liocarcinus holsatus	0.5	1.5	1.5	0.9
Hyas araneus	-	-	0.01	0.01
Eupagurus bernhardus	-	-	1.0	1.0
ECHINODERMS				
Echinocardium cordatum	1.5	9.5	1.15	0.62
Astropecten spec.	-	1.0	0.67	0.37
Ophiura albida	1.5	15.5	12.1	2.6
Ophiura texturata	-	-	0.3	0.16
Asterias rubens	-	-	68.0	23.8
Echinus esculetus	-	-	0.1	0.2

TABLE 3.9

Distribution of mean densities of nematodes and harpacticoids (n.10 cm-2) in layers of 1 centimetre at different depth in the sediment. Three cores were analysed on each transect (data DIHO).

		Mean densities (numbers . 10 cm^{-2}) in layers of 1 centimetre			
		Nematodes		Harpacticoids	
transect	depth (cm)	mean (n=3)	s.d	mean (n=3)	s.d
North	1-10	782.6	307.4	46.6	20.8
	0- 1	276.0	75.1	33.0	11.3
	1- 5	81.6	47.7	3.0	1.7
	5-10	36.0	13.0	0.3	0.6
Riff	1-10	717.0	252.0	39.6	2.5
	0- 1	365.6	259.0	23.3	8.1
	1- 5	60.0	50.4	2.7	1.2
	5-10	22.0	12.5	1.0	1.0
South	1-10	745.0	25.1	46.3	3.2
	0- 1	218.6	122.3	45.6	2.9
	1- 5	99.3	24.0	0.0	0.0
	5-10	26.3	14.3	0.0	0.0

TABLE 3.10

Percentual contribution of supplied variables (sedimenttype and fishing-factor) and unknown variables to the sum of the first three eigen-values (λ) with respect to species composition of benthic fauna.

	Species composition of		
	fish	macrobenthos epifauna	macrobenthos infauna
Sum of the first three eigen-values	0.26 (100%)	0.32 (100%)	0.72 (100%)
Sedimenttype	0.07 (26%)	0.12 (39%)	0.38 (54%)
Fishing-factor	0.03 (12%)	0.02 (6%)	0.09 (11%)
Unexplained	0.15 (56%)	0.17 (54%)	0.23 (33%)

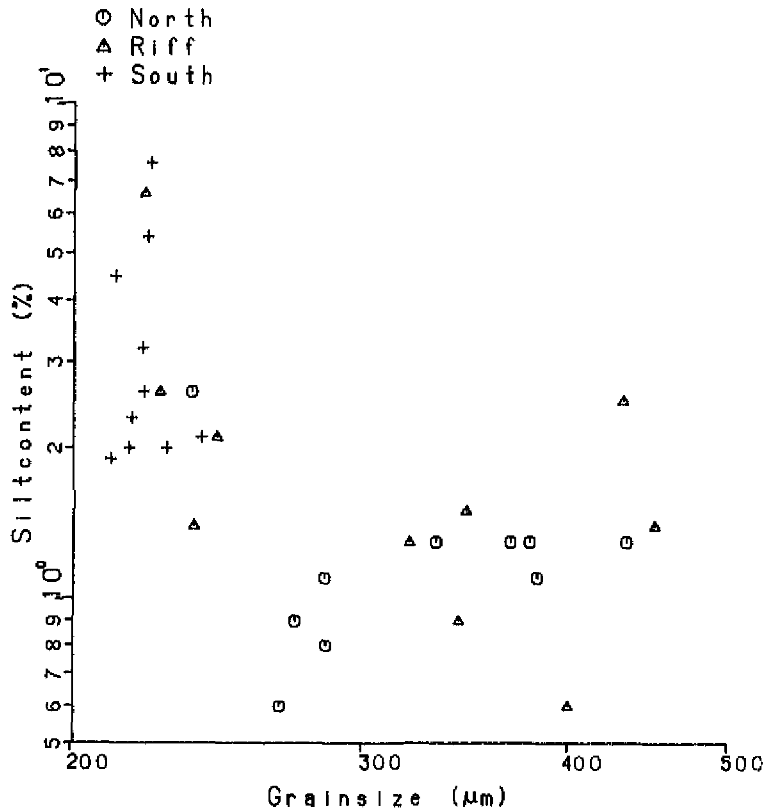

Fig. 3.1. Median grainsize of the fraction > 63 µm and silt content (≤ 63 µm) of the transects in and around Borkum Riff (analysed by RGD).

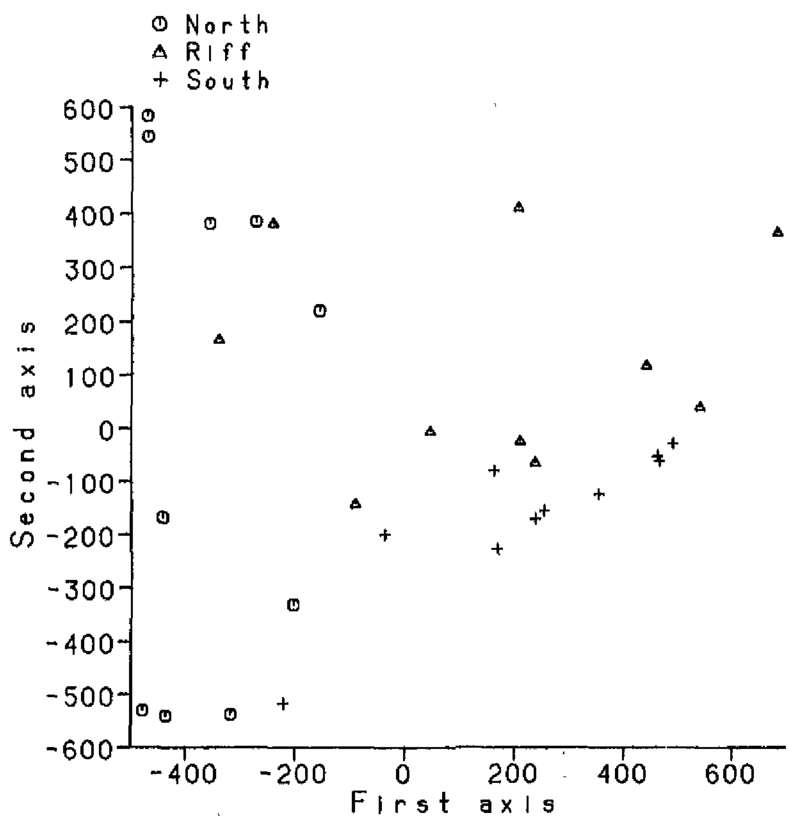

Fig. 3.2. Ordination of the species composition of demersal fish on the transects in and around Borkum Riff. These ordination axes are not constrained to environmental variables (CA-method).

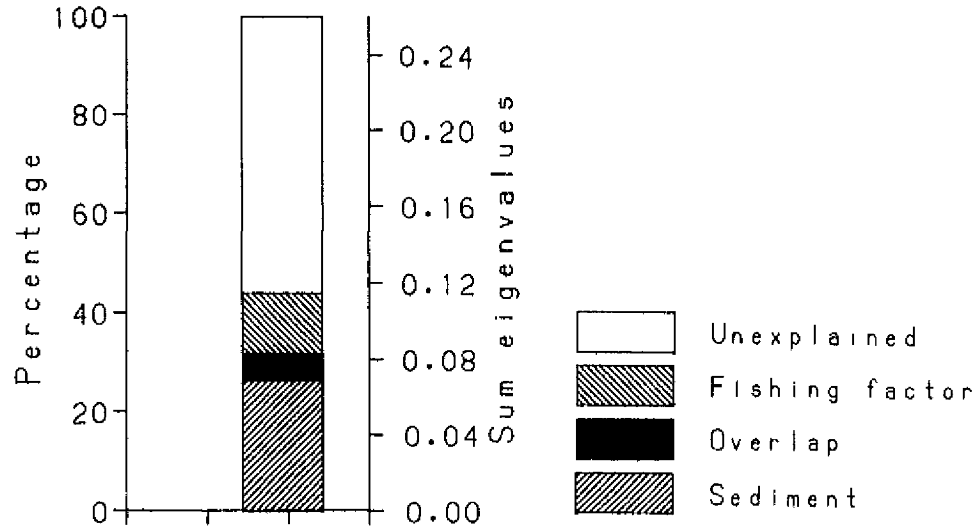

Fig. 3.3. Contribution of environmental variables (sedimenttype and fishing-factor) to the sum of the first three eigen-values of the species composition of fish according to the partial "CANOCO"-method (CCA-method).

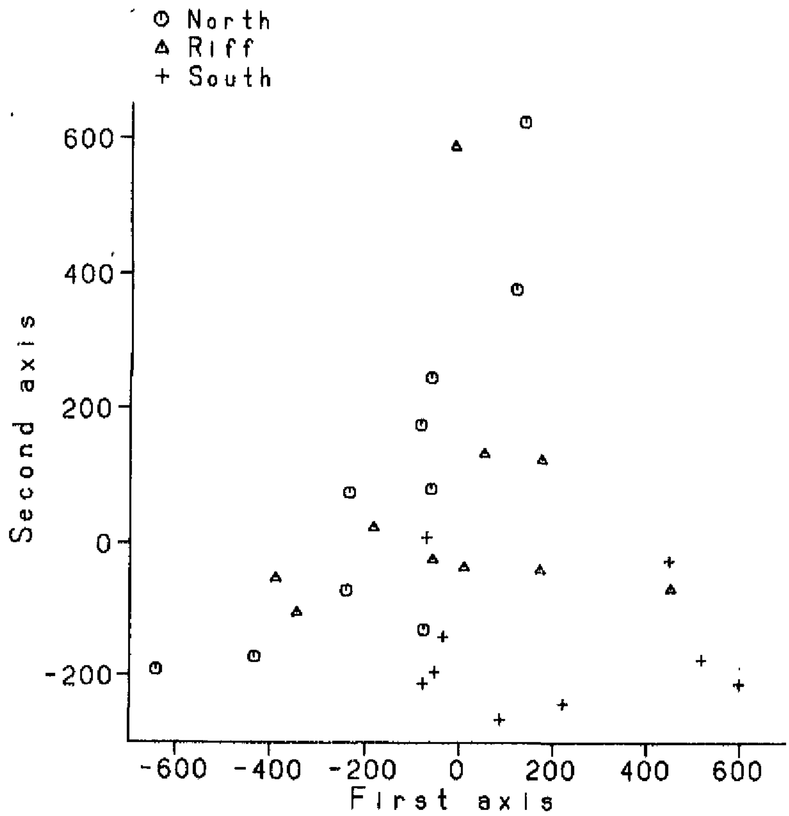

Fig. 3.4. Ordination of the species composition of macrobenthic epifauna on the transects in and around Borkum Riff. The ordination axes are not constrained to environmental variables (CA-method).

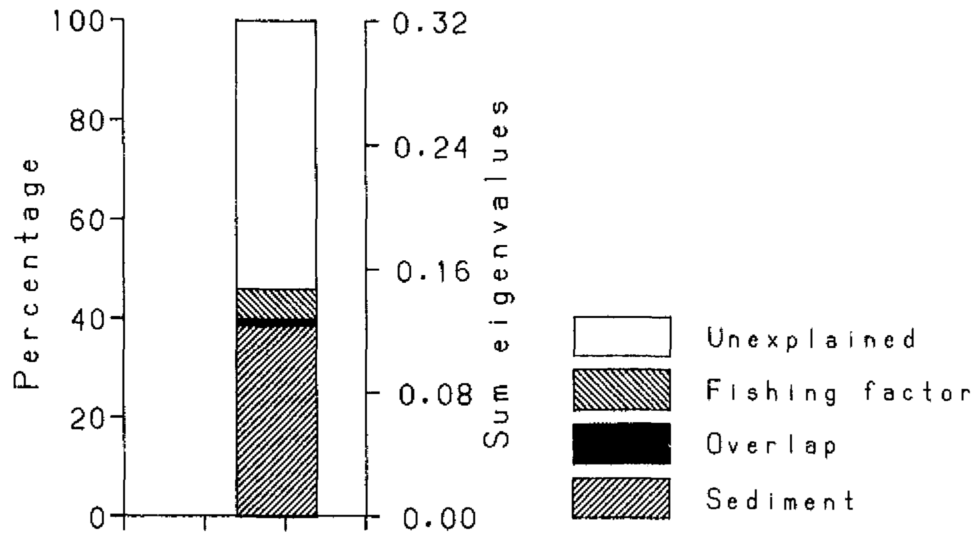

Fig. 3.5. Contribution of environmental variables (sedimenttype and fishing-factor) to the sum of the first three eigen-values of the species composition of epifauna according to the partial "CANOCO" method (CCA-method).

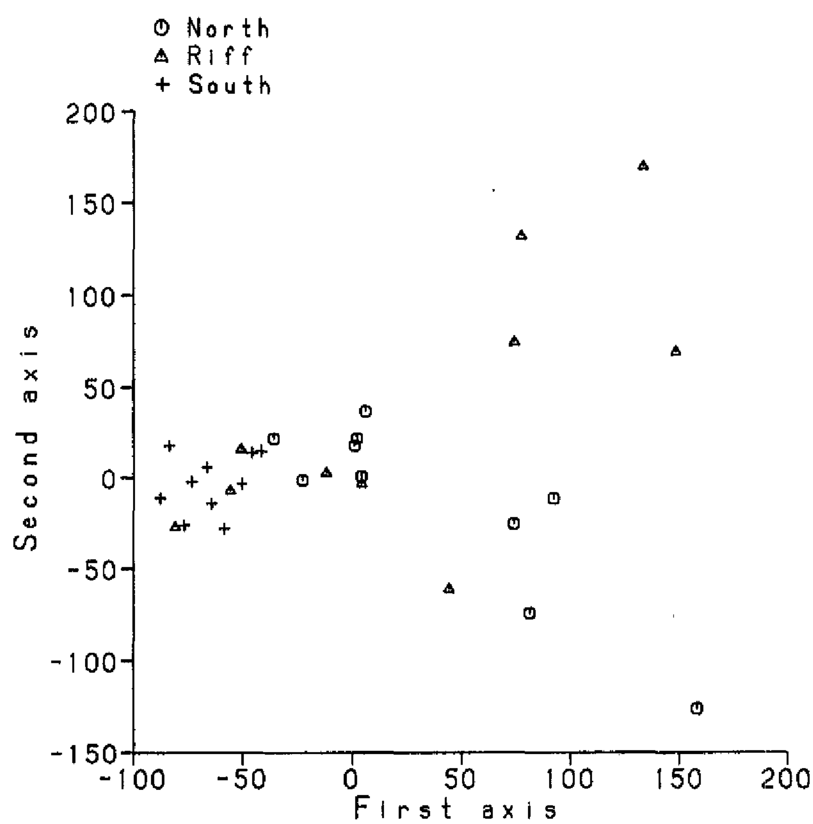

Fig. 3.6. Ordination of the species composition of macrobenthic infauna on the transects in and around Borkum Riff. The ordination axes are not constrained to environmental variables (CA-method).

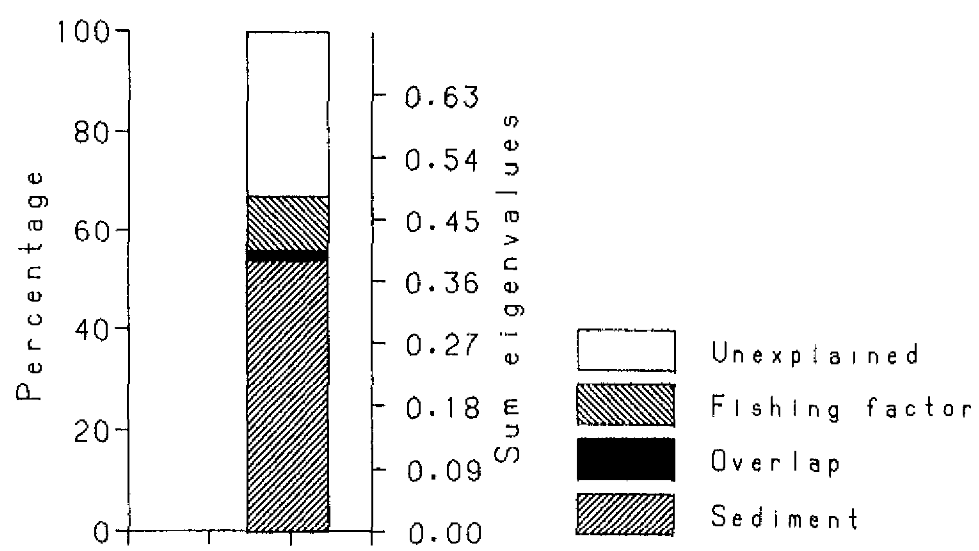

Fig. 3.7. Contribution of environmental variables (sedimenttype and fishing-factor) to the sum of the first eigen-values of the species composition of infauna according to the partial "CANOCO"-method (CCA-method).

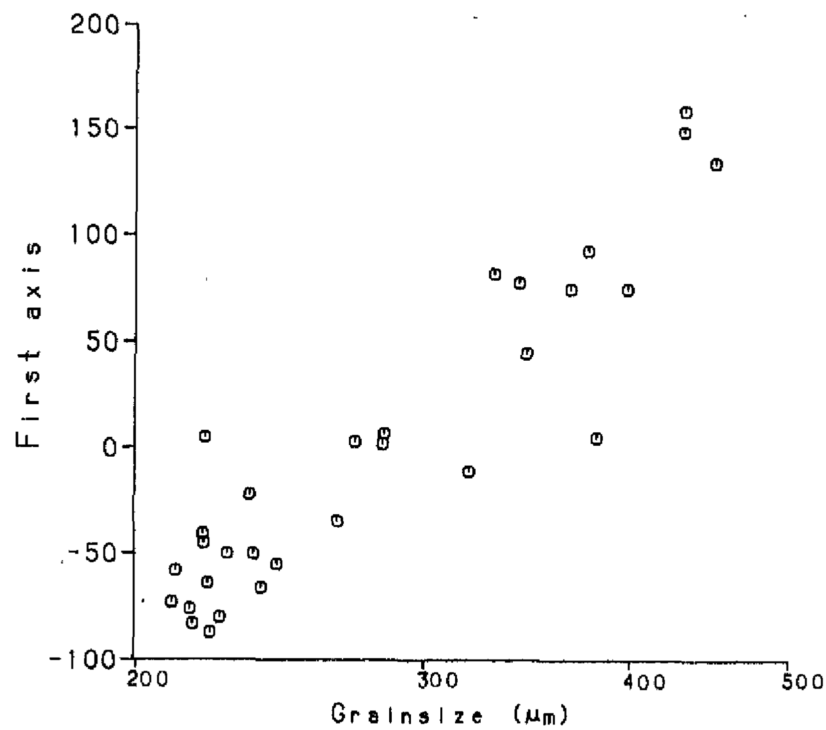

Fig. 3.8. Species composition of macrobenthic infauna in the samples of all transects (n=30) in relation with the first axis (unknown environ mental variable) (CA-method) and medium grainsize (μm).