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ENVIRONMENTAL IMPACT OF BOTTOM GEARS ON BENTHIC FAUNA IN RELATION TO NATURAL RESOURCES MANAGEMENT AND PROTECTION OF THE NORTH SEA

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PREFACE

This IMPACT-I report is the result of an international research project supported by the Commission of the European Communities. Eight institutes of four CEC-member states worked together. Sometimes waves were running high but always a calm followed. The good cooperation will continue in the follow-up project IMPACT-II, when thirteen institutes of five CEC-member states will participate.

It is impossible to thank the many persons who contributed to the realization of this report, however, we want to single out Anneke Bol-den Heijer (NIOZ) who produced a coherent lay-out of many loose papers, Mike Kaiser and Brian Spencer (both MAFF) who made many textual improvements and Magda Bergman (NIOZ) who always warned us when omitting too many relevant parts of the text.

IJmuiden - Den Burg
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SUMMARY

THE IMPACT PROJECT

The FAR research project MA 2-549 "Environmental Impact of Bottom Gears on Benthic Fauna in Relation to Natural Resources Management and Protection of the North Sea" was set up to investigate the effects of bottom trawl gear on benthic invertebrates and fish.

Trawling programmes were carried out in four main areas of the North Sea using various types of beam trawls for flatfish (sole and plaice) and shrimp. Sites of investigation were situated on the Flemish Banks, off the Dutch coast, north of the Frisian Islands, and in the German Bight (Fig. 1).

In the selected areas the effects on benthic communities of 4-m and 12-m beam trawls, commonly used by commercial fisheries, were studied. Before, and after, experimental trawling, both in- and epifauna were sampled using various pieces of equipment including; box corers, van Veen grabs, Day grabs, 3m beam trawls, and a specially developed dredge (Triple-D). Catch composition of the commercial trawls was determined. The survival of animals caught in, and those which pass through, the meshes of the net was examined over prolonged periods onboard ship. Catch composition of 1 m dredges attached to a 7 m beamtrawl was determined. Video records were made of a heavily trawled zone and compared to recordings of a relative undisturbed reference area. Possible immigration of scavengers into intensively trawled areas was examined by repeated trawling over the same line. Changes in sediment structure were also examined using side-scan sonar, sediment profiling photography (REMOTS) and video techniques. The effects of towing speed and direction of tow (in relation to current direction) on the pressure exerted by the gear on the sediment were examined with a 4-m beam trawl. An inventory of the Belgian, Dutch and German bottom trawling fleet and the different gears used was collated.

The project was undertaken by the following contractors: Rijksinstituut voor Visserijonderzoek (RIVO-DLO), Nederlands Instituut voor Onderzoek der Zee (NIOZ), and Nederlands Instituut voor Oecologisch Onderzoek (NIOO-CEMO) in the Netherlands, Rijksstation voor Zeevisserij in Belgium, Institut für Meereskunde Universität Kiel (IFM) and Alfred- Wegener- Institut für Polar- und Meeresforschung (AWI) in Germany. North Sea Directorate (RWS-DNZ) in the Netherlands made their research vessel RV Mitra available for the programme, mapped the study areas and cooperated in the sampling programme. Concurrently, the MAFF Fisheries Laboratory Conwy (UK), investigated the effects of 4-m beam trawling on benthic communities in the Irish Sea. The latter two institutes were subcontractors.

CONCLUSIONS

- Flatfish beam trawl fisheries form the most inportant part of the Belgium and the Netherlands fisheries producing about 81% and 66%, respectively, of the national catches.
- Studies on the physical impact of parts of the 4-m beam trawl on the seabed show that the sole plate exerts a force of about 2 $N.cm^{-2}$ at commercial trawling speeds. Trawl marks on coarse sand were visible for up to 52h after fishing.
- Discard composition of the catch of offshore 12-m beam trawlers differs from that of the inshore 4-m trawlers. In the North Sea sole fisheries, every kg of marketable sole may yield up to 10 kg of dead discarded fish and 6 kg of dead invertebrates.
- Fishing with commercial beam trawls causes a range in mortalities of discarded, non-target species due to capture and handling of the catch: high mortalities (70-100% of the total catch) for discarded undersized fish, 50% or less mortality for most crabs and molluscs and very little mortality (< 10%) for starfish. Benthic species, of which many are uncaught by the nets, show a high mortality caused by the passage of the tickler chains. Together with the mortality in the catch this leads to a decrease of: 0-85% of the initial numbers for different mollusc species, 4-80% for crustaceans, 0-60% for annelid species and 0-45% for echinoderm species.
- Considering the high mortality of certain species and the fishing intensity, it can be expected that commercial beam trawling affects the structure and composition of the benthic community in the North Sea.

- Benthic animals damaged, dislodged or discarded by beam trawls may contribute significantly to the diet of scavengers whose populations may thus become enhanced.
- The Reineck box corer and Van Veen grab were effective sampling tools for juvenile specimens and small sized species, but gave unrepresentative data for larger sized animals. Since commercial beam trawling appears to mainly affect the density of large species, box corer and grab sampler are inadequate to study the direct effects of beam trawling. The deep-digging dredge (Triple-D), is a valuable tool for estimating the densities of large invertebrate species.

RECOMMENDATIONS FROM THIS STUDY

- Conduct simultaneous experiments with different types of trawls, such as 12m, 4-m beam and otter trawls to compare the effects of different types of trawls on the marine ecosystem.
- Develop sampling gear to improve accuracy of sampling benthic infauna.The high variation in the numbers of many small-sized infaunal species sampled by box corer or grab reduced the probability of detecting changes in the abundance of these species due to fishing activity. In studies, looking for long-term changes in community structure, the use of a multiple corer, comprising relatively small and independently activated units, would allow rapid and routine sampling. It is proposed that an instrument with these specifications is developed in the future. In addition, trials should be undertaken with the Triple-D fitted with finer meshed nets for small, abundant animals and larger meshed nets, allowing longer hauls, for larger, less abundant animals.
- Collect data on the diet, feeding rate, initial density and immigration rate of species which benefit the most by scavenging.
- Estimate the pressure force exerted by the chain mat and the bobbin gear on the sediment. This can be done by subtracting the pressure force exerted by the sole plates from the total gear pressure force.

GENERAL RECOMMENDATIONS

- Create areas closed to fishing. Studies of the direct effects of fishing in areas which have been continually trawled in the last decades are inconclusive. The rarer and long-lived species may already have disappeared, while the relatively resistant species may predominate present-day fauna. More conclusive evidence for the long-term effects of beam trawling on the benthic ecosystem can only be obtained by studying relatively large areas closed to fisheries for many years. Such areas should be created as soon as possible. Until then, research in quasi-closed areas, eg. around wrecks, should be continued.
- Compare the long-term trends in contrasting areas such as the North and Irish Seas to distinguish between natural and anthropogenic changes in the marine ecosystem.
- Initiate research to reduce the unnecessary destruction of potentially valuable undersized fish.

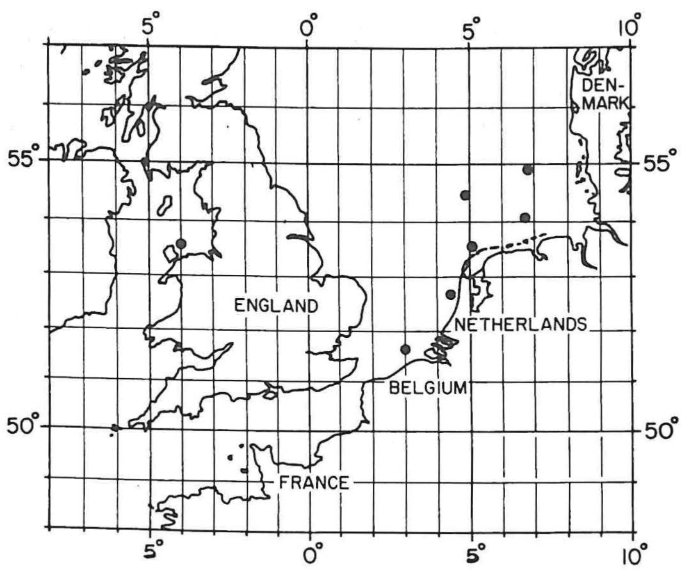

Fig. 1. The study areas of the IMPACT-project in the North Sea and the Irish Sea.

INVENTORY OF NATIONAL FISHING FLEETS

The flatfish beam trawl fisheries of Belgium and the Netherlands comprise the most important part of the national fisheries. Beam trawlers land about 81% of the Belgian and 66% of the Dutch catches. A small number of trawlers concentrate their effort on the roundfish or *Nephrops* fishery and some trawlers are multipurpose vessels.

The fleets can be classified into three groups:

- small multipurpose beam trawlers (engine power ≤ 221 kW, 300 HP)
- flatfish beam trawlers (engine power > 221 kW, 300 HP)
- otter trawlers.

The small multipurpose beam trawlers are vessels with engine power ≤ 221 kW, 300 HP. These are allowed to fish within the 12 mile zone so long as the beam length is less than 4.5 m (EC-regulation no. 55/87). Beam lengths > 4.5 m are only allowed for shrimp trawling. This regulation applies to 101 Belgian, 210 Dutch and 290 German beam trawlers. A limited number of these vessels are also licensed to catch sole within the 12 mile zone using trawls with a beam length over 4.5 m. The small multipurpose beam trawlers target different species with a variety of gears according to the season. Shrimp, flatfish and roundfish are caught respectively with the shrimp beam trawl, flatfish beam trawl and otter or pair trawl.

Flatfish beam trawlers are larger vessels with engine power > 221 kW (300 HP), operating in the open sea outside of the 12 mile zone. The length of the beams ranges from 4 to 12 m. The use of beam trawls over 12 m in length is prohibited by law. Beam trawls are equipped with tickler chains to disturb the flatfishes from the seabed. To facilitate the use of a large number of chains, the belly of the net is shortened. These nets are called V-nets because of the shape of this cut. To allow operation on very rough fishing grounds, beam trawls may be equipped with chain matrices. Chain matrices are rigged between the beam and the groundrope and prevent bolders from being caught by the net. The belly of the net of this type of trawl is not cut as far backwards as the V-net. Some vessels combine the chain matrix configuration with some extra tickler chains.

Vessels that target roundfish are either side or stern trawlers. They use a wide variety of demersal or semi-pelagic otter or pair trawls.

PRESSURE EXERTED ON THE SEDIMENT BY THE SOLE PLATES, AND TRAWL MARKS CAUSED BY A 4 M BEAM TRAWL

The present study provided a better insight into pressure exerted by the sole plates of a 4 m beam trawl on the seabed and the trawl marks caused by the trawl on the sediments.

An instrumented trawl head was constructed to measure the pressure of the sole plates on the seabed. This pressure was studied as a function of towing speed and current direction with the warp length/depth relationship at a value of approximately 3.

Pressure on the sediment is strongly related to the towing speed. With increase in speed, the gear lifts off the bottom and the resultant pressure force decreases. At the same time, however, the tilt of the sole plates increases resulting in a smaller surface area of contact with the bottom. The resultant pressure, expressed as force per unit surface area, tends to increase. At higher speeds, the weight of the gear is compensated by the upwards pull of the vessel causing the beam to lift off the bottom. Our experiments show that the pressure exerted by the sole plates varies from 1.7 $N.cm^{-2}$ to 3.2 $N.cm^{-2}$, when fishing against the current at towing speeds over the ground of 4 $nM.h^{-1}$ and 6 $nM.h^{-1}$, respectively. In commercial fishing, towing speeds are 3 $nM.h^{-1}$ when fishing against the current and 4 $nM.h^{-1}$ when fishing with the current. At these speeds the sole plate pressures are 2 $N.cm^{-2}$ and 1.7 $N.cm^{-2}$, respectively. Bottom contact was lost at 6 $nM.h^{-1}$ or 7 $nM.h^{-1}$ depending on whether the gear was towed against or with the current. Vessel movements induced by surface waves are transmitted to the gear, even at low amplitudes. This may cause the gear to bounce on the bottom. The comparison between the total gear pressure force and the pressure force exerted by the sole plates suggests that the chain mat and the bobbin gear exert only a limited pressure on the seabed.

The side scan sonar recordings revealed that some trawl marks remained visible for up to 52 h after fishing. Although the penetration depths of the beam trawl in the sediment could not be deduced from the records, it is likely that the depth of penetration was not very great. However, this is not necessarily the case for larger beam trawls. The presence of certain infaunal species in the cod-end, and the decreased densities of other infauna species after commercial trawling, indicated that the penetration depth was approximately 2 to 4 cm in the study area north of the Frisian Islands. Sediment type is probably an important factor in determining the duration of the visibility of the tracks. The clearest tracks were seen on coarse sand with shell debris. However, the classification of the different sediment types of the test area was rather crude.

COMPARISON OF HEAVILY FISHED AND QUASI PROTECTED AREAS.

In order to detect the direct effects of beam trawling on the macrobenthos, imaging methods were used. The video records showed a disturbed sediment surface nearly devoid of conspicuous epifauna, inside the German IMPACT box after it had been intensely fished with 12-m beam trawls by RV TRIDENS. In contrast, a relatively undisturbed reference area, 10 nM south east of the trawled area, showed a rich epifaunal community, including brittlestars *(Ophiura ophiura)*, *Lanice conchilega* and large decapods. The REMOTS sediment profile photographs revealed a disturbed surface sediment in the trawled box with no signs of layering or bioturbation. No sub-surface structures, such as feeding voids or burrows, were visible in the trawled area and *Lanice* tubes were damaged. Conversely, intact *Lanice* tubes and sub-surface structures, such as the burrows of *Aphrodite,* were found in the control area.

To examine the long-term effects of experimental fishing, the German Bight IMPACT Box has been frequently fished with different gears to impose additional stress on the benthic community. The fauna appears to be homogeneous, forming a poor variant of the *Amphiura filiformis* community. To date, the results indicate changes towards sandy sediment and its associated community. However, this may be a seasonal effect.

A quasi-closed area around the wrecked platform 'West Gamma', northwest of Helgoland, was investigated for mid-term effects of fishing activities on the assumption that this area is protected from heavy trawling. To date, the results indicate a natural gradient in the species richness of the *Tellina fabula* association extending north and south outside the closed area. It is uncertain whether this gradient is superimposed with another, associated with the unfished area around the wreck (where more than 150 species were found).

CATCH COMPOSITION

There are considerable differences between the catch composition from 12-m beam trawlers fishing in offshore areas (30-50 m water depth) and 4-m beam trawlers fishing in coastal areas (10-30 m depth). In offshore areas, undersized commercial fish are less abundant and, therefore, occur less frequently in discards.

Offshore 12-m beam trawl surveys estimated that at least 8 kg of dead discard fish and 6 kg of dead invertebrates were produced per kg of marketable sole. In the coastal areas, 4-m beam trawls collected at least 10 kg of dead discard fish and 4 kg of dead invertebrates per kg of marketable sole. The total annual production of dead discards by beam trawlers in the southern North Sea was estimated to be 270 000 tonnes of fish and 120 000 tonnes of invertebrates. These are probably underestimates since many damaged animals pass through the meshes.

Comparison of the catch composition of commercial beam trawls with the catch of fine-meshed benthos dredges, indicated that commercial trawls only catch a minor fraction of the benthic fauna.

SURVIVAL OF DISCARDS

The survival of discarded undersized fish and invertebrates from commercial beam trawl catches has been estimated in tanks onboard the research vessels. In general, the survival of discarded starfish and brittle stars was approximately 90%. Sea urchins, in particular the abundant sea potato, *Echinocardium cordatum,* that lives at depths of 5-10 cm in sandy sediments appeared to be vulnerable. At certain times of the year and at certain localities many tonnes of this sea urchin may be crushed in commercial beam trawl nets.

At least 25-50% of the crabs were already dead on arrival onboard the vessel, probably crushed by the action of the tickler chains. The remaining live specimens showed high survival rates (80-100%).

Most of the larger molluscs showed mortalities of about 30-50%. Some vulnerable species such as the quahog (*Arctica islandica*), showed mortality of 80-90%. Most of the smaller molluscs pass through the meshes of the nets, however, of those retained, about 25-40% were damaged. Intact survivors showed little or no mortality in the survival tanks.

The sea mouse (*Aphrodite aculeata*), a polychaete, frequently caught by beam trawlers fishing on soft bottoms offshore is quite hardy and shows less than 6% mortality when discarded.

The mortality of undersized discarded fish was extremely high. Discarded roundfish (e.g. whiting and gurnards) have no survival chance at all. Flatfish showed mortalities of 70-100%, with dab, the most abundant and vulnerable species showing the highest value (99%). Flounder, sole and plaice were slightly less vulnerable with mortalities of about 70%, 84% and 90% respectively. Mortalities of discarded fish from catches of 4-m beam trawls in coastal areas were usually about 10% lower, probably because the smaller beam trawls are lighter, and towed at a lower speed.

The survival of small fish and invertebrates that pass through the meshes of the net during trawling, was estimated from short hauls of 1-5 minutes with the cod-end fitted with a fine-meshed covering net. Most invertebrates showed mortalities that reflected the damage caused by the tickler chains (about 10-30% for crabs, about 20-50% for small molluscs). The results for small dab or plaice indicated that the survival of small fish that pass through the meshes is in the order of 80-100%. Some small fish species, such as solenettes, scaldfish and gobies, are so vulnerable that they died in the covering nets, even after short tows, rendering the method useless for these species. A high survival of small fish that pass through the meshes during trawling, leads to the suggestion that the populations of small fish species may benefit from the intensive beam trawl fishery in the southern North Sea.

DIRECT MORTALITY

Experimental fishing with commercial beam trawls in several study areas of the Dutch sector caused a decrease in the densities of a number of benthic species. This decrease was estimated by comparing samples which were taken before and after trawling. Larger animals had been caught in the trawls, showing a varying mortality after capture and subsequent handling onboard. An estimate of this catch mortality (expressed as a percentage of the initial numbers on the study area) was derived from the results of survival experiments onboard trawlers. Smaller benthic animals were damaged merely by the passage of the beam trawl. This non-catch mortality to fishes and macro-invertebrates was also demonstrated by the study in the German Bight, in which 1-m dredges were attached to the beam, shoes and the tickler chains of a 7m beam trawl. Direct mortality due to trawling was estimated by adding the catch mortality to the non-catch mortality.

After fishing a study area twice with a <u>12-m commercial beam trawl</u>, mortality could be estimated of benthic fauna associated with a soft bottom area north of the Frisian Islands:

- Mortality of scaldfish, dab and plaice varied considerably between species and size-classes (4-75% of the initial numbers). Mortality exceded 100% for large dab, as it rapidly immigrates into the trawled area, already during trawling.
- Mortality of echinoderms was generally low (3-19%), with starfish such as *Asterias rubens*, *Astropecten irregularis*, *Amphiura filiformis*, *Ophiura texturata* little affected and *Echinocardium cordatum* too deeply buried to be harmed.
- The solid-shelled or very small mollusc species, *Chamelea gallina*, *Corbula gibba*, *Nucula* spp., *Mysella bidentata*, *Dosinia lupinus* and *Apporhais pespelicani*, were not affected by beam trawling. More vulnerable species such as *Abra alba*, *Mactra corallina*, *Phaxas pellucidus*, *Mysia undata*, *Ensis ensis*, *Gari fervensis*, *Arctica islandica*, *Acanthocardia echinata* and *Turritella communis* had mortalities of between 12% and 85%, caused mainly by the tickler chains.
- The crustacean species *Corystes cassivelaunus* and *Ebalia* spp. showed a mortality of approximately 30%. *Eupagurus bernardus* showed size-dependent mortality (large animals 15%, small animals 74%). The burrowing species *Callianassa* sp. lived too deeply to be disturbed by beam trawling.
- In general, the mortality of annelid species due to trawling was low (< 1-14%). Only the fragile

tube-dwelling worm, *Pectinaria* sp., was seriously affected (56%). Some anthozoans were also clearly affected.

After fishing a study area in sandy areas off the Dutch coast twice with a commercial 4-m beam trawl mortality could be estimated for a number of species:

- Mortality of dab, plaice, scaldfish, solenette and sole varied considerably with species and size (2-70% of the initial numbers).
- Mortality of echinoderms was generally low for starfish and brittlestars (< 6%) and relatively high for *Echinocardium cordatum* (44%).
- The molluscs species *Angulus* spp., *Chamelea gallina* and *Ensis* spp. were hardly affected. Mortality of *Abra alba*, *Donax vittatus, Euspira poliana, Mactra corallina*, *Spisula subtruncata* and *Tellimya ferruginosa* varied between 4 and 84%, and was caused by the tickler chains, which damaged or exposed the animals to scavengers.
- Mortality of crustaceans was generally high (*Liocarcinus holsatus* 22 to 58%, *Corystes cassivelaunus* 45 to 69%, *Eupagurus bernardus* 47 to 82%). Mortality of annelid species and some anthozoans was < 24%.
- Trawling the same area twice indicated that an increase in trawling intensity leads to increased mortality, especially for immigrating or burrowing species.

SCAVENGING

After the passage of a beam trawl, benthic animals may be damaged or dislodged, and become available to scavengers.

Analyses of stomach contents collected before and after trawling, both in the Irish and North Seas, showed that dab, gurnards, dogfish and whiting increased their intake of prey after fishing. Dab largely scavenged on bivalves (*Arctica, Acanthocardium, Donax and Spisula),* and crustaceans (*Upogebia* and *Callianassa).* These bivalves are normally not accessible to dab. Both gurnards and whiting fed on dislodged amphipods, *Ampelisca spinipes*. Beam trawling damaged the burrowing heart urchin, *Spatangus purpureus*, which was subsequently fed upon by whiting. Material discarded after trawling may be a major food source for scavengers.

The immigration of species into a recently trawled area may indicate scavenging behaviour. Dab, plaice, whiting and bib, often showed increasing numbers in successive catches. Greater numbers of some invertebrate species (e.g. hermit crabs and starfish) were caught 24 h after intensive commercial trawling as compared with 1 h after trawling. However, it is not clear whether these species act as scavengers. Observations of the seabed using side-scan sonar revealed a greater concentration of fish marks around trawl tracks than in adjacent unfished areas. Generally, the results indicate that fish rapidly migrate into trawled areas to feed on animals that have been either damaged or disturbed by fishing.

AN INVENTORY OF VESSELS AND GEAR TYPES ENGAGED IN THE BELGIAN, DUTCH AND GERMAN BOTTOM TRAWLING

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1. ABOUT THE PROJECT

At the beginning of 1992 the EC project MA 2-549 "Environmental impact of bottom gears on benthic fauna in relation to natural resources management and protection of the North Sea" was started with six contractors and five subcontractors coöperating. As a first step in the project an inventory of fishing vessels, fishing methods, fishing areas and species fished for has been made based on data-extraction from several databases and an inquiry among skippers and vessel owners, fishing cooperatives, fishermen unions and fishing gear constructors. This inventory was ment as a background source for the following phases of the project. Three institutes coöperated in making up the overview:

- RIVO-DLO - Rijksinstituut voor Visserijonderzoek - Netherlands
- RVZ - Rijksstation voor Zeevisserij - Belgium
- Federal Research Station for Fisheries, Institute for Fishing Technology - Hamburg, Germany

The year 1990 was chosen as a reference because, at the time of the making of the inventory, complete data sets were only available for that year. The report contains data on the cutter-fleet only. The large stern trawlers, fishing mainly pelagic and semi-pelagic, are left out of consideration.

In the frame of IMPACT II (1994-1996) the present study will be expanded as a sub-project and will be coördinated by the Rijksstation voor Zeevisserij (sub-project I-b - coordinator H. Polet).

2. INVENTORY OF THE BELGIAN, DUTCH AND GERMAN TRAWLER FLEET

The flatfish beam trawl fishery is the most important part of the national fishery for Belgium and the Netherlands. Beamtrawlers land 81% of the Belgian and 66% of the Dutch catches. A small number of trawlers concentrate either on the roundfish or the Nephrops fishery only. Several trawlers are multipurpose vessels.

The fleets can be classified into three subgroups:

- flatfish beam trawlers (engine power > 221 kW, 300 hp)
- small multipurpose beam trawlers (engine power ≤ 221 kW, 300 hp)
- otter trawlers

The lists of vessel data for the three countries are given in Annex 1, Table 1; Annex 2, Tables 1 and 2; and Annex 3, Table 1, mentioning all registered cutters and their home port. Ship tonnages are expressed as BRT - bruto register tonnage. The length of the vessels is expressed as overall length.

2.1. INVENTORY OF BEAMERS AND BEAM TRAWL GEAR

Basically the beam trawl (Fig. 1) is a simple envelope of netting held open horizontally by a steel tube, the beam, and vertically by two hoop-like trawl heads. As no hydrodynamic forces are needed to open the trawl mouth little power is required to tow a small beam trawl. However, large beam trawls are often heavier due to the additional chainmat (Fig. 2) and tickler chain (Fig. 3) arrangements which is needed to assure good contact with the bottom at high towing speed, particularly over a rough sea floor.

Double-rig beam trawlers (Fig. 4) tow two trawls, one from either side, by means of two derrick booms. Double-rig beam trawling is used to catch shrimp and flatfish.

When considering bottomtrawls the engine power/swept area ratios are a relevant factor in environmental discussions. Table 1 gives an overview of these ratios. A split is made in northern and southern North Sea where trawlers use different gears related to bottom topography and surface sediments. It appears that swept area per unit of power for large cutters is smaller than for small cutters. A possible explanation is that the hydrodynamic component in the gear resistance is larger for higher than for smaller engine power, viz. 75% against 50%. Consequently when fishing speed is high, the hydrodynamic resistance increases much quicker than the bottomresistance. Hence the area swept by the large cutters is disturbed by more and heavier tickler chains and with a higher fishing speed.

Figure 5 gives an overview of the gear weights, beam lengths and speed in relation to engine power. One of the most important components of the gear in direct contact with the bottom are the tickler chains and/or chainmat. For the 4-m beamtrawl and the 12-m beamtrawl it can be estimated that 80% and 90% respectively of the swept area comes in contact with these parts of the gear. There is a relationship between bottom type and weight, number and diametes of chains. The heaviest gears are used on hard sandy bottoms. On a muddy, soft bottom only a few tickler chains, of smaller diameter, are used to prevent the gear getting stuck into the bottom due to excessive weight.

The warplength-depth ratio is related to the bottom type; the softer the bottom, the shorter the warplength used. Warplength and seastate also influence the bottom pressure of the trawlhead. If the gear weight is recorded it should be noted that to maintain contact with the bottom the weight of the gear (all the metal parts, e.g. beam, shoes, bridle) on the bottom is the total weight of the gear (emersed in water), minus the vertical vector. Variance in towing force is up to about 50% of the average towing force at Bf 4 to 5.

2.1.1. THE SMALL MULTIPURPOSE BEAM TRAWLERS

The small multipurpose beam trawlers are vessels with engine power ≤ 221 kW (300 hp). These are allowed to fish within the 12 miles zone with beam trawls, according to EC-regulation no. 55/87, if each beam length is below 4 m (4.5 m overall). Beams over 4 m long are also allowed for shrimp trawling. This applies to 101 Belgian, 210 Dutch and 290 German beam trawlers. According to EC regulation no. 3554/90 these vessels can also catch sole within the 12 miles zone with a beam length over 4 m (4.5 m overall) if, in a 12 month's period, 50% of the landings consist of shrimp. Every year the list with the vessels matching this condition is adapted based on the vessel's catch. For 1990, 39 Belgian vessels appear on that list. Included in this fleet are the so called eurocutters which derive their name from the EC-funding to support the development of modern small inshore trawlers with an engine power of 150-220 kW.

The small multipurpose beam trawlers target different species with different gears according to the season. Target species are shrimp, flatfish and roundfish and the respective gears used are shrimp beam trawl, flatfish beamtrawl and otter or pair trawl.

2.1.1.1. BEAM TRAWLING FOR SHRIMP

Shrimps (*Crangon crangon*) are caught along the coasts, in estuaria and in the "Wadden Sea". A typical shrimp beam trawl is 6 to 9 m wide. The height of the trawl head is 50-75 cm. The net itself is of a simple construction, consisting of a top panel, a lower panel and two gussets. Netting material is polyamide and the mesh size ranges from 28 mm in the front part of the net to 22 mm in the codend. The dimensions of the codend are 200 meshes round and 200 meshes deep. In order to protect the codend it is always covered with a large-mesh codend cover (80 mm). A bobbin groundrope with wooden or rubber bobbins keeps the trawl in contact with the sea bed and enables it to ride over stones and other small obstacles. The average towing speed of most vessels is 3 knots. The complete gear weighs between 600 and 900 kg with an average of 750 kg, but it must be kept in mind that these values are estimates.

The catch is sorted with an automatic sieve. Belgian vessels (and also Breskens, NL) use sieves with a 6.5 mm mesh, whereas Dutch vessels use sieves with a 6.88 mm mesh.

Usually, shrimp trawlers, without refrigeration, leave the harbour in the evening, fish for about 12 hours and return in the morning. In wintertime, if temperatures are quite low and shrimp can be preserved longer, some beamers tend to go fishing for up to 24 hours. In some harbours vessels leave and return at high tide. If vessels are equipped with a refrigerator (some vessels in the Netherlands) time at sea is up to two days.

About 20% (Belgium) and 45% (Netherlands) of these vessels fish for shrimp all year, mainly the smaller vessels. Approximately 40% (Belgium) and 35% (Netherlands) catch shrimp during a shorter period between June and November when the larger shrimp catches occur and switch to flatfish and/or roundfish species in the rest of the year. About 40% (Belgium) and 20% (Netherlands) catch shrimp during a longer period but switch to flatfish between March and June.

2.1.1.2. BEAM TRAWLING FOR FLATFISH

Most of the shrimp trawlers (80% for Belgium and 85% for the Netherlands) change to the flatfish fishery especially during the spawning season when adult sole begin migrating to the coastal nursery grounds. This seasonal fishery starts in March and lasts until the end of May. Some vessels (30%) continue this fishery during early summer. Then they all revert to shrimp trawling.

All shrimp trawlers are allowed to catch sole with beam trawls over 4.5 m wide. In this fishery two types of gears are used, round nets and V-nets. The so called round nets are traditional nets with few tickler chains. A more modern type of net is the V-net of which the belly has been cut away further backwards in a V-shape and can be rigged with more tickler chains. The average weight of the gear is 700 kg. A variation of approximately 100 kg applies to the variation in the number of tickler chains used.

The netting material used is polyethylene, single braided in the top panel and mostly double braided in the belly of the net. Mesh sizes range from 120 mm in the front part of the net to 80 mm in the codend. The majority of the fishermen use standard codends with 100 meshes round and 50 meshes deep.

2.1.1.3. OTTER TRAWLING OR PAIR TRAWLING FOR ROUNDFISH

Between October and February, when shrimp and sole catches are small, the roundfish fishery used to be commonly practised, with cod and whiting as the main target species. As roundfish stocks are very low in the coastal waters otter trawling (Fig. 6) and pair trawling (Fig. 7) have only occasionally been practised by the coastal vessels during recent years. However 50% of the skippers intend to switch to this fishery again during winter time if stocks return to normal levels.

For pair trawling large four panel semipelagic nets are used. The nettingmaterial is polyamide and the mesh size decreases from 600 mm in the front of the net to 90 mm in the codend. The netting for the codend is double braided polyethylene or polyamide and the dimensions are standard (100 meshes round and 50 meshes deep).

The otter trawls (two panel trawls) used have considerably varying dimensions. Again mesh sizes are frequently very large in the front part of the net and decrease to the legal minimum mesh size in the codend. The netting material is polyamide or polyethylene and the codends have standard dimensions. Usually oval otter boards, made of steel, are used.

2.1.2. FLATFISH BEAM TRAWLERS

Flatfish beam trawlers are larger vessel with engine power > 221kW (300 hp) operating in the open sea. These vessels are not allowed to fish within the 12 miles zone. The length of the beams ranges from 4 to 12 m. The use of beamlengths over 12 m is prohibited by law.

Beam trawls are equipped with tickler chains to disturb the flatfishes from the seabed. The tickler chains are attached between the beam trawl shoes. Additionally net-tickler chains often are included in the gear and are attatched to the groundrope. It is a main advantage of beam trawling that the number of tickler chains, and consequently the catching power, is only limited by the horse power of the vessel's main engine whereas the number of tickler chains that can be used in otter trawling is limited by the fishing method itself. In order to allow a large number of chains to be used the belly of the net is cut far backwards. These nets are called V-nets because of the shape of this cut.

For operation on very rough fishing grounds beam trawls can be equipped with chain maitrices. Chain matrices are rigged between the beam and the groundrope and prevent bolders from being caught by the net. The belly in this type of beam nets is cut less far backwards than in a V-net. Therefore chain mat nets are also called round nets (R-nets).

The largest vessels combine the chainmat configuration with some extra tickler chains (Fig. 8).

Both V-nets and R-nets may be equipped with so called flip-up ropes to prevent large stones from entering the trawl.

Flatfish beam trawl nets are of the same basic construction as the shrimp trawl nets, but of course they are made of heavier netting yarns and have bigger meshes.

2.1.2.1. BEAM TRAWLS WITH CHAIN MATRICES

The dimensions of the compartments in the chain matrices are 30x30 cm (3x3 links) or 30x45 cm (3x5 links). Flip-up ropes are usually used by the larger vessels. To release debris, many trawls have an opening cut in the lower panel, just in front of the codend. This is usually necessary as chain matrices beam trawls are used on dirty grounds. Yhe lower panel and the codend consist of mostly double braided polyethylene. The upper panel is made of single braided polyethylene. The mesh size in the net is usually 120 mm. The standard codend is 100 meshes round (selvedges included for Belgium and Germany and excluded for the Netherlands) and 50 meshes long.

2.1.2.2. BEAM TRAWLS WITH TICKLER CHAINS

The number of tickler chains and net-tickler chains is very variable, but the higher the engine power, the higher the number of chains. As V-nets are mainly used on clean grounds, most of the vessels fishing with V-nets do not install flip-up ropes in the net. The same counts for the debris opening in the lower panel. For V-nets the main netting material is polyamide, often double braided in the lower panel and the codend, single braided in the upper panel. The standard mesh size in the net is 120 mm but often larger meshes are used for the front part of the net in order to reduce water resistance.

2.2. INVENTORY OF OTTER TRAWLERS AND OTTER TRAWL GEAR

The most developed method for keeping towed trawls open horizontally is the use of otter boards. These are large boards of steel or wood and iron, weighted on their base by a protective iron shoe, designed for a firm contact with the bottom, and fitted with brackets, or beckets, to which is attatched the kelly's eye assembly. The otter board is designed to be towed over the bottom at such an angle that the pair of doors constantly try to "swim" away from each other, thus spreading the wings of the net and holding the trawl mouth open. The contact of the otter board with the bottom and the water turbulence behind the board can generate a sand cloud which, together with the noise, leads to a herding effect of the fish. At the trawl mouth, the groundrope, assures good contact with the bottom, and the square prevent fish from escaping.

Otter trawls used by the Belgian, Dutch and German "Cutter" fleet exist in a wide variety and mostly are demersal trawls targeted at roundfish as cod, whiting and haddock.

2.2.1. OTTER TRAWLING FOR NEPHROPS

Beside the traditional Nephrops fleet, many otter trawlers, especially in Belgium, have switched to the Nephrops fishery in recent years due to low roundfish stocks. The exact period when Nephrops is targeted cannot be clearly determined because skippers easily switch between the roundfish and Nephrops fishery depending on the availability of these species on the fishing grounds.

The average towing speed in the Nephrops fishery is 3 knots. The net is usually fished with rectangular wooden otter boards. The Nephrops trawl is a traditional two panel bottom trawl or a more modern twin trawl.

2.2.2. OTTER TRAWLING FOR ROUNDFISH

2.2.2.1. OTTER TRAWLING IN ICELANDIC WATERS

Three Belgian vessels are still (1990) allowed to fish in Icelandic waters but this situation will end once they are replaced by new vessels.

Towing speed is 4 knots. Polyvalent otter boards are used. The gear is based on the Vigneron-Dahl system. The netting material is polyethylene of 135 or 155 mm. The codend consists of double braided polyester. Target species are cod, haddock, saithe and whiting.

2.2.2.2. OTTER TRAWLING IN ICES AREAS IV AND VII

A high variety of trawls and otter boards are used, depending on vessel type (side trawler - stern trawler), fishing ground, target species and light conditions on the fishing ground.

TABLE 1
Fishing power related to the swept area

Engine-power (hp) (kW)	300 220	N*) 1500 1100	S 1500 1100	N 2200 1600	S 2200 1600	N 3000 2200	S 3000 2200
Beam-length N* (m)	4	12	-	12	-	12	-
Beam-length S* (m)	4	-	10.4	-	12	-	12
Fishing speed (kn)	4.3	6.0	6.0	7.2	7.0	8.0	7.7
Swept surface/h (m^2 x 10,000)	6.4	27	23	32	31	36	34
Ratio power/surface	35	41	48	50	51	62	64

*) N = Northern part of southern North Sea
S = Southern part of southern North Sea.

Note: the weight per meter Beamlength for the tall beamertrawlers is about 2 x the weight per meter of the 220 kW beamtrawlers (see figure 5) so it is not abnormally that the ratio for the tall ones is about twice that of the small ones.

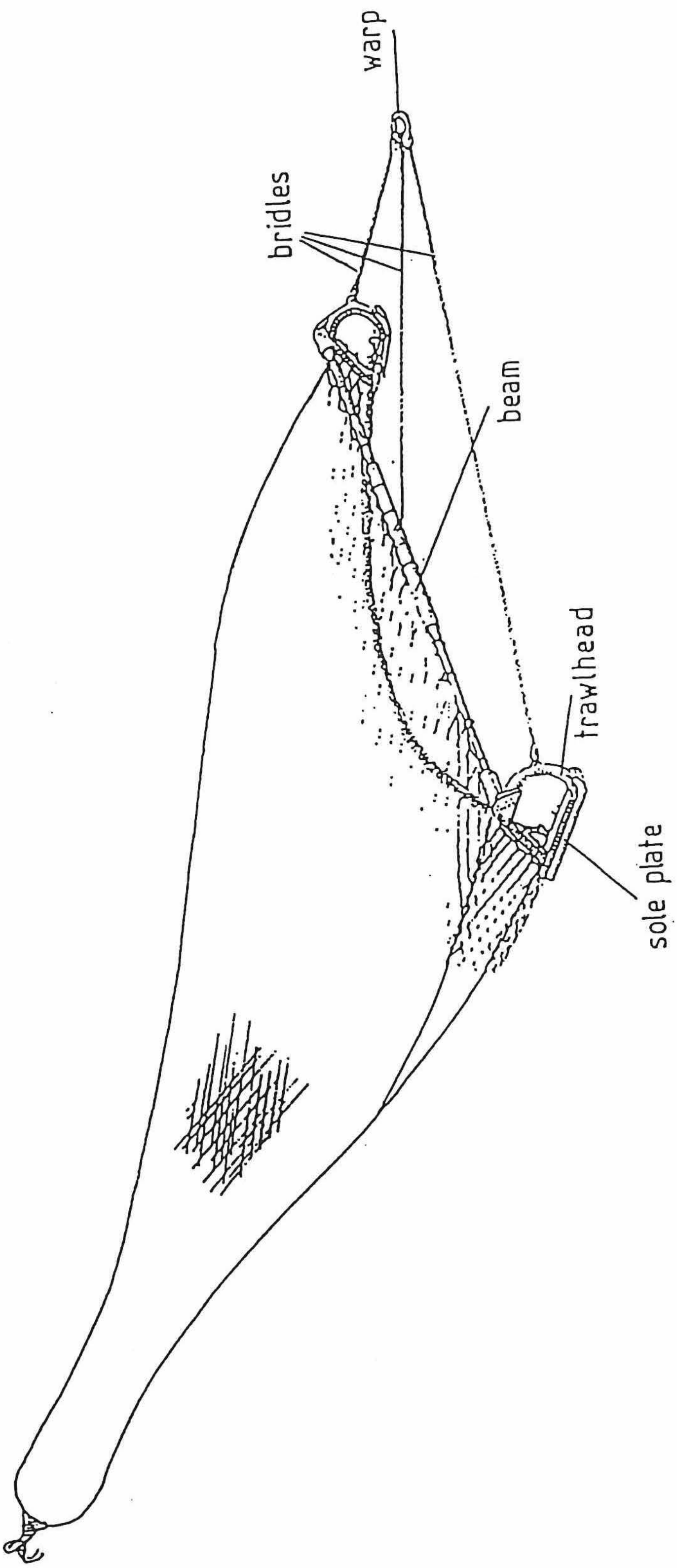


Fig. 1. Beamtrawl.

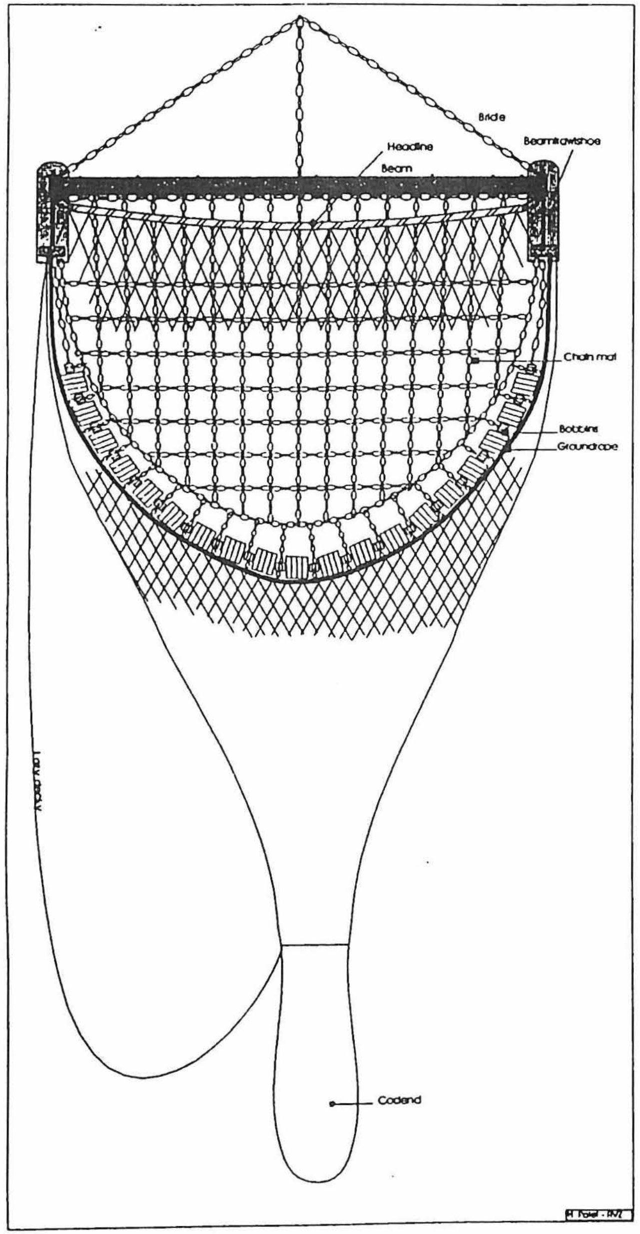
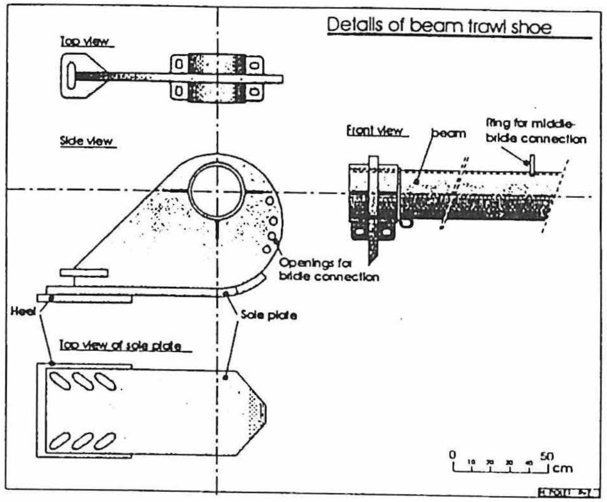


Fig. 2. Beamtrawl with chain matrices.



Vessel: 883 KW (1200 HP)
BEAMTRAWLER

Fishing gear: Chainmat beamtrawl

- beamlength: 10m, _ 25cm
- headline: 10m, mixed _ 28mm
- groundrope: 17.6m, polyamide
- bobbins: 18m, rubber _ 28cm
- bridles: 6.3m (outer bridle), _ 30mm
- chainmat: Each rectangle contains 5 vertical and 3 horizontal links, _ 18mm

weights for each gear:

- total: 5000kg new - 4500kg used (±1 month)
- beam: 800kg
- 1 trawl shoe: 450kg
- chainmat: 2000kg
- net + bobbins + bridles: 1200kg

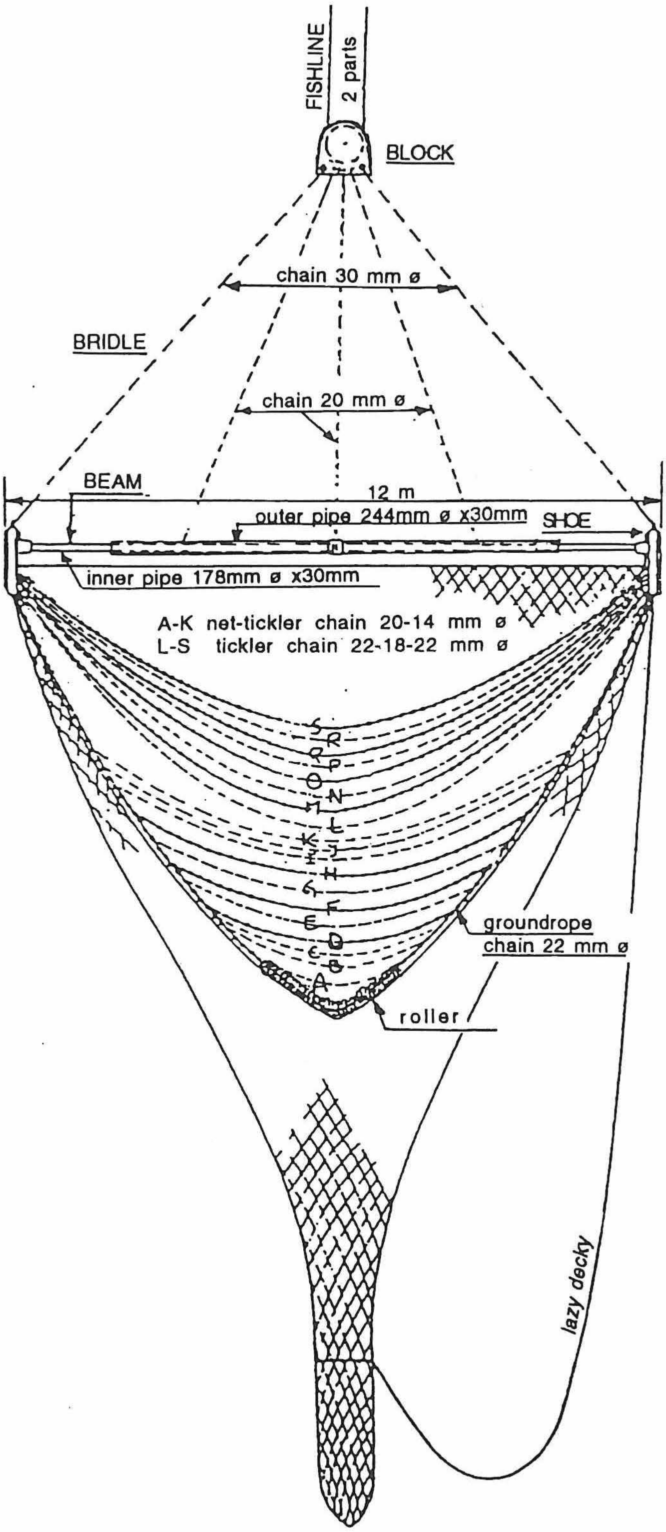


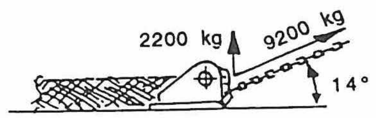
Fig. 3a. Beamtrawl-gear

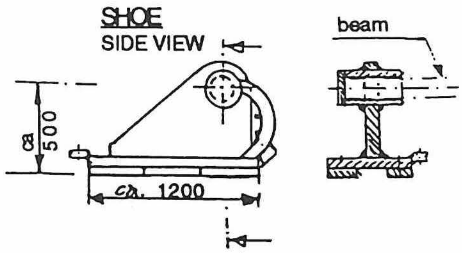
1600 kW (2200 HP) BEAMER
the 7.3 tons gears.

Each gear:	New weight above water	weight under water during approvals	
net	+500		
groundrope :			
chain 22 ø	260	/200	750kg
roller ca 250 ø (most rubber)	550	/200	
net-ticklerchains			
A-C = 3 x 20 ø	470	/350	
D-K = 8 x 14 ø			
tickler chains :			
L = 1 x 22 ø	240	/	1020 kg
M-O = 3 x 18 ø	435		
P-S = 4 x 22 ø	700		
(T-U = 2 x 26 ø	435		
	1810 kg)		
shoe and beam ca. 3200kg		/2800	1080 kg
bridle and block ca. 550 kg		/ 480	
vert. power : / sin 14°x9200 kg =		/-2200	
			2850kg

(chains weared off 15% ≙ 300 kg from new, after 6 weeks of fishing.)

(∡ fishline is 12 -16°, in the South. Northsea, with dunes and stones, up to more than 20°.)





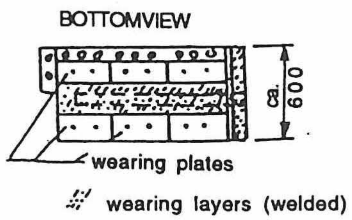


Fig. 3b. Gear-detail

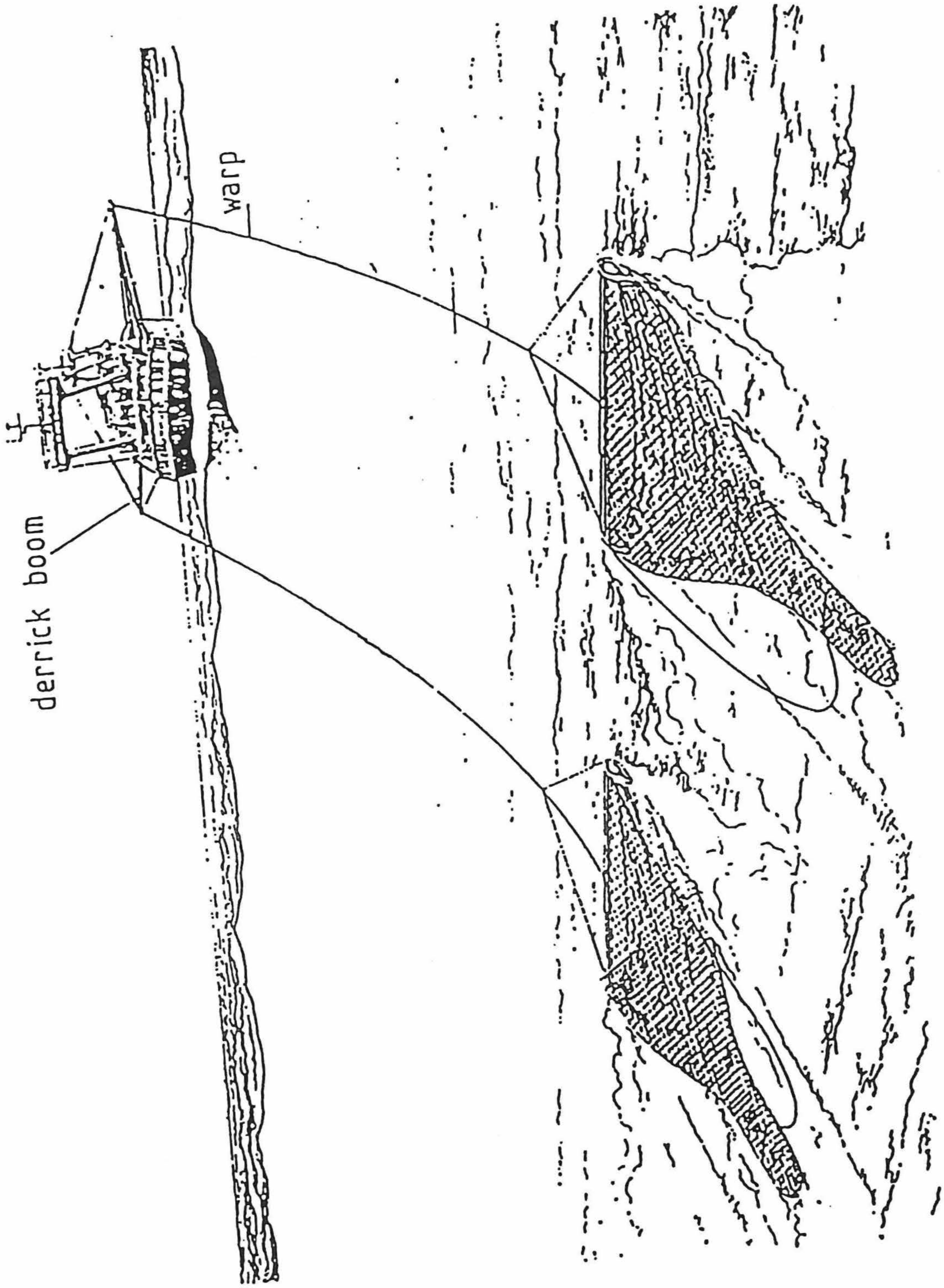


Fig. 4. Double rig beam trawling.

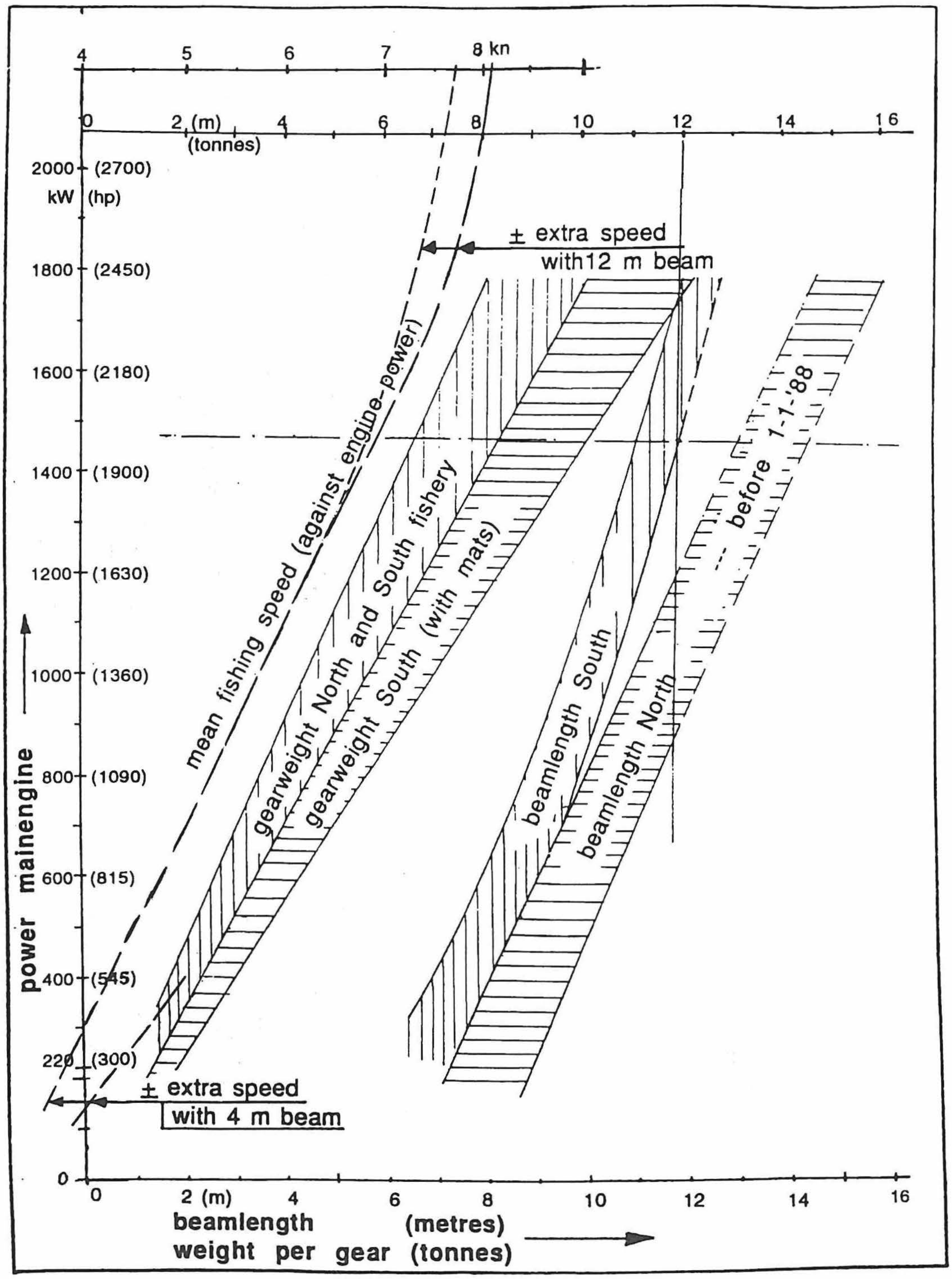


Fig. 5. Interrelation engine power, beamlength and gearweight.

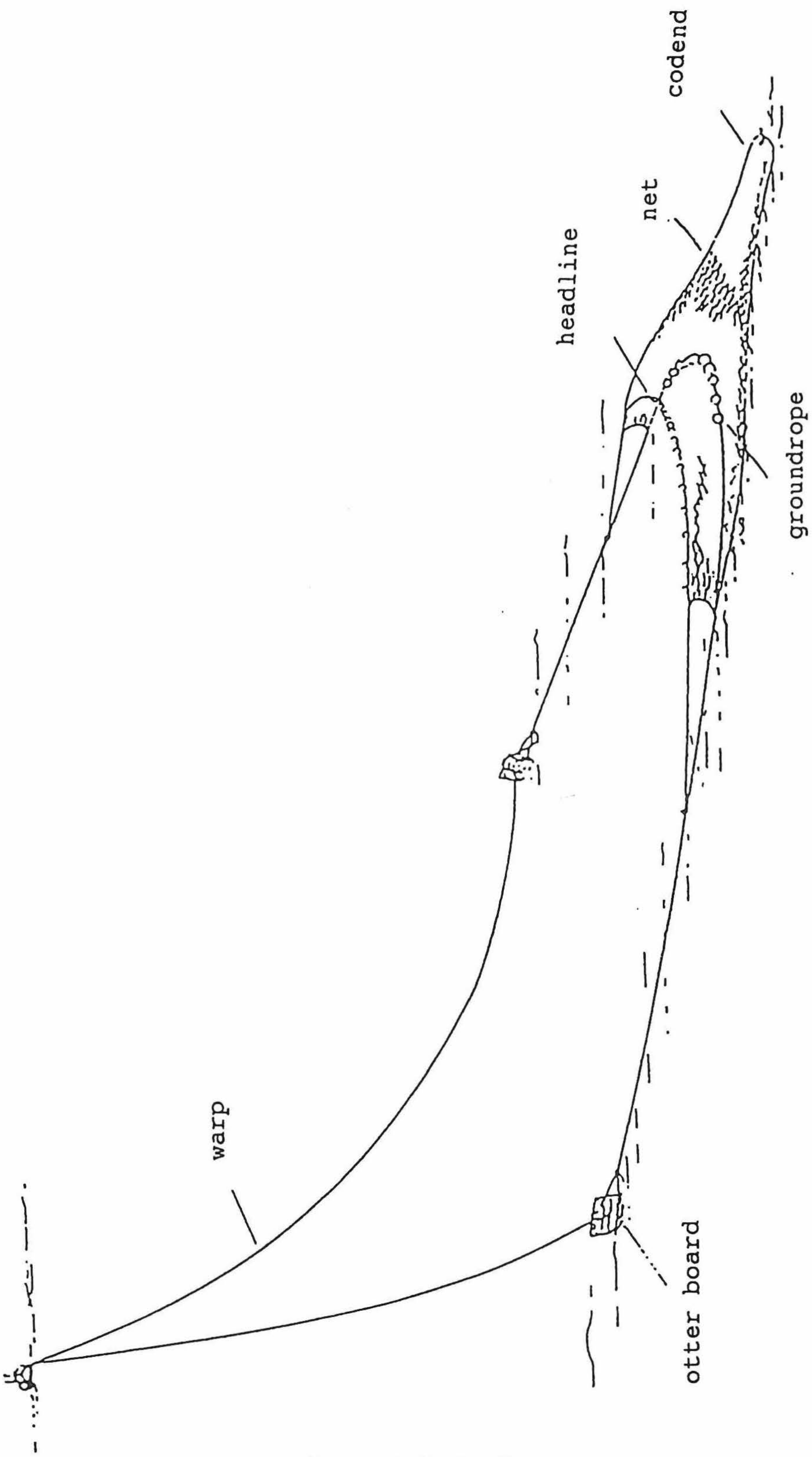


Fig. 6. Demersal otter trawling.

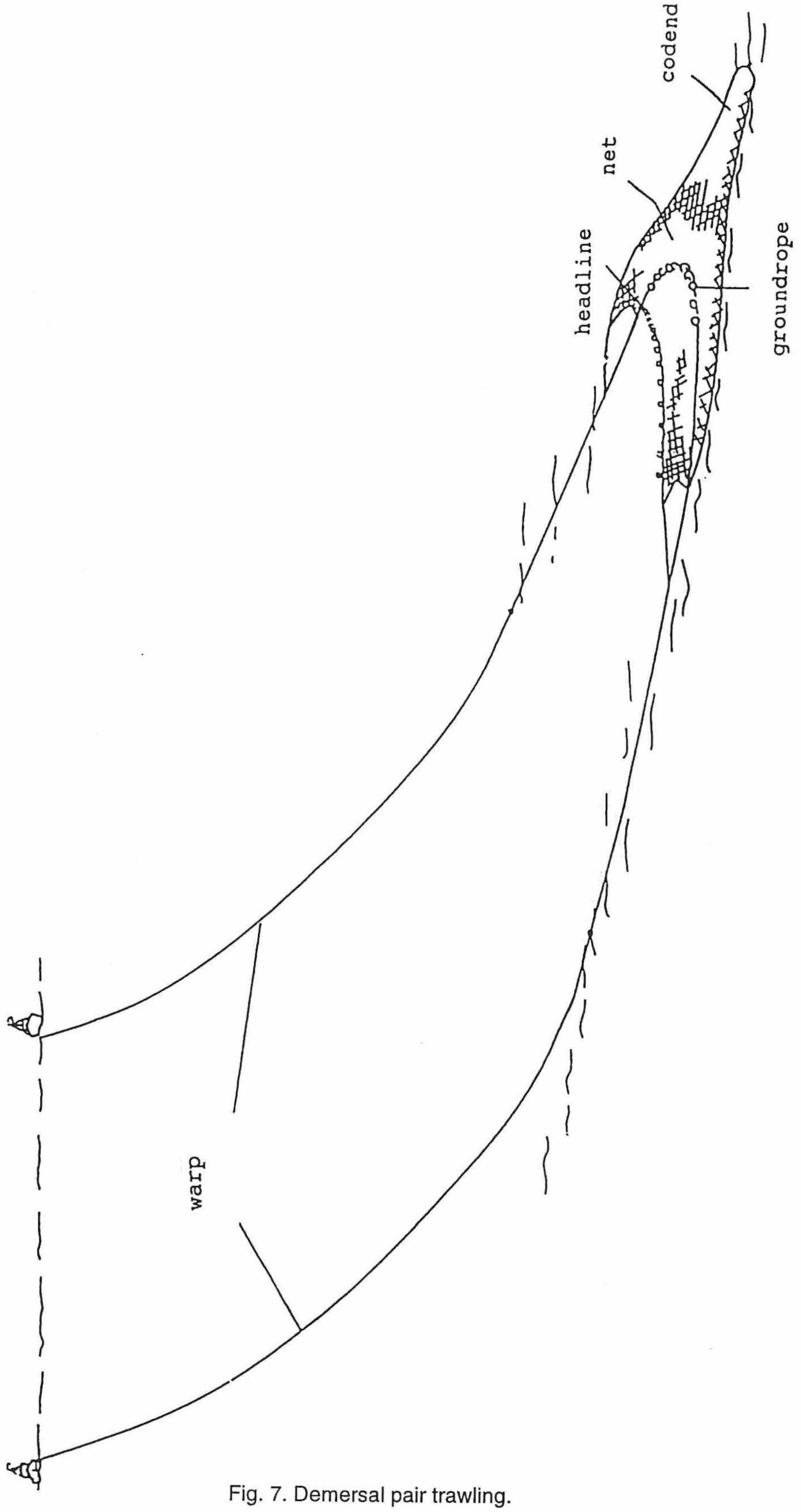
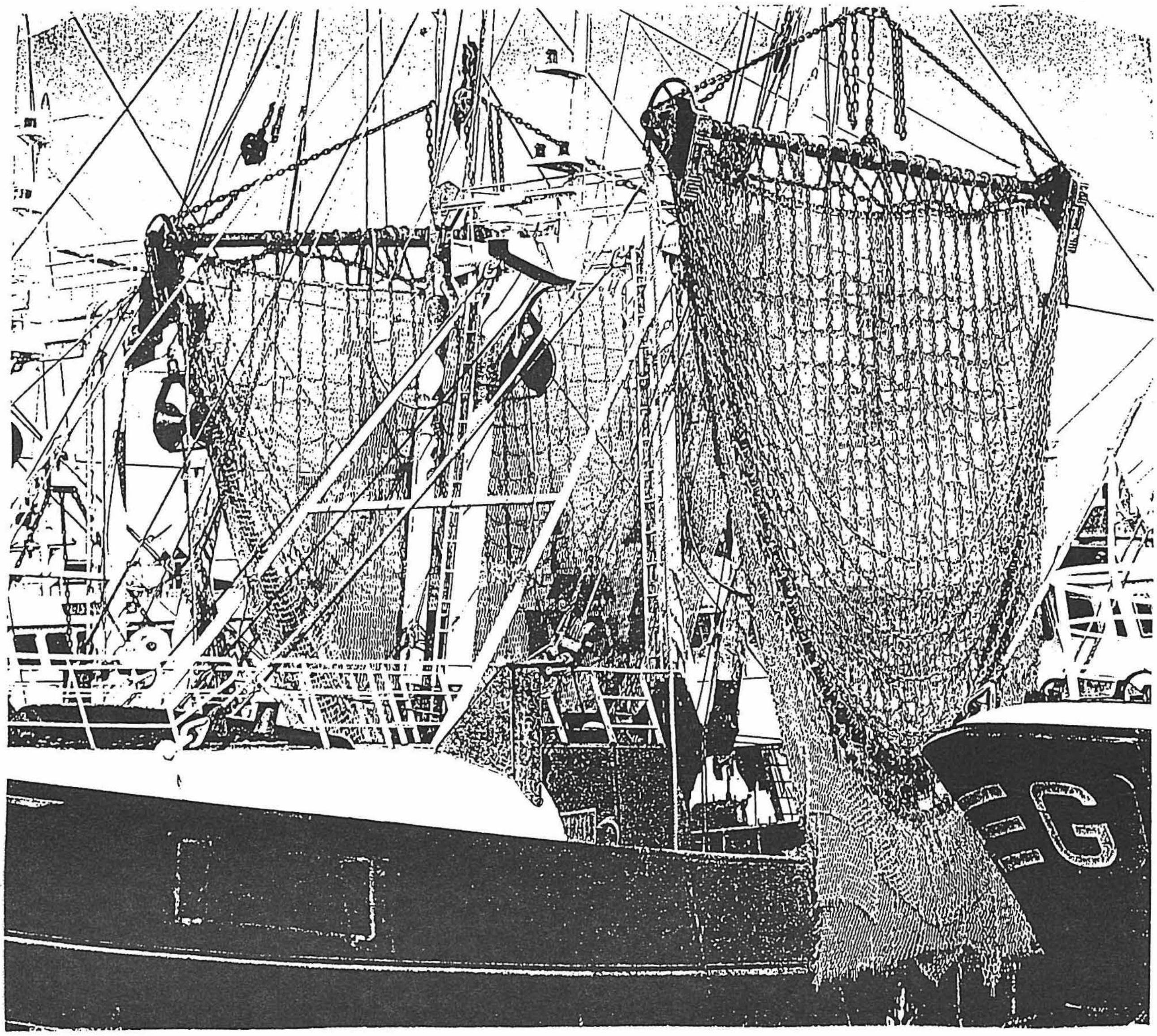


Fig. 7. Demersal pair trawling.



A 1025 kW beamer built in 1981 with chainmats and 5 ticklerchains
Wearing peaces (of old nets) over the bulwarks.

Fig. 8. Beamtrawl chainmat configuration combined with tickler chains.

PHYSICAL IMPACT OF A 4-M BEAM TRAWL

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ABSTRACT

In the frame of the "FAR" research project No MA 2-549 "ENVIRONMENTAL IMPACT OF BOTTOM GEARS ON BENTHIC FAUNA IN RELATION TO NATURAL RESOURCES MANAGEMENT AND PROTECTION OF THE NORTH SEA"(IMPACT) a series of experiments were carried out to study the physical impact of a 4-m beam trawl equipped with a chain matrix. An instrumented trawl head was developed to measure the pressure of the sole plates on the sea bed. The total gear pressure was calculated from the warp load. Side scan sonar recordings were made to estimate the persistency of the trawl marks on the sediment. Visual observations on the trawl path were made by divers.
The pressure of the trawl heads on the sea bottom varied between 1.7 N/cm² for full bottom contact of the beam shoe plate and 3.1 N/cm² for heel contact only. Under commercial fishing conditions prevailing on board Eurocutters the sole plate pressure will vary between 1.7 N/cm² and 2.0 N/cm². The instrumented trawl head also provided information on the dynamic behaviour of the beam trawl. The conditions under which the sole plates lose bottom contact could easily be defined. The towing speed at which the sole plates left the sea bed was 6 or 5 knots, depending on whether the gear was towed with or against the current. Pressure variations of the gear were related to vessel motion. The side scan sonar recordings revealed that some trawl marks remained visible for up to 52 hours after fishing. Too weak traces on the sonograph recordings prevented an accurate estimate of the penetration depths of the beam trawl in the sediment. However, it is unlikely that penetration depth was very great. Some sonographs indicated that the sediment type is probably an important factor in determining the duration of visibility of the trawl tracks but the results are not completely in agreement with earlier observations.

INTRODUCTION

Systematic research on the effects of beam trawling mainly dates from 1970 on, when ICES requested information on the effects of trawls and dredges on the sea bed (ICES, 1971: Council Resolution 1970/S/1). In 1988 the ICES Study Group on the Effects of Bottom Trawling was convened in response to Council Resolution 1987/2:7 (ICES, 1988a) to collect available information since 1972 and to report on the developments in bottom trawling gear, existing literature, national research and proposals for coordinated research (ICES, 1988b).

The effects of beam trawling, as with any other dragged bottom gear, may be classified into two main groups, viz. the physical effects on the sea bottom and the effects on the bottom fauna. As the present paper deals only with the physical impact of beam trawls, only the physical aspects of past research will be considered here.

The experiments carried out in the early 70's dealt with rather light gears. More recent studies consider the effects of modern, heavier gears. Almost all beam trawls in the experiments were equipped with tickler chains. In one case only the beam trawl was equipped with a chain matrix (DE CLERCK & HOVART, 1972).

The pressure exerted by the gear on the sea bed can be calculated from the weight of the gear and the dimensions of the gear elements in contact with the sea bottom. MARGETTS & BRIDGER (1971) calculated that the pressure of a 9 m beam plus trawl heads with a total weight of 324 kg (283 kg in water) is 0.1 kg/cm². For comparison, a 556 kg (in water) otterboard exerts a pressure of 0.236 kg/cm². However these values do not take account of the upwards pull of the warps. VAN DER HAK & BLOM (1990) measured the warp load to deduce the pressure on the sea bottom of a modern 12-m beam trawl with a weight of 7000 kg (5050 kg in water). At a speed of 6 knots, a pressure of 0.15 kg/cm^2 was exerted by the shoes of the trawl heads, and a pressure of 0.11 kg/cm^2 by the tickler chains.

Due to the pressure of the gear on the sea bed parts of the gear penetrate to some extend into the sea bottom. The penetration depth largely depends on the nature of the bottom (MARGETTS & BRIDGER, 1971; BRIDGER, 1972; DE GROOT, 1972; ICES, 1973). Penetration of bottom gear has been studied in different ways. Direct observations has been made by divers (BRIDGER, 1970; MARGETTS & BRIDGER, 1971) and by using equipment such as underwater television cameras (MARGETTS & BRIDGER, 1971; SYDOW, 1990) and side scan sonar (DE GROOT, 1972; SYDOW, 1990). BRIDGER (1972) implanted markers into the sea bed and determined which part had been touched by the tickler chains of a beam trawl passing over them. Other researchers estimated the penetration depth from the benthos species caught by the gear (HOUGHTON *et al.*, 1971; BERGMAN & HUP, 1992).

Depending on the sediment type, weight of the beam and shoes, weight per unit length, number and spacing of tickler chains, towing speed and tidal conditions, a beam trawl will cause a more or less distinct track, persisting for up to 16 hours (MARGETTS & BRIDGER, 1971; DE GROOT, 1972; BERGMAN *et al.*,1990). The disturbance is most distinct on muddy or soft sandy grounds. On hard sandy ground, the tracks are difficult to detect, being a more smoothed path. On very soft grounds the tracks are ill-defined and are soon erased. The most visible tracks are made by the sole plates. MARGETTS & BRIDGER (1971) observed sole plate marks 80-100 mm deep on muddy sand but only 15 mm deep on a sandy ridged ground. The tickler chains seem not to be in firm contact with the bottom and will only exert a limited pressure on the seabed (ICES, 1988b). Successive layers of sediment will be brought into suspension but will settle again after the gear passed. This is not likely to cause a problem in areas where natural sediment movement due to the effect of tidal action and gales is high (DE GROOT, 1984; ICES, 1973; ICES, 1988b). Based on measurements made with implanted markers in the sea bed, BRIDGER (1972) concludes that only the surface of the soil will be disturbed by a tickler chain. Even with an array of 15 tickler chains (1478 kg) operating on mud at a low speed of 2.2 knots the penetration depth did not exceed 30 mm. HOUGHTON *et al.* (1971) judged from the quantities of *Acanthocardia* and *Echinocardium* caught by a 9.5 m beam trawl fitted with 17 tickler chains that the gear disturbed the seabed to a depth of 10 to 20 cm. From the presence of benthic infauna (*Arctica islandica* and *Echinocardium cordatum*) in the catches of a 12 m/7000 kg beam trawl operating on a hard sandy bottom, BERGMAN *et al.* (1990) concluded that the tickler chains, possibly only in part of the trawled, area penetrated to a depth of at least 6 cm. The Work Programme of the FAR research project No MA 2-549 ENVIRONMENTAL IMPACT OF BOTTOM GEARS ON BENTHIC FAUNA IN RELATION TO NATURAL RESOURCES MANAGEMENT AND PROTECTION OF THE NORTH SEA (IMPACT), specifies "The penetration depth of gears into the bottom is not well known and may range from 6-15 cm, depending of the bottom sediment, time of the year and fishing methods".

One of the aims of the IMPACT research project was to determine "With the aid of e.g. underwater video equipment, side-scan sonar techniques, the penetration/depth of various gear parts (trawldoor, groundrope, beam trawl shoe, ticklers) will be studied. Fishing gear parameters as towing/pullforce, weight, resistance, penetration into the bottom, will be recorded and analyzed." The Fisheries Research Station in Ostend (Rijksstation voor Zeevisserij, RVZ) agreed to participate in the project and to make some observations on the physical impact on the sea bed of a 4-m beam trawl fitted with a chain matrix (also called chain mat). This gear is frequently used by the "Eurocutters" (beam trawlers of maximum 221 kW engine power) which under certain conditions are allowed to fish within the 12 mile coastal zone.

The field work was completed between April 1992 and March 1993 with three one-week cruises on RV BELGICA on the Belgian continental platform. Measurements of the pressure exerted by the sole plates on the sea bed was accomplished by developing and constructing an instrumented trawl head. Visual persistance of the trawl marks was estimated by side scan sonar. Additional observations were made by divers.

1. MATERIALS AND METHODS

1.1. FISHING GEAR

The 4-m beam trawl (Fig. 1) was equipped with a chain matrix. This type of gear is often used by the "Eurocutters", which are beam trawlers with a maximum engine power of 221 kW (300 hp), allowed to fish within the 12 mile limit in certain coastal areas. They are allowed to fish with a pair of beam trawls of lengths of maximum 4.5 m each. The net plan is shown in Fig. 2.

The weight of the gear and its components is:

Component	in air	in water
Complete trawl	23005 N	17020 N
Beam + trawl heads + bridles	10653 N	9870 N
Beam + trawl heads + bridles + chain mat	20005 N	16430 N
Net	3000 N	590 N

(1 N = 0.102 kgf)

During the second and third cruise, the port side of the beam trawl was equipped with an instrumented trawl head to measure the pressure of the sole plates on the sea bottom. This instrumented trawl head was 1960 N heavier than the original one. Consequently the starboard side of the trawl head was ballasted by the same weight thus producing a total weight increase of the gear of 3920 N. The total weight of the instrumented gear and its components is given in the table below:

Component	in air	in water
Complete trawl	26925 N	20440 N
Beam + trawl heads + bridles	14573 N	13290 N
Beam + trawl heads + bridles + chain mat	23925 N	19850 N
Net	3000 N	590 N

1.2. INSTRUMENTED TRAWLHEAD

In order to make direct measurements of the forces exerted by the sole plates on the bottom an instrumented trawl head was developed and built. The principle is shown in Fig. 3. The loose sole plate is connected to the trawl head by means of two measuring axles 1 and 2. Strain gauges on the axles measure the forces generated in the x- and y-directions. The forces in the y-direction are a measure for the pressure exerted by the sole plate on the bottom whereas the forces in the x-direction are a measure for the friction between the sole plate and the bottom sediment. By measuring the bottom reactions at two different points, the eccentricity e of the resultant R of these forces can be determined. The eccentricity results mainly from the difference between the forces F_1 and F_2. This difference depends on the difference in load on each axle as well as on the tilt angle between the sole plate and the bottom profile.

The measured values of the forces acting on the axles are averaged over a preset time interval and stored in an internal RAM memory for later readout by a MS-DOS compatible computer. The time interval between the two recordings is adjustable between 1, 2 and 4 seconds. In the present experiments, readings were made at 1 sec time intervals to enable a study of the peak values to be made.

Further details of the measuring principle and of the calculation of the eccentricity are given in Addendum.

1.3. EXPERIMENTAL CRUISES

Three cruises were undertaken in the project period 01.01.92-31.12.93, viz.

Cruise no	Period	Objectives
1992/09	6-10 April 1992	1. Observation of the trawl marks by side scan sonar and divers and determination of the penetration depth. 2. Determination of the warp load and pressure of the beam trawl on the bottom.
1992/25	2-6 November 1992	1. Testing the instrumented trawl head. 2. Determination of the total pressure of the beam trawl on the bottom. 3. Observation by divers of the trawl marks and determination of the penetration depth.
1993/07	22-26 March 1993	1. Measurement of the pressure exerted by the sole plates. 2. Determination of the total pressure of the beam trawl on the bottom. 3. Observation by side scan sonar of the trawl marks on the seabed.

1.4. WORKING AREA

The working area was situated on the Belgian continental shelf 35 km off Zeebrugge (Fig. 4). The location of the experimental trawl tracks for the pressure measurements and the side scan sonar and diver's observations are shown in Fig. 5. The depth of water over the tracks ranged between 20 m and 30 m. On zone I the seabed was very flat. Zone II was relatively flat with 7 sandwaves of about 1.5 m high detected along the total length of the zone during cruise 1992/09. On cruise 1993/07 however, the number of detected sandwaves had decreased to 5 and their height increased by 0.5 m to about 2.0 m. Along zone IV 13 distinct sandwaves up to a height of 3.5 m to 4.0 m were distinguished. A detailed description of the seabed morphology is given in Annexes 4 and 5.

Although these tracks were chosen for their expected sediment homogeneity, the grain-size analysis of the Van Veen grab samples taken on cruise 1992/09 showed considerable variations along the sample line of each individual track:

Zone	Gravel fraction > 4 mm	Sand fraction andnatural mean values	Silt fraction < 50 µm
I	0 - 2.32%	78.80% - 95.27% 293 µm - 530 µm	4.70% - 21.20%
II	0 - 8.90%	90.10% - 98.63% 438 µm - 591 µm	1.00% - 1.37%
IV	0.55% - 14.33%	83.19% - 98.13% 374 µm - >884 µm	1.43% - 12.10%

Figs. 6-8 give the natural mean values of the sand fraction along each zone. Details on the sediment data and analysis can be found in Annex 4.

On zone I and II Van Veen grab samples were also taken during cruise 1993/07. A description of the samples is given in Figs. 9 and 10. The sediment samples were analyzed by the Centre for Estuary and Marine Ecology of the Netherlands Institute for Ecological Research. As in 1992 the samples consisted mainly of medium-grained (250 µm - 500 µm) sand.

1.5. VESSEL

The experiments were undertaken from the Belgian research vessel BELGICA. The BELGICA is a multi-purpose oceanographic research vessel with a length over all of 50.90 m, a registered tonnage of 765 t and an engine power of 1154 kW (1567 hp). Unlike commercial beam trawlers the BELGICA is not equipped with derrick booms. Hence one beam trawl is towed from an A-frame at the stern of the ship. The following equipment was used during the experiments:

- precision position finding system SYLEDIS (a detailed description is given in Annex 4),
- echo sounder Atlas Deso 20 (see Annex 4 for description and calibration),
- doppler log Raytheon DSN 450,
- mainframe HP 1000 and ODAS (Oceanographic Data Acquisition System) software for data acquisition and processing with real time plots of the fishing tracks. Nautical parameters (time, position, depth, velocity, heading) were recorded every 30 sec.

1.6. SIDE SCAN SONAR OBSERVATIONS

At the request of RVZ, side scan sonar observations of the fishing tracks were made by the Research Unit Marine and Coastal Geomorphology of the University of Ghent during cruises 1992/09 and 1993/07.

1) Cruise 1992/09: For each of the test zones (I, II and IV, Figs 4 and 5) a set of 6 parallel routes at 10 m intervals and 2500 m long was calculated. Before fishing started, the test area was observed by side scan sonar to check for earlier trawling activity. For each set of routes 3 to 4 lines were fished. After trawling, successive side scan sonar observations were made until the trawl marks were no longer detectable.
2) Cruise 1993/07: Two passings with the beam trawl were made along track I. The trawl marks were observed 21 hours 35 minutes after fishing. Only on test zone II side scan sonar observations were made before fishing. Nine successive tows were made on track II. The trawl marks were observed with the side scan sonar up to 44 hours after trawling.

Detailed information on materials and methods for the side scan sonar observations is given in Annexes 4 and 5.

1.7. DIVERS' OBSERVATIONS

At the request of RVZ, divers from the Belgian Navy inspected the sea bottom for marks made by the trawl during cruises 1992/09 and 1992/25. Before fishing started the zone to be observed by the divers was marked by two buoys 100 m apart. The trawl was then towed along a track passing between the two buoys. After trawling, a rope connecting the two anchors of the buoys was laid over the track to lead the divers. The pe-netration depth of the trawl heads had to be measured by hand and manual bottom core samples had to be taken in and outside the trawl track. Video recordings were made of the seabed around the track.

2. RESULTS AND DISCUSSION

2.1. PRESSURE MEASUREMENTS

2.1.1. PRESSURE EXERTED BY THE SOLE PLATES.

The pressure exerted by the sole plates depends on:

- the weight of the gear;

- the surface area of the sole plates;

- the towing speed over the ground: a change in towing speed results in a change of the magnitude of the lift (vertical) force component of the warp load (P_u in Fig. 11) and hence in a change of the sole plate pressure on the bottom. An increase in towing speed will result in a lower sole plate pressure, a decrease will generate a higher pressure.

- the towing speed through the water: a change in speed of the gear relative through the water, independently from the speed over the ground will also result in a change of towing resistance and hence of the vertical component of the warp load. Again the sole plates will have more or less bottom contact depending on a decrease or increase of the speed of the water relative to the gear. Such a situation occurs when the magnitude or the direction of the current relative to the towing direction changes;

- the ratio between the warp length and the depth: a change of this ratio results in a change of the warp angle (Fig. 11) and consequently of the lift component of the warp tension. This leads to an increase in the pressure of the sole plates on the bottom when the warp length to depth ratio increases and to a decrease in pressure when this ratio decreases.

The lifting force component of the warp load determines not only the total pressure load by the sole plates but also influences the tilt of the sole plates relative to the bottom. A higher pressure force is coupled with a larger area of the sole plate being in contact with the bottom. As the gear tends to lift the centre of pressure shifts to the rear and the heels will sustain most of the pressure force.

Direct measurements of the pressure exerted by the trawl head by means of the instrumented trawl head were made during cruise 1993/07. The analysis yielded initial figures on the magnitude of the pressure exerted by the sole plate on the sea bottom. Important information on the dynamic behaviour of the gear could be derived.

Data interpretation

Figures 12 to 15 give typical representations in graphical form of measurements made with the instrumented trawlhead. They are the results of a series (1 hour) of measurements during a particular haul performed under normal trawling conditions. Figure 12 shows the vertical forces acting on the two measuring axles in the instrumented trawlhead. When fishing with the current at a speed of 6 knots over the ground, situation (1), the load on the aft axle (cell 2) has a positive value of about 3.5 kN, whereas the load on the first axle (cell 1) has a negative value. This indicates that the aft part of the sole plate is in firm contact with the bottom, whereas there is no bottom contact at all at the front part. The negative value measured in cell 1 is due to the moment of both the pressure and friction forces with regard to cell 2. After changing the course of the ship by 180°, the gear is towed against the current. As the speed over the ground is kept constant at 6 knots, the speed of the gear relative to the water increases and the gear tends to lift off the ground. This case occurs in situation (2) in which the sole plate has completely lost bottom contact. The forces now acting on the loads cells are determined by the water pressure on the sole plate only. When the speed is lowered to 5 knots, bottom contact is restored (situation (3)). The fact that both the loads in cell 1 and cell 2 are positive indicates that the sole plate touches the seabed more horizontally than in situation (1). The decrease in speed is however not enough to keep the sole plates on the ground all the time. The soles plates regularly lose bottom contact, which is indicated by the forces in cells 1 and 2 being equal to the water pressure, as in situation (2). The same sequences can be distinguished in Fig. 13, showing the resultant vertical force acting on the sole plate, and in Figs 14 and 15, illustrating the horizontal or friction forces. The position of the centre of pressure can be calculated from the equilibrium equation (moments) = 0 (see Addendum for calculation). The result is graphically represented in Fig. 16 and confirms the conclusions drawn above:

- in situation (1) the centre of pressure is near to the middle of the heel, which is in firm contact with the bottom,
- in situation (2) bottom contact is lost and the centre of pressure is no longer located in the sole plate area,
- in situation (3) the centre of pressure is located around the middle of the sole plate, which indicates that the whole sole plate is in contact with the bottom.

Results

Figure 17 shows the average pressure force, i.e. the resultant vertical force, as calculated from data obtained during four valid hauls. The warp length was kept at 90 m for depths varying from 23 m to 30 m. If the gear is towed against the current the pressure force decreases from 5300 N at a towing speed (over the ground) of 3 knots to 1000 N at 6 knots . If the gear is towed with the current an increase in towing speed from 4 to 7 knots results in a decrease of the average pressure force from 4500 N to 1000 N . At low speeds the pressure force will normally act on the full surface of the sole plate, while at high speeds only the heel of the sole plate will be in bottom contact. The pressure can be calculated as

pressure = pressure force / sole plate area.

The sole plate dimensions are 750 mm x 350 mm, the heels measure 250 mm x 350 mm. The average pressure in the present experiments:

- fishing at 3 kn against the current with full sole plate contact:
  5300 N / 75x35 cm^2 = 2.019 N/cm^2
- fishing at 5 kn against the current with heel contact only:
  2280 N / 25x35 cm^2 = 2.606 N/cm^2
- fishing at 4 kn with the current and with full sole plate contact:
  4500 N / 75x35 cm^2 = 1.71 N/cm^2
- fishing at 6 kn with the current and with heel contact only:
  2750 N / 25x35 cm^2 = 3.14 N/cm^2.

At towing speeds of 6 kn (against the current) and 7 kn (with the current) the downward force on the gear is not sufficient to keep the trawl heads in contact with the bottom (identical to situation 2 in Fig. 13). In general it can be stated that the 4-m beam trawl exerted average pressures on the sea bottom varying from 1.7 N/cm^2 to 3.1 N/cm^2 (or from c. 0.17 kgf/cm^2 to c. 0.32 kgf/cm^2). An inquiry among Belgian skippers (POLET *et al.*,1993) showed that in commercial fishing Eurocutters tow 4-m beam trawls at an average speed of 3 kn or 4 kn, depending on whether the gear is towed against or with the tide. Under these circumstances the sole plate pressure will be 2 N/cm^2 and 1.7 N/cm^2 respectively.

The pressures obtained are mean values at the given towing speeds. In general the pressure forces are not constant but vary constantly as can be seen in Figs. 12 and 13. These variations consist of more or less regular undulations of the average pressure and numerous peak values. Figure 18 gives the maximum and minimum values of the pressure force undulation at each towing speed. These maxima and minima all fall within the limits of the forces given above. The peak values, recorded at 1 sec intervals, did not exceed 6000 N.

In Fig. 19 the variation of the vertical resultant of the forces acting on the sole plate is given for a 2 minutes time interval. The periodic variations correspond well with the heave of the ship as indicated by the Atlas echo sounder's heave compensator (Fig. 20). The frequency of both phenomena is about 14 periods/sec. The same pattern can be recognised in all other force measurements as well as in the shift of the pressure centre. Variations of the seabed morphology however are also superimposed on the variations due to the ship's movements. It is clear that the transmission of vessel movements to the gear may cause lifting of the gear off the bottom in circumstances with light bottom contact. This will cause the sole plates to bounce over the seabed.

2.1.2 TOTAL GEAR PRESSURE

The pressure of the complete gear on the bottom can be calculated from the weight of the gear and the upwards pull of the warp. This upwards pull was measured by means of an underwater tension meter inserted between the warp end and the beam trawl's bridles (Fig. 11). The graphical representation of the warp load, for the same time interval as for the instrumented trawl head experiment discussed above, is given in Fig. 21. It should be noted that the warp loads are averaged over 4 sec intervals, whereas 1 sec intervals were used in the instrumented trawl head measurements.

The upwards pull exerted by the warp on the gear is determined by (Fig. 11)

$$P_u = L_w \,.\, \sin \_ = L_w \,.\, D/L$$

in which P_u is the upwards component of the warp tension,
L_w is the warp load,
D is the depth and
L is the warp length.

The pressure force P of one trawl head on the sea bottom is

$$P = (W_g - P_u)/2$$

in which W_g is the weight underwater of (trawl heads + beam + bridles), 13290 N.

The average pressure force calculated from the warp load as compared with the pressure force measured with the instrumented trawl head is presented in Fig. 22. Loads and pressures are given in the text table below. Pressures are calculated for full contact of the sole plate with the bottom (at 3 and 4 knots for towing against or with the current respectively) and for heel contact only (pressures at 5 and 6 knots). At higher speeds bottom contact is lost and only the water pressure affects the recordings.

		pressure force N		pressure N/cm²		
speed knots	bearing surface cm x cm	instr. trawl head	from warp load	instr. trawl head	from warp load	difference
towing against the current						
3	75 x 35	5300	4728	2.02	1.80	0.22
4		3750	3660			
5	25 x 35	2280	2803	2.61	3.20	-0.60
6		1000	1506			
towing with the current						
4	75 x 35	4500	4562	1.71	1.74	-0.02
5		4200	4224			
6	25 x 35	2750	3103	3.14	3.55	-0.40
7		1000	1823			

The difference in pressure obtained by both measurement methods is not substantial. However, when fishing with the current the difference in pressure load seems to increase with increasing speeds (Fig. 22a). At these higher speeds the trawl heads have lost bottom contact, but this is not yet the case for most of the chain mat and the bobbin rope. These gear components are attached to the trawl head at positions up the sole plate. The weight of groundgear affects the warp load, and hence the upwards component, but not the values recorded by the instrumented trawl head. This hypothesis is not as well supported by the differences in pressure when fishing against the current (Fig. 22b). More data are needed to confirm the present theory.

From the warp load of a 12 m/7000 kg beam trawl towed at a speed of 6 kn, VAN DER HAK AND BLOM (1990) calculated that the pressure exerted by the sole plates on the sea bottom was 0.15 kg/cm^2. Taken into account that it was presumed that the entire sole plate was in contact with the bottom, this value is quite close to our results (1.7 N/cm^2 - 2.0 N/cm^2 depending on the current). This comparison also indicates that under normal conditions light and heavy beam trawls exert pressure forces of the same magnitude as the difference in weight will be compensated by a higher towing speed and a larger sole plate surface.

2.2. SIDE SCAN SONAR OBSERVATIONS

This section gives the main results of the side scan sonar observations. A detailed report is given in Annexes 4 and 5.

1) Cruise 1992/09

Prior to fishing the test zones were inspected with the side scan sonar to make sure that the area was free from tracks from previous commercial fishing activities.

In test zone IV (Figs. 4 and 5) four parallel tracks about 3 km long and at a distance of about 40 m from each other were fished with the 4-m beam trawl. In total 10 side scan sonar observations of the trawl marks were made between 15 minutes and 52 hours after fishing. At the end, only very vague marks along 41 % of the track could be spotted. Selected sections of the registered sonographs are given in Annex 4.

In test zone II, again four parallel lines were fished in an area 40 m wide. Nine observations were made, up to 32 hours after fishing. At that time the complete track was still clearly visible.

In test zone I three parallel lines at distances of 10 m apart were fished. Three side scan sonar observations were made. The last observation, made 20 hours after fishing, showed relatively clearly visible marks on 70 % of the track.

The penetration depths of the beam trawl in the superficial sediment could not be deduced from the sonographs as the traces on the recordings were too weak. It is however probable that the depth of penetration is not very pronounced. No clear correlation could be made between the visibility of the trawl marks and the grain size of the sediment.

2) Cruise 1993/07

Zone I was fished twice on approximately the same track. The tracks were observed 20 hours 25 minutes after fishing. Vague trails on 20.4 % of the reference track could be detected. These trails showed a slightly different direction than the ship's bearing during fishing. This is probably due to a slight difference between the navigation routes during fishing and during the side scan sonar observations. As no side scan sonar observations of the test zone were made prior to fishing, the possibility that the trails were made by an other beamer cannot be ruled on.

An attempt was made to correlate the visibility of the trails on zone I with the type of bottom samples (Fig. 23). These samples were taken with a Van Veen sampler on six positions along the track and allowed for a crude division of the test area for different sediment types. The gear marks were visible on 85% of the section covered with mud, on 18% of the section covered with coarse sand and on 21% of the section covered with coarse sand with shells. No imprints could be seen on the sections covered with coarse sand with superficial mud or mainly mud with some sand.

A side scan sonar recording on zone II made before fishing showed no evidence of earlier fishing activities. Within nine hours, nine successive hauls were made on the same track. Six side scan sonar observations were made between 6.5 hours and 44 hours after fishing. Figure 24 shows the evolution of the visibility of the gear imprints relative to time and sediment type. The visibility was best 7 hours after fishing. At that time gear markings could be seen along 87% of the track. Afterwards the visibility of the markings decreased gradually but after 44 hours imprints could still be detected on 23% of the track. The visibility of the trails at that time is again different for the different sediment types: 100% for coarse sand with shell debris, 36% for coarse sand with superficial mud, 10% for coarse sand with superficial mud and gravel debris and 0% for coarse sand with some gravel elements.

The results obtained during cruise 1993/07 seem to indicate that the type of sediment is an important factor for the visibility of the trawl marks. The results obtained in zone I and II are not completely in agreement. It is probably that the results from zone II are more reliable as the trails were detected with more precision than in zone I. More reliable results requires a more precise detection of the boundaries between the different sediments. An acoustic bottom type discriminator seems to be indispensable for this purpose.

As on cruise 1992/09 the penetration depth could not be deduced from the recorded sonographs.

2.3. VISUAL OBSERVATIONS BY DIVERS

1) Cruise 1992/09

Due to a very poor visibility and strong currents near the bottom, no useful observations and measurements could be made by the divers. As it was not possible to locate the trawl marks no manual bottom samples were taken either.

2) Cruise 1992/25

Observations were made after fishing on tracks I and IV. The divers could not detect any traces of the gear that passed over the examined area about 90 minutes earlier. Also the video recordings too did not reveal any disturbance of the area. However, due to the rather poor visibility only the area in the direct vicinity of the rope connecting the two buoy anchors could be inspected.

As the trawl track could not be detected no bottom samples inside and outside the track could be taken for comparison.

CONCLUSIONS

The present study has allowed us to get a better insight on the pressure exerted by the sole plates of a 4-m beam trawl on the seabed and the trawl marks caused by the trawl on the sediments.

An instrumented trawl head was constructed to measure the pressure of the sole plates on the seabed. This pressure was studied as a function of the towing speed while the warplength/depth relationship was kept at a value around 3.

The pressure force is strongly related to the towing speed. As the speed increases the lift of the gear increases and the resultant pressure force decreases. At the same time however the tilt of the sole plates increases and a smaller surface of the sole plate will be in contact with the bottom. The resultant pressure, expressed as force per unit surface, tends to increase. At higher speeds the weight of the gear will be fully compensated by the upwards pull and the beam will lift off the bottom. From our experiments it appears that the pressure exerted by the sole plates varies from 1.7 N/cm^2 to 3.2 N/cm^2, when fishing against the current at towing speeds (over the ground) of 4 kn and 6 kn, respectively. In commercial fishing, towing speeds are 3 kn when fishing against the current and 4 kn when fishing with the current. At these speeds the sole plate pressures are 2 N/cm^2 and 1.7 N/cm^2, respectively. Bottom contact was lost at 6 kn or 7 kn depending on whether the gear was towed against or with the current. Vessel movements are transmitted to the gear, even at low amplitudes. This may cause the gear to bounce on the bottom. From the comparison between the total gear pressure force and the pressure force exerted by the sole plates it appears that the chain mat and the bobbin gear exert only a limited pressure on the seabed. Under project IMPACT-II further research will be carried out to confirm this.

The side scan sonar recordings revealed that some trawl marks remained visible for up to 52 hours after fishing. The penetration depths of the beam trawl in the superficial sediment could not be deduced from the sonographs as the traces on the recordings were too weak. It is however probable that the depth of penetration was not very pronounced. Some sonographs indicated that the sediment type is probably an important factor for the visibility of the trails but the results for different tracks are not completely in agreement. The best visibility, at the end of the observations, was obtained on coarse sand with shell debris. However, the division of the test area in different sediment types was rather crude. More precise results are expected if seabed classification based on hydroacoustic echo sounder signal analysis can be used.

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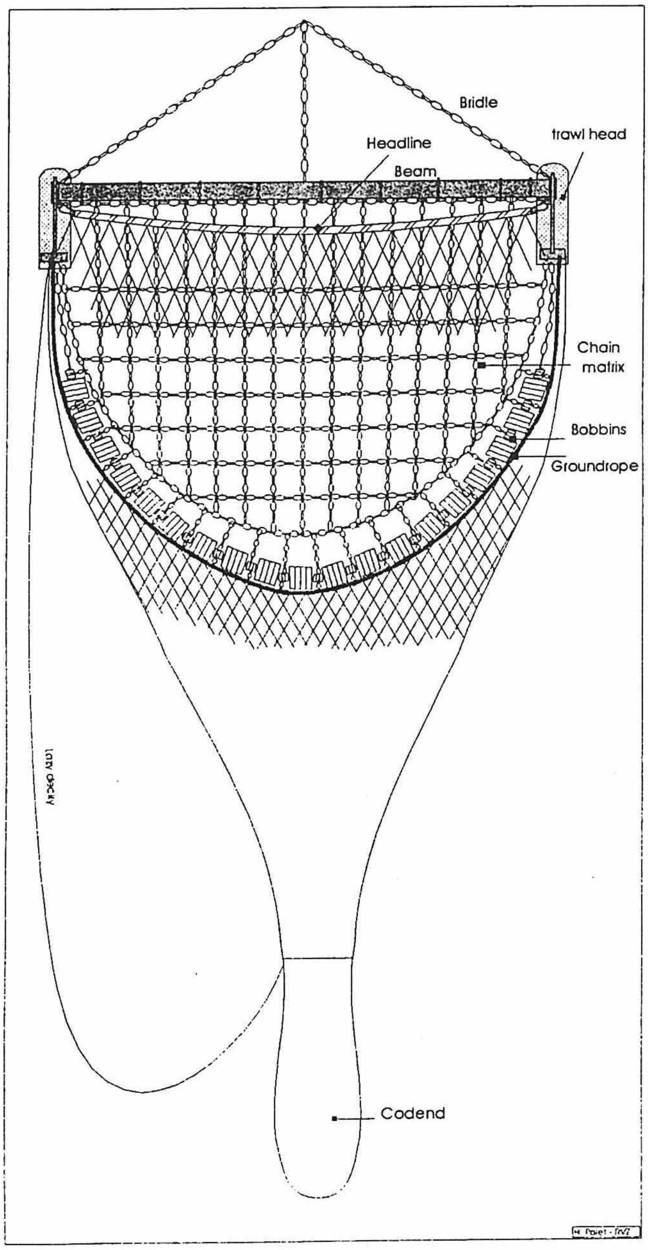
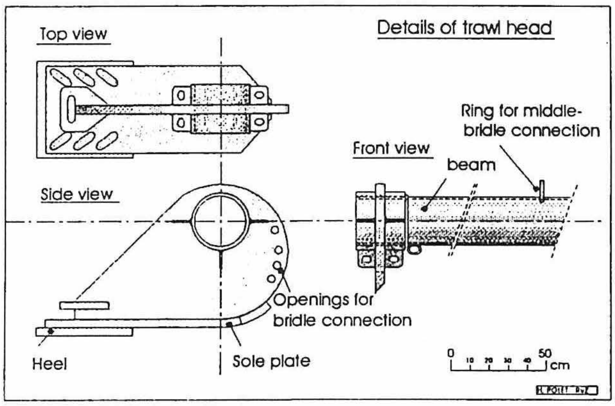




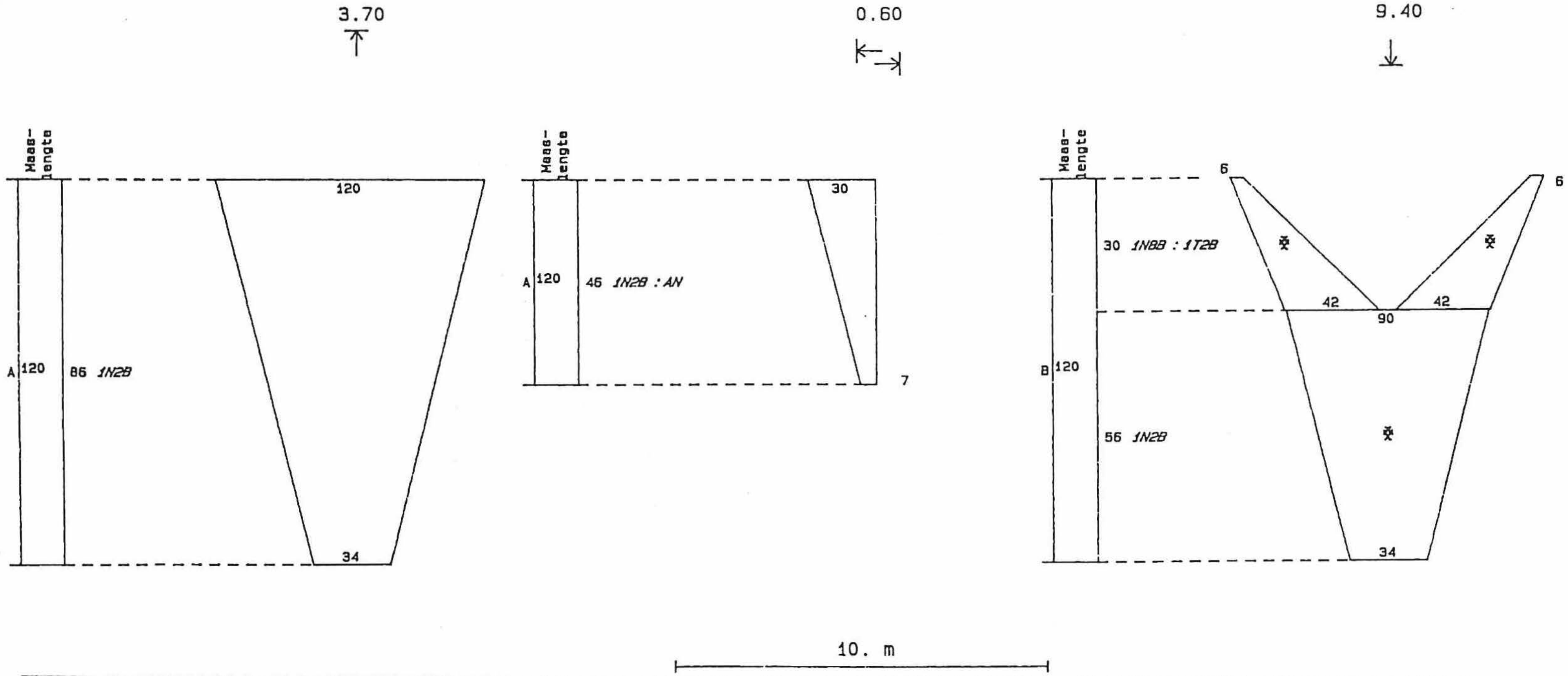
Vessel: BEAM TRAWLER . 221 KW (300 hp)
BEAMTRAWLER

Fishing gear: Chain matrix beam trawl

- beamlength: 4 m
- headline: 3.70 m
- groundrope: 9.40 m
- bobbins: 18m, rubber _ 28cm
- chain matrix : Each rectangle contains 3 vertical and 3 horizontal links, diam. 18mm
- sole plate (max. in contact with the bottom) : 750 mm x 350 mm
- heel : 250 mm x 350 mm

Total gear weight : 23.005 N (2340 kg)

Fig. 1. Beam trawl with chain matrices.



Rijksstation voor Zeevisserij Ankerstraat 1, 8400 Oostende tel: (059) 32 08 05 - 32 03 88 Copyright du logiciel: CENTRE NATIONAL DE LA MER / IFREMER	Ref : BV003 Datum : 18/12/89	NET 3.70m. / 9.40m. Type : Boomkor 4m stok Soorten : platvis Oorsprong : RvZ (RF / 0.87)	1 VAARTUIG 300pk

PEZEN

LENGTE MATERIAAL DIAM

NETWERK

A	120mm.	0.0 mm.	PA
B	120mm.	0.0 mm.	PADBL

"tweeling"-boomnet
selectiviteitsstudie
a/b BELGICA

Fig. 2. Netplan 4 m beam trawl

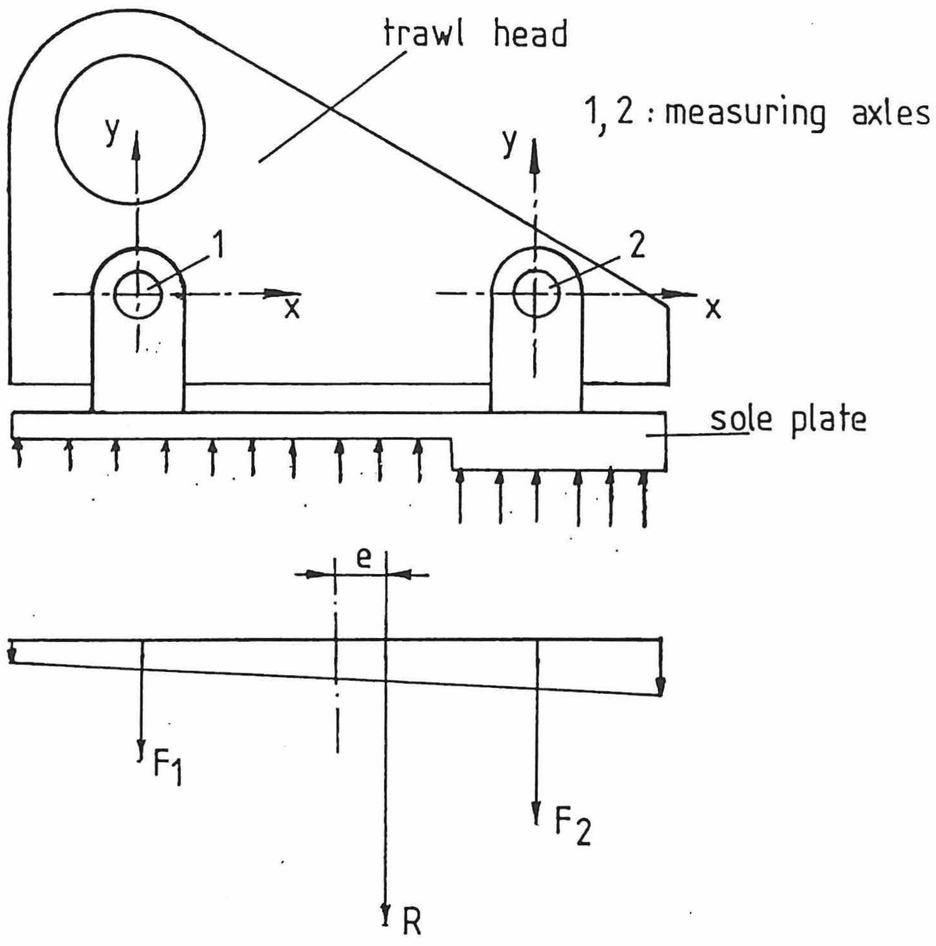


Fig. 3. Instrumented trawlhead-principle.

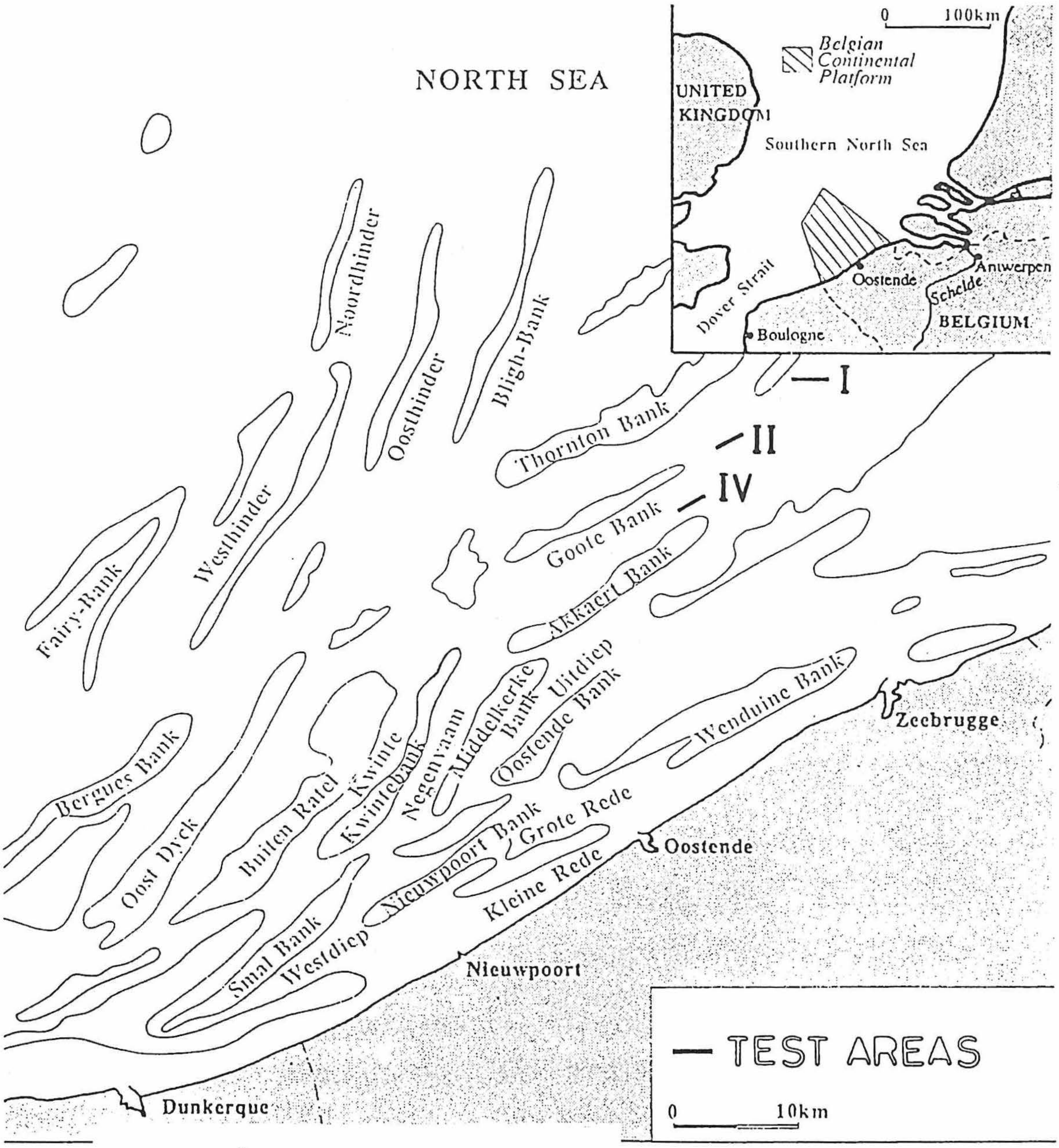


Fig. 4. Location of the test areas I, II and IV.

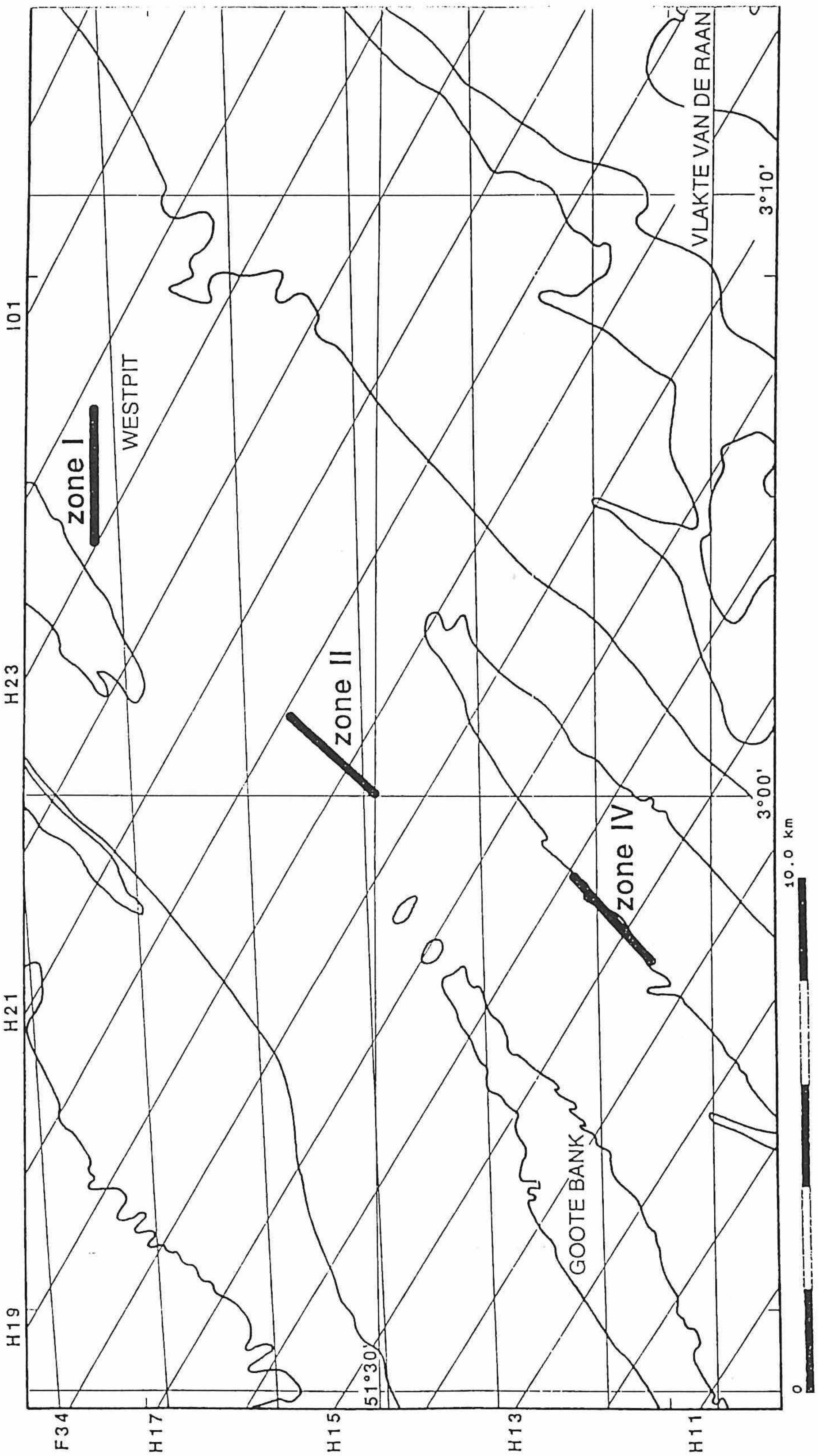


Fig. 5. Location of experimental trawl tracks.

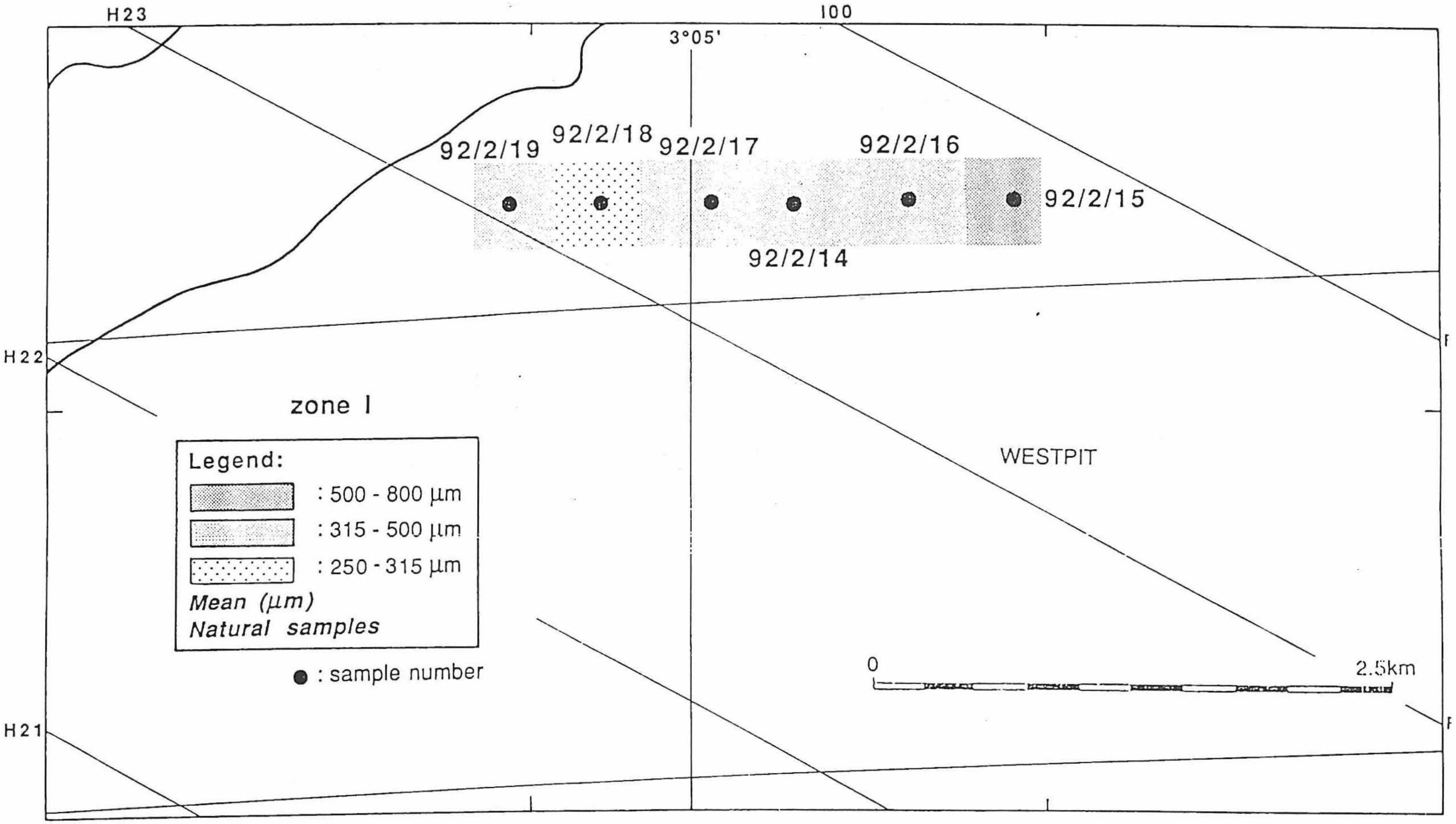


Fig. 6. Natural mean values of fraction with diameter < 4 mm (zone I).

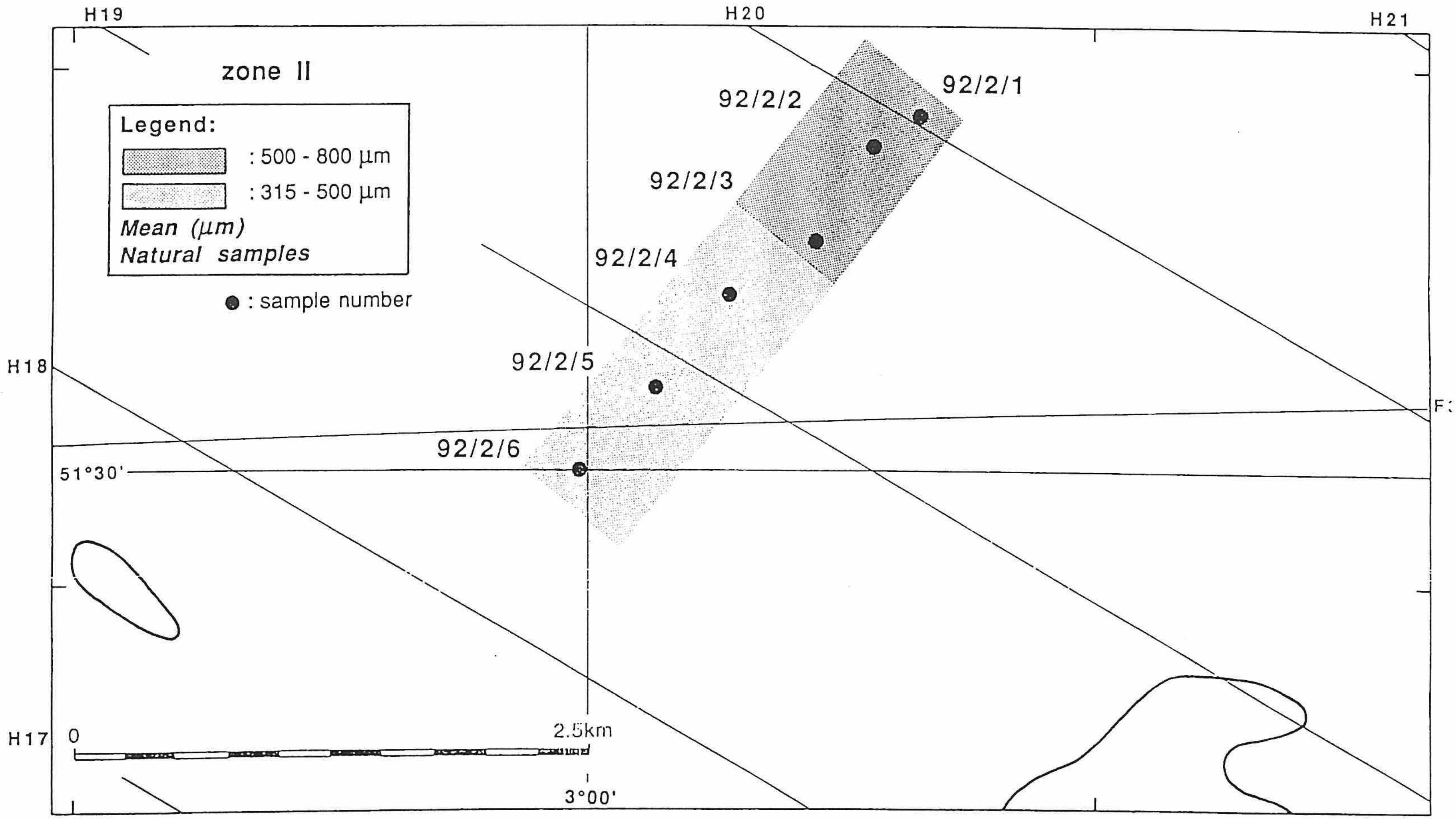


Fig. 7. Natural mean values of fraction with diameter < 4 mm (zone II).

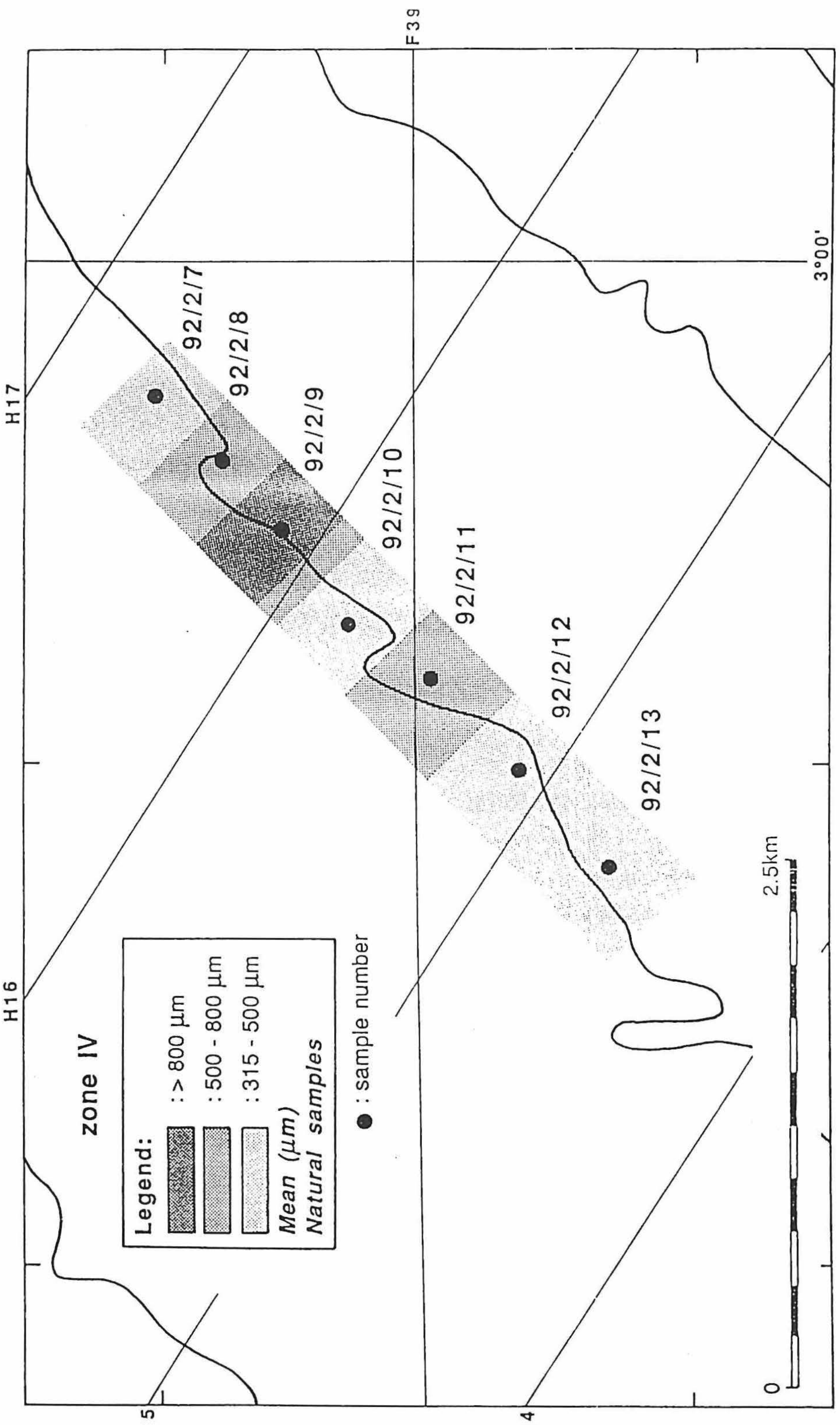


Fig. 8. Natural mean values of fraction with diameter < 4 mm (zone IV).

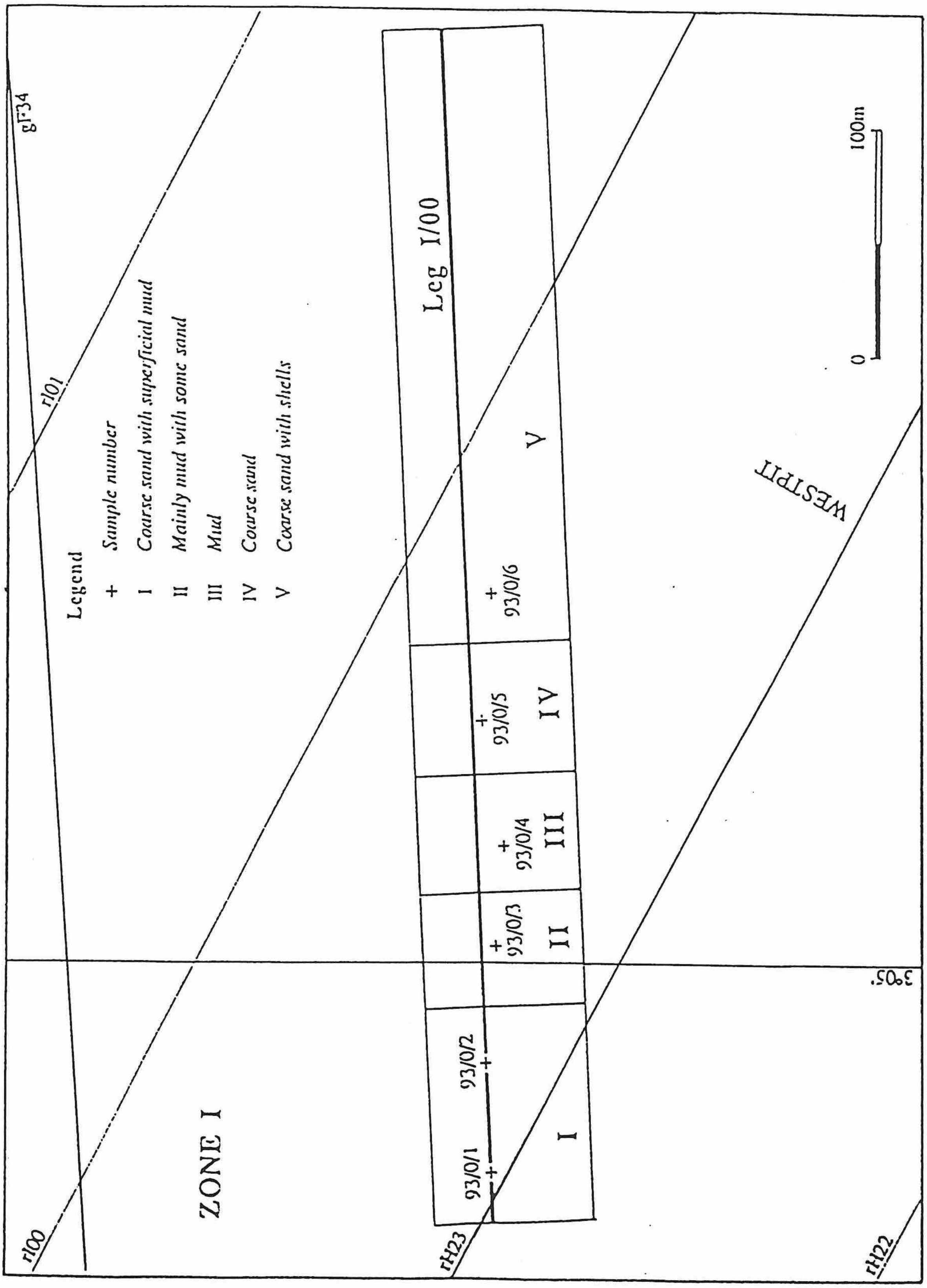


Fig. 9. Sediment types on zone ZEO1.

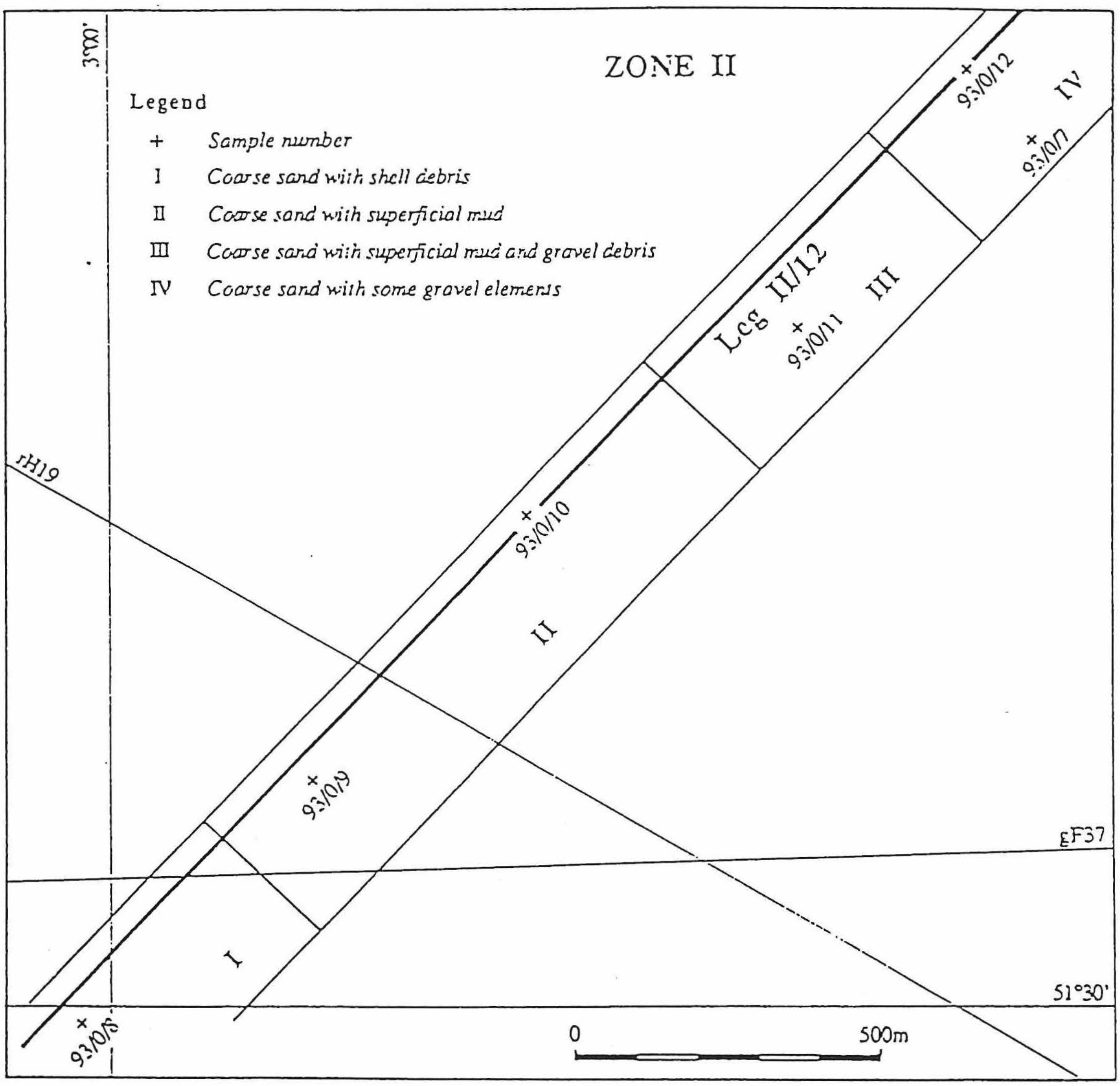


Fig. 10. The localisation of the samples and their according sediment type (Zone III).

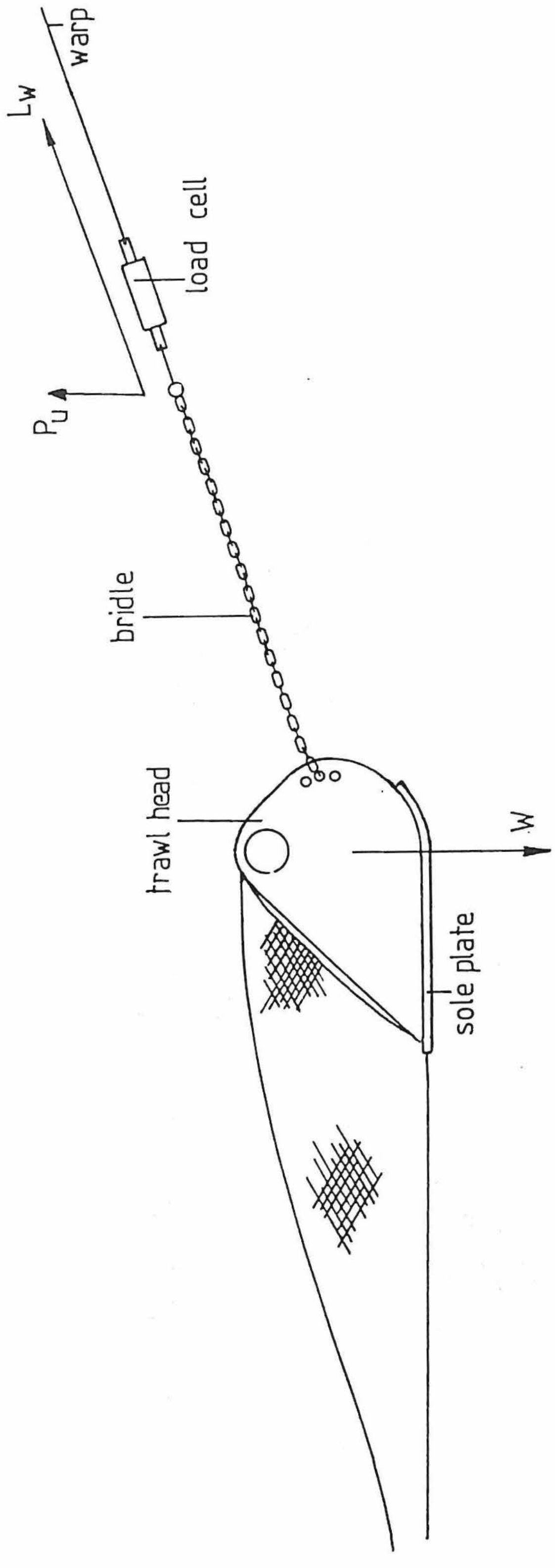


Fig. 11. Warp load measurement.

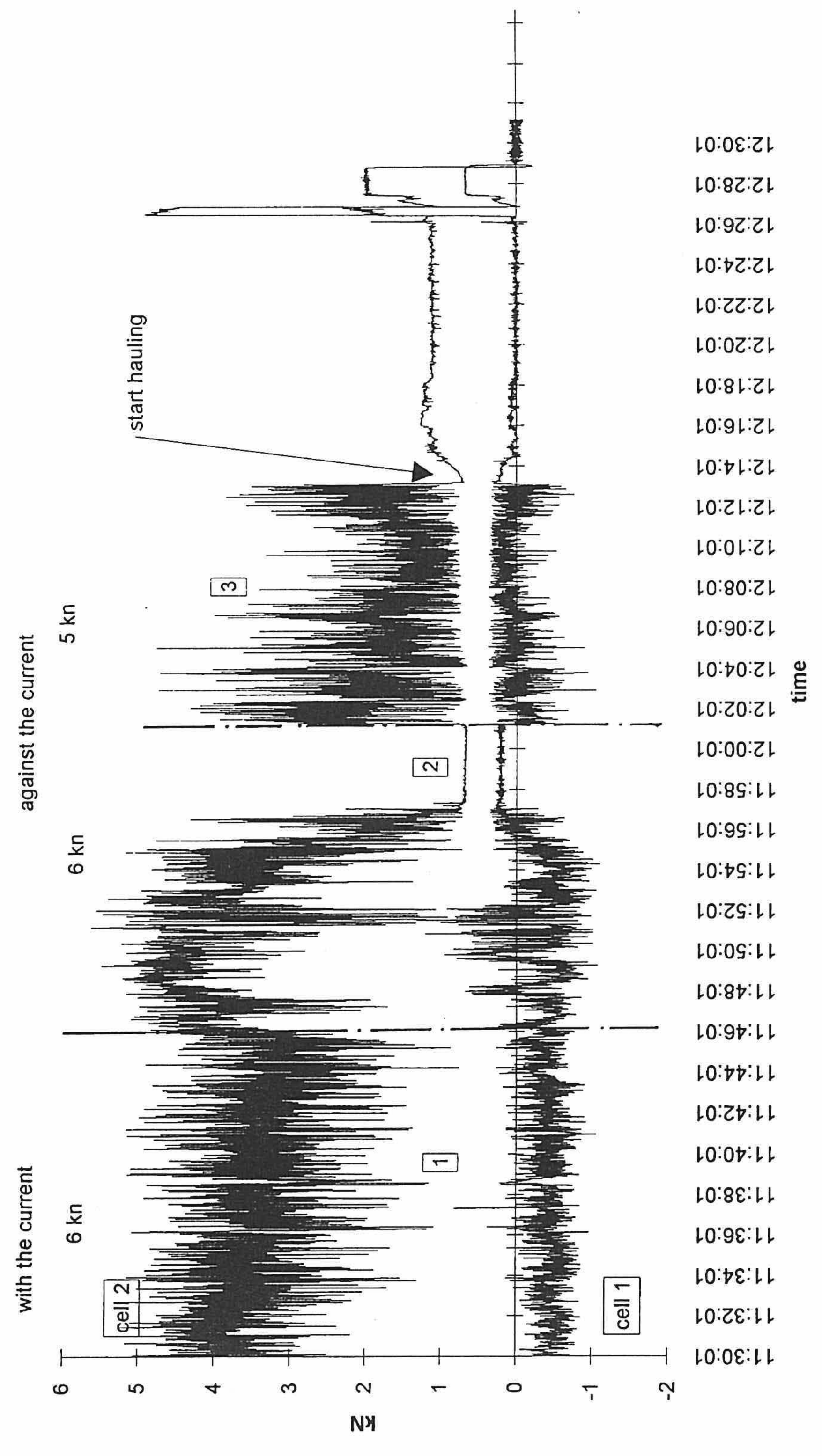


Fig. 12. Vertical forces (93/07 - haul 6).

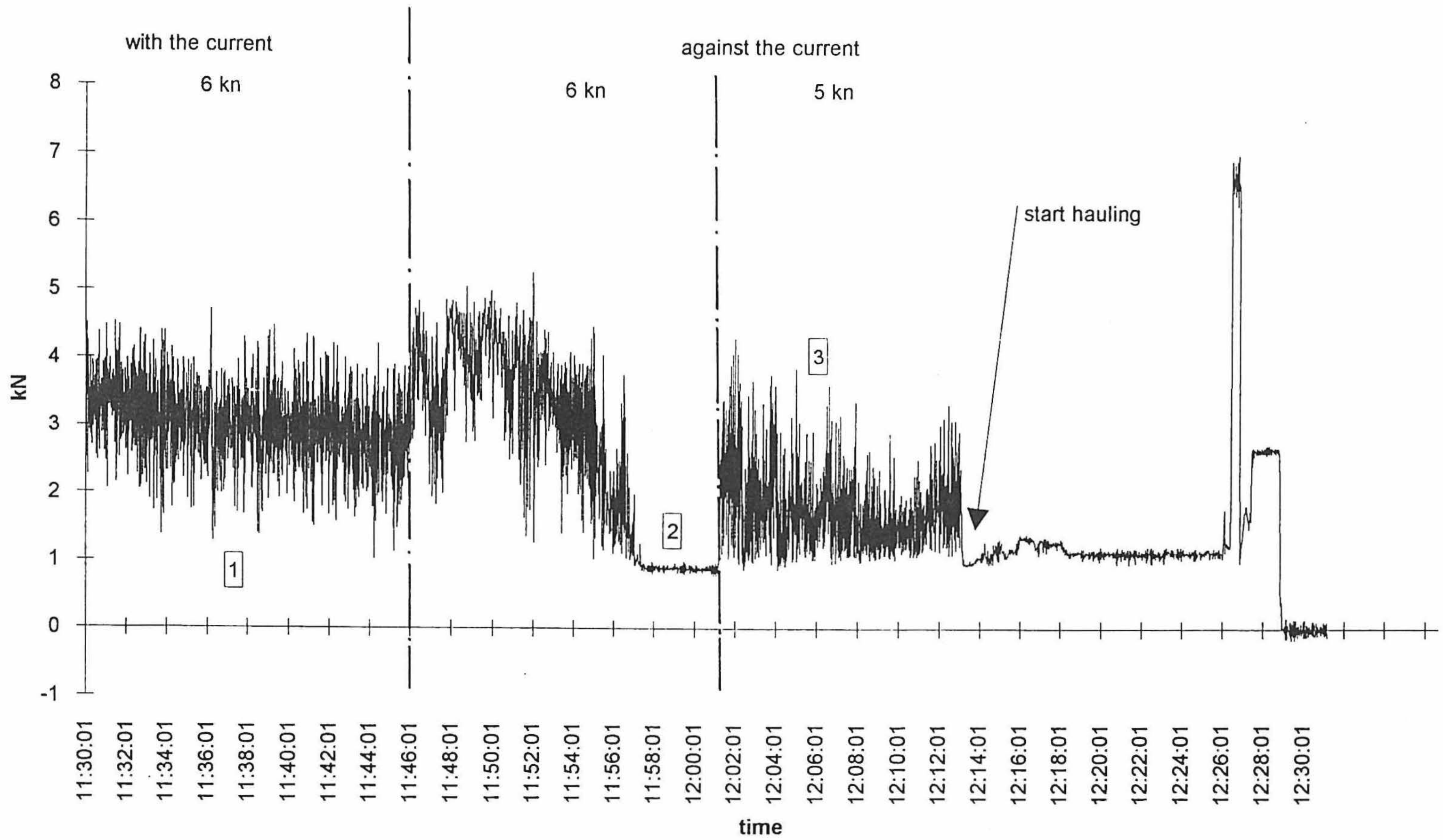


Fig. 13. Vertical resultant (93/07 - haul 6)

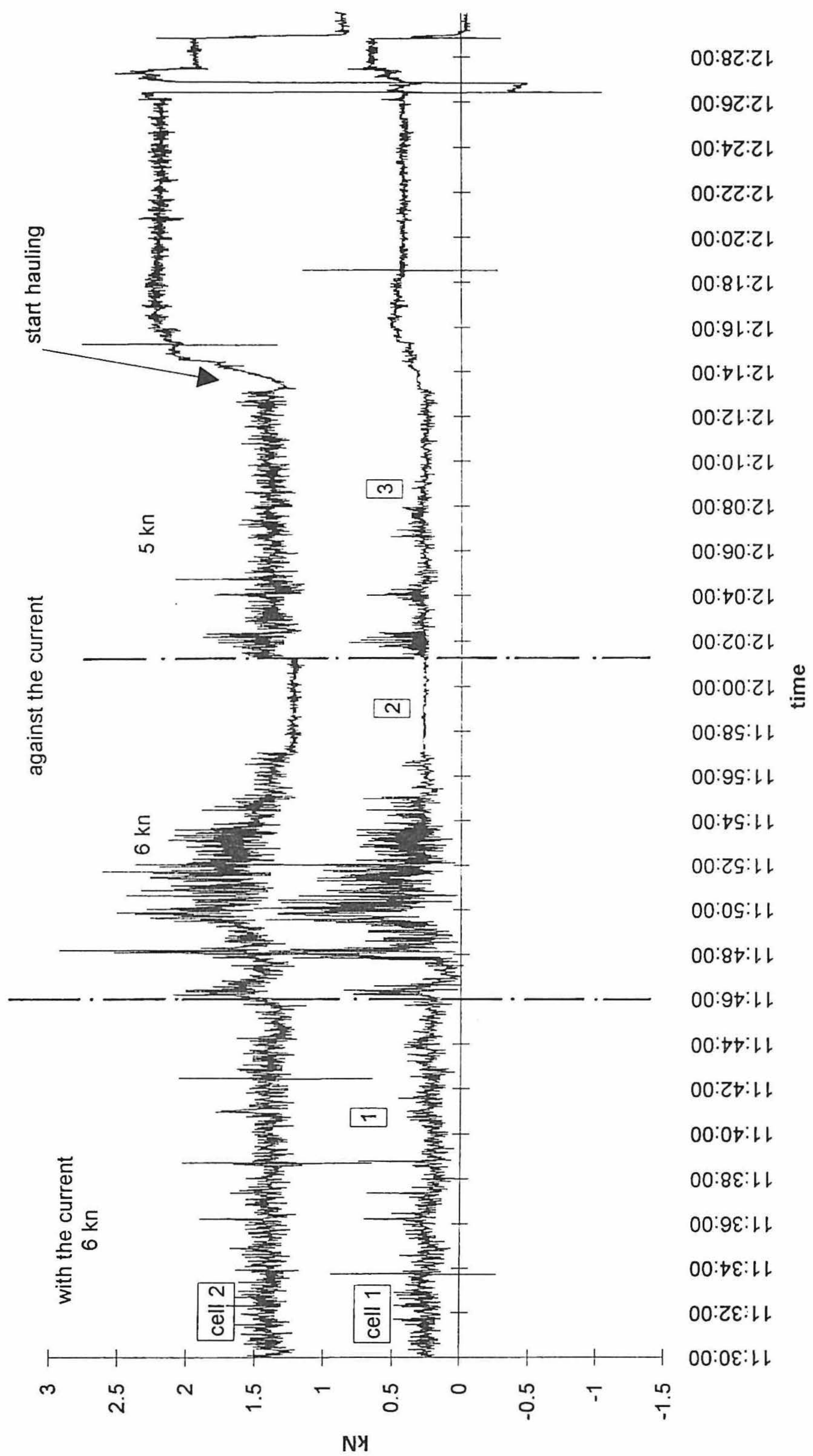


Fig. 14. Horizontal forces (93/07 - haul 6).

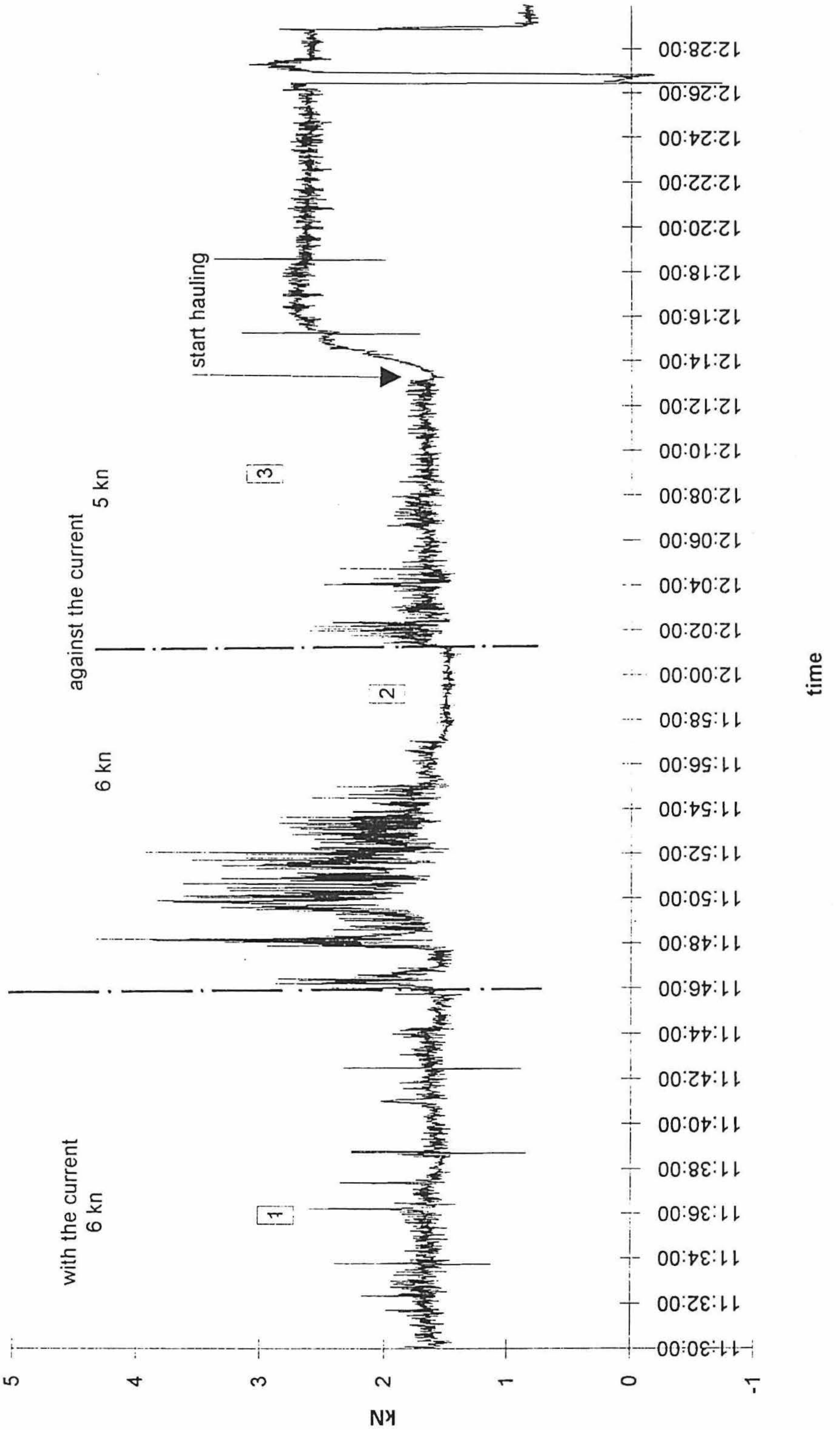


Fig. 15. Horizontal resultant (93/07 - haul 6)

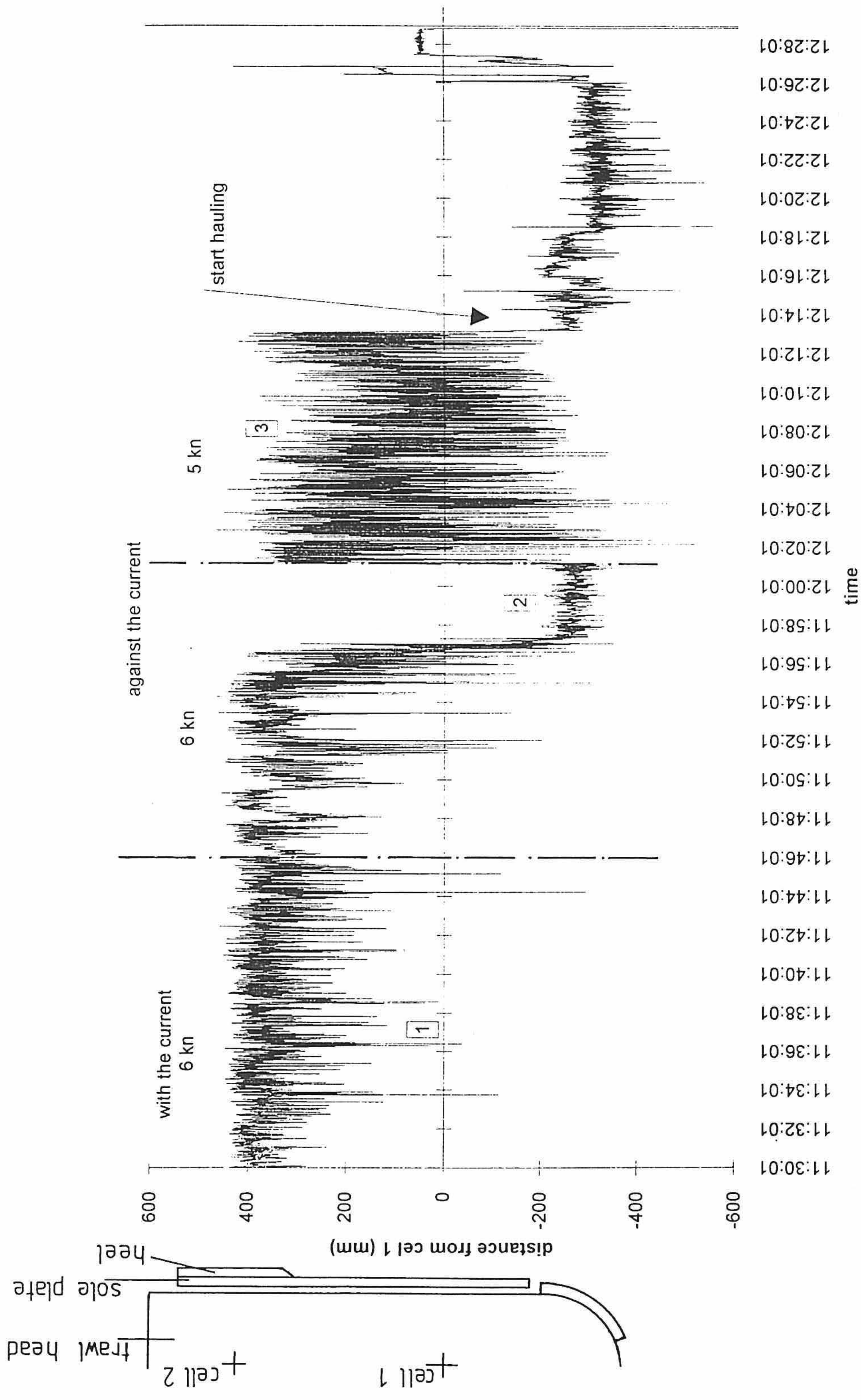


Fig. 16. Centre of pressure (93/07 - haul 6).

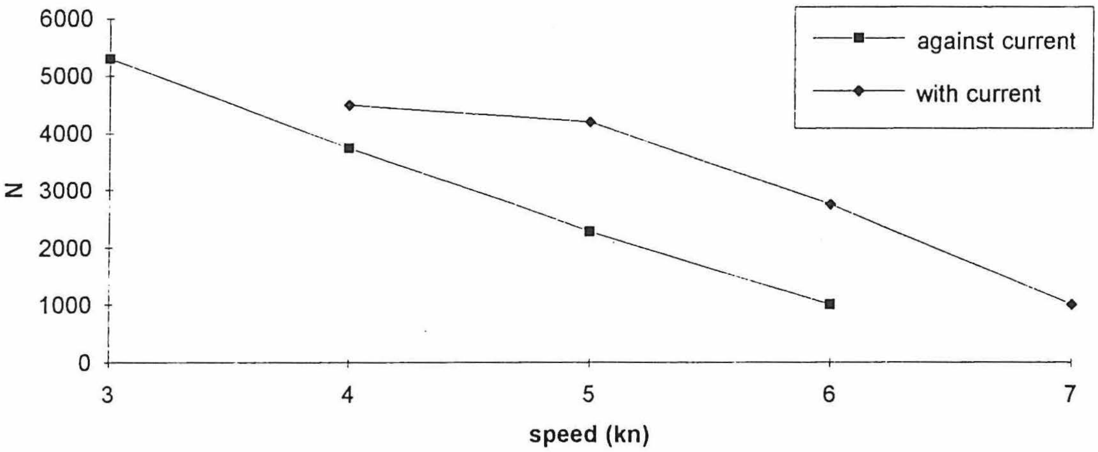


Fig. 17. Average pressure force.

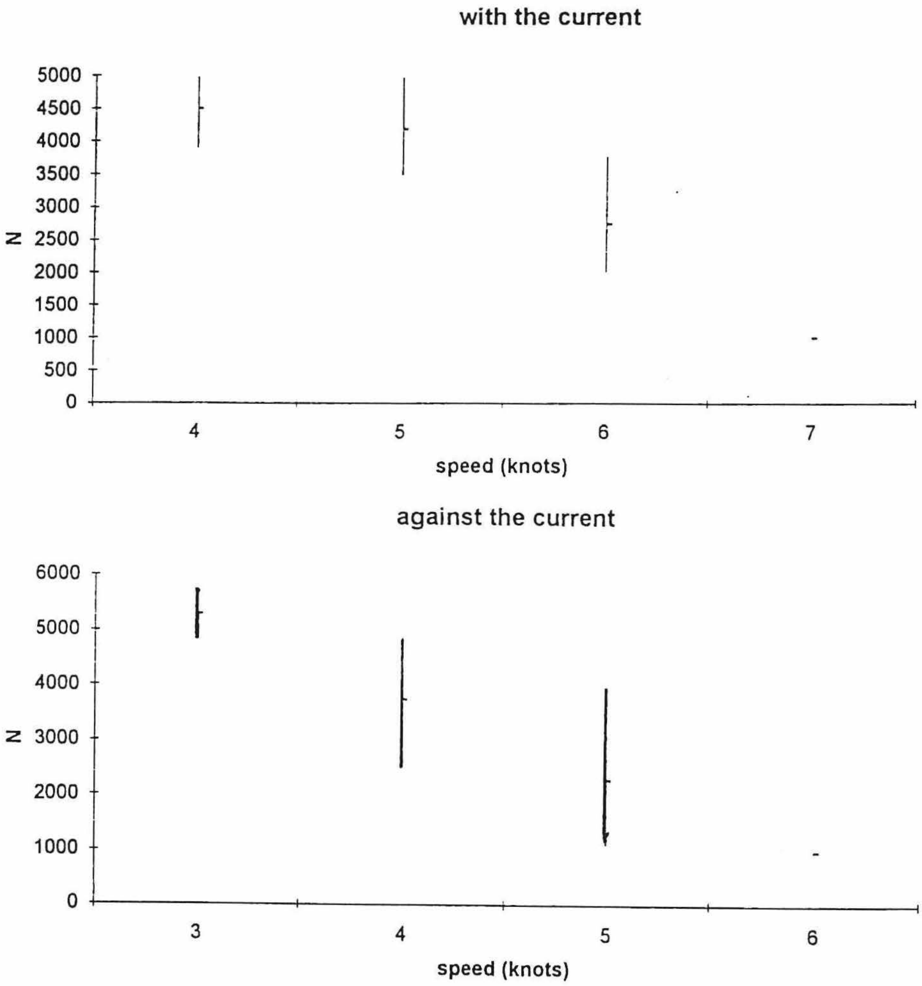


Fig. 18. Pressure force limits.

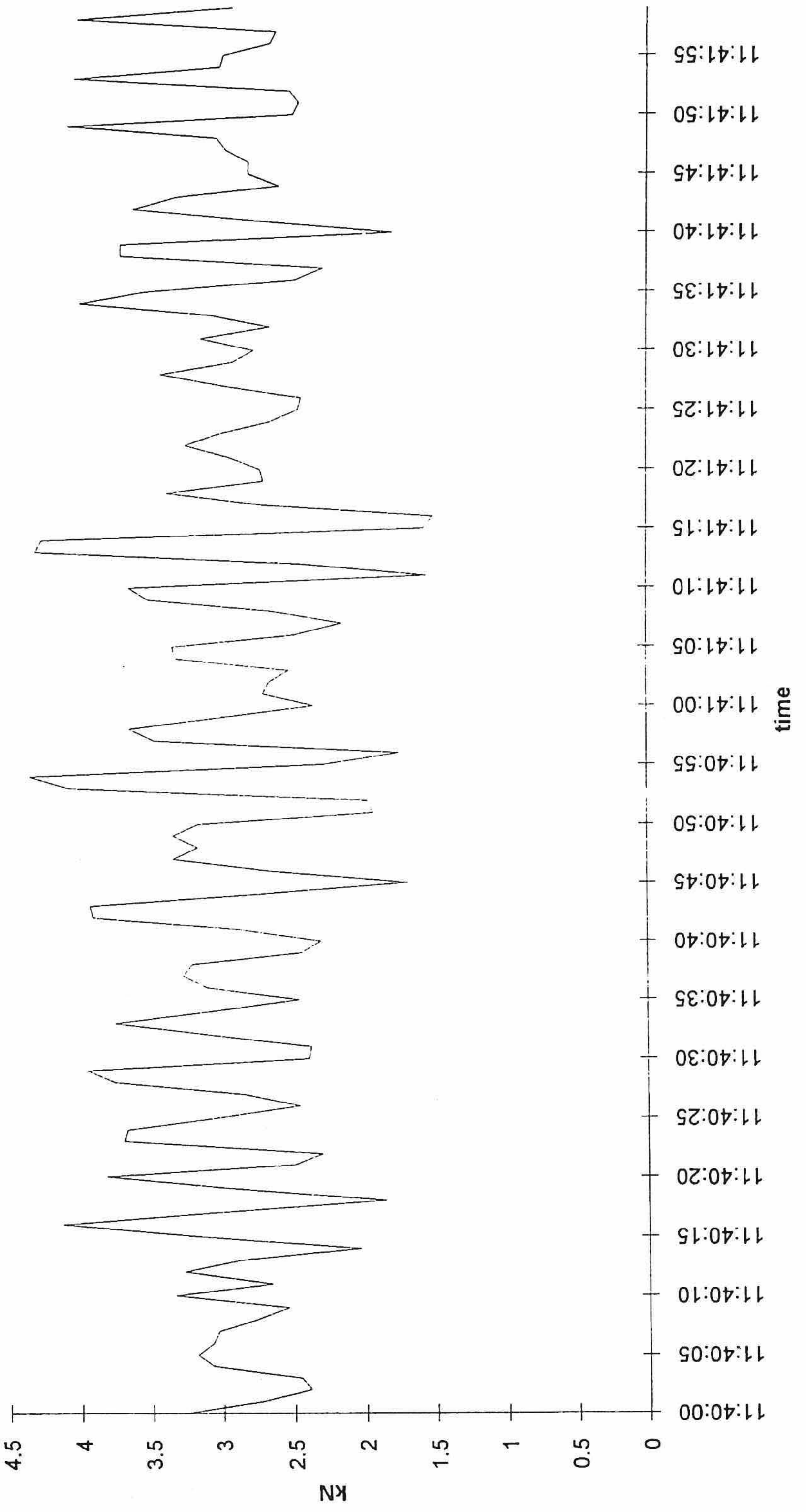


Fig. 19. Vertical resultant (93/07 - haul 6)

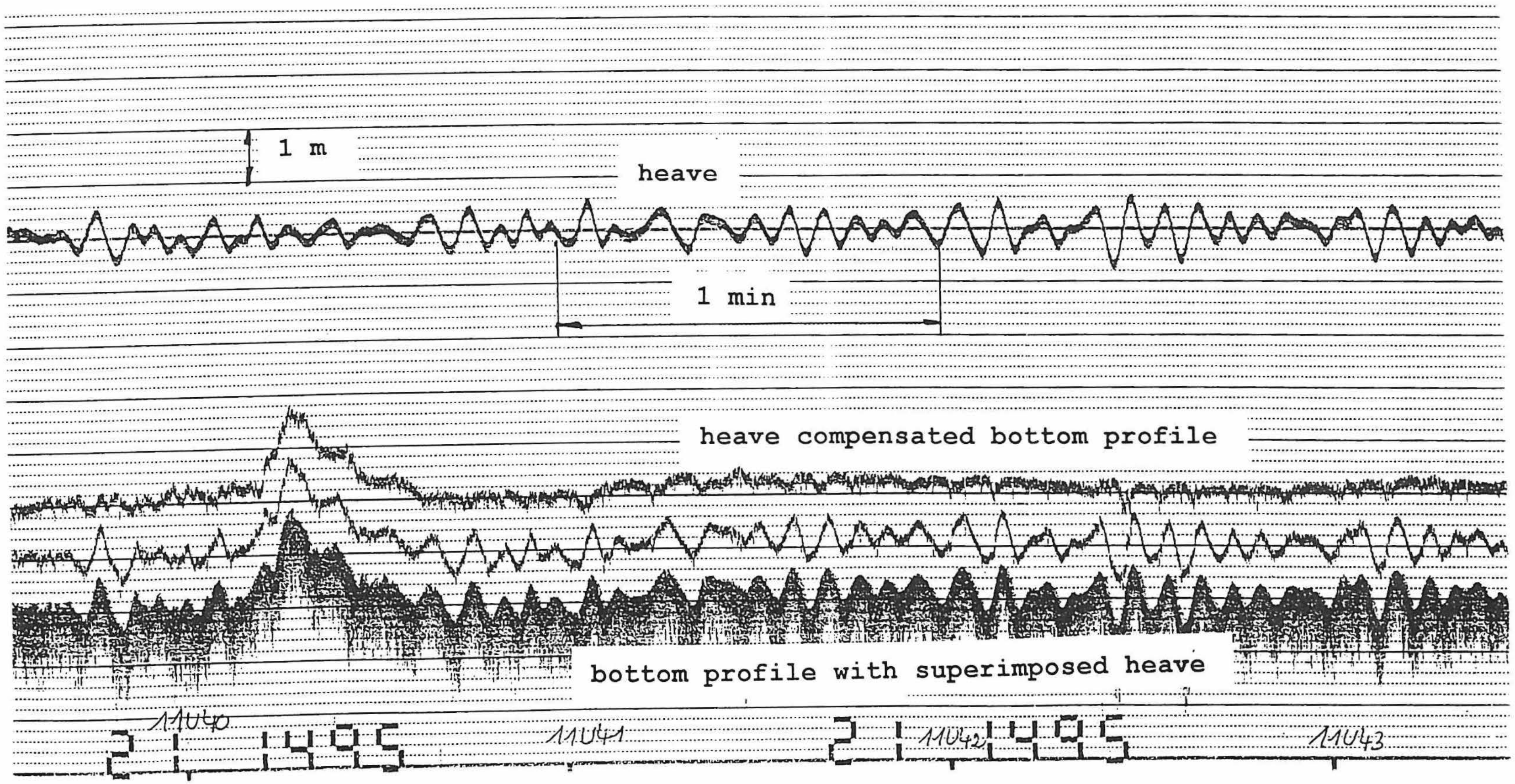


Fig. 20. Heave (93/07 - haul 6).

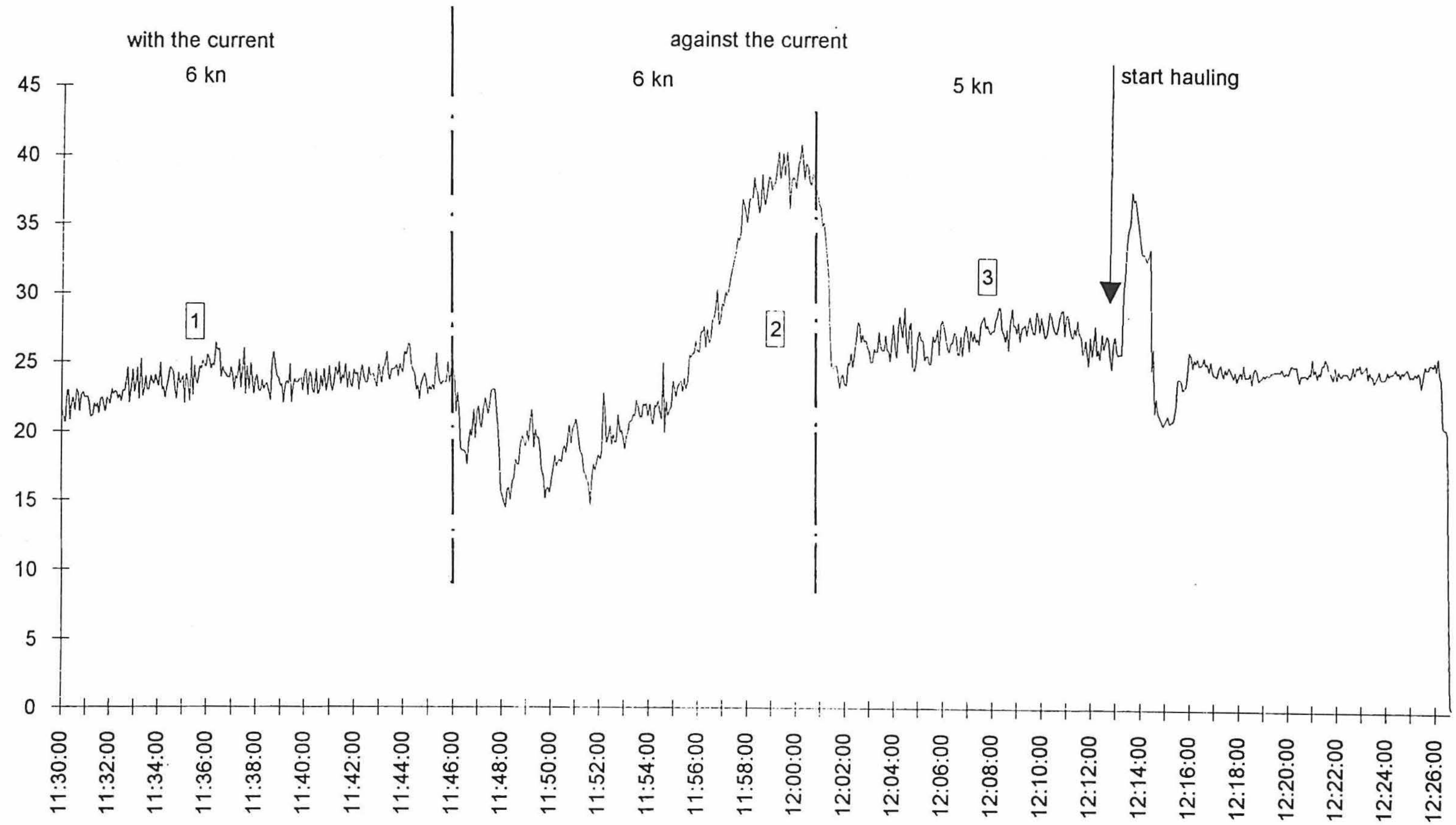
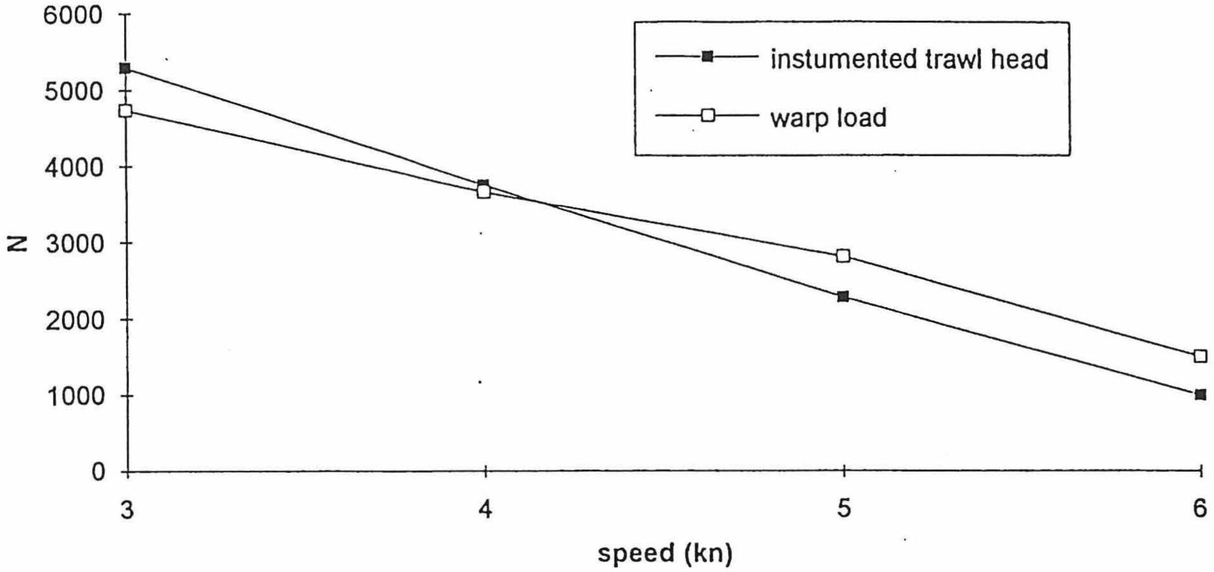


Fig. 21. Warp load.

a) against the current



b) with current

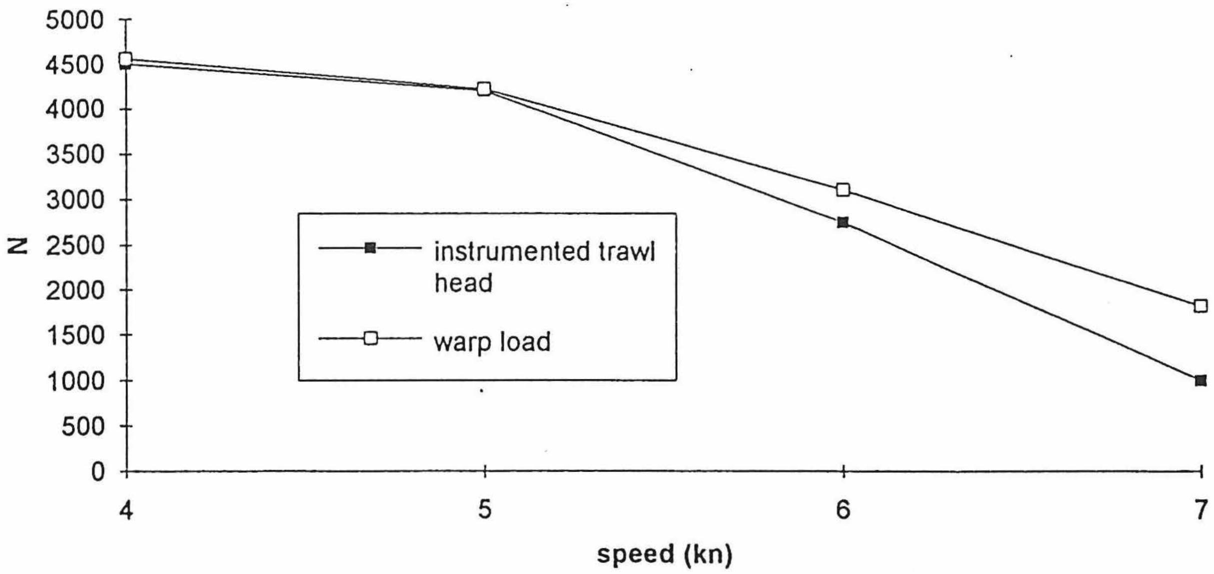


Fig. 22. Comparison of the pressure loads measured by the instrumented trawl head and calculated from the warp load.

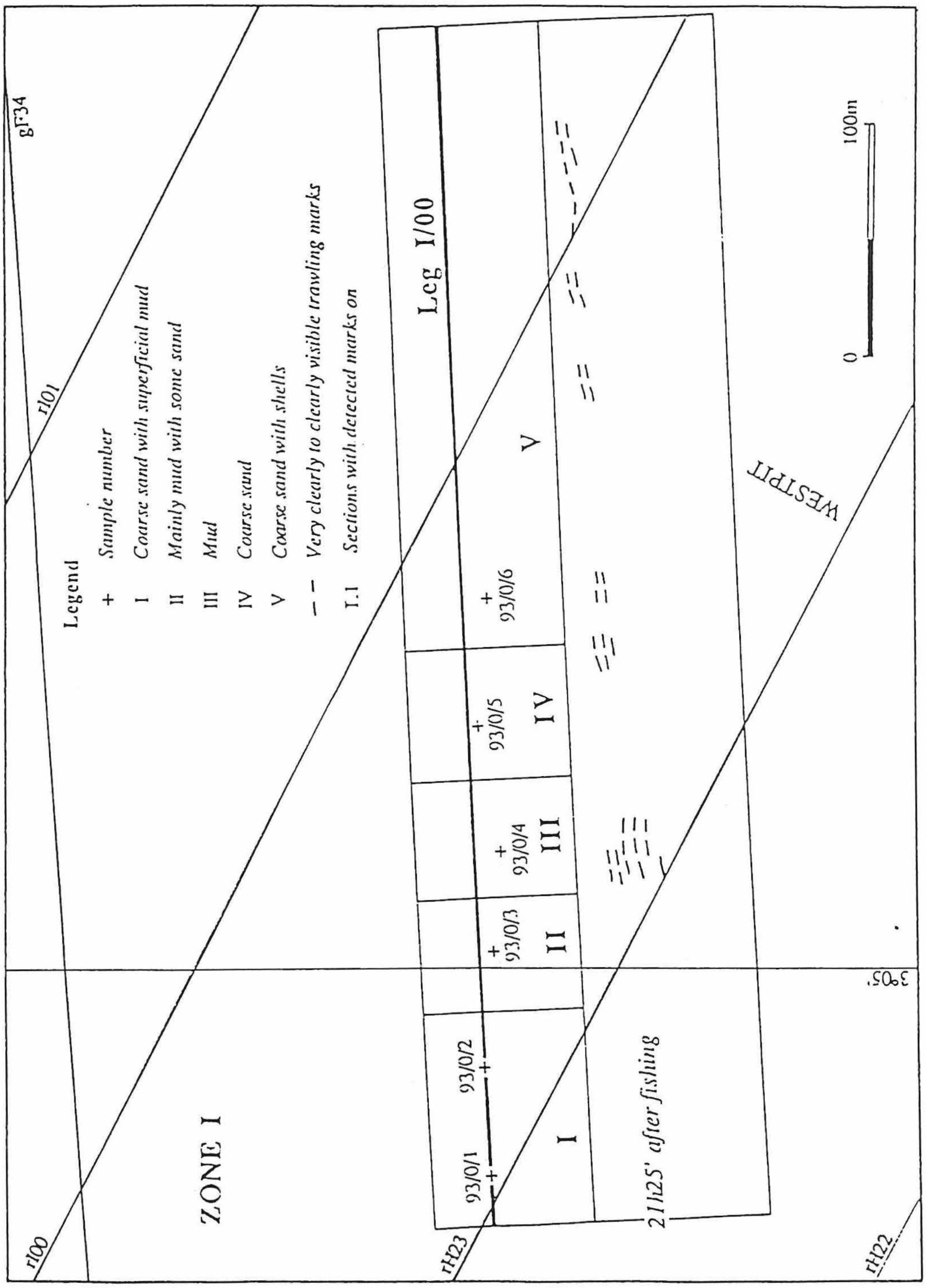


Fig. 23. Visibility of trails as function of time after fishing and related with the different sediment types (area I).

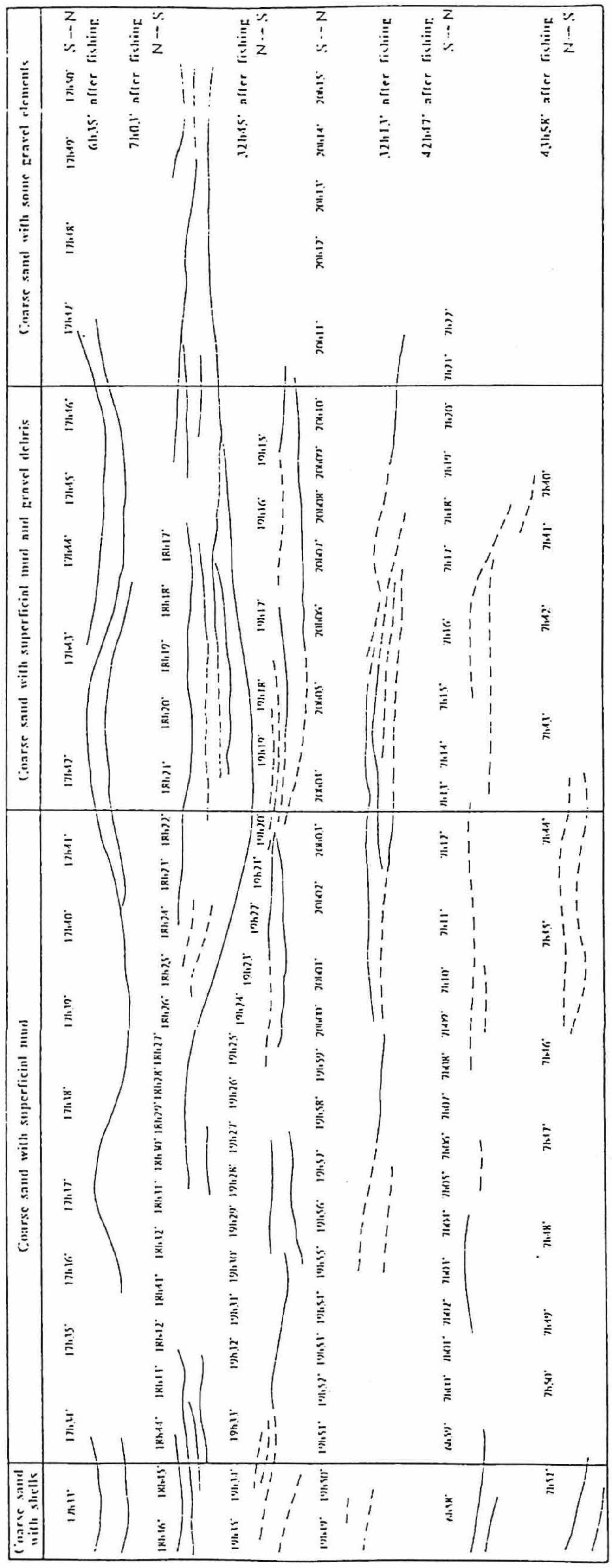


Fig. 24. Visibility of trails as function of time after fishing and their corresponding sediment types.

Addendum

Measuring principle of instrumented trawl head (Fig. 1)

The voltage from a strain gauge bridge is first amplified by a measuring amplifier and transformed in a DC voltage. In turn this voltage is linearly transformed in a frequency by a Voltage Controlled Oscillator (VCO). This frequency is then processed by the processor. At a chosen time interval (1, 2 or 4 seconds) the mean value is saved in an internal RAM memory. The maximum number of measures is 16384, ie a recording time from 4 hours (1 sec intervals) and 18 hours (4 sec intervals). At the end of each measurement (haul) the cell is opened and connected to a MS-DOS compatible computer. After setting of a number of parameters the data are read out and stored on a disk for later analysis e.g. by means of a suitable spread-sheet.

Full specifications of the load cells are given in the text table below:

1.1. <u>Mechanical construction</u>
- Dimensions : 450 (l) x 142 (d) mm
- Weight : - in air : 23 kg
  - in water : 18 kg
- Material : stainless steel
- Maximum working pressure : 10 kgf/cm² (100 m water column)

1.2. <u>Measuring performance</u>
- Measuring range : 20 kN
- Precision : 0.5 %
- Nominal load : 230 N
- Maximum dynamic load (load limit without zero-shift):
  - 1.5 x nominal load
  - 345 kN
- Limit of material elasticity:
  - 3 x nominal load
  - 690 kN

1.3. <u>Electronic construction</u>
- Lowpower QMOS components/micro-processor
- Adjustable time interval : 1 sec - 2 sec - 4 sec
- Internal memory 16 k x 16 bit
- Batteries :
  - Ni-Cd, rechargeable
  - 18 hours autonomy
- Overall precision : 0.5 %
- Temperature range : 0-30 °C
- Measurements autonomy :
  - time interval 1 sec : 4h3min4sec
    2 sec : 9h6min8sec
    4 sec : 18h12min8sec

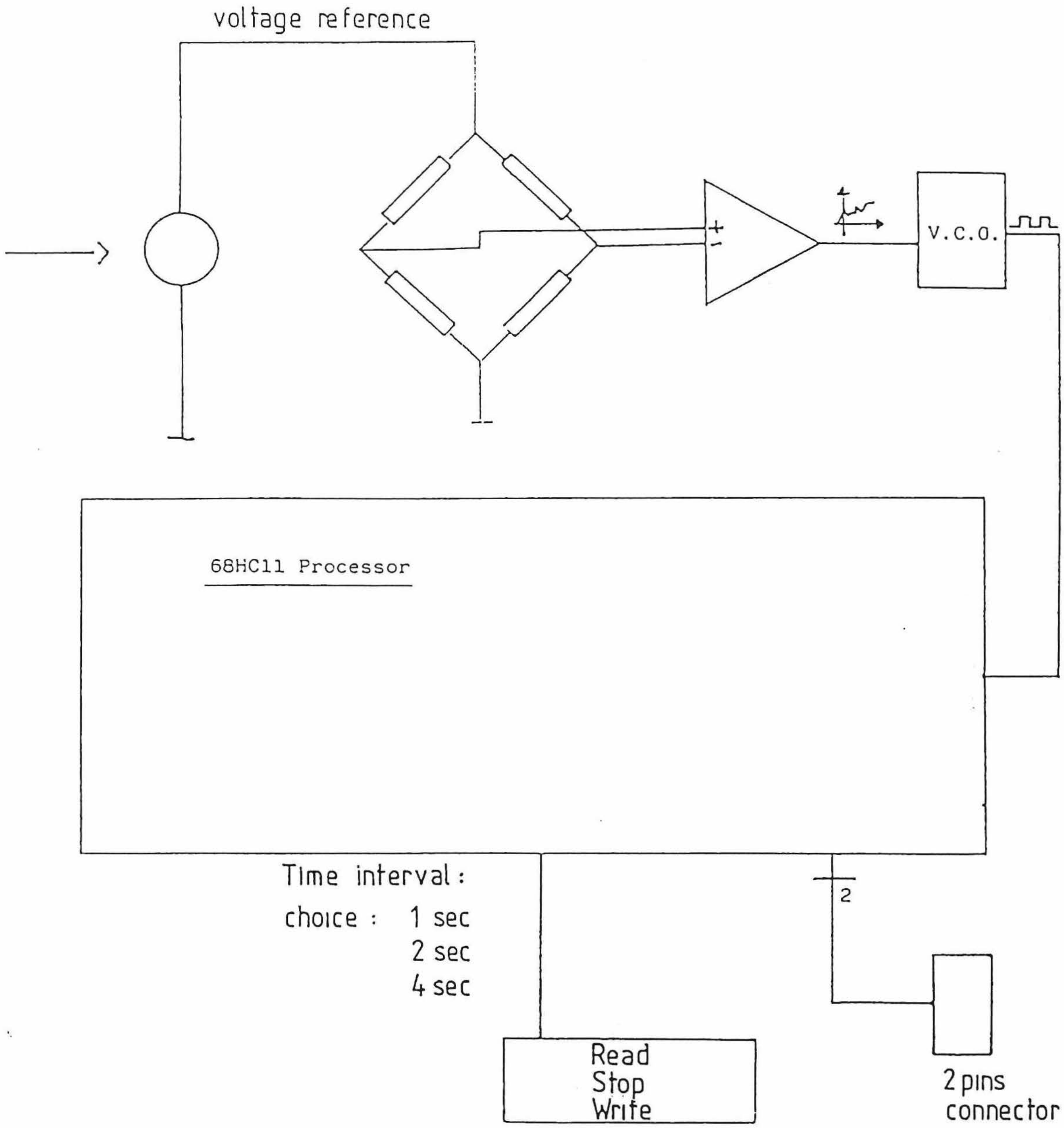
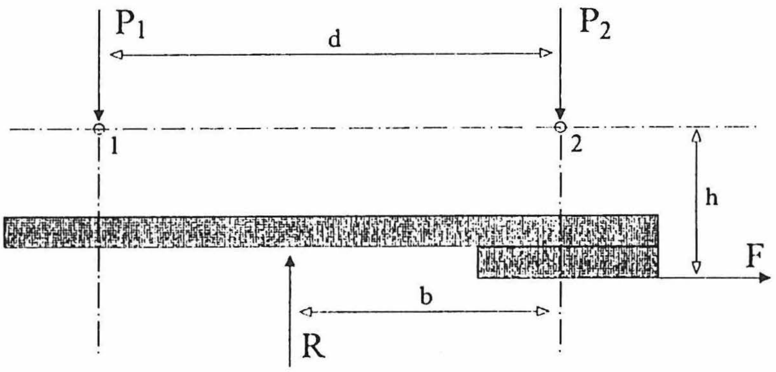


Fig. 1. Measuring principle.

Calculation of the position of the centre of pressure

The position of the centre of pressure is determined by the pressure components P_1 and P_2 and the friction force F. P_1 and P_2 are the vertical components measured by the load cells 1 and 2, F is the sum of the two horizontal components. The position of the centre of pressure is calculated from the equilibrium equation Σ (moments) = 0.

1. P_1 and P_2 are both positive

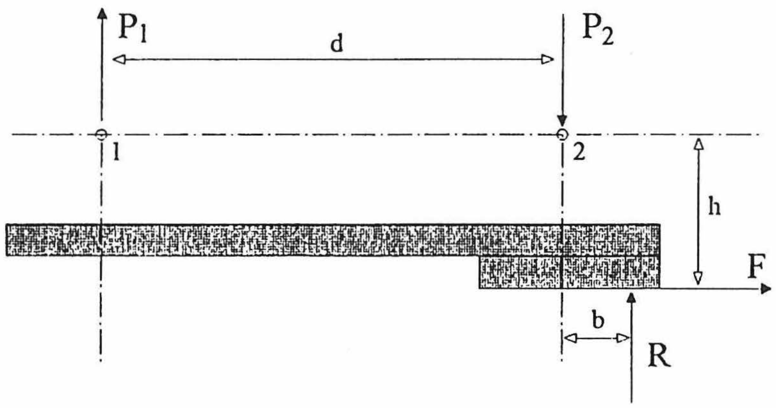


$\Sigma(\text{moments})_{\text{cell 2}} = 0$

$R.b-F.h-P_1.d = 0$

$b = (P_1.d+F.h)/R$
$R = P_1+P_2$

2. P_1 is negative, P_2 is positive



$\Sigma(\text{moments})_{\text{cell 2}} = 0$

$P_1.d-R.b-F.h = 0$

$b = (P_1.d-F.h)/R$
$R=P_1+P_2$

MID- AND LONG-TERM EFFECTS OF BOTTOM TRAWLING ON THE BENTHIC FAUNA IN THE GERMAN BIGHT

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ABSTRACT

Within the framework of the "IMPACT"-project, the Alfred-Wegener Institute for Polar and Marine Research in Bremerhaven (AWI) has carried out research on the persistent (mid- and long-term) effects of heavy bottom trawling on macrozoobenthos communities and populations in the German Bight. This research is closely related to longterm studies, initiated 25 years ago, of the variability and possible trends apparent in the North Sea macrozoobenthos. Two contrasting study areas were selected in the German Bight:

- **An area around the wreck of the "West Gamma" platform 60 nm northwest of Helgoland, which is enclosed by 4 buoys and accordingly regarded as protected from heavy fishing for 3 years;**
- **the "IMPACT-box" 20 nm west of Helgoland, where the fauna of a strongly fished area is being studied over a long time scale and compared with the fauna of neighbouring areas that are less heavily fished.**

The macrozoobenthos of these areas has been investigated by grab and small dredge sampling. To increase the effects of bottom gears, the "IMPACT-box" was heavily fished by the German research vessels "Solea" and "Victor Hensen", and the Dutch RV "Tridens".

The "IMPACT-box" fauna appears to be very homogeneous, belonging to the *Amphiura-filiformis*-association (poor variant, about 110 species). Conversely, the macrozoobenthos is less homogeneous in the "West Gamma" area, mainly due to an overall gradient in the composition of the *Tellina-fabula*-association of the region.

It is not yet possible to finally conclude whether the relative richness of this fauna (more than 150 species) is related to the reduced fishing gear stress around the wreck, because of the short duration of this experiment. The finding that some delicate, sensitive species were more abundant inside than outside the wreck area seem to indicate first changes.

In addition to the long-term investigations, studies of changes in the diet of demersal fish in the "IMPACT-box" before, during and after fishing have been performed. These studies indicate some changes in the availability of food items and in the feeding behaviour of the predators, which might also contribute to faunal changes.

INTRODUCTION

The North Sea has been subjected to demersal fisheries for more than hundred years (RSU, 1980). There are several indications in the scientific literature that the macrozoobenthos might have changed due to the fishing gear stress, on which recent trends are super-imposed. Among these recent trends, those related to eutrophication and organic enrichment in the bottom sediments are the most obvious (RACHOR, 1990a, b; DUINEVELD *et al.*, 1991). Pertinent changes in the fauna due to fishing activities are only documented for very restricted (nearshore) areas like the Wadden Sea (RIESEN & REISE, 1982; BERGHAHN, 1990).

In addition to the short-term investigations of IMPACT, which have shown immediate deleterious effects on the macrozoobenthos, longerterm population and community studies were initiated in autumn 1991 and included into the IMPACT framework. There is no well investigated open sea area which is closed to fishing in the North Sea and which would enable comparative work. Therefore, quasi-enclosed, protected areas are

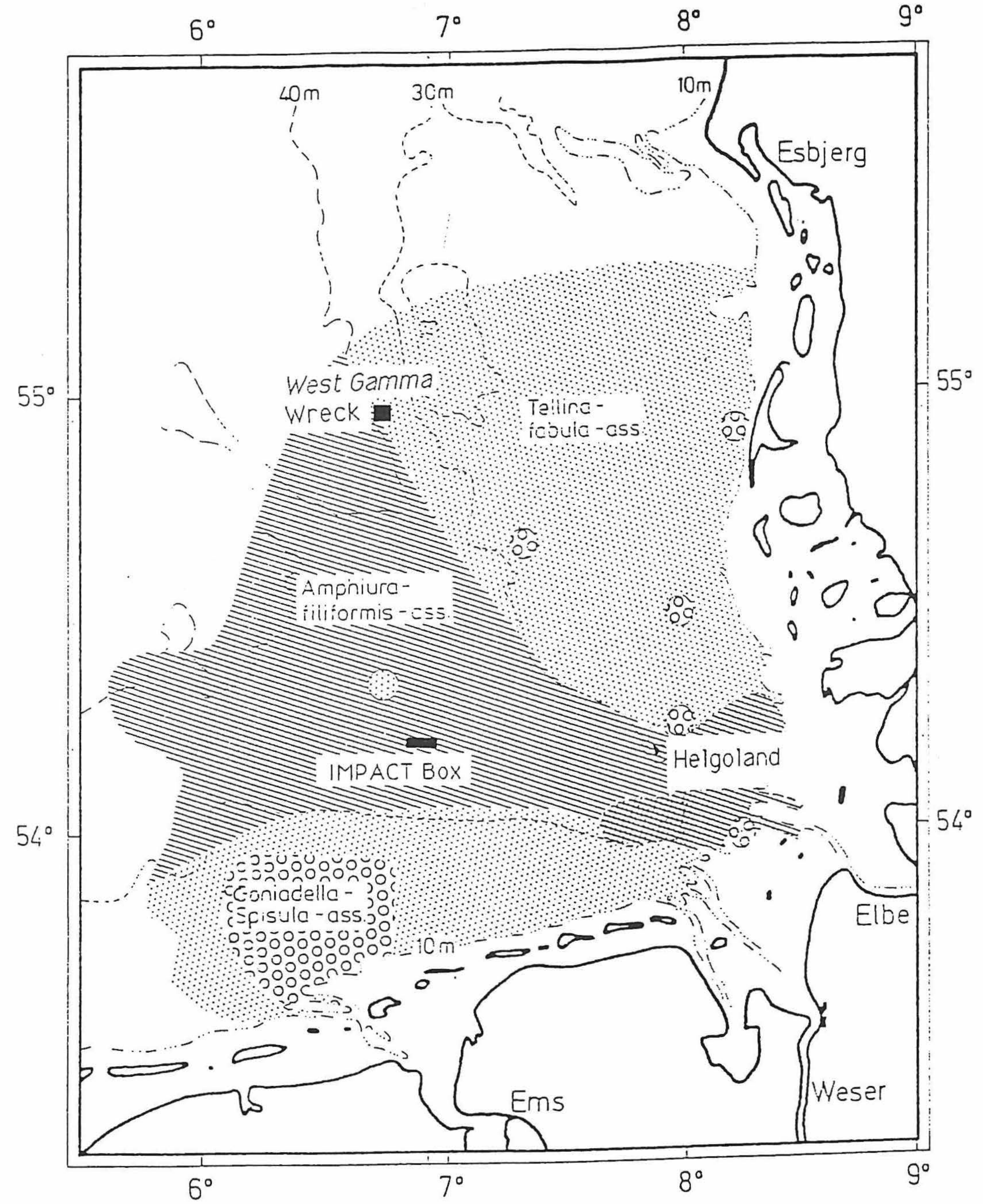

Fig. 1. Bottom communities of the German Bight and investigation areas ("IMPACT BOX" and "West Gamma Wreck Area") (The *Tellina-fabula*-association is characteristic of fine sand bottom habitats, the *Amphiura-filiformis*-ass. of more muddy substrates.).

the best alternative to study such long-term effects. A wreck area in the German Bight provided a suitable opportunity.

Another approach has been included: A normally fished area was, in addition, fished repeatedly, and the results on faunal development (esp. changes in the community structure) have been and will be compared with that in the neighbouring areas.

AREAS OF INVESTIGATION, MATERIAL AND METHODS

The German Bight study areas are indicated in Fig. 1.

The "IMPACT box" is an area about 20 nm west of Helgoland north of the deep water shipping lane (Figs. 1, 2). By additional experimental fishing, the stress on the bottom fauna was increased. The neighbouring shipping route area with several nautical buoys and two wrecks is regarded as a comparison site, since fishing stress is lower there. Water depths ranges between 34 and 35 m, and the sediments are very homogeneous (very fine sand with small amounts of silt and a low content of organic carbon, (0.12% of dry sediment weight, Fig. 3). According to SALZWEDEL *et al.* (1985), the zoobenthos of the area belongs to the *Amphiura filiformis*-association (s. Fig. 1).

The "West Gamma" area is located 60 nm northwest of Helgoland situated around a three years old drilling platform wreck, marked by four nautical buoys (Fig. 4). These buoys enclose an area of about one km2. The area is relatively well protected against normal fishing activities by the existence of these buoys, and the size and the nearsurface position of the wreck. Water depth is 44 m. The sediments show a north-to-south gradient from coarser sands in the north to finer sands in the south (Fig. 5). According to SALZWEDEL *et al.* (1985) the fauna belongs to a marginal variant of the sandy*Tellina-fabula*-association (s. Fig. 1).

Macrozoobenthos was sampled quantitatively with 0.1 m^2 van Veen grabs. Additional information about the larger and mobile fauna was obtained by trawling with a small frame dredge of 1m width, furnished with a 1cm mesh net, and by samples from the fishing nets used for trawling.

For the study of the fish diet, stomachs were taken from sized plaice (*Pleuronectes platessa*), dab (*Limanda limanda*) and grey gurnard (*Eutrigla gurnardus*) of the hauls of RV "Solea". The fish were measured, their stomachs and intestines dissected and preserved in 5-10 % formaldehyde.

The quantitative grab samples were separately sieved on 1.0 mm screens and preserved in 4 % buffered formaldehyde on board. These samples were sorted, counted and identified mainly to the species level in the laboratory. Other samples, such as the fish stomachs and unidentified dredge material, were also preserved and worked up in the laboratory.

Wet weights were determined after removing excess moisture with blotting paper.

ACTIVITIES

The investigations in the IMPACT-box area began already in 1991, initially to study the suitability of the area, the feasibility of the intended work and to obtain undisturbed samples of the status quo before the first experimental fishing.

The "West Gamma" work began in summer 1992 on board the RV "Atair" of the Bundesamt fur Seeschiffahrt und Hydrographie, Hamburg (BSH).

Stomachs of fish before and after trawling in the IMPACT-box were sampled during the "Solea" cruises by Dr. U. Damm, Bundesforschungsanstalt fur Fischerei. The "Solea" contributed to the experimental fisheries in the "box" with her beam trawl gear in a high degree.

The data of the main research activities are presented in the following table:

Date/Area	Ship	Gear	Number	
			of Stations	of Hauls
22./23.09.91 /IB	V.H.	vV	10	2 per station
		Dr	5	1 per station
		OT	2	1 per station
6.-8.10.1991 /IB	V.H.	vV	5	2 per station
22./23.04.92 /IB	V.H.	vV	10	2 per station
		Dr	5	1 per station
		OT (fishing)		5
2./3.06.92 /IB	V.H.	vV	15	2 per station
		Dr	5	1 per station
		OT (fishing)		3
	"Solea"	BT (fishing)		
5./6.08.92 /WG	"Atair"	vV	30	40
		Dr	4	4
27.-30.09.92 /IB	"Solea"	BT (fishing)		
21.-23.09.92 /WG	V.H.	vV	15	33
		Dr	4	4
21.-23.09.92 /IB		vV	13	29
		Dr	4	4
		OT		1
4.03.93 /IB	"Uthorn"	vV	5x6	30
		Dr	6	6
		OT		1
4.03.93/IB	"Tridens"	hBT (fishing)		
24.-28.5.93 /IB	"Solea"	BT (fishing)		
14.09.93 /IB	"Tridens"	hBT (fishing)		
6.-8.10.93 /IB	V.H.	vV	5	10
		Dr	5	5

Explanations:
V.H. = RV "Victor Hensen"; vV = van-Veen-grab of 0.1m2; Dr = small dredge; OT = otter trawl; BT = 7-m beam trawl; hBT = heavy 12-m beam trawl; IB = IMPACT box ; WG = "West Gamma" wreck area.

Additional grab samples were taken in the IMPACT box area and at the "West Gamma" site during other cruises of RV "Victor Hensen" (when sampling for AWI long-term studies).

The majority of the samples taken before summer 1993 have been worked up (some are kept unsorted as record material). Samples taken in autumn 1993 are partly sorted and will be kept for future analysis.

RESULTS AND DISCUSSION

The sediment characteristics and distribution in both study areas have been analysed (Figs. 2, 4) and have shown the IMPACT box to be a very homogeneous area, while in the "West Gamma" area there is a north-tosouth gradient (from coarser to finer sands).

The macrofauna of the **IMPACT box** area seems to be a poor, transitory variant of the *Amphiura-filiformis*-association of the German Bight (Tables 1, 2).

TABLE 2

The 10 most abundant benthos species in the IMPACT box and their mean abundances in individuals per m^2

Species	Mean Abundance (Ind. per m^2)
Spiophanes bombyx	2480
Echinocardium cordatum (juv.)	1740
Phoronis sp.	257
Magelona minuta	209
Decapoda, larvae	75
Nucula nitidosa	70
Nemertines	67
Sigalion mathildae	41
Nephtys hombergii	39
Ophiura albida	30

The species spectrum (more than 110 species/taxa) shows some similiarities also to the *Tellina-fabula-* and the *Spio-filicornis*-associations (sensu SALZWEDEL *et al.*,1985). The presence of the large, long-lived species *Aphrodita aculeata, Corystes cassivelaunus* and *Pagurus bernhardus* is regarded as advantageous, as these species have been shown to be strongly affected by heavy bottom gear fishery (s. BERGMAN and FONDS, this report).

By analysis of 10 grabs taken at one location it was shown that 2 grabs per station are sufficient to catch about 60% of the endofauna species present; and 4 grabs yield 75-80% (Fig. 6).

Until now, strong fluctuations especially of the smaller polychaete fauna (and juveniles, e.g. of Echinocardium cordatum) have been found (Table 3), which are regarded seasonal variations.

Whether the additional bottom gear stress, by remobilising the finer sediment components, favours a habitat development more suited for the sandy bottom *Tellina-fabula*-association, can only be clarified on the long term. The numerical increases of species like *Spiophanes bombyx, Magelona papillicornis, M. minuta, Phoronis* sp. and *Tellina fabula* are well fitting to such tenden-cies.

Other obvious changes in the fauna until now have not been detected, although direct impact of trawling was shown by imaging methods (RUMOHR *et al.*, this report).

The macrozoobenthos in the quasi-enclosed area of the "**West Gamma**" wreck belongs to the sand-inhabiting *Tellina-fabula*-association of the German Bight, with a tendency to the *Amphiura-filiformis*-association in its southern and western part. More than 150 species/taxa have been identified (Table 4).

The gradients in sediment and community characteristics until now do not allow firm statements about possible influences of the wreck and the closure of the area on species richness, although there are slight (non significant) increases in species numbers in three of four transects within the wreck area (Fig. 7).

There are also some differences in the faunal composition of the area enclosed by the buoys and of the stations outside: The small sea urchin *Echinocyamus pusillus*, the amphipods *Hippomedon denticulatus, Orchomene nana, Synchelidium haplocheles*, the polychaetes *Anaitides mucosa, Chaetopterus variopedatus, Gattyana cirrosa, Heteromastus filiformis, Scolelepis bonnieri* and sessile hydrozoans of the genera *Laomedea, Perigonimus* and *Campanularia* were only found in the "protected" area. According to dredge samples the echinoderm species *Amphiura filiformis, Asterias rubens, Astropecten irregularis, Cucumaria elongata* and *Leptosynapta inhaerens* were more common inside than outside the area.

Some of these delicate species may be regarded sensitive to heavy bottom gear stress, e.g. the small urchin *Echinocyamus,* the sea star *Astropecten,* the polychaete *Chaetopterus* and, particularly, the mentioned hydrozoans.

Our additional studies about the diet of demersal fish in the "IMPACTbox" before, during and after fishing indicate some changes in the availability of food items and in the feeding behaviour of the predators, which might also contribute to faunal changes. Food items to be mentioned in this context were *Nephtys* spp., *Pagurus bernhardus* and *Liocarcinus holsatus.*

The results of these investigations will be available as a diploma thesis of the University of Bremen in March 1994 (KOOPMANN, in prep.).

CONCLUSIONS AND IMPLICATIONS OF THE RESULTS SO FAR

Long-term changes in community and population structures of the macrofauna in the study areas of the German Bight can only be identified after several years of experimental fishing or closure of an area. In both investigated areas the tendencies observed so far seem to be promising. Accordingly, our work is to be continued for several years.

As long as strong additional fishing stress can be imposed in the "IMPACT-box", identificable changes on the faunal composition and community structure are to be expected. First indications seem to be the increases of small polychaetes and the bivalve *Tellina fabula*, adaptive species, typical for more sandy habitats.

The results from the wreck area are promising, too, although the area is relatively small and there exists the shown natural sediment gradient. The area will be kept closed at least for another year (1994). Four years of reduced fishing disturbance are regarded sufficient then to identify first significant trends of faunal change in comparison with the surrounding areas. Accordingly, extensive sampling and detailed analyses of the fauna will be performed again in 1994.

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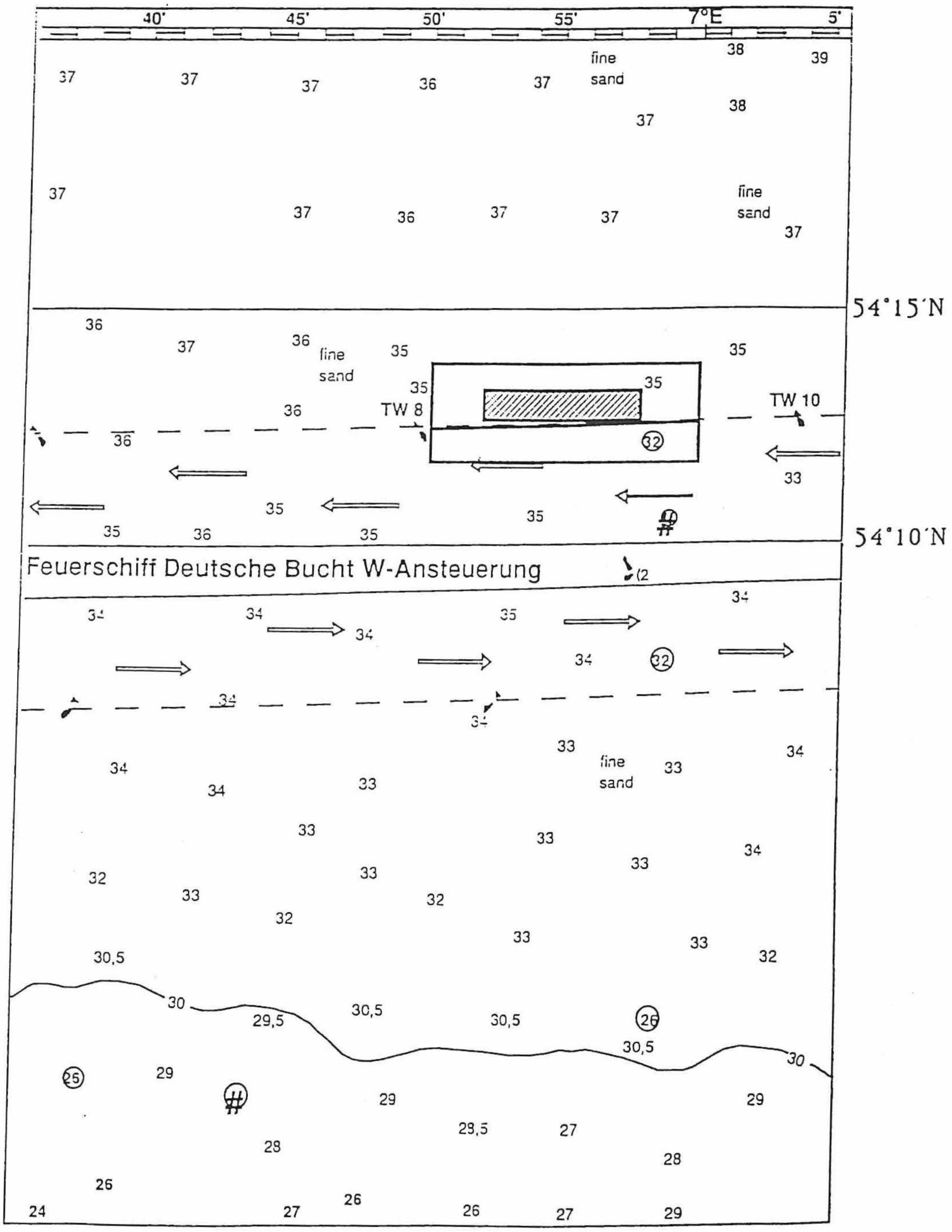

Fig. 2. The IMPACT box area 20 nm west of Helgoland.

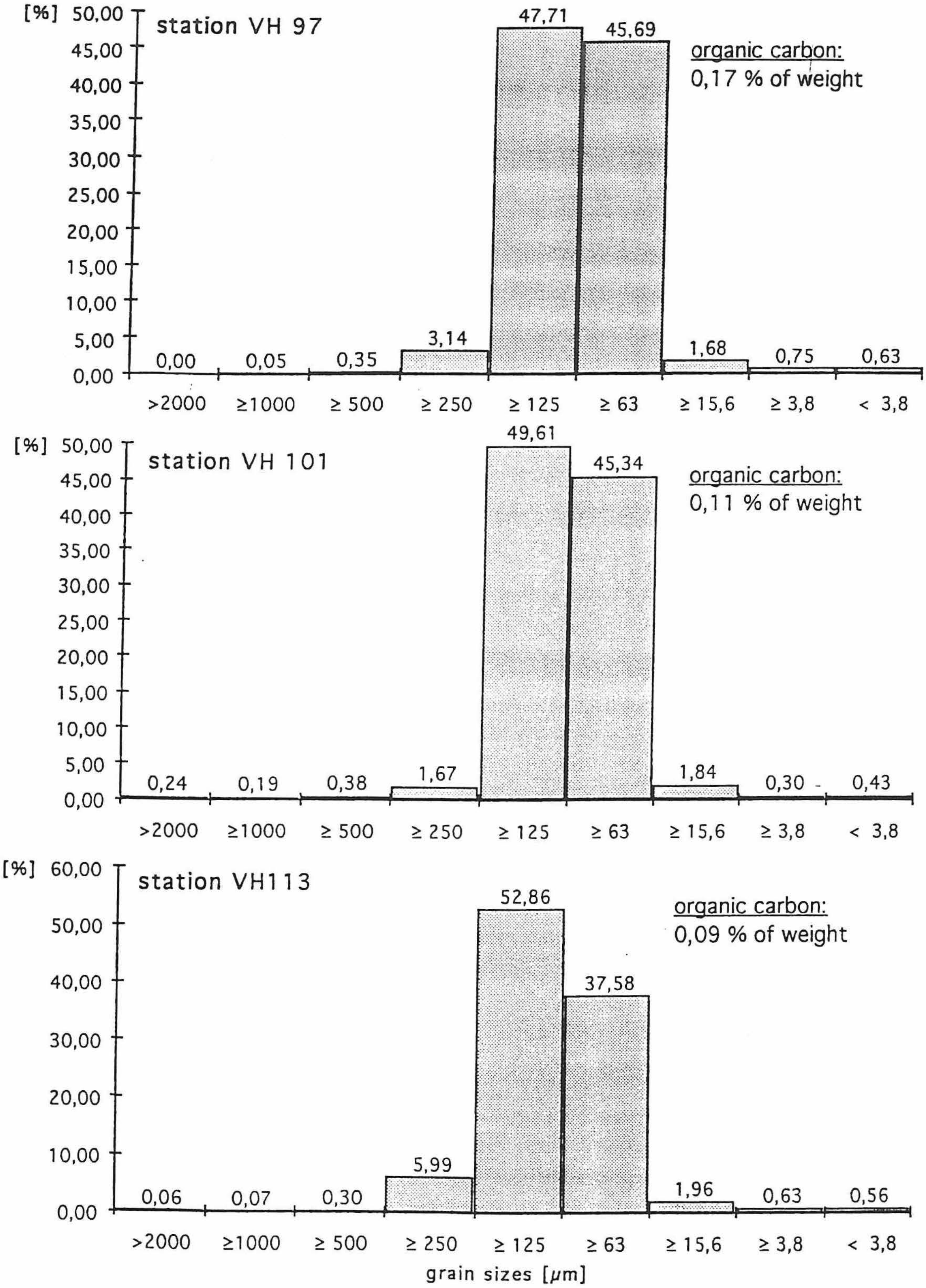

Fig. 3. Comparison of the grain size composition of the sediments at three stations in the IMPACT box and their organic carbon content.

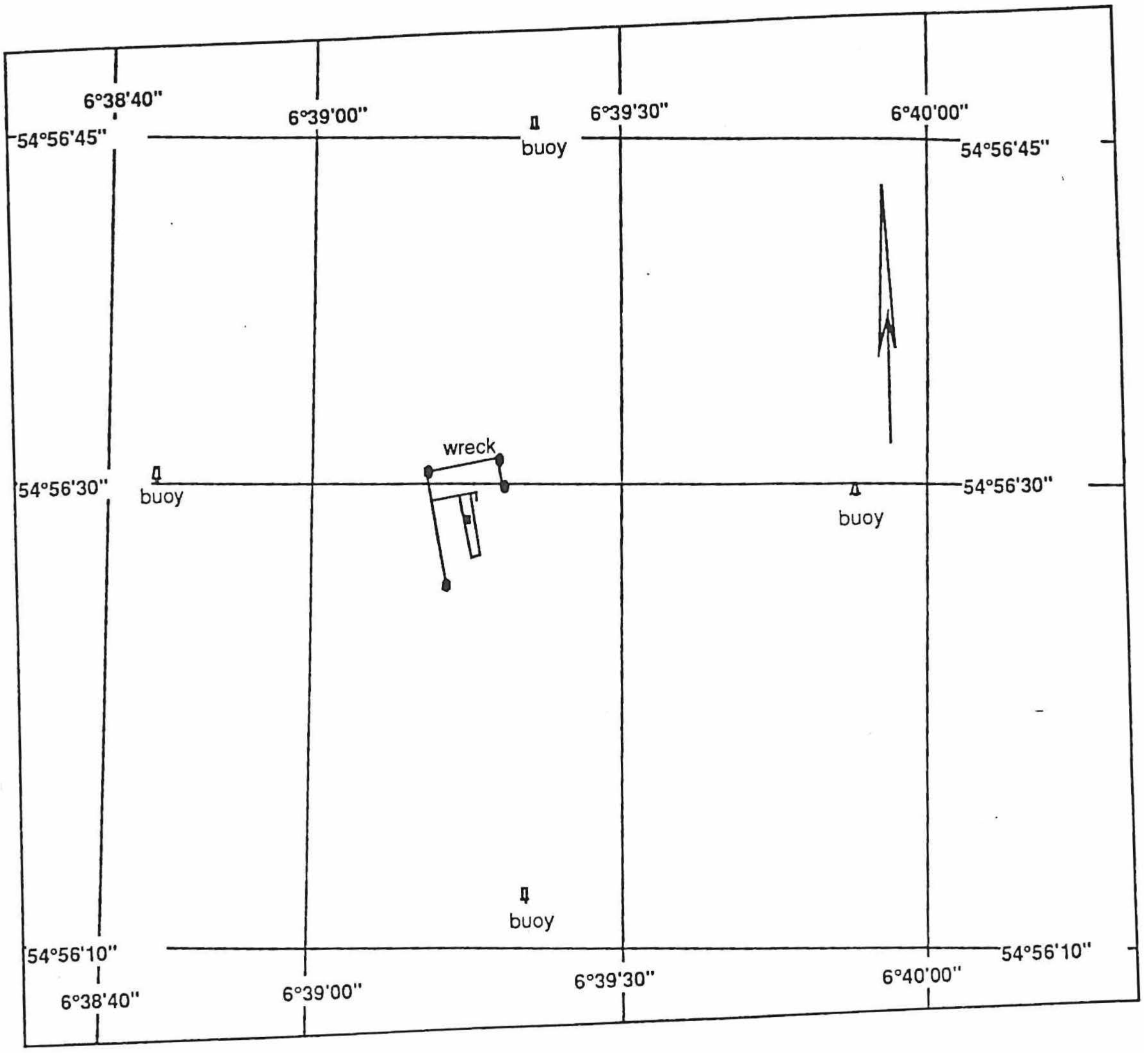

Fig. 4. The "West Gamma" wreck with four nautical buoys enclosing an area of about 1 km^2.

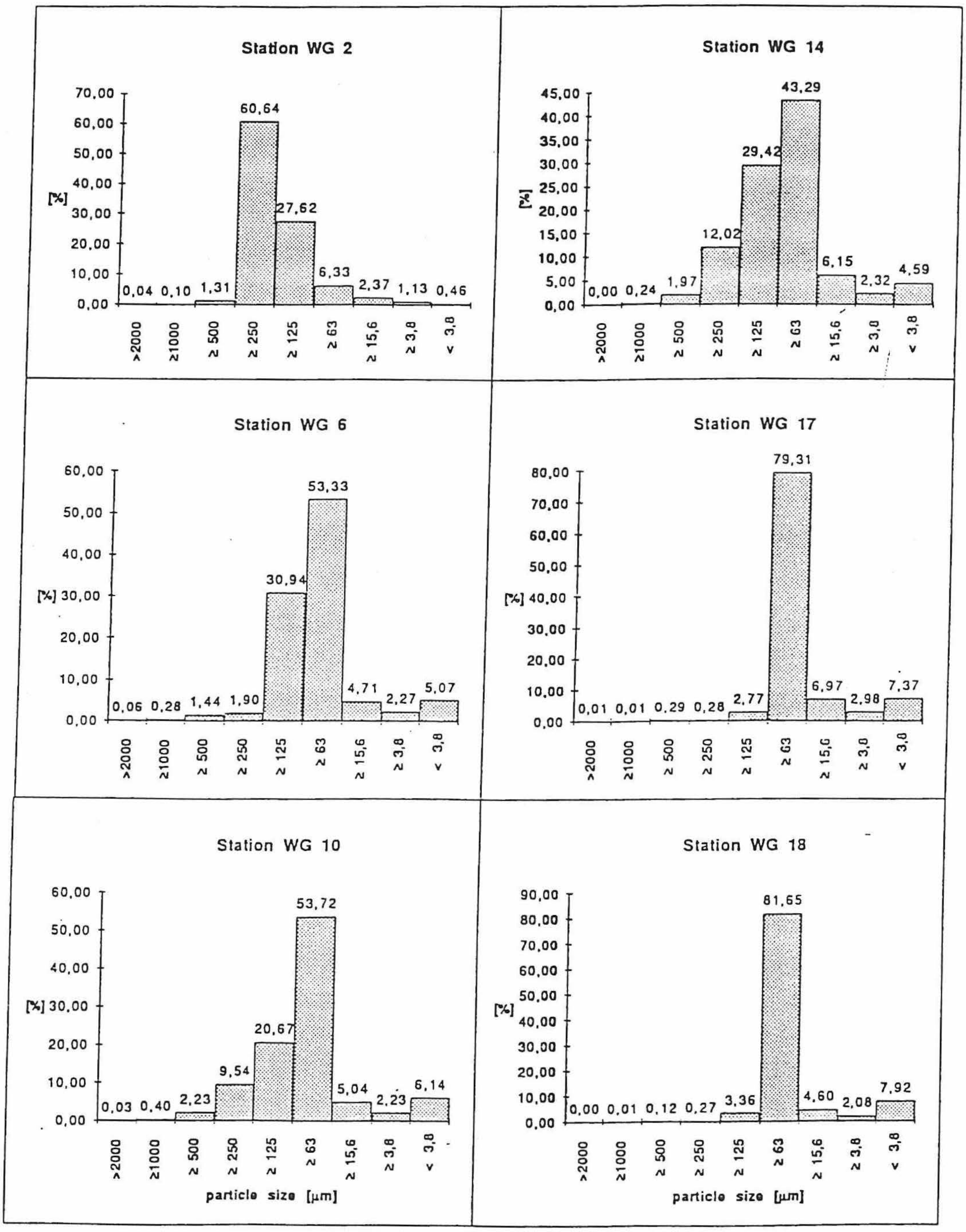

Fig. 5. Comparison of sediment grain size distribution within the wreck area (WG 2, 6, 10, 14) and south of it (WG 17, 18).

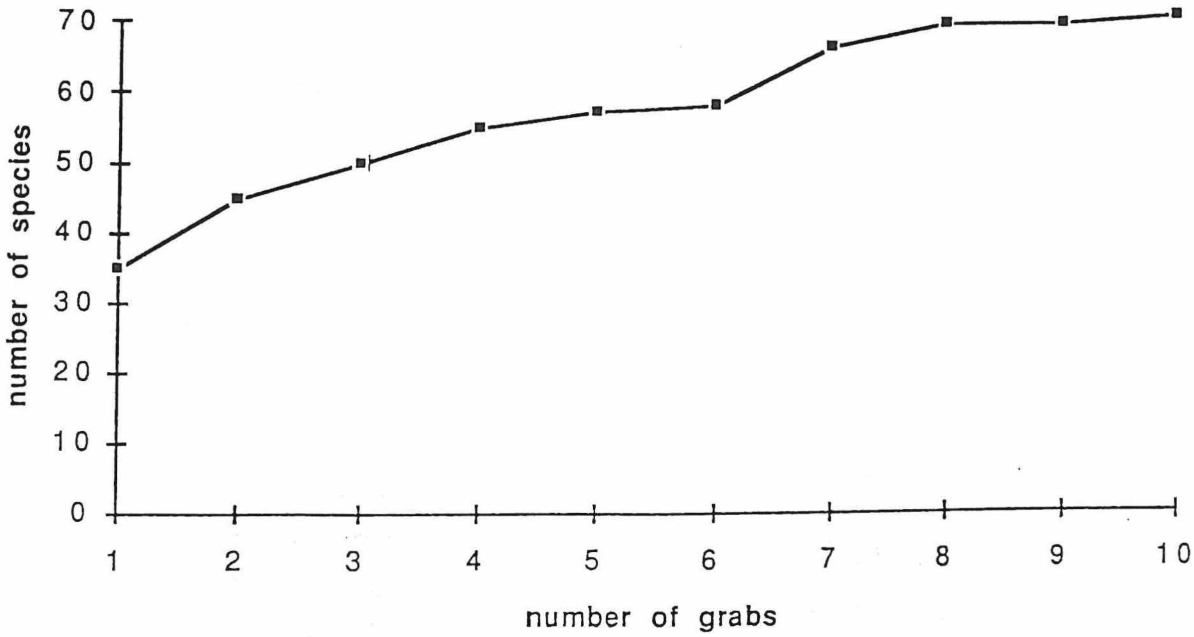

Fig. 6. Cumulative species number in the IMPACT box, based on 10 grabs at station VH 96.

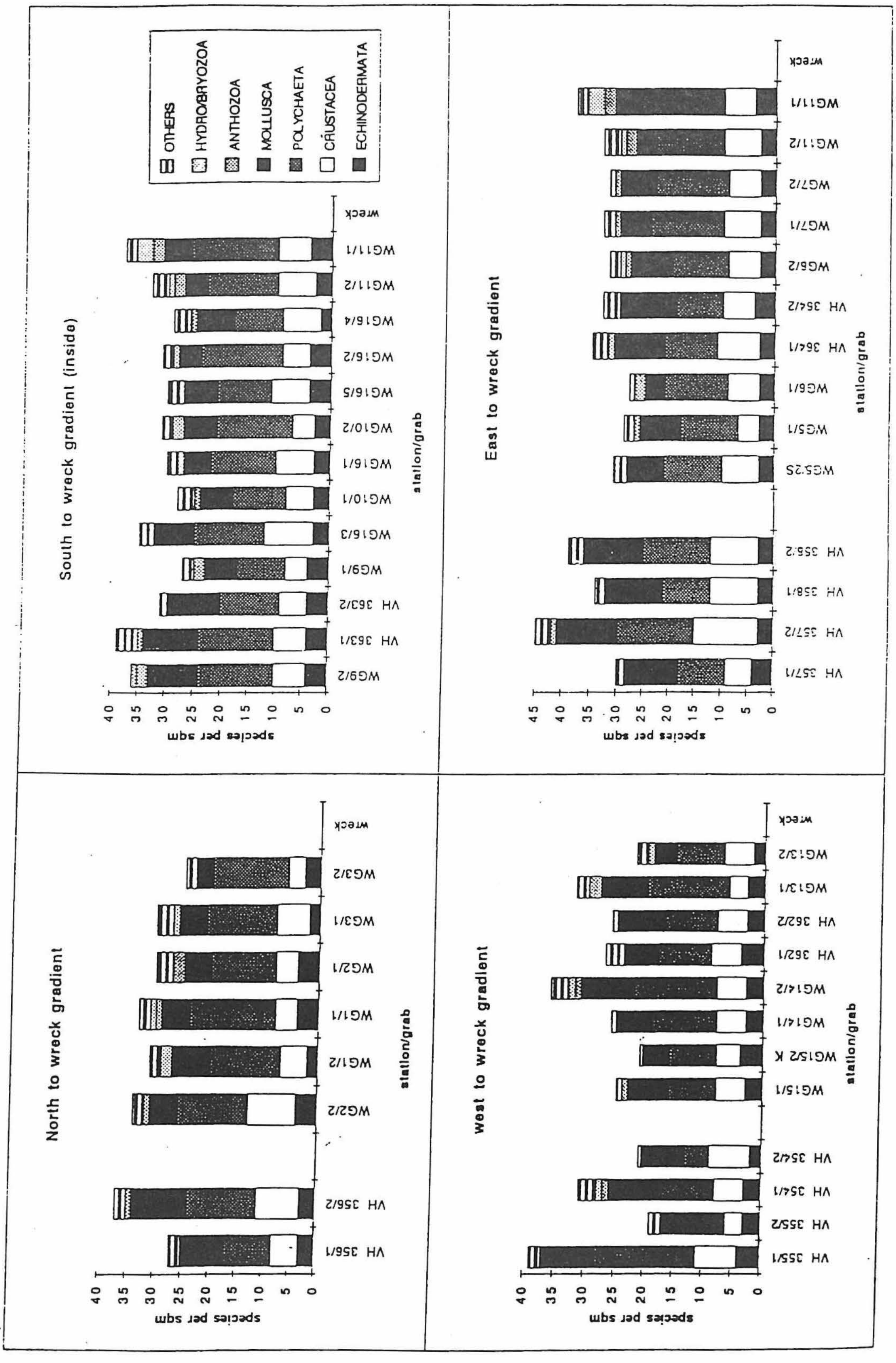

Fig. 7. Composition of the macrobenthos, German Bight "West Gamma" wreck area, indicating gradients.

TABLE 1

List of benthos species found in and south of the German Bight IMPACT box (from 14 grabs, 8 dredges and 4 otter trawls).

	IMPACT-Box	south of
VERTEBRATA		
Agonus cataphractus	X	
Ammodytidae	X	
Buglossidium luteum	X	X
Callionymus lyra	X	
Callionymus reticulatus	X	
Clupea harengus	X	
Eutrigla gurnardus	X	
Gadus morhua	X	
Gobiidae	X	X
Limanda limanda	X	
Merlangius merlangus	X	
Microstomus kitt	X	
Mullus barbatus	X	
Pleuronectes platessa	X	
Psetta maxima	X	
Sprattus sprattus	X	
Trachurus trachurus	X	
ECHINODERMATA		
Amphiura filiformis	X	X
Asterias rubens	X	X
Asteropecten irregularis	X	
Echinocardium cordatum	X	X
Ophiura albida	X	X
Ophiura texturata	X	X
CRUSTACEA		
Aora typica		X
Argissa hamatipes	X	
Atylus swammerd.	X	
Bathyporeia tenuipes	X	X
Callianassa subterranea	X	X
Calanoidea	X	X
Caprella linearis	X	X
Copepoda (parat.)	X	
Corystes cassivelaunus	X	X
Crangon almanni	X	
Crangon crangon	X	
Diastylis bradyi	X	X
Diastylis juv.	X	X
Ebalia aff. granulosa	X	
Eudorella truncatula	X	
Liocarcinus holsatus	X	X
Leucothoe richiardi	X	X
Macropodia rostrata	X	
Megaluropus aff. agilis	X	X
Melita obtusata	X	
Natantia larvae	X	X
Orochmene nana	X	X
Pagurus bernhardus	X	X
Pariambus typicus		X
Perioculodes longimanus	X	X
Processa holthousi		X
Synchelidium maculatum	X	X
Zoea	X	X
POLYCHAETA		
Aphrodite aculeata	X	X
Capitomastus aff. latericus	X	
Chaetozone setosa	X	X
Eteone barbata	X	
Eumida sanguinea		X
Glycinde nordmanni	X	X
Goniada maculata	X	X
Gyptis helgolandica	X	X
Harmothoe impar		X
Harmothoe longisetis	X	
Harmothoe lunulata		X
Lanice conchilega	X	X
Magelona alleni	X	X
Magelona minuta	X	X
Magelona papillicornis	X	X
Nephtys caeca	X	
Nephtys cirrosa	X	
Nephtys hombergi	X	X
Nereis juv.	X	
Ophiodromus flexuosa	X	X
Owenia fusiformis	X	X
Pectinaria koreni	X	X
Pholoe minuta	X	X
Phyllodocidae juv.	X	X
Poecilochaetus serpens	X	X
Scolelepis bonnieri	X	X
Scolelepis squamata	X	
Sigalion mathildae	X	X
Spiophanes bombyx	X	X
Sthenelais limicola	X	X
MOLLUSCA		
Abra nitida	X	
Apporrhais pespelicani	X	
Cephalopoda	X	
Cochledesma praetenue	X	
Cultellus pellucidus	X	X
Cylichna cylindracea	X	
Lunatia intermedia	X	
Lunatia nitida	X	X
Montacuta bidentata	X	X
Montacuta ferruginosa	X	X
Nucula nitidosa	X	X
Scaphander lignaris	X	
Spisula sp.	X	
Tellina fabula	X	X
Thracia villosciuscula		X
Thyasira flexuosa	X	X
Venus striatula	X	X
COELENTERATA		
Anthozoa	X	X
Cerianthus lloydi	X	X
Hydractinia echinata	X	
OTHERS		
fish larvae	X	
Nematodes	X	X
Nemertines	X	X
Phoronis	X	X
Sipunculidae		X

TABLE 3

Change in the faunal composition (10 dominant species) at one station in the IMPACT box (individuals per m^2).

April 1992	n=4	June 1992	n=2	September 1992	n=4
Calanoidea	513	Echinocardium juv.	7720	Magelona papillicornis	1920
Magelona minuta	248	Spiophanes bombyx	1825	Magelona minuta	1243
Fisch-Eier	218	Zoea	165	Phoronis	495
Zoea	95	Magelona minuta	130	Owenia fusiformis	300
Spiophanes bombyx	88	Pholoe minuta	55	Calanoidea	228
Magelona papillicornis	60	Bathyporeia tenuipes	45	Nephtys juv. (hombergi)	143
Nephtys hombergi	58	Lanice conchilega	45	Ophiuridae juv.	133
Nucula nitidosa	48	Pectinaria koreni	45	Nemertines	123
Nemertines	45	Nucula nitidosa	45	Tellina fabula	108
Ophiuridae juv.	40	Nephtys hombergi	40	Phyllodocidae juv.	95

TABLE 4

List of macrofauna species found inside and outside the quasi-enclosed wreck area in the German Bight (from 67 grabs and 8 dredges).

Species found	inside	outside
VERTEBRATA		
Arnoglossus laterna		X
Buglossidium luteum	X	X
Entelurus aequorus	X	
Eutrigla gurnardus	X	
Gobiidae	X	X
Solea solea	X	
BRYOZOA		
Triticella sp.	X	
ECHINODERMATA		
Amphiura filiformis	X	X
Asterias rubens	X	X
Asteropecten irregularis	X	X
Cucumaria elongata	X	X
Echinocardium cordatum	X	X
Echinocyamus pusillus	X	
Leptosynapta inhaerens	X	X
Ophiura albida	X	X
Ophiura texturata		X
Ophiuridae juv.	X	X
CRUSTACEA		
Ampelisca brevicornis	X	X
Ampelisca tenuicornis	X	X
Bathyporeia tenuipes	X	
Calanoidea	X	X
Callianassa subterranea	X	X
Cancer pagurus	X	
Caridea juv.	X	
Cirolina cranchii	X	
Copepoda (parasit.)	X	X
Corystes cassivelaunus	X	X
Crangon almanni	X	X
Crangon crangon	X	X
Cumopsis aff. goodsiri	X	
Diastylis bradyi	X	X
Diastylis sp.	X	
Ebalia tuberosa	X	
Epicaridae	X	
Eudorella truncatula	X	X
Euphausidae	X	X
Harpinia antennaria	X	X
Harpinia crenulata	X	X
Harpinia aff. laevis	X	
Hippomedon denticulatus	X	
Iphinoe trispinosa		X
Liocarcinus holsatus	X	X
Natantia juv.	X	X
Orochmene nana	X	
Pagurus bernhardus	X	X
Perioculodes longimanus	X	X
Porcellana longicornis		X
Processa canaliculata		X
Processa nouveli holthuisi	X	X
Processa spec.	X	X
Synchelidium haplocheles	X	
Socarnes erythrophthalmus	X	
Upogebia deltaura	X	
Upogebia gracilipes	X	
Upogebia stellata	X	X
Zoea larvae	X	X
POLYCHAETA		
Anaitides groenlandica	X	X
Anaitides mucosa	X	
Aphrodite aculeata	X	X
Capitomastus minimus	X	X
Chaetopterus variopedatus	X	
Chaetozone setosa	X	X
Chone duneri	X	
Diplocirrus glaucus	X	X
Eteone (c.f.) foliosa	X	
Eulalia bilineata	X	
Exogone hebes	X	X
Gattyana cirrosa	X	
Goniada maculata	X	X
Goniadella bobretzki	X	X
Glycera alba	X	
Glycinde nordmanni	X	X
Gyptis helgolandica	X	X
Harmothoe lunulata	X	X
Harmothoe longisetis	X	X
Heteromastus filiformis	X	
Lanice conchilega	X	
Lumbrineris gracilis	X	X
Lysilla loveni	X	

TABLE 4 (CONTINUED): Species in the wreck area.

Species	inside	outside
Magelona alleni	X	X
Magelona minuta	X	X
Magelona papillicornis	X	X
Nephtys caeca	X	X
Nephtys cirrosa	X	
Nephtys hombergi	X	X
Nereis aff. pelagica	X	X
Notomastus latericus	X	
Ophelina accuminata	X	X
Ophiodromus flexuosa	X	X
Owenia fusiformis	X	X
Paraonis gracilis	X	X
Pectinaria auricoma	X	X
Pectinaria koreni	X	X
Pholoe minuta	X	X
Phyllodocidae juv.	X	X
Poecilochaetus serpens	X	X
Polydora pulchra	X	
Polydora spec.	X	
Polynoe kinbergi	X	X
Prionospio spec.	X	
Scalibregma inflatum	X	X
Scolelepis bonnieri	X	
Scoloplos armiger	X	X
Spiophanes bombyx	X	X
Sthenelais limicola	X	X
Synelmis klatti	X	
MOLLUSCA		
Abra nitida	X	X
Abra prismatica	X	
Acanthocardia tuberculata	X	X
Arctica islandica	X	
Balcis devians		X
Buccinum undatum	X	X
Cephalopoda juv.	X	
Chaetoderma nitidulum	X	
Corbula gibba	X	X
Cultellus pellucidus	X	X
Hydrobia ulva	X	X
Lora turricula		X
Lunatia nitida	X	X
Cylichna cylindracea	X	X
Dosinia exoleta	X	
Macoma balthica		X
Mactra corallina	X	
Montacuta bidentata	X	X
Montacuta ferruginosa	X	X
Mya truncata	X	X
Nucula nitidosa	X	X
Scaphander lignarius	X	X
Spisula solida	X	
Spisula subtruncata	X	X
Tellina fabula	X	
Thracia villosciusculus	X	X
Thyasira flexuosa	X	X
Venus striatula	X	X
COELENTERATA		
Anthozoa sp.	X	
Campanularia hincksii	X	
Cerianthus lloydi	X	X
Edwardsia spec.	X	X
Hydractinia echinata	X	
Laomedea conferta	X	
Perigonimus conferta	X	
OTHERS		
Chaetognatha	X	X
Molgula sp.	X	
Nematodes	X	
Nemertines	X	X
Oligochaeta	X	
Phoronis	X	X
Plathelminthes	X	X
Sipunculidae	X	X

ENVIRONMENTAL IMPACT OF BOTTOM GEARS ON BENTHIC FAUNA IN THE GERMAN BIGHT

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ABSTRACT

This subproject concentrated on the investigation of direct effects of beam trawling on benthic fauna (including fishes). This was investigated using imaging methods (video, photo and REMOTS sediment profile photography), and with dredges directly attached to those parts of the gear that might cause damage to benthic animals (shoe, tickler chains). Reference values were obtained by a dredge attached to the beam. The dredge samples clearly revealed the effects of the beam trawl in some bigger taxa such as brittle stars, starfish, larger crustaceans and polychaetes (*Aphrodite aculeata*) although the sediment texture seemed to play an important role in this context. The "chain"-dredges contained more species than the "beam"-dredges, which is further proof of the effects of the tickler chains. The mean number of fishes was double in the chain dredges, and the species number was 1.5 times higher than in the reference sample. Video records displayed a sediment surface almost void of conspicuous epifauna in the heavily trawled zone compared with a relatively undisturbed reference area 10 sm SE. REMOTS photographs revealed a disturbed surface layer in the IMPACT box that showed no signs of layering or bioturbative action. Layers with mollusc shell debris were often found covered with coarse sediment. *Lanice conchilega* tubes were always damaged compared with intact ones in the contol area. The epifauna was reduced in abundance. No inner structures (feeding burrows, living chambers, tubes) were visible in the impacted area. At the control site a rich *Ophiura* community and *Lanice* as well as burrowed *Aphrodite* could be observed both in the video and in the sediment profiles. Close-up video inspections of a 10 m shrimp trawl in the German Wadden Sea showed the relatively low impact of this gear on the sediment and the behaviour of the shrimps in front of the trawl. Sea moss (*Sertularia*) and *Lanice* meadows remained relatively undisturbed after the passage of type of gear.

INTRODUCTION

Man is one of the main bioturbators of coastal benthic environments due to his trawling and dredging activities. It is questionable whether plowing of the sea bottom with beam trawls increases benthic productivity, or wether the nutrient regime is influenced. These questions have remained unanswered because of the limitations of existing research methods. This project aimed, in collaboration with other groups, to redress this gap.

Until recently the effects of bottom trawls on the sea-bed was poorly documented. This is despite increased large scale mechanical disturbance of marine ecosystems and especially the effects of fishing effort in coastal shelf areas. Since 1945, there has been an increase in the total number of fishing vessels in the North Sea. Concomitantly, the average engine performance of fishing vessels has also increased. This has allowed the use of larger nets (increased beam width and larger otter boards) and heavier gear (increased numbers of tickler chains) and higher trawling speeds (RAUCK, 1983).

Additionally, total trawling time has increased in the German sector (Annual Reports on German Fisheries).

In 1970 ARNTZ & WEBER initiated the opportunistic feeding habits of cod and dab linked to the bottom fishery, but this was only a tentative link. In the 70s a few papers focussed on the question of how deeply fishing gear penetrates into the seabed (DE GROOT & APELDOORN, 1971; HOUGHTON *et al.*, 1971; MARGETTS & BRIDGER, 1971; BRIDGER, 1970, 1972; DE GROOT, 1972; DE CLERCK & HOVART, 1972). Later, MAIN & SANGSTER (1984) documented the behaviour of bottom trawling gear on different sediments and the sediment clouds produced by trawl boards.

The action of various trawl gears, as they pass over the seabed, have been observed using video cameras. The effects of these gears on benthic fauna were examined by attaching dredges to different parts of a 7-m beam trawl, to collect those animals which had been affected by the gear. Additional information was gained from video recordings made close to the groundrope of a 10-m shrimp trawl.

VIDEO AND REMOTS OBSERVATIONS IN THE IMPACT BOX

In February 1993 (22/2-24/2 '93) a video survey was performed with RV "HEINCKE" in the sea area SW of Helgoland and in the German IMPACT box prior to intense trawling by RV "TRIDENS". Five video-profiles of a 200-300 m length of seabed outside and six profiles inside the IMPACT box were performed with the video sled in order to document the state of the epibenthic community. In addition 3 dredge samples were taken with the "Kieler Kinderwagen"(1 m dredge) both inside and outside the IMPACT box. Technical problems with the REMOTS sediment profile camera and bad visibility due to heavy storms in the southern North Sea, limited the quality of the results obtained on this cruise.

In March/April 1993 (31/3-6/4 '93) we repeated the February cruise programme. RV "TRIDENS" had intensively trawled the IMPACT box in early March with 2x8-m beam trawls (54°14,75 N; 06°81,80 E and 54° 14,50 N; 06°54,75 E). Again, the area was surveyed 200-300m video profile and REMOTS stations both inside (8) and outside (11) the impacted area. Results of the video recordings indicated that the presence and density of conspicuous epifauna like brittle stars, hermit crabs, other crustaceans as well as flatfishes seems to be higher in the untrawled areas. Also, the form of the sand ripples were different in their appearance. In the trawled area the sand ripples seemed to be in the state of formation or looked disturbed whereas we found round and well-developed ripples in the reference area.

THE EFFECTS OF A HEAVY 7-M BEAM TRAWL (RV SOLEA)

During a cruise on the RV SOLEA in June 1992 the effect of a 7-m beam trawl on the benthic fauna was investigated using a 1-m dredge ("Kieler Kinderwagen", Fig. 3). This dredge was developed from a botanical dredge with an opening of 1x0.4 m and a netbag approximately 3 m long with a strong covering net and an inner net with 5 mm meshes. It can be fitted with a set of tickler chains when appropriate. This dredge has been used in the cooperative North Sea survey in 1986 (ICES Benthos Ecology WG) and in routine investigations in Baltic Biological Monitoring (HELCOM).

The net of the beam trawl was removed for the duration of this investigation. For a reference sample, a second dredge was attached to the beam so that it worked in front of the tickler chains. This dredge tied as close to the centre of the beam as possible (such that the two dredges would not have an overlapping path). However, the position had to be altered when the other dredge was attached to the beam shoe, to counter-balance the effect of drag produced by the other dredges (Fig. 4). Six hauls (10 min duration) were carried out at the northern margin of the IMPACT study area on a hard sandy bottom, 3 of these with the dredge attached at the shoe and 3 at the chain. Four samples were taken on soft ground SW of Helgoland, but the experiment was stopped because of the large quantities of mud collection. There is evidence that the process of seperating the sample from the mud created some additional damage, thus these results have been disregarded.

From the first six hauls, the 3rd was not considered because the reference (beam) sample was too small.

Two "shoe" and three "chain" hauls await analysis. We chose 4 species/genera, which were abundant enough for more detailed analysis: *Asterias rubens, Ophiura* sp., *Corystes cassivelaunus* and *Nucula* sp. (*Corystes* was not abundant enough in the last of the "chain"hauls, thus a total of four hauls remain for this species).

Each species/genera was classified by size group and the types of damage sustained (not necessarily in order of severity as they appear in the tables), giving a contingency table for each sample. These were analysed by means of a log-linear model, using the GLIM routine with a poisson error and log-link function, and including the additional factors haul (1...5) and gear (beam, shoe, chain = 1,2,3). These together with the rows (damage type) and colums (size class) are the main effects. The effects of the different parts of the gear were significantly different in all cases.

In addition, the interaction of damage with size was tested. This was highly significant for *Asterias* and *Ophiura* (bigger animals were more severely damaged), weakly so for *Corystes* and not significant for *Nucula.*

The tickler chains and beam shoes were responsible for the damage sustained by *Ophiura, Asterias* and *Nucula,* but the tickler chains had a greater effect on *Asterias* and *Nucula* than the beam shoes. Although *Corystes* was damaged in the trawl, it was not possible to attribute this to the effects of the beam shoes or tickler chains. This species has a particularly spiny carapace which may become entangled in the meshes of the net resulting in carapace damage.

The number of benthic species (Fig. 5) and fish (Fig. 6) was always higher in the shoe and the chain samples on sandy ground. On soft bottoms a higher number of species were found in the beam samples. Greater error between samples was encountered over soft ground.

This experiment was repeated in September 1993 (RV SOLEA) when 18 dredge samples were taken with dredges mounted on the beam of a heavy 7-m beam trawl and behind the tickler chains. Again the net was removed for this investigation. The samples were taken in the IMPACT box on the same sandy sediment to reduce variability with the previous samples. Preliminary analysis shows that the chain samples contained more species than the beam samples. Decapods (*Portunids, Corystes*) were more common (x2) than the chain samples. The number of fish species was higher in the chain samples as were the numbers of individual fish (Fig. 7). The mean values for fish species were 5.8 species with 25.8 individuals in the beam samples compared with 7.4 species and 63.6 individuals in the chain samples. The mean species number in the beam samples (all groups) was 19.1 species compared with 23.3 in the chain samples. The investigated sample volumes were similar (ca. 4 litres) whereas the chain samples caught more material (2x). Analysis of the results was at times confounded as damaged species occasionally occurred on only in the chain samples.

The overall level of damage (including the reference samples) was high, we thus conclude that much of the damage is probably caused by the dredge itself. However, this was taken into account in our analysis.

Other species could not be tackled in a statistical manner because of their low abundances. Nevertheless the observed damage is reported here. Polychaetes were broken into many pieces in most of the samples. While this may be attributed not only to the trawling but also the process of sampling and sieving, there was substantial damage to the large polychaete *Aphrodite,* which were often torn on their dorsal surface.

Small gastropods, such as *Lunatia* sp., were normally not affected, but occasionally the rim of the shell was broken off. Large shells, such as *Buccinum* were broken in a variety of samples. Specimens of *Venus, Spisula* and *Corbula* showed no damage and *Nucula* sp. only in isolated cases. *Abra nitida* was crushed in all cases. This could be due to their storage in large plastic bags.

Gammarids, *Crangon crangon* and *Gastrosaccus spinifer* showed no damage except for a few specimens that were squashed or torn. The shells of *Eupagurus* were often broken, regardless of sample. large crustaceans like *Carcinus maenas* and *Corystes cassivelaunus* showed higher damage rates in the "chain" samples, i.e. legs were torn off and the thorax was squashed. Small individuals (20-25 mm) were damaged to a greater extent than the larger specimens.

Echinoderms were damaged both during the trawling process and by our own sampling. The arms of ophiuroids were broken in most cases, intact specimens were only found in the reference, "beam" samples (i.e. where the dredge had been towed fixed to the beam but still in front of the ground gear). Many of the brittle stas were severely damaged so that only the oral discs remained. 43% Of the ophiura in the reference samples were undamaged whereas only 17% in the chain/shoe samples were intact. Some specimens were totally squashed or torn, with the ambulacral system laid open. This occurred in 30% of the animals from the beam samples and in 50% from the chain samples. Damage to the oral disc occurred most frequently in larger specimens (> 40 mm oral disc diameter).

DIRECT OBSERVATIONS OF THE EFFECTS OF A 10-M SHRIMP TRAWL

Video recordings were made in August 1992 while fishing with a commercial shrimp trawler (FK "OSTPREUSSEN") near Hörnum/Sylt on various kinds of sediment from hard shell debris to a soft sandy/mud bottom. The camera was fixed in different positions to the shoe and to the net in order to observe the ground rope and its behaviour in detail. In addition the camera was mounted on a newly designed "mono sled" fixed to the beam and the ground rope with the camera looking backwards just in front of the net opening (Fig. 8). Immediately after the passage of the net divers surveyed the track of the trawl with a hand-held videocamera. The main results of this first attempt were that damage from this kind of fishing proved to be relatively light. The rollers did not roll as they were supposed to, the ground rope never touched the ground. Diver observations directly after the passage of the net showed only minor damage from the shoe of the beam trawl. *Lanice* meadows and *Sertularia* beds semed to be relative undisturbed by the net (although the meshes and the ground rope were festooned with Lanice worms). The track was densely inhabited by large epifauna (mainly *Carcinus maenas*) which were searching for freshly exposed food items.

BALTIC OBSERVATIONS

The following observations may be of interest to the project although they were obtained in the Baltic. During a cruis with RV "LITTORINA" to the Western Baltic (May 1993) (Arkona Basin, 45 m north of the island of Rügen) we observed old trawl tracks (which are visible much longer in this tide-free environment) covered with Beggiatoa. Our first impression is that the trawls may have removed the thin oxygenated surface layer and exposed the reduced deeper layers which were then firstly inhabited by the sulfur bacteria Beggiatoa in a stagnation period with increasing oxygen deficiency. This pattern has been observed in other sea areas of the Baltic.

The personel involved in these investigations was only partly paid by the project (T. Kujawski), the others (H. Rumohr, F. Kahl and H. Schomann) were funded from other sources in the Institut für Meereskunde. The dredge samples were analysed under contract by M. Romero-Wetzel and the sorting of the second set of samples by D. Willuweit. U. Damm (BfA, Cuxhaven) made the statistical analysis of these data.

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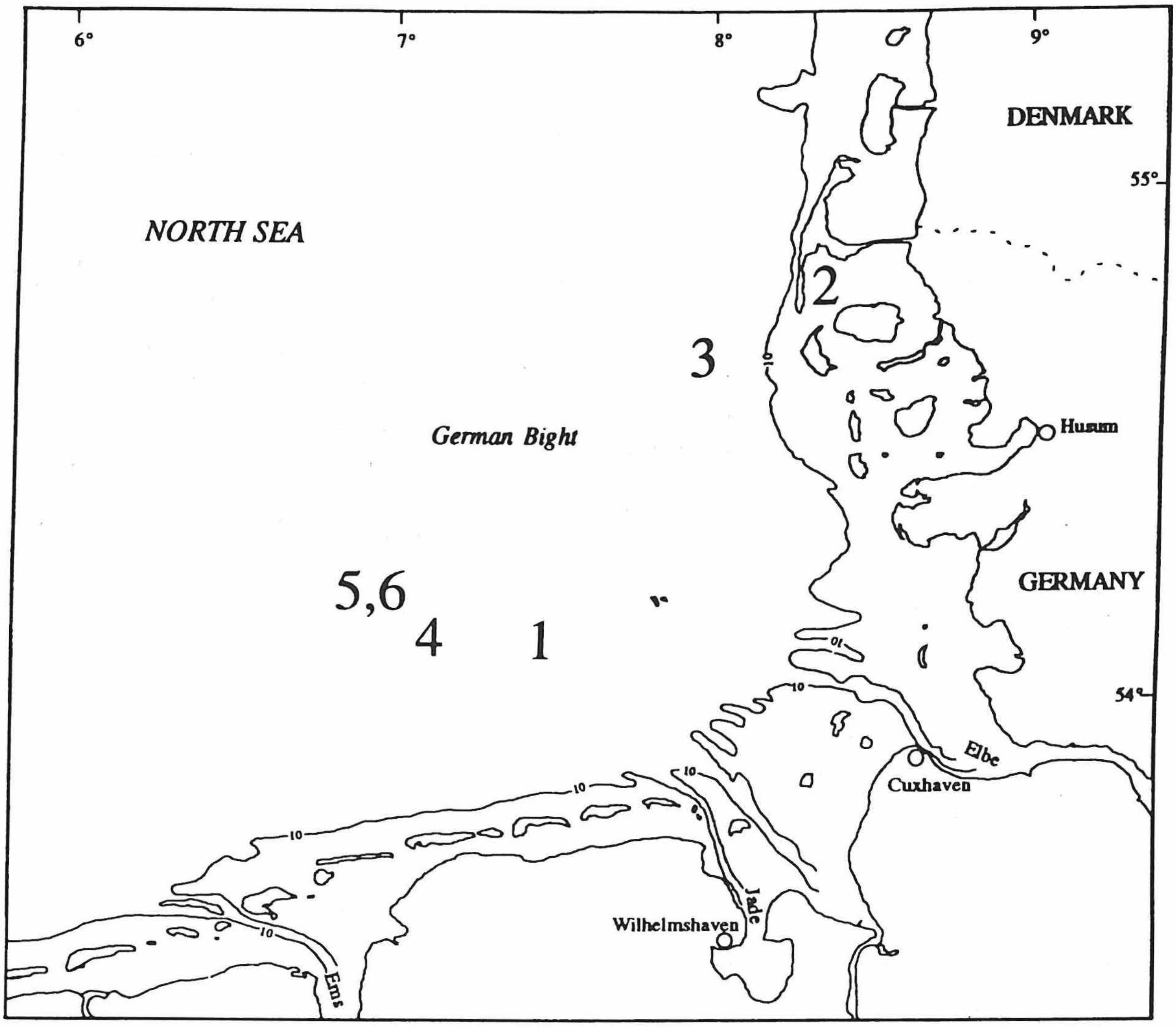


1	03.06-04.06.92	RV "SOLEA"	German Bight	dredge-sampling on 7m beamtrawl
2	19.08.93	FK "OSTPREUSSEN"	Hörnum / Sylt	video recording of 10m shrimptrawl
3	11.09-12.09.92	FK "OSTPREUSSEN"	Amrum Bank	video recording of 10m shrimptrawl
4	22.02-24.02.93	RV "HEINCKE"	IMPACT-Box	Video, REMOTS : 6 profiles inside, 5 profiles outside
5	31.03-06.04.93	RV "HEINCKE"	Box between :	REMOTS : 14 stations (65 photos) inside
			54°14.75N 06°51.80E -	REMOTS : 12 stations (63 photos) outside
			54°14.50N 06°54.80E	VIDEO : 7 profiles inside (a 15min)
				VIDEO : 12 profiles outside (a 15min)
6	14.05-28.05.93	RV "SOLEA"	German Bight	dredge-sampling on 7m beamtrawl

Fig. 1. Investigation areas and cruises.

station	date	time	depth [m]	REMOTS position [N]	REMOTS position [E]	REMOTS frame-No.I	Video profile-start [N]	Video profile-start [E]	Video profile-end [N]	Video profile-end [E]
1	31.03	18:15	20,2	54°03.07	08°05.24	6	54°03.07	08°05.24	54°03.07	08°05.24
2		20:00	33.5	54°01.71	07°48.44	5				
3	01.04	09:30	54.0	54°08.24	07°53.42	5				
			52.8-54.0				54°08.28	07°53.60	54°08.29	07°53.88
4	02.04	12:13	28.4				55°00.22	07°00.31	55°00.51	07°00.22
5		14:26	42.0				55°00.22	06°29.92	55°00.32	06°29.92
6	04.03	13.02	23.9	54°22.34	07°36.04	6				
			23.0-22.8				54°22.63	07°36.26	54°22.71	07°36.28
7		13:55	27.4	54°19.12	07°36.17	5				
			24.5				54°19.36	07°36.18	54°19.48	07°36.13
8		14:49	37.3	54°15.18	07°36.09	6				
			37.0-36.8				54°15.24	07°36.16	54°15.36	07°36.17
9	05.04	06:03	32.3	54°14.95	06°54.98	5				
			32.7-32.0				54°14.85	06°55.01	54°14.76	06°55.12
profile 1		06:52	32.8	54°14.73	06°51.82	5				
			33.0-32.6				54°14.65	06°52.10	54°14.37	06°52.55
		07:29	32.1	54°14.35	06°52.64	5				
profile 2		07:50	32.6	54°14.59	06°51.53	6				
			33.0-32.8				54°14.65	06°52.04	54°19.70	06°52.11
profile 3		08:18	33.5	54°14.71	06°53.00	4				
			32.3-33.1				54°14.71	06°53.01	54°14.46	06°53.02
		08:51	33.1	54°14.46	06°53.02	4				
profile 4		09:08	33.0	54°14.70	06°54.09	4				
			34.0-33.2				54°14.78	06°54.01	54°14.53	06°53.94
		09:42	33.2	54°14.53	06°53.94	5				
profile 5		09:58	33.6	54°14.91	06°54.84	4				
			33.5-33.2				54°14.80	06°54.97	54°14.46	06°55.11
		10:28	33.2	54°14.46	06°55.11	5				
profile 6		10:55	33.4	54°14.56	06°51.58	3				
			33.6-33.2				54°14.60	06°52.40	54°14.60	06°52.40
		11:20	33.2	54°14.60	06°52.40	4				
profile 7		12:00	33.4	54°14.87	06°53.41	4				
			33.3				54°14.87	06°53.52	54°14.16	06°53.88
		12:24	33.3	54°15.16	06°53.88	4				
profile 8		12:44	32.8				54°14.53	06°53.42	54°14.84	06°53.69
		13:02	33.4	54°14.86	06°53.75	4				
10		16:26	25.1	53°59.96	07°09.84	5				
			24.8				53°59.86	07°09.64	53°59.94	07°09.39
11		17:51	26.9	54°01.12	07°20.01	5				
			27.0-27.2				54°01.11	07°20.17	54°01.08	07°20.37
12		19:25	34.5	54°09.94	07°20.35	5				
			35.1-34.2				54°09.93	07°20.42	54°09.87	07°20.58
13		20:00	34.9	54°11.54	07°19.93	5				
14		21:11	32.8	54°.21.14	07°19.99	5				
			33.0-30.9				54°21.10	07°20.38	54°21.15	07°20.71

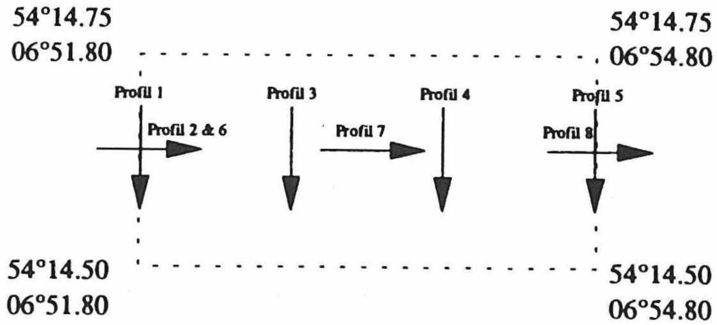


Fig. 2. Station list and plan of profiles in the IMPACT box.

Fig. 3. "Kieler Kinderwagen"-dredge with 1.0x0.4 m opening and 3 m netbag. Optionally equipped with a set of tickler chains.

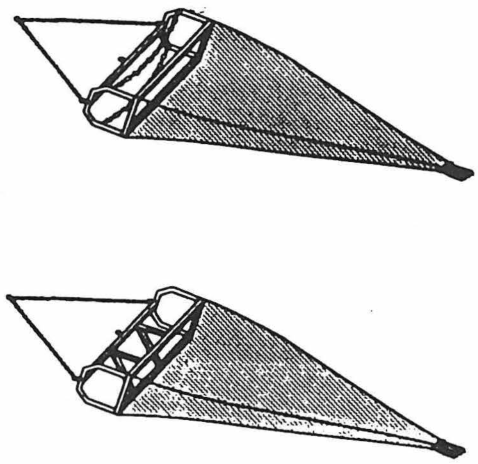
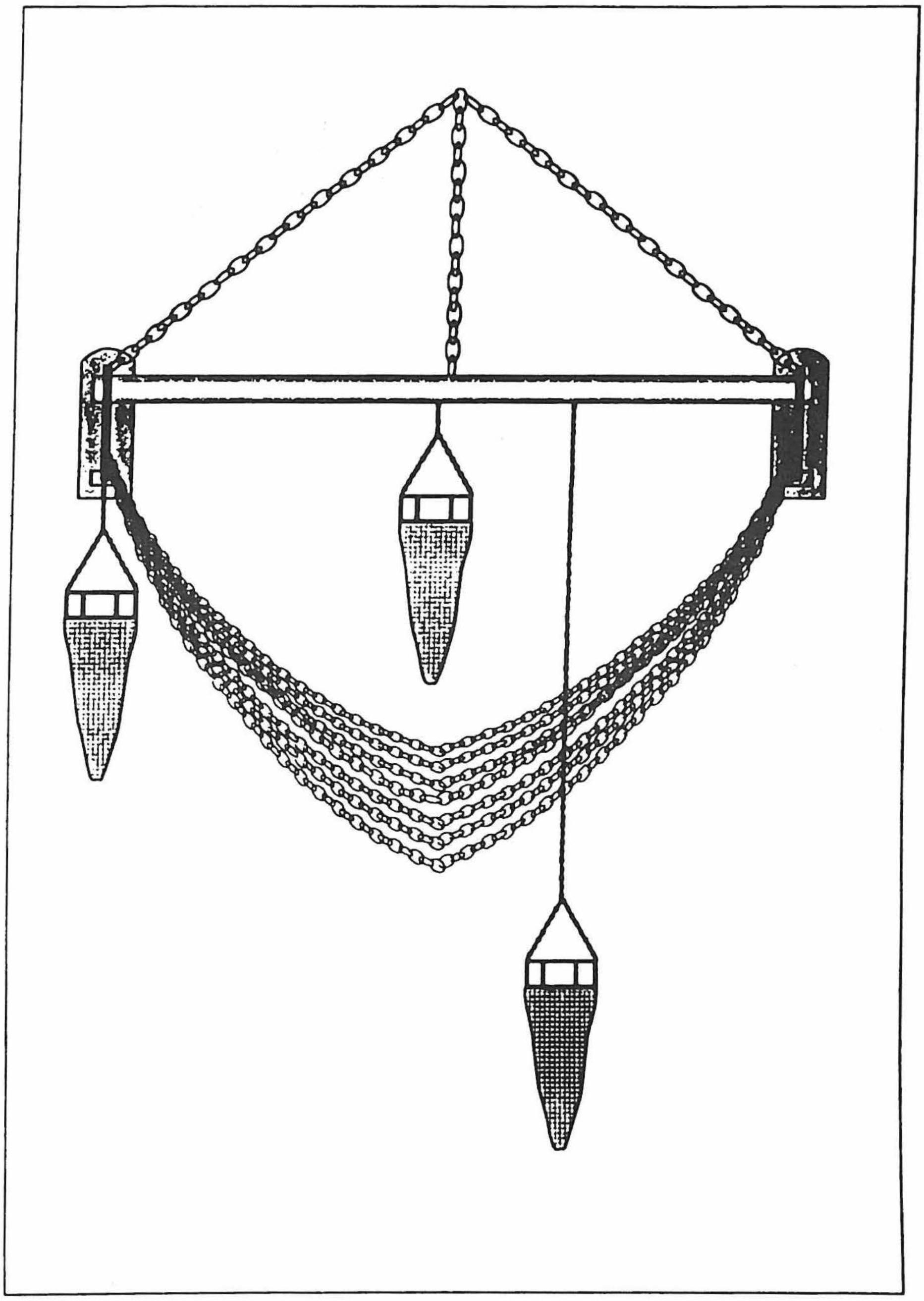


Fig. 4. Positions of dredges fitted to the 7-m beam trawl.



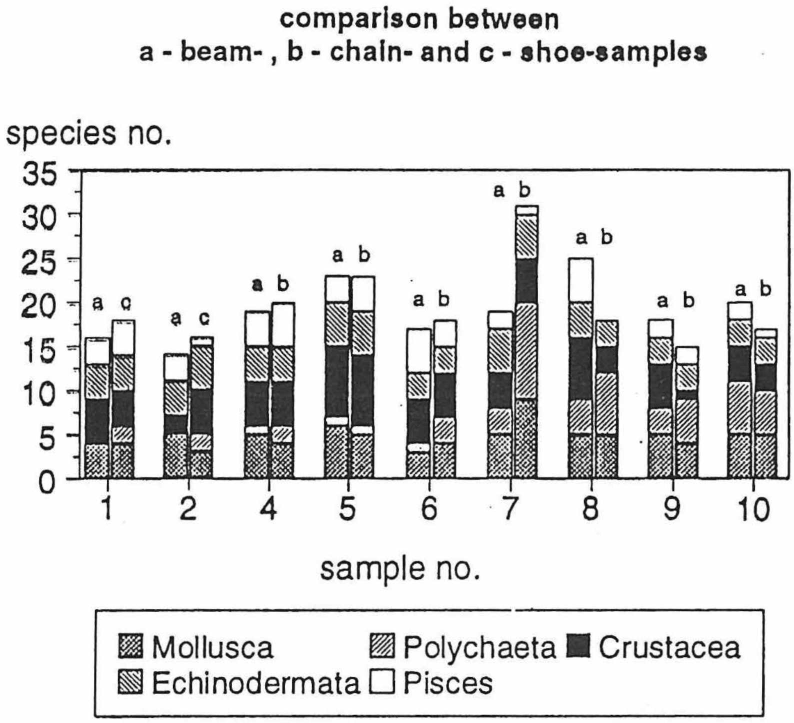
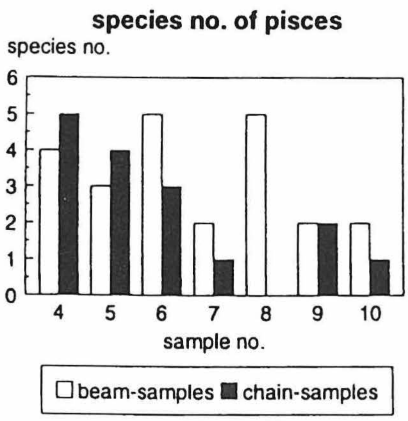


Fig. 5. Comparison of species numbers of groups between the different dredges (**a**-beam-, **b**-chain- and **c**-shoe-dredge.



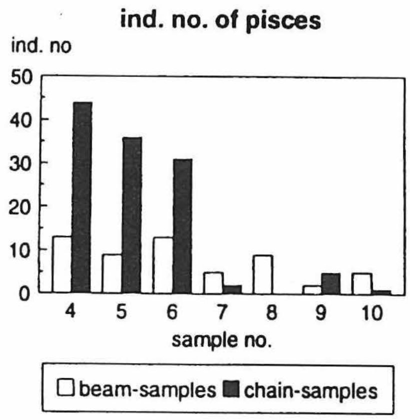


Fig. 6. Number of fish-species and abundance in the dredge samples.

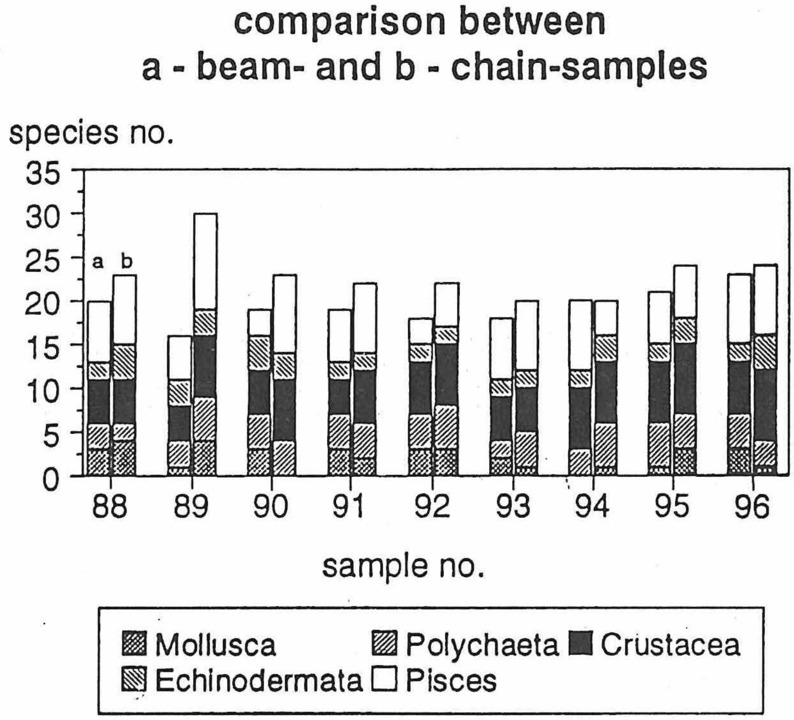


Fig. 7. Comparison of species numbers of taxonomic groups in **a**-beam- and **b**-chain samples.

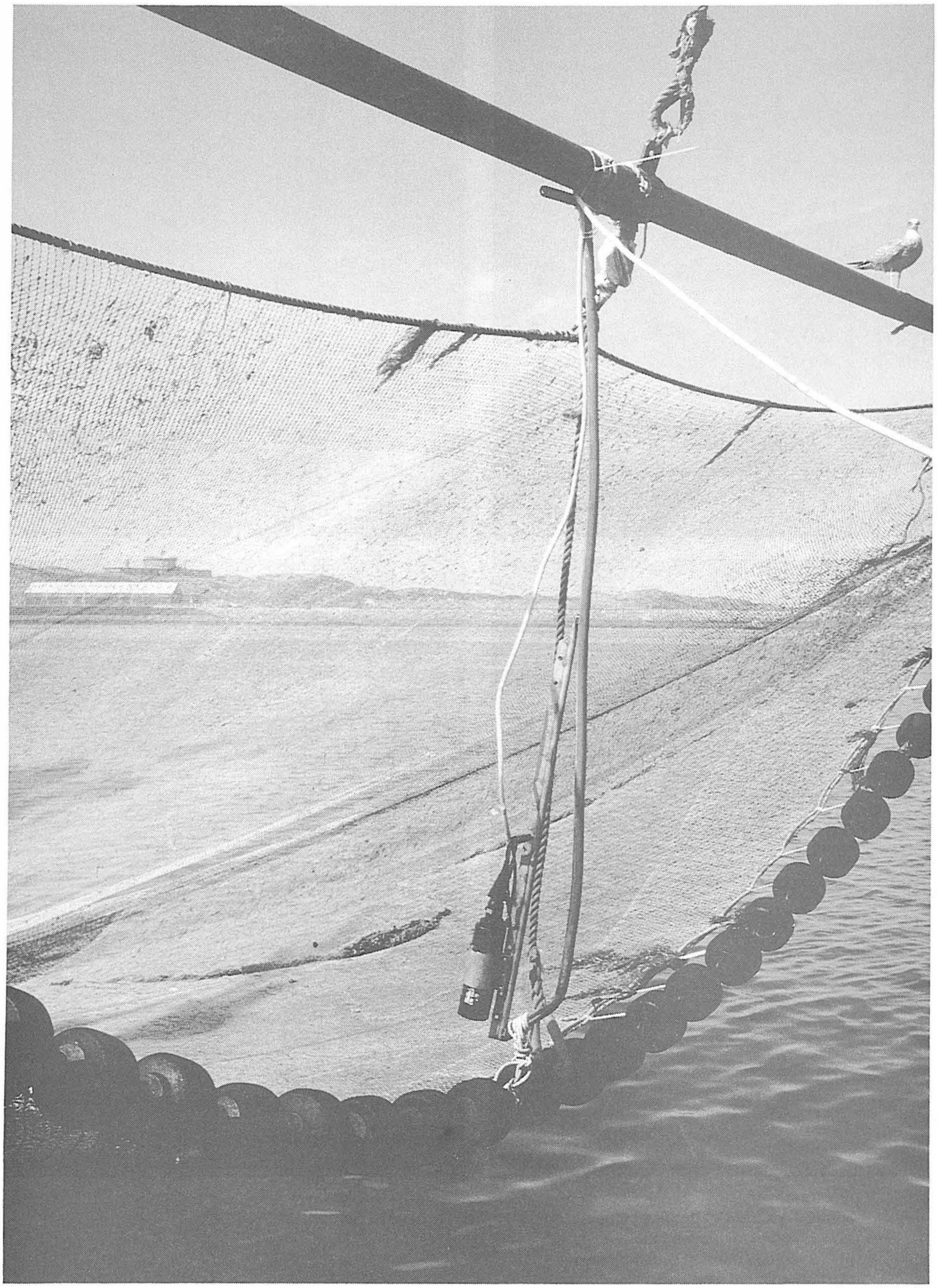


Fig. 8. Position of video-camera on mono-sled in the opening of 10 m shrimp trawl.

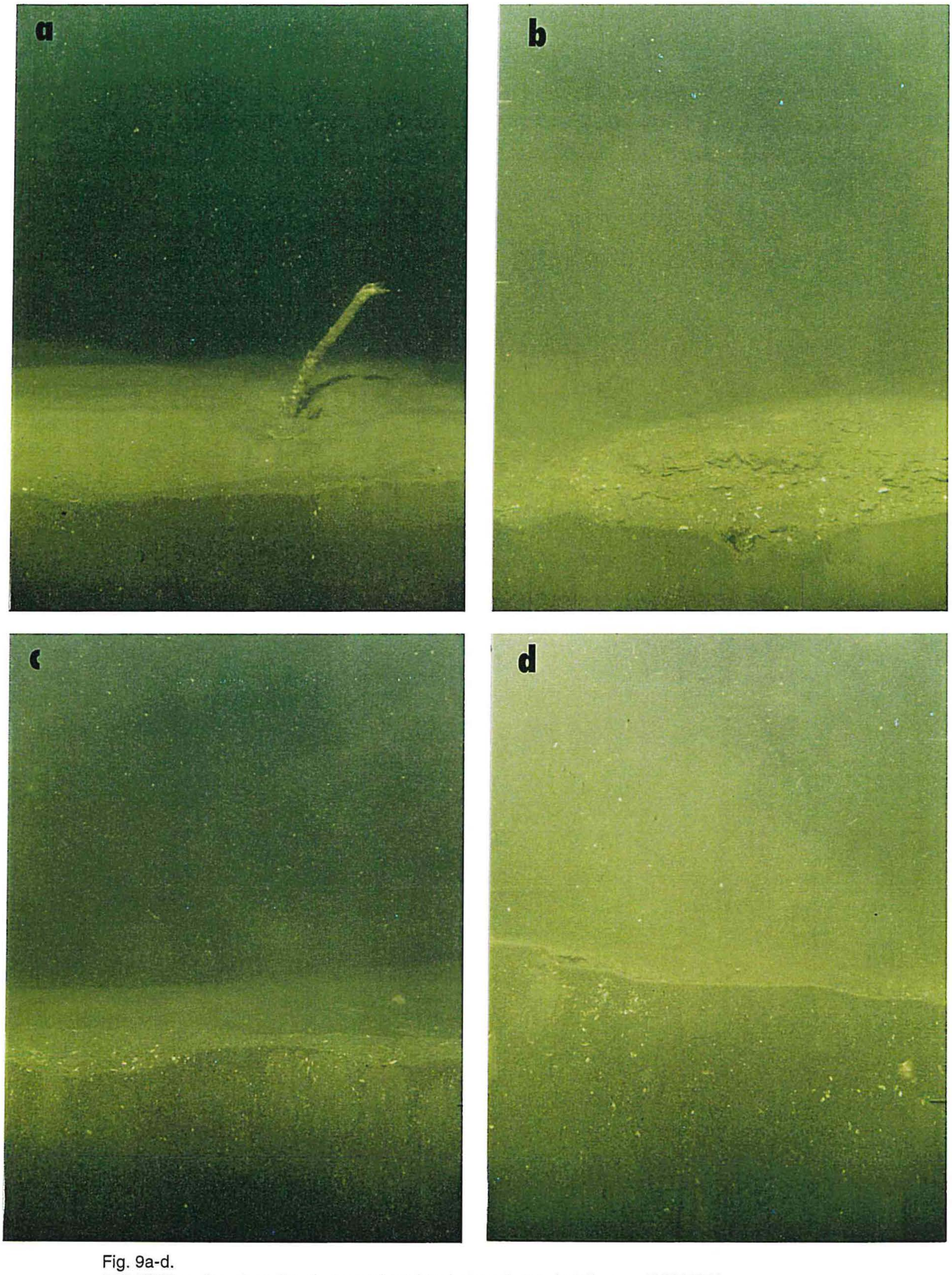


Fig. 9a-d.
REMOTS sediment profile photographs taken in heavily trawled German IMPACT box.
a) ripped off Lanice tube
b) eroded internal sediment layers
c) sediment inhomogenities
d) sediment inhomogenities

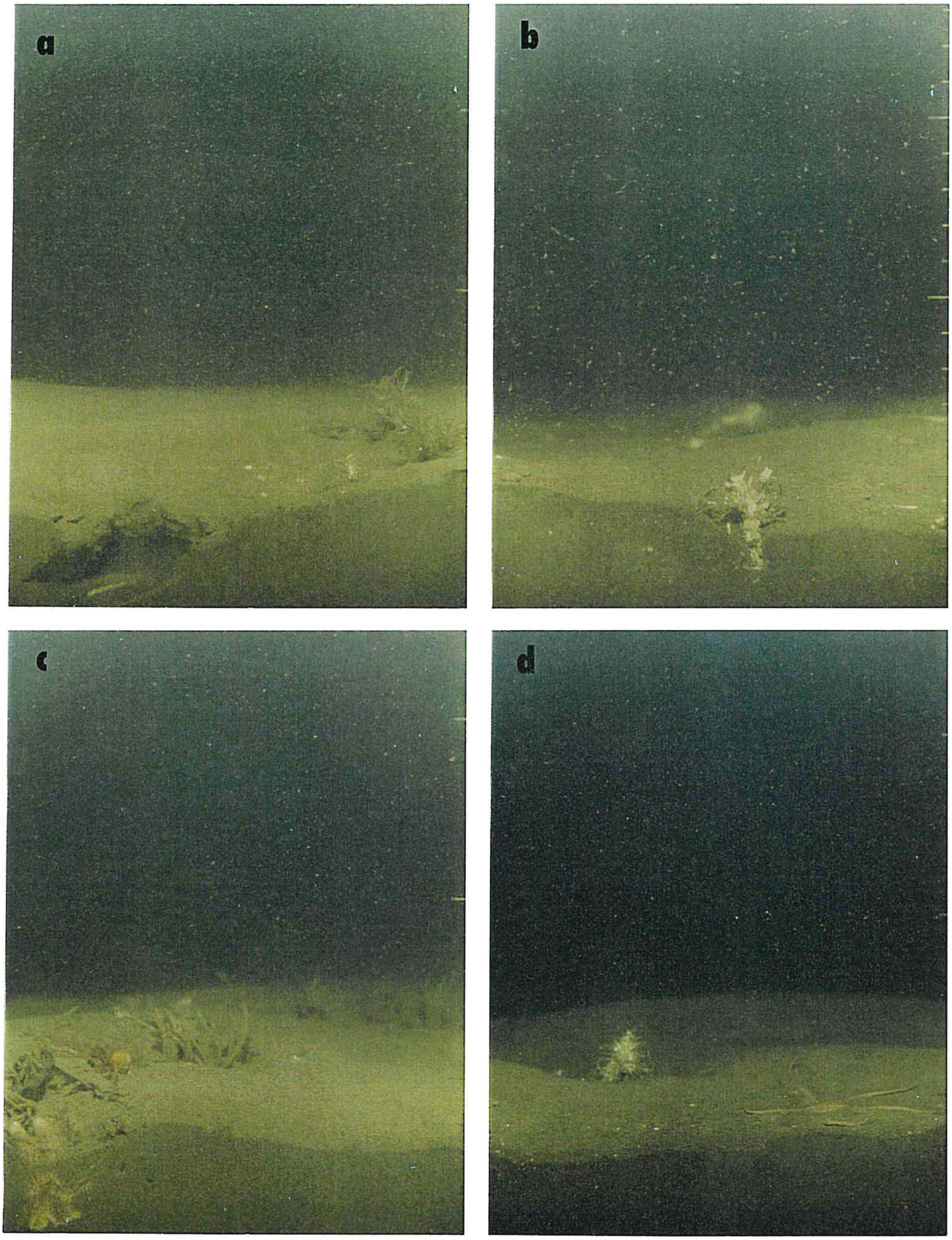


Fig. 10a-d.
REMOTS sediment profile photographs taken in a relatively undisturbed control area 10 nm SE

a) Lanice tube with worm and Aphrodite burrowed in sediment
b) section close to Lanic tube
c) Phoronis (?) tubes, Asterias position is an artefact
d) Ophiura albida and Lanice

A PRELIMINARY ASSESSMENT OF THE IMMEDIATE EFFECTS OF BEAM TRAWLING ON A BENTHIC COMMUNITY IN THE IRISH SEA

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ABSTRACT

After an experimental box had been fished 10 times with a 4-m commercial beam trawl, the density of sessile animals such as soft corals and hydroids decreased by ca. 50%. The density of more mobile animals, such as fishes, crabs and praws remained constant or increased. Assessment of the survival of animals caught in the codend indicated large variation between species. Echinoderms with flexible tests, e.g. common starfish, showed low mortality, whereas those with brittle tests, e.g. sea urchins, were readily damaged leading to high mortality. Mortality in fish was related to the amount epidermal armour such as scales, spines, boney plates and slime. Dragonets. suffered 68-97% mortality whereas between 34 and 38% of plaice and cuckoo rays died respectively. Those animals which have predatory/scavenging feeding behaviour, and are able to survive the trauma of being caught in the codend and handled on deck (e.g. common starfish), may increase in abundance as a result of fishing activities.

INTRODUCTION

Beam trawls are used extensively in the North and Irish Sea and are extremely effective for catching flatfish (e.g. CREUTZBERG *et al.*, 1987). The increase in the size and engine power of modern trawlers has required modifications to the gear which increase its weight, e.g. longer beams and the addition of more chain mat or more tickler chains. Typically, a Dutch 12-m beam trawl weighs 7 to 8 t of which 1 t is made up of 19 tickler chains (BEON, 1991). These chains are designed to penetrate the sediment and disturb sole, *Solea solea,* that remain buried by day. The total depth to which these chains penetrate depends on both the vessel towing speed and substrate hardness, estimates varying from 3 cm on hard sand to 8 cm in soft mud (BRIDGER, 1972; BEON, 1991). However, while tickler chains increase catches of commercial flatfish they also increase the by-catch of non-commercial fish, epi- and infaunal invertebrates. Fragile animals such as sea urchins and some bivalve molluscs tend to be damaged and killed by trawling activity (BERGMAN & HUP, 1992; RUMOHR & KROST, 1992). Conversely, other animals, such as starfish, survive in high numbers (BEON, 1991; present study) and may even benefit by scavenging the dead animals produced after the passage of the trawl. These effects, coupled with the intensity of the beam trawling effort in the North Sea, have led to suggestions that the latter is a possible cause of the long-term changes observed in the North Sea benthic community (PEARSON *et al.*, 1985; LINDEBOOM, 1990).

To date, most research has concentrated on large (6 to 12-m) beam trawls; no information exists on the effect of 4-m beam trawls on the benthic community. When fished over rough ground, as in the Irish Sea, 4-m beam trawls tend to be fitted with chain mat, i.e. tickler chains linked longitudinally to form a chain mat. This mat is designed to prevent rocks entering the net as well as to catch more flatfish. The Directorate of Fisheries Research, Conwy is investigating the short and long-term effects of this gear on a benthic community in the Irish Sea. A site in the Irish Sea was selected because it is representative of an area which is fished relatively infrequently (MCCANDLESS, 1992), characterised by the presence of an epifaunal filter-feeding community (dominated by soft corals and hydroids). This area presents opportunities for long-term research on the ecosystem effects of fishing unavailable in the North Sea through intense fishing pressure.

In March 1992 a preliminary investigation of an area between Point Lynas, Anglesey, and Great Ormes' Head, North Wales, was carried out to locate a suitable site for a short-term and long-term study of the effects of beam trawling on a benthic community. A suitable site with a conspicuous filter-feeding community, was found at approximately 4° 00' W, 53° 27' N. The presence of this community, which comprised long-lived species such as the soft coral, *Alcyonium digitatum* (dead man's fingers), indicated that trawling activity in the area is relatively infrequent.

In August 1992 we returned to this site to carry out experimental fishing with a commercial 4-m beam trawl fitted with chain mat to examine the following effects:

1. The immediate effects on the benthic community.
2. The survival capabilities of animals caught in the cod-end.

Objective 1 will be discussed in terms of the epibenthic data as the infaunal samples are currently being processed.

EFFECTS ON EPIBENTHOS

METHODS

An experimental box 40 m x 200 m, was marked on the ship's navigation plotter which was linked to a Sercel NR53 DGPS positioning system (accurate to ±2.5 m). Water depth varied between 32 and 34 m. All samples were taken from within this area. Prior to fishing with the commercial beam trawl, three 10 min tows (ship speed approximately 1 kt) were made through the box with a 2-m young flatfish beam trawl (ROGERS & LOCKWOOD, 1989). The position at the start and end of each tow was recorded. The number of individuals and wet weight (±1 g) of each species was recorded from each catch. Catch data was standardised by expressing values as density (numbers/1000 m^2) or biomass (g/1000 m^2). Following this preliminary sampling, the box was fished 10 times with the 4-m beam trawl. This was followed by another three tows with the 2-m beam trawl and the catch quantified as before. Many of the animals occurred too infrequently to determine whether numbers had changed after fishing (e.g. the starfish *Astropecten irregularis*). Therefore, animals were grouped according to their mobility (Table I) on the assumption that mobile animals would recolonise or scavenge on animals killed or exposed by the beam trawl.

RESULTS

The dominant macrofauna (expressed as numbers and biomass per 1000 m^2) in the community were *Alcyonium digitatum,* hydroids, echinoderms (*Psammechinus miliaris* (sea urchin), *Ophiura ophiura* (brittlestar), *Asterias rubens* (common starfish), *Ophiothrix fragilis* (brittlestar)) and crustaceans (*Macropodia tenuirostris* (spider crab), *Eupagurus bernhardus* (common hermit crab), *Pisa armata* (hairy spider crab)). These were also the most abundant animals (Fig. 1). In general the numbers and biomass per 1000 m^2 of animals in the community altered significantly after fishing with the commercial trawl (Table I, Wilcoxon matched-pairs signed-ranks test, numbers per 1000 m^2 $n=8$, $P<0.03$, biomass per 1000 m^2 $n=10$, $P<0.006$). The density and biomass of many of the sessile or slow moving animals (molluscs, echinoderms, anthozoans) was much lower after experimental trawling (Table I). However, the density of mobile invertebrates such as *Eupagurus bernhardus, Liocarcinus holsatus* (swimming crab), *Palaemon* spp. (prawn) and fish increased after trawling (Table I). After fishing with the commercial beam trawl the community structure had changed sufficiently to be differentiated by both cluster analysis and multidimensional scaling (Fig. 2). Moreover, MDS revealed that the variation between samples taken after fishing was much lower than samples otained before fishing, which suggests that beam trawling reduces spatial variation within the community in the trawled area.

ASSESSMENT OF SURVIVAL

METHODS

In March and August 1992 and April 1993, a 4-m beam trawl was towed for 30 min (n=3) on each occasion. After each haul, a sub-sample of the catch from the cod-end was placed immediately into a 50 l bin filled with sea water and then transferred to a survival system. The survival system consisted of six 4.0 x 0.5 x 0.3 m tanks, attached to a steel frame which was locked to the deck of the ship using twist locks. Each tank was fitted with three evenly spaced, removable partitions drilled with twenty 1 cm diameter holes which allowed free circulation of water. The entire system was enclosed with a tarpaulin cover to eliminate light which may have increased animal's stress. The species selected for examination were maintained in separate compartments with sea water flowing to waste. An assessment was made of the initial mortality of each species collected in the subsample. Only live animals were placed in the survival system. Their mortality was recorded at intervals of 24 h for up to 120 h, although the procedure varied from year to year depending on circumstances.

RESULTS

Echinoderms were, generally, highly resilient. The initial and delayed mortality (0 to 1%) of *Asterias rubens* and *Astropecten irregularis* was lower than other animals (Table II). *Ophiura ophiura* suffered low initial mortality, which increased to 14-19% after 120 h. Delayed mortality occurred in those animals which had badly damaged or crushed oral discs, which disintegrated with time. Amongst echinoderms, *Psammechinus miliaris* had the highest initial mortality (20%) and the greatest final mortality (51%). *Eupagurus bernhardus* showed low overall mortality (6%), the animals that died tended to be those which had abandoned their shells and had been crushed in the codend. However, *Eupagurus prideauxi* (hermit crab) suffered slightly higher mortality (<14%). Despite their fragile appearance, *Macropodia tenuirostris* suffered relatively low total mortality (32%) after 72 h. In March 1992, swimming crabs suffered 45% initial mortality, which only increased to 58% after 72 h. In April 1993 however, overall mortality was much lower (<15%). Although *Callionymus* spp. (dragonet) had an initial mortality of 6-12% final mortality increased to between 68 and 97%. *Pleuronectes platessa* (plaice) and *Raja naevus* (cuckoo ray) showed delayed mortality increasing from an initial 6 and 0% to 38 and 34% final mortality respectively. Although mortality of *Alcyonium digitatum*, was impossible to determine by casual inspection, it was apparent that polyps emerged with their tentacles extended within 24 h and retracted when exposed to light.

DISCUSSION

These results show that fishing with the 4-m beam trawl lowered the density and biomass of the sessile animals in the experimental box. In particular, the biomass of *A. digitatum* and hydroids was reduced by approximately 50% after trawling (Table I). How quickly these animals are likely to recolonize the area is unknown but the period could span months to years where natural recruitment is concerned. The density of some mobile species increased after trawling (Table I). Most of these species are scavengers or predators (e.g. *E. bernhardus*, *Callionymus* spp. and *Palaemon* spp.) and move rapidly (1-3 h) in response to chemical stimuli (NICKELL & MOORE, 1992) produced by damaged or killed animals which result from beam trawling activity. Other scavengers, such as *B. undatum* and *A. rubens*, may respond more slowly, arriving after 12 h (SAINTE-MARIE & HARGRAVE, 1987; NICKELL & MOORE, 1992). Other results also showed that dogfish, whiting and gurnards take advantage of this extra food source (KAISER & SPENCER, 1993), as do dabs, *Limanda limanda*, in the North Sea (M. FONDS, personal communication).

Animals that form the by-catch of a beam trawl can suffer injuries from a variety of sources. The beam shoes, chain mat and abrasion from the net can inflict wounds and injuries of different degrees of severity. On hauling the net, pressure from the weight of catch can inflict bruises and internal injuries which may lead to delayed mortality. Some animals survive this experience better than others (Table II). As in other studies

(BEON, 1990, 1991) echinoderms, in particular asteroids, showed a high percentage survival which is not surprising considering their ability to regenerate limbs (BARNES, 1980). The susceptibility to damage seems to be related to the flexibility of the test. Sea urchins have brittle tests, which are easily smashed and expose them to predation. Ophiuroids have flexible plates, which are more susceptible to damage than the more flexible test of asteroids. Although swimming crabs, *L. holsatus*, are able to regenerate limbs, they are killed when their carapaces are crushed. In another study (KAISER & ROGERS, unpublished data) tickler chains were identified as the part of the beam trawl that was mainly responsible for crushed carapaces. *Callionymus* spp. suffered high delayed mortality, which was contrary to our expectations as superficially they appeared undamaged. It is probable that a combination of stress and internal injuries contributed to their high mortality. More than 60% of *Pleuronectes platessa* and *Raja naevus*, were still alive after 120 h. This is probably attributable to their thick, armoured slimy skin. Those specimens which died showed signs of either severe (>30%) scale loss (*P. platessa*) and/or bruising (*R. naevus*).

Our results demonstrate that a 4-m commercial beam trawl fitted with chain mat reduces the biomass and density of, in particular, sessile invertebrates. However mobile animals quickly migrate into the trawl track and feed on some of the damaged and dead species. Not all the animals caught in the beam trawl are killed. The abundance of animals which are able to survive the fishing process and normally feed opportunistically, may increase in the long-term as a result of fishing activity. Thus beam trawling, as well as other forms of fishing that generate discards, could favour predatory populations such that these become abnormally elevated e.g. FURNESS (1982).

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TABLE I

The change in density (numbers/1000 m^2) and biomass (g/1000 m^2) (mean of 3 samples) of selected dominant species sampled with a 2-m juvenile flatfish beam trawl before and after experimental fishing with a 4-m beam trawl. Mobility of animals is indicated by (S) sessile/slow moving or (M) highly mobile.

Species	**Density**		**Biomass**		**Mobility**
	Before	**After**	**Before**	**After**	
Alcyonium digitatum	-	-	9570	4620	S
Bryozoan/hydroids	-	-	1055	670	S
Psammechinus miliaris	115	27	927	89	S
Asterias rubens	43	20	859	247	S
Ophiura ophiura	64	25	402	46	S
Macropodia tenuirostris	128	47	67	12	S
Palaemon spp.	17	27	2	3	M
Eupagurus bernhardus	34	47	313	513	M
Callionymus spp.	7	16	161	181	M
Pomatoschistus spp.	23	23	10	6	M

Table II Results of survival experiments carried out between March 1992 and April 1993. The cumulative % mortality for each species in 24 hourly intervals.

Species	Date	Nos.	CUMULATIVE % MORTALITY 0	24	48	72	96	120	Notes
Aphrodite aculeata	Mar. 92	46	0	5	7				No apparent reason for initial mortality.
	Apr. 93	65	0		3.1	3.1	3.1	6.2	Some intraspecific predation later.
Ophiura ophiura	Mar. 92	26	0	0	19				Mortality occurred in those individuals
	Apr. 93	34	5.9		5.9	11.7	11.7	14.7	with >50% damage to oral disc.
Astropecten irregularis	Mar. 92	17	0	0	0				No mortality, strong test, damage confined to arms.
Asterias rubens	Mar. 92	126	1	1	1				Mortality only occurred when whole animal crushed.
Psammechinus miliaris	Mar. 92	91	20	37	51				Delayed mortality indicated by loss of spines.
Eupagurus bemhardus	Mar. 92	39	6	6	6				Crabs well protected in shell.
	Apr. 93	15	0		0	0	0	0	
Eupagurus prideauxi	Apr. 93	29	13.7		13.7	13.7	13.7	13.7	Crabs not so well protected, only carrying piece of shell with attached anemone. Dead crabs severed at abdomen.
Macropodia tenuirostris	Aug. 92	22	8	22	25	25			Crabs fold delicate legs under body and avoid damage.
Liocarcinus depurator	Mar. 92	45	29	29	40				Mortality tends to occur as a result of
	Apr. 93	34	8.8		12.9	12.9	12.9	14.7	intraspecific predation when individuals moult.
Eledone cirrhosa	Apr. 93	15	0		0	0	0	13.3	Nine animals escaped from the tanks. Two dead animals at the end of the experiment.
Plueronectes platessa	Apr. 93	50	4		18	24	30	38	Dead animals tended to have >30% scale loss and bruising.
Agonus cataphractus	Apr. 93	13	7.6		25	25	25	25	No obvious reason for death.
Callionymus spp.	Aug. 92	65	12	71	89	97			Some fish showed signs of bruising. Mostly reason not obvious.
	Apr. 93	50	6		24	46	68		
Raja naevus	Apr. 93	32	0		0	12.5	34		Dead fish showed signs of bruising.
Alcyonium digitatum	Apr. 93	50	0		0	0	0	0	After 24 h the colonies appeared to have taken up water. All colonies had feeding polyps throughout the experiment.

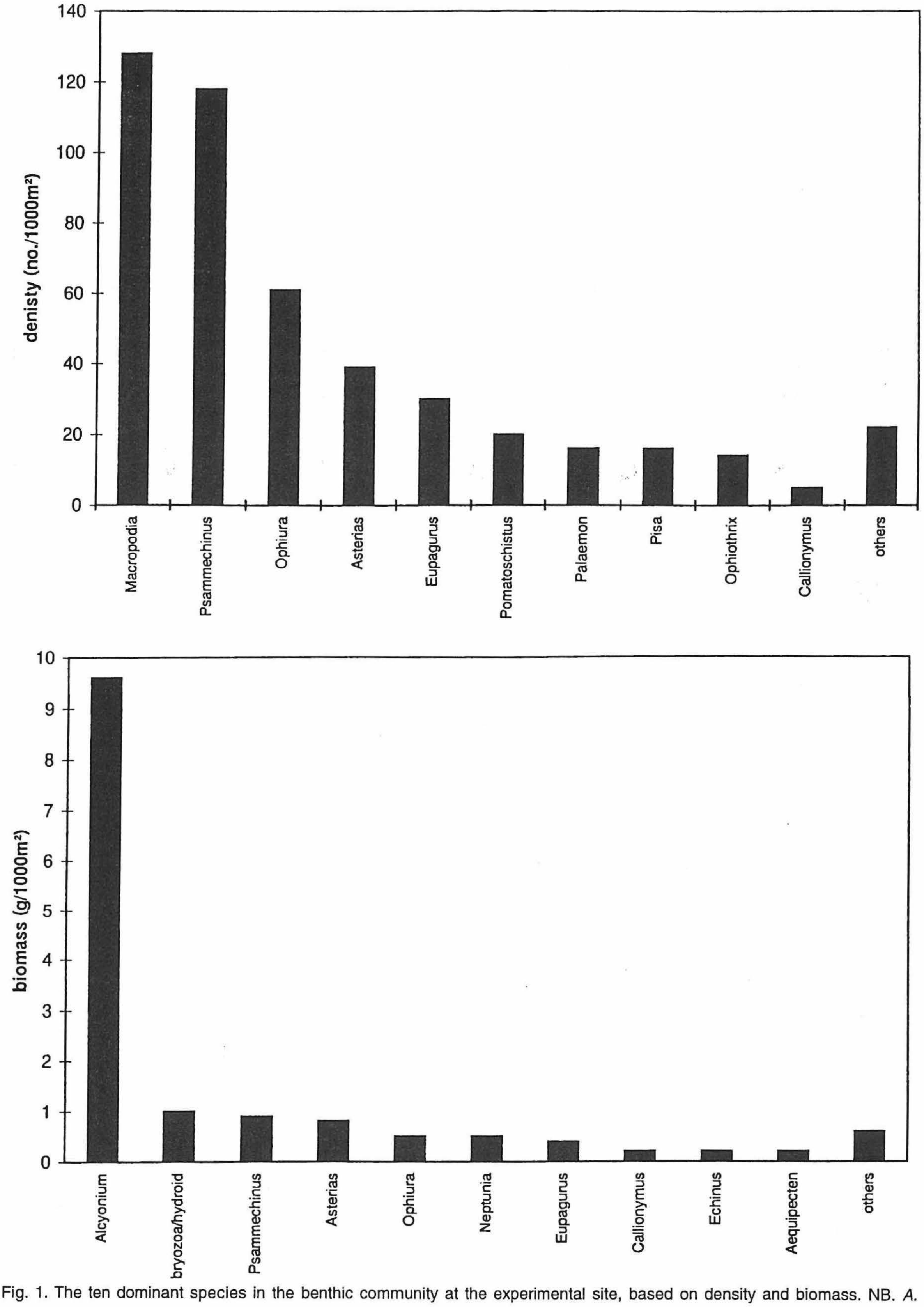

Fig. 1. The ten dominant species in the benthic community at the experimental site, based on density and biomass. NB. *A. digitatum* and bryozoans/hydroids have been omitted from the density analysis because of the difficulty of quantifying individuals or colonies.

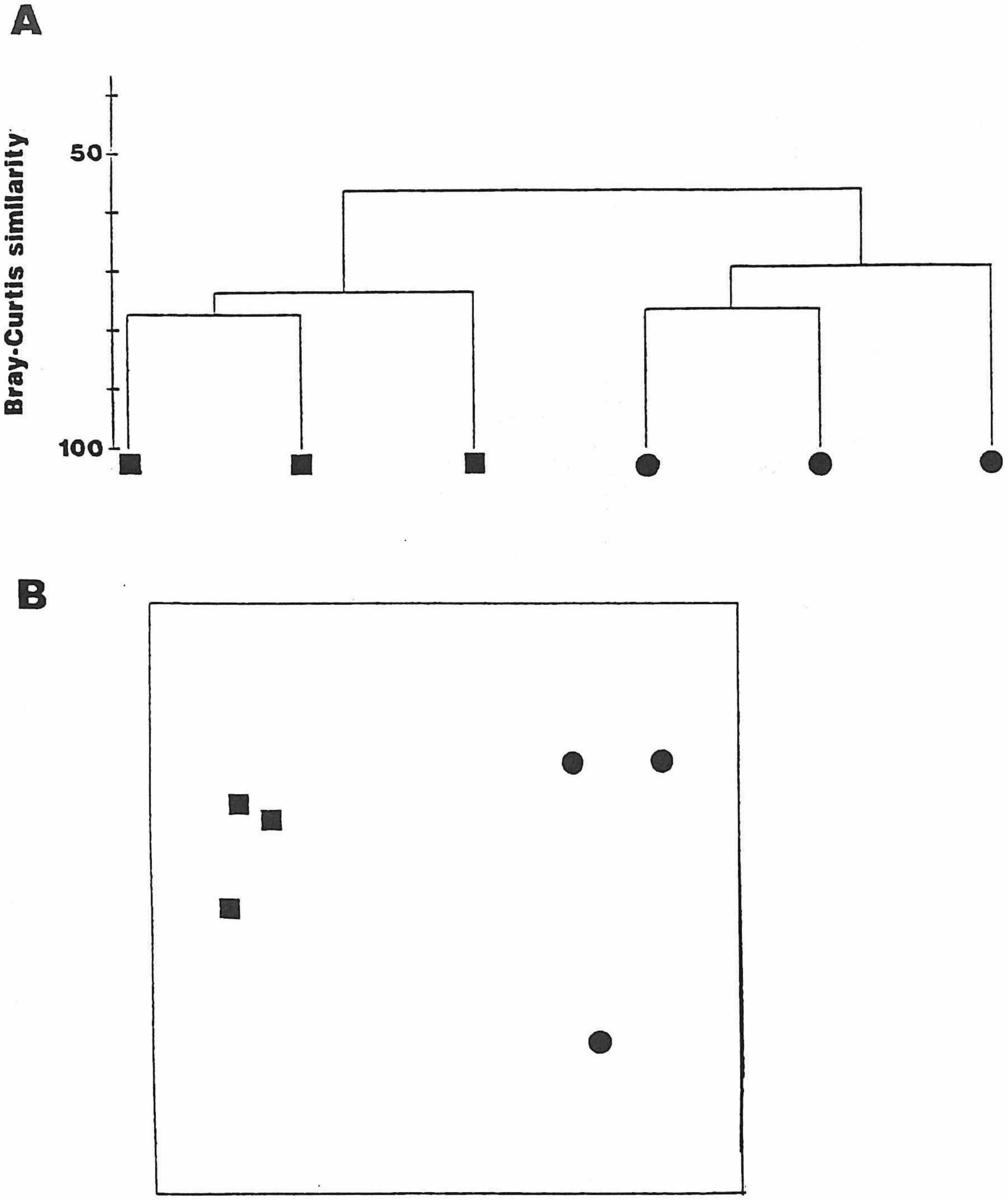

Figure 2. A comparison of the community sampled from the experimental box using a 2-m beam trawl as shown by A) a dendrogram derived from cluster analysis and B) the first two axes of multidimensional scaling, before (●) and after (■) fishing 10 times with a 4-m commercial beam trawl.

CATCH COMPOSITION OF 12-M BEAM TRAWL AND 4-M BEAM TRAWL FOR SOLE FISHING

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SUMMARY

The catch composition of commercial beam trawls used for sole fishing has been investigated. Catches of 12-m beam trawls used in offshore areas and catches with 4-m beam trawls used in the coastal areas have been analysed and the catch efficiency of the different trawls are compared.
Changes in the catch composition during repeated trawling over the same transect have been analysed.
The production of dead discard materials, invertebrates and fish, by commercial beam trawling, has been estimated per hectare (ha) and per kg marketable sole. The total annual production of discards in the southern North Sea was estimated as 270 000 tonnes dead discard fish plus 120 000 tonnes dead invertebrates.
The effect of sole beam trawl fishing on the benthic ecosystem, and the importance of discards as food for scavengers, is discussed.

1. INTRODUCTION

In the FAR research project IMPACT-I the effect of beam trawling on bottom fauna has been investigated using two gears: a12-m beam trawl in offshore waters and a 4-m beam trawl in the coastal areas. Large trawlers (in the Dutch fleet about 220 ships with 1500-3000 KW) use 12-m beam trawls with 10 tickler chains, trawling at a speed of approximately 6-7 nm/h (11-13 kmn/h). They are prohibited from fishing within 12 miles of the coast and also, most of the time, not in the protected "plaice box", an area bordering the Wadden Sea where young plaice and sole are abundant. Smaller beam trawlers, with less than 300 KW engines (about 110 ships in the Dutch fleet) are allowed to fish with 4m-beam trawls (usually with 8 tickler chains) in the coastal areas and also the whole year round in the "plaice box". They trawl at a speed of about 4-5 nm/h (7-9 km/h). For a general description of bottom trawls and the numbers of trawlers involved in different kinds of trawl fishery, see POLET, BLOM & THIELE (this report).

To investigate the effect of beam trawling on bottom fauna several trawling surveys have been carried out: two surveys with TRIDENS fishing with 12-meter beam trawls in the offshore areas north of the Wadden islands and two surveys with ISIS fishing with 4-meter beam trawls in the coastal areas. An important aspect in the surveys was the catch composition, the numbers and size of fish and invertebrates caught by commercial beam trawls. Catches were analysed in order to find out :

- What size of animals are retained by the nets and how many pass through the 4 x 4 cm meshes in the cod-end (measured: 7.5-8.5 cm stretched.)
- How many undersized fish and invertebrates are destroyed per surface area trawled or for each kg of marketable sole landed by beam tawlers. The survival chances of fish and invertebrates discarded after sorting of commercial catches, and the damage to animals that pass through the meshes during trawling, have been investigated and the results are described in another chapter (FONDS, this report).
- What proportion of the populations of benthic fish and invertebrates are caught in commercial beam trawling. This question is answered in more detail in the chapters on "direct effects on the bottom fauna" by BERGMAN & VAN SANTBRINK (this report).

2. METHODS

2.1. STUDY SITES

An outline of the general structure of the beam trawl nets used in 1993 is shown in Fig. 1 (W. BLOM, R.I.V.O.).

Trawling with 12-m beam trawls (12mBT) was carried out in March-April 1992 and in September 1993 with the 73 m R.V. TRIDENS in the offshore areas north of the Wadden islands (Oyster grounds) at about 35-50 m depth. Trawling with 4-m beam trawls (4mBT) was carried out in June 1992 and in April 1993 with the 28 m R.V. ISIS in the coastal areas north of Vlieland and west of North Holland (Egmond-IJmuiden) at about 15 to 25 m depth. Both ships are from the Directorate of Fisheries of the Ministry of Agriculture, Nature management and Fisheries, The Hague. The position of the areas is summarized below.

Net	Ship	Period	Year	Area	
				North	East
12-m BT	TRIDENS	24 Mrch-2 Apr.	1992	52° 40-52° 50	3° 25-4° 40
		6-16 Sept.	1993	52° 20-52° 42	4° 10-4° 23
			German IMPACT box:	54° 14-54° 15	6° 51-6° 52
			survival experiments:	54° 15-55° 00	4° 44-5° 07
4-m BT	ISIS	24 June-2July	1992	52° 32-53° 25	4° 32-5° 03
		19-29 April	1993	52° 35-52° 40	4° 25-4° 32

2.2. MEASUREMENTS AND ANALYSIS OF CATCH COMPOSITION

Beam trawl catches were sorted on a sorting belt and the total amount was estimated in numbers of baskets (1 basket = 31-35 kg). A subsample of 1 or 2 unsorted baskets was taken to estimate the total numbers of common fish and invertebrates, rare animals were counted in the whole catch.

Fish and some invertebrates (starfish) in the subsamples were measured in cm classes to the cm below (first class = 0). TRIDENS has the facility of balances that weigh up to 4 kg, independant of weather conditions. Samples of common species of invertebrates were weighed to estimate the mean weight for each species. Some fish were measured precisely and weighed, to estimate the length-weight relationship of the more common species.

Mean weight and the length-weight relationships estimated on board of TRIDENS have also been used to estimate the weight of animals in the catches with 4-m beam trawls on board ISIS.

2.3. ESCAPE

In order to estimate the proportion of fish and invertebrates that escape through the meshes during trawling, short hauls were made with the cod-end of one or both nets covered with a fine-meshed covering net (1 x 1 cm meshes). Animals passing through the 8 cm meshes in the cod-end were collected in the cod-end cover. Catches from the large net and the covering net were compared.

Catches with the commercial nets were also compared with catches from short hauls with a fine-meshed 3-m beam trawl or a fine-meshed 1-m wide epibenthos dredge. Both the fine-meshed net and the dredge were provided with a measuring wheel that recorded precisely the distance trawled over the bottom. In one series (ISIS 1992) the 4-m beam trawl with a cod-end cover and the epibenthos dredge were operated simultaneously and the catches compared.

2.4. REPEATED TRAWLING OVER THE SAME TRANSECT

Repeated trawling over the same transect was carried out in all four surveys, using DGPS navigation and a Macintosh MacSea plotter. Since the beam trawls are on both sides of the ship the area between the nets is not trawled. Trawl tracks of TRIDENS (12-m BT) and ISIS (4-m BT) were side-scanned by the R.V.MITRA (North Sea Directorate, Ministry of Public Works and Transport). According to these side-scan observations the distance between the two nets was approximately 18 m for TRIDENS fishing with 12-m beam trawls and 8 m for ISIS fishing with 4-m beam trawls. In repeated tows over the same line on the plotter, the position of the ship was shifted parallel to the line over a distance of about 10-20 m (TRIDENS) and 4-6 m (ISIS), in order to cover also the middle area between the nets.

In 1992 TRIDENS trawled along a transect of 1000 m length 8 times, fishing into the current one way and (after the net had been hauled) trawling back again with the current over the same line. In the second survey with TRIDENS (1993) a transect of one mile was trawled similarly ten times, but catches of haul 1+2, 3+4, etc. were combined in the analysis of catch composition.

In 1992 ISIS trawled a transect of 1000 m long 12 times. At the end of the transect the nets were lifted from the bottom and the ship was turned around to get into the right position and speed for trawling back over the same line on the plotter. The net was hauled each time after the ship had trawled twice along the line: with the current and against the current. After twelf times trawling (12 x 2 tows), the transect was side-scanned by MITRA and its area estimated as 1050 x 32 m. In 1993 ISIS similarly trawled a transect of 1000 m long ten times, but this time each haul was after three tows over the same plot-line, shifting the position of the ship over 4 m parallel to the plotted line, in order to trawl also the middle area of 8 m between the nets in such a way that the transect had been trawled for100% at each haul. It was assumed that the width of the transect trawled after three tows would be 3 x 2 x 4 = 24 m. After eight times trawling (8 x 3 tows) the transect was side-scanned by MITRA and its surface estimated at 1100 x 32 m.

It appeared in both cases that the actual width of the repeatedly trawled transect was one beam width more than expected on both sides, indicating that DGPS navigation with a MacSea plotter was fairly accurate and reliable. Unfortunately, due to rough weather conditions, the transects trawled by TRIDENS in 1992 and 1993 were not been side-scanned by MITRA. Judging from the confirmed accuracy of DGPS navigation with ISIS, the width of the transects trawled by TRIDENS may similarly have been at least one beam width more than expected on both sides: 12 + 18 + 12 + (2 * 12) = 64 m. However, considering the greater depth and the rough wheather conditions, it is more likely that the width of these transects was about six times the beam width: 6 * 12 m = 72 m. The latter value has been used to estimate the total surface of the transects trawled.

3. RESULTS

3.1. WEIGHT OF FISH AND INVERTEBRATES

Measurements of mean weight of different invertebrate species are presented in Table 1, the length to weight relationships of fish measured and weighed on board of TRIDENS are presented in Table 2.

Based on these length weight relationships and some additional data on length and weight of the same fish species collected in the North Sea and measured directly after catch in the NIOZ laboratory (Texel), the following length (L, cm) - weight (W, g) relationships were used to estimate the weight of the most common fish in the catches :

Plaice, flounder and dab:	W = 0.010 * L exp. 3.0
Sole :	W = 0.008 * L exp. 3.0
Turbot :	W = 0.020 * L exp. 3.0
Whiting and gurnards:	W = 0.007 * L exp. 3.0

Numbers and weights of different fish species and invertebrates have been estimated in catches after commercial hauls of 0.5 to 2 hours, carried out during the surveys with 12-m beam trawls offshore (Table 3) and 4-m beam trawls in the coastal areas (Table 4).

Mortality and survival chances of discarded fish and invertebrates have been estimated and the results are presented in another chapter (FONDS, this report). The total amounts of dead fish and dead invertebrates produced or discarded by beam trawling were estimated per ha (10000 m^2) trawled area as well as per kg marketable sole, and the results are presented in Table 5. In general, beam trawl fishery for sole with 12-m beam trawls in offshore areas produced less dead fish and invertebrates (about 3-4 kg fish + 3 kg invertebrates per ha) as compared to 4-m beam trawl fishery in coastal areas (8-10 kg fish + 14-15 kg invertebrates per ha). When expressed as per kg marketable sole, the differences were less promnounced and the amount of discarded dead invertebrates per kg sole became much lower for the 4-m beam trawls. Numbers or weight of discards per kg marketable sole depends on the catch of soles: when catches of sole were low the amount of discard per kg sole became high. In Table 5 different values are presented estimated in 1992 and 1993. The bycatch of roundfish in the surveys was rather low (0.1-0.4 kg per ha), but depends also on the occurrence or absence of a good stock of young whiting or gurnard: the bycatch in roundfish may be higher in other years.

3.2. ESCAPE

The length distributions of dab, plaice, sole, and some echinoderms in beam trawl catches are summarized in the Figs 2-5.

The length frequencies of some common roundfish are summarized in Table 6, the length frequencies of some common small fish species that pass through the meshes are presented in Table 7. In most species two or three peaks can be distinguished in the length distribution, probably representing different age groups. The youngest age class of plaice and sole (I-group) were only caught with fine-meshed nets in the coastal areas, while young dabs (O-group and I-group) were also found offshore.

Small fish species such as solenette, scaldfish, lesser weever and hooknose (Table 7) were only rarely observed in the commercial trawls, although they were often abundant in the investigated areas (see Table 11).

The percentages fish of different sizes escaping through the meshes were estimated by comparison of catches from the large net (8 cm meshes) with those from a fine-meshed covering net (2 cm meshes), the results are shown in Table 8 (12-m beam trawl) and Tables 9 and 10 (4-m beam trawl). The covering net in hauls with the 12-m beam trawls contained very few plaice, sole or turbot: small individuals of these species were scarce at 40-50 m on the oystergrounds and most of the undersized fish were retained by the commercial nets. Only dab, whiting and gurnards were found regularly in the covering net (Table 8). In the coastal areas young flatfishes were more abundant, together with many starfish (Table 9). The percentage escape of the most abundant species in relation to size is summarized in Table 10.

The total percentages of different species of fish and invertebrates that escape through the meshes of 12-m and 4-m beam trawls have been estimated and the results are presented in Table 11.

Most of the fish smaller than 10 cm escaped through the meshes. Size selective catch efficiency of the nets increased for fish from 10 to 20 cm length. Above 22-23 cm length most flatfish and also gurnards were retained by the commercial beam trawl nets. Only whiting and sole larger than 25 cm managed to escape: whiting probably because of their slender shape, sole probably because their body is more flexible than in other flatfish.

Table 11 shows that many small fish and invertebrates passed through the meshes: the commercial beam trawl nets caught only a fraction of the total numbers of benthic fauna in the trawled areas, mainly the larger specimens and species.

3.4. REPEATEDLY TRAWLING THE SAME TRANSECT

12-m beam trawls

Repeated trawling over the same transect was made possible by using DGPS navigation and a MacSea plotter. Unfortunately the precise surface of the transects repeatedly trawled by TRIDENS with 12-m beam trawls on the Oystergrounds are not known. The area was possibly about 64-72 m wide, the latter value has been used to calculate a surface of the trawled transect. Table 12 presents the numbers of animals per haul for successive catches on a transect of 1000 m long trawled 8 times on 2 April 1992. Each haul covered about 1000 * 24 m = 2.4 ha, approximately 30% of the presumed total surface of the transect (1000 * 72 m = 7.2 ha). Most species showed exponentially declining numbers in successive hauls. The rate of decrease in numbers in the catches was estimated by the relation between log number per haul (N) and haul number (t) as: $\ln Nt = \ln No + B * t$, where Nt is the numbers of a species in haul t and No is an estimate of the initial catchable numbers before trawling started (t=0). The mean percentage decrease in numbers of different species in successive catches was estimated as: (eexp.B -1) * 100. Values of No and B, with the correlation coefficient r2 for the linear regression of ln N against t, are presented in Table 12, together with values for the percentage decrease in numbers per haul. The total numbers, as the sum of all 8 hauls together, were compared with the numbers caught in the first haul. If all individuals of a species on the path of the trawl are caught in the net, the numbers in the first haul should be about 30% of the total sum, since each haul covered about 30% of the total area of the transect. Lower percentages in the first haul indicated that species were not caught for 100%. Some species live too deep in the bottom *(Echinocardium, Astropecten, Corystes,* Shellfish), while others probably passed through the meshes (swimming crabs, whiting) or managed to avoid the net. Some species possibly emigrated or immigrated into the area of the trawled transect. Immigration was evident for dab, plaice and whiting: between haul number 7 and haul number 8 was a time lapse of 2.5 hours, followed by a marked increase in numbers of these fish in haul 8. The three species did not show a significant decrease in numbers in successive catches, dabs even showed a (non significant) increase. Even though 30% of the fish may have been caught in each haul, others probably immigrated into the trawled area in search for food, with the result that the numbers per catch remained the same.

Two common shellfish species on the Oyster grounds, the quahog *(Arctica islandica)* and the spiny cockle *(Acanthocardia echinata)* showed very low numbers in the first haul (1-3% of the sum), much higher numbers in the second haul (17-21%) and a rather slow decline in numbers in the following hauls. Even after 7 tows over the transect, haul number 8 still contained many quahogs and cockles, indicating that the trawl caught only a small proportion of the population. Both species live in the bottom just below the surface. The cockles are rather small and many may pass through the meshes of commercial nets. The quahogs however, were all large old animals that cannot pass through the meshes. Some of these shellfish were possibly dug out of the bottom by the action of the tickler chains during the first passage of the net, but did not enter the net because the groundrope of the trawl is covered with rubber disks and rope in order to keep out unwanted rubbish such as shellfish. In the following passages of the trawl, shellfish that were already exposed, possibly entered the net because they were thrown up by the tickler chains.

The numbers of animals in successive single tows often showed an alternation of high-low-high- etc. (Table 12). This is probably due to the fact that the trawler fished alternately with the tidal current and back over the transect against the current, trawling more heavily with the current (see FONTEYNE & POLET, this report). Besides, in successive hauls the position of the ship was shifted parallel to the line over a distance of about 10-20 m, in order to trawl also the middle area between the nets. In order to compensate for the effect of the tide and coverage of the transect, data of the hauls were combined in pairs: haul 1+2, 3+4, etc. Each combined haul was approximately 1000 * 24 * 2 = 4.8 ha, about 60% of the total surface of the trawled transect. Numbers of animals in the hauls were expressed per ha (10000 m^2) and presented in Table 13. The total numbers of animals were summed for all hauls and divided by the (presumed) total surface of the trawled transect, in order to estimate the total numbers per ha caught and removed by repeated trawling. Catch efficiency of the net was estimated as: catch in the first haul (n/ha) as percentage of the total numbers per ha (sum, n/ha).

In the 1993 survey trawling over a transect was carried out in a similar way in the same area (Oystergrounds) and the data have been presented in the same way in Table 14. The transect was trawled 10 times, alternating hauls were made into the wind and with the wind on a plotted line SW-NE, in order to keep the ship on the line (see Fig. 6). The trawled transect was sampled with a fine-meshed 3-m beam trawl prior to and after repeated trawling with the 12-m trawls. The total sum of animals (n/ha) caught and removed by repeated trawling is expressed as percentage of the initial density (n/ha) estimated with the fine-meshed trawl. The percentage animals left on the transect after repeated trawling also follows from estimates with the fine-meshed beam trawl immediately after the repeated trawling. The percentage of a species removed by repeated trawling and the percentage left should together add up to about 100% of the initial density. This is rarily the case (starfish, Table 14). For most species the percentage were much lower or higher, indicating that many animals may have been washed away or crushed into small pieces *(Ophiura, Echinocardium)* while others may have emigrated (solenette, scaldfish) or immigrated (dab, plaice, whiting).

In order to get evidence of animals immigrating into a recently trawled area, the trawled transect was trawled twice again the next day, with one tow in the morning and one tow in the evening (Table14). The numbers of dab on the transect had increased considerably the next day, while plaice and starfish had also increased again in numbers.

Samples of fish have been collected for a further analysis of stomach contents in the laboratory.

4-m beam trawls

Trawling over a transect was carried out with 4-m beam trawls in the coastal areas by ISIS, in June 1992 (Table 15) and April 1993 (Table 16). The location and shape of the transect trawled in 1993 is illustrated in Fig. 7. In both years the transect was side-scanned by R.V. MITRA immediately after the repeated trawling, which allowed for a more precise estimate of the total surface of the trawled area. In June 1992 twelf hauls were made over a transect of 1000 m length in the coastal area north of Vlieland, each haul consisting of two tows over a plotted line: alternately with and against the current. In April 1993 eight hauls were made over a transect of 1000 m in the coastal area west of N-Holland, each haul consisting of three tows over a plotted line, shifting the position of the ship over 4 m parallel to the line in each tow, in order to cover also the area of 8 m between the nets. With successive tows the beam trawls were lifted from the bottom at the end of the transect, in order to enable the ship to turn around and move into the proper position for the next tow back over the transect. This may have resulted in some loss of animals that were washed through the meshes when the nets were lifted.

In 1993 the trawled transect was investigated more extensively:

a. prior to and immediately after repeated trawling the transect was sampled with a 3-m fine-meshed beam trawl and with a deep-digging bentos dredge (DDD, see BERGMAN & VAN SANTBRINK, this report).
b. the transect was trawled twice again the next day with one tow in the morning and one tow in the evening, in order to get evidence of animals immigrating into a recently trawled area. A reference transect was trawled similarly only three times, in order to collect immigrating fish for stomach analyses (reference transect in Fig. 7).

Numbers of fish and invertebrates in successive hauls were estimated per ha (10000 m^2) trawled area. For each species the sum of the numbers in all hauls was divided by the total surface (ha) of the trawled transect, to estimate the total numbers caught per ha and removed by the repeated trawling (sum, n/ha). The change in numbers of animals in successive hauls (N, numbers per ha trawled) was estimated by a plot of ln N against the haul number t. Paramaters of the equation and the correlation coefficient r2 for the linear regression of ln N against t are presented in the Table 17, together with the percentage decrease in numbers of animals in successive catches. The catch efficiency of the 4-m beam trawls was estimated in two ways:

1. catch in the first haul (n/ha) as percentage of the total sum per ha.
2. the total catch by repeated trawling (sum, n/ha) as percentage of the initial numbers of animals on the transect, estimated with fine-meshed nets prior to the repeated trawling (initial n/ha).

The percentage of animals left on the repeatedly trawled transect was estimated by sampling with fine-meshed trawls immediately after the repeated trawling had finished.

For both 12-m and 4-m beam trawls the repeated trawling over a transect resulted in the expected decrease in volume of the catches, with different species showing numbers decreasing by about 34-53% in successive hauls. Interpretation of repeated single hauls over a transect is difficult because of the effect of tide and the variable coverage of the area between the nets. When each haul was made after two tows in opposite directions, covering also the area between the nets, the results became less variable and 5-6 repeated hauls appeared to be sufficient to demonstrate the effect on catch composition. Increasing the number of times the area was trawled to 12, as in June 1992 with ISIS, did not not add much more information: 7-8 hauls would have been sufficient in that survey. Trawling three times over a transect for each haul, in the hope to cover 100% of the area of the transect, did not lead to better data: three tows covered only about 74% of the transect.

Catch efficiency (of "catchable" animals) estimated from the first haul as % of the sum of total catch on the transect, was for most species close to the expected percentage of the total surface of the transect covered by one haul. For some species the percentages caught in the first haul were low, particularly species that live in the bottom such as molluscs *(Arctica, Acanthocardia, Mactra)* or the sea urchin *Echinocardium*, indicating that animals living in the bottom are not directly dug out by the nets. The % catch efficiency of some fish species, such as dab, whiting and gurnard, was also sometimes low, which may have been due to the immigration of the fish. Some species showed relatively high proportions in the first haul *(Asteria, Astropecten, Ophiura*, plaice), possibly because they were picked up easily by the trawl and did not escape.

Hauls made on the same transect the next day (Tables 14 and 16) demonstrated that some species rapidly returned into the trawled areas. This was particularly evident for dab, but also for the other flatfishes, whiting, starfish and crabs: by the end of the next day the numbers of many species had increased again to about 50% of the initial numbers at the start of repeated trawling. Stomachs of dabs, plaice and whiting examined on board appeared to be full of pieces of shellfish *(Arctica, Acanthocardia, Donax or Spisula).* The fish were probably attracted by the smell of food and fed on damaged benthos, particularly molluscs. Smaller fish possibly also fed on intestines or gonads from crushed sea urchins *(Echinocardium).* In most cases it was not possible to estimate the amount of *Echinocardium* caught by the trawls, because the sea urchins were all crushed to pieces that passed through the meshes. In the few cases that they were still intact, however, they occurred in large numbers (Table 12). Even though this animal contains very little organic matter, it can still be an important food source because its abundance.

During the trawling survey with 4-m beam trawls in the coastal area off North Holland in April 1993 (Table 16), large numbers of dead or dying razor clams *(Ensis directus)* were caught in the nets. This shellfish normally lives deep into the bottom and cannot be caught by a beam trawl. *Ensis* species have a relatively short life-span and mass mortalities are often observed in Winter or Spring. It appeared that most fish were feeding on the dying razor clams, a scavenging behaviour not related to trawling.

Comparison of the total numbers of animals caught per ha by repeated trawling, with the initial numbers of animals present prior to the trawling (Tables 14, 16 & 17) showed that the trawls caught only a minor proportion of the benthic fauna. Even after 5-8 times trawling only larger animals such as starfish, larger crabs, sea mouse and the larger fish were caught in appreciable numbers (25-75%). Thousands of small invertebrates and fish apparently passed through the meshes or remained undisturbed because they lived deeper in the bottom. The numbers of dying razor clams were less than 1% of the population. More detailed information on the direct effects of beam trawling on bottom fauna is presented in another chapter by BERGMAN & VAN SANTBRINK (this report).

4. DISCUSSION

Beam trawling for sole with 8 cm mesh size nets catches a lot more benthos and undersized fish as compared to beam trawling for plaice with 10 cm meshsize nets (FONDS *et al.*, 1992). However, even sole nets catch only a small fraction of the benthic fauna. Most animals smaller than 4 cm pass through the meshes, fish > 20 cm long are most frequently retained by the net. Among the dead fish discarded by beam trawl fishery dab *(Limanda limanda)* appear to be most abundant.

In 12-m beam trawl catches in the offshore areas the numbers of dab were about 76% of the total numbers of discard fish (Table 3), which confirms estimates of Van Beek (1990). In catches with 4-m beam trawls in the coastal areas, however, dab comprised only 45% of the total numbers of discarded fish, about 47% of the discarded fish were undersized plaice (Table 4). This stresses the importance of measures to protect the stocks of juvenile flatfish in the coastal areas, such as in the "plaice box".

Damaged shellfish were often found in large numbers in beam trawl catches. Many more damaged shellfish passed through the meshes and remained in the trawl path as a source of food for scavenging opportunistic species like dab and whiting (BERGMAN & VAN SANTBRINK; VAN SANTBRINK & BERGMAN, this report). Evidence of scavenging by dogfish *(Scyliorhinus)*, gurnards *(Triglids)* and whiting on benthic fauna disturbed by beam trawling in the Irish Sea is presented by KAISER & SPENCER (1993). Feeding of dab on molluscs damaged by beam trawling was evident in the IMPACT surveys (see VAN SANTBRINK & BERGMAN, this report). The scavenging activity of seabirds (gulls, fullmars and gannets) on fishery discards has been described by CAMPHUYSEN *et al.* (1993). Seabirds prefer roundfish and offal, e.g. intestines of gutted fish.

Roundfish were only a small proportion of the discard fish. Since they float for some time after being discarded, they are probably eaten by seabirds following the trawlers. Under water, however, fish may do the same (KAISER & SPENCER, 1993) and many potentially scavenging invertebrate species (such as starfish, shrimps and crabs) may similarly take advantage of the large amounts of dead organic material produced by beam trawl fishery.

The total amount of dead material discarded after the sorting of commercial beam trawl catches has been estimated for 12-m beam trawls and 4-m beam trawls, both per ha (10000 m^2) as well as per kg marketable sole (Table 5). These data can be used to get an impression of the magnitude of discard production by beam trawl fishery in the southern North Sea.

If discard production per ha is taken as a base, the total area trawled must be known. Sole fishing occurs mainly in the southern North Sea. If the total coastal area within the 12 mile limit is roughly estimated at 24000 km^2 and the offshore area as about 110 000 km^2,

and assuming that these areas are at least trawled completely once per year on every m^2 (WELLEMAN, 1989), this leads to a rough estimate of annual discard production by sole fishery of about 60 000 - 70 000 ton dead invertebrates plus 60 000 - 70 000 ton dead fish, including about 4000 ton roundfish. All together about 0.8-1.0 g dead material per m^2 trawled, equivalent to about 0.1 g ash-free dry matter per m^2.

However, trawling in the southern North Sea is certainly not random (RIJNSDORP *et al.*,1991) and it is also difficult to assess whether the whole area is completely trawled only once each year on each m^2. Beam trawlers tend to prefer certain productive areas and also often fish repeatedly on the same transect or on a fixed navigation line.

The annual discard production can also be estimated from the annual sole landings, when discard production per kg marketable sole is known (Table 5). According to the FAO fishery statistics the annual landings of sole from the southern North Sea (Holland, Belgium, Gemany & Denmark) were about 29 000 ton in 1991. The total sole quotum for the area has been 30 000 ton in the past years. The data in Table 5 give a minimum of about 9 kg dead fish (including 0.1 kg roudfish) and about 4 kg dead invertebrates discarded for each kg marketable sole. This leads to an estimate of annual production of 270 000 ton dead fish (including 3000 ton roundfish) and 120 000 ton dead invertebrates by sole fishery in the southern North Sea. The amount of 270 000 ton fish agrees very well with the amount of 260 000 ton discard fish estimated by VAN BEEK (1990), based on the analysis of 360 hauls by 6 commercial beam trawlers. A comparison with the annual discard production estimated from discard production per ha trawled (total 70 000 ton), leads to the suggestion that the area of the southern North Sea is trawled about 3-4 times each year.

Annual total flatfish landings (plaice and sole) are about 200 000 ton. All these fish are gutted which means that about 5% of this amount was discarded during trawling as offal: about 10 000 ton. This food source is particularly important for seabirds feeding on discards from fishery (CAMPHUYSEN *et al.*, 1993). Seabirds may take about 20% of the discard flatfish and 10% of the dicarded invertebrates. Together with the 10 000 ton offal, the flatfish beam trawl fishery may support about 0.2 million seabirds. The annual production of discards not eaten by birds is approximately 210 000 ton discard fish and about 110 000 ton dead invertebrates. Scavenging fish usually concentrate on damaged molluscs, crustaceans, gonads of sea urchins, etc. Dead flatfish are probably not eaten immediately by other fish, particularly since large predatory (scavenging) species like cod have become scarce in the southern North Sea. In fact, dead fish discarded by the intensive beam trawl fishery can be found everywhere in the southern North Sea (M. FONDS, pers. obs.). The question rises what kind of scavengers will eat the dead fish? Starfish, swimming crabs, hermit crabs and shrimp are all abundant in the area and they all show scavenging behaviour in aquaria, feeding on dead fish. Considering their abundance they may play an important role in recycling fishery discard material in the North Sea. For a better understanding of the role of beam trawl fishery in the food web and the annual carbon cycle of the North Sea, it becomes important to get more information about the identity of scavengers and the magnitude of food consumption by scavengers.

The beam trawl fishery affects particularly the larger fish, smaller fish that escape through the meshes are probably not much affected (FONDS, this report). Small starfish and crustaceans also escape through the meshes and the larger ones that are sorted from commercial catches are discarded together with dead fish, a potential food source. Hence, intensive beam trawl fishery may favour particularly the small fish species, starfish and small crab species. All these animals are extremely abundant in the southern North Sea, but it is not known (yet) whether they always have been abundant. Vulnerable species, such as the poychaetes *Pectinaria* and *Lanice* for example, may have been much more affected than starfish or crabs. The composition of the benthic fauna in the southern North Sea today is already affected by, and adapted to the intensive beam trawl fishery. Investigations in an area completely closed for fishery may give more information about the effect of fishery on the ecosystem and particularly the bottom fauna.

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Table 1

Mean weight and weight range of the most common invertebrates in catches with 12-m beam trawls for sole fishing in different seasons and localities. Weight of small species was estimated from samples taken with a fine-meshed 3-meter beamtrawl in the same areas. Samples of animals were weighed, numbers and weight range of animals in the samples are indicated. "Exp. area" refers to the area trawled for investigations on "direct effects" (Bergman & Santbrink), German area is the german IMPACT box, "line" refers to areas repeatedly trawled.

Species	Season	Area	Net type and animal size	Mean wt, g	Stand. dev.	n samples	n animals	weight range, g
ECHINODERMS								
Starfish	Mrch-92	Borkum	small	6	2	16	464	3-19
Asterias rubens		Borkum	large	43	13	9	79	30-148
	Sep-93	Exp. area		11	2	5	85	9-14
		Line		15	4	8	168	10-22
		German - area		14	1	6	535	3-15
Starfish	Mrch-92	Borkum		4.6	0.7	33	2600	3-6
Astropecten irregularis	Sep-93	Exp. area		4.3	0.4	5	513	3.7-4.8
		Line		4.4	0.6	11	365	3.3-5.1
		German - area		5.5	0.2	3	263	
Starfish	Mrch-92	Borkum	small	4.1	3.8	17	212	0.3-12
Luidia sarsi		Borkum	large				3	24-118
Brittle stars	Mrch-92	Borkum		3.5	0.5	27	443	2.8-4.7
Ophiura ophiura	Sep-93	Exp. area		3.4	0.9	4	52	2.6-4.7
		Line		2.3	0.3	12	244	1.9-2.8
		German - area		2.2	0.3	4	64	2-2,5
Ophiura albida		German - area		0.48	0.02	2	114	
Sea urchins								
Psamechinus miliaris	Mrch-92	Borkum		6.1	2.8	.4	.5	4-10
Echinocardium cordatum	Mrch-92	Borkum		21	2	12	590	19-25
	Sep-93	Exp. area	3mBT	21	8	6	9	10-31
		Line		20	4	4	50	16-55
CRUSTACEANS								
Masked crab	Mrch-92	Borkum		10	2	33	949	8-14
Corystes cassivelaunus	Sep-93	Exp. area	males	11	1	4	71	10-12
		Exp. area	females	3.5	-	1	1	
		Exp. area	3mBT-males	10	1	15	712	7-12
		Exp. area	3mBT-females	4.4	0.4	5	18	4-5
		Line	males	12	1	11	240	10-15
		Line	females	4.7	1.1	6	77	3,6-8
		Line	3mBT-males	8	1	3	73	
		Line	3mBT-females	4	0.4	3	61	
		German - area		11	0.7	6	151	10-12
Swimming crab	Mrch-92	Borkum		8.3	1.9	36	503	4,3-10,5
Liocarcinus holsatus a.o.	Sep-93	Exp. area		12.7	0.9	5	83	11-14
		Exp. area	3mBT-small	0.8	0.3	19	401	0,5-1,7
		Exp. area	3mBT-large	11	2	16	198	8-13
		Line		13.5	2.7	12	258	8-17
		Line	3mBT-small	0.9	0.4	3	119	
		German - area		10.6	0.9	5	366	0,6-12
Hermit crab	Mrch-92	Borkum		17	7	18	100	9-29
Eupagurus bernhardus	Sep-93	Exp. area	large	21	10	4	52	9-34
		Exp. area	3mBT-small	3.2	1.5	14	104	0,7-5,9
Hermit crabs - continued		Exp. area	3mBT-large	21	10	13	50	11-41
		Line	large	25	8	10	596	15-57
		Line	3mBT-small	4.6	2.4	4	54	
		German - area		22	5	5	93	1,2-30
Edible crab	Mrch-92	Borkum		625	301	10	10	214-1032
Cancer pagurus	Sep-93	German - area	males-small	159	33	10	10	102-193
		German - area	males-large	541	190	6	6	326-809
		German - area	females	614	149	15	15	420-990

		(Table 1 - continued)						
Spider crab								
Hyas araneus	Mrch-92	Borkum		5.8	2.3	5	11	3-9
Langoustine (Norway lobster)								
Nephrops norvegicus	Mrch-92	Borkum		37	14	7	10	24-42
Amphipod	Sep-93	Exp. area	3mBT	0.5	0.1	4	22	
Cirolana borealis		Line	3mBT	0.5	-	1	19	
Shrimps,								
Crangon allmanni	Sep-93	Exp. area	3mBT	0.16	0.02	15	480	
Processa canaliculata a.o.	Sep-93	Exp. area	3mBT	0.31	0.03	16	712	
Upogebia	Sep-93	Exp. area	3mBT					0,7-1,0
		Line	3mBT	0.8	-	1	22	0,8-4,5
MOLLUSCS								
Quahog	Mrch-92	Borkum		144	28	13	117	82-191
Arctica islandica	Sep-93	Exp. area						77-197
Cockle	Mrch-92	Borkum		53	6	9	137	42-64
Acanthocardia echinata	Sep-93	Exp. area		46	11			39-59
		Line		38	9	5	47	30-52
		Line	small	0.8	1	4		
Queen scallop								
Chlamys opercularis	Mrch-92	Borkum		58	1	1		
	Sep-93	Exp. area						32-68
		Line						15-45
Dosinia lupinus	Mrch-92	Borkum		10	1	1		
Mya truncata	Sep-93	Line						16-55
Gari fervensis	Sep-93	Line		8.5	1	2		
Whelks	Mrch-92	Borkum		76	23	21	92	40-125
Buccinum undatum	Sep-93	Exp. area		74	4	4	39	71-80
(& Neptunea antiqua)		Line	small	18	5	9	73	
		Line	large	74	14	9	73	49-102
		Exp. area	3mBT-small	7.6	4.5	5	6	2-13
		Exp. area	3mBT-large	90	14	7	7	64-106
		German - area		81	8	5	23	68-89
Necklace shell (Natica)								
Euspira catena	Mrch-92	Borkum		11	2	3	8	9-12
	Sep-93	Exp. area				1	3	5-7,5
Aporrhais pes-pelicanae	Sep-93	Exp. area	3mBT				2	7-8
Turritella	Sep-93	Exp. area	3mBT	0.47	0.07	16	1040	0,37-0,53
POLYCHAETS								
Sea mouse	Mrch-92	Borkum		19	4	31	1500	13-27
Aphrodyte aculeata	Sep-93	Exp. area		26	5	5	29	21-33
		Line		26	5	10	100	18-38
		Exp. area	3mBT	22	6	10	20	13-30

Table 2.

The relationship between total length (L,cm) and wet weight (W,g) of common fish in catches with 12m-beam trawls for sole fishing. For some species data are added of measurements in other years.

			W = A * L exp.B		Correl. coeff.	Numbers of fish	Size range
Species	Year	Sex	A	B	r	n	cm
Sole - Solea solea	TRID.92	males	0.00212	3.415	0.98	11	23-30
		females	0.00228	3.431	0.992	30	14-39
	TRID.93	both	0.00798	3.018	0.967	28	23-49
	Lab.84	juv	0.00852	2.981	0.987	20	5-25
Plaice - Pleuronectes platessa	TRID.92	males	0.00968	2.971	0.985	55	17-41
		females	0.00995	2.978	0.982	39	17-45
		both	0.0082	3.026	0.99	94	17-45
Dab - Limanda limanda	TRID.92	males	0.00605	3.129	0.992	60	7-24
		females	0.00569	3.155	0.991	116	11-33
		both	0.00561	3.158	0.994	176	7-33
	TRID.93	males	0.00772	3.067	0.987	37	11-26
		females	0.00701	3.111	0.978	38	11-28
Turbot-Scophthalmus max.	TRID.92	juv.	0.00581	3.365	0.986	20	27-57
	TRID.93	juv.	0.0171	3.051	0.977	18	29-45
Solenette - Buglossidium luteum	TRID.93	both	0.00374	3.437	0.993	19	6-13
	Feb.90	both	0.00413	3.388	0.993	10	6-12
	Aug.90	both	0.00406	3.395	0.994	11	5-13
Scaldfish - Arnoglossus laterna	TRID.92	both	0.0018	3.589	0.999	6	6-14
	TRID.93	both	0.00274	3.412	0.99	28	9-15
	Aug.90	both	0.00538	3.163	0.995	20	3-16
Whiting - Merlangius merlangus	TRID.92		0.00527	3.086	0.982	88	13-35
	TRID.93		0.00571	3.108	0.997	33	8-38
Cod - Gadus morhua	TRID.92		0.00398	3.268	0.997	7	13-28
	Lab.83	juv.	0.00824	3.006	0.997	21	9-27
Bib - TRisopterus luscus	TRID.92		0.00306	3.402	0.996	5	17-32
	Lab.83		0.00565	3.263	0.995	17	6-25
Grey gurnard - Trigla gurnardus	TRID.92		0.00641	3.04	0.966	49	10-42
	TRID.93		0.00681	3.039	0.982	8	15-24
Dragonet - Callionymus lyra	TRID.93		0.0106	2.803	0.904	7	12-17
	AUG.90		0.00998	2.849	0.999	9	11-22
Rockling - Enchelyopus cimbrius	TRID.92		0.00339	3.106	0.997	12	7-27
	TRID.93		0.00252	3.218	0.997	25	6-20
Edible crab - Cancer pagurus	TRID.93	males	0.148	3.017	0.992	18	9-17
(Carapax width (cm) for L).		females	0.134	3.037	0.889	19	14-18
		both	0.173	2.947	0.987	37	9-18

Table 3.

Catch composition of commercial 12-m beam trawls in different seasons. TRIDENS, 1992, 1993. Total numbers and wet weight of fish and invertebrates, estimated by subsamples taken from the catch. The total area trawled is presented in hectare (1 ha = 10000 m2).

Date :	31-Mrch-92		1-Apr-92		2-Apr-92		7-Sep-93		8-Sep-93		13-Sep-93		14-Sep-93		15-Sep-93	
Area :	Oystergrounds		Oystergrounds		Oystergrounds		Oystergrounds		Oystergrounds		Coast N-Holland		German	area	Oystergrounds	
	54.30N-4.46E		54.30N-4.46E		54.31N-4.42E		54.05N-4.48E		54.30N-5.00E		?		54.13N-6.54E		54.32N-5.06E	
Depth :	44	m	44	m	45	m	42	m	43	m	30	m	35	m	45	m
Number of hauls :	3		2		1		1		4		1		4		1	
Bottom area covered :	13	ha	8.7	ha	9.6	ha	9.4	ha	47.3	ha	26	ha	140	ha	5.5	ha
Numbers (n) & weight (kg)	n	W	n	W	n	W	n	W	n	W	n	W	n	W	n	W
Marketable fish :																
Sole - S.solea	22	4.6	9	1.5	9	1.4	15	3.2	101	22.9	290	45	581	119	8	1.7
Plaice - P.platessa	36	10.5	10	3.7	13	3.3	158	36	160	43.4	60	15.7	166	53	154	39.8
Dab - L.limanda	4	1	6	1.3	14	3.2	1	0.3	-	-	-	-	-	-	-	-
Turbot & Brill	3	4.3					1	1	16	12.4	20	15.1	12	6	7	4.4
Other flatfish	1	0.4							17	4.3						
Roundfish (whiting & gurnard)	7	2.9			9	2.3	1	0.4			1	0.4	31	18	7	1.5
Other fish	1	4.5											4	1		
Discard flatfish :																
Sole - S.solea < 24 cm	2	0.2	-	-	-	-	-	-	10	0.7	60	6	268	25	-	-
Plaice-P.platessa < 27	42	5	10	1.2	18	2	209	33.3	210	32.2	120	12.4	518	54	56	9.1
Dab - L.limanda < 27	662	32.9	611	36.4	990	51.5	451	25.5	2210	98.5	90	4.8	2800	163	217	11.6
Turbot & Brill < 30 cm																
Flounder-P.flesus																
Small flatfish sp.	23	0.6	5	0.2	9	0.1	22	0.4	57	0.8	20	0.2	98	1	77	0.9
Whiting - M. merlangus	33	3	11	1.2	58	5.7	22	2.2	84	7.4	10	0.5	26	1	63	2.3
Gurnard - Trigla gurnardus	34	2.3	4	0.2	21	1.2	11	0.3	80	3.1			98	20	63	2.4
Small roundfish	8	0.3	5	0.2	10	0.4			24	0.3	30	0.9	75	2	14	0.7
Starfish - Asterias rubens	2130	13.9	175	1	96	0.6	44	1.9	4960	64.4	4760	205	28800	389	672	7.4
Astropecten irregularis	6470	28.7	2000	8.7	3270	15	6950	31.3	22820	91.2	-	-	17500	102	4256	15.1
Brittle star - Ophiura ophiura	550	2	58	0.2	328	1.2			3200	9.6	4120	14.4	940	21	616	1
Echinocardium cordatum	2525	55.2	760	16.8	16440	345										
Other species													109	<1		
Masked crab - Corystes	2370	27.4	476	6	1250	12.5	44	0.5	1728	19	-	-	1680	17	728	7.1
Swimming crabs - Liocarcinus	457	4	74	0.7	164	1.4	187	2.4	544	7.1	1290	17.5	3150	50	168	1.5
Hermit crabs - Eupagurus	254	5.8	24	0.5	61	1	99	2.1	206	4.9	40	1	1900	36	112	2.7
Edible crab - Cancer pagurus	2	1.2					22	12.4	6	3	10	5.8	128	52		
Other (small) species					1	<0,1									1	<0,1
Quahog - Arctica islandica	68	7.8	161	30	436	62.8	154	22.2	69	8.9			272	36	17	2.4
Cockle - Acanthocardia	64	2.4	162	8.5	225	11.9	220	10.1	282	10.6			67	3	143	5.4
Whelks-Buccinum & Neptunea	51	3			10	0.8	231	18.9	192	14.6			129	8	64	4.7
Small shellfish	4	<0,1					50	1	6	0.1	300	2.3			4	0.1
Sea mouse - Aphrodyte aculeat	1260	26.6	68	1.3	668	12.7	1012	26.3	2112	55			280	8	19	0.5
Sponges & Alcyonium							22	2								

Table 4.

Catch composition of 4-m beam trawls in the coastal areas. ISIS, 1992, 1993. Numbers (n) and weight (W, kg) of fish and invertebrates, estimated by subsamples taken from the catch. Surfaces of the trawled areas in hectares (1 ha = 10000 m2).

Date :	23-June-92		29-June-92		20-Apr-93		21-Apr-93		27-Apr-93	
Area :	N of Vlieland		Coast N-Holland		Coast N-Holland		Coast N-Holland		Coast N-Holland	
							Exp.. area		Transects A & B	
Depth, m :	25	m	13	m	20	m	20	m	20	m
Number of hauls :	3		3		4		6		7	
Bottom area covered :	32	ha	33	ha	17	ha	10	ha	7	ha
Numbers & weight (Kg)	n	W	n	W	n	W	n	W	n	W
Marketable fish :										
Sole	45	12.4	74	20.5	110	20.3	34	6.1	72	13.6
Plaice	45	12.3	28	10.1	31	9.2	18	5.9	13	3.5
Dab	-	-	-	-	65	12.1	110	26.4	27	6.4
Turbot & Brill	12	7.5	3	2.4	4	5.6	6	4.5	-	-
Flounder	5	1.9	39	12.9	201	74.7	33	14.2	98	40.1
Other flatfish										
Roundfish	20	5	1	0.4	8	3.3				
Other fish							7	2	12	3
Discarded undersized fish:										
Sole - < 24 cm	6	0.4	16	0.6	151	11.3	67	5.2	63	5.7
Plaice - < 27	850	90.9	745	66.5	779	57.7	1121	84.5	564	43.1
Dab - < 27	120	8.9	217	16	1428	106.1	1535	136	593	53.4
Turbot & Brill < 30 cm	27	10	45	11.7	10	4	11	3.4	3	1.2
Flounder					75	9.5	6	0.7		
Small flatfish sp.	15	0.3					8	0.1		
Whiting	1	0.1			14	1.2	4	0.2	11	0.7
Gurnard	2	0.1	21	2.6			6	0.3	11	0.5
Small roundfish	1	<0,1			158	0.5	15	0.4	4	0.2
Evertebrates :										
Starfish - Asterias	15240	655	16620	715	13700	589	4922	212	25300	1090
Astropecten	230	1	-	-	-	-				
Brittle star - Ophiura	275	1	1123	3.9	2340	4.7	1940	6.6	300	1.1
Echinocardium					196	0.5	32	0.7	56	1.2
Masked crab - Corystes	14	0.1	11	0.1						
Swimming crabs	418	5.4	1860	25.1	4356	56.6	984	12.5	352	4.8
Hermit crabs	1	<0,1	29	0.5	600	12.6	112	2.4	100	2.5
Edible crab - Cancer	18	11.3	24	15			2	0.3		
Shrimp (Crangon a.o.)			8	0.2	140	0.5	24	0.1		
Razor shell - Ensis					1164	18	408	6.1	256	4
Mactra					132	1.2	68	0.7		
Spisula			23	0.2	12460	59.2	754	3.8	25300	126
Sponges & Alcyonium							8	<0,1		

Table 5.

Estimates of the total amount of dead discards in commercial hauls with 12-m and 4-m beam trawls.
Mean numbers and weight of discards per hectare (1 ha = 10000 m2) and per Kg marketable sole.
The geometric means are calculated as the anti-log of mean ln n and mean ln W.

	Numbers per ha			Weight (kg) per ha				Numbers per kg sole			Weight per kg sole		
	Mean	S.D.	Geom. mean	Mean	S.D.	Geom. mean		Mean	S.D.	Geom. mean	Mean	S.D.	Geom. mean
12-m beam trawl;													
(8 locations, 260 ha)													
Commercial fish	12	10	9	3.0	2.5	2.3							
Dead discard fish;													
Flatfish :	60	27	52	3.7	1.7	3.3	1992 :	430	284	120	14	13	8
(81% dab, 12% plaice)							1993 :	113	96				
Roundfish :	7	7	5	0.4	0.3	0.3		25	31	11	1.5	1.8	0.8
Dead invertebrates	153	65	141	3.1	2.1	2.6		500	400	325	13	17	6
Sum of dead discards	219	87	203	7.3	3.7	6.4		768	660	470	29	31	15
Ash-free dry weight :				1.0	0.5	0.9							
4-m beam trawl;													
(5 locations, 99 ha)													
Commercial fish :	17	13	12	5.1	3.7	3.7							
Dead discard fish;													
Flatfish :	124	99	87	10.6	8.4	7.7		150	158	107	13	13	10
(46% dab, 48% plaice)													
Roundfish :	4	4	2	0.1	0.07	0.07		3	3	2	0.1	0.05	0.09
Dead invertebrates	500	700	182	15.6	11.5	14.2		350	347	226	4.0	2.0	3.8
Sum of dead discards	628	760	300	15.6	11.5	14.2		507	367	376	17	13	14.3
Ash-free dry weight :				2.1	1.5	1.5							

Table 6.

Measurements of the length of some common roundfish in catches with 12-m beam trawl offshore (12mBT), with 4-m beam trawl in the coastal areas (4mBT) and with fine-meshed 3-m beam trawl (3mBT) or 1-m fine-meshed dredge.

	Red gurnard			**Grey gurnard**			**Whiting**			**Dragonet**			**Rockling**	
	Trigla lucerna			Trigla gurnardus			Merlangius merlangus			Callionymus lyra			Enchelyopus cimbrius	
	Sep'93	Jun'92	Apr'93	Sep'93	Jun'92	Apr'93	September'93		Apr'93	March 1992		Apr'93	March 1992	
	12mBT	4mBT	4mBT	12mBT	4mBT	4mBT	12mBT	3mBT	4mBT	3mBT	Dredge	3mBT	12mBT	3mBT
Length class cm														
0														
1														
2														
3														
4								8						
5										1				1
6				2				5						2
7							1	23			1	2		5
8	2						7	42				13		12
9			1				2	50		2	2	36		11
10	2		2				1	32	1	2	4	55		9
11			1				3	25	1	1	16	36		5
12	1						9	34	5		11	17		
13			2	1	6		7	10		2	13	12	1	
14				5	8	1	5	9		6	14	17	3	
15	1		2	15	7	2	4	6	9	8	2	13	1	1
16	4		1	28	6		3	6	5	5	1	23	2	
17	1	1		29	1	4	2	8	5	3	1	20		
18		3		27	4	2		5	4	1	1	23	1	1
19	5	8		17		1	2	6	3	1		13		
20		16		12	5		12	1	1			11		
21	1	7		2	3	1	18		4			6	2	
22		7		2	2		16	4	1			3	1	
23	2	2		2	2		27	3					1	
24	12				2	1	20	1		1				
25	5	1	1		1		13			1				
26	13	2		1			9	1						
27	7	2		1	1		11	4		1				
28	6	3			1		9	1					1	
29	5	7			1		5	1					1	
30	2	9			1		3	2						
31		6	1	1			4							
32	3	6	1	1	1		8							
33		5					1							
34		1												
35	3	3					1							
36	1	1												
37	2	2												
38		1					1							
39	2	1												
40		1												
41	1	3												
42		1												
43														

Table 6 continued.

Length distribution of some larger flatfish species in catches with commercial beam trawls.
12-m beam trawls offshore (12-m BT) and 4-m beam trawls in coastal areas (4-m BT).

	TURBOT *Scophthalmus maximus*				**BRILL** *Scophthalmus laevis*				**FLOUNDER** *Platichthys flesus*	
	12-m BT		**4-m BT**		**12-m BT**		**4-m BT**		**4-m BT**	
Length class	Mch92	Sep.93	Jun.92	Apr.93	Mch92	Sep.93	Jun.92	Apr.93	Jun.92	Apr.93
cm	n	n	n	n	n	n	n	n	n	n
10										
11										
12										
13			1							
14										
15			1							
16										
17							1			
18			1							
19								3		3
20			1				2	5	1	3
21		2	2				5		1	7
22				3			5	1	2	4
23		5	4	8			5		1	7
24			3	18			2		5	5
25	1	1	13	17			2		6	17
26			10	10					10	13
27			12	14			1	1	7	10
28			9	8			1	3	16	24
29		1	9	3		2		3	14	17
30		1	3	1				9	13	22
31		8	5	1				3	9	21
32		2						5	14	7
33		1	4			1		2	5	23
34		3				1	1	1	4	13
35	1								5	11
36		3	2					1	5	16
37	1		1						3	7
38		1				1			2	8
39	1	1							2	5
40-45		4	1			3		1	2	6
45-50					1			1		
50-55										
55-60										
60-65	1									
65-70										
70-75	1									
75-80										

Table 7.

Length distribution of some common small fish species caught in commercial nets or in fine-meshed nets.
Numbers of fish measured in cm length classes for all hauls together.

Period	Net type	Length class in cm																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SOLENETTE - Buglossidium luteum																			
March '92	12m BT							1	2	1	4	1							
	Cover						2	12	20	30	16	4							
Sept. '93	12m BT							1	1	2	6	4	3	1					
	3m BT		7	82	21	20	157	108	132	94	69	33	20	4					
June '92	4m BT						1	2	6	5	7	3							
	3m BT				1	10	46	46	103	89	107	39	5						
April '93	3m BT						3	3	9	3	8	2	3						
SCALDFISH - Arnoglossus laterna																			
March '92	12m BT									1		1	10	8	4				
	Cover					2	4	6	2	10	14	12	8	20	4	2			
Sept. '93	12m BT				5			1		21	16	16	31	21	4	3	2		
	3m BT			28	10	12	14	18	80	213	120	44	38	17	8	4	1		1
June '92	all nets							1	19	5	2	3	6	16	16	5			
April '93	4m BT											2	2	4	1	3			
	3m BT					3	7	9	8	7	3	1	3	2	1	2			
WEEVER - Trachinus vipera																			
March '92	3m BT							7	19	23	15	6	5	2	1				
June '92	3m BT				1	9	10	26	12	4	2	2	1	1					
HOOKNOSE - Agonus cataphractus																			
June '92	4m BT				1	4	7	1		1	3		3	2					

Table 8.

Estimates of the % fish escaping through the 8 cm meshes of 12-m beam trawls..
Numbers of fish collected in a fine-mesh cod-end covering net compared to the
the numbers in the large net. TRIDENS, March 1992, Oystergrounds 45 m.

	Whiting - Merlangius merlangus			Grey gurnard-T.gurnardus			Dab - Limanda limanda		
	17 hauls			14 hauls			10 hauls		
Net :	12mBT	Cover	Escape	12mBT	Cover	Escape	12mBT	Cover	Escape
	n	n	%	n	n	%	n	n	%
Length class cm									
5								2	*100*
6								4	*100*
7					4	*100*		22	*100*
8								30	*100*
9					2	*100*		10	*100*
10		2	*100*	1	6	*86*		2	*100*
11	1	4	*80*	7	16	*70*	4	20	*83*
12		12	*100*	7	12	*63*	21	38	*64*
13		10	*100*	14	10	*42*	67	72	*52*
14	1	6	*86*	23	2	*8*	84	116	*58*
15	6	32	*84*	10	10	*50*	181	136	*43*
16	6	30	*83*	19	8	*30*	205	124	*38*
17	10	26	*72*	19	6	*24*	272	96	*26*
18	13	10	*43*	31	4	*11*	258	56	*18*
19	16	34	*68*	49	2	*4*	138	20	*13*
20	14	30	*68*	42	4	*9*	83	6	*7*
21	28	34	*55*	18		*0*	80		*0*
22	37	44	*54*	24	2	*8*	60		*0*
23	48	22	*31*	9		*0*	40		*0*
24	36	42	*54*	13		*0*	16		*0*
25	43	30	*41*	9		*0*	11		*0*
26	34	16	*32*	6		*0*	10		*0*
27	21	2	*9*	3		*0*	4		*0*
28	18		*0*	4		*0*	3		*0*
29	15	4	*21*	3		*0*			
30	7	2	*22*	2		*0*	1		*0*
31	7		*0*	2		*0*	1		*0*
32	1		*0*	2		*0*	1		*0*
33				1		*0*			
34				1		*0*			
35	1		*0*	1		*0*			
36									
37				2		*0*			
38				1		*0*			

Table 9

Mesh size selection of 4-meter beam trawls in the coastal areas off N-Holland (10-15 m depth). Comparison of the length distribution and numbers of the most abundant fish in catches of 4-m beam trawl (4mBT, 8 cm meshes) with those in a fine-meshed covering net (2 cm meshes) and catches with a 1 m dredge with fine-meshed net (2 cm meshes). Beam trawl and dredge were trawled simultaneously in the coastal area between IJmuiden and Petten, numbers in the dredge x 4. ISIS, 29 June to 2 July 1992.

Species:	**SOLE - *Solea solea***				**PLAICE - *Pleuronectes platessa***				**DAB - *Limanda limanda***				**STARFISH - *Asterias rubens***			
Net :	4mBT	Cover	4mBT	Dredge	4mBT	Cover	4mBT	Dredge	4mBT	Cover	4mBT	Dredge	4mBT	Cover	4mBT	Dredge
n hauls:	16	16	10	10	16	16	10	10	15	15	9	9	9	9	6	6
L class,																
cm	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
0																
1																
2														1		4
3														9		12
4								4		31		200	22	114	18	216
5						1		24		32		156	55	84	49	348
6						5		8		1		4	131	154	113	264
7									1				207	81	174	224
8										10		4	173	58	137	188
9						1				8		8	187	47	176	256
10		2		8		1		8	1	25		8	46	17	38	52
11		2		16	1	11		8	8	35	3	16	17	2	14	16
12	1	15	1	72	2	12	1	4	11	41	3	40	30	4	20	12
13	2	19	1	72	9	27	4	28	13	47	3	44	8		7	8
14	6	32	4	140	20	32	11	60	16	27	11	16	7	1	4	8
15	7	38	5	104	39	43	7	40	14	24	3	8	3	1	1	4
16	7	36	3	52	77	73	21	68	25	31	4	24	1			
17	6	17	3	24	69	61	30	40	17	18	5	24				
18	1	5	1	4	48	41	12	44	21	10	2	12				
19					32	22	10	44	19	9	2	12				
20				4	26	10	14	12	11	5	2					
21	1	1		4	36	12	11	20	7	7	1	8				
22	5	3	2	4	23	5	13	8	11	7	2	4				
23	2		1		20	2	9	12	7	2	3					
24	1	2			11		5		2							
25	1	2			10		4	4	2		1					
26		1		4	3		1		1							
27	6		1													
28		1		4												
29	3	1			1		1									
30	1	1	1	4												
31	5	1	2													
32	5		3													
33	2				1											
34	3	1	2													
35				4												
36																
37																
38	1															
39																
40																

Table 10.

Mean % escape for different size classes of fish and starfish in catches with 4-meter beam trawl (4mBT) with fine-meshed cod-end cover, compared with catches of a 1-m dredge with fine-meshed net (n x 4).

Size range cm	4mBT n	Cover n	Mesh escape %	4mBT n	Dredge n	Total escape %
SOLE - Solea solea						
10-15	9	70	*89*	6	308	*98*
15-20	21	96	*82*	12	184	*93*
20-25	9	6	*40*	3	12	*75*
25-30	10	5	*33*	1	8	*88*
30-38	17	3	*15*	8	8	*0*
PLAICE - Pleuronectes platessa						
4-10	0	7	*100*	0	36	*100*
10-15	32	83	*72*	9	108	*92*
15-20	265	240	*48*	80	236	*66*
20-25	116	29	*20*	52	52	*0*
25-33	15	0	*0*	6	4	*0*
DAB - Limanda limanda						
4-10	0	64	*100*	0	372	*100*
10-15	49	175	*78*	20	124	*84*
15-20	96	92	*49*	16	80	*80*
20-27	41	21	*34*	9	12	*25*
STARFISH - Asterias rubens						
2-4	0	10	*100*	0	16	*100*
4-8	415	433	*51*	354	1052	*66*
8-12	423	124	*23*	365	512	*29*
12-16	49	6	*11*	32	32	*0*

Table 11.

General catch composition and the % animals that escape through the 8 cm meshes of 12-m beam trawls (TRIDENS) trawled in the offshore areas (40-50 m depth) and 4-m beam trawls (ISIS) trawled in the coastal areas (10-25 m depth). The % escape is estimated by comparison with the numbers of animals collected in a fine-meshed cod-end cover or by comparison of catches from the large net with those of a fine-meshed 3-m beam trawl or 1-m dredge operated at the same time.

Area and depth :	Oystergrounds, 44 m			German IMPACT box, 36 m			Coast N-Holland (IJmuiden to Egmond), 13-25 m					
Position :	54o.35 N-04o.28 E			54o35 N-06o53 E			52o.20-52o.33 N - 04o.32-05o.03 E					
Date :	31-Mrch-1992			14-Sep-1993			29-30 June - 1992					
Net :	**12mBT**	**Cover**	**Mesh**	**12mBT**	**3mBT**	**Total**	**4mBT**	**Cover**	**Mesh**	**4mBT**	**Dredge**	**Total**
Number of hauls :	11	11	**escape**	1	2	**escape**	16	16	**escape**	10	10	**escape**
			%			**%**			**%**			**%**
Numbers of fish	n	n		n/ha	n/ha		n	n		n	n	
MARKETABLE FISH :												
Sole	16	0	*0*	3	17	*82*	28	10	*26*	9	16	*44*
Plaice	50	0	*0*	4	3	*0*	2	0	*0*	1	0	*0*
Dab	5	0	*0*	0	0	-	-	-	-	-	-	-
Flounder							24	1	*4*	12	16	*25*
Whiting	9	1	*10*									
Gurnards	6	0	*0*	1	0	-						
UNDERSIZED DISCARD FISH,												
Sole < 24 cm	1	4	*80*	3	20	*85*	38	170	*82*	21	504	*96*
Plaice < 27 cm	128	1	*1*	8	0	*0*	426	359	*46*	153	436	*65*
Dab < 10 cm	-	-		<1	300	*100*	1	82	*99*	0	372	*100*
Dab 10-27 cm	765	377	*33*	38	50	*24*	187	288	*61*	44	216	*80*
Turbot & Brill < 30 cm				1	0	*0*	13	0	*0*	6	4	*0*
Buglossidium	6	42	*88*	0	1600	*100*	12	413	*97*	1	744	*100*
Arnoglossus	12	38	*76*	1	130	*99*	0	18	*100*	0	60	*100*
Whiting	174	192	*52*	1	28	*96*	8	13	*33*	0	40	*100*
Gurnards	155	44	*22*	3	6	*50*	13	14	*50*	3	0	*0*
Callionymus	7	4	*36*	<1	21	*97*	0	30	*100*	0	84	*100*
Hooknose - Agonus				<1	3	*80*	2	12	*86*	2	12	*83*
Other small species	0	12	*100*	0	1300	*100*	2	13	*87*	2	628	*100*
(gobies, sandeels,herring)												
ECHINODERMS												
Asterias rubens	106	44	*29*	220	2200	*90*	6526	5120	*44*	3084	8036	*62*
Astropecten irregularis	1240	434	*26*	400	30	*?*	78	13	*14*	32	0	*?*
Ophiura ophiura	235	54	*19*	53	43000	*100*	467	1184	*77*	187	33056	*99*
Echinocardium cordatum	5920	5490	*48*									
Psamechinus miliaris				8	43	*81*						
CRUSTACEANS												
Corystes cassivelaunus	327	185	*36*	2	14	*86*	17	12	*41*	2	0	*0*
Liocarcinus holsatus	300	240	*44*	84	555	*85*	1225	3190	*74*	441	16816	*97*
Eupagurus bernhardus	180	40	*19*	36	400	*91*	79	78	*50*	14	1668	*99*
Cancer pagurus	1	0	*0*	1	0	*0*	1	1	*50*			
Shrimp - Crangon				0	4900	*100*	0	2120	*100*	0	14360	*100*
(a.o., Processa, Upogebia)												
MOLLUSCS												
Arctica islandica	7	0	*0*	<1	10	*95*						
Acanthocardia echinata	7	1	*13*	<1	7	*91*						
Small shells (Nucula etc.)				0	200	*100*						
Spisula subtruncata							29	122	*82*	2	14452	*100*
Donax serratus							0	69	*100*	0	52912	*100*
Ensis directus							39	17	*30*	39	664	*94*
Buccinum undatum	27	1	*4*	4	0	*0*						
Natica - Euspira (small)										0	1204	*100*
Squid - Allotheuthis							0	15	*100*			
POLYCHAETS and others,												
Aphrodyte aculeata	802	683	*46*									
Anemone - Sagartia				<1			0	4624	*100*	0	4624	*100*

Table 12

Repeated trawling of a transect with 12-m beam trawls at 45 m depth on the Oystergrounds on 2 April 1992 (TRIDENS). Position of the transect : from 54o 30,75 N - 04o 41,75 E to 1000 m east. Trawling speed 6-7 nm/h, alternately with and against the current. The total surface of the trawled transect was estimated at approximately 7.2 ha. Numbers of animals (N) per haul of 2.4 ha (30 % of the transect). n.s. = not significant.

									Catch efficiency		Correlation of ln N per haul				
									Sum	Haul 1	with haul number t (n hauls).				Mean
									haul	as %					change
Haul number (t) :	1	2	3	4	5	6	7	8	1-8	of sum	ln N = ln No - B * t				of N
Time of the day :	8.45	9.12	9.40	10.24	10.49	11.19	11.43	14.20							% /haul
Species ;											No	B	r2	n	%
Sea urchin-Echinocardium	1440	1760	2160	1076	1160	296	525	90	8507	17	3997	-0.373	0.72	8	-31
Starfish - Astropecten	888	1520	760	104	680	72	99	178	4301	21	1331	-0.313	0.49	8	-27
Asterias rubens	40	56	0	0	16	0	12	0	124	32	65	-0.248	0.87	4	-22
Brittle star - Ophiura	104	144	56	24	?	4	15	18	365	28	158	-0.375	0.63	7	-31
Masked crab - Corystes	240	272	224	516	176	48	96	25	1597	15	589	-0.318	0.61	8	-27
Swimming crab - Liocarcinus	48	32	56	28	32	11	12	7	226	21	78	-0.275	0.8	8	-24
Hermit crab - Eupagurus	24	9	?	28	32	11	3	2	109	22	37	-0.291	0.55	7	-25
Quahog - Arctica	9	151	170	106	69	63	85	59	712	1	216	-0.169	0.74	7	-16
Spiny cockle-Acanthocardia	14	72	95	44	81	38	50	41	435	3	39	-0.111	0.44	7	-11
Sea mouse - Aphrodyte	416	144	64	44	56	18	42	15	799	52	332	-0.393	0.8	8	-33
Dab - L.limanda	261	201	274	277	503	202	273	471	2462	13-11	244	0.027	0.04	7	n.s.
Plaice - P.platessa	13	9	4	4	13	5	1	25	74	18-27	8	-0.054	0.02	8	n.s.
Sole - S.solea	3	4	2	0	1	2	1	1	14	21	4	-0.182	0.71	7	-17
Whiting - M.merlangus	16	22	9	27	5	12	8	65	21	10-16	21	-0.139	0.25	7	n.s.
Gurnards - Trigla gurnardus	12	1	2	8	0	0	3	0	4	46	4	-0.05	0.01	5	n.s.
Other (small) fish	7	5	2	4	5	4	0	2	6	24	6	-0.11	0.33	7	n.s.

Table 13

Repeated trawling with 12-m beam trawls over a transect of 1000 m long with DGPS navigation. TRIDENS, 2 April 1992, Oyster grounds.
Same data and position as in Table 12. Hauls combined : each haul was 4.8 ha, about 67 % of the total surface of the transect. (n.s.= not significant).

					Catch efficiency		Correlation of ln N with haul number t.				
					Sum	Haul 1					
					of haul	as %					
Haul number (t) :	1	2	3	4	1-4	of sum			ln N = ln No + B * t		Change
					N per ha		Corr.	Number			of N
Original hauls (Table 12) :	1+2	3+4	5+6	7+8	(1-8)		coeff.r2	of hauls	No	B	% per haul
Numbers of animals per ha (N)											
Sea urchin - Echinocardium	667	674	303	128	1180	56	0.884	4	1531	-0.575	-44
Starfish - Astropecten	502	180	157	58	597	84	0.935	4	884	-0.661	-48
Brittle star - Ophiura	52	17	?	7	51	102	0.936	3	81	-0.636	-47
Masked crab - Corystes	107	154	47	25	222	48	0.766	4	266	-0.555	-43
Swimming crabs - Liocarcinus	17	18	9	4	31	55	0.859	4	36	-0.503	-40
Quahog - Arctica islandica	33	58	28	30	99	33	0.155	4	46	-0.101	n.s.
Cockle - Acanthocardia	18	29	25	19	60	30	0.001	4	22	-0.001	n.s.
Sea mous - Aphrodyte	117	23	15	12	111	105	0.829	4	162	-0.726	-52
Dab - L.limanda	96	115	147	155	342	28	0.950	4	83	+0.168	+18.
Plaice - P. platessa	5	2	4	5	10	50	0.043	4	3	+0.070	n.s.
Sole - S.solea	1.5	0.4	0.6	0.4	2	75					
Whiting - M.merlangus	8	5	2	10	14	57					
Gurnard - Trigla gurnardus	2	1	0	0.4	4	50					

Table 14

Repeated trawling of a transect of 1 mile on the Oystergrounds with 12-m beam trawls on 15-16 September 1993. Position : 54. 32,05 N / 5. 05,30E - 54. 32,87 N / 5. 06,83 E.
Each haul was twice along the transect, covering about 2 * 1800 * 24 m = 8.6 ha = 66% of the total surface of the transect (13 ha). Numbers of animals per hectare (10000 m2).
After ten-fold trawling (hauls 1 to 5) on 15 Sept, the line was trawled twice again the next day (16-9), once in the morning and once in the evening. Prior to the repeated trawling
and immediately after ten-fold trawling on 15-9, the line was sampled by two short hauls (10 minutes, 1200 m) with a fine-meshed 3-m beam trawl. (N = density per ha).

						Hauls next day		Estimates with fine-meshed nets		Sum	Haul 1	Sum	Correlation : ln N = ln No + B * t				
Date (September 1993)	15-9	15-9	15-9	15-9	15-9	16-9	16-9	15-9	15-9	haul	as %	as %	Correl.				Change
Haul number (t) :	1	2	3	4	5	6	7	Prior to	After	1-5	of sum	initial	coeff.				of N
Time of the day :	10-12	14-15	16-17	17-18	19-20	9.00	19.00	8-10	21-22			N	r2	n	No	B	% per haul
ECHINODERMS																	
Starfish - Astropecten	583	214	157	70	20	7	6	2130	1700	694	84	33	0.965	5	1294	-0.786	-54
Asterias rubens	93	34	12	3	5	12	24	1260	65	98	95	8	0.794	5	209	-0.841	-57
Brittle star - Ophiura	105	73	40	17	9	5	1	2170	890	162	64	7	0.983	5	231	-0.637	-47
CRUSTACEANS																	
Masked crab - Corystes	78	42	48	34	19	10	1	490	474	147	53	30	0.868	5	99	-0.304	-26
Swimming crab-Liocarcinus	21	15	16	8	8	18	7	317	339	45	47	13	0.860	5	28	-0.256	-23
Hermit crab - Eupagurus	12	14	6	2	2	4	5	143	37	24	50	17	0.867	5	28	-0.553	-43
Small crabs (Ebalia etc.)	0.1		0.1					100	176								
Shrimp (Crangon, Processa)								800	35								
Upogebia & Callianassa								0	160								
Amphipods - Cirolana bor.								0	155								
MOLLUSCS																	
Quahog - Arctica	3	4	8	6	6	4	2	0	7	18	17	-	0.540	5	3	+0.179	+20.
Spiny cockle-Acanthocardia	35	54	46	53	32	7	12	16	42	146	24	-	(0.02)	5	46	-0.020	-
Turritella communis								6300	7000								
Phaxas pellucidus								45	1000								
Other small shellfish	0.7	0.9		0.3				200	680								
(Abra,Nucula,Chamelea, etc.)																	
POLYCHAETS																	
Sea mouse - Aphrodyte	4	4	16	3	2	4	0	7	22	19	21	86	(0.11)	5	7	-0.167	-15
Other worms								0	170								
FISH																	
Dab - L.limanda	32	27	107	65	31	275	303	166	85	174	18	105	(0.05)	5	35	+0.082	+ 9.
Dab - L.limanda < 10 cm								128	25								
Plaice - P.platessa	16	7	7	5	5	29	26	15	13	27	59	180	0.783	5	16	-0.266	-23
Sole - S.solea	1.7	2.3	1.6	1	0.9	3.5	2.4	16	4	5	34	31	0.726	5	3	-0.21	-19
Turbot & Brill	0.7	0.3	0	0.1	0	0	0	0	0	0.7	100	-	0.987	3	1.2	-0.634	-47
Solenette - Buglossidium	0	0	0	0	0	0	0	118	72	0	0	0					
Scaldfish - Arnoglossus	9	1	1	0	0	0	1	100	33	7	100	7					
Whiting - M.merlangus	9	4	16	5	4	3	4	76	100	25	36	32	Roundfish :				
Gurnards - Trigla	8	1	1	1	1	3	1	9	3	8	100	89	(0.312)	5	17	-0.227	-20
Rockling - Enchelyopus c.								32	4	0		0					
Gobies - Pomatoschistus								93	?	0		0					

Table 15

Repeated trawling of a transect with 4-m beam trawls in the coastal area at 24 m depth on 25 June 1992.Position of the transect :
53o 25,116 N / 05o 03,882 E - 53o 25,326 N / 05o 04,783 E. The total surface of the transect was estimated as 1070 x 32 m = 3.4 ha.
Each haul was after two tows over the transect, covering an area of 1070 x 8 x 2 = 1.7 ha = 50 % of the total surface of the transect.
Numbers of animals per haul per ha (1 ha = 10000 m2).

Haul number :	1	2	3	4	5	6	7	8	9	10	11	12
Time of the day :	8.30	10.00	10.45	11.20	12.00	14.00	14.50	15.20	16.00	16.30	17.00	17.30
Total weight of catch in kg :	124	103	62	41	41	41	26	21	21	21	15	9
Starfish - Asterias rubens	4200	4100	2900	1060	1650	1620	740	350	300	540	260	250
% Asterias regenerating :	-	23	13	26	26	18	14	15	22	19	29	9
Astropecten irregularis	11	15	7	1	1	2	6	1	1	3	0	1
Brittle star - Ophiura ophiura	145	247	166	165	88	101	89	95	87	165	87	86
Swimming crabs-Liocarcinus	162	74	64	40	40	44	40	26	21	33	19	23
Hermit crab - Eupagurus	4	0	5	1	1	1	2	1	2	2	0	0
Dab - Limanda limanda	148	147	146	67	63	139	114	67	84	79	45	36
Plaice - Pleuronectes platessa	148	91	60	21	18	44	21	15	18	21	8	8
Flounder - Platichthys flesus	2	1	0	0	1	1	0	0	0	0	0	0
Sole - Solea solea	11	5	6	1	2	3	1	0	2	2	2	1
Turbot & Brill (Scophthalmus)	2	4	3	1	2	2	1	2	2	0	1	1
Gurnards - Trigla spp.	4	2	1	2	2	1	2	4	6	4	3	1
Other fish	4	2	4	1	2	2	2	1	0	1	0	2

Table 16.

Repeated trawling of a transect with 4-m beam trawls in the coastal area at 15 m depth on 27-28 April 1993 (ISIS). Position of the transects A and B :
Transect A : 52o 38,386 N / 04o 33,193 E - 52o 37,859 N / 04o 33,245 E. ; Transect B : 52o 38,357 N / 04o 33,464 E - 52o 37,819 N / 04o 33,245 E.
The total surface area of the trawled transect A was estimated as 1100 * 32 m = 3.5 ha. Each haul was after three tows over the transect, covering about 3 * 1100 * 8 m = 2.6 ha = 74 % of the total transect. Numbers of animals in the successive catches are estimated per hectare trawled. The density of animals on the transect, prior to and immediately after repeated trawling, was estimated with a fine-meshed 3-m beam trawl (3mBT) and with a deep-digging dredge (DDD, see Bergman & Santbrink). Densities estimated with the DDD are indicated by *. Transect A was trawled twice again the next day.

	Transect A										Transect A		Transect B		
									next day		Fine-meshed trawl				
Date (1993) :	27-4	27-4	27-4	27-4	27-4	27-4	27-4	27-4	28-4	28-4	3mBT or * DDD		27-4	27-4	27-4
Haul number :	1	2	3	4	5	6	7	8	9	10	Initial N	N left	1	2	3
Time of the day :	10.45	11.30	12.00	12.50	15.40	16.30	17.00	17.30	11.00	20.00	prior to	after	9.00	15.00	20.00
Starfish - Asterias rubens	625	108	58	89	52	20	29	29	88	328	1370	430	269	431	438
Brittle star - Ophiura ophiura	97	8	18	4	5	1	1	2	1	48	580	220	18	69	38
Sea urchin - Echinocardium	3	3	1	3	3	3	3	0	3	3	*1320	*260	-	-	-
Masked crab - Corystes	-	-	1	-	-	-	-	-	-	5	*268	*0	-	-	-
Swimming crabs-Liocarcinus	86	16	12	10	8	5	5	9	19	39	*525	*292	49	23	19
Hermit crab - Eupagurus	22	5	1	1	0	2	2	1	1	14	490	400	17	0	4
Edible crab - Cancer pagurus	-	-	-	-	-	-	-	-	1	-			-	1	-
Shrimp - Crangon spp.											23800	4800			
Shellfish- Spisula subtruncata	9650	1530	3100	250	46	330	32	77	17	35	*750000	*180000	74	62	42
Mactra corallina	3	5	13	6	2	3	3	3	3	7	*135	*188	0	0	4
Razorshell - Ensis directus	86	0	0	0	3	3	3	1	8	23	*12800	*12200	12	8	19
(Razorshell empty shells)	?	115	39	52	21	26	14	12	10	138			?	150	190
Small shellfish (Angulus,Venus)											*2830	*3080			
Squid - Loligo	7	1	1	2	0	0	0	5	0	1					
Anemonies - Sagartia											*20400	*31100			
Polychaets (Nephthys, lanice)											*3880	*8030			
Dab - Limanda limanda	132	40	18	25	32	8	12	7	33	88	890	700	130	40	350
Plaice - Pleuronectes platessa	153	27	5	4	15	5	6	3	17	92	610	210	69	33	123
Flounder-Platichthys flesus	13	4	1	2	<1	1	1	1	5	8			11	7	3
Sole - Solea solea	30	7	3	2	3	2	2	3	2	7	*630	*1040	17	4	5
Turbot & Brill (undersized)	<1	0	<1	<1	<1	<1	0	0	1	0			1	1	<1
Buglossidium & Arnoglossus											70	60			
Roundfish (undersized)	5	2	1	2	0	0	0	<1	2	1			3	1	1
Dragonet - Callionymus lyra	0	2	1	1	<1	0	<1	<1	1	0	290	100			
Gobies - Pomatoschistus											4760	3520			

Table 17

Catch efficiency and the decrease in numbers of animals in the catches of 4-m beam trawls during repeated trawling over a transect on 25 June1992 (N of Vlieland) and 27 April 1993 (W of N-Holland). Catch efficiency of the nets is estimated by (1) the catch in haul 1 as % of the sum in all hauls; and (2) by the sum of all catches as % of the initial densities estimated prior to the repeated trawling with fine-meshed nets (only in 1993).

		Catch efficiency			Correlation of ln N with haul number t,			
						ln N = ln No + B * t		
	Sum	Haul 1	Initial	Sum as				
	1-12	as %	density	% of	Correl.	No	B	% change
June 1992 - Vlieland	N per ha	of sum	N per ha	initial N	coeff. r2			per haul
One haul is 50 % of the transect								
					(n=5)			
Total weight of catch in kg :	262							
ECHINODERMS								
Starfish - Asterias rubens	9000	47			0.719	6462	-0.322	-28
Astropecten irregularis	24	46			0.813	39	-0.750	-53
Brittle star - Ophiura ophiura	760	19			0.357	234	-0.140	-13
CRUSTACEANS								
Swimming crabs - Liocarcinus spp	290	56			0.881	183	-0.341	-29
Hermit crab - Eupagurus	9	44			0.625	8	-0.402	-33
FISH								
Dab - Limanda limanda	570	26			0.755	224	-0.249	-22
Plaice - Pleuronectes platessa	240	62			0.959	274	-0.568	-43
Flounder - Platichthys flesus	2	100						
Sole - Solea solea	18	61			0.699	17	-0.502	-40
Turbot & Brill (Scophthalmus)	10	20			0.176	3	-0.139	n.s.
Gurnards - Trigla spp.	19	21			0.200	3	-0.139	n.s.
Other fish	9	44			0.321	4	-0.208	n.s.
April 1993 - North Holland	Sum 1-8	%		%	(n=4)	No	B	% change
One haul is 74 % of the transect								
ECHINODERMS								
Starfish - Asterias rubens	750	83	1370	55	0.637	688	-0.647	-48
Brittle star - Ophiura ophiura	102	95	580	18	0.677	137	-0.875	-58
Sea urchin - Echinocardium	14	21	1320	1				
CRUSTACEANS								
Masked crab - Corystes	1	0	268	0.4				
Swimming crabs - Liocarcinus	113	76	525	22	0.779	109	-0.674	-49
Hermit crab - Eupagurus	26	85	490	5	0.894	49	-1088	-66
Shrimp - Crangon spp.	0	0	23800	0				
MOLLUSCS								
Spisula subtruncata	11260	86	750000	1.5	0.747	23873	-1025	-64
Mactra corallina	29	10	180	16				
Razorshell - Ensis directus	72	119	12800	0.6				
(Razorshell empty shells)	209				0.865	164	-0.340	-29
Small shellfish (Angulus,Venus)	0	0	3000	0				
Squid - Loligo	12	58	-					
FISH								
Dab - Limanda limanda	206	64	890	23	0.734	167	-0.579	-44
Plaice - Pleuronectes platessa	164	93	610	27	0.997	908	-1769	-83
Flounder - Platichthys flesus	18	72	-		0.683	18	-0.700	-50
Sole - Solea solea	39	77	630	6	0.936	56	-0.897	-59
Roundfish (undersized)	7	70	-		0.453	5	-0.344	-29
Dragonet - Callionymus lyra	4	0	290	1.4				
Gobies - Pomatoschistus spp.	0	0	4760	0				

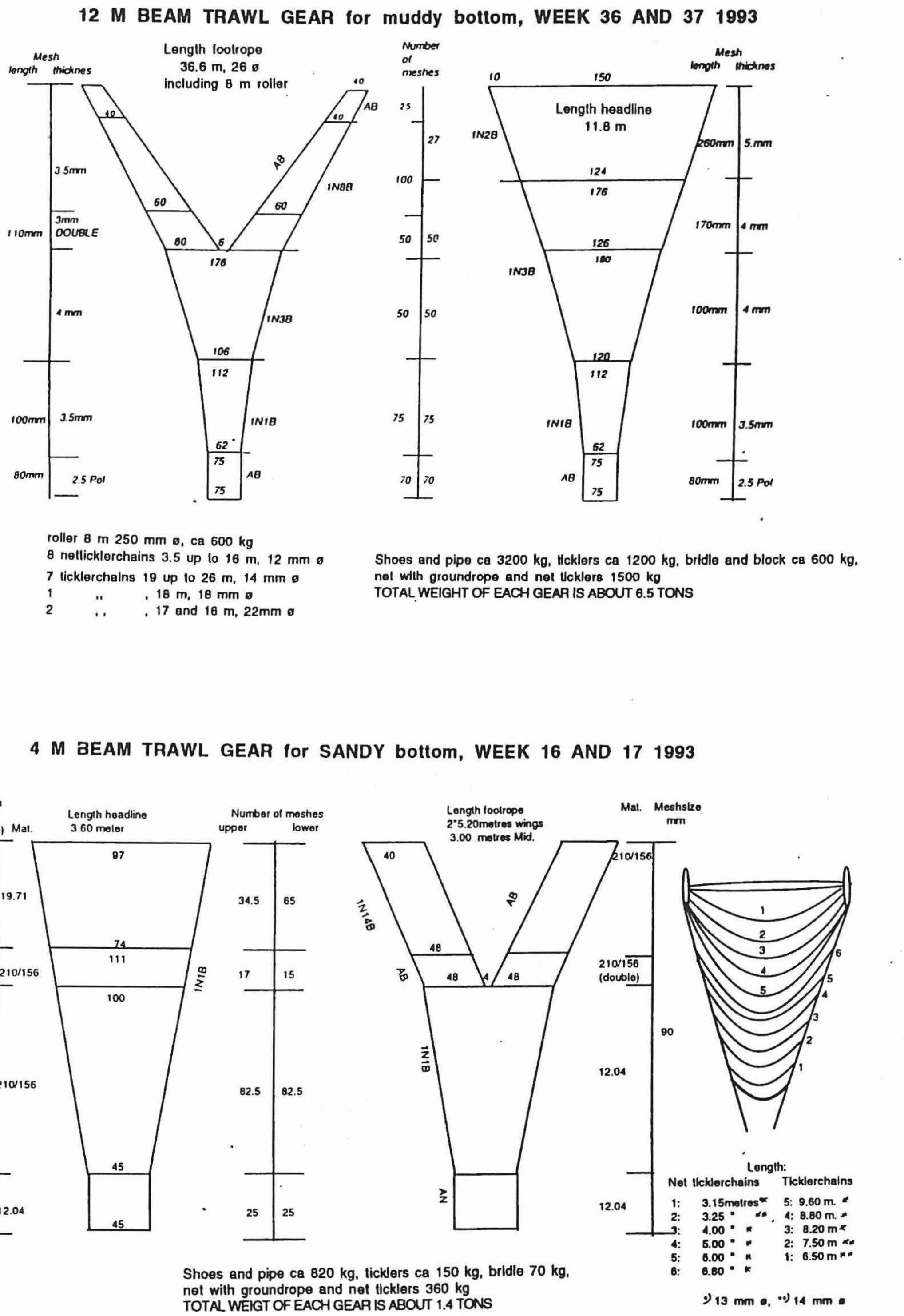

Fig. 1. Structure, size and weight of 16-m beam traw l and 4-m beam trawl (W. Blom, Fisheries Institute IJmuiden).

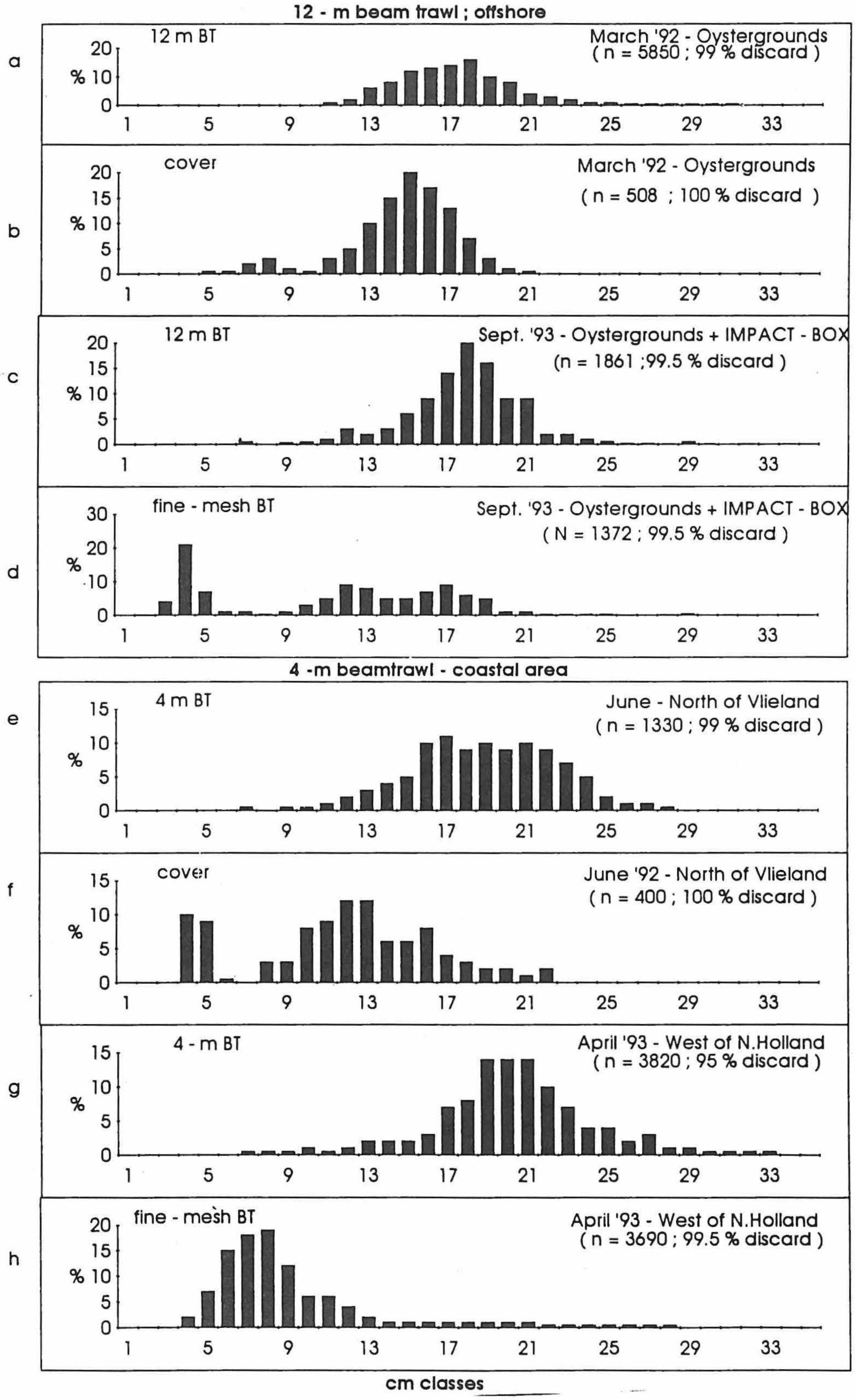

Figure 2. The length frequency distribution of dab *(Limanda limanda)*. Catches with 12-m beam trawls (12mBT) offshore (a,c) and 4-m beam trawls (4mBT) in coastal areas (e,g) compared with catches in fine-meshed cod-end covering net (cover,b,f) or fine-meshed trawl (d,h).

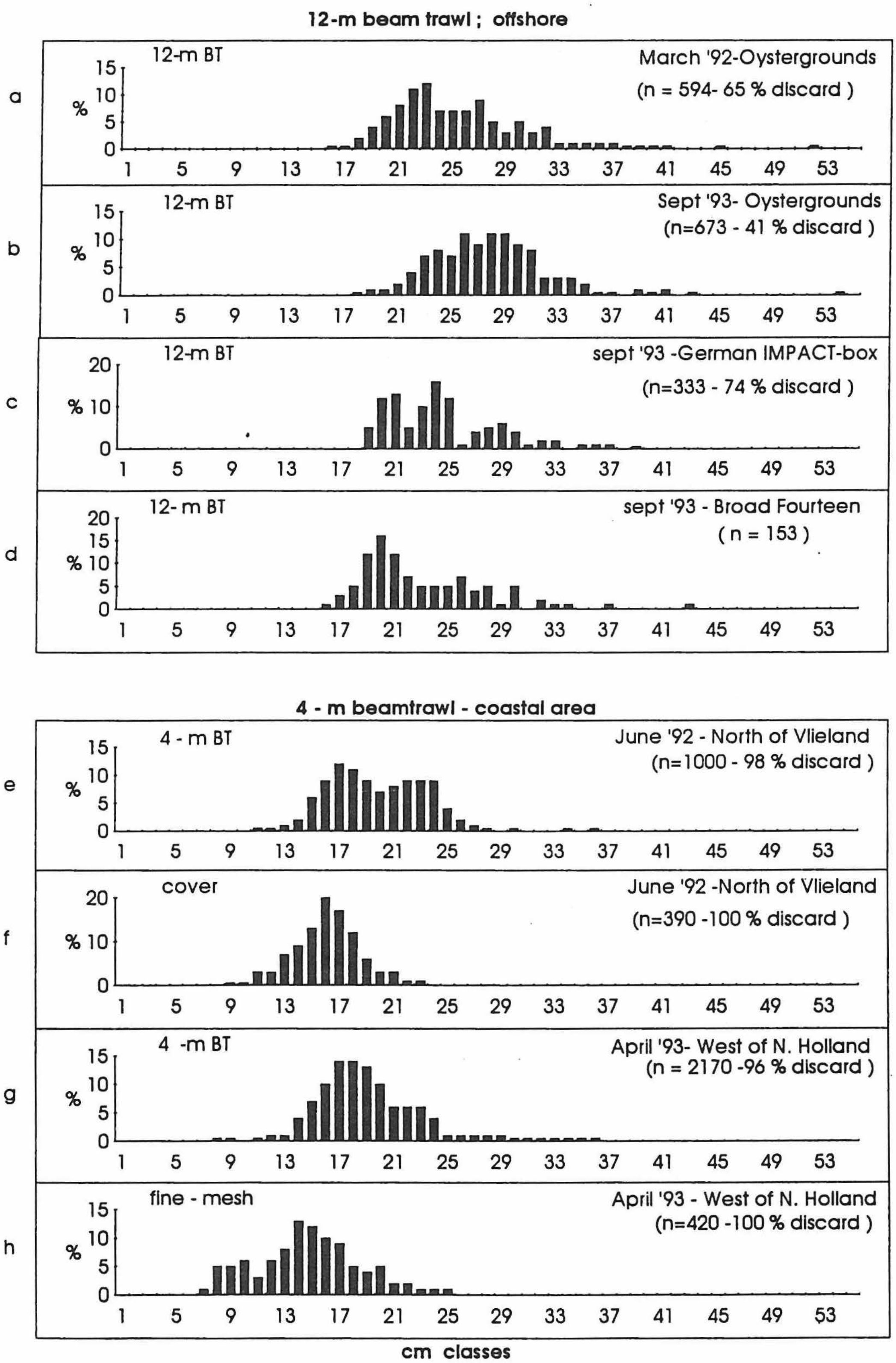

Figure 3. The length frequency distribution of plaice *(Pleuronectes platessa)*. Catches with 12-m beam trawls (12mBT) offshore (a-d) and 4-m beam trawls (4mBT) in coastal areas (e,g) compared with catches in fine-meshed cod-end covering net (cover,f) or fine-meshed trawl (h).

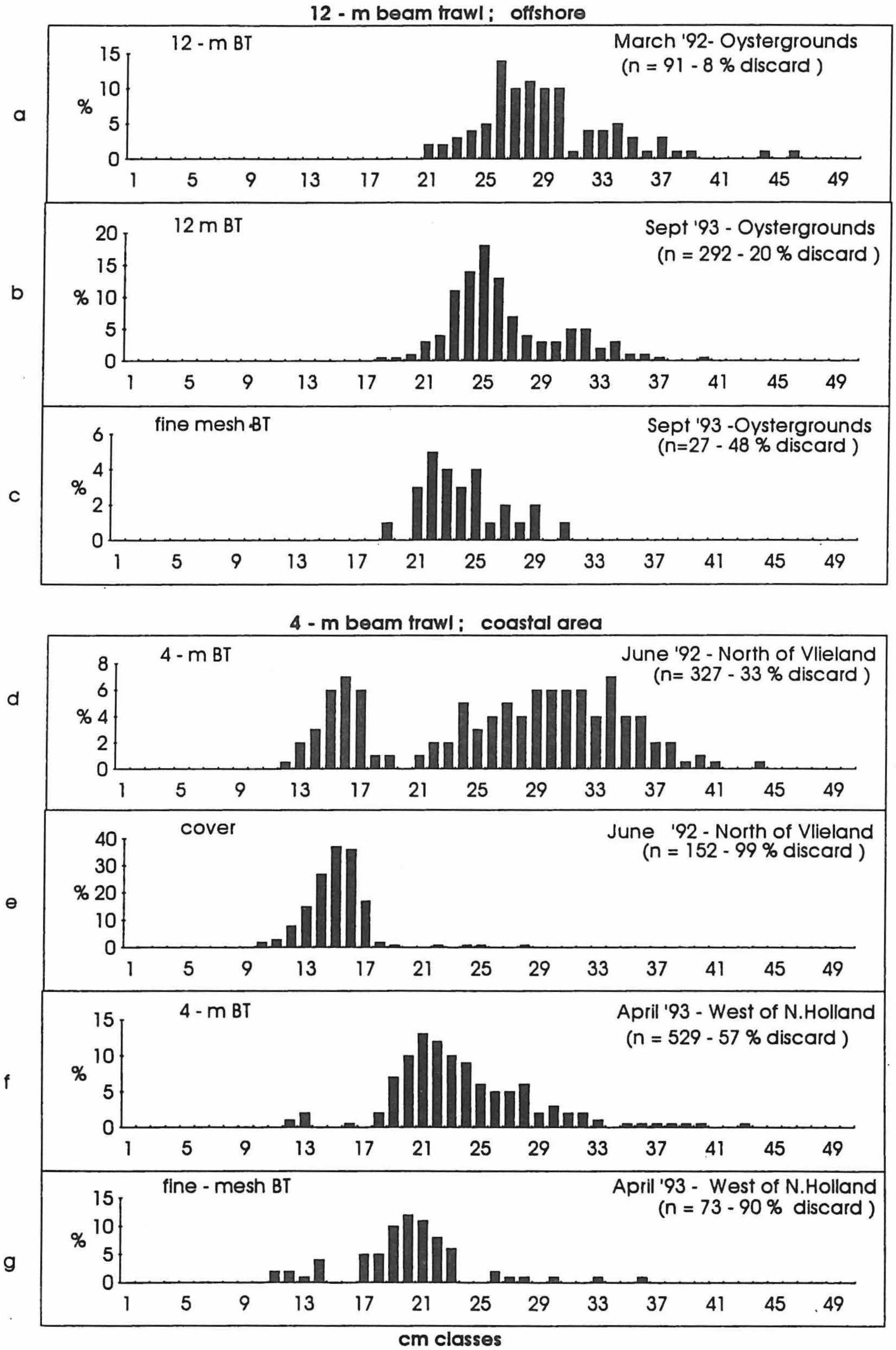

Figure 4. The length frequency distribution of sole *(Solea solea)*. Catches with 12-m beam trawls (12mBT) offshore (a,b) and 4-m beam trawls (4mBT) in coastal areas (d,f) compared with catches in fine-meshed cod-end covering net (cover,e) or fine-meshed trawl (c,g).

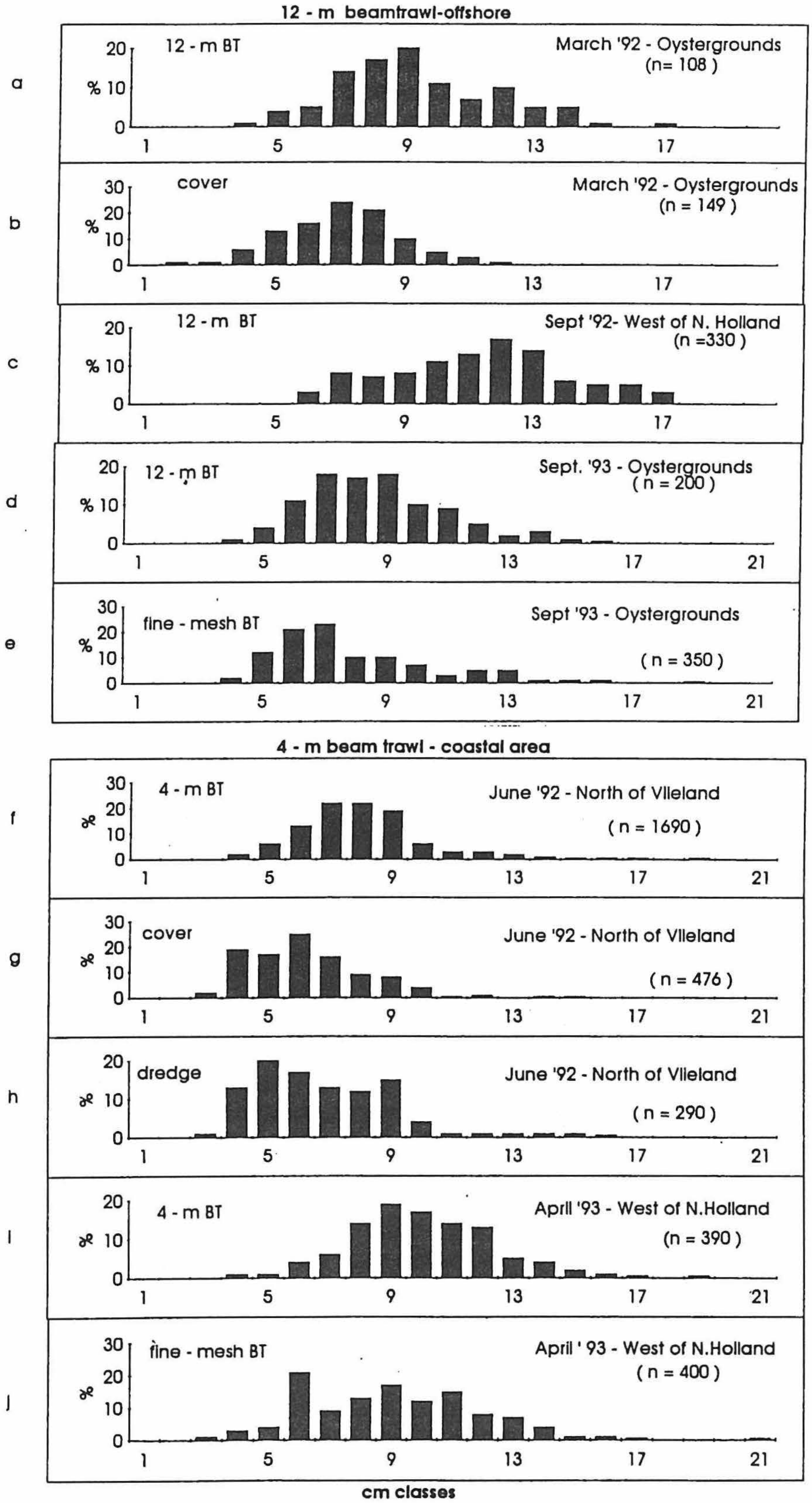

Figure 5. The length frequency distribution of starfish *(Asterias rubens)*. Catches with 12-m beam trawls (12mBT) offshore (a,c,d) and 4-m beam trawls (4mBT) in coastal areas (f,i) compared with catches in fine-meshed cod-end covering net (b,g), fine-meshed trawl (e,j) or dredge (h).

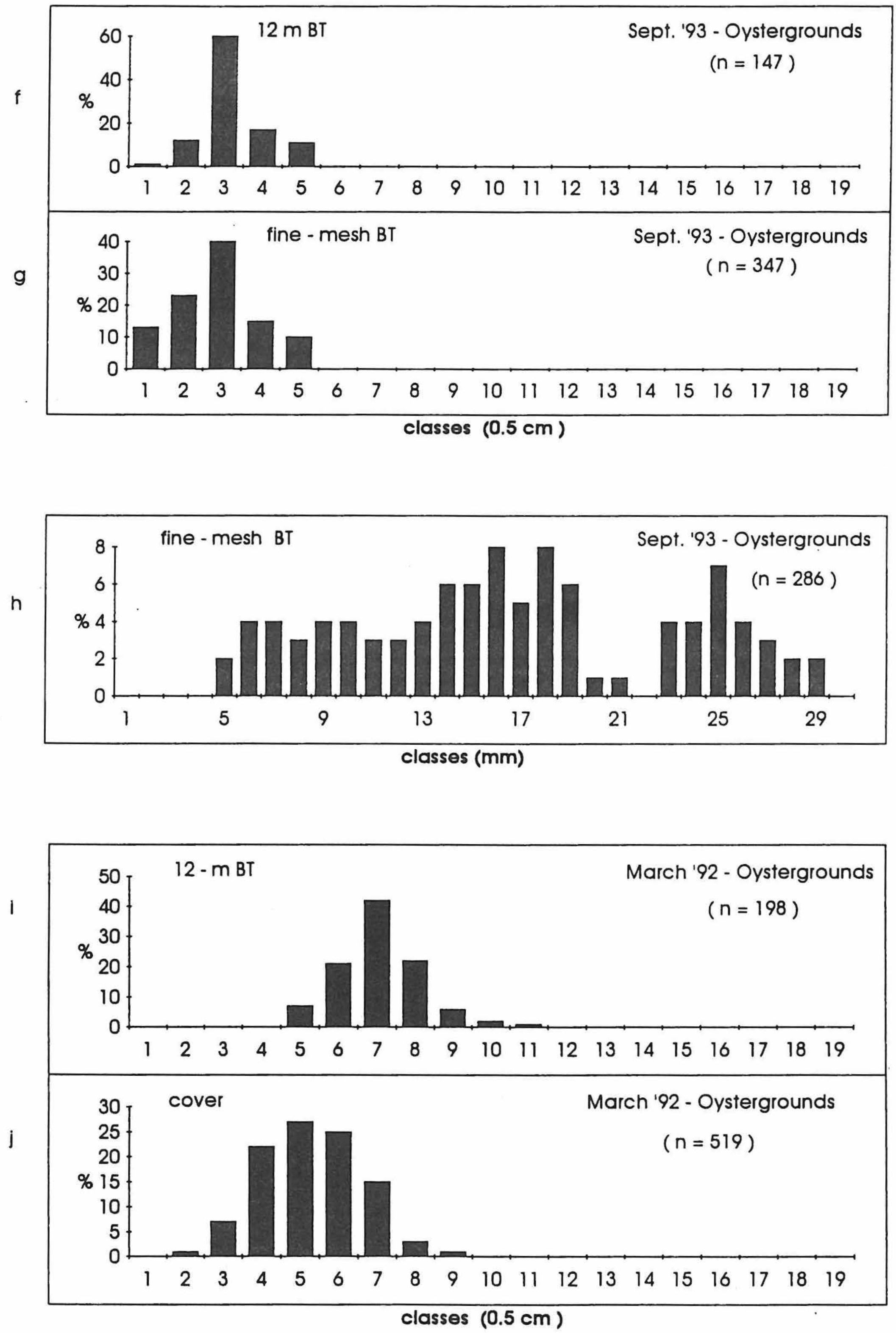

Figure 6. The length frequency distribution of common echinoderms Catches with 12-m beam trawls (12mBT) offshore and 4-m beam trawls (4mBT) in coastal areas, compared with catches in fine-meshed cod-end covering net or fine-meshed trawl. *Astropecten irregularis* (a-e), *Ophiura ophiura* (f-h) and *Echinocardium cordatum* (i-j).

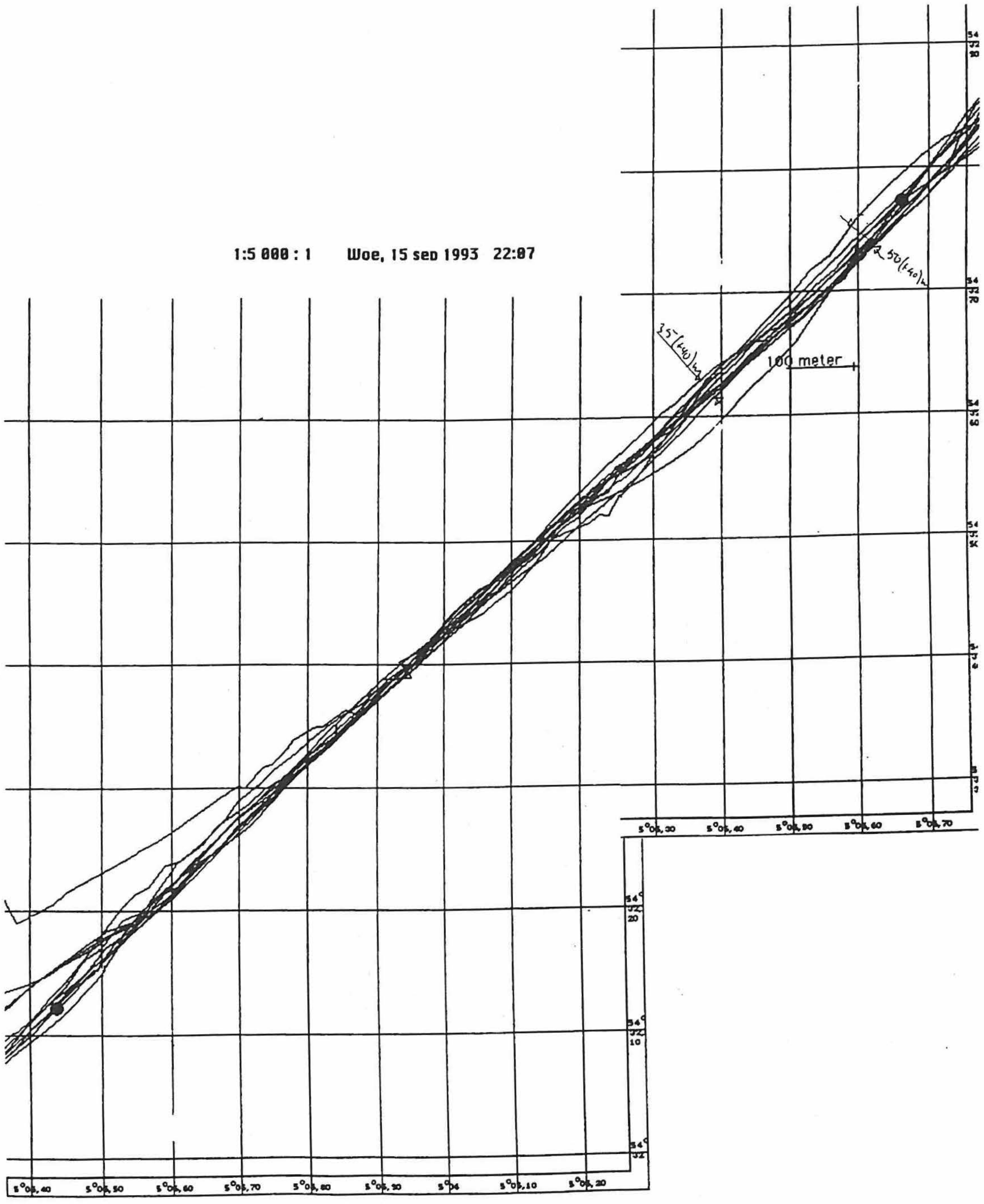

Fig. 7. Plot of the transect repeatedly trawled with 12-m beam trawls by TRIDENS, on 15 September 1993 in the Oystergrounds.

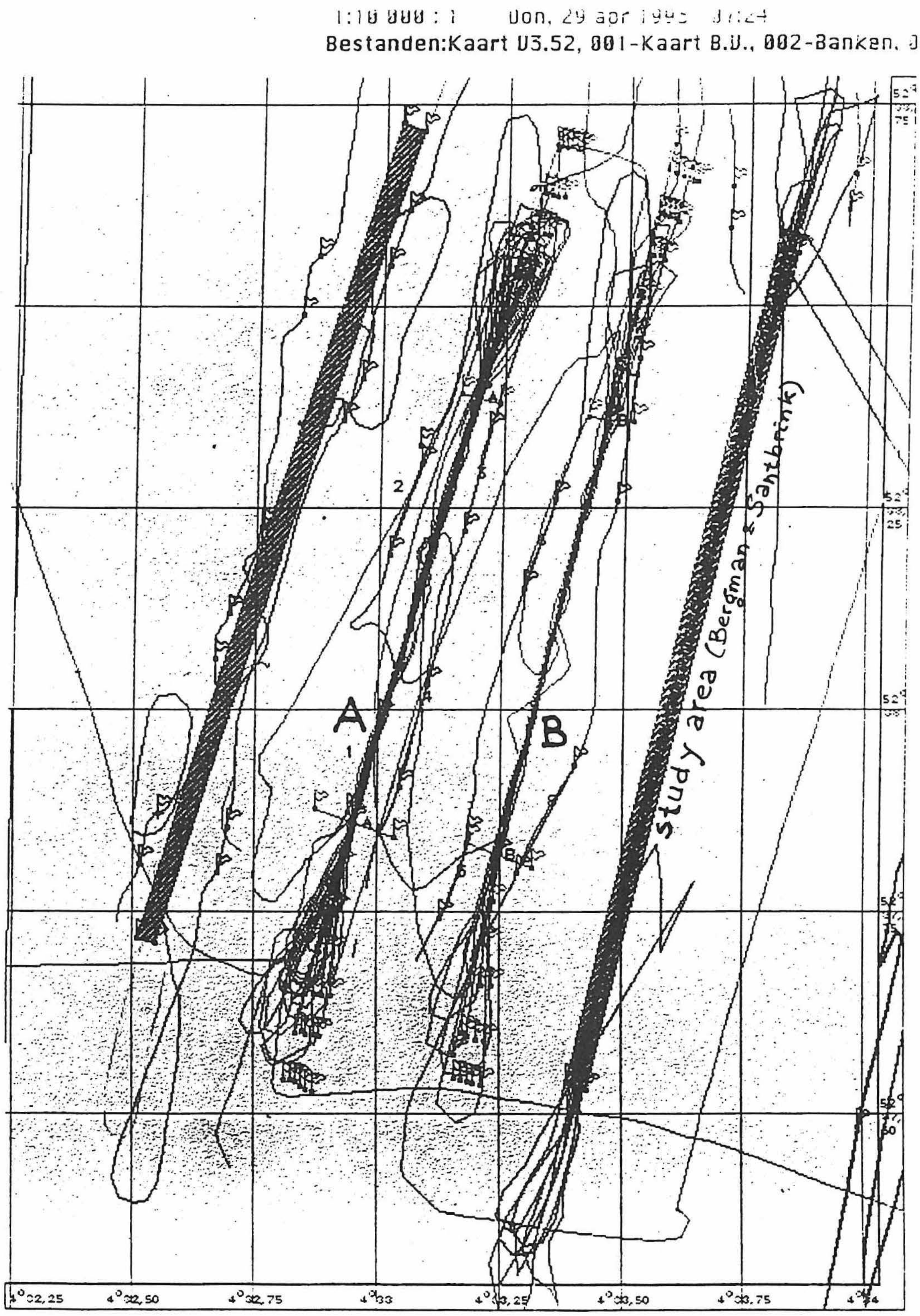

Fig. 8. Plot of the lines trawled with 4-m beam trawls by ISIS on 27-28 April 1993. Line A was trawled 10 times, the reference line B only 3 times. The other marked areas are the experimental plots used for estimations of "Direct effects on bottom fauna" (BERGMAN & VAN SANTBRINK).

MORTALITY OF FISH AND INVERTEBRATES IN BEAM TRAWL CATCHES AND THE SURVIVAL CHANCES OF DISCARDS

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ABSTRACT

Survival experiments have been carried out with fish and invertebrates collected from the by-catch of commercial beam trawls for sole fishing. The percentage mortality of discards was very low for starfish (< 10%), very high for undersized fish (> 90%) and about 30-60% for most crustaceans and shellfish. Of the latter, only whelks and hermit crabs showed a very low mortality. Mortality was lower for discards from 4-m beam trawls as compared to the much heavier 12-m beam trawls. Mortality of small animals that pass through the 8 cm meshes of the nets during trawling ranges from less than 5% for starfish, 10-20% for small fish, 20-30% for crustaceans, to 40-80% for the more vulnerable shellfish.

1. INTRODUCTION

Beam trawls are specifically designed to catch flatfish. When fishing for plaice, the nets have meshes of 20 cm in the front part and 13 cm meshes in the cod end, and five tickler chains in front of the ground chain. Such nets catch relatively few undersized fish and invertebrates and the survival prospects of discards from commercial beam trawling for plaice are relatively high (FONDS *et al.*, 1992).

Beam trawls designed to capture sole have meshes of 10 cm in the front part, 8 cm meshes in the cod end and 8-10 tickler chains in front of the ground chain. Such nets scrape off more sediment and catch a considerable amount of undersized fish and benthic invertebrates (BEON, 1991, 1992). Small fish and invertebrates pass through the meshes, the larger fish and benthos are retained by the net and hauled on board of the trawler. In commercial trawling operations tows of 1 to 2 hours are made and catches amount to 300-1000 kg per net. They are rapidly sorted on a sorting belt to collect the commercial fish. The rest, mainly invertebrates and undersized fish, are discarded back into the sea within about half an hour.

Two main questions arise; (a) what are the survival chances of the discarded animals and (b) what are the survival chances of small animals that pass through the meshes during trawling and that may have been damaged by the ground chains. In order to answer these questions survival experiments were carried out on board of beam trawlers. Fish and invertebrates were collected randomly from the sorting belt to estimate the numbers damaged and dead. Mortality of the survivors was tested in survival tanks with running sea water on board of the trawlers. The combination of direct mortality on the sorting belt and the mortality of survivors estimated in the tanks, gives an impression of the total survival chances of undersized fish and invertebrates discarded by commercial beam trawling for sole.

Two kinds of beam trawling were investigated: trawling with 12-m beam trawls in offshore waters and trawling with 4-m beam trawls in the coastal areas. The total numbers of beam trawlers registrated in Belgium, Holland and Germany are presented by POLET & BLOM (this report). Large trawlers (in the Dutch fleet about 220 ships with 1500-3000 KW) use 12-m beam trawls with 10 tickler chains, trawling with a speed of approximately 6-7 nm/h (11-13 nm/h). They are not allowed to fish within 12 miles of the coast. Smaller beam trawlers with less than 300 KW engines (about 110 ships in the Dutch fleet) are allowed to fish with 4-m beam trawls (usually with 8 tickler chains) in the coastal areas. They trawl at a speed of about 4-5 nm/h (7-9 km/h).

2. METHODS

2.1. STUDY SITES

Trawling with 12-m beam trawls (12mBT) was carried out with the 70 m R.V. TRIDENS, trawling with 4-m beam trawls (4mBT) was carried out with the 25 m R.V. ISIS, both ships from the Directorate of Fisheries of the Ministry of Agriculture, Nature management and Fisheries, The Hague.

Survival of discards was estimated during two cruises with TRIDENS and two cruises with ISIS in the following periods and regions :

Net	Ship	Period	Year	Area	
				North	East
12-m BT	TRIDENS	24 Mrch-2 Apr.	1992	52° 40-52° 50	3° 25-4° 40
		6-16 Sept.	1993	52° 20-52° 42	4° 10-4° 23
			(AWI-exp.area)	54° 14-54° 15	6° 51-6° 52
				54° 15-55° 00	4° 44-5° 07
4-m BT	ISIS	24 June-2July	1992	52° 32-53° 25	4° 32-5° 03
		19-29 April	1993	52° 35-52° 40	4° 25-4° 32

2.2. DISCARD MORTALITY

Direct mortality on the sorting belt was estimated for commercial tows of 1-2 hours. During sorting of the commercial fish the sorting belt was stopped regularly and all animals in a section of the belt were collected in a number of 100 L tubs filled with fresh seawater. The procedure was repeated until the whole catch had been sorted. The tubs were emptied on the sorting belt to count the numbers dead and alive of the different species. The survivors were stored in survival tanks (Fig. 1) with running sea water to test their survival chances over the next 2-3 day.

2.3. SURVIVAL OF ESCAPING ANIMALS

In order to estimate the mortality or survival chances of small animals that pass through the 8 cm meshes of sole nets during trawling, one of the nets was provided with a fine-mesh covering net with meshes of 2 cm stretched. Very short tows of 1-2 minutes were made. After hauling the net, the cod end of the covering net was put immediately in a 100 liter containers with seawater, to be opened under water. The catch in the large mesh cod end of the other net was treated in the same way. Both tubs were carried to the survival tanks to estimate the survival chances of small fish and invertebrates over the next 2-3 days.

2.4. SURVIVAL TESTS

Survival tests with living animals were carried out in "survival tanks" with a continuous sea water flow, designed by the Fisheries Institute IJmuiden (BEEK *et al.*, 1990). The system consists of ten shallow plastic tanks (60 x 40 x 12 cm) stacked on top of each other (see Fig. 1). Originally each tank was provided with one stand pipe of 3 cm diameter and 11.5 cm height. Sea water is pumped in the upper tank and flows through all the tanks below by way of the overflow stand pipes. Fish can not escape because the tanks are stacked closely. The tanks are numbered and two towers with 10 tanks each are supported and secured in a wooden frame on board of the ship. Design and operation of the system is very simple and effective, particularly for flatfish and benthic evertebrates. Two operational problems were solved by minor modifications:

- With only one overflow stand pipe in each tank, in alternating corners, the water flow stopped when the ship was not precisely horizontal. Therefore each tank was provided with two stand pipes in opposite corners.

- Water flow also stopped when one of the overflow pipes was clogged by a small flatfish, starfish or crab. Therefore all pipes were provided with small holes just below the top (Fig. 1).

For some species that live normally buried in the sand, such as the starfish *Astropecten* and the brittle star *Ophiura*, the tanks were initially provided with a thin layer (1 cm) of sand. This made no difference in survival rate in comparison with bare tanks and sand was therefore omitted in later experiments. In some fish species that normally stay buried in the sand bottom, such as lesser weever *Trachinus vipera* and sandeel *Ammodytes*, addition of a 2 cm layer of clean sand in the tank improved survival.

Each tank was stocked with about 25-100 smaller evertebrates, or 25-75 small fish (5-10 cm), or 10-30 larger fish (10-25 cm). Water flow was kept at about 8-10 liters per minute for each tower of 10 tanks. Water temperature was checked regularly: temperature in the tanks was usually about 1 °C higher than the ambient sea water temperature.

Most animals were kept for 2-3 days in the survival tanks. Mortality was checked every day and dead animals were removed, counted and measured. After 2-3 days the surviving animals were counted, measured and released into the sea. Mortality was usually high during the first day, much less during the second day and often nil during the third day.

3. RESULTS

3.1. DISCARD MORTALITY

The percentage animals dead or damaged on the sorting belt during the sorting of commercial catches of 12-m beam trawls are presented in Table 1, together with estimates of mortality of animals in earlier cruises in August 1990 and May 1991 (BEON reports 1991, 1992). Direct mortality was estimated for animals from commercial tows of 1-2 hours and for animals from very short tows of 1-5 minutes. Percentage mortality of animals that were collected alive from the sorting belt and kept in seawater tanks for 2-3 days, is presented in Table 2. For catches with 4-m beam trawls the percentages dead or damaged discards on the sorting belt are presented in Table 3, the % mortality of survivors in seawater tanks is presented in Table 4. The size range of animals used in the survival tests is presented in Table 5. Finally, in Table 6 the overall mean % mortality is estimated as the sum of % dead on the sorting belt and % mortality of discarded survivors.

The mortality of different species in the discards of 4-m beam trawl catches was generally lower than those from the 12-m beam trawls. Vulnerable fish species, such as gadoid fish (mainly *Merlangius & Trisopterus*), gurnards *(Trigla gurnardus & hirundo)*, solenettes *(Buglossidium luteum)*, scaldfish *(Arnoglossus laterna)* and dragonets *(Callionymus lyra)* died when discarded from commercial catches. Invertebrates with rounded strong shells, such as whelks *(Buccinum undatum & Neptunea antiqua)* and Natica *(Euspira catena)*, showed no mortality at all. Hermit crabs *(Eupagurus bernhardus)*, protected by the same shells, always survived. Only hermit crabs that panic and leave their shell during handling of the catch, risk their lives when they are discarded and they are possibly eaten by predators before they have found a new shell. Therefore Table 1 does not show percentage mortality of hermit crabs but the percentage animals that lost their shell.

Starfish *(Asterias rubens, Astropecten irregularis, Ophiura ophiura)* showed very little mortality. Many were damaged, particularly the vulnerable brittle stars *(Ophiura)*. Starfish can easily regenerate lost arms and they showed a remarkably high survival in the survival tanks, even those that had lost all their arms. Populations of *Asterias rubens* in the southern North Sea generally show 20-30% individuals with missing or regenerating arms, possibly due to the beam trawl fishery.

Large vulnerable shellfish, such as the Quahog *(Arctica islandica)* in 12-m beam trawl catches on the oyster grounds and *Mactra corallina* in 4-m beam trawl catches in coastal areas, showed high mortalities of approximately 85% because they were broken by the tickler chains.

Quahogs also broke during processing and sorting of catches, when they dropped on the steel floor of the fish-hold or from the carry-up conveyor belt on the sorting belt. Catches from very short tows were carefully collected in tubs with sea water and therefore give an impression of damage by the tickler chains. This damage was at least 75%, but lower for catches from soft (muddy) bottom (45%, Table 1).

Smaller shellfish (mainly *Acanthocardia echinata, Spisula elliptica* & *subtruncata, Donax vittatus, Chamaelia striata* and *Dosinia lupinus*) suffered less damage, approximately 30-50%. Intact shellfish stored in the survival tanks usually showed little mortality.

Mortality of crabs in catches after short tows was lower than in commercial catches, indicating that the mortality was due to both the damaging effect of the tickler chains as well as the effect of being pressed in the bulk of the catch. Secondary mortality of crabs that were collected alive from the sorting belt was low (about 15-25%). Edible crab (*Cancer pagurus*) sometimes showed a high proportion of "decarapitated" animals (84%, Table 1): the upper half of the carapace was chopped off by the tickler chains as the crabs were buried in the sand bottom. Edible crabs are active during the night and than suffer less from the effect of trawling. The masked crab *Corystes cassivelaunus* also buries in the bottom and therefore suffers more from the scraping effect of the tickler chains, leading to a total mortality of about 66% in the 12-m beam trawl catches (Table 5).

The total mortality of undersized flatfish in the discards was very high, approximately 90-100% for most species (Table 5). Dab (*Limanda limanda*) appears to be more vulnerable than the other species. Sole (Solea solea), flounder (*Platichthys flesus*) and turbot (*Scophthalmus maximus*) appeared to be more hardy species, showing a mortality of about 85% in the 4-m beam trawl catches.

When only the most abundant and common animals in the catches are considered, the mortality of discards can be summarized as follows :

	Direct mort.		Secondary		Total mort.	
Trawl type:	12M	4M	12M	4M	12M	4M
Starfish:						
(*Asterias, Astropecten,Ophiura*)	4%	0%	12%	7%	15%	7%
Crabs:						
(*Corystes, Liocarcinus, Cancer*)	43%	26%	30%	22%	60%	42%
Small shellfish:						
(*Acanthocardia, Spisula, Venus*)	48%	33%	4%	1-7%	50%	38%
Flatfish:						
(Sole, plaice, dab, turbot)	45%	75%	96%	70%	98%	93%

3.2. DAMAGE OF ANIMALS ESCAPING THROUGH THE MESHES

It appeared to be very difficult to estimate the survival chances of small fish that pass through the 8 cm meshes of commercial sole nets. In order to collect these fish the codend of the large net was covered with a fine-meshed covering net. However, this inevitably means that the fish were still caught in a net. In general, fish in the codend suffered most from skin damage due to "sharp" evertebrates in the catch, such as Starfish (*Asterias & Astropecten*) or Sea urchins (*Echinocardium*). In areas where such echinoderms were abundant they dominated in the catches. Many small starfish and sea urchins passed through the 8 cm meshes of the sole net and accumulated in the covering net, even in short tows. In such areas small fish in the covering net were often embedded in a mass of echinoderms, which resulted in very high mortalities. It was obvious that this was mainly due to crowded conditions in the fine-meshed covering net, and not representative for fish escaping through the meshes of the commercial nets during trawling.

In order to minimize the effect of by-catch, areas were sought with low densities of starfish and sea urchins. This appeared to be difficult because these animals are abundant everywhere in the southern North Sea. Tows with the covering net were also kept as short as possible, tows of more than 5 minutes often already contained so much by-catch as to render them unsuitable for survival experiments. The percentage mortality estimated in short hauls, as presented in Table 2 and 3, represents a maximum value, the actual mortality of small fish that escape through the meshes is probably lower. Some very vulnerable species, such as Solenette *(Buglossidium)*, Scaldfish *(Arnoglossus)*, gurnards *(Trigla)* and whiting *(Merlangius)* always showed a very high mortality, even with very short tows in areas with less starfish. Survival chances of these fish can not be estimated with a fine-meshed covering net. Dab appeared to be more vulnerable than Sole or Plaice, suffering more from the damaging effect of echinoderm by-catch, even in very short tows (Tables 1-3). The actual survival of small dab passing through the 8 cm meshes is probably lower, as shown by the value of 12% (1992, Table 2) observed in a catch that contained few starfish.

3.3. SURVIVAL TANKS

Experiments with survival tanks on board of the trawlers were in general successful for most of the larger flatfish and invertebrates. Mortality was usually high in the first day and decreased during the second and third day. However, for some species the mortality increased in the course of three days, indicating that the survival tank system was not optimal for keeping these animals in good condition.

Temperature affected the mortality of fish in the survival tanks, eg. percentage mortality was in general higher at higher temperatures. This may have been a "tank effect"; the effect of crowded conditions in the survival tanks would be more pronounced at higher temperatures.

Some problems that may have affected the survival of animals have to be considered.

- With rough weather the tanks swayed with the movement of the ship, which resulted in a very high mortality, but only of scaled flatfish species such as sole and dab. The fish were not able to maintain position on the smooth surface of the plastic tanks and they were shuffled over each other. This resulted in skin erosion and high mortality because they damaged each other with their scales. These data have not been included in our estimates of mortality. Estimates of the survival of fish in tanks on board can only be carried out in reasonable wheather or, with rough weather conditions, only on a stable (large) ship (e.g. Tridens).
- For some invertebrate species the percentage mortality of survivors in the seawater tanks was estimated for only two days. Mortality of swimming crabs often increased during the third day, because the surviving crabs became too lively and showed increasing aggressive behaviour, possibly due to hunger.
- For some small fish species the plastic tanks appeared to be less suitable. For example, lesser weever (*Trachinus vipera*) showed increasing mortality rates over 3 days, in stead of the expected decrease in mortality. These fish normally stay buried in the sand and they had problems in staying upright in a bare plastic tank. The weevers were often lying on their side and showed rapidly increasing infection with *Vibrio* and increasing mortality obviously caused by the conditions in the tank system. With a layer of 2-3 cm clean sand in the tank survival of the fish improved, but they still suffered from Vibriosis. For this species percentage mortality was estimated only for one day.

4. DISCUSSION

4.1. SURVIVAL CHANCES OF DISCARDS

In general the mortality of starfish was low, mortality of molluscs much higher and mortality of fish very high. The experiments with survival tanks can only give an estimate of the survival. It is not possible to give a precise estimate of the survival chances for the different species in the field, because damage and the survival prospects of discards depend on many factors such as bottom substrate (sandy or muddy), the method of fishing (trawling light with short lines, or heavy with long lines), the type of nets (4-mBT or 12-mBT), numbers and weight of tickler chains, size and composition of the catch (amount of echinoderms), etc. The method of fishing is rather variable, adapted to season or area, and also depends on the skill of the skipper. A proper analysis of the effect of all these factors would ask for a special investigation, which is beyond the scope of this report. The effect of haul duration and numbers of tickler chains, on the condition and survival chances of discarded undersized plaice and sole were estimated by BEEK *et al.* (1990). In general, the data presented here confirm their conclusions. Many factors affected the survival chances of the discard fish, such as catch size, catch composition, numbers of tickler chains, temperature, and in particular the duration of the hauls. According to BEEK *et al.* (1990) the % survival chances (S%) of discard plaice and sole decreased with increasing haul duration (t, minutes) according to the linear equation: $S_t= S_o\text{-}B^*t$. The % survival of sole discards was estimated at about 10% for hauls of 2 hours, about 25% for hauls of 1 hour, and S_o was estimated at 50-60%, indicating that 40-50% of the fish were already lethally damaged by the tickler chains when they entered the net at t=0. This is not in agreement with the high survival rates observed in our experiments with very short hauls of ≤ 5 minutes (usually 80-90% survival for plaice and sole). In fact, the relationship between % survival (S%) and haul duration (t) is probably exponential, according to the equation $S_t= S_o.e\text{-}exp.^{-B^*t}$ (FONDS *et al.*, 1992). This sets the value of S_o at 80-90%, indicating that the damaging effect of the tickler chains is lower than suggested by BEEK *et al.* (1990).

In commercial catches many animals are damaged because they are pressed together in the large mass of the catch, while some animals become damaged as they drop on the steel floor of the fish-hold or from the carry-up belt on the sorting belt. Mortality and damage of animals in very short tows, where the catches were collected in tubs with sea water and not sorted over the bellt, may give an impression of the damaging effect of the tickler chains. For several species the direct mortality in short hauls was similar as for commercial tows, e.g. masked crabs, quahog, Spiny cockle. This indicates that these species are mainly damaged by the tickler chains. For swimming crabs and flatfish the direct mortality in short tows was lower than in commercial hauls, indicating that the tickler chains may have some effect, but that the mass of the catch and the sorting procedure further reduced the survival chances. Secondary mortality of crabs in the seawater tanks was more similar for short and for long tows. Mortality of flatfish discards from commercial hauls was very high, highest for dab (Table 5), survival chances for roundfish were nil.

Mortality of invertebrates and flatfish were slightly lower in catches with the 4 meter beam trawl as compared to the 12-m beam trawl (Table 6). This is probably due to the lower weight, lower number of tickler chains and lower trawling speed of 4-m beam trawls.

Similar suvival experiments have been carried out by KAISER & SPENCER (1993) and CRAEYMEERSCH (1994) with animals collected from catches with 4-m beam trawls. Mortality rates of invertebrates were similar as the rates reported here, and they were mainly attributed to the damaging effect of tickler chains. However, the mortality of plaice *(Pleuronectes platessa)* reported by KAISER & SPENCER and by CRAEYMEERSCH was much lower (< 40%). This may have been due to differences in trawling time (0.5 hrs is mentioned by KAISER & SPENCER), differences in size and composition of the catch, and differences in handling of the catch (no sorting belt). On modern beam trawlers sorting of the catches from a conveyor belt, washed with sewater from the deckwash, proceeds fairly rapidly (≤ ½ hr) and adds little to the mortality of discarded undersized fish (BEEK *et al.*, 1990). The mortality of fish in commercial hauls with beam trawls depends very much on the size and composition of the catch. Massive catches containing many starfish lead to much higher mortalities, and this was the case in the trawling surveys by R.V. ISIS with 4-m beam trawls in the Dutch coastal areas. Plaice collected from low catches with a 12-m plaice-beam trawl (10 cm mesh-size) showed much higher survival rates as compared to plaice caught in massive catches with 12-m sole beam trawl, carried out at the same time and place (FONDS *et al.*, 1992).

The duration of hauls by commercial beam trawling will always be at least about 1-2 hours and the catches are probably always massive, otherwise beam trawling would not be profitable. For an assesment of the survival chances of discards from commercial beam trawling, it is important to simulate as much as possible the normal procedures of commercial trawling or, even better, carry out survival experiments on board of commercial trawlers (see BEEK *et al.*, 1990). In future experiments more attention should be paid to the initial mortality observed in sorting of the catch.

The results can be summarized as follows:

Mortality of starfish was very low, generally less than 10%, with the exception of brittle stars (*Ophiura*, 10-25%) and 100% mortality for very vulnerable species like *Luidia sarsi* (large specimens in commercial hauls). Some species of sea urchins like *Echinus* and *Psamechinus* likewise showed little mortality. However, the very vulnerable sea urchin *Echinocardium cordatum* showed 100% mortality. *Echinocardium* is very abundant in the southern North Sea, living in the sand bottom to a depth of 5-10 cm below the surface.

Commercial hauls often contain large numbers of *Echinocardium*, which are all broken into pieces or damaged beyond repair.

Crustaceans showed about 50% (4mBT) - 60% (12mBT) mortality, with the exception of hermit crabs that are protected by their shell. Only the 14% hermit crabs that have lost their shell during handling and sorting of the catch may be eaten by predators when they are discarded.

Small molluscs *(Spisula, Donax, Venus)* are damaged for about 25%, larger species like *Mactra* & *Acanthocardium* for at least 50%, while about 85-90% of Quahogs *(Arctica islandica)* are damaged. This is mainly due to the tickler chains, with additional mortality of *Arctica* because some break during sorting of the catch. *Arctica* caught on soft muddy bottom may show a lower mortality (Table 1), possibly because the shells are more easily dug out by the tickler chains as compared to a harder sandy substrate.

Survival chances of flatfish discards are very low. In 12-m beam trawl catches sole and plaice may show some 5% survival and this probably concerns mainly the fish that entered the net shortly before hauling. Dab appear to be more vulnerable, with a survival chance of discards of 1% or less. Mortality of discard flatfish from commercial catches with 4-m beam trawls appears to be lower, but still 85% for the more hardy species (sole, flounder and turbot) and between 90-100% for plaice, dab and brill.

Roundfish (whiting, gurnards, etc.) discarded during commercial fishing have no survival chance at all, neither in 4mBT nor in 12mBT.

4.2. MORTALITY OF ANIMALS THAT PASS THROUGH THE MESHES

Invertebrates that passed undamaged through the meshes of commercial sole nets showed little mortality afterwards. Most of the observed mortalities were due to damage by the tickler chains. Additional mortality of some species collected from very short tows probably concerned those animals that had suffered invisible damage. For starfish the mortality was very low, less than 5%, even for the very vulnerable species *Luidia sarsi* (small specimens of about 2-4 cm diameter). Molluscs that were still visibly intact and alive similarly showed a low mortality in survival tanks 2-3 days after catch. They may have suffered invisible damage and show some mortality over the following weeks. Living crustaceans from the 12mBT showed a higher secondary mortality and a rather high value for masked crab *(Corystes)*. These crabs are usually buried in the bottom and they are possibly damaged more than other crabs when they are dug out by the tickler chains. Percentage mortality for small crustaceans, like *Crangon* or juvenile crabs, were generally low. Small animals have little resistance in the water column and they are probably pushed aside or upwards by the tickler chains, passing through the meshes without much harm.

Survival chances of flatfish in very short hauls suffered from problems of the damaging effect of echinoderm bycatch. Hence, the observed mortalities are overestimations, the actual mortality of fish that escape through the meshes in the sea is probably much lower. In general this mortality is probably not more than about 10-15%, and for plaice even lower (5%). However, for soles escaping from the 12 meter beam trawl the data suggest a higher mortality of about 20%. Sole are buried deeper in the sand than other flatfish. That is the main reason why sole nets have to be equipped with so many tickler chains. A higher mortality of soles escaping through the meshes is possibly due to the fact that they are dug up with more force because they react later when the tickler chains pass over their head. Nevertheless, according to observations, the survival chances of undersized sole and plaice passing through the meshes of commercial beam tral nets, are higher (80-90%) than estimated by BEEK *et al.*, 1990 : 50-60%), indicating less damage by the tickler chains.

Attempts to estimate the survival chances of small flatfish species that pass through the meshes, failed because these species are so vulnerable that they suffered heavily from the damaging effect of bycatch in the covering net, even in very short tows. The same can be said for small roundfish (young gadoids, gurnards, sandeels, etc.). The additions of sand in survival tanks for the more vulnerable small fish species (Solenette, lesser weever, sandeels etc.) has to be reconsidered. Lesser weever *(Trachinus vipera)* showed a fairly low mortality of 6% after one day. Similar values were observed in some experiments with hooknose (*Agonus*, Table 2) and gobies (Table 3). Low mortalities of 6-12% (Table 2) and 11-17% (Table 3) were observed for plaice and dab collected from short tows. On account of these observations we may presume that the survival chances of small fish that pass through the meshes are probably high, in the same order of magnitude as for undersized sole, plaice and dab. When small fish escape immediately through the meshes, the mortality due to the ground chains of the nets is probably not more than 10-15%.

In general, the mortality rates estimated for invertebrates and fish in commercial hauls indicate that most of the undersized flatfish are killed and discarded together with relatively unharmed starfish,

The starfish *Asterias* is a wellknown scavenger, that certainly also eats dead fish, while *Astropecten* is also able to eat dead fish (pers. obs.). Small fish that pass through the meshes are probably hardly affected, while the large fish are taken away leading to reduced food competition and predation for the small fish. This suggests that beam trawl fishery for soles may have a negative effect on populations of commercial flatfish (particularly dab, *Limanda limanda*) and a positive effect on populations of starfish *(Asterias)* and small fish species such as Solenette *(Buglossidium)*, Scaldfish *(Arnoglossus)*, Dragonets *(Callionymus)*, lesser weever *(Trachinus vipera)*, sandeels *(Ammodytes)* and gobies (*Pomatoschistus*).

SUMMARY

Survival experiments with fish and invertebrates from the by-catch of beam trawls indicate that the mortality of discarded undersized fish in commercial trawling is very high, while the mortality of discarded starfish appears to be very low. Mortality of crustaceans and shellfish varies between 30 and 90%, and is generally lower for catches with 4-m beam trawls as compared to 12-m beam trawls. The survival chances for small fish that escape through the 8 cm meshes of sole nets are high, probably 80-90%. Crabs and shellfish that pass through the meshes are damaged by the tickler chains and their mortality is estimated at about 10-30% for crabs and 25-75% for shellfish.

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Table 1.

Direct mortality of animals in catches with 12m-beam trawl. Percentage animals dead on the sorting belt after short tows (1-5 minutes) and commercial tows (1-2 hours) at 35-55 m depth. In brackets the numbers of animals counted.

	Short tows of 1-5 minutes						**Commercial tows of 1-2 hours**					
	March-April		September		August		May		March-April		September	
	1992		1993		1990		1991		1992		1993	
	Mort.		**Mort.**		**Mort.**		**Mort.**		**Mort.**		**Mort.**	
	%	*(n)*	%	*(n)*	%	*(n)*	%	*(n)*	%	*(n)*	%	*(n)*
Starfish - Asterias							**2%**	*.(950)*				
Starfish - Astropecten							**4%**	*.(658)*				
Brittle star - Ophiura							**5%**	*.(789)*				
Masked crab - Corystes	**32%**	*.(357)*					**42%**	*.(4200)*	**39%**	*.(696)*		
Swimming crab-Liocarcinu	**25%**	*.(414)*			**53%**	*.(66)*	**44%**	*.(380)*	**52%**	*.(146)*	**42%**	*.(215)*
Hermit crab - Eupagurus	**18%**	*.(240)*	without shell)				**18%**	*.(456)*				
Edible crab - Cancer					**46%**	*.(68)*	**84%**	*.(45)*	**40%**	*.(14)*	**41%**	*.(70)*
Quahog - Arctica	**73%**	*.(66)*	**81%**	*.(118)*	**74%**	*.(231)*	**94%**	*.(419)*	**87%**	*.1384*	**84%**	*.(84)*
Arctica on soft bottom :			**45%**	*.(358)*								
Cockle - Acanthocardia	**50%**	*.(66)*	**45%**	*.(403)*	**42%**	*.(104)*	**54%**	*.(220)*	**44%**	*.(898)*	**52%**	*.(529)*
Dosinia lupinus							**10%**					
Spisula elliptica											**24%**	*.(102)*
Whelk - Buccinum					**0%**	*.(27)*	**0%**	*.(153)*			**0%**	*.(198)*
Sea mous - Aphrodyte							**1%**	*.(377)*				
Fish :												
Sole - Solea solea											**47%**	*.(55)*
Plaice - Pleuronectes									**42%**	**.(48)**	**34%**	*.(93)*
Dab - Limanda	**31%**	*.(94)*							**57%**	**.(108)**	**67%**	*.(74)*
Turbot (Scophthalmus) &											**33%**	*.(9)*
Brill (Rhombus)											**.(9)**	
Gurnards - Trigla	**45%**	*.(33)*							**65%**	**.(81)**	**73%**	*.(73)*

Table 2

Secondary mortality of animals in discards of 12m-beam trawl fishing. Percentage mortality of animals collected alive from catches after short tows (1-5 minutes) and commercial tows (1-2 hours) at 35-55 m depth. The animals were stored in survival tanks with running sea water for 2-3 days. In brackets the total numbers of animals in the tests.

	Short tows (1-5 min).						Commercial tows (1-2 hrs).					
Period :	August		March-April		September		August		May		September	
	1990		1992		1993		.1990		1991		1993	
Water temperature, oC :	17-19		9-11		16-17		17-19		9-11		16-17	
	Mort.	*(n)*	**Mort.**	*(n)*	**Mort.**	*(n)*	**Mort.**	*(n)*	**Mort.**	*(n)*	**Mort.**	*(n)*
	%		%		%		%		%		%	
Starfish - Asterias rubens									4%	.(550)	3%	.(215)
Starfish - Astropecten irregularis			3%	.(270)			9%	.(233)	10%	.(163)	4%	.(214)
Brittle star - Ophiura texturata			1%	.(600)			29%	.(112)	8%	.(656)	31%	.(328)
Luidia sarsi			2%	.(246)								
Masked crab-Corystes cassivelaunus			32%	.(536)					43%	.(746)		
Swimming crab-Liocarcinus spp.			17%	.(529)			16%	.(61)	15%	.(151)	23%	.(321)
Hermit crab - Eupagurus bernhardus							9%	.(112)	13%	.(112)		
Edible crab - Cancer pagurus							27%	.(26)			28%	.(29)
Langoustine - Nephrops norvegicus			18%	.(40)								
Quahog - Arctica islandica							0%	.(54)	13%	.(30)	7%	.(15)
Spiny cockle-Acanthocardia echinata							3%	.(58)	8%	.(50)	3%	.(391)
Spisula elliptica											3%	.(134)
Scallop - Chlamys opercularis									0%	.(52)		
Whelk - Buccinum undatum							0%	.(20)	0%	.(138)	0%	.(36)
Natica - Euspira catena			0%	.(10)								
Sea mous - Aphrodyte aculeata			1%	.(511)	4%	.(142)			5%	.(246)	4%	.(142)
Fish												
Sole - Solea solea	17%	.(29)	24%	.(34)	23%	.(35)					91%	.(57)
Plaice - Pleuronectes platessa	13%	.(29)	6%	.(164)	22%	.(90)					92%	.(85)
Dab - Limanda limanda	29%	.(24)	12%	.(484)	45%	.(210)					99%	.(87)
Turbot-Scophthalmus maximus											100%	.(6)
Scaldfish - Arnoglossus laterna			100%	.(21)	100%	.(12)						
Solenette - Buglossidium luteum	0%	.(74)	25%	.(63)	24%	.(92)						
Lemon sole - Microstomus witt					0%	.(2)						
Lesser weever - Trachinus vipera			6%	.(35)	6%	.(219)						
Dragonet - Callionymus lyra			50%	.(12)	45%	.(11)						
Hooknose - Agonus cataphractus			0%	.(7)								
Gurnards-Trigla gurnards & hirundo					100%	.(18)					100%	.(20)
Whiting - Merlangius merlangus					100%	.(42)						

Table 3.

Direct mortality of animals in catches with 4m-beam trawl. Percentages of animals dead on the sorting belt after very short tows (1-5 minutes) and after commercial tows (1-2 hours). In brackets the numbers of animals counted.

	Short	**tows**	**(1-5**	**min.)**		**Comm.**	**tows**	**(1-2**	**hrs)**
Period :	June		April			June		April	
	1992		1993			1992		1993	
Number of hauls :	15		10			4		4	
	Mort.	*(n)*	**Mort.**	*(n)*		**Mort.**	*(n)*	**Mort.**	*(n)*
	%		%			%		%	
Spisula subtruncata	**24**	*.(97)*	**40**	*.(417)*				**32**	*.(210)*
Mactra corallina			**.87**	*.(54)*				**78**	*.(9)*
Corystes cassivelaunus						**29**	*.(17)*		
Liocarcinus holsatus	7	*.(2140)*	**12**	*.(26)*		**22**	*.(701)*	**33**	*.(36)*
Cancer pagurus						**22**	*.(49)*		
Solea solea								**60**	*.(5)*
Pleuronectes platessa						**77**	*.(144)*	**29**	*.(45)*
Limanda limanda						**94**	*.(64)*	**97**	*.(115)*
Platichthys flesus						**89**	*.(8)*	**6**	*.(52)*
Scophthalmus maximus						**79**	*.(28)*		

Table 4

Secondary mortality of animals discarded from catches with 4m-beam trawl. Percentage mortality of animals collected from very short tows (1-5 minutes) and from commercial tows (1-2 hours) and stored alive in survival tanks with running sea water. In brackets the numbers of animals.

	Short tows (1-5 min).				Commercial tows (1-2 hrs).			
Period :	June		April		June		April	
	1992		1993		1992		1993	
Number of tows :	12		4		7		3	
Water temperature, oC :	17-19		9-11		17-19		9-11	
	Mort.	*.(n)*	**Mort.**	*.(n)*	**Mort.**	*.(n)*	**Mort.**	*.(n)*
	%		%		%		%	
Starfish - Asterias rubens					**4%**	*.(200)*		
Starfish - Astropecten irreg.					**7%**	*.(88)*		
Brittle star - Ophiura text.	**9%**	*.(85)*			**9%**	*.(153)*		
Spisula subtruncata	**9%**	*.(126)*	**11%**	*.(164)*			**1%**	*.(245)*
Masked crab-Corystes cassiv.					**30%**	*.(10)*		
Swimming crab-Liocarcinus	**9%**	*.(54)*	**4%**	*.(26)*	**22%**	*.(117)*		
Hermit crabs-Eupagurus					**7%**	*.(27)*		
Edible crab - Cancer pagurus					**15%**	*.(41)*		
Brown shrimp - Crangon			**8%**	*.(106)*				
Sole - Solea solea	**15%**	*.(169)*	**11%**	*.(103)*	**67%**	*.(27)*	**55%**	*.(99)*
Plaice - Pleuronectes platessa	**12%**	*.(125)*	**3%**	*.(211)*	**80%**	*.(69)*	**83%**	*.(89)*
Dab - Limanda limanda	**17%**	*.(150)*	**18%**	*.(200)*	**89%**	*.(37)*	**84%**	*.(101)*
Flounder - Platichthys flesus			**21%**	*.(14)*	**58%**	*.(26)*	**76%**	*.(42)*
Brill - Rhombus laevis					**87%**	*.(15)*	**75%**	*.(16)*
Turbot-Scophyhalmus maximus					**48%**	*.(27)*	**23%**	*.(35)*
Solenette - Buglossidium lut.	**86%**	*.(35)*	**78%**	*.(9)*				
Dragonet - Callionymus lyra			**100%**	*.(19)*				
Gobies - Pomatoschistus sp.			**5%**	*.(19)*				

Table 5

Size range of animals in the survival experiments. Total length (fish) or diameter (starfish) in cm, wet weight of evertebrates in g.

Period :	June 92	Mr-Apr.93	Mrch 92	Sep.93
Ship :	ISIS	ISIS	TRIDENS	TRIDENS
Type of beamtrawl :	4 MBT	4 MBT	12 MBT	12 MBT
Starfish - Asterias rubens	5-10 cm	8-12 cm	8-9 cm	6-10 cm
Starfish-Astropecten irregularis	8-10 cm	-	5-7 cm	5-7 cm
Brittle star-Ophiura texturata	-	-	2-3 g	1.5-2.5 g
Ophiura albida	-	-		(0.5 g)
Luidia sarsi (small)	-	-	1-12 g	-
Masked crab - Corystes cassiv.	-	-	9-14 g	6-12 g
Swimming crabs- Liocarcinus sp.	-	-	6-12 g	8-16 g
Hermit crab - Eupagurus bernh.	-	-	8-36 g	15-30 g
Edible crab - Cancer pagurus	-	-	200-900 g	100-800 g
Langoustine-Nephrops norvegicus	-	-	30-66 g	-
Quahog - Arctica islandica	-	-	80-140 g	130 g
Cockle-Acanthocardia echinata	-	-	24-56 g	30-52 g
Whelks - Buccinum undatum	-	-	40-125 g	63-90 g
Natica - Euspira catena	-	-	9-14 g	-
Fish :				
Sole - Solea solea	11-25 cm	12-38 cm	-	17-28 cm
Plaice - Pleuronectes platessa	11-25 cm	9-28 cm	20-27 cm	16-23 cm
Dab - Limanda limanda	5-24 cm	8-29 cm	6-20 cm	5-29 cm
Turbot - Scophthalmus maximus	24-30 cm	22-29 cm	-	20-26 cm
Brill - Rhombus laevis	20-30 cm	19-36 cm	-	-
Flounder - Platichthys flesus	25-32 cm	19-36 cm	-	-
Solenette - Buglossidium luteum	6-12 cm	8 cm	6-12 cm	5-12 cm
Scaldfish - Arnoglossus laterna	6 cm	6-8 cm	9-13 cm	-
Lemon sole - Microstomus witt	-	-	-	14-16 cm
Lesser weever-Trachinus vipera	5-10 cm	-	-	7-11 cm
Dragonet - Callionymus lyra	10-15 cm	11-21 cm	-	-
Hooknose - Agonus cataphractus	10-12 cm	-	-	15-20 cm
Gurnards - Trigla spp.	13-20 cm	-	14-22 cm	17-33 cm

Table 6

Total mortality of animals discarded by beam trawl fishery for sole, and the estimated % mortality of some species that pass through the meshes during trawling.

	Total mortality of discards		Mortality of escapes through the meshes	
	12 MBT	4 MBT	12 MBT	4 MBT
	% mort.	% mort.	% mort.	% mort.
Starfish - Asterias rubens	5%	4%		
Starfish - Astropecten irregularis	11%	7%		
Brittle star - Ophiura texturata	27%	10%		
Masked crab - Corystes cassivelaunus	66%	50%	54%	
Swimming crab - Liocarcinus holsatus	57%	43%	38%	14%
Hermit crab - Eupagurus bernhardus	13%	7%	<10%	<7%
Edible crab - Cancer pagurus	58%	34%	42%	15%
Langoustine - Nephrops norvegicus	46%			
Quahog - Arctica islandica	86%		78%	
Spiny cockle-Acanthocardia echinata	51%		50%	
Small shellfish (Spisula, Venus, etc.)	26%	33%		39%
Whelks - Buccinum & Natica	0%		0%	
Sea mous - Aphrodyte aculeata	5%		<2%	
Fish :				
Sole - Solea solea	95%	84%	< 21%	< 13%
Plaice - Pleuronectes platessa	95%	91%	< 14%	< 8%
Dab - Limanda limanda	99%	99%	< 30%	< 18%
Flounder - Platichthys flesus	-	86%		
Brill - Rhombus laevis	100%	98%		
Turbot - Scophthalmus maximus	100%	86%		
Solenette - Buglossidium luteum	100%	100%	< 24%	
Scaldfish - Arnoglossus laterna	100%	100%		
Dragonets - Callionymus lyra	100%	100%		
Weever - Trachinus vipera	100%	100%	< 6%	
Gurnards-Trigla gurnardus & hirundo	100%	100%		
Whiting - Merlangius merlangus	100%	100%		

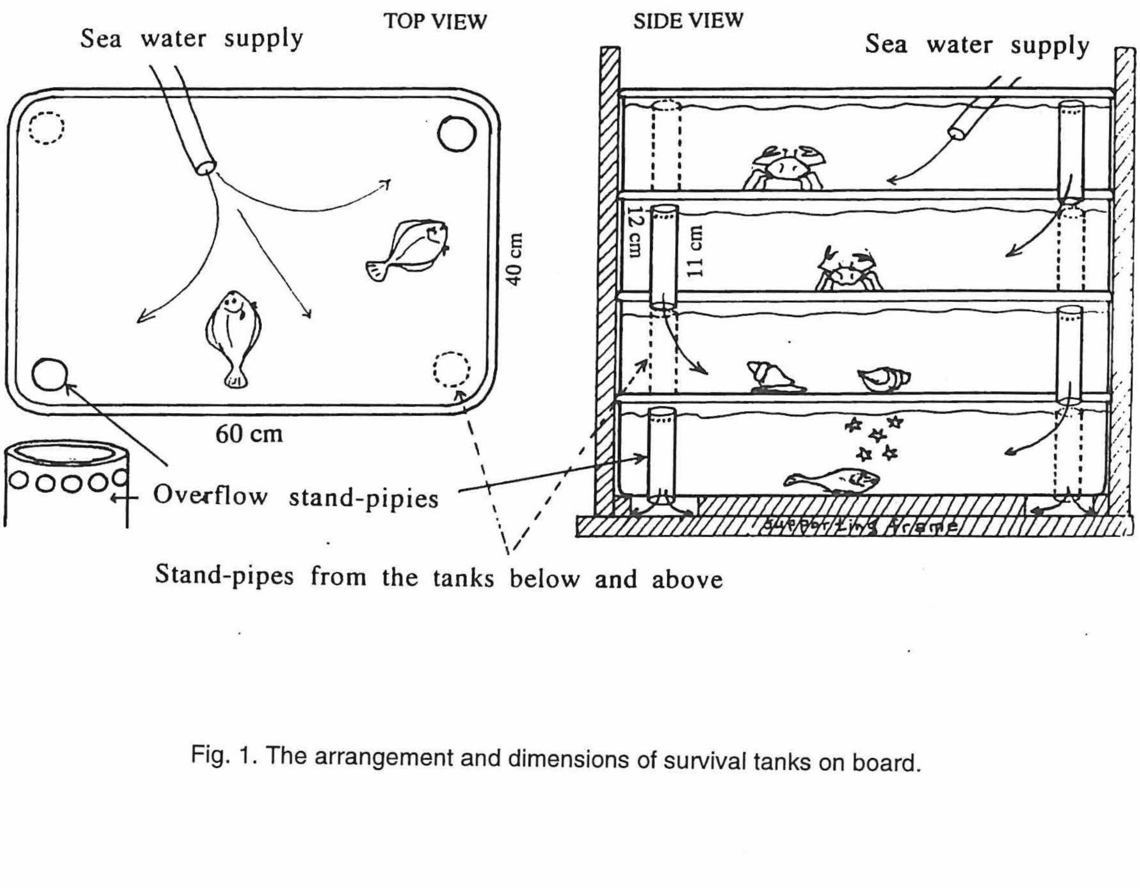
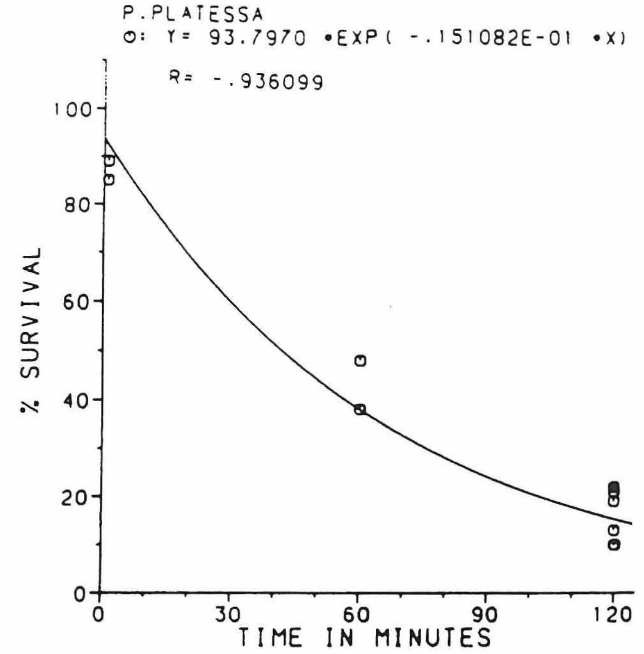


Fig. 1. The arrangement and dimensions of survival tanks on board.



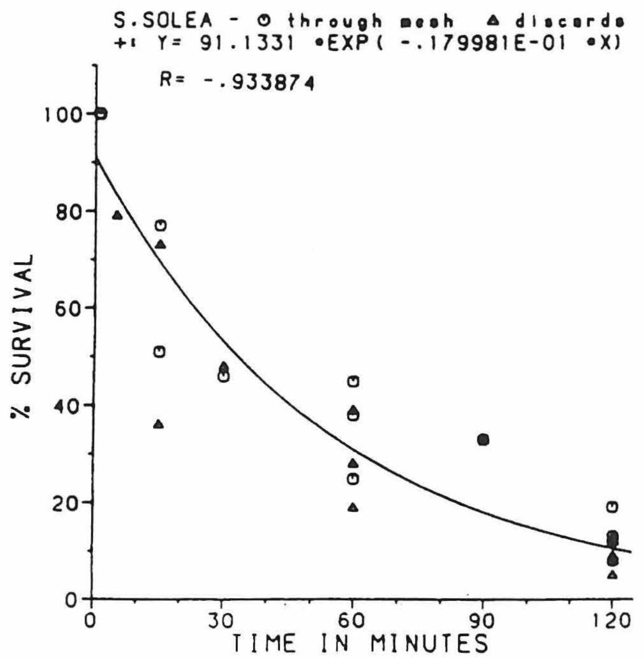


Fig. 2. A non-linear relationship calculated for % survival of discard flatfish in relation to duration of hauls in minutes. Data from VAN BEEK *et al.* (RIVO, 1990) and FONDS *et al.* (BEON report 16, 1992).

DIRECT EFFECTS OF BEAM TRAWLING ON MACROFAUNA IN A SOFT BOTTOM AREA IN THE SOUTHERN NORTH SEA.

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ABSTRACT

Direct effects of trawling with commercial 12-m beam trawls on the abundance of benthic species in a soft bottom area in the southern North Sea were studied by comparing densities before and after trawling. Various sampling gears were used, including a benthos dredge (Triple-D) developed especially for this study. After trawling a study area twice, mortality could be estimated for a number of species. For fish species, mortality varied from 4% (small fish) to 75% (larger fish) of the numbers initially present. Mortality exceded 100% for dab, *Limanda limanda*, as it rapidly immigrates into the trawled area already during trawling. For invertebrate species, mortality was variable as well, and estimated at 3-19% for echinoderms, 0-85% for molluscs, 4-74% for crustaceans, < 1-56% for annelids, and 70% for anthozoans. Dab was a predominant scavenger on damaged or exposed fauna on the recently trawled seabed. The presence of infauna species in catches of the 12-m beam trawls indicated, that the sediment was disturbed by the tickler chains to a depth of approximately 2 to 4 cm.

I. INTRODUCTION

The Dutch sector of the North Sea has been fished intensively by beam trawlers during the last 20 years. In 1990, it was estimated that Dutch beam trawlers (> 300HP) fished on average each m^2 of the seabed at least once, while areas with the highest mean trawl intensity were trawled almost three times (RIJNSDORP *et al.*, 1991; ANONYMOUS, 1992).

Previous studies on trawling effects concentrated on damage to fauna caught in commercial beam trawls. Damage to fauna is shown to occur in coelenterates, annelids, molluscs, echinoderms, crustaceans and fish (GRAHAM, 1955; BRIDGER, 1970; MARGETTS & BRIDGER, 1971; DE GROOT, 1973). The effects of beam trawling on the densities of macrofauna have been studied only recently. In that study, three-fold trawling of a sandy area with 12-m beam trawls resulted in lower densities of a number of echinoderm, mollusc and annelid species. The presence of certain species in the catches of the beam trawls suggested that the tickler chains disturbed the sandy sediment to a depth of at least 6 cm (BERGMAN *et al.*, 1990; BERGMAN & HUP, 1992). However, since species composition as well as penetration depth of the beam trawl may differ, depending on the sediment characteristics, these results cannot be extrapolated to soft bottom areas, which make up a large part of the Dutch sector.

In this paper, the results are presented of two studies on the direct effects of commercial 12-m beam trawls, rigged for sole fishing, on macrofauna in a soft bottom area in the Oystergrounds. The set-up of both studies was similar to that described in BERGMAN & HUP (1992). A well defined study area was fished in such a way, that on average each m^2 was trawled twice (two-fold trawling). This was done in order to create a more or less homogenuously fished area. Benthic fauna in the area was sampled with various sampling gears, before and after this "commercial" trawling. In addition to conventional sampling gears such as a fine meshed 3-m beam trawl, a box corer and a Van Veen grab, a newly developed benthos dredge (the Triple-D) was used (BERGMAN & VAN SANTBRINK, this EC-FAR report).

The two major objectives of this study were to determine (i) direct mortalities of macrofauna due to trawling, and (ii) which species may act as active scavengers in a trawled area. Direct mortality may occur in two ways: firstly in the catches of the trawls and due to handling the catch on board the trawler ("catch mortality"), and secondly among animals that were not present in the catches but that were mortally damaged due to the trawling ("non-catch mortality"). To determine catch mortality, data on the mortality of discarded animals (FONDS, this EC-FAR report) were used. The catch mortality was determined after trawling the area once, as well as twice, because animals might respond to the trawling by horizontal or vertical migration, and influence the size of the catch in the last hauls, that were fished over an already trawled area. Non-catch mortality and scavenging behaviour were estimated by comparing densities of benthic fauna only before and after trawling the area twice. Analysis of the stomach contents of dab, *Limanda limanda*, gave information on the role of this species as scavenger. The alteration of the depth frequency distribution of nematodes in the sediment was used as an estimate of the penetration depth of the 12-m beam trawl (LABAN & LINDEBOOM, 1991).

2. MATERIALS AND METHODS

Two field studies were carried out, in April 1992 and September 1993, in the same area using RV TRIDENS (RIVO-DLO) and RV MITRA (RWS/DNZ).

2.1. APRIL 1992 STUDY

2.1.1. STUDY SITE

A study was carried out on the Oystergrounds (central position 54°30'N and 04°58'E; ICES quadrant 37F4) in an area with very fine sandy sediments (median grain size 170 µm; silt content 6%). Water depth was about 43 m, water temperature was 10°C. In 1990, the registrated mean trawling frequency by Dutch beam trawlers (> 300 HP) in this ICES quadrant was 1-2 times per year (RIJNSDORP *et al.*, 1991). This may be considered as representative for the Dutch sector.

An area of 1850*240 m was chosen as study area. Before the start of the experiment, the surface of the seabed was scanned with a side scan sonar to check for homogenuity, and to assess the amount of recent trawling activities. The side scan sonar recorded trawl tracks of 50-80 trawlers, fishing with 12-m beam trawls, on a transect of 1.5 nM across the study area. Thus, the study area had been intensively trawled during the preceding weeks. All positions were verified during the experiments with high accuracy (error less than a few meters) navigational equipment (DGPS). Exact positioning was obtained using a computorised Dynamic Positioning (D.P.) system on board RV MITRA.

2.1.2. TRAWLING

After initial sampling with the box corer, RV TRIDENS fished the study area with a pair of commercial 12-m beam trawls, rigged for sole fishing (Fig. 1). The trawls were rigged with 10 tickler chains (Ø 14-22 mm), 8 net-tickler chains (Ø 12 mm), rollers (Ø 25 cm) around the middle of the groundrope over a length of 8 m, and sole nets (stretched mesh size in the cod-end 8 cm). Fishing speed was about 7 $nM \cdot h^{-1}$. Over a period of 28 hours, trawling was carried out in a series of parallel hauls, each with a length of one mile, in such a way that the study area (1850*240 m) was fished twice. Coverage of the study area with trawl tracks was checked with side-scan sonar. Catches of the first 3 and the last 2 hauls were sorted seperately. Catches of the intermediate hauls were not analyzed.

2.1.3. SAMPLING BEFORE AND AFTER TRAWLING

The macrofauna in the study area was sampled with a box corer, a benthos dredge and a fine meshed 3-m beam trawl on board RV MITRA. These various gears were used to estimate densities of both small and large sized in- and epifauna species. It is assumed, that the mean density of macrofauna species in the sampled area is representative for the mean density in the study area.

Twenty one samples were taken with a 0.071 m^2 Reineck box corer, 5 days before (t_0) and 12 hours after (t_1) trawling. Samples were sieved over 1 mm mesh size and preserved in 8% neutralized formalin solution in seawater. The macrofauna was sorted and identified in the laboratory within 5 months. Changes in mean densities were tested for statistical significance, by using log (n+1) transformed data (t-test). One-sided probabilities were assumed for sessile animals (H_1: the density has decreased), and two-sided for mobile animals (H_1: the density has decreased or increased).

Larger and less abundant in- and epifauna were sampled with an early prototype of the benthos dredge, rigged with a 15 cm wide blade which sampled to a depth of 15 cm into the sediment. During the hauls, samples were collected in a net (2 cm stretched mesh-size). The length of each haul was about 750 m, and the fishing speed was about 3 $nM \cdot h^{-1}$. Due to heavy swell, it was not possible to sample before trawling. Instead, a "t_0"-sampling was carried out 20 hours after the start of the trawling, with 3 hauls immediately north and 3 hauls immediately south of the study area. A t_1-sampling in the study area (6 hauls) was carried out within 24 hours after trawling. Recent tests with an improved prototype indicated that the reliability of the first prototype with respect to the expected working depth (15 cm) is doubtful. The results, therefore, are used qualitatively only.

Changes in densities of demersal fish and epifauna were investigated with a 3-m beam trawl (actual width 2.8 m) rigged with 3 tickler chains and a chain tied to the ground rope. An extra rope was wound around the middle of the ground chain over a length of about 80 cm. The mesh size of the body of the net was 2 cm stretched, and 1 cm in the cod-end. Fishing speed was about 3 $nM \cdot h^{-1}$. Due to severe weather conditions, it was only possible to sample 24 hours after trawling. Two hauls were made inside and a third and fourth immediately to the north and south of the study area. In order to optimize the catch efficiency of the sampling gear, all hauls were carried out after sunset. The limited number of hauls did not allow tests for statistical significance, and the results were interpreted qualitatively only.

In order to investigate the scavenging behaviour of dab, stomachs were collected from all hauls and preserved in 8% formaline. In the laboratory, the stomach contents from dabs caught inside and outside the study area were pooled separately and sorted in categories. Each categorie was weighed (ash free dry weight, weighed after 48h at 60°C and 3h at 540°C).

2.1.4. PENETRATION DEPTH OF THE COMMERCIAL TRAWL

The penetration depth of the 12-m beam trawl in the seabed was estimated by recording changes in the depth-frequency distribution of nematodes in the sediment. Due to heavy swell, box corer sampling could not be carried out before 17 hours after trawling. Four box corer samples were taken inside the track of the last haul, and another four 20 m outside of this track (which extended to outside the trawled study area). A subsample (surface area of 5.3 cm^2) was taken from each sample, and divided into slices of 1 cm deep. These slices were stored in 4% formalin. Nematode densities in the slices were determined in the laboratory (NIOO-CEMO, Yerseke). Vertical lacquer peels were made from the same 8 box corer samples in order to determine changes in the sedimentary structure due to trawling.

2.2. SEPTEMBER 1993 STUDY

2.2.1. STUDY SITE

A second study was carried out a few miles to the east (central position 54°30'N and 05°04'E; ICES quadrant 37F5) of the April 1992 study area. The medium grain size of the fine sandy sediment at this location was about the same (median grain size 171 µm; silt content 7%). The water depth was about 43 m, and the water temperature was 17°C. In 1990, the registrated mean trawling frequency by Dutch beam trawlers (>300HP) in this ICES quadrant was also 1-2 times per year (Rijnsdorp *et al.*, 1991).

An area of 2000 * 60 m was chosen as study area. This area was narrower than in the April study, to reduce the time required for trawling the area twice. The seabed was scanned with side scan sonar before the start of the experiment, to check for homogenuity, and to assess the amount of recent trawling activities in this area. The side scan recordings did not show any trawl tracks, indicating the area had not been beam trawled in the previous weeks. All positions were verified with high accuracy navigational equipment (DGPS), and exact positioning was obtained using a computorised D. P. system on board RV MITRA.

2.2.2. TRAWLING

After the initial sampling with the Van Veen grab, Triple-D and 3-m beam trawl, RV TRIDENS fished the study area with a pair of commercial 12-m beam trawls, rigged for sole fishing (Fig. 1). Fishing speed was about 7 $nM \cdot h^{-1}$. A series of 5 parallel hauls was carried out in such a way, that the study area (2000*60 m) was fished on average twice in a 3 hour period. Coverage of the study area with trawl tracks was checked with side-scan sonar. The catches of the first and last haul were sorted seperately. Catches of the intermediate hauls were pooled and sorted.

2.2.3. SAMPLING BEFORE AND AFTER TRAWLING

Various gears were used to estimate densities of both small and large sized in- and epifauna species. It is assumed, that for each sampling gear, the mean density of macrofauna species in the total sampled area is representative for the mean density in the study area.

Van Veen grab

Van Veen grab sampling was carried out on RV TRIDENS. T_0-sampling (n=18) was carried out 1 day before trawling, and t_1-sampling (n=24) 12 hours after trawling. Samples were sieved over 5 mm mesh size. Macrofauna was sorted and identified on board. Changes in mean densities were tested for statistical significance (Mann Whitney U-test, two-sided for mobile animals; one-sided for sessile animals).

Triple-D

Larger and less abundant in- and epifauna were sampled with the deep digging dredge (Triple-D), rigged with a blade of 20 cm width and with a maximum penetration depth into the sediment of 10 cm (BERGMAN & VAN SANTBRINK, this EC-FAR report), deployed from RV MITRA. During the hauls, the samples were collected in a net with a 2 cm stretched mesh-size. The length of each haul was about 300 m, and fishing speed was about 3 $nM \cdot h^{-1}$. The t_0-sampling (10 hauls) was carried out within 24 hours before trawling. It is assumed that any effect of the t_0-sampling (involving < 5% of the total study area) on the catches of later trawling or sampling is neglectible. The t_1-sampling (10 hauls) started about 12 hours after trawling. Catches were sorted and fauna was identified on board. Specimens of some of the smaller species found in the samples may have escaped through the meshes of the Triple-D, which would lead to an underestimate of density. However, it was assumed, that this error was consistent between samples, and that at least the changes in densities were estimated reliably. The changes in mean densities were tested for statistical significance using log (n+1) transformed data (t-test, two-sided for mobile animals; one-sided for sessile animals). For some species that show a large variation in size, animals in a subsample from a mixture of all catches in each sampling period were measured, in order to estimate the length frequency distribution.

3-m beam trawl

Changes in the density of epifauna and demersal fish (some pelagic fish species caught were excluded from this study) were investigated with a 3-m beam trawl (actual width 2.8m) deployed from RV MITRA. To increase the catch efficiency, the gear was much heavier than that used in the April study, and was rigged with 3 ticklerchains (13 mm Ø), 2 net-tickler chains (13 mm Ø) and a heavy chain (16 mm Ø) tied to the ground rope. The mesh size of body of the net was 2 cm stretched, and 1 cm in the cod-end. The t_0-sampling (6 hauls, about 1000 m in length), was carried out 20 hours before trawling, and was followed by

t_1-sampling (6 hauls) starting within 1 hour after trawling. About 24 hours later, a t_2-sampling (6 hauls) was carried out to estimate immigration of mobile species into the study area. All hauls were carried out after sunset. To minimize the possible effect of the 3-m beam trawl t_0-sampling on the densities of macrofauna, 4 of the 6 hauls were made along the north and south borders of the study area. During the t_1- and t_2-sampling, all hauls were made well inside the study area.

A reference area, not trawled with the 12-m beam trawls, was sampled to estimate the amplitude of natural fluctuations in densities of mobile species. When changes in densities in the reference area are in the same order of magnitude as in the study area, changes in densities cannot be ascribed to trawling. This reference area, situated 0.5 mile south of the study area, was sampled with a similar 3-m beam trawl deployed from RV TRIDENS, simultaneously with the t_0-, t_1- and t_2-samplings in the study area.

Catches were sorted and fauna was identified on board. For some species, a subsample of animals from a mixture of catches in each sampling period was measured, to estimate the length frequency distribution. Only dab and plaice (*Pleuronectes platessa*) were measured from each catch. If no size related mortality was found, seperate size classes were pooled to estimate total mortality. Changes in densities in the study and reference areas were tested for statistical significance using log (n+1) transformed data (Tukey comparisons in ANOVA). If this test could not be applied, a non parametric test was used (Mann Whitney U test).

2.2.4. CALCULATION OF MORTALITY

Two types of direct mortality due to trawling were distinguished: catch mortality and non-catch mortality. Catch mortality was estimated after trawling the area once and twice. Non-catch mortality, as well as total mortality (the sum of catch mortality and non-catch mortality) could only be estimated after trawling the area twice.

Catch mortality

Catch mortality is defined as that which occurs among animals that are caught in the commercial trawls and then are discarded into the sea after handling onboard the trawler.

The catch mortality after trawling the area once (CM_1; expressed as a percentage of the initial density) was calculated by multiplying the percentage of mortality of discarded animals after being handled on board (determined in survival experiments on board, in: FONDS, this EC-FAR report) with the catch efficiency of the trawls. This catch efficiency is calculated by expressing the density estimate of the first haul as a proportion of the initial density estimated with the Triple-D or 3-m beam trawl. It is assumed, that the density in the area covered by the first haul is representative for the whole study area. The sampling gear yielding the highest initial density estimate is used in this calculation.

$$CM_1 = \text{mortality of discard} * \frac{\text{density estimate from 12-m beamtrawls in haul 1}}{\text{initial density estimate sampling gear}}$$

The catch mortality after trawling the area twice (CM_2) is estimated in a similar way, by using the total number of animals caught after trawling twice (hauls 1 to 5). The total numbers of animals caught after trawling twice was calculated as the ratio between the actual numbers caught in the 5 hauls and the surface of the study area. Also the catch mortality after trawling twice is expressed as a proportion of the initial density:

$$CM_2 = \text{mortality of discard} * \frac{\text{total numbers caught in 12-m beam trawls in the 5 hauls}}{\text{initial density estimate sampling gear}}$$

The catch mortality after trawling the area twice is influenced by migration of animals during the 3h-period between the first and the last haul. An indication of this migration is found in the difference between the estimated and the expected catch mortality after trawling the area twice. The expected catch mortality ($CM_{2,expected}$) is calculated as the sum of the catch mortality after trawling the area once (CM_1) and the (same) rate of catch mortality applied to the numbers of animals expected to remain in the area after trawling it once:

$$CM_{2,expected} = CM_1 + CM_1 * (1\text{-catch efficiency})$$

It is assumed, that the catch efficiency of the commercial beam trawl does not depend on the actual density of a species. If CM_2 is higher than $CM_{2,expected}$, i.e. when the catches of the last hauls were higher than expected, immigration of animals has taken place, or animals may have been dug out of the sediment, leading to an increased catchability. A lower CM_2 indicates that emigration has taken place, either of mobile animals that were disturbed and chased off the study area, or of animals that were caught in the trawls, but washed through the meshes and dispersed outside the study area. Because the catch efficiency of the sampling gear itself may be less than 100%, the estimated mean catch efficiency of the trawls - and therefore the mean catch mortalities - should be considered as a maximum estimate.

Non-catch mortality

Non-catch mortality is defined as mortality occurring among those animals that interfered with, but were not caught by the trawl. This mortality may be due to damage caused by by the tickler chains, or by disturbance of animals (e.g. exposed infauna) leading to an increased availability to predation. Non-catch mortality also occurs when animals, initially caught in the trawls, are washed through the meshes after being mortally damaged by the bulk of the catch.

Contrary to catch mortality, non-catch mortality can only be esimated indirectly, from changes in densities of living animals (killed animals are presupposed to be consumed by scavengers before the t_1-sampling). Non-catch mortality, of animals killed both in the area and outside, is estimated from the number of "missing" animals (M), which is calculated by substracting both the density still present after trawling and the total numbers caught in the commercial trawls in haul 1 to 5, from the density before trawling. The total number of animals caught after trawling twice was calculated as the ratio between the actual numbers caught in the 5 hauls and the surface of the study area. The number of missing animals is expressed as a percentage of the initial density.

M = percentage missing animals,

$$= \frac{100 * [(\text{initial density})-(\text{density at } t_1)-(\text{total numbers caught in 12-m beam trawls in the 5 hauls})]}{\text{initial density estimate sampling gear}}$$

The sampling gear yielding the highest initial density estimate is used in these calculations. Species that in the initial sampling were caught in higher densities in the Triple-D than in the 3-m beam trawl, are considered to be burrowing species. The 3-m beam trawl is not suitable to estimate changes in densities of burrowing species, not only because density estimates are not realistic, but especially because trawling may cause a change in vertical distribution of these species, leading to an enhanced catchability.

It should be noted, that this percentage missing animals and therefore non-catch mortality, can only be assessed after trawling the area twice, as t_1-sampling was only carried out after trawling twice. Obviously, M is influenced by migration of animals into or out of the study area.

Because migration within the period between the initial sampling and the t_1-sampling could not be determined, the non-catch mortality can not be estimated in this way for highly mobile species, such as fish and shrimps. For sessile or low mobile species, with a neglectible horizontal migration, non-catch mortality equals M, if none of the animals are washed through the meshes of the trawl outside the study area. If all animals are washed through the meshes, non-catch mortality is estimated by multiplying M by the mortality in the discard (FONDS, this report).

2.2.5. INDICATIONS FOR SCAVENGING

Increasing densities of species after trawling may provide indirect evidence for scavenging. As random movement of animals eventually replenishes the reduced density in a trawled area to that in its surroundings, evidence of scavenging is found only when the density in the study area exceeds that in its surroundings, ie. when accumulation occurs. In this study, species are considered to accumulate when densities at t_2 or t_1 (when sampled with the 3-m beam trawl or Triple-D respectively) exceded the initial densities (t_0). It is assumed that these initial densities were similar to the densities just outside the area during the t_1- or t_2-sampling.

3. RESULTS

3.1. APRIL STUDY

3.1.1. TRAWLING OF THE STUDY AREA

Of all 32 fish- and invertebrate species caught in the trawls, 10 species showed lower densities in each of the last 2 hauls than in the first 3 hauls (Table 1). The most abundant fish species, dab, did not decrease in density. The infauna species *Arctica islandica*[1] and *Acanthocardia echinata* showed higher numbers in each of the last 2 hauls.

3.1.2. BOXCORE SAMPLING

In the box corer samples, 72 taxa were distinguished (Table 2). Species composition is characteristic for the "*Amphiura filiformis*" assemblage, with dominant species such as *Amphiura filiformis, Mysella bidentata, Callianassa subterranea, Pholoe minuta* and Phoronides (HOLTMANN & GROENEWOLD, 1992). Only juvenile *Arctica islandica, Magelone papillicornis* and *Pectinaria* sp. showed a significant decrease in density after trawling. Several species of cumaceans and gammarids were found in the box corer samples. All these species showed a decrease in density after trawling, which was significant for the total of each group. *Nephtys hombergii*, showed a significant increase in density after trawling.

3.1.3. DREDGE AND 3-M BEAM TRAWL SAMPLING

Species composition and size distribution in the catches of the experimental dredge (Table 3) clearly differed from those in the box corer samples. Small sized annelid species were lacking in the catches of the dredge, due to the larger mesh size of the net. Of species that were caught with both gear, specimens caught in the box corer often were juvenile (Table 2), while nearly all specimens in the dredge catches were adult.

Of all species caught in the 3-m beam trawl inside and outside the study area 24 hours after trawling, dab, *Crangon allmani*, *Upogebia* sp., *Arctica islandica* and *Mysia undata* showed higher densities in each of the hauls inside the trawled area. *Echinocardium cordatum, Phaxas pellucidus, Corystes cassivelaunus, Liocarcinus holsatus* and *Eupagurus bernhardus* showed lower densities in each of the hauls inside the trawled area (Table 4).

3.1.4. STOMACH CONTENT OF DAB

Stomach contents were analyzed of 50 dabs, that were caught in the 3-m beam trawl in the study area 24 hours after trawling had finished, and of another 50 dabs, that were caught outside the study area simultanuously. Prey items were divided into 6 different categories: larger pieces of flesh from *Arctica*

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[1] Common English names of a number of species are given in the Appendix

islandica or *Acanthocardia echinata*, small pieces of mollusc flesh (probably largely from the same 2 species), crustaceans (mainly *Upogebia* sp. and *Callianassa* sp.), annelids, other recognizable items like small echinoderms and molluscs, and fine debris (Fig. 2). Total stomach content was much higher in animals from the study area, mainly due to large pieces of shellfish. Worms were present in both groups in nearly equal amounts. Fine, digested material was present in slightly higher amounts in the stomachs of animals from outside the study area.

3.1.5. PENETRATION DEPTH OF TICKLER CHAINS

To date, 4 samples have been analyzed, 2 from inside the trawl track and 2 from outside. The mean abundance of nematodes in the samples taken outside the trawl track decreased with depth, from over 500 per 10 cm^3 in the upper cm, to less than 200 individuals per 10 cm^3 below a depth of 7 cm (Fig. 3). Densities in the samples from inside the trawl track appeared to be reduced in the upper 3 cm of the sediment.

The lacker peels of the samples outside as well as inside the trawltrack showed a homogeneous distribution of the sediment from the surface to a depth of over 10 cm. Apparently, in this area, lacker peels give no information about the depth to which sediment is disturbed by tickler chains.

3.2. SEPTEMBER STUDY

3.2.1. TRAWLING OF THE STUDY AREA.

In total 25 species were caught in the 5 hauls with the trawls (Table 5). Of the 16 most commonly caught species, plaice (*Pleuronectes platessa*), sole (*Solea solea*), *Arnoglossus laterna*, *Trigla* spp., *Astropecten irregularis*, *Asterias rubens*, *Aphrodita aculeata* and *Liocarcinus holsatus* showed lower densities in both catches of the last haul than in the first catches. Densities of *Merlangius merlangus*, *Arctica islandica*, *Acanthocardia echinata*, and male *Corystes cassivelaunus* increased in each of the last hauls. Densities of dab and *Eupagurus bernhardus* at first increased, followed by a decrease to a level below the initial densities. Densities of *Ophiura texturata* and *Buccinum undatum* remained more or less the same. Also *Echinocardium cordatum* was caught in the commercial trawls, but these could not be counted as they were too much damaged to distinghuish between specimens.

3.2.2. VAN VEEN GRAB SAMPLING

In the Van Veen samples, 24 species were found (Table 6). The density of *Nucula* spp. increased significantly after trawling, whereas *Dosinia lupinus*, *Turritella communis*, and *Pectinaria* sp. showed a significant decrease. However, estimates of (changes in) densities should be considered as unreliable, because the numbers in the samples were low for all these species. Furthermore, the results for small species and size classes are unreliable, as probably many animals were washed through the meshes of the 5 mm sieve. The density estimate therefore depends to a large extend on the duration of the washing of the samples.

3.2.3. TRIPLE-D SAMPLING

In the Triple-D samples, a number of invertebrates were found in significantly lower mean densities, 12 hours after commercial trawling: *Abra alba*, *Arctica islandica*, *Mactra corallina*, *Phaxas pellucidus*, female *Corystes cassivelaunus*, large *Eupagurus bernhardus*, *Echinocardium cordatum* and Anthozoa (Table 7). Almost significantly decreased densities were found for *Turritella communis* and *Mysia undata.*

3.2.4. 3-M BEAM TRAWL SAMPLING

Changes in densities In the study area

Densities of species in the study area are presented in Table 8[a], as well as the percentage change in density between t_0 and t_1 (S_1), t_1 and t_2 (S_2), and t_0 and t_2 (S_{tot}). Changes in densities in the study area of those species, that were present in all sampling periods in both study and reference area, are plotted in Fig. 4.

In general, most fish species showed a decrease in density immediately after trawling, followed by an increase 24 hours later. This decrease was significant for dab, plaice, *Arnoglossus laterna* and *Merlangius merlangus*, and this increase was significant for dab, plaice, *Arnoglossus laterna*, *Callionymus lyra*, *Pomatoschistus* spp. and *Trigla* spp. At 24 hours after trawling, the density of only the largest size classes of dab had significantly increased to a level above the initial density (i.e. accumulation of animals), whereas only *Buglossidium luteum* showed a significantly lower density at this time. For separate length classes of dab, a size dependent decrease was found immediately after trawling, in which the smallest animals showed the largest decrease. No size dependent trend was found in the increase over the next 24 hours (it should be noted that size dependent trends were not tested). In contrast to all other length classes, the 0-group dab showed hardly any change in density.

Of the mobile invertebrate epi- and infauna species, *Asterias rubens*, *Crangon allmani* and *Eupagurus bernhardus* showed a significant decrease in densities immediately after trawling. Over the next 24 hours, only *Eupagurus bernhardus* showed a significant increase in density, whereas the density of *Corystes cassivelaunus* (male) showed a significant (further) decrease. At 24 hours after trawling, densities of none of the species, that showed decreased densities immediately after trawling had returned to their initial levels.

A significant increase in densities immediately after trawling was found for the following species: *Astropecten irregularis*, *Apporhais pespelicani*, *Euspira poliana*, *Callianassa* sp., *Upogebia* sp. and *Corystes cassivelaunus* (female). A clear decrease over the next 24 hours was found for all these species. However, at 24 hours after trawling, densities of all these mobile species were still well above their initial levels.

For seperate length classes of *Asterias rubens* a size dependent increase was found in the 24 hour interval after trawling, in which larger animals showed a larger increase. Also *Astropecten irregularis* showed a size dependent trend: immediately after trawling the smallest animals showed the highest increase in densities, followed by the highest decrease 24 hours later.

All sedentary species, except *Echinocardium cordatum*, showed a considerable increase in density immediately after trawling, followed by a decrease in the following 24 hours. The increase was significant for *Abra alba*, *Acanthocardia echinata*, *Dosinia lupinus*, *Mactra corallina*, *Nucula* spp. and *Turritella communis*. The decrease was significant only for *Mactra corallina*. At 24 hours after trawling, densities of all these sedentary species were still well above their initial levels, except *Corbula gibba*, *Gari fervensis*, *Turritella communis*, *Mysia undata*, and *Phaxas pellucidus*.

Changes in densities In the reference area

Densities of species in the reference area are presented in Table 8[b], as well as the percentage change in density between t_0 and t_1 (R_1), t_1 and t_2 (R_2), and t_0 and t_2 (R_{tot}). In general, the changes in densities in the reference area were less pronounced than in the study area (Fig. 4). Excluding the changes in seperate size classes, a significant change was found only for: 0-group dab (R_2, increase), female *Corystes cassivelaunus* (R_2, increase), and *Cirolana borealis* (R_2, decrease). No size dependent trends in changes of densities were found in the reference area.

Although not significant, the amplitude of the changes in densities of roundfish species and of *Cirolana borealis* were in the same order of magnitude in the reference area as in the study area. Therefore, for these species, changes in densities in the study area cannot be ascribed to effects of trawling. Although highly mobile, the flatfish species showed only minor changes in density during the sampling periods in the reference area. It may be assumed, that for these species natural fluctuations in the study area were low.

3.2.5. CATCH MORTALITY

Catch efficiency, total numbers caught after trawling the area twice, mortality of discard after handling the catch onboard, and catch mortalities are given in Table 9.

Catch efficiency for some species could not be determined, as:

(i) the catch efficiency of the sampling gear was evidently less than 100%, as density estimates by the trawls were even higher (large sized dab and plaice),

(ii) the initial density estimate (24 hours before the trawling) may not be representative for the density at the start of the trawling, because considerable fluctuations in densities were found in the reference area (roundfish species),

(iii) these species were not or hardly found in the sampling gear (e.g. sole, *Scophthalmus maximus*, *Aequipecten opercularis*, *Buccinum undatum*).

The catch efficiency for the swimming crab, *Liocarcinus holsatus*, could not be estimated, as the size frequency distribution of animals caught in the trawls is likely to differ from that in the sampling gear (this species was not measured in the catches of the12-m beam trawl).

For discarded fish, the mortality after being handled onboard the trawler is high (≥ 95%), resulting in a catch mortality after trawling the area twice which about equals total catch in haul 1 to 5 (4 to 139% of the initial density). For discarded invertebrates, the mortality in the discard varied considerably, but for all invertebrates, catch mortality estimates after trawling twice are less than 15%.

3.2.6. PERCENTAGE MISSING ANIMALS AND NON-CATCH MORTALITY

The percentage of missing animals was estimated only for species that were frequently caught in the sampling gear (Table 10). For a number of these species, the number of samples may have been yet too low for a reliable density estimate. The percentage of missing animals of these species may therefore be less reliable (in Table 10, these values are placed between brackets). The percentage of missing *Liocarcinus holsatus* could not be estimated, as the size frequency distribution of animals caught in the trawls is unknown. Of *Echinocardium cordatum*, the percentage missing animals, and therefore the non-catch mortality, could not be estimated, as in the April study not all catches of the trawls were analyzed.

As the non-catch mortality estimate is based on the percentage missing animals and therefore is influenced by migration, it is not possible to give a reliable estimate for highly mobile species. Fish, therefore, are not included in Table 10, just like a number of crustaceans (*Crangon allani, Processa* sp., gammarids and cumaceans), that may disperse into the water column after being disturbed.

The highest percentages of missing animals were found for some molluscs, crustaceans, annelids and anthozoans. In all these groups, the percentages varied considerably. The smallest range was found in echinoderms, which showed percentages of missing animals of less than 20%.

4. DISCUSSION

4.1. CATCH MORTALITY

For larger dab, *Acanthocardia echinata*, *Arctica islandica*, *Corystes cassivelaunus* and *Eupagurus bernhardus*, the catch mortality after trawling the area twice was higher than could be expected (Table 9). Dab apparently immigrated into the trawled area, as also in the period after trawling this species showed a considerable immigration (Table 8[a]). Probably this is also the case in *Eupagurus bernhardus*, a highly mobile epibenthic species. A likely explanation for the increased catchability of *Arctica islandica* and *Acanthocardia echinata* is that for each specimen caught in the net, many more were partially dug up by the tickler chains and did not enter the net. In the last hauls, which covered an area already trawled during the first hauls, these animals were caught in the nets as well (leading to 4 times higher numbers in the last haul than in the first haul). This explanation is supported by the catches of the 3-m beam trawl in both studies, in which these species were almost exclusively caught after trawling (Table 4 and 8[a]). Also the enhanced catchability of *Corystes cassivelaunus* during the second trawling may be explained by the fact that this burrowing species is likely to be dug up by the tickler chains, but this species may also become active on the surface as scavenger. Immigration, however, seems unlikely to play an important role, considering the 13-fold increase found within 3 hours.

For *Astropecten irregularis* and *Aphrodita aculeata*, the catch mortality after trawling the area twice was lower than could be expected. This indicates, that emigration has taken place during the 3 hour period of commercial trawling. As these are low mobile species, active emigration is not likely. Animals were probably caught in the trawls, washed through the meshes and were dispersed outside the study area. Of *Aphrodita aculeata*, the total number caught in haul 1 to 5 was even lower than the catch efficiency (in haul 1). This cannot be explained by emigration alone, and may be caused by an extreme heterogene distribution of this species, or irregularities during the processing of the catches.

4.2. NON-CATCH MORTALITY

For highly mobile species such as fish and shrimps, the percentage missing animals, and therefore the non-catch mortality, could not be estimated reliably. In fish, non-catch mortality will probably occur mainly in the trawls, when mortally damaged animals are washed through the meshes. By using a fine meshed net covering the commercial trawl, this mortality is tentatively estimated as in the order of 10% of the animals that escaped through the meshes of the trawl (FONDS, this EC-FAR report). As it is not clear, what percentage of the animals that were initially present in the study area had escaped through the meshes, this 10% estimate cannot be applied in the calculations of non-catch mortality.

The invertebrates mentioned in Table 10 are unlikely to show substantial immigration during the interval between t_0 and t_1, with a possible exception for large *Eupagurus bernhardus*. Emigration, however, may play a role in the interpretation of the percentage of missing animals, as specimens of all species listed in Table 10 may be dispersed outside of the study area *un*damaged after being washed through the meshes of the trawl, e.g. at the moment when the trawls were hauled onboard. It is assumed that, for invertebrates, the mortality among those animals that were washed through the meshes, approaches the mortality in the discard (FONDS, this EC-FAR report). A minimum non-catch mortality (in case all missing animals are washed through the meshes) can therefore be estimated by multiplying the percentage missing animals by the mortality estimate in discard. If species are small (i.e. commonly found in fine meshed sampling gear but not in the trawls), it is assumed that this dispersion plays only a minor role. These small animals pass through the meshes immediately, while the trawl is still on the study area. Also in the large bivalves *Arctica islandica* and *Acanthocardia echinata*, dispersion probably plays a minor role, because these species are too large to be washed through the meshes in the cod-end of the trawls.

The minimum non-catch mortality of those species mentioned in Table 10 that may show such dispersion, is estimated as 1% for *Asterias rubens*, 1% for *Astropecten irregularis*, 8% and 1% for large and small *Ophiura texturata*, 25% for male *Corystes cassivelaunus* and 0.5% for *Aphrodita aculeata*. For the two species that were sampled with the 3-m beam trawl, *Asterias rubens* and *Ophiura texturata*, it is assumed that most of the missing animals were dispersed outside the study area, as the t_1-sampling with this gear took place almost immediately after trawling and it is unlikely that high numbers of damaged animals were consumed in this short period. Therefore, the non-catch mortality for these two species is assumed to be little more than the minimum estimate. The found indication (in the comparison of the found and expected catch mortality after trawling the area twice, Table 9), that in *Asterias rubens* no emigration has taken place, which contradicts this assumption, is probably erratic. As the other species, *Astropecten irregularis*, *Corystes cassivelaunus* (male) and *Aphrodite aculeata*, were sampled with the Triple-D (of which the t_1-sampling took place more than 12 hours after trawling), the non-catch mortality is estimated as between this minimum estimate and the percentage missing animals (i.e. all missing animals are killed on the study area, and have been consumed).

Non-catch mortality may be underestimated, when animals that were damaged or exposed due to trawling were not yet consumed during the t_1-sampling (within 24 hours after trawling). All damaged animals in the catch were counted as alive, as these could be damaged also by the sampling gear itself (this became clear in the initial sampling). It is not clear, to what extent this problem figures in the estimates of non-catch mortality, i.e. to what extend damaged or exposed animals have not been consumed before t_1-sampling. In a similar study in the Dutch coastal zone (BERGMAN & VAN SANTBRINK, this EC-FAR report), it was found that 12 to 23% of the initial density of *Spisula subtruncata* that was damaged by trawling, was not yet consumed 24 hour later. An underestimation is more likely to occur in species that were sampled with the 3-m beam trawl, as sampling with this gear took place immediately after trawling. In most of these species, however, this problem is assumed to be of minor importance: starfish e.g. are little vulnerable, and moreover are capable to regenerate. Only of *Eupagurus bernhardus*, the non-catch mortality may have been underestimated due to this problem.

The non-catch mortality of *Echinocardium cordatum* could not be estimated. However, as this is an extremely fragile species, it is likely that all specimens caught in the trawls, or hit by the tickler chains, did not survive. Therefore, total mortality can be directly estimated from the decrease in density found in the box corer sampling (showing a non significant decrease of 6%). As the majority of large animals of *Echinocardium cordatum* lived at a depth of over 5 cm (as was observed in the box corer samples), this species probably burrows too deep to be reached by the tickler chains. The same conclusion was drawn in a previous study on sandy sediments (BERGMAN & HUP, 1992). A likely explanation for the considerable decrease in density (86%) that was found in the Triple-D sampling, may be found in the limited working depth (10 cm) of this gear. In this gear, only the animals living in the uppermost sediment layer are caught, those that are likely to be hit by the passing trawl. This explanation is supported by the Van Veen grab samples, reaching to a depth well over 10 cm and showing a much higher mean density estimate than the Triple-D samples. In conclusion, mortality of *E. cordatum* due to trawling is highly dependent on the burrowing depth of the animals. Therefore, the results of this study can not be extrapolated, as the mean burrowing depth depends on location (e.g. type of sediment), season, and size of the animals.

Also *Callianassa* sp., a small fragile crustacean species, is known to live deep into the sediment. As in this study hardly any change in density was found after trawling, it is likely that also this species lives too deep to be much disturbed by trawling.

In mollusc species, the non-catch mortality seems to be related to the solidity of the shell. Species with fragile shells, such as *Mactra corallina*, *Abra alba*, and *Phaxas pellucidus*, show the highest decreases in density, whereas solid shelled species such as *Aporrhais pespelicani*, *Nucula* spp., *Chamelea gallina*, *Dosinia lupinus* and *Corbula gibba* seem hardly affected by beamtrawling. On the other hand, size of the species may play a role as well, as non-catch mortality in some small and fragile species (*Mysella bidentata*, *Cylichna cylindracea*) appeared to be remarkably low. Possibly these species were merely displaced by the tickler chains, although this explanation alone is in contradiction to the result found for juvenile *Arctica islandica*.

The tube dwelling *Pectinaria* sp. was the most abundant annelid species in the box corer sampling. It is remarkable that, in the samples taken after trawling, an increased percentage of animals that had lost their tube (from 30% to 48%) was found. This may indicate, that some specimens had lost their tube due to trawling. As it is likely that the survival of these specimens was at least reduced, the non-catch mortality estimate (56%), might be too low.

4.3. TOTAL MORTALITY

Catch mortality after trawling the area once, as well as catch mortality, non-catch mortality and total mortality (i.e. the sum of catch mortality and non-catch mortality) after trawling the area twice, are given in Table 11.

In general, the catch mortality after trawling the area twice is higher than after trawling once. The difference is the most pronounced for dab and some large burrowing species, like *Arctica islandica*, *Acanthocardia echinata* and *Corystes cassivelaunus*. For these species, immigration of animals (dab) or upward displacement (dug out infauna) after the first trawling may have played an important role in this increase.

Analoguous to the catch mortality, it is likely that also non-catch mortality after trawling the area twice is generally higher than after trawling once, and may be disproportionately higher for immigrating or burrowing species: of the first, relatively more animals are affected in the second trawling; of the second (especially *Arctica islandica, Acanthocardia echinata* and *Corystes cassivelaunus*), specimens dug out in the first hauls are more likely to be damaged by the tickler chains during the second trawling.

This indicates that for most species, the total mortalities after trawling twice, as found in this study, are higher than after trawling an area once. This difference may be considerable for e.g. the species mentioned above.

The total mortality estimate for *Eupagurus bernhardus* is uncertain, because the catch mortality may be overestimated, while the non-catch mortality may be underestimated.

Total mortality could not be determined for 70% of the fish species that were found, as well as 30% of the echinoderms, 40% of the molluscs and crustaceans, and 90% of small annelids and other groups. Most of these species were caught in very low numbers.

4.4. INDICATIONS FOR SCAVENGING

All carnivorous animals, that are present in the study area shortly after trawling, can be considered as potential scavengers or predators on animals that are damaged or exposed by the trawls. In several roundfish and flatfish species, as well as invertebrates, scavenging has been described (e.g. ARNTZ & WEBER, 1970; CADDY, 1973; RUMOHR & KROST, 1991; KAISER & SPENCER, this EC-FAR report).

A direct indication for scavenging can be found in the comparison of stomach contents of predatory animals, that are caught in the study area after trawling, to stomach contents of animals caught in an untrawled reference area at the same time. In this study, scavenging is clearly demonstrated in dab, as the weight of the total stomachs content of animals from the trawled area was higher, and the composition of prey items had changed. Furthermore, these stomach contents consisted to a large extend of species that were unlikely to have normally fallen prey to dab, such as *Arctica islandica, Acanthocardia echinata* and large crustaceans.

The accumulation of a predatory species in a recently trawled area can be considered as an indirect indication for scavenging. In the 3-m beam trawl sampling, a significant accumulation of epifauna species (those species that in the initial sampling are caught in higher densities in the 3-m beam trawl than in the Triple-D) is found only in dab (all sizes > 15cm) (Table 8^a, S_{tot}). In the Triple-D sampling, no indications for accumulation were found for burrowing species.

It should be noted that, as accumulation of epibenthic species is estimated only by sampling within 24 hours after trawling, any accumulation *after* this moment (e.g. in slow moving species such as starfish) remained unnoticed. Also, scavenging behaviour cannot be excluded when a species does *not* accumulate.

Of a species that act as scavenger, the contribution to the total scavenging is depending on the feeding rate, the initial density, the percentage of animals still present on the area immediately after trawling, and the immigration rate of animals into the trawled area. In this study, the species dependent immigration rate can be calculated from the 3-m beam trawl sampling, as the increase in density in the interval between t_1 and t_2 proportional to the initial density. It was assumed, that this initial density was similar to the density just outside the area during t_1 and t_2 sampling. The highest immigration rate was found for >0 group dab showing a size dependent trend, ranging from 82% (specimens <13cm) to 357% (>19 cm). Besides the largest sized animals (102%), all other size classes of plaice showed a immigration rate of 50-60%, just like *Arnoglossus laterna*. Of all invertebrate species, the immigration rate of only *Eupagurus bernhardus* was in a same order of magnitude (65%), the other species showing considerably lower immigration rates (*Asterias rubens* <23%, *Ophiura texturata* 3%, *Crangon allmani* 26%). These relative differences in immigration rate between species may also appear in other areas under similar conditions (e.g. temperature, season, bottom type), however, this has yet to be established in future studies. As the possible feeding rate of these immigrating species is unknown, no conclusions can be drawn on the contribution of these species to total scavenging.

Scavenging animals not only feed on animals that are exposed or damaged in the trawl track, but also on damaged or killed animals that are discarded to the sea. Obviously, the relative participation of scavenging species may differ in these two situations. For example, regarding the relatively low migration rate, the role of *Asterias rubens* as scavenger on a recently trawled area may not be that large, however regarding the high survival of starfish that are discarded by the trawler, starfish may play a more prominent role as scavenger on other discarded (dead) animals.

4.5. PENETRATION DEPTH OF THE 12-M BEAM TRAWL

When after trawling, nematodes do not settle simultanuously with the resuspended sediment, their depth frequency distribution will change. In this study, mean density of nematodes in the upper 3 cm of the sediment in the trawl track clearly differed from in the untrawled seabed. Assuming a similar distribution in densities at both sites, this difference may be caused by the trawling. A number of uncertainties hamper an exact estimate of the penetration depth. As the samples were taken 17 hours after trawling, the nematodes could have reentered the deepest section of newly settled sediment, leading to an underestimation of the penetration depth. Furthermore, the absence of a reference stratum in the sediment made it impossible to estimate whether a layer of sediment was dispersed in the water column, leading to an underestimation, or an extra thick layer settled, leading to a overestimation of the penetration depth. Using a similar method, penetration depth in a fine sandy area was estimated at about 5 cm (LABAN & LINDEBOOM, 1991). However, also in that study, the penetration depth could not be estimated exactly, due to the absence of a reference stratum. In the present study, the presence of infauna species in the trawls, and the decreased densities of other infauna species after trawling, indicates that the penetration depth was approximately 2 to 4 cm.

5. CONCLUSIONS

The following conclusions on the total mortality of benthic fauna, due to trawling an area twice with 12m beam trawls, can be drawn from this study:

Total mortality could only be estimated for three flatfish species, *Arnoglossus laterna*, dab and plaice, and appeared to vary considerably between species and size classes (4-139% of the numbers initially present in the area). Values over 100% are due to animals moving into the trawled area. Total mortality appeared to be size dependent. It should be stressed, that total mortality of fish may be underestimated, as the non-catch mortality could not be estimated.

Total mortality of the echinoderm species, was generally low (3-19%). These species appeared to be little vulnerable (*Asterias rubens, Astropecten irregularis, Amphiura filiformis, Ophiura texturata*), or lived out of reach of the trawls (*Echinocardium cordatum*).

The mollusc species, *Chamelea gallina, Corbula gibba, Nucula* spp., *Mysella bidentata, Dosinia lupinus* and *Apporhais pespelicani*, were not affected by trawling. These species were either solid shelled or very small. Total mortality of *Abra alba, Mactra corallina, Phaxas pellucidus, Mysia undata, Ensis ensis, Gari fervensis, Arctica islandica, Acanthocardia echinata* and *Turritella communis* varied between 12% and 85%, and is considered to be a direct effect of the passage of tickler chains, which damaged the animals or exposed them to scavengers. The most fragile species showed the highest mortality.

Total mortality of the burrowing crustacean species *Callianassa* sp. is very low (4%), as it lives too deep to be disturbed. *Corystes cassivelaunus* and *Ebalia* spp. showed a mortality of approximately 30%. Total mortality of *Eupagurus bernhardus* showed a remarkable size dependence: 15% due to catch mortality for large animals and 74% due to non-catch mortality for small animals.

In general, the total mortality of annelid species was low (<1-14%). Only the fragile tube dwelling species *Pectinaria* sp. was seriously affected (56%). Some anthozoans were also clearly affected.

It should be noted, that for most species, the total mortality after trawling the area twice, as found in this study, is generally higher than after trawling once. This difference may be considerable for immigrating (e.g.

dab) or - in particularly large - burrowing species (*Acanthocardia echinata*, *Arctica islandica* and *Corystes cassivelaunus*).

The deep digging dredge (Triple-D), which was developed during the IMPACT-1 project, appeared to be a valuable tool in this effect study. Without the Triple-D, mortality estimates could only have been made for half of the number of species.

None of the carnivorous species present in the study area after trawling could be excluded as potential scavenger or predator on exposed infauna. In this study, stomach contents and immigration behaviour after trawling showed that dab (> 0-group) may be considered as the predominant scavenger on a recently trawled seabed.

The change in depth frequency distribution of nematodes was not a suitable parameter to accurately measure the penetration depth of the 12-m beam trawl. However, the presence of infauna species in the trawls, and the decreased densities of infauna species after trawling, indicated that the penetration depth was approximately 2 to 4 cm.

6. FUTURE RESEARCH

Some comments can be made regarding the methods used in this study:

Non-catch mortality may be underestimated when animals that were killed due to the trawling, were not yet consumed during the t_1-sampling. It was not possible to seperate animals that were damaged by the trawls from those that were damaged by the sampling gear. To avoid this problem, the final sampling should be carried out at least a few days after trawling, to ensure that animals mortally damaged by the trawling are all consumed by scavengers.

The immigration rate of scavengers into a trawled area may be estimated more accurately by a series of sampling moments after trawling, rather than by sampling on two discrete moments. Sampling in the trawled area should be synchronised with sampling in an untrawled reference area. Data on the feeding rate of scavenging species have to be obtained, in order to estimate their contribution to scavenging.

Juvenile specimens and small sized species were frequently caught in the Reineck box corer and the Van Veen grab, while larger sized animals were hardly caught. Since trawling appears to affect the density of especially large species, box corer and grab sampler do not seem adequate sampling gear. In this study, also the fine meshed beam trawl was an inadequate gear for most invertebrate species, except for epifauna species such as *Asterias rubens* and *Ophiura texturata*.

The Triple-D appears to be a reliable sampling gear to estimate the densities of most invertebrate species. A number of species were caught in low numbers. This problem may be solved by using finer meshed nets for small animals and larger meshed nets, allowing longer hauls, for larger animals.

The very presence of species in the Dutch sector, which has been frequently trawled during the last twenty years, indicates that these species are at least to some extend resistant to beam trawling. However, abundancies of species may have changed due to trawling, and more vulnerable species may have become rare or may even have disappeared in certain areas. Consequently, studies on the direct effects of beam trawling, give incomplete information on the impacts on a natural ecosystem in the Dutch sector. Therefore, the long term effects of beam trawling on the benthic ecosystem should be studied only in an area closed for fisheries for many years.

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TABLE 1

Numbers of animals (n.1000 m^{-2}) in catches of the first 3 and the last 2 hauls of 12-m beam trawls on the study area (April study). During each haul, both port and starboard trawls were used (haul lenght 1 nM). Catches of intermediate hauls were not analyzed.

species	numbers in catch (n*1000m-2)						
	first hauls				last hauls		
	F1	F2	F3	mean	L1	L2	mean
FISH							
Agonus cataphractus	0.00	0.00	0.00	0.00	0.02	0.00	0.01
Ammodytes tobianus	0.00	0.00	0.02	0.01	0.00	0.00	0.00
Arnoglossus laterna	0.09	0.16	0.23	0.16	0.07	0.00	0.03
Callionymus lyra	0.05	0.14	0.09	0.09	0.07	0.02	0.05
Clupea harengus	0.00	0.02	0.00	0.01	0.00	0.00	0.00
Cyclopterus lumpus	0.00	0.00	0.00	0.00	0.02	0.00	0.01
Enchelyopus cimbrius	0.00	0.00	0.02	0.01	0.00	0.00	0.00
Gadus morrhua	0.05	0.05	0.02	0.04	0.05	0.02	0.03
Hyperoplus lanceolatus	0.00	0.02	0.00	0.01	0.00	0.00	0.00
Limanda limanda	4.86	6.22	4.01	5.03	5.47	8.42	6.95
Merlangius merlangus	0.25	0.25	0.32	0.27	0.11	0.07	0.09
Microstomus kitt	0.00	0.02	0.00	0.01	0.00	0.00	0.00
Molva molva	0.00	0.02	0.00	0.01	0.00	0.00	0.00
Pleuronectes platessa	0.72	0.59	0.45	0.59	0.25	0.20	0.23
Scophthalmus maximus	0.00	0.02	0.02	0.02	0.00	0.00	0.00
Scophthalmus rhombus	0.00	0.05	0.00	0.02	0.00	0.00	0.00
Solea solea	0.27	0.14	0.14	0.18	0.05	0.16	0.10
Squalus acanthias	0.00	0.02	0.00	0.01	0.00	0.00	0.00
Trigla spp.	0.50	0.32	0.05	0.29	0.00	0.09	0.05
ECHINODERMS							
Asterias rubens	19.71	11.89	16.22	15.94	1.94	2.00	1.97
Astropecten irregularis	43.92	77.84	23.96	48.57	18.02	27.03	22.52
Echinocardium cordatum	16.33	24.32	16.22	18.96	4.50	12.61	8.56
Ophiura texturata	3.94	5.95	2.52	4.14	0.23	1.08	0.65
MOLLUSCS							
Acanthocardia echinata	0.32	0.32	0.81	0.48	1.96	1.69	1.82
Aequipecten opercularis	0.00	0.05	0.00	0.02	0.00	0.00	0.00
Arctica islandica	0.52	0.45	0.56	0.51	1.51	2.12	1.81
Buccinum undatum	0.00	0.95	0.07	0.34	0.00	0.00	0.00
CRUSTACEANS							
Cancer pagurus	0.00	0.05	0.00	0.02	0.00	0.00	0.00
Corystes cassivelaunus	22.25	16.49	14.59	17.78	5.59	5.14	5.36
Eupagurus bernardus	3.51	1.62	1.26	2.13	0.23	0.32	0.27
Liocarcinus holsatus	5.07	3.24	1.98	3.43	0.50	1.17	0.83
ANNELIDS							
Aphrodita aculeata	11.55	9.46	7.39	9.47	0.36	1.17	0.77

TABLE 2.

Numbers of animals (n_*m^{-2}) in Reineck box corer samples taken 5 days before (n=21) and 12 hours after trawling (n=21) (April study). Statistical significance of changes in mean densities was tested with a t-test using log(n+1) transformed data (2-sided probabilities for mobile species, 1-sided* for sessile species).

species	size	numbers in samples (n*1m-2)				t0-1	P	t0-1
		t0-sampling		t1-sampling		in/decrease	t-test	
		mean	st.dev.	mean	st.dev.	%	*=one-sided	
ECHINODERMS	(length or diameter)							
Echinocardium cordatum	35-50mm (1x5mm)	10.7	10.8	10.1	15.5	-6	n.s.	
Amphiura sp.	2-6mm (disc)	790.1	335.8	727.0	344.1	-8	n.s.	
Astropecten irregularis	2-6mm (2x55mm)	4.0	7.9	0.7	-	-83	n.s.	
Asterias rubens	65mm	0.0	-	0.7	-	>>100	n.s.	
Ophiura sp.	2mm (disc)	0.7	-	0.0	-	-100	n.s.	
Holothuridea	10-75mm	2.0	5.1	1.3	4.2	-33	n.s.	
MOLLUSCS, Bivalves	(length)							
Abra alba	20mm	0.7	-	0.0	-	-100	n.s.	
Abra prismatica	15mm	0.7	-	0.0	-	-100	n.s.	
Arctica islandica	2-3mm	23.5	20.6	15.4	17.8	-34	0,038*	
Chamelea gallina	2-3mm (1x30mm)	8.7	12.2	11.4	18.2	31	n.s.	
Corbula gibba	1-11mm	629.8	378.8	611.0	584.0	-3	n.s.	
Dosinia lupinus	8-15mm	2.0	5.1	0.0	-	-100	n.s.	
Gari fervensis	3mm (1x50mm)	3.4	7.6	2.0	5.1	-40	n.s.	
Lepton squamosum	2mm	1.3	4.2	0.0	-	-100	n.s.	
Mysella bidentata	2-3mm	698.9	320.1	759.2	562.5	9	n.s.	
Mysia undata	6-10mm	0.0	-	1.3	4.2	>>100	n.s.	
Nucula nitidosa	2-10mm	13.4	15.7	12.1	16.8	-10	n.s.	
Phaxas pellucidus	10-15mm	6.7	11.5	4.7	6.8	-30	n.s.	
Tellimya ferruginosa	2-7mm	8.0	11.4	9.4	19.6	17	n.s.	
Thracia sp.	2mm	0.7	-	1.3	4.2	100	n.s.	
MOLLUSCS, Gastropods	(height)							
Cylichna cylindracea	3-8mm	36.2	27.3	31.5	30.8	-13	n.s.	
Euspira catena	8mm	0.0	-	0.7	-	>>100	n.s.	
Euspira poliana	10mm	0.0	-	0.7	-	>>100	n.s.	
Philine catena	3mm	0.7	-	2.7	5.7	300	n.s.	
Turritella communis	5-15mm	18.8	21.5	10.7	16.6	-43	n.s.	
CRUSTACEANS	(length)							
Corystes cassivelaunus	10-30mm	2.0	5.1	0.7	-	-67	n.s.	
Callinassa sp.	5-40mm	76.5	24.2	73.8	29.2	-4	n.s.	
Ione thoracica	3-4mm	0.7	-	1.3	4.2	100	n.s.	
Processa sp.	30-40mm	2.0	5.1	2.7	5.7	33	n.s.	
Cirolana borealis	15-20mm	0.7	-	0.7	-	0	n.s.	
Mysiacea sp.	15mm	0.7	-	0.0	-	-100	n.s.	
Cumacea (3 species)	3-7mm	8.7	13.7	0.7	3.1	-92	0.003	
Gammaridea (8 species)	2-11mm	24.1	26.8	10.7	16.0	-56	0.039	
Crustacea indet.	3mm	0.0	-	1.3	4.2	>>100	n.s.	
ANNELIDS	(length)							
Anaitides cf. mucosa	1-4cm	2.0	5.1	0.7	-	-67	n.s.	
Anaitides maculata	1-2cm	3.4	7.6	0.7	-	-80	n.s.	
Aphrodita aculeata	4cm	0.0	-	0.7	-	>>100	n.s.	
Chaetozone setosa	1-2cm	2.0	5.1	0.0	-	-100	n.s.	
Diplocirrus glaucus	1cm	0.0	-	1.3	4.2	>>100	n.s.	
Eumida sanguinea	1cm	0.7	-	0.0	-	-100	n.s.	
Glycera sp. (juv.)	1cm	0.0	-	0.7	-	>>100	n.s.	
Goniada sp./Glycinde sp.	1-3cm	4.0	7.9	8.7	13.7	117	n.s.	
Gyptis capensis	1-1.5cm	1.3	4.2	2.0	5.1	50	n.s.	
Harmothoe lunulata	2.5cm	0.0	-	0.7	-	>>100	n.s.	
Magelona alleri	2-5cm	4.0	6.5	4.0	6.5	0	n.s.	
Magelona papillicornis	1-2cm	19.5	20.2	6.7	11.5	-66	0.006	
Nephtys hombergii	3-11cm	4.7	8.1	12.7	12.5	171	0.018	
Nephtys sp. (juv.)	1-2cm	0.7	-	2.0	5.2	200	n.s.	
Notomastus latericeus	5-10cm	4.0	8.0	0.7	-	-83	n.s.	
Ophelina acuminata	2cm	0.7	-	0.0	-	-100	n.s.	
Ophrodomus flexuosus	1-2cm	10.7	12.6	14.1	16.1	31	n.s.	
Owenia fusiformis	2-5cm	6.7	16.2	2.7	5.7	-60	n.s.	
Pectinaria sp.; in tube	*0.7-2.5cm (tube)*	*46.3*	*39.9*	*15.4*	*17.3*	*-67*	*0,005**	
Pectinaria; without tube	*0.3-1cm*	*20.1*	*28.0*	*14.1*	*14.8*	*-30*	*n.s.*	
Pectinaria (total)		66.4	57.9	29.5	23.1	-56	0,034*	
Pholoe minuta	0.5-1cm	8.7	16.9	13.4	13.0	54	n.s.	
Poecilochaetus serpens	1cm	0.7	-	0.0	-	-100	n.s.	
Scololepis bonneri	1cm	0.0	-	0.7	-	>>100	n.s.	
Scoloplos armiger	1-2cm	20.8	25.4	12.1	18.0	-42	n.s.	
Sigalron mathildae	1-2cm	3.4	7.7	2.7	5.7	-20	n.s.	
Sphiophanes bombyx	0.5-1cm	3.4	-	0.7	-	-80	n.s.	
Sthenelais limicola	1-5cm	8.7	15.1	8.0	9.5	-8	n.s.	
TOTAL ANNELIDS excl. Pectinaria sp.		110.0	62.5	94.6	46.5	-14	n.s.	
Other groups								
Phoronidea	1-2cm	24.1	23.2	23.5	25.3	-3	n.s.	
Nemertini	0.5-5cm	0.7	-	0.7	-	0	n.s.	

TABLE 3

Numbers of animals (n∗100 m^{-2}) in catches of 6 Triple-D hauls in the study area at 24 hours after trawling, and of 6 hauls in a reference area (April study).

species	numbers in catch (n*100m-2)			
	research area		reference area	
	mean	st.dev.	mean	st.dev.
FISH				
Agonus cataphractus	0.13	0.36	0.00	0.00
Arnoglossus laterna	0.52	1.07	0.00	0.00
Limanda limanda	0.13	0.36	0.00	0.00
Solea solea	0.13	0.36	0.00	0.00
ECHINODERMS				
Asterias rubens	0.39	0.74	0.13	0.36
Astropecten irregularis	15.66	10.20	10.96	8.15
Echinocardium cordatum	2.22	1.18	5.22	2.28
Ophiura texturata	0.00	0.00	0.13	0.36
MOLLUSCS				
Abra alba	0.39	0.74	0.13	0.36
Acanthocardia echinata	0.39	0.74	0.52	0.91
Aporrhais pespelicani	3.92	2.37	2.74	3.05
Arctica islandica	0.65	0.36	0.65	0.67
Chamelea gallina	5.61	2.77	3.65	1.55
Corbula gibba	12.14	6.50	4.44	5.97
Dosinia lupinus	1.04	1.33	0.26	0.46
Euspira catena	0.13	0.36	0.00	0.00
Euspira poliana	1.17	2.08	0.78	0.56
Gari fervensis	0.26	0.46	0.26	0.72
Mysia undata	0.39	0.74	0.65	1.03
Nucula spp.	1.70	1.18	0.65	1.03
Phaxas pellucidus	0.39	0.48	0.65	1.42
Turritella communis	13.57	5.39	6.66	4.18
CRUSTACEANS				
Corystes cassivelaunus	3.79	2.05	3.26	1.81
Ebalia spp.	2.61	2.72	0.65	0.67
Liocarcinus holsatus	0.52	0.91	1.70	1.30
Upogebia sp.	0.13	0.36	0.00	0.00
ANNELIDS				
Aphrodita aculeata	1.04	1.33	1.44	1.72

TABLE 4.

Numbers of animals ($n \cdot 1000\ m^{-2}$) in catches of hauls with the 3-m beam trawl in the study area (n=2) and in a reference area (n=2), 24 hours after trawling (April study).

species	numbers in catch (n*1000m-2)					
	research area			reference hauls		
	1	2	mean	north	south	mean
FISH						
Arnoglossus laterna	6.48	2.78	4.63	4.63	4.81	4.72
Buglossidium luteum	4.63	6.85	5.74	12.96	6.85	9.91
Callionymus lyra	0.56	1.30	0.93	0.56	1.48	1.02
Clupea harengus	0.56	0.19	0.37	0.00	0.74	0.37
Enchelyopus cimbrius	0.37	0.56	0.46	1.11	0.56	0.83
Gadus morhua	0.00	0.00	0.00	0.00	0.19	0.09
Limanda limanda	31.30	29.26	30.28	6.48	9.63	8.06
Merlangius merlangus	2.04	1.67	1.85	1.85	2.78	2.31
Pleuronectes platessa	0.37	0.00	0.19	0.00	0.19	0.09
Solea solea	0.00	0.56	0.28	0.19	0.56	0.37
Trigla spp.	0.56	0.00	0.28	0.37	0.37	0.37
ECHINODERMS						
Asterias rubens	41.48	11.85	26.67	38.89	22.22	30.56
Astropecten irregularis	63.70	28.89	46.30	62.22	62.22	62.22
Echinocardium cordatum	0.00	0.00	0.00	0.37	0.93	0.65
Ophiura texturata	4.44	1.48	2.96	7.04	4.44	5.74
Psammechinus miliaris	0.00	0.19	0.09	0.00	0.19	0.09
MOLLUSCS						
Abra alba	0.37	0.00	0.19	0.00	0.00	0.00
Acanthocardia echinata	1.67	0.56	1.11	0.00	1.11	0.56
Aporrhais pespelicani	2.41	0.19	1.30	7.96	2.22	5.09
Arctica islandica	1.30	0.56	0.93	0.00	0.19	0.09
Buccinum undatum	0.00	0.19	0.09	0.19	0.19	0.19
Chamelea gallina	0.00	0.19	0.09	0.19	0.19	0.19
Euspira poliana	1.67	0.56	1.11	0.56	0.37	0.46
Mactra corallina	1.85	0.37	1.11	0.00	0.00	0.00
Mysia undata	0.37	0.37	0.37	0.00	0.00	0.00
Phaxas pelludidus	0.00	0.00	0.00	2.78	1.48	2.13
Turritella communis	16.30	0.93	8.61	22.22	5.74	13.98
CRUSTACEANS						
Corystes cassivelaunus	31.11	20.74	25.93	46.67	44.44	45.56
Eupagurus bernardus	0.00	0.19	0.09	4.07	1.67	2.87
Cirolana borealis	0.00	2.22	1.11	0.00	0.00	0.00
Liocarcinus holsatus	7.41	2.22	4.81	8.15	16.30	12.22
Crangon allmani	10.37	11.11	10.74	6.67	2.96	4.81
Upogebia sp.	4.44	0.74	2.59	0.00	0.00	0.00
ANNELIDS						
Aphrodita aculeata	1.11	2.96	2.04	7.96	2.96	5.46

TABLE 5

Numbers of animals (n*1000 m^{-2}) in catches of the first haul, the next 3 hauls (catches of these hauls were pooled before sorting), and the last haul of 12-m beam trawls on the study area (September study). During each haul, both port and starboard trawls were used. Total numbers caught after trawling the area twice (in n*1000 m^{-2}) were calculated as 1000 * the ratio between the actual numbers caught in the 5 hauls (each covering 48 000 m^2) and the surface of the study area (120 000 m^2).

species	numbers in catch (n*1000m-2)			
	haul 1	hauls 2 to 4	haul 5	total catch haul 1 to 5
FISH				
Arnoglossus laterna:				
total	0.50	0.48	0.18	0.85
<9cm	0.00	0.05	0.00	0.06
9-10cm	0.00	0.16	0.05	0.21
10-11cm	0.00	0.05	0.05	0.08
>11cm	0.50	0.21	0.09	0.49
Belone belone	0.02	0.00	0.00	0.01
Buglossidium luteum	0.00	0.05	0.00	0.06
Callionymus lyra	0.05	0.00	0.02	0.03
Hippoglossoides platessoides	0.00	0.01	0.00	0.01
Limanda limanda:				
total	5.30	9.65	2.36	14.65
<13cm	0.41	0.52	0.16	0.86
13-15cm	0.41	1.05	0.21	1.51
15-17cm	0.91	1.78	0.50	2.71
17-19cm	2.05	3.25	0.85	5.06
>19cm	1.51	3.04	0.64	4.51
Merlangius merlangus:				
total	0.09	0.01	0.18	0.12
<13cm	0.05	0.00	0.00	0.02
>20cm	0.05	0.01	0.18	0.10
Pleuronectes platessa:				
total	1.48	0.94	0.23	1.81
19-22cm	0.25	0.29	0.05	0.47
>22cm	1.22	0.65	0.18	1.34
Scophthalmus maximus	0.00	0.01	0.00	0.01
Solea solea:				
total	0.16	0.16	0.05	0.27
<24cm	0.09	0.02	0.02	0.07
>24cm	0.07	0.14	0.02	0.20
Trigla spp.	0.82	0.21	0.07	0.61
ECHINODERMS				
Asterias rubens:				
total	11.39	8.73	2.45	16.01
<6cm	0.50	0.00	0.11	0.24
6-7cm	1.49	2.18	0.11	3.26
7-8cm	2.97	2.18	0.56	4.03
8-9cm	2.97	1.45	0.33	3.07
9-10cm	1.98	0.73	0.67	1.93
>10cm	1.49	2.18	0.67	3.48
Astropecten irregularis:				
total	73.82	32.73	40.00	84.80
<4cm	2.64	1.17	1.43	3.03
4-5cm	2.64	1.17	1.43	3.03
5-6cm	50.09	22.21	27.14	57.54
>6cm	18.45	8.18	10.00	21.20
Echinocardium cordatum	(not counted)			
Ophiura texturata:				
total	2.91	2.18	2.91	4.95
<3cm	1.35	1.01	1.35	2.30
>3cm	1.56	1.17	1.56	2.65
MOLLUSCS				
Acanthocardia echinata	0.39	1.17	1.98	2.35
Aequipecten opercularis	0.05	0.01	0.00	0.03
Arctica islandica	0.02	0.58	0.59	0.95
Buccinum undatum	0.93	0.80	0.70	1.61
Gari fervensis	0.00	0.00	0.02	0.01
Neptunea antiqua	0.02	0.03	0.02	0.05
CRUSTACEANS				
Cancer pagurus	0.00	0.02	0.00	0.02
Corystes cassivelaunus (male)	0.73	4.36	10.36	9.67
Eupagurus bernardus	1.82	3.27	0.43	4.83
Liocarcinus holsatus	6.18	5.11	1.18	9.07
ANNELIDS				
Aphrodita aculeata	5.09	0.36	0.32	2.60

TABLE 6

Numbers of animals (n_*m^{-2}) in van Veen grab samples, taken 24 hours before (t_0, n=18) and 12 hours after (t_1, n=24) trawling (September study). Statistical significance of changes in mean densities was tested with Mann Whitney U-test (2-sided probabilities for mobile species, 1-sided* for sessile species).

species	numbers in samples (n*1m-2)				t0-1	P
	t0-sampling		t1-sampling		in/decrease	MWhU-test
	mean	st.dev.	mean	st.dev.	%	*=one-sided
ECHINODERMS						
Amphiura filliformis	130.00	160.76	77.00	71.86	-41	n.s.
Astropecten irregularis	0.00	0.00	0.75	2.03	>>100	n.s.
Echinocardium cordatum (adult)	4.67	6.02	2.50	3.02	-46	n.s.
Ophiura texturata	0.00	0.00	2.25	6.81	>>100	n.s.
MOLLUSCS						
Abra alba	0.33	1.41	0.50	1.69	50	n.s.
Chamelea gallina:						
total	1.33	3.29	1.00	2.28	-25	n.s.
<2cm	0.67	0.00	0.75	0.00	13	n.s.
>2cm	0.67	0.00	0.25	0.00	-63	n.s.
Corbula gibba	1.00	2.30	0.25	1.22	-75	n.s.
Dosinia lupinus	1.00	2.30	0.00	0.00	-100	0.02*
Euspira poliana	0.67	1.94	1.25	3.05	88	n.s.
Mactra corallina	0.33	1.41	0.00	0.00	-100	n.s.
Mysia undata	0.00	0.00	0.25	0.00	>>100	n.s.
Nucula spp.	0.67	2.83	2.75	3.95	313	0.013*
Phaxas pellucidus	4.67	5.27	3.25	3.95	-30	n.s.
Turritella communis	1.67	2.77	0.50	1.69	-70	0.049*
CRUSTACEANS						
Callianassa sp.	2.00	3.56	0.75	2.03	-63	n.s.
Corystes cassivelaunus (female)	1.33	2.57	0.75	2.03	-44	n.s.
Corystes cassivelaunus (juv.)	0.67	1.94	1.00	2.28	50	n.s.
Eupagurus bernardus	0.00	0.00	0.25	1.22	>>100	n.s.
Cirolana borealis	0.67	1.94	0.25	1.22	-63	n.s.
Upogebia sp.	1.67	4.51	0.50	1.69	-70	n.s.
ANNELIDS						
Pectinaria sp.	1.33	2.57	0.00	0.00	-100	0.008*
Polychaetes exl. Pectinaria	2.33	4.67	1.75	3.74	-25	n.s.
other groups						
Anemones	0.00	0.00	0.25	1.22	>>100	n.s.
Nemertini	0.33	1.41	0.50	1.69	50	n.s.

TABLE 7

Numbers of animals (n$_*$100 m^{-2}) in catches of Triple-D hauls, taken 24 hours before (n=10) and 12 hours after trawling (n=10) (September study). Statistical significance of changes in mean densities was tested using log(n+1) transformed data with a t-test (2-sided probabilities for mobile species, 1-sided$_*$ for sessile species).

species	numbers in catch (n*100m-2)				t0-1	P
	t0-sampling		t1-sampling		in/decrease	t-test
	mean	st.dev.	mean	st.dev.	%	*=one-sided
FISH						
Arnoglossus laterna	1.0	1.2	1.4	1.3	35	n.s.
Buglossidium luteum	1.1	1.0	0.6	0.8	-44	n.s.
Limanda limanda	1.1	1.3	0.8	2.0	-30	n.s.
Ammodytes tobianus	0.0	0.0	0.1	0.4	>>100	n.s.
ECHINODERMS						
Asterias rubens	1.3	2.1	2.1	3.1	60	n.s.
Astropecten irregularis	50.9	12.1	40.7	17.6	-20	n.s.
Echinocardium cordatum	40.1	37.6	5.7	8.4	-86	0.000
Ophiura texturata	1.5	1.2	1.3	1.0	-14	n.s.
Psammechinus miliaris	0.3	1.1	0.0	0.0	-100	n.s.
MOLLUSCS						
Abra alba	4.2	4.0	0.7	1.0	-83	0.008*
Acanthocardia echinata	1.0	1.2	1.4	1.6	40	n.s.
Aporrhais pespelicani	4.9	3.2	5.2	3.2	6	n.s.
Arctica islandica	2.4	1.8	1.2	1.1	-50	0.036*
Buccinum undatum	0.2	0.5	0.0	0.0	-100	n.s.
Chamelea gallina:						
total	23.2	9.4	20.7	9.7	-11	n.s.
<2cm	6.3	-	6.7	-	7	-
2-3cm	16.6	-	13.6	-	-18	-
>3cm	0.3	-	0.5	-	31	-
Dosinia lupinus	5.1	3.1	4.8	3.5	-6	n.s.
Ensis ensis	1.2	1.4	0.6	0.8	-51	n.s.
Euspira catena	1.6	1.3	1.1	1.3	-32	n.s.
Gari fervensis	1.9	2.6	0.9	1.3	-52	n.s.
Mactra corallina	1.4	2.0	0.2	0.5	-88	0.025*
Mysia undata	3.6	3.4	1.6	2.4	-54	0.055*
Nucula spp.	0.1	0.5	0.0	0.0	-100	n.s.
Phaxas pellucidus	2.3	1.8	0.5	0.8	-79	0.004*
Turritella communis	45.4	14.9	35.6	8.1	-22	0.053*
CRUSTACEANS						
Corystes cassivelaunus:						
female	36.7	8.1	22.9	10.4	-38	0.008
male	7.6	8.5	4.7	2.5	-37	n.s.
Eupagurus bernardus:						
large	1.1	1.4	0.0	0.0	-100	n.s.
small	0.3	0.7	0.4	0.7	23	n.s.
Liocarcinus holsatus	1.4	1.3	1.5	2.0	11	n.s.
Upogebia sp.	0.2	0.6	0.0	0.0	-100	n.s.
ANNELIDS						
Aphrodita aculeata	5.1	6.3	4.4	2.2	-13	n.s.
Nereis sp.	1.6	2.0	0.7	1.6	-59	n.s.
other groups						
Anemones	1.5	1.6	0.4	0.7	-70	0.043*
Nemertini	2.4	1.7	1.5	2.0	-36	n.s.

TABLE 8a

Numbers of animals (n*1000 m^{-2}) in catches of hauls with the 3-m beam trawl in the study area (September study), 20 hours before (t_0; n=6), 1 hour after (t_1; n=6) and 24 hours after (t_2; n=6) trawling, and changes in mean densities between t_0 and t_1 (S_1), t_1 and t_2 (S_2), and t_0 and t_2 (S_{tot}). Statistical significance was calculated using Tukey comparisons in ANOVA or, between brackets, Mann Whitney U test.

species	numbers in catch (n*1000m-2)							t0-t1 in/decrease		t1-t2 in/decrease		t0-t2 in/decrease	
	t0 (n=6)		t1 (n=6)		t2 (n=6)								
	mean	st.dev.	mean	st.dev.	mean	st.dev.		%	sign.	%	sign.	%	sign.
FISH													
Agonus cataphractus (juv.)	0.10	0.15	0.05	0.12	0.17	0.18		-51	[n.s.]	242	[n.s.]	66	[n.s.]
Arnoglossus laterna:							-100						
total	14.37	3.52	4.34	2.05	11.54	2.40		-70	0.000	166	0.000	-20	n.s.
<9cm	4.42	-	1.89	-	3.31	-		-57	0.000	76	0.016	-25	n.s.
9-10cm	5.34	-	1.54	-	4.42	-		-71	0.000	186	0.000	-17	n.s.
10-11cm	2.58	-	0.23	-	1.99	-		-91	0.000	770	0.000	-23	n.s.
>11cm	2.03	-	0.69	-	1.82	-		-66	0.000	166	0.000	-10	n.s.
Buglossidium luteum	20.48	3.90	14.69	5.98	8.89	2.17		-28	n.s.	-39	n.s.	-57	0.001
Callionymus lyra	0.55	0.32	0.20	0.24	1.25	0.86		-64	n.s.	519	0.020	126	n.s.
Enchelyopus cimbrius	0.70	0.77	0.57	0.59	0.33	0.37		-18	n.s.	-43	n.s.	-53	n.s.
Gadus morhua	0.00	0.00	0.05	0.13	0.00	0.00		>>100	[n.s.]	-100	[n.s.]	-	-
Limanda limanda:													
0-group	9.11	1.16	10.48	6.97	5.08	1.67		15	n.s.	-51	n.s.	-44	n.s.
>0-group (total)	18.30	4.28	5.44	2.19	42.44	15.32		-70	0.000	680	0.000	132	0.008
<13cm	6.43	1.50	0.83	0.33	6.08	2.20		-87	0.000	634	0.000	-5	n.s.
13-15cm	3.19	0.75	0.62	0.24	4.89	1.77		-80	0.001	687	0.000	53	n.s.
15-17cm	3.80	0.89	1.55	0.61	13.35	4.82		-59	n.s.	759	0.000	251	0.003
17-19cm	3.65	0.85	1.61	0.63	12.82	4.63		-56	n.s.	699	0.000	251	0.001
>19cm	1.23	0.29	0.88	0.35	5.29	1.91		-29	n.s.	500	0.005	329	0.030
Merlangius merlangus:													
total	16.24	3.06	6.31	2.14	12.70	6.04		-61	0.003	101	n.s.	-22	n.s.
<13cm	13.70	2.58	4.86	1.65	9.07	4.31		-65	0.001	87	n.s.	-34	n.s.
13-20cm	1.59	0.30	0.26	0.09	2.06	0.98		-84	0.000	698	0.000	30	n.s.
>20cm	0.96	0.18	1.19	0.40	1.57	0.75		24	n.s.	32	n.s.	65	n.s.
Pleuronectes platessa:													
total	1.30	0.50	0.11	0.26	0.88	0.47		-92	0.000	725	0.004	-32	n.s.
<19cm	0.27	0.10	0.00	0.00	0.11	0.06		-100	[0.007]	>>100	[n.s.]	-59	[n.s.]
19-22cm	0.60	0.23	0.05	0.13	0.28	0.15		-91	[0.050]	416	[n.s.]	-54	[n.s.]
>22cm	0.43	0.17	0.05	0.13	0.50	0.26		-88	n.s.	828	n.s.	14	n.s.
Pomatoschistus spp.	0.70	0.58	0.52	0.51	3.42	1.69		-25	n.s.	553	0.039	392	n.s.
Scophthalmus maximus	0.00	0.00	0.00	0.00	0.00	0.00		-	-	-	-	-	-
Solea solea:													
total	0.25	0.12	0.31	0.62	0.74	0.90		23	n.s.	143	n.s.	199	n.s.
>24cm	0.10	0.15	0.25	0.50	0.43	0.52		158	n.s.	67	n.s.	331	n.s.
<24cm	0.15	0.16	0.05	0.13	0.32	0.48		-66	n.s.	514	n.s.	112	n.s.
Trachurus trachurus	0.30	0.73	0.00	0.00	0.05	0.13		-100	[n.s.]	>>100	[n.s.]	-82	[n.s.]
Trigla spp.	1.29	0.68	0.32	0.35	1.53	0.71		-76	n.s.	385	0.018	19	n.s.
Trisopterus luscus	0.00	0.00	0.00	0.00	0.00	0.00		-	-	-	-	-	-
ECHINODERMS													
Asterias rubens:													
total	29.42	5.83	8.00	4.53	11.62	9.48		-73	0.000	45	n.s.	-60	0.001
<6cm	3.24	-	1.30	-	1.13	-		-60	[0.010]	-13	[n.s.]	-65	[0.010]
6-7cm	6.95	-	2.49	-	2.83	-		-64	0.001	14	n.s.	-59	0.001
7-8cm	5.33	-	1.42	-	2.27	-		-73	0.000	59	n.s.	-57	0.002
8-9cm	5.10	-	0.89	-	1.59	-		-83	0.000	79	n.s.	-69	0.000
9-10cm	2.32	-	0.77	-	1.30	-		-67	0.000	69	n.s.	-44	0.037
>10cm	6.49	-	1.13	-	2.49	-		-83	0.000	122	n.s.	-62	0.001
Astropecten irregularis:													
total	32.94	9.64	109.99	18.70	46.61	17.49		234	0.000	-58	0.013	42	n.s.
<4cm	7.72	-	33.84	-	10.85	-		338	0.000	-68	0.000	41	n.s.
4-5cm	5.83	-	24.17	-	10.61	-		315	0.000	-56	0.007	82	n.s.
5-6cm	12.61	-	41.09	-	18.00	-		226	0.000	-56	0.010	43	n.s.
>6cm	6.78	-	10.88	-	7.15	-		61	n.s.	-34	n.s.	6	n.s.
Echinocardium cordatum	1.53	1.99	1.14	1.27	1.66	1.30		-25	n.s.	45	n.s.	8	n.s.
Ophiura texturata:													
total	20.44	2.53	13.07	6.36	13.50	4.42		-36	n.s.	3	n.s.	-34	n.s.
<3cm	14.09	-	11.31	-	11.83	-		-20	n.s.	5	n.s.	-16	n.s.
>3cm	6.35	-	1.76	-	1.67	-		-72	0.000	-5	n.s.	-74	0.000
Psammechinus miliaris	0.30	0.26	0.11	0.16	0.05	0.13		-64	[n.s.]	-48	[n.s.]	-82	[n.s.]
MOLLUSCS													
Abra alba	0.06	0.15	2.65	2.22	0.76	0.45		4321	[0.003]	-71	[n.s.]	1176	[0.005]
Acanthocardia echinata	0.00	0.00	1.09	1.15	0.32	0.63		>>100	[0.007]	-71	[n.s.]	>>100	[n.s.]
Aequipecten opercularis	0.05	0.12	0.00	0.00	0.00	0.00		-100	[n.s.]	-	-	-100	[n.s.]
Aporrhais pespelicani	0.31	0.34	6.19	3.73	0.54	0.43		1908	[0.004]	-91	-	74	[n.s.]
Arctica islandica	0.00	0.00	0.20	0.24	0.11	0.17		>>100	[n.s.]	-46	[n.s.]	>>100	[n.s.]
Buccinum undatum	0.75	0.46	1.38	0.56	1.58	0.61		83	n.s.	15	n.s.	110	n.s.
Chamelea gallina	0.52	0.18	1.94	1.33	1.03	0.58		273	n.s.	-47	n.s.	99	n.s.

TABLE 8a (continued)

species	numbers in catch (n*1000m-2)						t0-t1 in/decrease		t1-t2 in/decrease		t0-t2 in/decrease	
	t0 (n=6)		t1 (n=6)		t2 (n=6)							
	mean	st.dev.	mean	st.dev.	mean	st.dev.	%	sign.	%	sign.	%	sign.
Corbula gibba	0.61	0.48	0.89	0.55	0.44	0.57	46	n.s.	-51	n.s.	-28	n.s.
Dosinia lupinus	0.00	0.00	0.27	0.26	0.17	0.18	>>100	[0.022]	-38	[n.s.]	>>100	[n.s.]
Ensis ensis	0.00	0.00	0.00	0.00	0.05	0.13	-	-	>>100	[n.s.]	>>100	[n.s.]
Epitonium sp.	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Euspira catena	0.11	0.17	0.59	0.57	0.76	0.75	431	n.s.	29	n.s.	584	n.s.
Euspira poliana	0.62	0.98	5.51	2.28	2.43	1.77	787	0.008	-56	n.s.	292	n.s.
Gari fervensis	0.05	0.13	0.20	0.24	0.05	0.13	286	[n.s.]	-72	[n.s.]	6	[n.s.]
Hiatella arctica	0.00	0.00	0.05	0.13	0.00	0.00	>>100	[n.s.]	-100	[n.s.]	-	-
Loligo sp.	0.00	0.00	0.00	0.00	0.22	0.34	-	-	>>100	[n.s.]	>>100	[n.s.]
Mactra corallina	0.00	0.00	0.93	0.43	0.32	0.20	>>100	[0.002]	-65	[0.037]	>>100	[0.007]
Mysia undata	0.11	0.17	0.35	0.33	0.11	0.17	224	[n.s.]	-68	[n.s.]	3	[n.s.]
Nucula spp.	4.20	1.49	26.47	21.48	6.22	5.09	531	0.023	-76	n.s.	48	n.s.
Phaxas pellucidus	0.57	0.64	2.65	2.04	0.60	0.87	367	n.s.	-77	n.s.	6	n.s.
Thracia sp.	0.00	0.00	0.05	0.13	0.00	0.00	>>100	[n.s.]	-100	[n.s.]	-	-
Turritella communis	139.13	101.55	325.67	169.66	153.42	52.92	134	0.009	-53	n.s.	10	n.s.
CRUSTACEANS												
Callianassa sp.	0.00	0.00	1.79	0.97	0.05	0.13	>>100	[0.002]	-97	-	>>100	[n.s.]
Cancer pagurus	0.00	0.00	0.00	0.00	0.11	0.17	-	-	>>100	[n.s.]	>>100	[n.s.]
Cirolana borealis	5.81	3.38	7.45	6.41	2.91	4.48	128	n.s.	-61	n.s.	-50	n.s.
Corystes cassivelaunus (female	1.03	1.67	6.77	2.62	5.80	2.86	554	[0.010]	-14	[n.s.]	460	[0.010]
Corystes cassivelaunus (male)	34.98	9.22	23.83	6.76	9.59	3.06	-32	n.s.	-60	0.000	-73	0.000
Crangon allmani	20.45	11.89	8.05	7.61	13.42	4.49	-61	0.024	67	n.s.	-34	n.s.
Ebalia spp.	1.01	0.94	0.72	0.44	0.49	0.45	-29	n.s.	-32	n.s.	-52	n.s.
Eupagurus bernardus (large)	4.53	1.85	0.57	0.22	2.62	0.70	-88	0.000	363	0.013	-42	n.s.
Eupagurus bernardus (small)	4.50	1.87	1.19	0.67	4.97	1.07	-74	0.002	318	0.001	10	n.s.
Liocarcinus holsatus:												
total	24.64	9.18	19.07	5.58	20.31	7.52	-23	n.s.	-93	n.s.	-18	n.s.
<4cm	22.70	-	16.58	-	19.31	-	-27	n.s.	16	n.s.	-15	n.s.
>4cm	1.94	-	2.49	-	1.00	-	29	n.s.	-60	0.004	-48	n.s.
Macropodia sp.	0.00	0.00	0.06	0.14	0.11	0.27	>>100	[n.s.]	90	[n.s.]	>>100	[n.s.]
Processa sp.	32.78	20.09	13.66	7.47	7.86	6.78	-58	n.s.	-42	n.s.	-76	0.011
Upogebia sp.	0.44	0.58	42.08	17.14	0.91	1.18	9376	0.000	-98	0.000	106	n.s.
ANNELIDS												
Aphrodita aculeata	0.64	0.42	0.40	0.45	0.44	0.54	63	n.s.	109	n.s.	68	n.s.
other groups												
Anemones	0.00	0.00	0.46	0.54	0.06	0.14	>>100	[n.s.]	12	[n.s.]	>>100	[n.s.]

TABLE 8b

Numbers of animals (n$*$1000 m^{-2}) in catches of hauls with the 3-m beam trawl in the reference area (September study), 20 hours before (t_0; n=6), 1 hour after (t_1; n=6) and 24 hours after (t_2; n=6) "commercial" trawling, and changes in mean densities between t_0 and t_1 (R_1), t_1 and t_2 (R_2), and t_0 and t_2 (R_{tot}). Statistical significance was calculated using Tukey comparisons in ANOVA or, between brackets, Mann Whitney U test.

species	numbers in catch (n*1000m-2) t0 (n=4) mean	t0 st.dev.	t1 (n=6) mean	t1 st.dev.	t2 (n=6) mean	t2 st.dev.	t0-t1 in/decrease %	t0-t1 sign.	t1-t2 in/decrease %	t1-t2 sign.	t0-t2 in/decrease %	t0-t2 sign.
FISH												
Agonus cataphractus (juv.)	0.10	0.20	0.14	0.21	0.40	0.63	36	- (n.s.)	198	- (n.s.)	307	- (n.s.)
Arnoglossus laterna:												
total	13.10	3.29	13.49	4.14	13.59	3.64	3	n.s.	1	n.s.	4	n.s.
<9cm	2.43	-	2.34	-	0.59	-	-4	n.s.	-75	0.000	-76	0.000
9-10cm	6.76	-	5.73	-	4.99	-	-15	n.s.	-13	n.s.	-26	n.s.
10-11cm	2.11	-	3.01	-	3.81	-	43	n.s.	26	n.s.	81	0.020
>11cm	1.80	-	2.41	-	4.20	-	34	n.s.	74	0.021	134	0.001
Buglossidium luteum	16.12	4.45	16.32	5.08	19.83	6.96	1	n.s.	22	n.s.	23	n.s.
Callionymus lyra	0.50	0.50	0.26	0.28	0.69	0.43	-48	n.s.	170	n.s.	39	n.s.
Clupeidae	0.10	0.20	0.96	1.34	1.22	1.26	870	- (n.s.)	26	- (n.s.)	1125	- (n.s.)
Enchelyopus cimbrius	0.45	0.10	0.97	0.64	1.28	0.60	117	n.s.	33	n.s.	188	n.s.
Gadus morhua	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Limanda limanda:												
0-group	6.40	1.72	4.65	2.11	9.18	3.49	-27	n.s.	98	0.047	44	n.s.
>0-group (total)	14.19	5.70	13.83	3.61	13.67	3.69	-3	n.s.	-1	n.s.	-4	n.s.
<13cm	5.61	2.25	4.64	1.21	3.69	1.02	-17	n.s.	-20	n.s.	-34	n.s.
13-15cm	2.55	1.02	2.90	0.76	3.99	1.10	14	n.s.	38	n.s.	56	n.s.
15-17cm	2.45	0.98	2.82	0.74	2.39	0.66	15	n.s.	-15	n.s.	-2	n.s.
17-19cm	2.45	0.98	2.82	0.74	2.89	0.80	15	n.s.	3	n.s.	18	n.s.
>19cm	1.12	0.45	0.66	0.17	0.80	0.22	-41	n.s.	20	n.s.	-29	n.s.
Merlangius merlangus:												
total	10.62	1.66	7.78	4.05	13.67	4.58	-27	n.s.	76	n.s.	29	n.s.
<13cm	8.94	1.40	5.89	3.06	9.54	3.20	-34	n.s.	62	n.s.	7	n.s.
13-20cm	1.34	0.21	1.26	0.66	3.34	1.12	-6	n.s.	165	0.001	149	0.012
>20cm	0.34	0.05	0.63	0.33	0.79	0.26	88	n.s.	25	n.s.	135	n.s.
Pleuronectes platessa:												
total	1.34	0.75	1.23	0.74	1.28	0.70	-8	n.s.	4	n.s.	-4	n.s.
<19cm	0.10	0.06	0.00	0.00	0.00	0.00	-100	- (n.s.)	-	-	-100	- (n.s.)
19-22cm	0.21	0.12	0.00	0.00	0.18	0.13	-100	- (n.s.)	>>100	- (n.s.)	-12	- (n.s.)
>22cm	1.03	0.58	1.23	0.74	1.00	0.71	19	n.s.	-19	n.s.	-3	n.s.
Pomatoschistus spp.	5.41	8.74	5.38	3.02	8.29	6.12	-1	n.s.	54	n.s.	53	n.s.
Scophthalmus maximus	0.00	0.00	0.08	0.20	0.00	0.00	>>100	- (n.s.)	-100	- (n.s.)	-	-
Solea solea:												
total	0.30	0.38	0.30	0.39	0.19	0.30	1	n.s.	-36	n.s.	-36	n.s.
>24cm	0.20	0.40	0.08	0.20	0.10	0.25	-58	n.s.	22	n.s.	-49	n.s.
<24cm	0.10	0.20	0.22	0.24	0.09	0.22	120	n.s.	-59	n.s.	-9	n.s.
Trachurus trachurus	0.20	0.23	0.18	0.31	0.38	0.30	-8	- (n.s.)	110	- (n.s.)	93	- (n.s.)
Trigla spp.	0.50	0.60	1.49	0.96	1.18	0.57	200	n.s.	-20	n.s.	139	n.s.
Trisopterus luscus	0.20	0.23	0.17	0.27	0.09	0.22	-12	- (n.s.)	-48	- (n.s.)	-55	- (n.s.)
ECHINODERMS												
Asterias rubens:												
total	42.61	12.03	41.19	12.01	45.40	8.21	-3	n.s.	10	n.s.	7	n.s.
<6cm	3.67	-	1.21	-	0.00	-	-67	- (0.011)	-100	- (0.002)	-100	- (0.004)
6-7cm	6.61	-	4.85	-	7.57	-	-27	n.s.	56	n.s.	14	n.s.
7-8cm	10.28	-	16.96	-	10.81	-	65	n.s.	-36	n.s.	5	n.s.
8-9cm	6.61	-	4.85	-	7.57	-	-27	n.s.	56	n.s.	14	n.s.
9-10cm	7.35	-	2.42	-	5.40	-	-67	0.001	123	0.010	-26	n.s.
>10cm	8.08	-	10.90	-	14.05	-	35	n.s.	29	n.s.	74	n.s.
Astropecten irregularis:												
total	17.51	3.84	24.39	10.17	25.48	20.58	39	n.s.	4	n.s.	45	n.s.
<4cm	3.93	-	1.81	-	7.57	-	-54	n.s.	319	0.000	93	n.s.
4-5cm	1.79	-	3.61	-	3.44	-	102	n.s.	-5	n.s.	93	n.s.
5-6cm	7.50	-	13.55	-	9.98	-	81	n.s.	-26	n.s.	33	n.s.
>6cm	4.29	-	5.42	-	4.48	-	26	n.s.	-17	n.s.	4	n.s.
Echinocardium cordatum	0.30	0.60	1.74	2.74	0.90	0.63	485	n.s.	-48	n.s.	202	n.s.
Ophiura texturata:												
total	16.96	5.24	21.94	8.71	17.09	3.84	29	n.s.	-22	n.s.	1	n.s.
<3cm	11.31	-	17.68	-	11.68	-	56	n.s.	-34	n.s.	3	n.s.
>3cm	5.65	-	4.27	-	5.41	-	-25	n.s.	27	n.s.	-4	n.s.
Psammechinus miliaris	0.00	0.00	0.00	0.00	0.38	0.59	-	-	>>100	- (n.s.)	>>100	- (n.s.)
MOLLUSCS												
Abra alba	0.00	0.00	0.29	0.71	0.10	0.25	>>100	- (n.s.)	-65	- (n.s.)	>>100	- (n.s.)
Acanthocardia echinata	0.00	0.00	0.37	0.90	0.00	0.00	>>100	- (n.s.)	-100	- (n.s.)	>>100	- (n.s.)
Aequipecten opercularis	0.15	0.30	0.00	0.00	0.10	0.25	-100	- (n.s.)	>>100	- (n.s.)	-32	- (n.s.)
Aporrhais pespelicani	0.00	0.00	0.17	0.27	0.00	0.00	>>100	- (n.s.)	-100	- (n.s.)	-	-
Arctica islandica	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-

TABLE 8b (continued)

species	numbers in catch (n*1000m-2)						t0-t1 In/decrease		t1-t2 In/decrease		t0-t2 In/decrease	
	t0 (n=4)		t1 (n=6)		t2 (n=6)							
	mean	st.dev.	mean	st.dev.	mean	st.dev.	%	sign.	%	sign.	%	sign.
Buccinum undatum	0.50	0.50	0.68	0.82	0.20	0.31	38	n.s.	-70	n.s.	-59	n.s.
Chamelea gallina	0.99	1.50	0.37	0.90	1.76	2.26	-63	n.s.	381	n.s.	78	n.s.
Corbula gibba	0.99	1.50	0.77	0.85	2.01	2.26	-23	n.s.	161	n.s.	102	n.s.
Dosinia lupinus	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Ensis ensis	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Epitonium sp.	0.10	0.20	0.00	0.00	0.11	0.26	-100	- (n.s.)	>>100	- (n.s.)	7	- (n.s.)
Euspira catena	0.15	0.30	0.37	0.70	0.10	0.25	151	n.s.	-73	n.s.	-32	n.s.
Euspira poliana	2.88	2.03	2.38	3.16	1.48	1.80	-17	n.s.	-38	n.s.	-49	n.s.
Gari fervensis	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Hiatella arctica	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Loligo sp.	0.00	0.00	0.00	0.00	0.40	0.99	-	-	>>100	- (n.s.)	>>100	- (n.s.)
Mactra corallina	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Mysia undata	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Nucula spp.	3.72	3.63	0.85	0.95	3.19	2.91	-77	n.s.	276	n.s.	-14	n.s.
Phaxas pellucidus	1.79	3.07	2.27	2.51	3.88	3.18	27	n.s.	71	n.s.	117	n.s.
Thracia sp.	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Turritella communis	113.29	50.91	89.08	25.51	89.62	29.62	-21	n.s.	1	n.s.	-21	n.s.
CRUSTACEANS												
Callianassa sp.	0.00	0.00	0.00	0.00	0.40	0.99	-	-	>>100	- (n.s.)	>>100	- (n.s.)
Cancer pagurus	0.00	0.00	0.00	0.00	0.09	0.22	-	-	>>100	- (n.s.)	>>100	- (n.s.)
Cirolana borealis	2.68	2.45	5.51	4.46	0.46	0.87	106	n.s.	-92	0.038	-83	n.s.
Corystes cassivelaunus (female	0.79	1.59	0.00	0.00	1.63	1.22	-100	- (n.s.)	>>100	- (0.007)	105	- (n.s.)
Corystes cassivelaunus (male)	45.34	11.06	44.12	11.61	41.03	7.33	-3	n.s.	-7	n.s.	-9	n.s.
Crangon allmani	38.44	16.86	50.25	40.44	49.57	24.63	31	n.s.	-1	n.s.	29	n.s.
Ebalia spp.	2.98	3.45	3.24	2.92	1.22	1.79	9	n.s.	-63	n.s.	-59	n.s.
Eupagurus bernardus (large)	3.37	2.87	2.52	0.96	2.50	1.42	-25	n.s.	-1	n.s.	-26	n.s.
Eupagurus bernardus (small)	7.79	5.27	7.07	3.76	7.01	2.73	-9	n.s.	-1	n.s.	-10	n.s.
Liocarcinus holsatus:												
total	32.49	17.87	37.54	7.48	38.59	7.04	16	n.s.	3	n.s.	19	n.s.
<4cm	25.74	-	29.20	-	27.44	-	13	n.s.	-6	n.s.	7	n.s.
>4cm	6.75	-	8.34	-	11.15	-	24	n.s.	34	n.s.	65	n.s.
Macropodia sp.	0.00	0.00	0.35	0.70	0.28	0.46	>>100	- (n.s.)	-20	- (n.s.)	>>100	- (n.s.)
Processa sp.	59.42	29.72	65.88	12.89	56.74	25.57	11	n.s.	-14	n.s.	-5	n.s.
Upogebia sp.	0.30	0.38	0.08	0.20	0.20	0.49	-72	n.s.	144	n.s.	-32	n.s.
ANNELIDS												
Aphrodita aculeata	0.94	0.71	0.48	0.61	1.17	0.77	-49	n.s.	142	n.s.	24	n.s.
other groups												
Anemones	0.10	0.20	0.06	0.15	0.28	0.46	-37	- (n.s.)	349	- (n.s.)	184	- (n.s.)

TABLE 9

Catch efficiency of the commercial trawls based on the catch of the first haul, and on the total catch of hauls 1 to 5 (both as a proportion of the initial density), gear used to estimate the initial density, mortality found for discarded animals (as a proportion of the total catch), catch mortality in the first haul as well as in hauls 1 to 5, and the expected catch mortality in haul 1 to 5 (all as a proportion of the initial density). Only those species are included, that were caught in the sampling gear in sufficient numbers for a reliable density estimate (ddd = Triple-D; box = box corer).

*) The catch mortality for the infauna species *Echinocardium cordatum* is estimated in the April study. As in this study not all catches in the trawls were analyzed, a catch mortality after trawling the area twice could not be estimated.

**)Those specimens that live in adult shells of *Euspira catena* or larger shells.

species	catch efficiency haul 1 % of init.dens.	total catch haul 1 to 5 % of init.dens.	gear used for estimate of initial density	mortality in discard % of tot.catch	estimated catch mortality haul 1 % of init.dens.	estimated catch mortality haul 1 to 5 % of init.dens.	expected catch mortality haul 1 to 5 % of init.dens.
FISH							
Limanda limanda:							
<13cm	6	13	3mb	99	6	13	12
13-15cm	13	47	3mb	99	13	47	24
15-17cm	24	71	3mb	99	24	71	42
17-19cm	56	139	3mb	99	56	139	81
Pleuronectes platessa:							
19-22cm	42	78	3mb	95	40	74	63
Arnoglossus laterna:							
<11cm	2	4	3mb	100	2	4	4
>11cm	14	24	3mb	100	14	24	26
ECHINODERMS							
Asterias rubens	39	54	3mb	6	2	3	3
Astropecten irregularis	14	17	ddd	12	2	2	4
Echinocardium cordatum*	<<1	?	box	100	<<1	?	
Ophiura texturata:							
<3cm	10	16	3mb	27	3	4	6
>3cm	25	42	3mb	27	7	11	12
MOLLUSCS							
Acanthocardia echinata	4	24	ddd	50	2	12	4
Arctica islandica	0.7	4	ddd	87	0.6	3.5	1
CRUSTACEANS							
Corystes cassivelaunus (male)	1	13	ddd	65	0.6	8.5	1
Eupagurus bernardus (large)**	40	100	3mb	15	6	15	10
ANNELIDS							
Aphrodita aculeata	10	5	ddd	6	0.6	0.3	1

TABLE 10

Sampling gear used for estimating percentage of "missing animals", and percentage of missing animals. Fish species were excluded, as well as invertebrate species that were caught in the sampling gear in too low numbers for a reliable density estimate.

* percentage missing animals is based on a significant change in density between t_0 and t_1;

c. percentage missing animals is lower than the tested change in density between t_0 and t_1, because species is present in catch of 12-m beam trawl;

[ ] percentage missing numbers is unreliable, as t_0- and t_1-sampling are based on low numbers in catch, or show large variations between the samples (resulting in large, but non significant differences).

ddd = Triple-D; 3mb = 3-m beam trawl; box = box corer

1) 25 species, of which none were caught in sufficient numbers for a reliable density estimation.

species	gear used to determine percentage missing animals	missing animals % of init.dens.
ECHINODERMS		
Amphiura filiformis	box	8
Asterias rubens	3mb	18 *c
Astropecten irregularis	ddd	3 c
Echinocardium cordatum	box	? c
Ophiura texturata (large)	3mb	31 *c
Ophiura texturata (small)	3mb	3 c
MOLLUSCS		
Acanthocardia echinata	ddd	[~0] c
Arctica islandica (adult)	ddd	[46] *c
Arctica islandica (juv.)	box	35 *
Abra alba	ddd	85 *
Mactra corallina	ddd	[85] *
Phaxas pellucidus	ddd	[85] *
Ensis ensis	ddd	[50]
Gari fervensis	ddd	[50]
Mysia undata	ddd	[50]
Aporrhais pespelicani	ddd	~0
Chamelea gallina	ddd	~0
Corbula gibba	box	~0
Dosinia lupinus	ddd	~0
Mysella bidentata	box	~0
Nucula spp.	box	~0
Turritella communis (adult)	ddd	22
Turritella communis (juv)	box	[43]
Cylichna cylindracea	box	13
CRUSTACEANS		
Callianassa sp.	box	4
Corystes cassivelaunus (female)	ddd	38 *c
Corystes cassivelaunus (male)	ddd	25 c
Ebalia sp.	3mb	[29]
Eupagurus bernhardus (large)	3mb	~0 *c
Eupagurus bernhardus (small)	3mb	74 *
ANNELIDS		
Aphrodita aculeata	ddd	9 c
Pectinaria sp.	box	56 *
other annelids (total) 1)	box	14
other groups		
Anthozoa indet.	ddd	[70] *

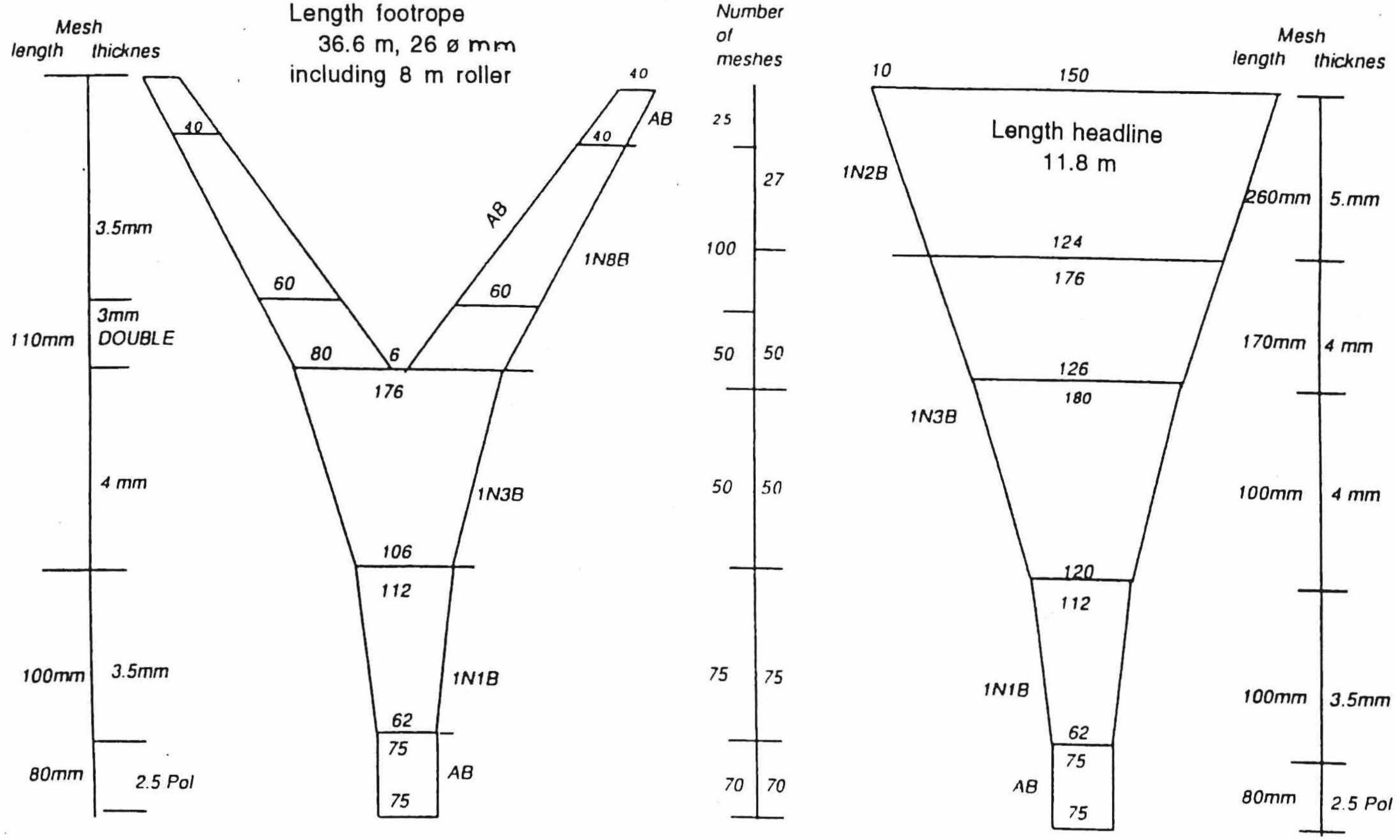
TABLE 11

Catch mortality (in discarded animals, after handling the catch onboard the trawler) after trawling the area once and twice, as well as non-catch mortality (in animals in the study area due to passage of the trawl, or outside the study area after being washed through the meshes), and total mortality (sum of catch mortality and non-catch mortality) after trawling twice. All mortality estimates as a proportion of the initial density. ~ order of magnitude; [ ] unreliable density estimate or unreliable mortality estimate (*Eupagurus bernhardus*).

*) total mortality was estimated directly

species	TRAWLING ONCE	TRAWLING TWICE		
	catch mortality % of init.dens.	catch mortality % of init.dens.	non-catch mortality % of init.dens.	total mortality % of init.dens.
FISH				
Arnoglossus laterna (<11cm; >11cm)	2; 14	4; 24	?	4; 24
L. limanda >0-group (<13 to 19cm)	6-56	13-139	?	13-139
Pleuronectes platessa (19-22cm)	40	74	?	74
ECHINODERMS				
Asterias rubens	2	3	1	4
Astropecten irregularis	2	2	1-3	3-5
Echinocardium cordatum *	<1	?	?	[6]
Ophiura texturata (<3cm; >3cm)	3; 7	4; 11	3; 8	7; 19
Amphiura filiformis	0	0	8	8
MOLLUSCS				
Acanthocardia echinata	2	12	~0	[~12]
Arctica islandica (adult)	<1	3	[46]	[49]
Arctica islandica (juv., <3mm)	0	0	35	35
Abra alba	0	0	85	85
Mactra corallina	0	0	[85]	[85]
Phaxas pellucidus	0	0	[85]	[85]
Ensis ensis	0	0	[50]	[50]
Gari fervensis	0	0	[50]	[50]
Mysia undata	0	0	[50]	[50]
Chamelea gallina	0	0	~0	~0
Corbula gibba	0	0	~0	~0
Nucula spp.	0	0	~0	~0
Mysella bidentata	0	0	~0	~0
Dosinia lupinus	0	0	~0	~0
Aporrhais pespelicani	0	0	~0	~0
Cylichna cylindracea	0	0	13	13
Turritella communis (adult)	0	0	22	22
Turritella communis (juv., <15mm)	0	0	[43]	[43]
CRUSTACEANS				
Callianassa sp.	0	0	4	4
Corystes cassivelaunus (female)	0	0	25-38	25-38
Corystes cassivelaunus (male)	<1	8	16-25	24-33
Ebalia spp.	0	0	[29]	[29]
Eupagurus bernardus (large)	6	15	~0	[15]
Eupagurus bernardus (small)	0	0	74	74
ANNELIDS				
Aphrodita aculeata	<1	<1	<1-9	<1-9
Pectinaria sp.	0	0	56	56
other annelids	0	0	14	14
other groups				
Anthozoa	0	0	[70]	[70]

12 M BEAM TRAWL GEAR for muddy bottom, WEEK 36 AND 37 1993



roller 8 m 250 mm ø, ca 600 kg
8 netticklerchains 3.5 up to 16 m, 12 mm ø
7 ticklerchains 19 up to 26 m, 14 mm ø
1 ,, , 18 m, 18 mm ø
2 ,, , 17 and 16 m, 22mm ø

Shoes and pipe ca 3200 kg, ticklers ca 1200 kg, bridle and block ca 600 kg, net with groundrope and net ticklers 1500 kg
TOTAL WEIGHT OF EACH GEAR IS ABOUT 6.5 TONS

Fig. 1.Commercial 12-m beam trawl used in April 1992 and September 1993 (Fig. RIVO).

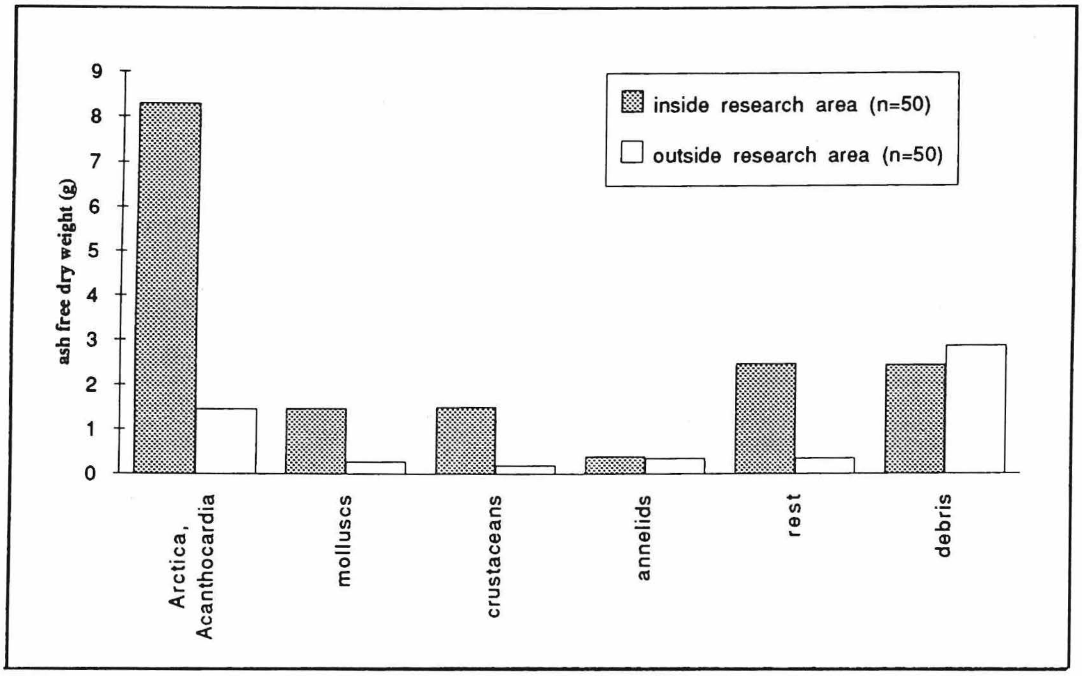


Fig. 2.Total stomach content (g ash free dry weigth) of dab (*Limanda limanda*) caught inside the trawled study area and outside this area, 24 hours after trawling with 12-m beam trawls (April study).

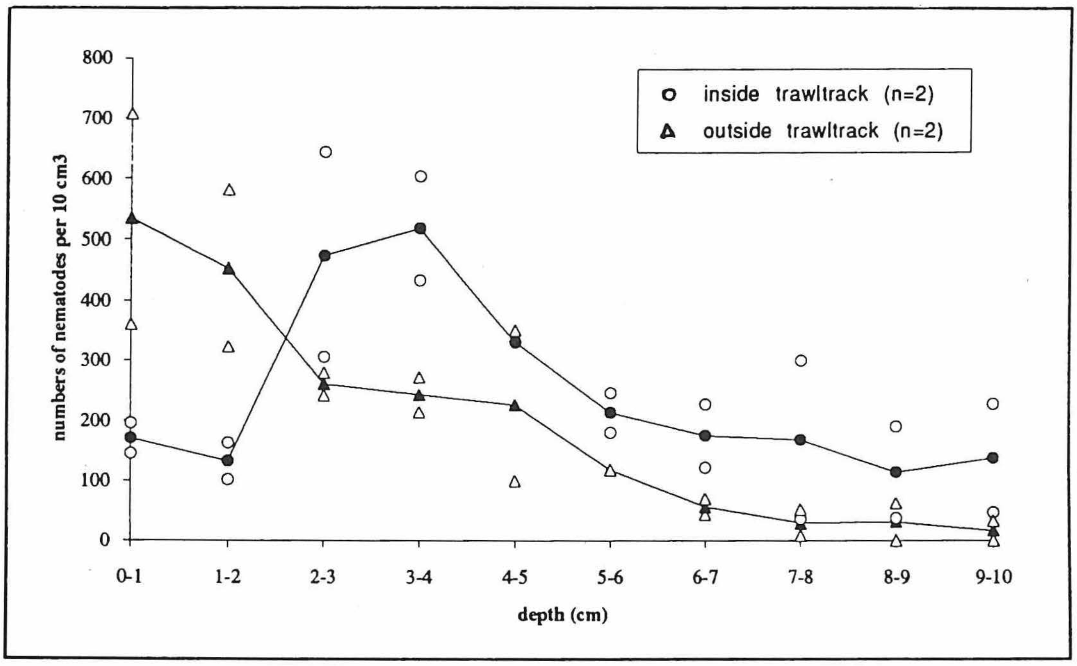


Fig. 3. Mean densities of nematodes ($n_{*}10\ cm^{-3}$) in sediment samples taken inside (n=2) and outside (n=2) the track of a 12-m beam trawl, 17 hours after trawling (April study) (data NIOO-CEMO). Open symbols denote the measured values, black symbols denote mean values.

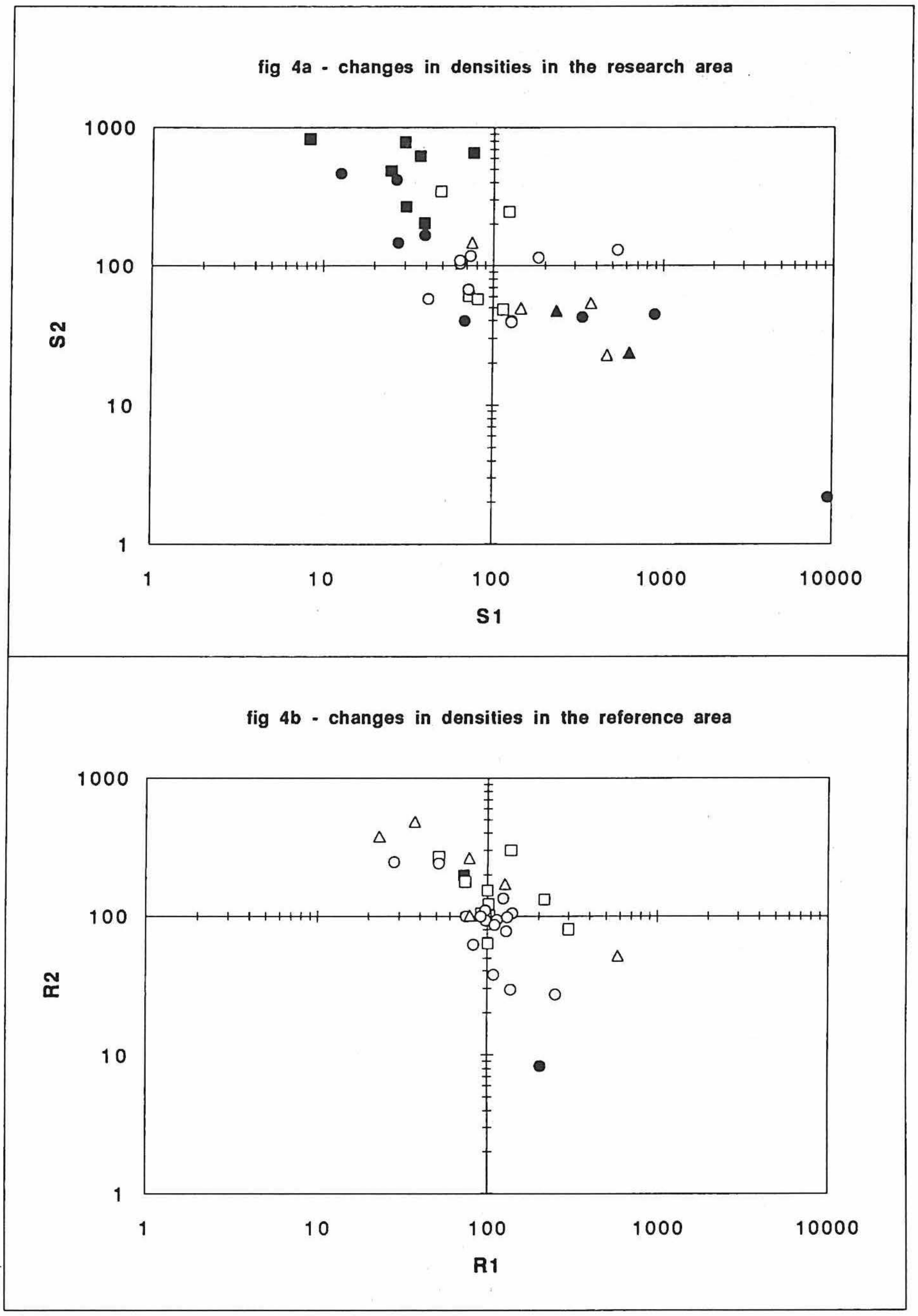


Fig. 4. Changes in density (%) in the study area between t_0 and t_1 ($S_1 = 100 * t_1/t_0$) and between t_1 and t_2 ($S_2 = 100 * t_2/t_1$), as well as in the reference area between t_0 and t_1 (R_1) and between t_1 and t_2 (R_2), of those species that were present in the three sampling periods in both area's (September study). Percentages >100% denote an increase in density, percentages <100% denote a decrease. M fish species; O mobile epi- and infauna; Δ sedentary epi- and infauna; dark symbols indicate statistical significance of one or both changes in mean density.

APPENDIX

Common English names for some of the well known species found during the IMPACT-studies in the Dutch coastal zone and in the Oystergrounds.

FISH	
Agonus cataphractus	HOOKNOSE
Ammodytes tobianus	SANDEEL
Arnoglossus laterna	SCALDFISH
Buglossidium luteum	SOLENETTE
Callionymus lyra	DRAGONET
Clupea harengus	HERRING
Enchelyopus cimbrius	FOUR-BEARDED ROCKLING
Gadus morhua	COD
Limanda limanda	DAB
Merlangius merlangus	WHITING
Platichtys flesus	FLOUNDER
Pleuronectes platessa	PLAICE
Pomatoschistus spp.	GOBIES
Scophthalmus maximus	TURBOT
Scophthalmus rhombus	BRILL
Solea solea	SOLE
Trachinus vipera	LESSER WEEVER
Trigla spp.	GURNARD
ECHINODERMS	
Asterias rubens	COMMON STARFISH
Astropecten irregularis	a STARFISH
Echinocardium cordatum	SEA POTATOE or HEART-URCHIN
Ophiura texturata	a BRITTLE STAR
Psammechinus miliaris	a SEA URCHIN
MOLLUSCS	
Acanthocardia echinata	PRICKLY COCKLE
Angulus tenuis (= *Telina tenuis*)	a TELLIN
Angulus fabulus (=*Tellina fabulus*)	a TELLIN
Aporrhais pespelicani	PELICAN'S FOOT SHELL
Aequipecten opercularis	QUEEN SCALLOP
Arctica islandica	QUAHOG
Chamelea gallina (=*Venus striatula*)	STRIPED VENUS
Corbula gibba	COMMON BASKET SHELL
Buccinum undatum	WHELK
Donax vittatus	BANDED WEDGE SHELL
Dosinia lupinus	SMOOTH ARTEMIS
Ensis ensis	a RAZOR SHELL
Euspira catena (=*Natica catena*)	LARGE NECKLACE SHELL
Euspira poliana (=*Natica alderi*)	COMMON NECKLACE SHELL
Gari fervensis	FAROE SUNSET SHELL
Mactra corallina	RAYED TROUGH SHELL
Neptunea antiqua	BUCKIE
Nucula spp.	NUT SHELLS
Spisula subtruncata	TROUGH SHELL
Turritella communis	TOWER SHELL
CRUSTACEANS	
Cancer pagurus	EDIBLE CRAB
Carcinus maenas	SHORE CRAB
Corystes cassivelaunus	MASKED CRAB
Eupagurus bernhardus	HERMIT CRAB
Liocarcinus holsatus	a SWIMMING CRAB
Necora puber	VELVET SWIMMING CRAB
Thia polita	THUMB-NAIL CRAB
other groups	
Aphrodita aculeata	SEA MOUSE
ANTHOZOA indet.	ANEMONES

DIRECT EFFECTS OF BEAM TRAWLING ON MACROFAUNA IN SANDY AREAS OFF THE DUTCH COAST

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ABSTRACT

Direct effects of trawling with commercial 4-m beam trawls on the abundance of benthic species in areas with sandy sediments off the Dutch coast were studied by comparing densities before and after trawling. Various sampling gears were used, including a benthos dredge (Triple-D) developed especially for this IMPACT-project. For a number of species, the mortality due to trawling a study area twice, could be estimated. For these species, mortality was found to be very variable, and was estimated for fish as 2-70% of the numbers initially present on the area, for echinoderms as 0-44%, for molluscs as 0-84%, for crustaceans as 0-82%, and for annelids as 0-24%. Dab, *Limanda limanda*, was a predominant scavenger on damaged or exposed fauna on a recently trawled seabed.

1. INTRODUCTION

The Dutch coastal zone has been fished intensively by beam trawlers during the last twenty years. Only EURO-cutters (< 300HP) and shrimpers, are allowed to fish with beam trawls within the 12 miles zone. The maximum width of trawls, rigged for catching sole and plaice, is restricted to 4.5 m in this area. In 1990, EURO-cutters trawled on average once over each m^2 of the seabed in this zone. Although the total engine power of middle class cutters (300 to 1500 HP) has sharply decreased from the early eighties, the fleet of EURO-cutters, as well as beam trawlers > 2000 HP, almost doubled (POLET *et. al.*, this report).

Studies on effects of beam trawling indicated that damaged fauna was regularly found in the nets (GRAHAM, 1955; BRIDGER, 1970; MARGETTS & BRIDGER, 1971; DE GROOT, 1973). Effects of beam trawling on the densities of bottom fauna have been studied only recently. The studies showed that trawling with 12-m beam trawls, in a sandy as well as a soft bottom seabed, resulted in mortality of a number of fish, echinoderms, molluscs, crustaceans, annelids and anthozoans (BERGMAN & HUP, 1992; VAN SANTBRINK & BERGMAN, this report). Since the effects of beam trawling on bottom fauna may be related to penetration depth of the trawl into the seabed, effects of 12-m beam trawls cannot be extrapolated to effects of the 4-m beam trawls of EURO-cutters.

In this paper, the results are presented of three studies on direct effects of commercial 4-m beam trawls on macrofauna in the sandy 12 miles zone off the Dutch coast. The lay-out of the field experiments is similar to that in the studies on the effects of 12-m beam trawls (VAN SANTBRINK & BERGMAN, this report). In three locations, a study area was fished with commercial trawls, rigged for the catch of flatfish, in such a way, that on average each m^2 was trawled 1.5 to 2 times. This set-up was chosen in order to create a homogenuously trawled area. Changes in densities of benthic fauna were estimated by sampling with various gears, prior to and after "commercial" trawling. A box corer and a fine meshed beam trawl, as well as a newly developed deep digging dredge (Triple-D; BERGMAN & VAN SANTBRINK, this report), were used in the field studies in order to estimate densities of all size classes infauna and epifauna species.

The major objectives in these studies were to determine: (i) direct mortalities of macrofauna due to trawling and (ii) species that may act as scavengers in a recently trawled area. Two occasions in which direct mortality may occur are distinguished (i) among animals that were caught in the trawl, after handling the catch on board ("catch mortality"), and (ii) among animals that were not caught, but remained on the seabed after the passage of the trawl or were washed through the meshes of the net ("non-catch mortality"). To estimate catch mortality, data on the mortality of discarded animals (FONDS, this report) were used. Non-catch mortality, and therefore "total" mortality, could only be determined after the complete trawling (i.e., after trawling a study area 1.5 to 2 times). Scavenging behaviour of species was estimated by comparing densities before and after trawling. Stomach contents of dab (*Limanda limanda*) were analysed, to establish the role of this species as scavenger in a recently trawled area.

2. MATERIALS AND METHODS

Three field studies were carried out in the Dutch coastal zone: off the isle of Vlieland (June 1992), off IJmuiden (November 1992) and off Egmond (April 1993). In June 1992 and April 1993, RV MITRA (RWS/DNZ) and RV ISIS (RIVO-DLO) participated in the project, in November 1992 trawling and sampling programs were carried out using RV ISIS.

2.1. STUDY OFF VLIELAND (JUNE 1992)

2.1.1. STUDY SITE

Direct effects of 4-m beam trawls on macrofauna were studied 8 miles off the Isle of Vlieland (central position 53°24',48N and 04°57',54E; ICES-quadrant 35F4), in an area with medium grained sediments (mean grain size 284 µm, s.d. 30.3 µm; silt content 0.6%). The study area was situated a few miles outside the ebb delta of the sea inlet. Water depth was about 24 m and water temperature 18°C.

A study area of 1850 * 75 m was defined. Before the start of the experiment, the seabed was scanned with side scan sonar, to check for homogenuity, and to assess the frequency of recent commercial beam trawling. Side scan recordings showed that the surface of the seabed was heterogenuous. Areas with a flat seabed alternated with series of sandwaves (wave height 2-4 m, wave length about 40 m, steep slope at NE-side). Several tracks of commercial 4-m beam trawls were present on the sonar recordings, some of which were already registrated on recordings made 3 weeks earlier. Apparently, the study area had been trawled frequently during the previous weeks. Ship's position was verified with high accuracy (error less than a few meters) navigational equipment (DGPS). Exact positioning was obtained by using a computorised Dynamic Positioning system (D.P.) onboard RV MITRA.

2.1.2. TRAWLING

After initial sampling with a box corer, a dredge and a 3-m beam trawl, RV ISIS trawled over the study area with a pair of commercial 4-m beam trawls, rigged for the catch of sole and plaice (Fig.1). The beam trawls were rigged with typical "south-nets", which are mainly used south of Hoek van Holland, on fishing grounds with mobile sand dunes. The beam trawls were rigged with 5 tickler chains (Ø 4*14 mm and 1*20 mm), 5 net-tickler chains (Ø 3*20 mm and 2*18 mm) and rollers (Ø 15 cm) around the groundrope over a length of 4.5 m. "North-nets", which are used normally north of the Frisian Islands, are rigged with a ground chain without these rubber rollers, to maximise the catch efficiency on flat fishing grounds. Stretched mesh size in the upper side of the net was 17 cm and in the cod-end 9 cm. Total weight of each trawl was 1175 kg and fishing speed was 4.5 $nM \cdot h^{-1}$. The area was trawled in a series of parallel hauls, in such a way that the whole study area (1850*75 m) was fished on average twice. Coverage of the study area with trawl tracks was checked with side-scan sonar, 12 hours after trawling. Side scan recordings showed that the tracks were still visible in areas with a flat seabed, about 5 days after trawling. In areas with sandwaves, the tracks had disappeared within 5 days.

The trawling of the study area was carried out between 08.30 and 20.30 hour. The first 2 hauls were fished over the full length of the study area. The last 2 hauls were twice as long as the first and were fished in two directions: the ship turned at the end of study area and immediately fished the area again, before the catch was hauled on board. The catches in the first hauls as well as in the last hauls were sorted separately and both nets were also kept apart. The intermediate hauls (n=7) were fished uninterruptedly, i.e. the ship lifted the nets off the seabed at the end of the study area, turned and fished the area again in opposite direction. Catches of the intermediate hauls were pooled before sorting.

2.1.3. SAMPLING BEFORE AND AFTER TRAWLING

The densities of macrofauna in the study area were estimated by sampling with a box corer, a benthos dredge and a fine meshed beam trawl using RV MITRA. Twenty samples were taken with a 0.071 m^2 Reineck box corer, 24 hours before (t_0) and 6 days after (t_1) the trawling. The samples were sieved over 1mm mesh size and preserved in 8% formalin solution. The macrofauna was sorted and identified in the laboratory within 6 months. It is assumed that the mean density of species in the sampled area was representative for the mean density in the study area. Changes in mean densities were tested for statistical significance using log (n+1) transformed data (t-test). If the t-test could not be applied, the Mann Whitney U-test was used. One-sided probabilities were assumed for sessile animals (H_1: the density has decreased), and two-sided probabilities for mobile animals (H_1: density has decreased or increased). Densities of mobile crustaceans were not taken in account, because migrations in and out the study area cannot be excluded in the 6 days period between trawling and box corer sampling.

Larger and less abundant in- and epifauna were sampled with an early prototype of the benthos dredge, rigged with a 30 cm wide blade that sampled to a depth of 10 cm into the sediment. The mesh size in the net was 2 cm (stretched). A hydraulic pump was fitted on the dredge to improve the transport of sediment into the net. Sampling was carried out 12 hours before (6 hauls at t_0) and 6 days after the trawling (6 hauls at t_1). Length of each haul was about 600 m and fishing speed was about 1.5 $nM \cdot h^{-1}$. Catches of the dredge were sorted on board immediately. As the t_1-sampling was carried out 6 days after the trawling, mobile species (fish and crustaceans) were not counted. Changes in mean densities were tested for statistical significance using log (n+1) transformed data (t-test; one-sided for sessile species; two-sided for mobile species). If the t-test could not be applied, the Mann Whitney U-test was used. Recent tests with an improved prototype indicated that the expected working depth (10 cm) of this first prototype was doubtful. The results, therefore, were only used for qualitative indications in changes in densities.

Densities of demersal fish and epifauna were estimated with a 3-m beam trawl, rigged with 3 tickler chains and a rope wound around the middle of the ground chain over a length of 80 cm. The stretched mesh size of the body of the net was 2 cm and 1 cm in the cod-end. Sampling was carried out 12 hours before (6 hauls at t_0) and immediately after trawling (3 hauls at t_1), as well as 21 hours later (4 hauls at t_2). Length of each haul was about 600 m and fishing speed was about 3 $nM \cdot h^{-1}$. All hauls were fished in the evening (after 18.00 hour). Catches were sorted on board immediately. It is assumed, that the mean density of species in the sampled area was representative for the mean density in the study area. Changes in mean densities were tested for statistical significance using log (n+1) transformed data (Tukey comparisons in ANOVA).

In order to investigate the scavenging behaviour of dab, stomachs were collected from successive sampling periods and preserved in alcohol 96%. The pooled stomach contents from each sampling period were sorted into categories. Each category was weighed (dry weight after 48h at 60°C; ash weight after 2h at 540°C) in the laboratory, within a few months.

2.2. STUDY OFF IJMUIDEN (NOVEMBER 1992)

2.2.1. STUDY SITE

Direct effects of commercial 4-m beam trawls were studied approximately 1 mile off the Dutch coast near IJmuiden, in an area with fine grained sandy sediments (central position 52°30'N and 04°32'E in ICES-quadrant 34F4). Water depth was about 11 m and water temperature 11°C. A small sized study area of only 650 * 65 m was defined, because the available period for trawling was very limited due to an imminent gale. A limited sampling program could be carried out, because of the heavy swell.

2.2.2. TRAWLING

After the t_0-sampling with the Triple-D, RV ISIS fished the study area with a pair of commercial 4-m beam trawls, rigged with "north nets" for catching sole and plaice (Fig 2). The beam trawls were rigged with 5 tickler chains (Ø 3*13 mm and 2*14 mm) and 6 net-tickler chains (Ø 4*13 mm and 2*14 mm). Rollers were lacking around the groundrope. Stretched mesh size in the upper side of the net was 12 cm and in the cod-end 9 cm. Total weight of each trawl was 1400 kg and fishing speed was 4.5 $nM \cdot h^{-1}$. The area was trawled in a series of parallel hauls, in such a way that the study area (650*65 m) was trawled for on average 1.5 times.

The trawling was carried out between 09.00 and 11.30 hour. Catches of the first 2 hauls and the last 2 hauls were sorted separately, port and starboard nets were also kept apart. The intermediate hauls (n=8) were fished uninterruptedly, which means that the ship lifted the nets off the seabed at the end of the study area, turned and immediately fished the area again. Catches of port and starboard nets were pooled and sorted out.

2.2.3. SAMPLING BEFORE AND AFTER TRAWLING

Densities of larger and less abundant in- and epifauna were estimated by sampling with the deep digging benthos dredge (Triple-D) deployed from RV ISIS. A depressor to force the blade into the seabed, that became a standard part of the Triple-D in later studies, was not yet mounted. The dredge was rigged with a cutting blade, 15 cm wide and deep, and the stretched mesh size in the net was 2 cm. Sampling was carried out 24 hours before (11 hauls at t_0) and 24 hours after the trawling (11 hauls at t_1). Length of each haul was about 200 m and fishing speed was about 3 $nM \cdot h^{-1}$. Catches of the Triple-D were sorted on board immediately. Fish and highly mobile species were not involved in this study, as the t_1-sampling was carried out 24 hours after the trawling, and the heavy swell in the relatively shallow area may have influenced densities of these species. It is assumed, that the mean density of species in the sampled area was representative for the mean density in the study area. Specimens of some of the smaller species, found in the samples, may have escaped through the meshes of the Triple-D, which would lead to an underestimate of density. However, it is assumed, that this error was consistent between samples and that the changes in densities were estimated reliably. Changes in mean densities were tested for statistical significance using log (n+1) transformed data (t-test; one-sided for sessile species, two-sided for mobile species). If the t-test could not be applied, the Mann Whitney U-test was used.

2.3. STUDY OFF EGMOND (APRIL 1993)

2.3.1. STUDY SITE

Direct effects of 4-m beam trawls were studied approximately 2 miles off the Dutch coast near Egmond, in an area with fine grained sandy sediments (central position 52°38'N and 04°33'E in ICES-quadrant 34F4). Water depth was about 20 m and water temperature 10°C. A study area of 2000 * 50 m was defined. The seabed was scanned with side scan sonar before the start of the experiments, to check for homogenuity, and to assess the frequency of recent commercial beam trawling.Tracks of commercial 4-m beam trawls were clearly visible on the sonar recordings, indicating that the study area had been frequently trawled during the previous weeks. Ship's position was verified with DGPS (error less than a few meters) and exact positioning was obtained by using the Dynamic Positioning system onboard RV MITRA.

2.3.2. TRAWLING

After the t_0-sampling, RV ISIS trawled over the study area with a pair of commercial 4-m beam trawls, normally used in this area, and rigged for catching sole and plaice (Fig. 2). The beam trawls were rigged with 5 tickler chains (Ø 3*13 mm and 2*14 mm) and 6 net-tickler chains (Ø 4*13 mm and 2*14 mm). Rollers were lacking around the groundrope. Mesh size in the upper side of the net was 12 cm stretched and 9 cm stretched in the cod-end. Total weight of each trawl was 1400 kg and fishing speed was 4.5 $nM{\cdot}h^{-1}$. The area was trawled in a series of parallel hauls (length of a haul about 2000 m), in such a way that the study area (2000∗50 m) on average was trawled twice. Coverage of the study area with trawl tracks was checked with side-scan sonar, 24 hours after trawling.

Trawling started at 06.45 and ended at 11.30 hour. Catches of the first 3 hauls and the last haul were sorted separately. In the first hauls, port and starboard net were also kept apart. In the last haul catches of both nets were pooled. The intermediate hauls (n=10) were fished in two series of 5 hauls uninterruptedly. The ship lifted the nets off the seabed at the end of the study area, turned and fished immediately the area again. The catches of the intermediate hauls of both nets were pooled and sorted out immediately.

2.3.3. SAMPLING BEFORE AND AFTER TRAWLING

Densities of larger and less abundant macrofauna were estimated by sampling with the deep digging benthos drege (Triple-D) using RV MITRA. A depressor was mounted on the Triple-D to force the blade into the seabed. The dredge was rigged with a 20 cm wide blade, which sampled 10 cm deep into the sediment. The stretched mesh size in the net was 2 cm. The macrobenthic fauna was sampled 24 hours before (19 hauls at t_0) and 24 hours after the trawling (19 hauls at t_1). In the t_0-sampling, 10 hauls were fished on transects 50 m outside of and parallel to the study area, in order to disturb the study area as little as possible. In the t_1-sampling, all hauls were fished in the study area. Length of each haul was about 300 m and fishing speed was about 3 $nM{\cdot}h^{-1}$. The catches were sorted out immediately. Fish and mobile epibenthos species were sorted from 7 catches only. Sedentary species were sorted from 11 catches. The bivalve *Spisula subtruncata* was sorted from another 8 catches as well. It is assumed, that the mean density of species in the sampled area was representative for the mean density in the study area. Specimens of some of the smaller species, found in the samples, may have escaped through the meshes of the Triple-D, which would lead to an underestimate of the density. However, it is assumed, that this error was consistent between samples and that the changes in densities were estimated reliably. Changes in mean densities were tested for statistical significance using log (n+1) transformed data (t-test). One-sided probabilities were assumed for sessile animals (H_1: the density has decreased), and two-sided probabilities for mobile animals (H_1: density has decreased of increased). If the t-test could not be applied, the Mann Whitney U-test was used.

Demersal fish and epifauna were sampled with a 3-m beam trawl, rigged with 3 tickler chains and a rope around the middle of the ground chain over a length of 80 cm. The stretched mesh size in the body of the net was 2 cm and 1 cm in cod-end. Sampling was carried out 24 hours before (6 hauls at t_0) and immediately after the trawling (9 hauls at t_1) using RV MITRA. Sampling was carried out during daylight. Length of each haul was about 500 m and fishing speed was about 3 $nM{\cdot}h^{-1}$. Catches were sorted on board immediately. It is assumed, that mean density in the sampled area is representative for the mean density in the study area. Changes in mean densities were tested for statistical significance using log (n+1) transformed data (two-sided; t-test). If the t-test could not be applied, the Mann Whitney U-test was used.

2.3.4. TRAWLING FREQUENTLY OVER THE SAME LINE

In an additional experiment, carried out in the proximity of the study area, two well defined narrow areas (lenght 1000 m and width 30m) were frequently fished with commercial 4-m beam trawls, similar to those used in the study area. Area I was trawled on average 3 times, area II for on average 8 times (see also FONDS, this report). Trawling was completed within 12 hours. In both areas, sampling with the Triple-D (4 hauls in each period) was carried out 12 hours before and 12 hours after trawling. Length of each haul was about 250 m and fishing speed was about 3 $nM{\cdot}h^{-1}$. The catches were sorted out immediately and, because the t_1-sampling was 12 hours after the trawling, only the numbers of infauna species were counted. Changes in mean densities were tested for statistical significance (Mann Whitney U-test; 2-sided).

2.4. CALCULATION OF MORTALITY

Changes in density of species, found in the study area after trawling, may be generally due either to the absence of animals that are caught in the trawls or to "non-catch mortality" as a direct effect of the passage of the trawls over the seabed. A certain percentage of the animals caught in the trawls may be killed in the net or during the subsequent handling onboard the trawler ("catch mortality"). The "total mortality" of a species due to trawling can be estimated as the sum of catch mortality and non-catch mortality.

2.4.1. CATCH MORTALITY

Catch mortality is defined as that which occurs among animals that are caught in the trawls and then are discarded into the sea after handling onboard the trawler.

The catch mortality after trawling once (CM_1; expressed as a percentage of the initial density), is calculated by multiplying the percentage of mortality of discarded animals after being handled onboard (determined in survival experiments in tanks onboard, see FONDS, this report) with the catch efficiency of the trawls. This catch efficiency is calculated by expressing the density estimate from the first haul of the trawl ($n*1000\ m^{-2}$) as a proportion of the initial density estimated with the Triple-D or 3-m beam trawl ($n*1000\ m^{-2}$). It is assumed, that the density in the area fished in the first haul is representative for the mean density in the study area. Because the catch efficiency of the sampling gear itself may be less than 100%, the estimated mean catch efficiency of the trawls - and therefore the mean catch mortality - should be considered as a maximum estimate. The sampling gear yielding the highest initial density estimate is used in this calculation.

$$CM_1 = \text{mortality of discard} * \frac{\text{density estimate from 4-m beamtrawls in haul 1}}{\text{initial density estimate sampling gear}}$$

The catch mortality after trawling 1.5 or 2 times (CM_2) is estimated in a analoguous way, by using the total number of animals caught in all hauls. The total numbers of animals caught ($n*1000\ m^2$ of the study area) in all hauls is calculated by the ratio between the actual numbers of animals caught in all hauls and the surface of the study area. Also CM_2 is expressed as a proportion of the initial density:

$$CM_2 = \text{mortality of discard} * \frac{\text{total numbers caught in 4-m beam trawls in all hauls}}{\text{initial density estimate sampling gear}}$$

In all studies, the first hauls with the trawls were fished in a single straight line over the study area. The further hauls, however, were fished uninterruptedly, i.e. between the hauls, the net was lifted off the seabed during the turn of the ship outside the study area. During these turns, when the nets were lifted off the seabed, many animals may have been washed through the meshes. The catch mortality estimate after twofold trawling (CM_2) may therefore be considerably less than when a twofold trawling is carried out by fishing straight hauls, without making turns with the nets under water. This discrepancy can be made clear by comparing the numbers of animals caught in all hauls, with the numbers that are expected to be caught in all hauls (both expressed as a percentage of the initial density). Under the assumption, that the catch efficiency of the trawls does not depend on the actual density of a species (i.e. does not change during the trawling), this expected number is calculated as the sum of the catch efficiency in the first haul (straight line) and the same catch rate applied to the numbers of animals expected to remain in the area after trawling once.

$$\text{expected numbers of animals caught in all hauls} = CE_1 + x*CE_1*(1-CE_1)$$

In this equation:

$x = 1$ (in study off Vlieland and Egmond, where the study area was trawled 2 times)
$x = 0.5$ (in study off IJmuiden, where the study area was trawled 1.5 times)

For species showing a catch in all hauls that was lower than expected, the estimates of total catch and therefore of total catch mortality (CM_2) are considered to be not realistic. For these species, the expected catch mortality is used in the calculation of the total mortality.

2.4.2. NON-CATCH MORTALITY

Non-catch mortality is defined as direct mortality occurring among the animals that interfered with, but were not present in the catches of the trawl. This mortality may be due to damage caused by a hit by the tickler chains, or by disturbance of animals (e.g. exposed infauna) leading to an increased availability to predation. Non-catch mortality also occurs when animals initially caught in the trawls, are washed through the meshes after being mortally damaged by the bulk of the catch. Contrary to catch mortality, non-catch mortality can only be estimated indirectly from changes in density of living animals. Assuming that all killed animals were consumed by scavengers before t_1-sampling, non-catch mortality is estimated from the numbers of "missing" animals (M), which is calculated by substracting the density of animals still present after trawling and the total numbers caught in all hauls from the initial density. This total number of animals caught in all hauls was calculated by the ratio between the actual numbers of animals caught in all hauls and the surface of the study area. The numbers of "missing" animals are presented as a percentage of the initial densities.

M = percentage missing animals,

$$= 100 * \frac{((\text{initial density}) - (\text{density at } t_1) - (\text{total numbers caught in 4-m beam trawls in all hauls}))}{\text{initial density estimate sampling gear}}$$

For this estimate of the percentage of missing animals, the catch in all hauls is a major factor. However, as is suggested above, this total catch may have been underestimated, because of the loss of animals that were washed out during the turn of the ship between the successive hauls. If so, the percentage missing animals can only be estimated from the changes in densities and the expected catch in all hauls.

The sampling gear yielding the highest initial density estimate is used in all calculations. Species that in the initial sampling were caught in higher densities in the Triple-D than in the 3-m beam trawl, were considered to be burrowing species. The 3-m beam trawl is not suitable to estimate changes in densities of burrowing species, not only because density estimates are not realistic, but especially because trawling may change the vertical distribution of these species, leading to an enhanced catchability.

It should be noted, that M and therefore non-catch mortality, can only be assessed after complete (1.5 or 2 times) trawling of the study area, since only then t_1-sampling was carried out. Because migration rate within the period between the initial sampling and the t_1-sampling could not be determined, non-catch mortality can not be estimated in this way for highly mobile species, such as fish and shrimps. For sessile and low mobile species, with a negligible horizontal migration, non-catch mortality equals M, if none of the animals are washed through the meshes of the trawl outside the study area. If all animals are washed through the meshes, non-catch mortality is estimated by multiplying M by the mortality in the discard (Fonds, this report).

2.5. INDICATIONS FOR SCAVENGING

Reduced densities in a trawled area increase gradually by random movements of animals from the surroundings. Evidence for immigration of scavenging species into a trawled area is found, when the density exceeds that of the surroundings, i.e. when accumulation occurs. Species sampled with the 3-m beam trawl (t_2) or the Triple-D (t_1), are considered to accumulate when densities exceed the densities at t_0. It is assumed, that these initial densities were similar to the densities just outside the study area during this t_1- or t_2-sampling.

3. RESULTS

3.1. STUDY OFF VLIELAND (JUNE 1992)

3.1.1. TRAWLING

Of the most commonly caught species, dab, plaice (*Pleuronectes platessa*), *Trigla* spp.[1], *Solea solea, Arnoglossus laterna, Asterias rubens, Astropecten irregularis, Liocarcinus holsatus* and *Eupagurus bernhardus* showed lower mean densities in the last hauls than in the first hauls (Table 1). Mean densities of *Platichthys flesus* and *Ophiura texturata* showed hardly any change during trawling.

3.1.2. BOX CORER SAMPLING

In the samples of the box corer, 46 taxa were distinguished (Table 2). Species composition is characteristic for the macrobenthos community in the sandy coastal zone. Juvenile *Ophiura texturata* (2-3 mm) showed a significantly decreased density, 6 days after trawling. Juvenile *Echinocardium cordatum* (2-5 mm), *Etione* and Nemertini showed a significant increase in density. All other taxa did not show significant changes in mean densities.

3.1.3. DREDGE SAMPLING

Species composition, as well as size distribution of species caught in the benthos dredge (Table 3) clearly differed from those in the box corer samples. In the dredge, generally (sub)adults were found, while mainly juvenile specimens were present in the box corer. In the catches of the dredge, only large sized annelid species (*Ophelia, Nereis* and *Nephthys)* were found, due to the mesh size of the net. The catch efficiency of this first prototype of the dredge was limited: for *Donax vittatus* in the order of 15%, when compared to the densities estimated in the box corer. The results of the dredge samples are therefore only used to qaulitatively indicate changes in densities and are certainly not suitable to estimate mean densities. *Chamelea gallica* and *Donax vittatus* showed a significantly decreased density, 6 days after trawling.

3.1.4. 3-M BEAM TRAWL SAMPLING

Densities of species, caught in the 3-m beam trawl, are given in Table 4, including the changes in density in the intervals t_0 - t_1, t_1 - t_2 and t_0 - t_2.

Most fish species, showed decreased densities, immediately after trawling (only significant for *Callionymus lyra*). About 24 hours later, plaice had significantly increased in density. At that moment, the densities of plaice, *Pomatoschistus* spp. and the largest specimens of dab had increased to a level above the initial densities (accumulation), although none of these changes were significant.

Of the invertebrate species, *Asterias rubens* and *Eupagurus bernhardus* showed (non significant) lower densities, immediately after trawling. About 24 hours after trawling, the density of *Eupagurus bernhardus* was still far below the initial density, while the density of *Asterias rubens* approximated the initial levels.

3.1.5. STOMACH CONTENT OF DAB

The stomach contents were analysed of dabs, caught in the 3-m beam trawl before trawling as well as immediately after, 12 hours after, and 24 hours after trawling. From each sampling period, stomachs of 30 dabs were analyzed. Prey items were divided into two categories: pieces of flesh from *Donax vittatus* , and a mix of annelid worms including fine debris (Fig. 3). Total stomach content (AFDW) had sharply increased,

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[1]Common English names of a number of species are given in the Appendix

immediately after trawling, especially due to the presence of a huge amount of pieces of *D. vittatus*. About 24 hours after trawling, total stomach content was on a similar level as before trawling.

3.2. STUDY OFF IJMUIDEN (NOVEMBER 1992)

3.2.1. TRAWLING

Of the most commonly caught species, *Asterias rubens, Ophiura texturata, Eupagurus bernhardus* and *Liocarcinus holsatus,* the mean densitiy in the last hauls was lower than in the first hauls (Table 5). Densities of fish were not mentioned, as these species were not counted in the catches of the sampling gear (Triple-D), that was used before and after trawling.

3.2.2. TRIPLE-D SAMPLING

Ophiura texturata and *Eupagurus bernhardus* showed significant lower densities in the Triple-D catches, taken 24 hours after trawling (Table 6). Reduced densities, although not significantly, were also found for the abundant *Spisula subtruncata.*

3.3. STUDY OFF EGMOND (APRIL 1993)

3.3.1. TRAWLING

In the 4-m beam trawls, 28 fish and evertebrate species were caught (Table 7). Of the commonly caught species, the density in the last haul was lower than the mean density in the first hauls for dab, plaice (>0-group), *Solea solea, Platichthys flesus, Asterias rubens, Ophiura texturata, Liocarcinus holsatus, Eupagurus bernhardus, Crangon crangon, Spisula subtruncata, Ensis americanus* and *Echinocardium cordatum.*

3.3.2. TRIPLE-D SAMPLING

In the catches of the Triple-D (Table 8), *Echinocardium cordatum, Abra alba, Spisula subtruncata* and large *Liocarcinus holsatus* showed significant lower densities, 24 hours after trawling. Dab (>0-group), *Pomatoschistus* spp and small *Liocarcinus holsatus* were found in significant higher densities. Densities of e.g. *Asterias rubens, Ophiura texturata, Angulus* spp., *Chamelia gallina* and *Ensis* spp. hardly showed any change.

3.3.3. 3-M BEAM TRAWL SAMPLING

Densities of fish and evertebrate species, caught in the 3-m beam trawl, before and after trawling, are presented in Table 9. Only *Buglossidium luteum* was found in a significant lower density, immediately after trawling.

Of all invertebrate species, *Asterias rubens, Echinocardium cordatum, Crangon crangon* and *Eupagarus bernhardus* showed significant lower densities, immediately after trawling. Of the sedentary species, the densities of *Spisula subtruncata* and *Chamelea gallina* had significantly increased after trawling.

3.3.4. FREQUENTLY TRAWLING OVER THE SAME LINE

In area I (3 times trawled), densities had significantly (p=0.021) decreased of *Echinocardium cordatum* (with 95%) and *Spisula subtruncata* (with 64%), 12 hours after the trawling. In area II (8 times trawled), significant decreases were found for *Echinocardium cordatum* (with 80%; p=0.021) and *Spisula subtruncata* (with 76%; p=0.043), whereas densities of a number of annelids (except *Pectinaria* spp.) were found in significant higher densities (+106%; p=0.043).

3.4. CATCH EFFICIENCY AND CATCH MORTALITY

3.4.1. CATCH EFFICIENCY

For the three studies, catch efficiency in the first haul, and found as well as expected numbers of animals caught in all hauls, are given in Table 10.

Catch efficiency could not be determined for large sized dab and large sized plaice, as density estimates by the trawls were similar or even higher than in the sampling gear. Catch efficiency could also not be determined for highly mobile species (e.g. roundfish), because the initial density estimate (24 hours before the trawling) may not be representative for the density at the start of the trawling (VAN SANTBRINK & BERGMAN, this report). For species that were not or hardly (on average <1 specimen per catch) found in the sampling gear, catch efficiency could not be reliably estimated (e.g. *Cancer pagurus* (Vlieland study), *Necora puber* and *Palaemon* spp. (IJmuiden study), *Agonus cataphractus, Platichthys flesus* and *Scophthalmus* spp. (Egmond study)). For some other species, the number of samples may have been too low for a reliable density estimate. The percentage of missing animals of these species may, therefore, be less reliable (in Table 10 these values are placed between brackets).

For a number of species, the catch efficiency of the 4-m beam trawl in the three studies, could be compared. Catch efficiencies appeared to be estimated in the same order of magnitude, with an exception for *Asterias rubens* and *Ophiura texturata* that were both caught with a higher efficiency in the IJmuiden study and especially in the Egmond study. This enlarged catch efficiency may be explained by the use of "south nets" in the Vlieland study, rigged with rollers around the groundrope that possibly reduced the catch of starfish.

For nearly all species, indications for an enlarged escape of animals through the meshes during the turn of the ship, were found in the comparison between the found catch in all hauls and the expected catch in all hauls. Fish species (dab, plaice, *Arnoglossus laterna, Solea solea*) as well as evertebrates (*Asterias rubens, Ophiura texturata, Eupagurus bernhardus, Liocarcinus holsatus*) appeared to be washed out to a high percentage. For *Buglossidium luteum* only, the expected total catch was lower, which was probably caused by a underestimate of the catch efficiency. Therefore it is assumed that for all these species, the found total catch in all hauls is an underestimation of the expected total catch after 1.5 - to twofold trawling, and cannot be considered as a realistic value.

3.4.2. CATCH MORTALITY

For the three studies, mortality estimates in the discard (FONDS, this report) and catch mortality in both the first haul and all hauls of the trawling are given in tabel 11. As the found catch in all hauls is considered to be unrealistic, the catch mortality in all hauls was estimated from the expected catch in all hauls.

For discarded fish species, the mortality after being handled onboard the trawler is high (≥84%), resulting in an expected catch mortality after trawling the area 1.5 or 2 times, ranging from 0% to 70%. For invertebrates, the mortality in the discard varied considerably, but for all invertebrates (except *Liocarcinus holsatus*), the expected catch mortality in all hauls was less than 4%. For *L. holsatus*, this mortality estimate varied from 9% to 27%. Except for this species, the estimates of mortality did not show clear differences between the three studies.

3.5. PERCENTAGE MISSING ANIMALS AND NON-CATCH MORTALITY

The percentages of missing animals on the study area, after trawling the area 1.5 or 2 times, are given in Table 12. These percentages were calculated from the decreases in densities, after correction for the numbers of animals caught in the trawls (i.e. expected catch in all hauls).

The percentage of missing animals was estimated only for species that were frequently caught in the sampling gear. However, for a number of other species, the number of samples may have been too low for a reliable density estimate. The percentage of missing animals of these species may therefore be less reliable (in Table 12 these values are placed between brackets). The percentages missing numbers of species, that were based on catches in the first prototype of the dredge (study off Vlieland), have to be considered as less reliable (these values are placed between brackets) than the data based on catches in the Triple-D (studies off IJmuiden and Egmond).

As the non-catch mortality is based on the percentage of missing numbers and therefore is influenced by migration, it is not possible to give a reliable estimate of non-catch mortality for highly mobile species, such as *Crangon crangon* (brown shrimp) and fish. Therefore missing numbers of these species are not included in Table 12.

An increased density of juvenile *Echinocardium cordatum* (2-5 mm), sampled with the box corer in the Vlieland study, may be caused by settlement of young animals in the period of 6 days between the trawling and the t_1-sampling. Also the decreased densities of the low mobile juvenile *Asterias rubens* and juvenile *Ophiura texturata* were estimated in the box corer sampling, 6 days after trawling. It is not clear, whether the changes in these species were due to the trawling, or to active migration as well as to lateral passive displacement of animals in the dynamic area off Vlieland, in the 6 days interval. Percentages missing numbers of juvenile *Echinocardium cordatum, Asterias rubens* and *Ophiura texturata* are not included in Table 12.

For some other species, the percentage of missing numbers appeared to be a positive value. As an increase in densities of sessile or low mobile species over a 12 hour interval is regarded as not realistic, these values are considered as erratic, and are given in Table 12 as "~0".

The highest percentages of missing animals were found for some molluscs, crustaceans, and echinoderms. In all these groups, the percentages varied considerably. The smallest range was found in annelids which showed percentages of missing animals less than 17%.

4. DISCUSSION

4.1. CATCH MORTALITY

Catch mortality in all hauls of the trawls could only be estimated based on the expected catch in all hauls, as the found catch in all hauls appeared to be a serious underestimate due to the escape of animals during the turn of the ship. This expected catch in all hauls (Table 11), however, may still be an underestimate for scavengers and predators (e.g. dab, *Eupagurus bernhardus*) that were attracted to damaged animals in the tracks after the first trawling or for infauna species (e.g. bivalves, *Corystes cassivelaunus*) that have been dug out by the tickler chains in th efirst hauls. For these species, the catch efficiency in the first haul is not representative for the catch efficiency in all hauls. This assumption is supported by the increased densities of bivalves, e.g. *Spisula subtruncata* and *Chamelea gallina,* in the catches of the 3-m beam trawl in the t_1-sampling (Table 9).

The catch efficiency of the trawls for *Ensis americanus,* as found in the Egmond study, is probably considerably overestimated compared to the other studies, as many dead and dying specimens were present in that area. For *Liocarcinus holsatus,* the range in expected total catch mortality may be explained by a different size distribution of animals in the different areas, or by a larger catch efficiency of the Triple-D (Egmond study), compared to the 3-m beam trawl (Vlieland study) and the Triple-D without depressor (IJmuiden study). It cannot be excluded, that the use of various sampling gears caused differences in the expected catch mortality for other species as well. Furthermore, catch mortality may also be influenced by the difference in intensity of trawling (1.5 times in the IJmuiden study and 2 times in the other studies), as well as by the use of different trawls ("south nets" off Vlieland and "north nets" off IJmuiden and Egmond) and by the different seasons in which the studies were carried out. As it is not possible to distinguish the impact of all these factors, a range of percentage expected catch mortality in all hauls is estimated for those species that show different results in the 3 studies (Table 13).

4.2. NON-CATCH MORTALITY

Non-catch mortality cannot be estimated from the percentage of missing numbers for mobile species such as fish and shrimps. In fish, non-catch mortality will probably mainly occur in the trawls, when mortally damaged fish are washed through the meshes. By using a fine meshed net covering the commercial trawl, this mortality is tentatively estimated as in the order of 10% of the animals that escaped through the meshes of the trawl (Fonds, this report). As it is not clear, what percentage of the animals, initially present in the study area, had escaped through the meshes, this 10% estimate cannot be applied in the calculations of non-catch mortality (Table 13).

The invertebrates mentioned in Table 12, probably do not show substantial immigration during the interval between t_0 and t_1, with a possible exception for *Eupagurus bernardus*. For some of these species, however, emigration may play a role in the interpretation of the percentage of missing animals as they may be dispersed *un*damaged outside the study area, after having escaped through the meshes of the trawls (e.g. when these were hauled onboard). It can be assumed, that the mortality among those animals that were washed through the meshes, approaches the mortality in discard (Fonds, this report). A minimum non-catch mortality (in case all missing animals were washed through the meshes) can therefore be estimated by multiplying the percentage missing animals by the mortality estimate of discard. If species are small (e.g. commonly found in fine meshed sampling gear but not in the trawls), it can be assumed, that this dispersion plays only a minor role. These small animals pass through the meshes immediately, while the trawl is still on the study area. The minimum non-catch mortality of those species mentioned in Table 12, that may show such dispersion outside the area, is estimated as about 1% for adult *Asterias rubens*, 2% for adult *Ophiura texturata*, 45% for *Corystes cassivelaunus* and 13% for large *Liocarcinus holsatus*. For *Asterias rubens* and *Ophiura texturata*, species that were sampled with the 3-m beam trawl almost immediately after trawling, it is unlikely that high numbers of damaged animals were consumed in this short period after trawling. It is therefore assumed, that the majority of the missing animals were dispersed outside the study area, and that the non-catch mortality for adults of these two species is little more than the minimum estimate. For *Corystes cassivelaunus* and *Liocarcinus holsatus* that were sampled with the Triple-D (of which the t_1-sampling took place more than 12 hours after trawling), the non-catch mortality is estimated as between the minimum estimate and the percentage missing animals (i.e. all missing animals are killed in the study area).

Non-catch mortality may be underestimated, when animals that were damaged or exposed due to trawling, were not yet consumed during the t_1 sampling (within 24 hours after trawling in the studies in IJmuiden and Egmond). All damaged animals in the catch were counted as alive, as these could be damaged also by the sampling gear itself (this became clear in the initial sampling). For species caught in large numbers in the sampling gear (e.g. *Spisula subtruncata* in the Triple-D) it was possible to estimate the percentage of animals that were damaged by the sampling gear itself, by using the percentages broken in the initial sampling. The percentage of animals, that were damaged by the commercial trawling, but were not yet consumed before the t_1-sampling, could therefore be calculated. In *S. subtruncata*, the underestimation of non-catch mortality appeared to be considerable (IJmuiden study 30%; Egmond study 38%). For species that are less abundant, or are caught in other sampling gears, it appeared not possible to separate animals that were damaged by the sampling gear from those, that were damaged by the trawls. For these species, it is not clear to what extend this problem influences the estimates of non-catch mortality. An underestimation is most likely to occur in species that were sampled with the 3-m beam trawl, immediately after trawling. In most of these species, however, this problem is assumed to be of minor importance, as starfish e.g. are little vulnerable, and moreover are capable to regenerate. The non-catch mortality of only *Eupagurus bernardus* may have been underestimated due to this problem.

Adults of the extremely fragile species *Echinocardium cordatum* showed a (non significant) decrease in density in the box corer sampling (Vlieland study), whereas the density in the Triple-D sampling showed a significant decrease of 56% (Egmond study). A likely explanation for this extremer decrease in density in the Triple-D sampling, may be found in the limited working depth (10 cm) of this gear. In this gear, only the animals living in the uppermost sediment layer were caught, those that were likely to be hit by the passing trawl. The decrease found in the box corer sampling is therefore more realistic (Table 13). In a study in a soft bottom area, mortality of this species was found to be much lower, apparently because the majority lived deep in the sediment, out of reach of the tickler chains (van Santbrink & Bergman, this report). Since mortality of *E. cordatum* due to commercial trawling is highly dependent on the burrowing depth of the animals, results of a study can not be extrapolated to other part of the North Sea, as the mean burrowing depth depends on e.g. type of sediment, season, and size of the animals.

For *Donax vittatus* a non significant decrease (42%) in density was found in the box corer sampling, whereas in the sampling with the first prototype of the dredge a significant decrease of 49% was found. Although both sampling methods had limitations, as the box corer is not suitable for reliably estimating densities of clustered species and the first prototype of the dredge did not sample quantitative reliable, both results indicated that the density of this species is probably considerably lowered due to trawling (Table 13). The unchanged density of *D. vittatus*, as observed after trawling in the Triple-D sampling in the Egmond study, is probably caused by the low numbers in the catches.

In studies on effects of beam trawling on soft bottoms, the non-catch mortality of mollusc species seemed to be related to the solidity of the shell (van Santbrink & Bergman, this EC-FAR. report). In this study on sandy sediments however, this relation is not found. High mortalities were found in both fragile species (*Mactra corallina, Abra alba*), and solid shelled species (*Donax vittatus, Spisula subtruncata*). A more frequent trawling of the seabed resulted in an increased non-catch mortality in the bivalve *Spisula subtruncata*, ranging from 60-64% (after trawling the area 2 to 3 times) to 76% (after trawling 8 times). It is remarkable, that the percentage non-catch mortality shows only little increase with an increase in trawling frequency. The significantly decreased density of *Chamelea gallina*, as found in the dredge samples in the Vlieland study may be due to the too low numbers in the catches or to the unreliability of this early prototype, and is therefore considered to be less realistic (Table 13).

Densities of fragile species as *Angulus* spp. appeared not to be affected. Possibly this species lives to deep in the sandy seabed to be hit by the tickler chains. Also the deep burrowing bivalve *Ensis* spp. appeared also to live out of reach of the beam trawl.

It is not possible, to ascribe differences in the non-catch mortality, as found in the three studies, to the intensity of trawling (1.5 times the study area in the IJmuiden study and 2 times in the other studies). The use of different sampling gears (first prototype dredge, Triple-D, 3-m beam trawl) as well as different commercial gears ("south nets" off Vlieland and "north nets" off IJmuiden and Egmond), the different seasons in which the studies were carried out as well as the heavy swell in the IJmuiden study, may have influenced the non-catch mortality. As it is not possible, to distinguish the impacts of all these factors, a range of percentages of non-catch mortality after trawling the area 1.5 to 2 times is estimated for each species (Table 13).

4.3. TOTAL MORTALITY

Catch mortality after trawling an area once, as well as expected catch mortality, non-catch mortality and total mortality after trawling 1.5 or 2 times, are given in Table 13. This total mortality is calculated as the sum of expected catch mortality and non-catch mortality after trawling an area 1.5 or 2 times.

In general, the (expected) catch mortality after trawling an area 1.5 to 2 times, is higher than after trawling once. Non-catch mortality after complete trawling, is probably also higher than after trawling once. It is likely, that non-catch mortality after trawling 1.5 to 2 times may be even disproportionately higher for immigrating or burrowing species. Of immigrating species, relatively more animals are affected in the second trawling. Of burrowing species (such as bivalves and *C. cassivelaunus*), specimens that were dug out in the first hauls were more likely to be damaged by the tickler chains during the second trawling. Apparently, for most species, the total mortality after trawling an area 1.5 to 2 times, as found in this study, is higher than after trawling an area once.

Total mortality could not be determined for 70% of the fish species that were found, as well as 25% of the echinoderms, 30% of the molluscs, 65% of the crustaceans, and 35% of small annelids and other groups. Most of these species were caught in very low numbers.

4.4. INDICATIONS FOR SCAVENGING

All carnivorous animals, that are present in the study area shortly after trawling, can be considered as potential scavengers or predators on animals that are damaged or exposed by the trawls. For several roundfish and flatfish species as well as invertebrates, scavenging has been described (e.g. ARNTZ & WEBER, 1970; CADDY, 1973; KAISER & SPENCER, this report; RUMOHR & KROST, 1991).

In this study, a direct indication for scavenging can be found in the comparison of stomach contents of animals, that are caught in the study area after trawling, to stomach contents of animals caught before trawling. Scavenging is clearly demonstrated in dab, as the weight of the stomach content of animals after trawling was higher, and the composition of prey items had changed. Furthermore, these stomach contents consisted to a large extend of species that were unlikely to have normally fallen prey to dab, such as *Donax vittatus.* The small amount of flesh of *D. vittatus* (<3% of the amount in the t_1-sampling), that was found in stomachs of dab in the t_0-sampling, can presumably be ascribed to scavenging on bivalves, that were dug out during the t_0-sampling of the dredge.

The accumulation of a predatory species in a recently trawled area can be considered as an indirect indication for scavenging. In the 3-m beam trawl sampling, a significant accumulation of epifauna species (those species that in the initial sampling are caught in higher densities in the 3-m beam trawl than in the Triple-D) is not found. A non significant increase in density is found for dab (>20 cm), plaice (>0-group) and *Asterias rubens* (Table 4, t_0-t_2). In the Triple-D sampling, a significant accumulation was found for small *Liocarcinus holsatus.* It should be noted, that accumulation of epibenthic species was estimated only by sampling 24 hours after trawling, and accumulation *after* this moment (e.g. in slow moving species such as starfish) has not been noticed. In general, scavenging behaviour cannot be excluded, even when a species does not accumulate.

Of a species that acts as scavenger, the contribution to the total scavenging is depending on the feeding rate, the initial density, the percentage of animals still present on the area immediately after the passing of the trawl, and the immigration rate of animals into the trawled area. In these studies, the species dependent immigration rate can be calculated from the 3-m beam trawl sampling, as the increase in density in the interval between t_1 and t_2 proportional to the initial density. It was assumed, that this initial density was similar to the density just outside the area during t_1 and t_2 sampling. The highest immigration rate was found for plaice (>0 group; 72%). *Solea solea* showed an immigration rate of 49%. In the 24 hours period after trawling, dab showed a negative immigration rate, indicating that this species was leaving the area, after an initial immigration during trawling. Dab is probably a scavenging species, that, attracted by damaged animals on the seabed, rapidly invades an area to scavenge during a relative short period.

Of all invertebrate species, the immigration rate of only *Asterias rubens* is in a same order of magnitude as fish (58%), the other species showing considerably lower immigration rates (19% for *Eupagurus bernhardus*). These relative differences in immigration rate between species may also appear in other areas under similar conditions (eg. temperature, season, bottom type). However, this has yet to be established in future studies. As the possible feeding rate of the immigrating species is unknown, no conclusions can be drawn on the contribution of these species to total scavenging.

Scavenging animals not only feed on animals that are exposed or damaged in the trawl track, but also on damaged or killed animals that are discarded to the sea. Regarding the high survival of starfish (*Asterias rubens*), when discarded from the trawler, this species may play a prominent role as scavenger on other discarded (dead) animals.

5. CONCLUSIONS

The following conclusions on the total mortality of benthic fauna, due to trawling an area 1.5 to 2 times with 4-m beam trawls, can be drawn from this study:

Total mortality could only be estimated for a number of flatfish species (dab, plaice, *Arnoglossus laterna*, *Buglossidium luteum* and *Solea solea*) and appeared to vary considerably between species and size classes (2-70% of the numbers initially present on the area). It should be stressed, that the total mortality of fish may be underestimated, as the non-catch mortality could not be estimated.

Total mortality in echinoderms was generally low (<6%) for *Asterias rubens* and *Ophiura texturata* and considerable (44%) for *Echinocardium cordatum*.

The mollusc species, *Angulus* spp., *Chamelea gallina* and *Ensis* spp. were hardly affected. Total mortality of *Abra alba, Donax vittatus, Euspira poliana, Mactra corallina, Spisula subtruncata* and *Tellimya ferruginosa* varied between 4 and 84%, and is considered to be a direct effect of the passage of the tickler chains, which damaged the animals or exposed them to scavengers.

Corystes cassivelaunus showed a total mortality of approximately 45 to 69%. Large *Liocarcinus holsatus* showed a similar level of mortality (22-58%), whereas mortality of juvenile specimens was very low (~0%)

Total mortality of *Eupagurus bernardus* was estimated as 47 to 82%.

In general, the total mortality of annelid species and some anthozoans was low (<24%).

It should be noted that for most species, the total mortality after trawling an area 1.5 to 2 times, is generally higher than after trawling an area once. This difference may be considerable for immigrating (e.g. dab) or burrowing species (e.g. bivalves and *Corystes cassivelaunus*)

The deep digging dredge (Triple-D), which was developed during this EC-FAR project, appeared to be a valuable tool in this effect study.

None of the carnivorous species, present on the study area after trawling, could be excluded as potential scavenger or predator on exposed infauna. In this study, stomach content analysis and immigration behaviour after trawling, showed that dab (>0-group) may be considered as the predominant scavenger on a recently trawled seabed.

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TABLE 1

Numbers of animals (n.1000 m^{-2}) in catches of the 11 hauls wih a pair of 4-m beam trawls in the study area (Vlieland study). Total catch after trawling the study area twice (n.1000 m^{-2}) was calculated as 1000 . the ratio between the actual numbers caught in the 11 hauls and the surface of the study area.

species	numbers in catch (n*1000m-2)			
	hauls 1-2	hauls 3-9	hauls 10-11	total catch hauls 1 to 11
FISH				
Arnoglossus laterna	0.24	0.11	0.05	0.15
Limanda limanda (>0-group)	6.22	3.52	2.96	5.22
Platichthys flesus	0.34	0.38	0.34	0.50
Pleuronectes platessa	13.82	7.51	3.56	10.08
Scophthalmus maximus	0.03	0.32	0.12	0.30
Solea solea	0.27	0.14	0.10	0.21
Trigla spp.	0.17	0.25	0.08	0.26
other fish species	0.03	0.00	0.08	0.04
ECHINODERMS				
Asterias rubens	181.01	103.36	62.94	142.65
Astropecten irregularis	0.41	0.49	0.17	0.53
Ophiura texturata	2.97	2.35	2.31	3.37
MOLLUSCS				
Allotheutis sp.	0.03	0.00	0.00	0.01
Donax vittatus	0.07	0.05	0.02	0.06
CRUSTACEANS				
Cancer pagurus	0.03	0.04	0.03	0.05
Corystes cassivelaunus	0.00	0.03	0.05	0.04
Eupagurus bernhardus	0.47	0.14	0.27	0.32
Liocarcinus holsatus	8.01	2.83	2.45	4.86

TABLE 2

Numbers of animals ($n_* m^{-2}$) of sessile or low mobile benthos species in Reineck box corer samples, taken 24 hours before (t_0; n=20) and 6 days after (t_1; n=20) trawling (Vlieland study). Statistical significance of changes in mean densities was tested with a t-test using log (n+1) transformed data or with Mann Whitney U test, (one-sided probabilities for sessile species, two-sided for mobile species).

species	size	numbers in samples (n*1m-2)				t0-t1	P
		t0-sampling		t1-sampling		in/decrease	t-test [MannWh.U test]
		mean	st.dev.	mean	st.dev.	%	*=one sided
MOLLUSCS	**(length)**						
Angulus fabulus	11-20mm	1.41	6.33	2.12	6.92	50	n.s.
Angulus fabulus juv	3-10mm	20.51	49.32	19.81	25.31	-3	n.s.
Angulus tenuis	30-40mm	1.41	4.35	2.12	5.18	50	n.s.
Donax vittatus	30-40mm	21.93	44.14	12.73	21.48	-42	n.s.
Donax vittatus juv	10mm	0.00	0.00	0.71	3.16	>>100	n.s.
Ensis sp. (fragm. of juv.)	fragm of juv	0.71	3.16	1.41	4.35	100	n.s.
Mysella bidentata	2-4mm	0.00	0.00	2.12	6.92	>>100	n.s.
Spisula sp. juv	1-6mm	28.29	22.95	18.39	16.61	-35	n.s.
Tellimya ferruginosa	3-6mm	14.15	31.47	2.83	7.40	-80	n.s.
Euspira poliana	6-10mm	3.54	10.13	2.12	5.18	-40	n.s.
Euspira poliana juv	2-5mm	3.54	12.88	2.83	8.71	-20	n.s.
ECHINODERMS	**(diameter of length)**						
Echinocardium cordatum (juv)	2-5mm	448.47	745.69	1639.67	2143.30	266	0.011
Echinocardium cordatum	20-50mm	6.37	12.55	3.54	6.29	-44	n.s.
Ophiura texturata	ca.10mm	4.24	8.08	1.41	4.35	-67	n.s.
Ophiura texturata (juv)	2-3mm	5.66	9.63	0.71	3.16	-88	0.033
Asterias rubens (juv)	2-3mm	12.73	29.35	7.78	14.13	-39	n.s.
Asterias rubens	50-70mm	0.71	3.16	0.71	3.16	0	n.s.
ANNELIDS	**(length)**						
Spiophanes sp.	0.5-3cm	10464.03	9676.85	12323.69	10378.01	18	n.s.
Spio sp.	0.5-2cm	52.34	64.11	68.61	110.09	31	n.s.
Scololepis sp.	0.5-3cm	96.20	59.42	114.59	80.80	19	n.s.
Etione sp.	2-3cm	18.39	32.16	38.20	37.03	108	0.026
Anaitides cf. maculata	0.5-2cm	122.37	172.43	120.96	134.56	-1	n.s.
Magelona papillicornis	1-7cm	99.74	101.55	150.67	186.29	51	n.s.
Capitella capitata	0.5-1cm	449.88	1088.13	342.36	580.75	-24	n.s.
Lanice sp.	0.5-3cm	123.08	141.33	93.37	136.27	-24	n.s.
Neptys sp.	0.5-6cm	106.10	57.60	99.03	36.43	-7	n.s.
Pectinaria sp.							
without tube	0.4-1.5cm	43.15	90.58	45.27	80.11	5	n.s.
in tube	0.5-2.5cm	9.20	22.14	7.78	16.85	-15	n.s.
total		52.34	111.12	53.05	94.61	1	n.s.
Anaitides cf. groenlandica	1-2cm	10.61	17.70	9.90	13.06	-7	n.s.
Anaitides cf. mucosa	0.5-1.5cm	118.84	110.86	96.20	87.28	-19	n.s.
Scoloplos armiger	1.5-3cm	26.17	28.02	21.93	19.19	-16	n.s.
polychaetes indet. (b)	0.2-1.4cm	1.41	4.35	0.74	3.25	-47	n.s.
polychaetes indet. (c)	1cm	3.54	6.29	2.98	5.93	-16	n.s.
polychaetes indet. (d)	1-2cm	2.83	7.40	2.83	7.40	0	n.s.
polychaetes indet. (e)	1-1.5cm	2.83	9.84	0.00	0.00	-100	n.s.
polychaetes indet. (f)	0.5-2cm	2.12	9.49	0.00	0.00	-100	n.s.
polychaetes indet. (g)	0.5-2cm	0.71	3.16	2.12	5.18	200	n.s.
polychaetes indet. (h)	1-3cm	1.41	4.35	0.00	0.00	-100	n.s.
polychaetes sp. aff. Nereis	8-10cm	0.71	3.16	0.71	3.16	0	n.s.
other groups							
Nemertini	0.3-2cm	99.03	112.24	227.77	232.37	130	0.029
Phoronids	0.3cm	2.12	9.49	2.12	6.92	0	n.s.

TABLE 3

Numbers of animals ($n_* 100\ m^{-2}$) of sessile or low mobile species, in 6 catches of an early prototype of a dredge in the study area at 12 hours before (t_0), and of 6 hauls at 6 days after (t_1) trawling (Vlieland study). Statistical significance of changes in mean densities was tested with a t-test using log (n+1) transformed data or with Mann Whitney U test, (one-sided probabilities for sessile species, two-sided for mobile species).

species	numbers in catch (n*100m2)				t0-t1	P
	t0-sampling (n=6)		t1-sampling (n=6)		in/decrease	t-test [MannWh.U test]
	mean	st.dev.	mean	st.dev.	%	*=one sided
ECHINODERMS						
Asterias rubens	7.50	7.22	5.37	5.06	-28	n.s.
Astropecten irregularis	0.09	0.23	0.00	0.00	-100	n.s.
Echinocardium cordatum	0.65	0.55	0.37	0.45	-43	n.s.
Ophiura texturata	69.35	53.07	40.37	32.85	-42	n.s.
MOLLUSCS						
Angulus fabulus	0.00	0.00	0.37	0.45	>>100	n.s.
Angulus tenuis	4.63	2.71	2.96	2.18	-36	n.s.
Chamelea gallina	1.39	1.30	0.37	0.45	-73	0.022*
Donax vittatus	326.67	195.63	166.11	147.39	-49	0.046*
Ensis sp.	2.04	0.91	2.13	1.47	5	n.s.
Euspira catena	0.09	0.23	0.09	0.23	0	n.s.
Mactra corallina	0.09	0.23	0.00	0.00	-100	n.s.
Spisula elliptica	0.09	0.23	0.09	0.23	0	n.s.
Spisula solida	0.46	0.55	0.46	0.55	0	n.s.
ANNELIDS						
Ophelia	1.11	1.53	0.93	0.91	-17	n.s.
Polychaetes sp.	0.65	1.02	2.13	1.66	229	n.s.

TABLE 4

Numbers of animals ($n_{*}1000\ m^{-2}$) in catches of the 3-m beam trawl in the study area, 12 hours before trawling (t_0; n=6), immediately after trawling (t_1; n=3) and 21 hours after trawling (t_2; n=4) (Vlieland study). Statistical significance was calculated using Tukey comparisons in ANOVA. Statistical significance of changes in mean densities was tested with a t-test using log(n+1) transformed data (two-sided probabilities).

species	numbers in catch (n*1000m-2)						in/decreases in densities					
	t0-sampling (n=6)		t1-sampling (n=3)		t2-sampling (n=4)		t0-t1		t1-t2		t0-t2	
	mean	st.dev.	mean	st.dev.	mean	st.dev.	%	P	%	P	%	P
FISH												
Agonus cataphractus	0.74	0.45	0.19	0.32	0.00	0.00	-75	-	-100	-	-100	-
Ammodytes tobianus	0.93	1.35	0.37	0.32	0.28	0.56	-60	n.s.	-25	n.s.	-70	n.s.
Arnoglossus laterna	8.06	1.88	6.30	5.01	4.44	0.79	-22	n.s.	-29	n.s.	-45	n.s.
Buglossidium luteum	75.37	7.23	63.70	28.66	46.94	9.62	-15	n.s.	-26	n.s.	-38	n.s.
Callionymus lyra	6.94	2.55	2.59	1.79	3.75	0.28	-63	0.020	45	n.s.	-46	n.s.
Limanda limanda:								n.s.		n.s.		n.s.
0-group	21.85	26.87	23.70	36.24	14.17	7.24	8	n.s.	-40	n.s.	-35	n.s.
10-15cm	6.94	4.85	9.63	6.24	6.25	5.47	39	n.s.	-35	n.s.	-10	n.s.
15-20cm	10.09	5.10	12.59	5.62	10.56	4.47	25	n.s.	-16	n.s.	5	n.s.
>20cm	1.39	1.10	2.78	1.67	2.64	1.15	100	n.s.	-5	n.s.	90	n.s.
Platichthys flesus	0.00	0.00	0.19	0.32	0.00	0.00	>>100	-	-100	-	-	-
Pleuronectes platessa	26.76	8.91	14.81	8.93	34.03	10.31	-45	n.s.	130	0.030	27	n.s.
Pomatoschistus spp.	2.87	1.55	5.37	5.04	5.28	3.03	87	n.s.	-2	n.s.	84	n.s.
Scophthalmus maximus	0.09	0.23	0.19	0.32	0.00	0.00	100	-	-100	-	-100	-
Scophthalmus rhombus	0.09	0.23	0.00	0.00	0.00	0.00	-100	-	-	-	-100	-
Solea solea	4.63	2.62	0.93	0.64	3.19	3.50	-80	n.s.	245	n.s.	-31	n.s.
Trachinus vipera	29.26	9.52	22.22	16.19	17.92	5.87	-24	n.s.	-19	n.s.	-39	n.s.
Trigla spp.	0.65	0.55	0.74	0.85	0.00	0.00	14	-		-		-
ECHINODERMS												
Asterias rubens	1478.70	300.99	885.93	574.03	1750.83	761.79	-40	n.s.	98	n.s.	18	n.s.
Astropecten irregularis	0.00	0.00	0.19	0.32	0.00	0.00	>>100	-	-100	-	-	-
Ophiura texturata	3265.19	1754.65	2850.37	989.24	2880.00	1017.74	-13	n.s.	1	n.s.	-12	n.s.
MOLLUSCS												
Allotheutis sp.	0.46	0.74	0.00	0.00	0.00	0.00	-100	-	-	-	-100	-
Donax vittatus	170.22	193.75	272.59	212.10	151.11	208.08	60	n.s.	-45	n.s.	-11	n.s.
CRUSTACEANS												
Corystes cassivelaunus	0.00	0.00	0.19	0.32	0.00	0.00	>>100	-	-100	-	-	-
Eupagurus bernhardus	30.93	29.72	5.93	10.26	11.67	3.80	-81	n.s.	97	n.s.	-62	n.s.
Liocarcinus holsatus	31.48	19.80	38.52	28.57	26.11	5.56	22	n.s.	-32	n.s.	-17	n.s.

TABLE 5

Numbers of animals ($n \cdot 1000\ m^{-2}$) of invertebrate species, in catches of the 12 hauls with a pair of 4-m beam trawls in the study area (IJmuiden study). Total catch after trawling the study area 1.5 times ($n \cdot 1000\ m^{-2}$) was calculated as 1000 • the ratio between the actual numbers caught in the 12 hauls and the surface of the study area.

species	numbers in catch (n*1000m-2)			
	hauls 1-2	hauls 3-10	hauls 11-12	total catch all hauls
ECHINODERMS				
Asterias rubens	16.66	0.36	1.14	4.77
Echinocardium cordatum	0.29	0.00	0.00	0.07
Ophiura texturata	40.81	1.94	21.59	17.31
MOLLUSCS				
Ensis americanus	0.00	0.00	0.09	0.02
Mactra corallina	0.00	0.00	0.29	0.07
Spisula subtruncata	0.76	0.02	0.57	0.35
CRUSTACEANS				
Cancer pagurus	0.00	0.00	0.10	0.02
Carcinus maenas	0.29	0.02	0.19	0.14
Corystes cassivelaunus	0.09	0.00	0.00	0.02
Eupagurus bernardus	0.48	0.03	0.10	0.17
Liocarcinus holsatus	23.17	0.31	3.49	6.91
Necora puber	0.19	0.00	0.00	0.05
Palaemon sp.	0.09	0.00	0.00	0.02
other groups				
Anthozoa indet.	0.29	0.00	0.00	0.08

TABLE 6

Numbers of animals (n*100 m^{-2}) of sessile or low mobile species, in catches of 11 Triple-D hauls in the study area, 24 hours before trawling (t_0), and 24 hours after trawling (t_1) (IJmuiden study). The number of *Spisula subtruncata* broken by the 4-m beam trawl and not yet consumed at t_1-sampling was estimated by assuming a constant ratio of intact animals and animals that were broken by the dredge. The "total" denotes the density of living animals in the sampled area at t_0 and t_1. Statistical significance of changes in mean densities was tested with a t-test using log(n+1) transformed data or with Mann Whitney U test, (one-sided probabilities for sessile species, two-sided for mobile species).

species	numbers in catch (n*100m2)				t0-t1	P
	t0-sampling		t1-sampling		in/decrease	t-test [MannWh.U test]
	mean	st.dev.	mean	st.dev.	%	*=one sided
ECHINODERMS						
Asterias rubens	2.62	4.17	0.87	1.50	-67	n.s.
Echinocardium cordatum	3.66	7.35	3.22	5.57	-12	n.s.
Ophiura texturata	16.38	6.19	10.97	3.91	-33	0.023
MOLLUSCS						
Abra alba	0.57	1.27	1.17	2.21	105	n.s.
Angulus spp.	2.36	2.99	1.81	3.43	-24	n.s.
Chamelea gallina	0.00	0.00	0.30	1.01	>>100	n.s.
Donax vittatus	0.29	0.96	0.00	0.00	-100	n.s.
Ensis americanus	47.64	24.49	69.92	32.39	47	n.s.
Euspira poliana	1.19	2.17	0.30	1.01	-75	n.s.
Mactra corallina	5.13	5.99	2.57	3.02	-50	n.s.
Spisula subtruncata:						
undamaged	970.91	635.11	567.89	269.71	-42	
broken (by dredge)	401.30	325.91	234.73	111.48	-42	
broken (by 4mb)	0		171.10	147.45		
total	1372.21	957.74	802.62	381.19	-42	n.s.
CRUSTACEANS						
Carcinus maenas	2.31	7.66	0.00	0.00	-100	n.s.
Corystes cassivelaunus	0.85	2.82	1.16	1.62	37	n.s.
Diogenes pugilator	0.86	1.47	2.01	2.11	135	n.s.
Eupagurus bernardus	5.14	4.39	0.84	1.44	-84	0.002
Liocarcinus holsatus	5.14	5.22	3.49	3.94	-32	n.s.
Liocarcinus holsatus (juv. <1cm)	0.28	0.93	1.44	2.96	410	n.s.
Macropodia sp.	0.00	0.00	0.29	0.96	>>100	n.s.
ANNELIDS						
Pectinaria sp.	0.56	1.25	0.30	0.99	-47	n.s.
other groups						
Anthozoa indet.	10.18	9.86	22.87	18.46	125	n.s.

TABLE 7

Numbers of animals (n$\cdot$1000 m^{-2}) in catches of the 14 hauls with a pair of 4-m beam trawls in the study area (Egmond study). Total catch after trawling the study area twice (n$\cdot$1000 m^{-2}) was calculated as 1000 $\cdot$ the ratio between the actual numbers caught in the 14 hauls and the surface of the study area. The "total" of *Spisula subtruncata* denotes the density of living animals in the sampled area at t_0 and t_1 (see Table 6).

species	numbers in catch (n*1000m-2)			
	hauls 1-3	hauls 4-13	haul 14	total catch haul 1 to 14
FISH				
Agonus cataphractus	0.03	0.01	0.00	0.02
Ammodytes tobianus	0.03	0.00	0.00	0.01
Arnoglossus laterna	0.13	0.00	0.00	0.05
Buglossidium luteum	0.00	0.06	0.00	0.09
Callionymus lyra	0.20	0.08	0.38	0.27
Ciliata mustela	0.00	0.01	0.00	0.01
Gadidae spp.	0.10	0.00	0.00	0.04
Limanda limanda:				
0-group	0.65	0.04	0.25	0.36
>0-group	18.78	4.21	11.25	16.04
Myoxocephalus scorpius	0.03	0.00	0.00	0.01
Platichthys flesus	0.55	0.21	0.06	0.57
Pleuronectes platessa:				
0-group	0.05	0.02	0.00	0.05
>0-group	19.13	1.52	2.56	10.49
Potamoschistus spp.	0.20	0.00	0.00	0.08
Scophthalmus spp.	0.13	0.08	0.00	0.17
Solea solea:				
0-group	1.10	0.13	0.19	0.67
>0-group	0.48	0.06	0.25	0.33
Syngnathus spp.	0.03	0.00	0.00	0.01
Trigla spp.	0.08	0.05	0.00	0.11
ECHINODERMS				
Asterias rubens	52.80	16.95	6.25	49.24
Echinocardium cordatum	0.80	0.00	0.00	0.32
MOLLUSCS				
Allotheutis sp.	0.08	0.03	0.00	0.07
Ensis americanus	2.80	0.90	0.50	2.64
Mactra corallina	0.40	0.15	0.25	0.44
Spisula subtruncata:				
undamaged	5.40	0.30	1.75	2.68
damaged	6.00	1.20	1.25	4.04
total	11.40	1.50	3.00	6.72
CRUSTACEANS				
Cancer pagurus	0.03	0.01	0.00	0.02
Crangon crangon	0.60	0.15	0.00	0.48
Eupagurus bernhardus	2.40	0.00	0.50	1.04
Liocarcinus holsatus	14.60	2.25	2.50	9.84
Macropodia sp.	0.00	0.01	0.00	0.01
other groups				
Anthozoa indet.	0.20	0.00	0.00	0.08

TABLE 8

Numbers of animals ($n \cdot 100\ m^{-2}$) in catches of 7 hauls (fish and mobile epibenthos), 11 hauls (sedentary species), or 19 hauls (*Spisula subtruncata*) with the Triple-D in the study area, 24 hours before trawling (t_0), and 24 hours after trawling (t_1) (Egmond study). The "total" of *Spisula subtruncata* denotes the density of living animals in the sampled area at t_0 and t_1 (see Table 6). Statistical significance of changes in mean densities was tested with a t-test using log(n+1) transformed data or with Mann Whitney U test, (one-sided probabilities for sessile species, two-sided for mobile species).

species	numbers in catch (n*100m-2)				t0-t1	P
	t0-sampling		t1-sampling		in/decrease	t-test [MannWh.U test]
	mean	st.dev.	mean	st.dev.	%	*=one sided
FISH						
Ammodytes tobianus	0.46	0.80	0.00	0.00	-100	n.s.
Arnoglossus laterna	0.00	0.00	0.21	0.56	>>100	n.s.
Buglossidium luteum	0.00	0.00	0.67	0.84	>>100	n.s.
Callionymus lyra	0.26	0.67	1.02	1.43	299	n.s.
Limanda limanda:						
0-group	5.34	3.75	12.95	9.92	143	n.s.
>0-group	0.00	0.00	0.72	0.81	>>100	[0.025]
Platichthys flesus	0.00	0.00	0.23	0.62	>>100	n.s.
Pleuronectes platessa:						
0-group	0.00	0.00	0.21	0.56	>>100	n.s.
>0-group	0.89	0.55	0.57	1.22	-36	n.s.
Pomatoschistus spp.	2.59	3.13	10.47	7.14	304	0.034
Scophthalmus spp.	0.00	0.00	0.23	0.62	>>100	n.s.
Solea solea	2.13	2.00	0.54	0.73	-75	n.s.
ECHINODERMS						
Asterias rubens	5.87	4.71	4.71	6.23	-20	n.s.
Echinocardium cordatum	8.81	8.55	3.81	5.72	-57	0.028*
Ophiura texturata	18.99	5.48	21.81	9.15	15	n.s.
MOLLUSCS						
Abra alba	0.80	1.03	0.13	0.42	-84	0.027*
Angulus fabulus	10.84	14.40	12.70	16.67	17	n.s.
Angulus tenuis	22.99	14.03	22.62	13.69	-2	n.s.
Chamelea gallina	8.83	4.98	10.45	5.33	18	n.s.
Donax vittatus	1.64	2.61	1.67	2.42	2	n.s.
Ensis americanus	18.40	16.94	18.54	22.60	1	n.s.
Ensis ensis	1.25	1.22	1.30	1.58	4	n.s.
Euspira poliana	1.58	1.99	0.47	0.80	-70	n.s.
Mactra corallina	2.84	3.52	2.65	2.50	-7	n.s.
Spisula solida	0.00	0.00	0.17	0.56	>>100	n.s.
Spisula subtruncata:						
undamaged	864.32	426.46	342.03	198.03	-60	
broken by dredge	340.78	220.08	134.14	77.67	-60	
broken by 4mb			283.90	275.14		
total (=und.+br.b.dredge)	1202.52	615.58	476.17	275.70	-60	0.000
CRUSTACEANS						
Corystes cassivelaunus	1.43	1.11	0.44	0.76	-69	n.s.
Crangon crangon	54.54	31.95	43.03	25.01	-21	n.s.
Eupagurus bernhardus	3.06	1.23	3.18	3.02	4	n.s.
Liocarcinus holsatus:						
large	9.32	4.74	4.34	2.02	-53	0.017
small	2.96	1.92	7.63	5.45	158	0.036
total	12.29	5.41	11.97	6.49	-3	n.s.
Thia polita	0.44	0.77	0.50	0.85	14	n.s.
ANNELIDS						
Pectinaria sp.	0.20	0.54	1.31	2.36	541	n.s.
other annelids	9.31	4.74	8.82	5.11	-5	n.s.
other groups						
Anthozoa indet.	91.34	87.10	119.63	82.25	31	n.s.

TABLE 9

Numbers of animals (n*1000 m^{-2}) in catches of hauls with the 3-m beam trawl in the study area, 24 hours before trawling (t_0; n=6), and immediately after trawling (t_1; n=9) (Egmond study). Statistical significance of changes in mean densities was tested with a t-test using log(n+1) transformed data or with Mann Whitney U test (two-sided probabilities).

species	numbers in catch (n*1000m-2)				t0-t1	P
	t0-sampling (n=6)		t1-sampling (n=9)		in/decrease	t-test [MannWh.U test]
	mean	st.dev.	mean	st.dev.	%	
FISH						
Ammodytes tobianus	0.24	0.26	6.16	11.81	2488	0.022
Arnoglossus laterna	3.34	1.61	2.99	2.63	-10	n.s.
Buglossidium luteum	2.19	1.30	0.65	0.98	-70	0.010
Callionymus lyra	9.65	5.41	10.08	8.95	4	n.s.
Gadidae spp.	0.36	0.30	0.22	0.33	-38	n.s.
Limanda limanda:						
0-group	79.30	33.80	91.40	44.65	15	n.s.
>0-group	18.55	7.20	30.89	13.75	67	n.s.
Platichthys flesus	0.00	0.00	0.43	0.89	>>100	n.s.
Pleuronectes platessa:						
0-group	0.67	1.64	0.59	1.18	-11	n.s.
>0-group	12.03	2.48	20.10	12.46	67	n.s.
Pomatoschistus spp.	195.44	147.06	273.23	148.23	40	n.s.
Solea solea	0.64	0.72	0.83	0.74	30	n.s.
Syngnathus spp.	0.95	1.88	1.30	1.78	37	n.s.
Trigla spp.	0.87	1.69	0.14	0.28	-84	n.s.
ECHINODERMS						
Asterias rubens	58.86	20.72	26.80	15.87	-54	0.030
Echinocardium cordatum	5.77	4.81	0.29	0.49	-95	0.010
Ophiura texturata:						
large	118.80	39.60	87.22	61.27	-27	n.s.
small	0.00	0.00	4.44	13.33	>>100	n.s.
total	118.80	39.60	91.66	56.99	-23	n.s.
MOLLUSCS						
Angulus fabulus	0.00	0.00	0.35	1.05	>>100	n.s.
Angulus tenuis	0.00	0.00	0.67	1.33	>>100	n.s.
Chamelea gallina	0.00	0.00	4.11	4.53	>>100	[0.007]
Donax vittatus	0.00	0.00	0.32	0.97	>>100	n.s.
Ensis americanus	3.86	4.61	5.52	5.67	43	n.s.
Mactra corallina	0.94	0.95	1.51	1.88	60	n.s.
Spisula subtruncata	223.39	112.81	3328.32	2198.27	1390	0.000
CRUSTACEANS						
Corystes cassivelaunus	0.25	0.60	0.28	0.67	14	n.s.
Crangon crangon	966.61	323.27	400.93	168.42	-59	0.001
Eupagurus bernhardus	36.02	18.97	14.36	8.47	-60	0.022
Liocarcinus holsatus:						
large	20.38	15.17	8.75	4.27	-57	n.s.
small	28.04	25.03	34.44	35.32	23	n.s.
total	48.42	39.56	43.19	35.48	-11	n.s.
other groups						
Anthozoa indet.	3.51	6.20	17.78	17.96	407	n.s.

TABLE 10

Gear used to estimate the initial density, catch efficiency of the commercial trawls based on the catch of the first haul, found catch in all hauls and expected catch in all hauls (all as a proportion of the initial density). Species that were sampled in too low numbers (less than 1 animals in each catch) for a reliable density estimate are excluded. Results for species that were sampled in low numbers (less than 20 animals in t_0) are placed between brackets.

ddd = Triple-D; 3mb = 3-m beam trawl; box = box corer

species	VLIELAND STUDY				IJMUIDEN STUDY				EGMOND STUDY			
	sampling gear	catch efficiency	found total catch	expected total catch	sampling gear	catch efficiency	found total catch	expected total catch	sampling gear	catch efficiency	found total catch	expected total catch
		%	%	%		%	%	%		%	%	%
FISH												
Arnoglossus laterna	3mb	3	2	6	-	-	-	-	3mb	4	1	7
Buglossidium luteum	3mb	0	0	0	-	-	-	-	3mb	0	4	0
Limanda limanda:												
0-group	3mb	0	0	0	-	-	-	-	3mb	1	0	2
>0-group	3mb	34	28	56	-	-	-	-	-	-	-	-
Pleuronectes platessa (>0-gr)	3mb	52	38	77	-	-	-	-	-	-	-	-
Solea solea	3mb	6	5	11	-	-	-	-	ddd	[4]	[4]	[8]
ECHINODERMS												
Asterias rubens	3mb	12	10	23	ddd	[64]	[18]	[79]	3mk	90	84	99
Echinocardium cordatum	box	0	0	0	ddd	[1]	[0]	[1]	ddd	1	0	1
Ophiura texturata	3mb	0	0	0	ddd	25	11	38	ddd	13	-	23
MOLLUSCS												
Donax vittatus	ddd	0	0	0	-	-	-	-	-	-	-	-
Ensis americanus	ddd	0	0	0	ddd	0	0	0	ddd	2	1	3
Mactra corallina	-	-	-	-	ddd	0	0	0	ddd	[1]	[1]	[3]
Spisula subtruncata	-	-	-	-	ddd	0	0	0	ddd	0	0	0
CRUSTACEANS												
Eupagurus bernhardus	3mb	2	1	3	ddd	[1]	[0]	[2]	3mb	7	3	13
Liocarcinus holsatus	3mb	25	15	44	ddd	[45]	[13]	[62]	ddd	12	8	22

TABLE 11

Mortality estimated for discarded animals (as a proportion of the total catch), estimated catch mortality in the first haul and expected catch mortality in all hauls (both as a proportion of the initial density). Species that were sampled in too low numbers (less than 1 animals in each catch) for a reliable density estimate are excluded. Results for species that were sampled in low numbers (less than 20 animals in t_0) are placed between brackets.

species	mortality of discard	catch mortality after trawling once			expected total catch mortality		
		VLIELAND study	IJMUIDEN study	EGMOND study	VLIELAND study	IJMUIDEN study	EGMOND study
	% of tot. catch	% of init.dens.	% of init.dens.	% of init.dens.	% of init.dens.	% of init.dens.	% of init.dens.
FISH							
Arnoglossus laterna	100	3	-	4	6	-	7
Buglossidium luteum	100	0	-	0	0	-	4
Limanda limanda:							
0-group	99	0	-	1	0	-	2
>0-group	99	33	-	-	55	-	-
Pleuronectes platessa (>0-gr)	91	47	-	-	70	-	-
Solea solea	84	5	-	[3]	9	-	[7]
ECHINODERMS							
Asterias rubens	4	<1	[3]	4	1	[3]	4
Echinocardium cordatum	100	0	[1]	1	0	[1].	1
Ophiura texturata	10	<1	3	1	<1	4	2
MOLLUSCS							
Donax vittatus	33	<1	-	-	<1	-	-
Ensis americanus	?	0	0	<2	0	0	<3
Mactra corallina	33	-	0	[<1]	-	0	[1]
Spisula subtruncata	33	-	<1	<1	-	<1	<1
CRUSTACEANS							
Eupagurus bernhardus	7	<1	[<1]	<1	<1	[<1]	1
Liocarcinus holsatus	43	11	[19]	5	19	27	9

TABLE 12

Sampling gear used in estimating percentage of "missing animals" and percentage of "missing animals" (M), expressed as a proportion of the initial density. Fish species were excluded, as well as invertebrate species that were caught in the sampling gear in too low numbers (less than 1 animals in each catch) for a reliable density estimate.

* percentage missing animals is based on significant change in density between t_0 and t_1;

c. percentage missing animals is lower than the change in density between t_0 and t_1, because the species is caught in the commercial trawls.

[ ] percentage missing numbers is unreliable, as t_0 and t_1 sampling are based on low numbers in catch, or show large variations between the samples (resulting in large, but non significant differences).

ddd = Triple-D; 3mb = 3-m beam trawl; box = box corer

species	VLIELAND STUDY			IJMUIDEN STUDY			EGMOND STUDY		
	M %		sampling gear	M %		sampling gear	M %		sampling gear
ECHINODERMS									
Asterias rubens (adult)	-17	c	3mk	[~0]	c	ddd	~0*	c	3mb
Echinocardium cordatum (adult)	[-44]		box	[-11]	c	ddd	-56*	c	ddd
Ophiura texturata (adult)	-13	c	3mk	~0*	c	ddd	~0	c	ddd
MOLLUSCS									
Abra alba	-		-	-		-	[-84]*		ddd
Angulus fabulus (juv)	-3		box	-		-	-		-
Angulus fabulus (adult)	-		-	-		-	~0		ddd
Angulus tenuis	[-36]		ddd	-		-	-2		ddd
Chamelea gallina	[-73]*		ddd	-		-	~0		ddd
Donax vittatus	-42	c	box	-		-	[~0]		ddd
Ensis americanus	-		-	~0	c	ddd	~0	c	ddd
Ensis ensis	[~0]		ddd	-		-	[~0]		ddd
Euspira poliana	-		-	-		-	[-70]		ddd
Mactra corallina	-		-	[-50]	c	ddd	[-4]	c	ddd
Spisula subtruncata	-		-	-42	c	ddd	-60*	c	ddd
Spisula sp. juv	-35		box	-		-	-		-
Tellimya ferruginosa	-80		box	-		-	-		-
CRUSTACEANS									
Corystes cassivelaunus	-		-	-		-	[-69]		ddd
Eupagurus bernhardus	-78	c	3mk	[-82]*	c	ddd	-47*	c	3mb
Liocarcinus holsatus:									
large	-		-	[~0]	c	ddd	-31*	c	ddd
small	-		-	-		-	[~0]		ddd
total	-		-	-		-	-		-
ANNELIDS									
Ophelia sp.	[-17]		ddd	-		-	-		-
Pectinaria in tube	[-15]		box	-		-	-		-
Pectinaria without tube	~0		box	-		-	-		-
Pectinaria total	~0		box	-		-	-		-
Anaitides cf. groenlandica	[-7]		box	-		-	-		-
Anaitides cf. maculata	-1		box	-		-	-		-
Anaitides cf. mucosa	-19		box	-		-	-		-
Capitella capitata	-24		box	-		-	-		-
Etione sp.	~0		box	-		-	-		-
Lanice sp.	-24		box	-		-	-		-
Magelona papillicornis	~0		box	-		-	-		-
Neptys sp	-7		box	-		-	-		-
Scololepis sp.	~0		box	-		-	-		-
Scoloplos armiger	-16		box	-		-	-		-
Spio sp.	~0		box	-		-	-		-
Spiophanes sp.	~0		box	-		-	-		-
polychaetes indet (1)	-17		box	-		-	-		-
Polychaetes spp.	[~0]		ddd	-		-	-5		ddd
other groups									
Nemertini	~0		box	-		-	-		-
Anthozoa indet.	-		-	~0	c	ddd	~0	c	ddd

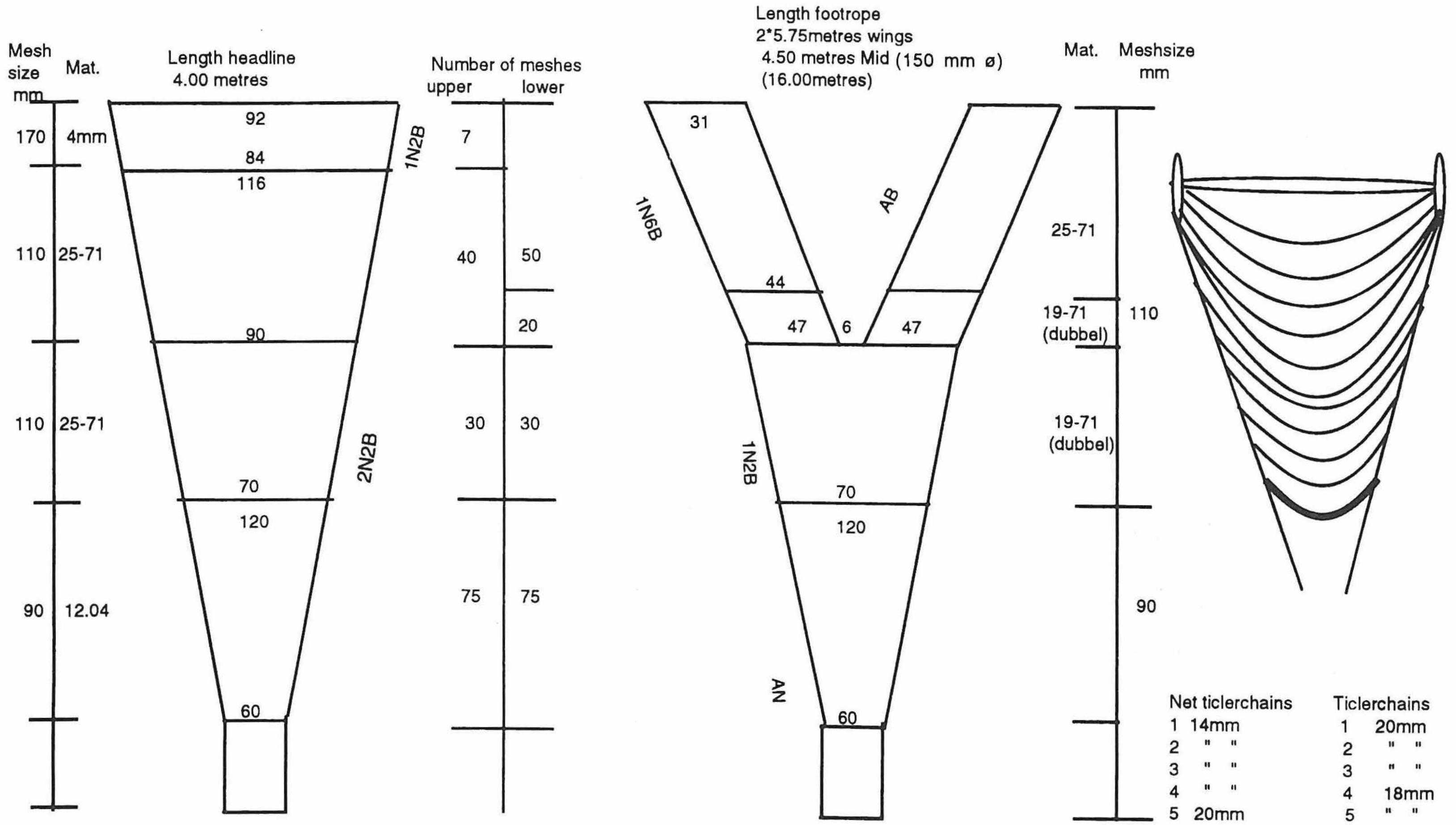
TABLE 13

Catch mortality (occuring in the trawls and after handling the catch onboard the trawler) after trawling the study area once), expected catch mortality in all hauls (i.e. in trawling the area 1.5 or 2 times), non-catch mortality (occuring in the study area due to passage of the trawl, or outside the study area after being washed through the meshes of the trawl), and total mortality (as a sum of catch mortality and non-catch mortality) after trawling the area 1.5 or 2 times. All mortality estimates as a proportion of the initial density.

~ order of magnitude; [ ] unreliable density estimate or unreliable mortality estimate.

species	TRAWLING ONCE	TRAWLING AN AREA 1.5 OR 2 TIMES		
	catch mortality % of init.dens.	expected catch mortality % of init.dens.	non-catch mortality % of init.dens.	total mortality % of init.dens.
FISH				
Arnoglossus laterna	4	7	?	7
Buglossidium luteum	<1	<4	?	<4
Limanda limanda:				
0-group	1	2	?	2
>0-group	33	55	?	55
Pleuronectes platessa (>0-gr)	47	70	?	70
Solea solea	4	8	?	8
ECHINODERMS				
Asterias rubens	1-4	1-4	<1	1-5
Echinocardium cordatum	<1	<1	[44]	[44]
Ophiura texturata	0-3	0-4	<2	0-6
MOLLUSCS				
Abra alba	0	0	[84]	[84]
Angulus fabulus (adult)	0	0	~0	~0
Angulus fabulus (juv)	0	0	~0	~0
Angulus tenuis	0	0	~0	~0
Chamelea gallina	0	0	~0	~0
Donax vittatus	0	0	42	42
Ensis americanus	0-2	0-3	~0	<3
Ensis ensis	0	0	~0	~0
Euspira poliana	0	0	[70]	[70]
Mactra corallina	<1	<1	[4-50]	[4-50]
Spisula subtruncata (adult)	0	0	42-60	42-60
Spisula sp. juv	-	-	35	35
Tellimya ferruginosa	0	0	80	80
CRUSTACEANS				
Corystes cassivelaunus	0	0	[45-69]	[45-69]
Eupagurus bernhardus	<1	<1	47-[82]	47-[82]
Liocarcinus holsatus:				
large	5-19	9-27	13-31	22-58
small	0	0	~0	~0
ANNELIDS				
Ophelia sp.	0	0	[17]	[17]
Pectinaria total	0	0	~0	~0
polychaetes spp.	0	0	<24	<24
other groups				
Nemertini	0	0	~0	~0
Anthozoa indet.	0	0	~0	~0

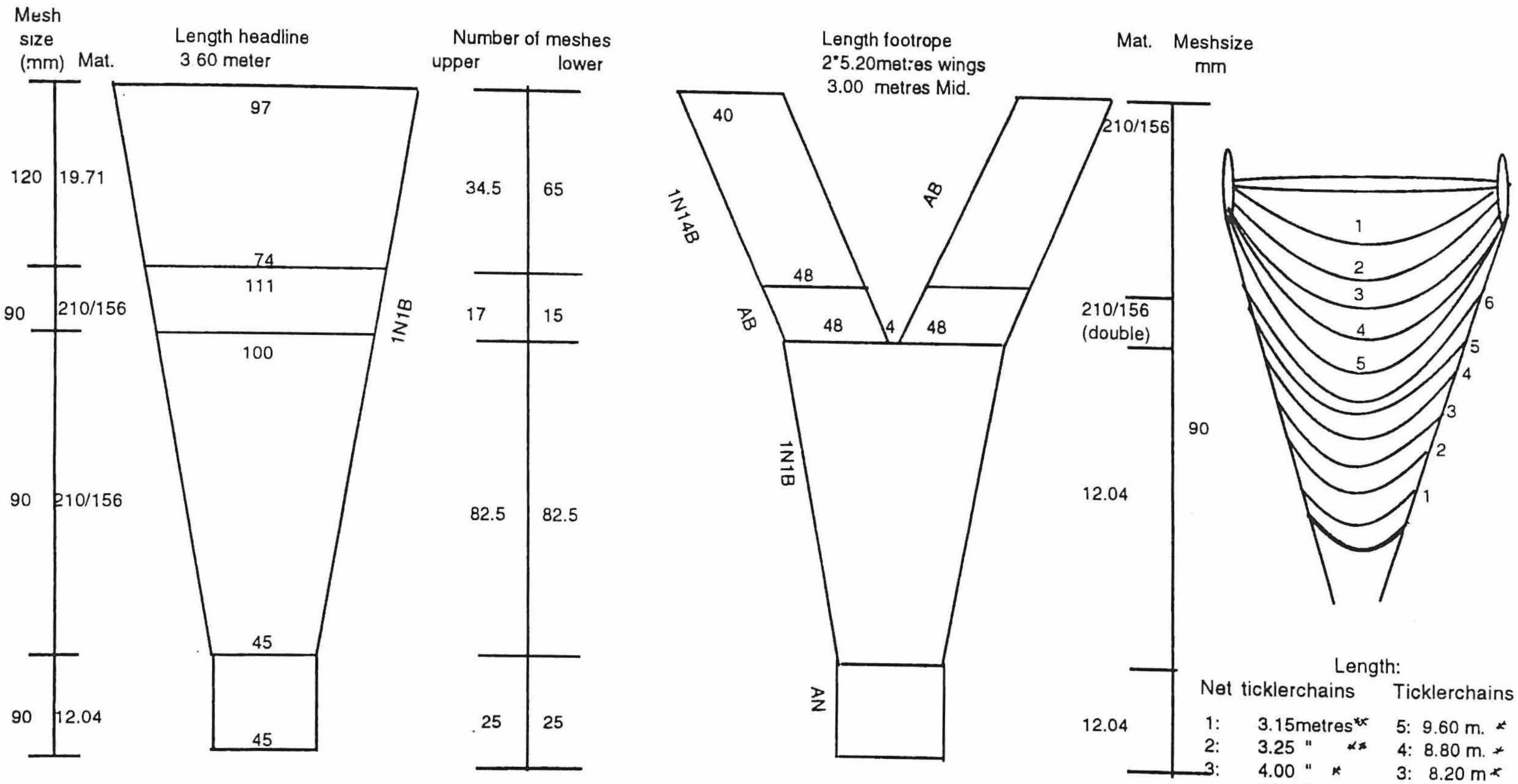
4 M BEAM TRAWL GEAR for HARD bottom, 'SOUTH GEAR', used in 1992



Shoes and pipe ca 900 kg, ticklers ca 300 kg, bridle 100kg
net with groundrope and netticklers ca 450 kg
TOTAL WEIGHT OF EACH GEAR IS ABOUT 1.175 TONS

Fig. 1. Commercial 4-m beam trawls used in the Vlieland study.

4 M BEAM TRAWL GEAR for SANDY bottom, WEEK 16 AND 17 1993



Shoes and pipe ca 820 kg, ticklers ca 150 kg, bridle 70 kg,
net with groundrope and net ticklers 360 kg
TOTAL WEIGT OF EACH GEAR IS ABOUT 1.4 TONS

Length:

Net ticklerchains		Ticklerchains	
1:	3.15metres **	5:	9.60 m. *
2:	3.25 " **	4:	8.80 m. *
3:	4.00 " *	3:	8.20 m *
4:	5.00 " *	2:	7.50 m **
5:	6.00 " *	1:	6.50 m **
6:	6.80 " *		

*) 13 mm ø, **) 14 mm ø

Fig. 2. Commercial 4-m beam trawls used in the IJmuiden and Egmond studies.

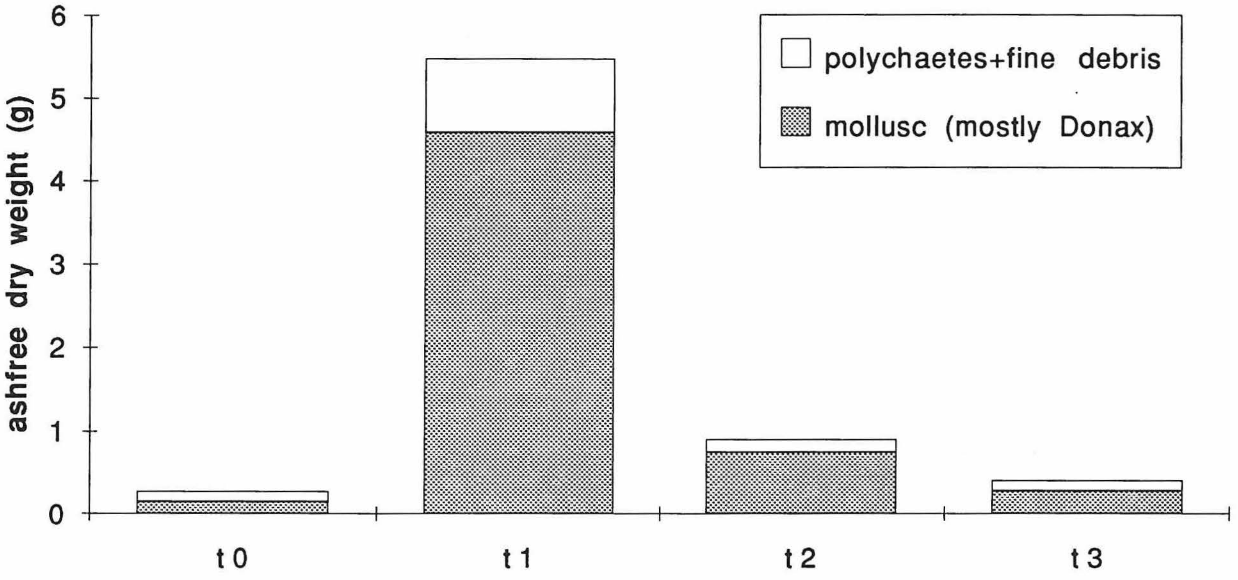


Fig. 3. Total stomach content (g ash free dry weigth) of 30 dab (*Limanda limanda*) caught in the 3-m beam trawl, 12 hours before trawling (t_0), immediately after trawling (t_1), 12 hours after trawling (t_2), and 24 hours after trawling (t_3) (Vlieland study).

APPENDIX

Common English names for some of the well known species found during the IMPACT-studies in the Dutch coastal zone and in the Oystergrounds.

FISH	
Agonus cataphractus	HOOKNOSE
Ammodytes tobianus	SANDEEL
Arnoglossus laterna	SCALDFISH
Buglossidium luteum	SOLENETTE
Callionymus lyra	DRAGONET
Clupea harengus	HERRING
Enchelyopus cimbrius	FOUR-BEARDED ROCKLING
Gadus morhua	COD
Limanda limanda	DAB
Merlangius merlangus	WHITING
Platichtys flesus	FLOUNDER
Pleuronectes platessa	PLAICE
Pomatoschistus spp.	GOBIES
Scophthalmus maximus	TURBOT
Scophthalmus rhombus	BRILL
Solea solea	SOLE
Trachinus vipera	LESSER WEEVER
Trigla spp.	GURNARD

ECHINODERMS	
Asterias rubens	COMMON STARFISH
Astropecten irregularis	a STARFISH
Echinocardium cordatum	SEA POTATOE or HEART-URCHIN
Ophiura texturata	a BRITTLE STAR
Psammechinus miliaris	a SEA URCHIN

MOLLUSCS	
Acanthocardia echinata	PRICKLY COCKLE
Angulus tenuis (= *Telina tenuis*)	a TELLIN
Angulus fabulus (=*Tellina fabulus*)	a TELLIN
Aporrhais pespelicani	PELICAN'S FOOT SHELL
Aequipecten opercularis	QUEEN SCALLOP
Arctica islandica	QUAHOG
Chamelea gallina (=*Venus striatula*)	STRIPED VENUS
Corbula gibba	COMMON BASKET SHELL
Buccinum undatum	WHELK
Donax vittatus	BANDED WEDGE SHELL
Dosinia lupinus	SMOOTH ARTEMIS
Ensis ensis	a RAZOR SHELL
Euspira catena (=*Natica catena*)	LARGE NECKLACE SHELL
Euspira poliana (=*Natica alderi*)	COMMON NECKLACE SHELL
Gari fervensis	FAROE SUNSET SHELL
Mactra corallina	RAYED TROUGH SHELL
Neptunea antiqua	BUCKIE
Nucula spp.	NUT SHELLS
Spisula subtruncata	TROUGH SHELL
Turritella communis	TOWER SHELL

CRUSTACEANS	
Cancer pagurus	EDIBLE CRAB
Carcinus maenas	SHORE CRAB
Corystes cassivelaunus	MASKED CRAB
Eupagurus bernhardus	HERMIT CRAB
Liocarcinus holsatus	a SWIMMING CRAB
Necora puber	VELVET SWIMMING CRAB
Thia polita	THUMB-NAIL CRAB

other groups	
Aphrodita aculeata	SEA MOUSE
ANTHOZOA indet.	ANEMONES

ENVIRONMENTAL IMPACT OF BOTTOM GEARS ON BENTHIC FAUNA IN RELATION TO NATURAL RESOURCES MANAGEMENT AND PROTECTION OF THE NORTH SEA

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ABSTRACT

Some of the possible impacts of fishing with a 4-m beam trawl by 'Eurocutters' on the bottom fauna were examined. Research was carried out on the Flemish Banks, southern North Sea. For each kg marketable flatfish about 1 kg undersized flatfish and other fishes, and 8 kg invertebrates were caught. Survival experiments were performed with large invertebrates and undersized flatfish discards that have been collected from the cod-end, and with species that escaped the cod-end. Almost all of the invertebrates examined, both those discarded and escaping the fishing net, survived. The percentage survival of flatfish was 0-20% for dab, 15% for sole and 70% for plaice. About 90% of the sole that escaped the cod-end survived. Several fish species moved into the trawled area after fishing, predating on the exposed invertebrate species. Different fish species immigrated on the trawled seabed, depending on the benthic composition of that area. Due to lack of statistical power it was impossible to detect effects on densities of the macrobenthic infauna. Moreover, it was uncertain whether the samples taken after fishing were actually situated within a trawl mark, or not. In conclusion, traditional sampling programmes seems to be insufficient to evaluate the impact of fishing with 4-m beam trawls on the macrobenthic infauna.

INTRODUCTION

Over the past decade, there has been a considerable increase in the number of large, powerful fishing vessels operating in the European waters, particularly beam trawlers (FOWLER, 1989). Large beam trawls are very heavy due to the heavy chainmat and tickler chain arrangements. The weight assures good bottom contact at high towing speed and rough sea floor (POLET *et al.*, this report). From this, is has been inferred that disturbance of sediments may have increased. Consequently, non-target species (epibenthic and shallow-burrowing infaunal invertebrates, non-commercial fish species) may be more affected than in the former years. Fishing can have an impact on the seabed and the benthic communities in several ways. Animals may be damaged mechanically by the gear, or, in the case of non-target fish species, in the process of wriggling or squeezing through the various objects in the cod-end (such as starfish and stones) (VAN BEEK *et al.*, 1989). At the same time, more benthic animals may become exposed and predated, again increasing mortality. Finally, the catches in the beam trawl fishery are characterized by a substantial by-catch of various species of invertebrates and non-target fish species (undersized commercial flatfish species, unmarketable species) (VAN BEEK *et al.*, 1989). These species are further discarded into the sea. However, as these species comprise a large component of the catch, investigations into the mortality are all the more relevant in the context of the effects of trawling on the ecosystem.

Within the framework of the FAR-research project MA 2.549, three trawling programs were carried out in the Southern North Sea with the R.V. BELGICA fishing with a 4-m beam trawl equipped with chainmats. This type of gear is often used on rough grounds by the so-called 'Eurocutters', small trawlers allowed to fish within the 12 miles zone with beam trawls. Vessels using chain matrices fish mainly in the ICES areas IV_c and VII_{adef}. When adult sole starts migrating to the coastal nursery grounds, these vessels change from trawling for shrimp to flatfish fishery (POLET *et al.*, this report). Chainmats are rigged between the beam and the groundrope to prevent big stones from being caught by the net. The Fisheries Research Station at

Oostende (Belgium) did research on the physical impact of this gear (see FONTEYNE, this report). The Netherlands Institute for Ecology at Yerseke (the Netherlands) concentrated on:

- the quantity of discards;
- damage on flatfish;
- the primary and secondary mortality of invertebrates and flatfish in the cod-end, and of animals escaping the cod-end;
- changes in infaunal invertebrate composition and densities after a beam trawler has fished an area, including an analysis of the effectiveness of the followed sampling programme in detecting changes;
- changes in the faunal composition (fish and epibenthic animals) in an area repeatedly fished by a beam trawler.

MATERIAL AND METHODS

1. AREA OF INVESTIGATION

The research was carried out on the Flemish Banks (southern North Sea) (Fig. 1). The study area is situated in the ICES quadrants 31F2 (zone 4) and 32F2 (zones 1, 2 and 5) of the ICES area IV_C.

Zone 1 has a flat seabed morphology with no distinct sandwaves but there are large megaripples mostly in the western and central part (wavelength: 5-8m). About 80 % of the seabed is covered with coarse sand, sometimes with superficial mud or shells, 20% of the seabed is covered with mud or mud with some sand.

Similarly, zone 2 also has a flat seabed morphology with 7 sandwaves of maximum 1.5 - 2 m height. Megaripples have a general NW-SE strike and a wavelength of ± 7m. The seabed is covered with coarse sand with shell, superficial mud or gravel.

Along zone 4, 13 distinct sandwaves of maximum 3.5 - 4 m height and a NNW-SSE direction were distinguished. Megaripples are only present on the flanks of the sandwaves.

In zone 5 sediment ranges from muddy sand to sand.

A detailed description of the seabed morphology in zones 1, 2 and 4 is given in annexes 2 and 3 of FONTEYNE (this report).

2. SURVIVAL EXPERIMENTS

In April 1992 and March 1993 survival experiments were carried out with epibenthic invertebrates and flatfishes that were frequently caught in the commercial net: starfish (*Asterias rubens*), portunid crabs (the shore crab *Carcinus maenas* and the swimming crabs *Liocarcinus holsatus, L. puber* and *L. pusillus, L. depurator)*, brittlestars *(Ophiura* sp.), hermit crab (*Pagurus bernhardus),* sea mouse (*Aphrodite aculeata),* sole (*Solea solea),* dab (*Limanda limanda*), plaice (*Pleuronectes platessa)* and flounder (*Pleuronectes flesus*). In April 1992, animals were collected from a single haul of 70 minutes in zone 2, and in March 1993 from a haul of 58 minutes in zone 1. Specimens caught were discharged onto the vessel's deck. Fishes were placed immediately in tanks with sea water. Invertebrates were put into baskets and sorted within half an hour.

In March 1993 additional experiments were carried out to estimate the survival of individuals that escaped through the 8 cm meshes. Two short hauls of 10 minutes were carried out in area 1 with the cod-end covered with a narrow-meshed (4 cm) net. The cod-end covering net was discharged directly in a tank with sea water, and survival experiments were set up with swimming crabs *(Liocarcinus depurator* and *L. holsatus*), brittlestars (*Ophiura* sp.) and sole (*Solea solea*).

Living animals were placed in seawater tanks as designed by the Netherlands Institute for Fisheries Research at IJmuiden (VAN BEEK *et al.*, 1989). The system consists of plastic holding tanks of 40 by 60 cm and 12 cm height. Two stacks of ten holding tanks were placed in a wooden frame and supplied with a continuous flow of fresh sea water. Water was pumped into the top tanks, flowing vertically from one tank into the next through vertical overflow pipes (Fig. 2). The same equipment was used by BEON (1990, 1991, 1992) and within the framework of this project in experiments by the Netherlands Institute for Sea Research (see FONDS, this report). In order to avoid effects associated with overcrowding, the number of individuals per tank depended on the species type: 4-11 for fishes, 6-95 for invertebrate species. The tanks were checked and dead animals recorded and removed daily over a period of three days. The length of all fishes was measured to the nearest millimetre. In order to evaluate the importance of the mortality of the animals surviving fishing in relation to the direct mortality, any dead fish caught in March 1993 were identified and measured to the millimetres.

3. DISCARDED MATERIAL

In an attempt to characterise the typical by-catch, the species composition was analyzed in April 1992 for one tow in zone 1 (haul duration 128 minutes), one in zone 2 (haul duration 156 minutes), and one in zone 4 (haul duration 66 minutes). Depending on the size of catch, either the whole catch or a subsample was analyzed. Animals were sorted to species level, and the numbers of all species and the weight (wet weight, ± 1 g) of invertebrates and some smaller fishes were recorded. The total length of all fish species was measured to the nearest mm. The biomass of the numerically most important fish species was estimated from following length-weight regressions ($W = aL^{b}$, with wet weight (W) in gram and length (L) in cm) (COULL *et al.*, 1989; FONDS, pers. comm.):

	a	b
Pleuronectes platessa	0.008	3.10
Platichthys flesus	0.008	3.10
Limanda limanda	0.008	3.10
Solea solea	0.008	3.00
Merlangius merlangus	0.007	3.10
Trigla lucerna	0.004	3.20
Gadus morhua	0.007	3.00
Clupea harengus	0.005	3.09
Trisopterus luscus	0.005	3.30

Sole < 24cm, dab < 23 cm, plaice < 27cm, and all other flatfish were considered as discards.

In zone 3 fishing was done with a net covering the cod-end. This enables us to compare the species composition in the fishing net and the species escaping the fishing net.

4. DAMAGE TO FISH

In April 1992, sole caught during the haul of about 2 hours in zone 1 (mentioned above) were inspected for physical injuries attributable to being caught in the beam trawl. The presence of cuts, evidence of scale loss and bruisng were recorded.

5. EFFECTS ON MACROBENTHIC INFAUNA

Sampling

In April 1992, the research for direct effects on the macrobenthic infauna took place in zone 2 (Fig. 1). Before fishing, the seabed was observed using side scan sonar to detect the presence of other trawl marks, made by fishing boats (see annex 2 of Fonteyne, this report). No trawl tracks were detected. In this zone 4 parallel transects at 10 m intervals and 2500 m long were fished using the 4-m beam trawl. Total coverage of an area - as done by e.g. BERGMAN & VAN SANTBRINK (this report) - was impossible. As only a single 4-m beam trawl was towed, trawling would have to be carried out over too long a period. The macrobenthic infauna was sampled the day before and the day after using a van Veen grab (0.1 m^2).The t_0 sampling was performed on the first two transects: 6 samples spaced at 400 m intervals on the first transect and 14 samples spaced every 150 m on the second. In order to maximize the chance of sampling within the trawl marks, the t_1 sampling was performed on the middle two of the four fished transects. Both transects were sailed three times. Samples were taken at 250 or 500 m intervals. Thus, a total of 50 samples were taken. At every sampling point, the exact position of the ship, the time of sampling and the water depth were recorded at the moment the grab touched the bottom. The position of the R.V. BELGICA was determined by means of the SYLEDIS system. A detailed description of this system is given in annex 3 of FONTEYNE (this report). The exact position of every grab taken at t_1 was calculated from the known translation of the ship position to the position where the grab was entering the water, and the sailing direction of the ship (recorded every 30 seconds), assuming that the grab went down vertically. Because the sampling time was mostly in between two records of ship position (e.g. sampling at 10 h15'14", ship position recorded at 10 h15'00" and 10h15'30"), the grab position was determined for both ship headings. Whether the t_1-samples fell within the trawl marks or not, was determined using two approaches. First, assuming that 1) the side scan sonar followed the same position as the ship, 2) the ship followed a straight line during scanning, and 3) the depth was constant, the position of each sampling point on the side scan sonar records was determined. Secondly, assuming that the beam trawl followed the same track (as the 4-m beam trawl was towed from an A-frame at the stern of the ship) samples within two meters of the sailed track were considered situated in the trawl marks.

In November 1992 the effects of fishing on the benthos were studied in zone 5 (Fig. 1). Fishing (03.11.1992) was repeated 5 times within 9 hours on a single transect of 1500 m long. The macrobenthic infauna along that transect was sampled at 15 stations before (t_0: 03.11.1992) and after trawling (t_1: 05.11.1992) using van Veen grabs (0.1 m^2). No side scan sonar was available to check the exact position of the trawl marks. Therefore, we assumed that all t_1-samples were situated within one of the trawl marks.

Samples were washed through a 1 mm sieve on board and were preserved in 7% buffered formalin. In the laboratory, the residues were sorted, all animals were identified to species level (when possible), and the abundances of each species was determined.

Statistical analyses

Differences between densities of the individual species before and after fishing were tested by a t-test and its nonparametric equivalent, a Mann-Whitney U-test. All calculations were made on transformed data:

$$y' = \log(y) \quad \text{if } y>0$$
$$y' = 0 \quad \text{if } y=0,$$

where y is the number of individuals per one square meter.

The effectiveness of the programme in detecting changes in the abundance of the infauna due to the effects of fishing was measured. Effectiveness is defined in terms of statistical power which quantifies the types and magnitudes of changes likely to be detected (FRYER & NICHOLSON, 1993). Power depends on several factors, including the precision of the estimates of abundance, the magnitude of the actual rate of change in abundance, and the level (α) of Type 1 error (the conclusion that the abundance changed, when in fact it did not). Power is defined as 1 - ß, where ß is the chance of making a Type 2 error (the conclusion that there was no change in abundance, when in fact abundance changed). An overview is given in the following table (PETERMAN, 1989).

Four possible outcomes for a statistical test of some null hypothesis, depending on true state of nature. Probability for each outcome is given in parentheses.

	Decision	
State of nature	Do not reject null hypothesis	Reject null hypothesis
Null hypothesis actually true	Correct (1 - α)	Type 1 error (α)
Null hypothesis actually false	Type 2 error (β)	Correct (1 - β) (= power)

The number of replications needed to detect a given difference between means is given by (SOKAL & ROHLF, 1981):

$$n \leq 2*(\frac{\alpha}{\delta})^2*(t_v(\alpha/2)+t_v(\beta))^2$$

Thus, power can be calculated from:

$$t_v(\beta)=\frac{\delta*\sqrt{n}}{\delta*\sqrt{2}}-t_v(\alpha/2)$$

with $t_v(\beta)$ = the tabled t-value for $_v$ degrees of freedom and proportion β in one tail
σ = the true standard deviation
v = a*(n-1), the degrees of freedom of the sample standard deviation s with a groups and n replications per group; and
δ = the smallest true difference desired to be detected.

Using s as an estimate of σ, δ/σ is equal to the ratio of the coefficient of variation ($100*s/\mu$ with μ the sample mean) and the percentage of difference that is desired to detect ($100\delta/\mu$). The power was estimated at a significance level α=0.20 and differences (δ) of 5, 10, 20 and 50% for a few selected species with different coefficients of variation.

6. EFFECTS OF REPEATED TRAWLING

In order to assess possible changes in the density of epibenthic invertebrates and fishes due to trawling, fishing was performed on a single transect. In November 1992, repeated trawling using a 4-m beam trawl was performed 6 times within 9 hours on a track in zone 5. In March 1993, fishing was repeated 10 times within 9 hours on a track in zone 2. Length and duration of each tow is given in Table 1.

The catch composition was analyzed for each of the hauls. Depending on the size of the catch, either the whole catch or a subsample was analyzed. The numbers of each species were counted. Fishes were measured to the nearest millimetre.

In the March 1993 survey, a side scan sonar survey was performed before and after fishing, and the visibility of the beam trawl tracks was monitored for about 44 hours to estimate the rate of disappearance of the tracks (see annex 3 of Fonteyne, this report).

RESULTS

1. DISCARDED MATERIAL

In the three zones examined, about 20 kg fish and almost 80 kg invertebrates were caught per hour trawling. From the fish about 50% is undersized flatfish, other demersal fish or roundfish. For each kg marketable flatfish about 1 kg undersized flatfish and other fishes, and 8 kg invertebrates are caught. In Table 3 the results are given for the three zones. The most abundant invertebrate species were starfish (*Asterias* *rubens*) and swimming crabs (*Liocarcinus*). In zone 1, sea urchins (*Echinocardium cordatum*) were also a large component of the catch.

2. DAMAGE TO FISH

Of the 25 specimens of sole examined, only one had no damage at all. The others had missing scales, and, except for one, showed signs of haemorrhages.

3. SURVIVAL EXPERIMENTS

The results of the survival experiments are presented in Table 2 and Fig. 3, together with the number of fishes brought dead aboard.

Almost 100% of the invertebrate species (starfish, crabs and brittlestars) caught in the cod-end survived. Only 15-17% of sole survived, 55-66% already died during the first day. In April 1992, a larger % of dabs survived (21%), and mortality was equal over the three days. In the March 1993 experiment, however, no animals survived and 82% died the first day. In April 1992, 68% of plaices survived, 31% died the third day. In March 1993 only two plaices were caught, and both survived.

Most of the animals, both invertebrates and sole, escaping the cod-end, survived.

Direct mortality in the cod-end was very high for flatfish: about 30% of sole, 40% of dab, and 85% of plaice were brought dead aboard. But half of the dab and sole, and all plaice were maketable fishes.

The overall survival of unmarketable sole is about 10%, of dab 0-20% and of plaice 70-100%.

4. EFFECTS ON MACROBENTHIC INFAUNA

April 1992

Assuming that the ship heading at the time of sampling was the same as the one recorded either before or after sampling, 15 out of the 50 t_1-samples would have been situated in one of the five trawl marks. In the second approach, based on the assumption that the beam trawl followed the same way as the ship, samples within two meters of the sailed track were considered situated in the trawl marks. Assuming that the ship heading at the time of sampling was the same as the one recorded either before or after sampling, only 5 stations - and all different from the 15 assessed in the first approach - would have been situated in one of the five trawl marks.

Figure 4a gives the power of seven species in function of the differences desired to be detected. The power in all cases is very low. For example, the probability to detect a 50% difference at the 20% level for *Ophiura albida* was about 30%. Only 10 species had a coefficient of variation (s/μ) below 2, the lowest being the c.v. of *Urothoe brevicornis.*

Given the low densities recorded at t_0 (Table 4), the low probability that a t_1-sample actually fell in a trawl mark, and the low power of the programme, the t_1-samples were not analyzed.

November 1992

About 75 species were found, half of them only recorded in one sample (Table 5).

Figure 4b gives the power of nine species in function of the differences desired to detect. The coefficients of variation were lower than recorded in the April survey. Now, 25 species had a c.v. < 2. But, as in April, a power of 80% for $\alpha = 0.20$ is only reached for differences of 50% for four species with a coefficient of variation below about 0.6: *Scoloplos armiger, Abra alba, Notomastus latericeus* and *Spiophanes bombyx.*

For $\alpha = 0.05$ only the mean density of *Montacuta ferruginosa* was found to be significantly different (Table 5). *Eteone* spec., *Mysella bidentata* and *Scoloplos armiger* were found to have a different density at a 10% probability. The difference of the means (of the transformed data) were respectively 153%, 167%, 34% and 9.5%.

5. REPEATED TRAWLING

November 1992 survey

The densities of invertebrates and fishes caught during the different hauls are given in Table 6. The numbers of starfish (*Asterias rubens*) and swimming crabs (*Liocarcinus holsatus*) were higher during the first haul (Table 6). Plaice (*Pleuronectes platessa*) seem to have increased in density. During the last haul more sole were caught than in preceding hauls. The density fluctuations of other species (e.g. the sea urchin *Echinocardium cordatum*, brittlestars (*Ophiura* spec.), flounder (*Platichthys flesus*) and the hooknose (*Agonus cataphractus*)) did not show a regular pattern.

March 1993 survey

As haul no. 5 was twice as long as the others (both in time and space), this haul was not further taken into account. The numbers of fish and invertebrates caught in the other 9 hauls are given in Table 7. The results point to a decrease in starfish (*Asterias rubens*), swimming crabs (*Liocarcinus holsatus)* and sole (*Solea solea*) after 2 hauls. In contrast, dab (*Limanda limanda*) and bib (*Trisopterus luscus*) showed an increase in numbers after 5 hauls. At the last haul, numbers of sole had increased.

DISCUSSION

Amount of discards

Beam trawls may catch large quantities of debris, invertebrates and unmarketable fishes. In our studies we found that in a catch of 10 kg only 1 kg consisted of marketable flatfish, 0.4 kg undersized flatfish, 0.6 kg other fishes and 8 kg invertebrates. If this figures are representative for the Belgian flatfish beam trawler fleet, with a landing of 20,500 tons of flatfish (POLET *et al.*, this report), this would mean a by-catch of 7,600 tons of undersized flatfish, 38,300 tons of invertebrates and 4,800 tons of other fishes. As the total landings of these fish species is about 8,500 tons, our figures form too low an estimate of the by-catch of fish species as whiting, haddock, cod and unmarketable demersal fishes. About 1,100 tons of crustaceans and molluscs are landed, only 20% of the estimated by-catch of these taxa, and 2.5% of the total invertebrate by-catch. Thus, some 37,000 tons of invertebrates are dumped as 'waste', primarily echinoderms.

In coastal areas further north, FONDS (this report) found bycatches in 4-m beam trawls of 4-20 kg invertebrates (80-97% starfish), 1.5-4 kg undersized flatfish and 0.05-0.15 kg roundfish per kg marketable flatfish. Differences could be due to the different localities, but it is noticeable that the catch rates of flatfish in our area were very low. A better understanding into the reasons for differences in catch composition, could be gained from fieldstudies conducted simultaneously with different trawling in the same area and season. Part of this discarded animals will be predated by birds (DUNNET *et al.*, 1990; CAMPHUYSEN *et al.*, 1993). Little information is available about the effects of discarding fisheries wastes on the seabed. In future research, more information on the impact of discard material on the benthic ecosystem should be obtained.

Survival experiments

Survival rates were checked for three days. Indeed, experiments over 96 hours by VAN BEEK *et al.*, (1989) indicated that most mortality occurs within the first few days. In general they found that the mortality rate was highest in the first 24 or 48 hours and levelled off afterwards. Thus, the experiments give a good estimate of the survival chances of un-marketable flatfish that have been caught, discharged on board, and returned to the sea. Several factors may contribute to the mortality of discards. The fact that survival rates for sole caught in the cod-end covering net are very high indicates that the low survival rates of fish from long hauls are not due to changes in water pressure, temperature, handling on deck or lack of food.

The high % survival of starfish, brittlestars and swimming crabs caught in commercial hauls with a 4m-beam trawl are in agreement with other experiments. FONDS (this report) reports survival rates of 96% for starfish, 91% for brittlestars and 78% for swimming crabs caught in the trawl, 91% for brittlestars and 91-96% for swimming crabs from the cod-end covering net. KAISER & SPENCER (1993b) report survival rates of 99% for starfish, 97% for seamice, 88% for brittlestars, 87% for swimming crabs and 84-100% for hermit crabs. High survival rates were recorded as well for invertebrates from hauls with a 12m-beam trawl. In experiments with animals from the trawl, survival rates of 79-97% for starfish, 60-99% for brittlestars, 60-91% for swimming crabs, 81-100% for hermit crabs, and 77-96% for sea mouse were recorded (BEON 1990, 1991, 1992; FONDS, this report). In experiments with species from a cod-end cover, BEON (1990) and FONDS (this report) recorded after two days survival rates of 97-99% for starfish, 99% for brittlestars and 83-98% for swimming crabs. As sea urchins have brittle tests may be lower than other echinoderms (see KAISER & SPENCER, 1993b). However, no survival experiments were performed with this species.

The recorded survival rates of discarded dab (0-21%) seems to be in agreement with other figures reported by FONDS (this report) for discards of a 4m-beam trawl (11-25%) and in experiments with dab from hauls with a 12m-beam trawl (0-38% after two days) (BEON 1990, 1991; FONDS this report).

The survival of 68% for plaice recorded in the April 1992 experiment is in agreement with the survival rate of 76% reported by KAISER & SPENCER (1993b), but much higher than the rates recorded by Fonds (this report): 17-20%. For plaice caught in a 12m-beam trawl, survival chances of 5-89% after 48 hours, and 3-60% after three days are reported (VAN BEEK *et al.,* 1989; BEON 1990, 1991; FONDS, this report).

The recorded survival rates for sole (15-17%) from the net are in the lower range reported by VAN BEEK *et al.* (1989) in beam trawl hauls of 60 minutes (15.1-33.3%). Whereas survival rates recorded by Fonds (this report) and BEON (1991) are higher, Fonds found survival rates of 33-45% after 2-3 days in experiments with sole from hauls with a 4m-beam trawl. For sole from a 12m-beam trawl catch, BEON (1991) recorded a survival rate of 79% after two days, whereas FONDS (this report) found only 9% still alive after 2 days.

The survival rates of sole from the covering net are in agreement with most rates recorded earlier: 76-100% (BEON 1990, 1991; FONDS, this report).

VAN BEEK *et al.* (1989) found survival in both sole and plaice discards to be negatively correlated with haul duration and total weight of the catch. Because haul duration and total weight of the catch were positively correlated themselves, a distinction between the contribution of both could not be made. As the catch builds up at the rear of the cod-end, the cod-end netting is drawn out into a pear shape, and the meshes in the forward zone become more elongated and closed, reducing fish escapes in this area. Fish has to squeeze themselves through the meshes, resulting in scale removal and damages. The prolonged time in the cod-end also increases the likelihood of superficial damage by contact with crustaceans or rough skinned species (as e.g. starfish, dogfish, gurnards) (MAIN & SANGSTER, 1990). Moreover, on hauling the net, pressure from the weight of the catch can inflict bruises and internal injuries which may lead to delayed mortality (KAISER & SPENCER, 1993b). Considering the high number of damaged sole in the net, a high mortality rate is not strange. The high amount of starfish possibly also explains the high direct mortalities recorded: 30% for sole, 40% for dab and 85% for plaice.

One can conclude that the survival chances of some of the epibenthic species examined in this study are almost 100%. Part of the discarded animals will, however, suffer from mortality related to subsequent predation by e.g. birds. The survival chance of the caught fishes on the other hand are very low. Sole that escaped the fishing net will survive. We expect this to be the same with other, small fish species escaping the cod-end, as e.g. dragonet, hooknose or lesser weever (see Table 8), as reported by FONDS (this report). But, KAISER & SPENCER (1993b) reported survival rates of only 3-32% for dragonet. The reason for the high mortality is not clear, as the dragonets appeared undamaged.

Impact on macrobenthic infauna

If fishing disturbance causes a higher mortality of the benthic infauna, either directly or indirectly by subsequent predation, this should be reflected by a decrease in density. On the other hand, disturbance can bring more species to the surface, and one might find an increase in density as the van Veen grab used only sampled the upper 8-10 cm of the sediment. FONDS (this report) found an increase in the numbers of the bivalves *Arctica* and *Mactra* after trawling, because the animals had been dug out by the beam trawl and, therefore, had more chance to be caught. Moreover, some species might migrate to the upper sediment, attracted by an increased food availability. In our experiments, no decreases were found. Four species showed a significant increase in density: the bivalves *Montacuta ferruginosa* and *Mysella bidentata* (Montacutidae), and the polychaetes *Eteone* sp. (Phyllodocidae) and *Scoloplos armiger* (Orbiniidae).

At least two of the four species are living associated with other invertebrates. *Montacuta ferruginosa* lives associated with spatangoids as e.g. the common sand urchin *Echinocardium cordatum* (GAGE, 1966b). *Mysella bidentata* lives associated with amphiurids, and, in the absence of amphiurid hosts, with other invertebrates (polychaetes, sipunculids, ophiuroids, holothurians, bivalves) (OCKELMANN & MUUS, 1978). No significant increase in numbers was found for any possible 'host species'. Moreover, in the case of the montacutids, the animals are known to burrow almost immediately when placed on the sediment, re-establishing the association with their 'host' (GAGE 1966a, b; OCKELMANN & MUUS, 1978). It is, therefore, unlikely that the higher densities are due to plouging of the surface sediment layers by beam trawling.

Are these species responding to an increase in food items? Mysella bidentata is mostly considered as a filter feeder (e.g. DEKKER, 1989; ELEFTHERIOU & BASFORD, 1989), but also utilizes deposited food by resuspensing it by themselves (OCKELMANN & MUUS, 1978). The animals are known to appear on the sediment now and then, plough for a distance and re-burrow. The polychaete *Scoloplos armiger* is a subsurface deposit-feeder (FAUCHALD & JUMARS, 1979). Phyllodocids are considered hunting carnivores or scavengers. Members of the subfamily Eteoninae also have the possibility of sustaining themselves on ingested sediments (FAUCHALD & JUMARS, 1979). But, did food availability increase? In the area examined natural sediment movement is very high, and it is unlikely that trawling contributed much to the total suspended sediment load. We also don't see how trawling activies could increase the food supply for subsurface deposit feeders. For scavengers, on the other hand, it is very likely that the damaged benthos temporarily increases the available food sources. The same genus was found in larger numbers 6 days after trawling in a study off the isle of Vlieland (BERGMAN & VAN SANTBRINK, this report).

But, the pattern observed may be an artefact as well. There is reasonable doubt about the positioning of the post-fishing samples. Were they really taken within the trawled area? Sonographs made after repeated sampling in zone 2 (March 1993) showed several trails (see FONTEYNE, this report). Thus, the probability that the samples were actually taken within a trawl mark, as was assumed, is very low. Besides, power analysis indicated that the experiment had insufficient power. The probability, even in the case all samples were within a trawl mark, that for many species the null hypothesis was actually false, but not rejected by the test, is very high.

Minimizing the sample variance and, thus increasing power, can be achieved by taking more samples. In that case, one has 1) to ensure that samples are taken in the beam trawl marks, and 2) to reduce the time and costs of sampling and analyses. In recent Canadian research programs, a high resolution colour video system is mounted on the grab (report BEWG, 1993). The grabbing operation can be watched on a monitor, and samples can be taken in habitats of particular interest, as e.g. trawl marks. But in our area, visibility is very low, and the trawl marks would not be seen. In fact, even divers couldn't detect any traces of the gear (FONTEYNE, this report). A solution could be to attach an acoustic transponder to both the fishing gear and the grab, as recently done in impact studies on the Grand bank, Canada (T. Rowell, pers. comm.). The exact position of the sampler and the beam trawl track should be followed on screen, enabling in situ site selection. Ideally the sampler should be capable of being reset without being brought aboard the research boat so that e.g. samples collected outwith the trawl tracks or where the sampler has not closed properly the contents can be released and another sample taken. Moreover, if multiple cores are used, with each unit being relatively small and able to be activated independently, an area equivalent to the one 0.1 m^2 of the van Veen grab commonly used, could be sampled with a similar precision to that of five 0.1 m^2 grab samples. Such a device would allow a rapid and routine corer sampling, reducing the total sediment requiring faunal analysis while increasing the number of unit samples. The need for such a sampling device has been mentioned before (KINGSTON, 1988), but, at present, there is no instrument capable of supporting such a sampling demand.

Another solution for minimizing sample variability may be the use of a different sampling gear, as e.g. the benthosdredge developed by the Netherlands Institute for Sea Research (BERGMAN & VAN SANTBRINK, this report). Here, a larger area is covered in one sample. This equipment can be used as a replacement for the grab sampler in studies concerning densities of larger, lower abundant benthic species.

Repeated trawling

After a passage of a beam trawl, benthic species on the bottom are disturbed, resulting in a larger number of exposed animals. This increase in the quantity of food available attracts several fish species (e.g. FONDS, this report; KAISER & SPENCER, 1993a). Moreover, fishermen take advantage of this by trawling in the track of other vessels, thus capturing fish which moves into the area (FOWLER, 1989). In the November 1992 survey, we noticed an increase in plaice and sole, in March 1993 an increase in dab and bib. In contrast to the November survey, densities of sole first decreased, and remained at a low level untill the last haul.

The main reason for the differences in the density fluctuations of plaice in the two surveys is probably a difference in available food items. Plaice feed mainly on molluscs (FONDS, this report) and polychaetes (BRABER & DE GROOT, 1973), the preference for either polychaetes or molluscs depending on their availability on the feeding ground). Only in zone 5, where molluscs (e.g. *Abra alba, Spisula subtruncata*) and sessile polychaetes (e.g. *Lanice conchilega, Pectinaria koreni*) were very abundant (Table 5), plaice were observed to imigrate onto the tracks.

Dab feed on a great variety of food items (BRABER & DE GROOT, 1973; DEGEL & GISLASON, 1988), and abundances in the catches were higher in both study areas after 5 or 6 hauls.

Bib feed mainly on crustaceans (shrimp, hermit crab) and small fishes (e.g. gobies, dragonet, postlarval flatfish) (BENTHEM, 1983; HAMERLYNCK & HOSTENS, 1993). It is likely that, in the November experiment, they were predating on hermit crabs that left their house and small fish that escaped the cod-end.

But, diurnal activity rhythms of the fishes may, at least partially, account for the differences between the catches as well. Dab eats during day light (ORTEGA-SALAS, 1988), plaice feeds during the morning and evening (JONES, 1952 in KRUUK, 1963), and sole is a noctural animal that starts feeding at dusk (KRUUK, 1963). If the animals are not dug up out of the sand by beam trawling, the higher numbers of sole in the morning (March 1993) and evening (November 1992, March 1993) may be a simple consequence of differences in accessability.

In future research, a more accurately designed experiments should allow to make a distinction between the migration of fish into the trawl tracks after fishing, and the start of the feeding phase of the potential scavengers/predators. Stomach contents of the fish should be analyzed. This should clarify which species are eating what kind of discard material and how much.

As might have been expected, densities of epibenthic invertebrates as starfish and swimming crabs decreased. But the results should be interpreted with care, as fishing was not done exactly on the same spot for each trawl. On the sonographs made in March 1993, at least 5 trails were visible, covering an area of about 70 m width (see FONTEYNE, this report, annex 3, Fig. 11). Thus, not every haul was exactly on the same track, and the catch composition may reflect the spatial distribution of the invertebrate fauna. Differences in catch composition may also be due to differences in bottom contact of the fishing gear. Fonteyne (this report) showed that in the situation where the gear was fished at 6 knots with the current, the trawl heads, bobbin gear and chain mat were in firm contact with the bottom. When fishing was performed at the same speed but against the current, only the centre part of the bobbin line and the chain mat were in contact with the bottom. When reducing the speed to 5 knots, the sole plates touched the bottom very slightly, and the other parts of the ground gear became again in full contact with the sea bed. Therefore, depending on the fishing speed and the direction of the currents, the catch composition might change. Unfortunately, no pressure measurements were made during the March 1993 experiment of repeated trawling. In November 1992 the instrumented trawl head was tested during the five hauls of the repeated trawling experiment, but due to several major problems no measurements of the pressure exerted by the sole plates could be made. But in future research, the use of the instrumented trawl head will allow to obtain more information on changes in catch composition, at least if we can assure that trawling can be repeated on the very same track.

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TABLE. 1

Repeated trawling on a track: length (meters), start and end time (hours), and duration (minutes) of each haul in November 1992 and March 1993 experiments.

	Haul no.	Length	Start	End	Duration
Nov. 1992	1	1426[a]	11.09	11.20	11
	2	4550	11.49	12.22	33
	3	3680	13.57	14.25	28
	4	4250	17.50	18.20	30
	5	3680	18.36	19.05	29
	6	4020	19.30	19.58	28
Mar. 1993	1	2149	7.45	8.02	17
	2	1524	8.36	8.48	12
	3	2117	9.27	9.44	17
	4	2555	10.17	10.36	19
	5	4440	11.06	11.38	32
	6	2094	13.05	13.17	12
	7	2342	14.02	14.18	16
	8	2286	14.50	15.05	15
	9	1984	15.34	15.48	14
	10	2649	16.19	16.37	18

a: estimated from haul duration

TABLE 2

Results of survival experiments in April 1992 (A92) and March 1993 (M93)

Species	N_d	N_a	Numbers dead after day 1	2	3	Total numbers alive	Total; survival %
A92 - commercial net							
starfish	-	62	0	0	0	62	100
portunid crabs	-	33	1	1	1	32	97
sea mouse	-	15	0	0	0	15	100
hermit crab	-	23	0	0	0	23	100
brittlestars	-	59	0	0	0	59	100
dab	-	14	5	8	11	3	21
sole	-	29	16	22	24	5	17
flounder	-	5	3	5	5	0	0
plaice	-	22	0	1	7	15	68
M93 - covering net							
swimming crabs	-	134	13	16	22	112	84
dab	0	1	1	1	1	0	0
brittlestar.	-	80	1	1	2	78	98
sole	0	39	3	5	5	34	87
M93 - commercial net							
swimming crabs	-	66	10	13	13	53	85
flounder	1	2	0	2	2	0	0
dab	7	11	9	11	11	0	0
plaice	11	2	0	0	0	2	100
sole	16	41	27	34	35	6	15

N_d = number of individuals coming dead aboard

N_a = number of individuals used at start of the experiment

In March 1993 the sum of N_a and N_d is the total catch

- : numbers not estimated

TABLE 3

Numbers and weight (g wet weight) of fish and invertebrates caught in areas 1, 2 and 4 (average fishing speed about 4 knots) per hour fishing.

		latin name	numbers	biomass
zone 2	marketable flatfish	*Limanda limanda*	12	2318
		Pleuronectes platessa	3	2065
		Solea solea	7	1741
	discarded flatfish	*Limanda limanda*	14	1269
		Pleuronectes platessa	4	417
		Scophthalmus maximus	<0.5	387
		Scophthalmus rhombus	1	906
		Solea solea	1	72
	roundfish	*Callionymus lyra*	1	40
		Gadus morhua	1	778
		Merlangius merlangus	2	4155
		Trisopterus luscus	1	180
	invertebrates	*Aphrodite aculeata*	<0.5	10
		Asterias rubens	412	14462
		Cancer pagurus	<0.5	62
		Carcinus maenas	1	21
		Echinidae indet.	5	94
		Echinocardium cordatum	2	73
		Liocarcinus holsatus	62	310
		Liocarcinus puber	<0.5	22
		Ophiura sp.	10	31
		Pagurus bernhardus	8	208
zone 4	marketable flatfish	*Limanda limanda*	5	2631
		Pleuronectes platessa	10	11261
		Solea solea	15	6955
	discarded flatfish	*Limanda limanda*	5	1108
		Platichthys flesus	1	909
		Pleuronectes platessa	2	643
		Scophthalmus rhombus	<0.5	-
		Solea solea	8	1182
	roundfish	*Clupea harengus*	<0.5	123
		Gadus morhua	1	3807
		Merlangius merlangus	4	10697
		Trisopterus luscus	1	1612
	invertebrates	*Aphrodite aculeata*	7	878
		Asterias rubens	3729	211636
		Carcinus maenas	2	404
		Echinocardium cordatum	30	1636
		Liocarcinus holsatus	99	2073
		Liocarcinus puber	2	196
		Liocarcinus pusillus	7	-
		Lunatia sp.	2	-
		Mactra corallina	2	-
		Ophiura sp.	58	469
		Pagurus bernhardus	16	955
zone 1	marketable flatfish	*Limanda limanda*	37	3749
		Pleuronectes platessa	20	4402
		Solea solea	14	1335
	discarded flatfish	*Lepidorhombus whiffiagonis*	1	-
		Limanda limanda	51	2286
		Pleuronectes platessa	36	2126
		Solea solea	8	181
	roundfish	*Agonus cataphractus*	1	-
		Callionymus lyra	3	-
		Gadus morhua	1	1289
		Merlangius merlangus	3	1689
		Trigla lucerna	1	39
		Trisopterus minutus	1	-
	invertebrates	*Aphrodite aculeata*	6	97
		Asterias rubens	3869	81333
		Echinocardium cordatum	318	3717
		Liocarcinus holsatus	165	1083
		Ophiura sp.	1037	500
		Pagurus bernhardus	19	273

- : not estimated

Pagurus bernhardus: biomass without shells

TABLE 4

Number of stations (n) at which each species was found, and the maximum (max), minimum (min), and mean number (and standard deviation of the mean) per sample at t_0 in the April 1992 survey (untransformed data).

Species	n	min	max	mean	se
Actinaria indet.	7	0	80	14	5.5
Ampelisca brevicornis	1	0	10	0.5	0.50
Anaitides mucosa	1	0	10	0.5	0.50
Anaitides subulifera	1	0	20	1.0	1.00
Aonides paucibranchiata	1	0	30	1.5	1.5
Aricidea minuta	1	0	10	0.5	0.50
Ascidiae indet.	1	0	40	2.0	2.00
Atylus falcatus	2	0	10	1.0	0.69
Atylus swammerdami	1	0	10	0.5	0.50
Bathyporeia guilliamsonian	1	0	10	0.5	0.50
Bathyporeia pelagica	8	0	30	6.0	1.97
Bathyporeia sarsi	1	0	10	0.5	0.50
Bathyporeia spec.	1	0	10	0.5	0.50
Bodotria pulchella	1	0	10	0.5	0.50
Callianassa tyrrhena	1	0	10	0.5	0.50
Capitella capitata	1	0	10	0.5	0.50
Chaetozone setosa	2	0	30	2.0	1.56
Crangon crangon	1	0	10	0.5	0.50
Diastylis bradyi	2	0	10	1.0	0.69
Echinocardium cordatum	10	0	30	6.5	1.82
Ensis spec.	1	0	10	0.5	0.50
Gammaridea indet.	1	0	10	0.5	0.50
Gastrosaccus spinifer	2	0	10	1.0	0.69
Harmothoe spec.	1	0	10	0.5	0.50
Heteromastus filiformis	1	0	10	0.5	0.50
Lanice conchilega	3	0	10	1.5	0.82
Magelona papillicornis	1	0	10	0.5	0.50
Megaluropus agilis	1	0	10	0.5	0.50
Montacuta ferruginosa	3	0	30	2.5	1.6
Natica spec.	2	0	10	1.0	0.69
Nemertinae indet.	16	0	50	14.5	2.94
Nephtys cirrosa	18	0	140	67	8.3
Nephtys hombergii	5	0	20	3.0	1.28
Nephtys spec.	3	0	20	2.0	1.17
Nereis diversicolor	1	0	10	0.5	0.50
Nereis longissima	2	0	10	1.0	0.69
Notomastus latericeus	1	0	20	1.0	1.00
Oligochaeta indet.	3	0	20	2.5	1.43
Ophelia limacina	5	0	30	3.5	1.67
Ophiura albida	3	0	10	1.5	0.82
Ophiura spec.	1	0	10	0.5	0.50
Owenia fusiformis	1	0	10	0.5	0.50
Pagurus bernhardus	1	0	10	0.5	0.50
Pectinaria koreni	1	0	10	0.5	0.50
Phyllodocinae indet.	3	0	10	1.5	0.82
Poecilochaetus serpens	1	0	10	0.5	0.50
Pontocrates altamarinus	1	0	10	0.5	0.50
Pseudocuma gilsoni	1	0	20	1.0	1.00
Pseudocuma spec.	1	0	20	1.0	1.00
Pygospio elegans	1	0	10	0.5	0.50
Scoloplos armiger	19	0	380	120	21.3
Scolelepis bonnieri	1	0	10	0.5	0.50
Scolelepis foliosa	1	0	10	0.5	0.50
Spiophanes bombyx	20	10	520	95	27.7
Spisula elliptica	3	0	20	2.0	1.17
Spisula spec.	1	0	10	0.5	0.50
Spisula subtruncata	1	0	20	1.0	1.00
Tellina fabula	1	0	10	0.5	0.50
Thia scutellata	6	0	30	4.0	1.69
Urothoe brevicornis	20	10	170	81	12.3
Urothoe poseidonis	4	0	20	3.0	1.47
Urothoe spec.	2	0	10	1.0	0.69
total density				460	126

TABLE 5

Number of stations (n) at which each species was found, and the maximum (max), minimum (min), and mean number (and standard deviation of the mean) per sample at t_0 in the November 1992 survey (untransformed data). The p-value of the t-test and Mann-Whitney U-test (MW) are given (if a test could not be performed, this is indicated by a minus sign).

	before					after					t-test	MW
	n	min	max	mean	se	n	min	max	mean	se	p	p
Abra alba	15	10	900	310	66	15	70	650	310	54	0.711	0.934
Actinaria indet.	4	0	20	3.3	1.59	8	0	60	11	4.2	0.110	0.118
Ampelisca brevicornis	4	0	20	3.3	1.59	1	0	10	0.7	0.67	0.143	0.141
Ampharete acutifrons				0	0	1	0	10	0.7	0.67	-	0.317
Anaitides mucosa	10	0	150	43	14.6	12	0	180	39	11.8	0.526	0.643
Anaitides spec.				0	0	1	0	10	0.7	0.67	-	0.317
Ascidiae indet.	1	0	10	0.7	0.67				0	0	-	0.317
Atylus falcatus	1	0	10	0.7	0.67				0	0	-	0.317
Bivalvia indet.	4	0	40	4.7	2.74				0	0	-	0.035
Bodotria pulchella				0	0	2	0	20	2.0	1.45	-	0.150
Capitella capitata	11	0	240	61	18.6	12	0	690	140	53	0.539	0.530
Capitellidae indet.				0	0	2	0	100	7	6.7	-	0.150
Caprella spec.				0	0	1	0	20	1.3	1.33	-	0.317
Caulleriella spec.	1	0	10	0.7	0.67				0	0	-	0.317
Chaetozone setosa				0	0	2	0	20	2	1.45	-	0.150
Chaetognatha indet.	1	0	10	0.7	0.67				0	0	-	0.317
Cirratulidae indet.	3	0	10	2	1.07	3	0	20	3.3	1.87	0.813	0.858
Crangon crangon	1	0	10	0.7	0.67				0	0	-	0.317
Crepidula fornicata	1	0	10	0.7	0.67				0	0	-	0.317
Decapoda indet.				0	0	1	0	10	0.7	0.67	-	0.317
Diastylis bradyi	3	0	10	2	1.07	2	0	20	2.7	1.82	0.869	0.773
Diastylis lucifera	1	0	10	0.7	0.67				0	0	-	0.317
Echinocardium cordatum				0	0	1	0	20	1.3	1.33	-	0.317
Ensis arcuatus	10	0	40	15	3.6	10	0	50	13	3.4	0.847	0.698
Ensis directus	1	0	10	0.7	0.67				0	0	-	0.317
Ensis spec.	5	0	30	4.7	2.15	6	0	10	4.0	1.31	0.858	0.825
Eteone spec.	3	0	10	2	1.07	8	0	10	5.3	1.33	0.062	0.063
Gammaridea indet.	1	0	10	0.7	0.67				0	0	-	0.317
Glycera spec.	10	0	50	15	3.8	10	0	50	13	3.6	0.480	0.475
Gyptis rosea				0	0	2	0	20	2.0	1.45	-	0.150
Harmothoe impar	1	0	10	0.7	0.67				0	0	-	0.317
Harmothoe lunulata	3	0	20	2.7	1.53	2	0	10	1.3	0.91	0.567	0.586
Harmothoe spec.	1	0	10	0.7	0.67				0	0	-	0.317
Heteromastus filiformis	3	0	10	2	1.07	4	0	40	7	3.7	0.407	0.501
Kefersteinia cirrata				0	0	1	0	10	0.7	0.67	-	0.317
Lanice conchilega	6	0	80	10	5.3	3	0	20	2.7	1.53	0.193	0.208
Magelona papillicornis				0	0	1	0	10	0.7	0.67	-	0.317
Melita obtusata	2	0	20	2	1.45				0	0	-	0.150
Melita palmata				0	0	1	0	10	0.7	0.67	-	0.317
Melita spec.	1	0	10	0.7	0.67	3	0	10	2.0	1.07	0.301	0.291
Microprotopus maculatus	1	0	10	0.7	0.67				0	0	-	0.317
Microphthalmus spec.	2	0	10	1.3	0.91				0	0	-	0.150
Montacuta ferruginosa	4	0	50	5	3.4	9	0	50	15	4.1	0.048	0.050
Mysella bidentata	12	0	150	50	11.5	14	0	520	140	43	0.099	0.100
Mytilus edulis	1	0	10	0.7	0.67				0	0	-	0.317
Natica catena				0	0	2	0	10	1.3	0.91	-	0.150
Nemertinae indet.	12	0	160	33	10.5	14	0	120	38	8.7	0.355	0.489
Nephtys spec.	16	0	150	82	7.8	16	0	320	108	17.7	0.232	0.370
Nereis longissima	12	0	60	18	4.9	12	0	80	25	6.2	0.612	0.456
Nereis spec.	2	0	10	1.3	0.91				0	0	-	0.150

TABLE 5

	before					after					t-test	MW
	n	min	max	mean	se	n	min	max	mean	se	p	p
Notomastus latericeus	15	10	1100	220	76	15	20	760	190	52	0.891	0.901
Oligochaeta indet.	9	0	140	21	9.7	11	0	90	25	7.2	0.425	0.393
Ophiura albida	14	0	580	120	45	14	0	420	114	28.9	0.463	0.429
Ophiura spec.	8	0	200	36	15.8	9	0	180	25	11.9	0.949	0.879
Ophiura texturata				0	0	2	0	20	2.0	1.45	-	0.150
Owenia fusiformis	4	0	20	3.3	1.59	3	0	30	3.3	2.11	0.763	0.715
Pectinaria koreni	9	0	60	16	5.1	12	0	50	15	3.4	0.472	0.621
Pholoe minuta	6	0	40	8	3.3	10	0	30	9.3	2.28	0.273	0.325
Pholoe spec.				0	0	1	0	10	0.7	0.67	-	0.317
Phyllodocinae indet.				0	0	1	0	10	0.7	0.67	-	0.317
Poecilochaetus serpens	1	0	10	0.7	0.67	2	0	10	1.3	0.91	0.559	0.550
Polychaeta indet.	2	0	20	2	1.45				0	0	-	0.150
Porifera indet.				0	0	1	0	10	0.7	0.67	-	0.317
Pygospio elegans	1	0	10	0.7	0.67				0	0	-	0.317
Schistomysis kervellei	1	0	10	0.7	0.67				0	0	-	0.317
Scoloplos armiger	15	40	530	210	38	15	60	590	290	36	0.078	0.110
Scolelepis foliosa				0	0	1	0	10	0.7	0.67	-	0.317
Spiophanes bombyx	14	0	290	58	19.1	14	0	190	71	13.9	0.425	0.173
Spio martinensis				0	0	2	0	10	1.3	0.91	-	0.150
Spionidae indet.	1	0	10	0.7	0.67				0	0	-	0.317
Spisula elliptica	1	0	10	0.7	0.67				0	0	-	0.317
Spisula solida	1	0	10	0.7	0.67				0	0	-	0.317
Spisula subtruncata	13	0	250	77	19.9	12	0	230	73	18.8	0.877	0.868
Sthenelais boa	2	0	30	2.7	2.06	6	0	20	4.7	1.65	0.169	0.140
Tellina fabula				0	0	1	0	10	0.7	0.67	-	0.317
Tharyx marioni	2	0	20	2	1.45	3	0	10	2.0	1.07	0.759	0.701
Venerupis pullastra	1	0	10	0.7	0.67	1	0	10	0.7	0.67	1.000	1.000
Total				1500	420				1700	430		

TABLE 6

Repeated trawling on a transect (November 1992 survey): numbers of fish and invertebrates caught in each tow. The numbers are presented per haul of 1000 meters.

	haul number					
Species	1	2	3	4	5	6
Echinodermata						
Asterias rubens	4067	1378	2196	2050	2774	2794
Echinidae indet.	11	5	0	3	7	10
Echinocardium cordatum	0	4	1	0	1	2
Ophiura spec.	231	106	162	182	203	173
Arthropoda	0	0	0	0	0	0
Liocarcinus holsatus	73	33	33	45	40	39
Liocarcinus puber	0	<0.5	3	0	7	11
Pagurus bernhardus	1	4	1	1	1	21
Cancer pagurus	0	<0.5	0	0	0	0
Mollusca	0	0	0	0	0	0
Ensis spec.	1	1	4	0	1	3
Mactra spec.	0	0	0	0	0	0
Polychaeta	0	0	0	0	0	0
Aphrodite aculeata	3	2	1	1	1	2
Pisces	0	0	0	0	0	0
Platichthys flesus	7	7	13	8	10	4
Pleuronectes platessa	0	<0.5	1	1	1	2
Limanda limanda	1	<0.5	0	0	2	<0.5
Solea solea	1	<0.5	<0.5	<0.5	<0.5	2
Merlangius merlangus	0	1	0	0	1	0
Clupea harengus	0	0	0	0	0	<0.5
Trisopterus luscus	0	0	0	0	1	0
Agonus cataphractus	6	1	3	6	2	5
Gadus morhua	0	<0.5	<0.5	0	<0.5	<0.5
Pomatoschistus spec.	1	<0.5	1	1	3	0
Liparis liparis	0	0	0	0	<0.5	0
Callionymus lyra	1	0	0	0	0	0

TABLE 7

Repeated trawling on a transect (March 1993 survey): numbers of fish and invertebrates caught in each tow. The numbers are presented per haul of 1000 meters.

	haul number								
Species	1	2	3	4	6	7	8	9	10
Echinodermata									
Asterias rubens	195	210	82	85	64	72	70	53	72
Echinidae indet.	2	1	<0.5	1	<0.5	0	0	1	0
Echinocardium cordatum	8	15	2	5	7	3	5	1	8
Ophiura sp.	9	15	11	9	2	10	14	14	8
Arthropoda									
Corystes cassivelaunus	0	0	0	0	0	0	0	0	0
Carcinus maenas	0	0	<0.5	0	0	0	0	0	0
Liocarcinus depurator	4	3	0	0	0	0	1	2	1
Liocarcinus holsatus	40	52	28	21	15	14	14	13	23
Liocarcinus puber	0	1	0	1	0	<0.5	0	0	0
Pagurus bernhardus	4	8	4	4	1	3	4	2	2
Mollusca									
Buccinum undatum	<0.5	0	1	0	0	0	0	0	0
Lunatia sp.	0	0	0	0	0	<0.5	<0.5	0	1
Mactra corallina	0	0	0	0	0	0	<0.5	0	0
Polychaeta									
Aphrodite aculeata	0	0	0	0	<0.5	0	0	0	<0.5
Pisces									
Agonus cataphractus	0	0	<0.5	0	0	0	0	0	0
Ciliata mustela	0	1	0	<0.5	0	0	0	0	0
Dasyatis pastinaca	0	0	<0.5	0	0	0	0	0	0
Gadus morhua	<0.5	0	0	0	0	0	0	0	0
Limanda limanda	<0.5	0	0	0	3	4	3	7	2
Merlangius merlangus	1	1	<0.5	1	1	0	0	2	0
Pleuronectes flesus	0	0	0	0	0	0	0	0	<0.5
Pleuronectes platessa	1	0	0	0	1	1	0	0	1
Scophthalmus maximus	0	1	0	0	0	0	0	0	0
Solea solea	10	15	5	2	1	2	3	2	6
Trachinus vipera	0	0	0	0	0	<0.5	0	0	0
Trisopterus luscus	0	4	<0.5	2	8	4	3	18	11

TABLE 8

Numbers of fish and invertebrates caught in a fine-mesh covering net (April 1992, zone 4, haul duration 66 minutes) (numbers in the cod-end are given in Table 3).

Phylum	Species	Numbers
Arthropoda	*Carcinus maenas*	14
	Liocarcinus puber	8
	Liocarcinus holsatus	1554
	Pagurus bernhardus	46
Echinodermata	*Asterias rubens*	2504
	Echinocardium cordatum	78
	Ophiura sp.	56
Mollusca	*Ensis* sp.	4
	Lunatia sp.	2
Polychaeta	*Aphrodite aculeata*	44
Pisces	*Agonus cataphractus*	34
	Callionymus lyra	34
	Lepidorhombus whiffiagonis	10
	Limanda limanda	26
	Merlangius merlangus	44
	Pleuronectes platessa	8
	Solea solea	486
	Trachinus vipera	2
	Trisopterus luscus	174

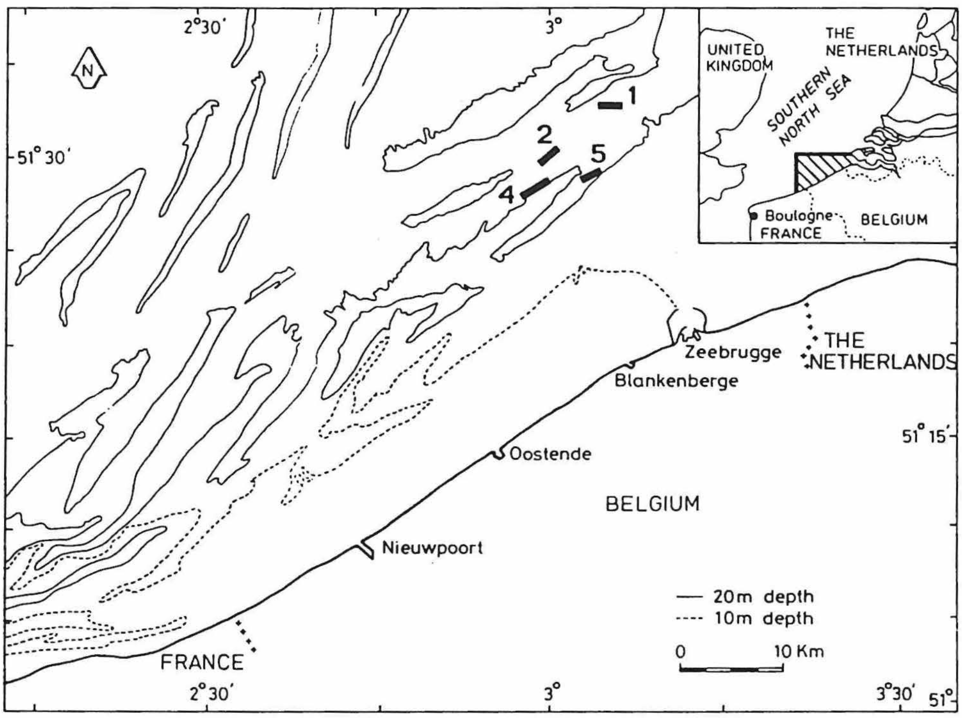


Figure 1. Area of investigation.

Figure 2. Experimental set up to estimate the survival of discards (after VAN BEEK *et al.*, 1989).

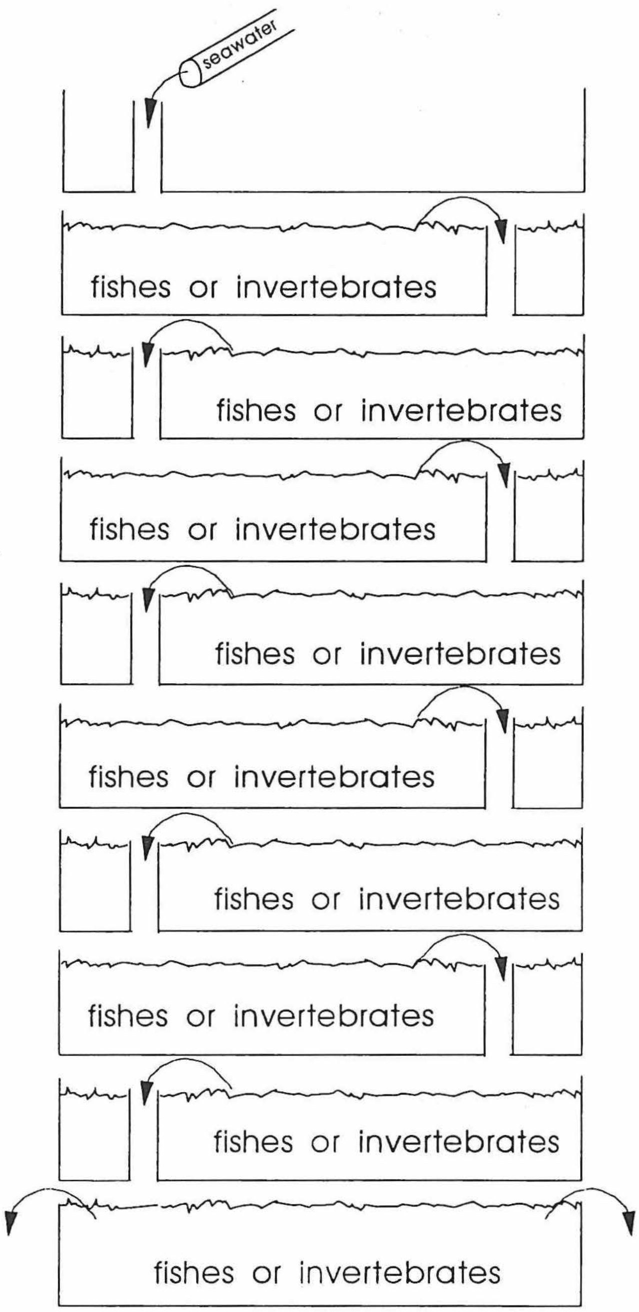
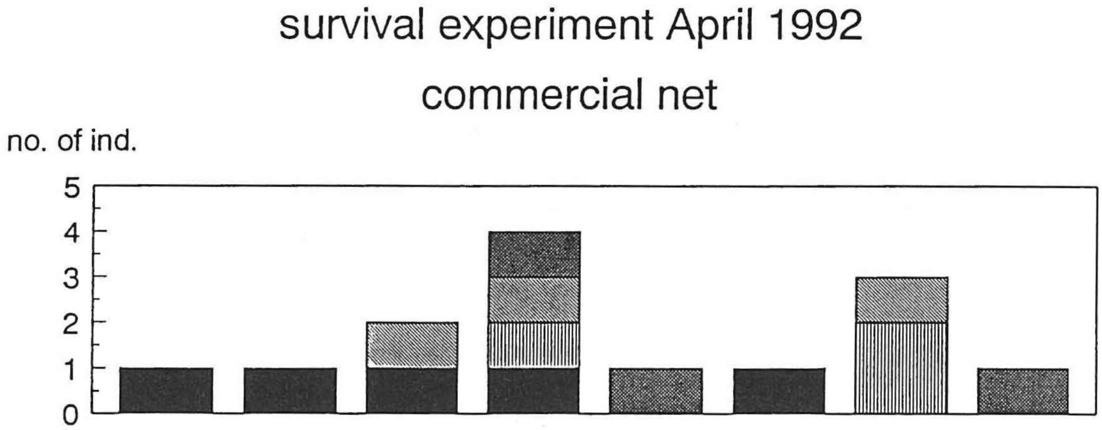
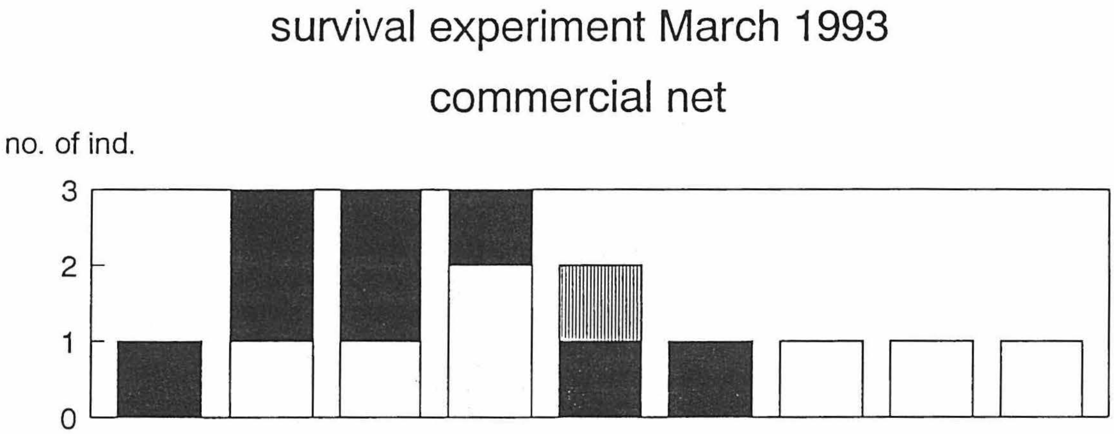


Figure 3. Length-frequency distribution of dab used in the survival experiments in April 1992 and March 1993. The number of animals brought dead aboard (March 1993 experiment) and dead at day 1, 2 and 3 of the experiment are indicated.

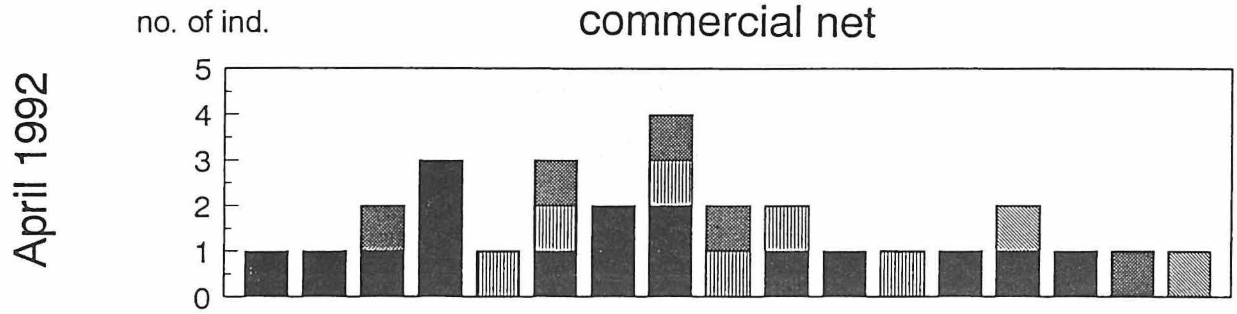


Length (cm)	19	21	22	23	24	26	28	29
dead day 1	1	1	1	1	0	1	0	0
dead day 2	0	0	0	1	0	0	2	0
dead day 3	0	0	1	1	0	0	1	0
survived	0	0	0	1	1	0	0	1

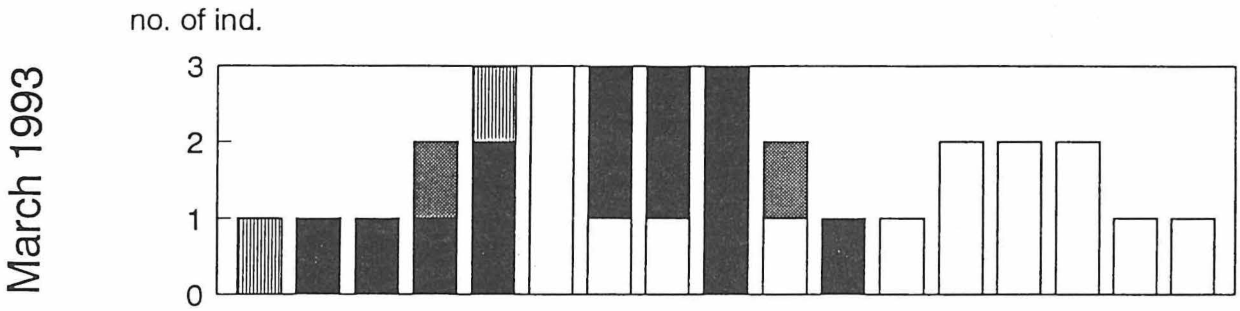


Length (cm)	18	19	20	21	22	24	25	26	28
dead aboard	0	1	1	2	0	0	1	1	1
dead day 1	1	2	2	2	1	1	0	0	0
dead day 2	0	1	0	0	1	0	0	0	0
dead day 3	0	0	0	0	0	0	0	0	0
survived	0	0	0	0	0	0	0	0	0

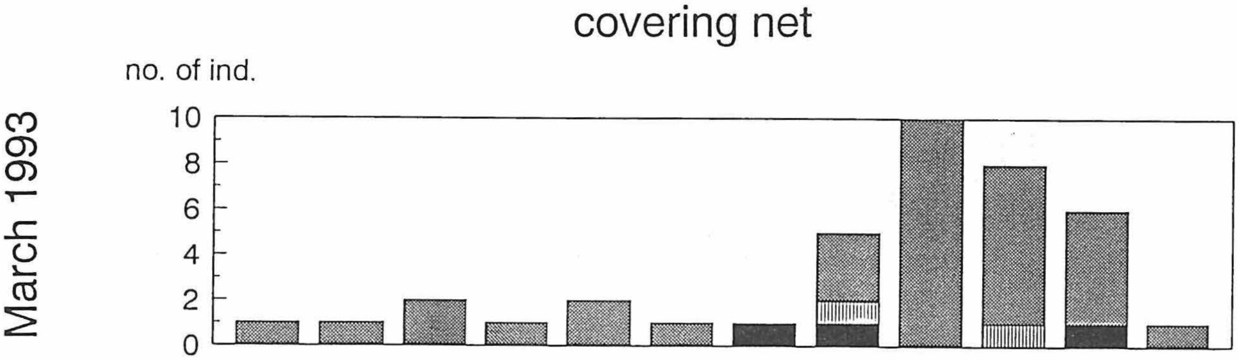
Figure 3. Length-frequency distribution of sole used in the survival experiments in April 1992 and March 1993. The number of animals brought dead aboard (March 1993 experiment) and dead at day 1, 2 and 3 of the experiment are indicated.



Length (cm)	9	10	11	12	14	19	22	23	24	25	26	28	29	31	32	34	38
dead day 1	1	1	1	3	0	1	2	2	0	1	1	0	1	1	1	0	0
dead day 2	0	0	0	0	1	1	0	1	1	1	0	1	0	0	0	0	0
dead day 3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
survived	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1	0

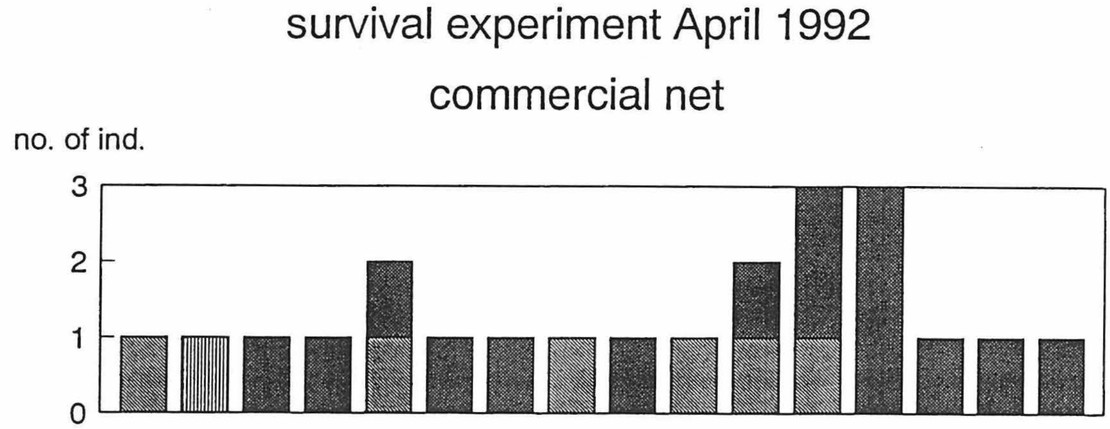


Length (cm)	9	13	14	17	18	19	20	21	22	23	24	27	30	31	34	36	42
dead aboard	0	0	0	0	0	4	1	1	0	1	0	1	2	2	2	1	1
dead day 1	0	1	1	1	2	6	5	8	4	0	1	0	0	0	0	0	0
dead day 2	1	0	0	0	1	1	3	1	0	0	0	0	0	0	0	0	0
dead day 3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
survived	0	0	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0

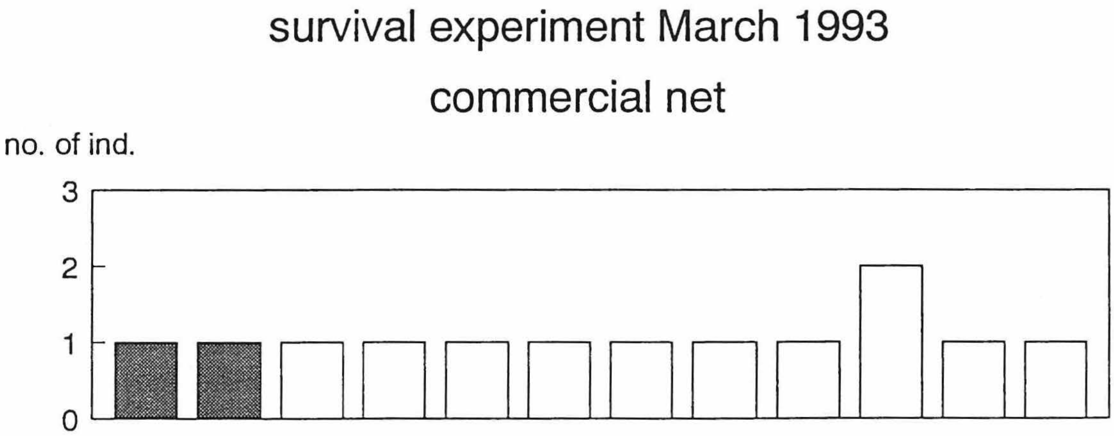


Length (cm)	9	12	13	14	15	17	18	19	20	21	22	30
dead aboard	0	0	0	0	0	0	0	0	0	0	0	0
dead day 1	0	0	0	0	0	0	1	1	0	0	1	0
dead day 2	0	0	0	0	0	0	0	1	0	1	0	0
dead day 3	0	0	0	0	0	0	0	0	0	0	0	0
survived	1	1	2	1	2	1	0	3	10	7	5	1

Figure 3. Length-frequency distribution of plaice used in the survival experiments in April 1992 and March 1993. The number of animals brought dead aboard (March 1993 experiment) and dead at day 1, 2 and 3 of the experiment are indicated.

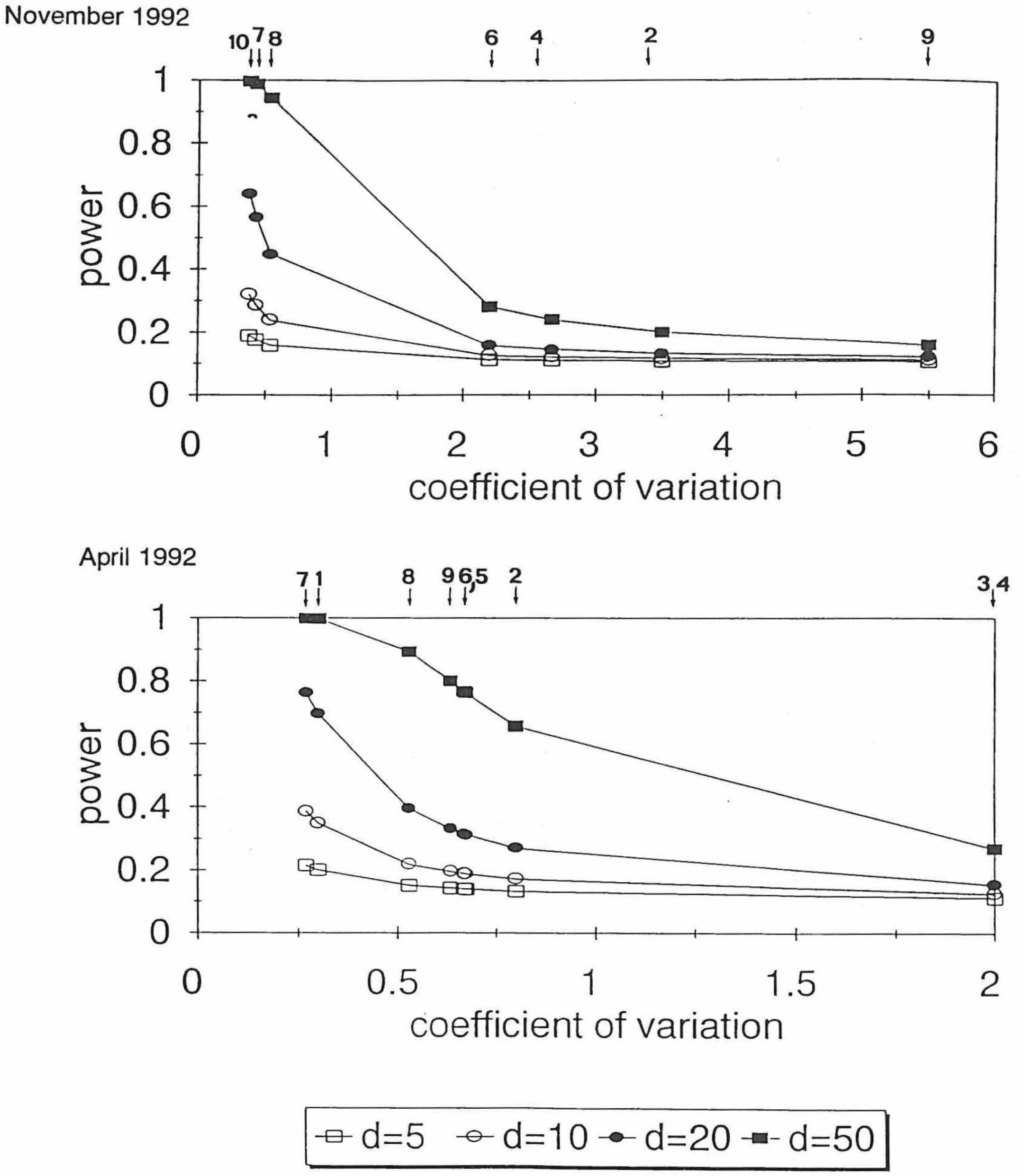


Length (cm)	17	19	23	24	28	29	30	31	33	34	35	36	37	39	41	47
dead day 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dead day 2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dead day 3	1	0	0	0	1	0	0	1	0	1	1	1	0	0	0	0
survived	0	0	1	1	1	1	1	0	1	0	1	2	3	1	1	1



Length (cm)	23	27	28	30	31	33	34	35	37	39	41	43
dead aboard	0	0	1	1	1	1	1	1	1	2	1	1
dead day 1	0	0	0	0	0	0	0	0	0	0	0	0
dead day 2	0	0	0	0	0	0	0	0	0	0	0	0
dead day 3	0	0	0	0	0	0	0	0	0	0	0	0
survived	1	1	0	0	0	0	0	0	0	0	0	0

Figure 4. Power curves for a two-side t-test for different species (= different coefficients of variation (s/μ)) with α=0.20. Species: *1. Abra alba - 2. Capitella capitata - 3. Eteone* spec. *- 4. Montacuta ferruginosa - 5. Mysella bidentata - 6. Ophiura albida -7. Scoloplos armiger - 8. Spiophanes bombyx - 9. Spisula subtruncata - 10. Urothoe brevicornis.*



NAME

Phylum	Latijnse naam	Nederlandse naam	Engelse naam
Pisces	Limanda limanda	schar	dab
Pisces	Pleuronectes platessa	schol	plaice
Pisces	Pleuronectes flesus	bot	flounder
Pisces	Microstomus kitt	tongschar	lemon sole
Pisces	Hippoglossus hippoglossus	heilbot	halibut
Pisces	Hippoglossoides platessoides	lange schar	long rough dab
Pisces	Solea solea	tong	sole
Pisces	Solea lascaris	franse tong	sand sole
Pisces	Buglossidium luteum	dwergtong	solenette
Pisces	Scophthalmus rhombus	griet	brill
Pisces	Scophthalmus maximus	tarbot	turbot
Pisces	Lepidorhombus whiffiagonis	scharretong	megrim
Pisces	Zeugopterus punctatus	gevlekte griet	topknot
Pisces	Arnoglossus laterna	schurftvis	scaldfish
Pisces	Callionymus lyra	pitvis	dragonet
Pisces	Trachinus draco	grote pieterman	greater weever
Pisces	Trachinus vipera	kleine pieterman	lesser weever
Pisces	Agonus cataphractus	harnasmannetje	hooknose
Pisces	Trigla lucerna	rode poon	tub gurnard
Pisces	Aspitrigla cuculus	engelse poon	red gurnard
Pisces	Eutrigla gurnardus	grauwe poon	grey gurnard
Pisces	Trigloporus lastovitza	gestreepte poon	streaked gurnard
Pisces	Gadus morhua	kabeljauw	cod
Pisces	Merlangius merlangus	wijting	whiting
Pisces	Micromesistius poutassou	blauwe wijting	blue whiting
Pisces	Melanogrammus aeglefinus	schelvis	haddock
Pisces	Pollachius pollachius	pollak, witte koolvis	pollack
Pisces	Pollachius virens	(zwarte) koolvis	saithe
Pisces	Trisopterus luscus	steenbolk	bib
Pisces	Trisopterus minutus	dwergbolk	poor cod
Pisces	Molva molva	leng	ling
Pisces	Raniceps raninus	vorskwab	tadpoole-fish
Pisces	Ciliata mustela	(vijfdradige) meun	five-bearded rockling
Pisces	Ciliata septentrionalis	noorse meun	northern rockling
Pisces	Gaidropsarus vulgaris	driedradige meun	three-bearded rockling
Pisces	Enchelyopus cimbrius	vierdradige meun	four-bearded rockling
Pisces	Clupea harengus	haring	herring
Pisces	Sprattus sprattus	sprot	sprat
Pisces	Sardina pilchardus	sardien, pelser	pilchard
Pisces	Alosa alosa	elft	allis shad
Pisces	Alosa fallax	fint	twaite shad

Phylum	Latijnse naam	Nederlandse naam	Engelse naam
Pisces	Engraulis encrasicolus	ansjovis	anchovy
Pisces	Salmo salar	zalm	salmon
Pisces	Salmo trutta trutta	zeeforel	sea trout
Pisces	Osmerus eperlanus	spierinhg	smelt
Pisces	Maurolicus muelleri	lichtend sprotje	pearl-side
Pisces	Lophius piscatorius	zeeduivel	angler
Pisces	Anguilla anguilla	paling, aal	eel
Pisces	Conger conger	zeepaling	conger
Arthropoda	Liocarcinus puber	fluwelen zwemkrab	velvet fiddler
Arthropoda	Liocarcinus depurator	blauwpootzwemkrab	swimming crab
Arthropoda	Callinectes sapidus	blauwe zwemkrab	
Arthropoda	Pagurus bernhardus	gewone heremietkreeft	hermit crab
Arthropoda	Cancer pagurus	noordzeekrab	edible crab
Arthropoda	Carcinus maenas	strandkrab	shore crab
Arthropoda	Liocarcinus holsatus	gewone zwemkrab	
Arthropoda	Liocarcinus pusillus	kleine zwemkrab	
Mollusca	Ensis sp.	mesheft	razor-shell
Mollusca	Lunatia sp.	tepelhoorn	necklace-shell
Mollusca	Mactra corallina	grote strandschelp	rayed trough-shell
Annelida	Aphrodite aculeata	fluwelen zeemuis	
Echinodermata	Asterias rubens	gewone zeester	starfish
Echinodermata	Echinocardium cordatum	zeeklit	heart urchin
Echinodermata	Echinidae indet.	zeeëgel	
Echinodermata	Ophiura sp.	slangster	
Mollusca	Buccinum undatum	wulk	
Arthropoda	Corystes cassivelaunus	helmkrab	
Pisces	Dasyatis pastinaca	pijlstaartrog	

ESTIMATES OF SCAVENGING BEHAVIOUR IN RECENTLY TRAWLED AREAS

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ABSTRACT

The diets of gurnards, dogfish and whiting were examinied to determine whether they migrated into recently trawled areas to feed on animals that may be damaged or dislodged by the action of a 4-m beam trawl. All fish increased their intake of prey after fishing. Both gurnards and whiting increased the proportion of the amphipod, *Ampelisca spinipes*, in their diets. Beam trawling damaged the burrowing heart urchin, *Spatangus purpureus*, which was consequently fed on by whiting. Some invertebrate scavengers, such as the prawn, *Palaemon serratus*, only occurred in diets after the area had been fished, suggesting that these animals were also scavenging over the trawl tracks. Observations of the seabed using a side-scan sonar revealed a greater concentration of fish marks around the trawl tracks than in adjacent unfished areas. Our results indicate that fish rapidly migrate into beam trawled areas to feed on benthic animals which have been either damaged or disturbed by fishing or on scavenging invertebrates. In areas where certain benthic communities occur, beam trawling intensity may be such that it creates a significant food resource for opportunistic fish species. This is possible mechanism whereby long-term community structure could be altered by fishing activity.

INTRODUCTION

Recent research indicates that a variety of fishing gears such as beam trawls (BERGMAN & HUP, 1992), otter trawls (VAN DOLAH *et al.*, 1987, 1991; RUMOHR & KROST, 1991) and dredges (VAN DER VEER *et al.*, 1985; ELEFTHERIOU & ROBERTSON, 1992), cause increased local mortalities of some epi- and infaunal benthic organisms. Consequently, this may lead to increased opportunistic feeding by invertebrate (WASSENBERG & HILL, 1984) and fish predators. Repeated fishing in areas such as the North Sea (RIJNSDORP *et al.*, 1991) has been cited as one possible cause of observed long-term changes in benthic community structure (PEARSON *et al.*, 1985; BERGHAHN, 1990; LINDEBOOM, 1990; HALL *et al.*, 1993). In the Irish Sea, otter and beam trawling are the main fishing methods used to catch demersal fish (MCCANDLESS, 1992). Although otter trawling is more common than beam trawling (MCCANDLESS, 1992), because of their design and method of deployment, beam trawls have greater potential to affect the seabed and benthic communities. Typically, they are fished with chain matrices (ARKLEY, 1991) which are designed to disturb flatfish, in particular sole, *Solea solea,* that remain buried in the sediment during the day. Early studies demonstrated that tickler chains penetrate down to a total depth of 3 cm in firm sand (BRIDGER, 1970, 1972) and up to 8 cm in softer ground (BEON, 1991). An unavoidable side-effect of this digging action is that the gear removes and/or damages fragile infauna, for example burrowing heart urchins, *Echinocardium cordatum* and the quahog, *Arctica islandica* (BERGMAN & HUP, 1992), and also increases the epifaunal by-catch (CREUTZBERG *et al.,* 1987; KAISER *et al.*, in press). The consequences of these short-term effects on changes in faunal abundance and mortality have been the main subject of recent studies (BEON, 1991; BERGMAN & HUP, 1992).

While it is important to understand the direct effects of fishing on marine communities, the indirect effects are equally pertinent and may be most obviously manifested in populations of predators higher-up the food chain which exploit prey that are killed, damaged or discarded by fishermen (WASSENBERG & HILL, 1987; FURNESS, & HISLOP, 1981; FURNESS, 1982). For example, the observed population explosion of some species of marine birds has been linked to the increase of discards from fisheries in the North Sea (FURNESS, 1982). To date, few studies have examined the use of discards by non avian scavengers (but see WASSENBERG & HILL, 1987), and most of the available data is either circumstantial or unpublished, for example dabs, *Limanda limanda,* have been filmed feeding on trawl tracks in the North Sea several hours after fishing occurred (G. RAUCK, samples on video; M. FONDS, pers. comm.) and it is common practice for fishermen to re-fish recently trawled areas to exploit these aggregations of fish.

As part of a wider programme to examine some aspects of the short and long-term effects of beam trawling on a benthic community in the Irish Sea, we have investigated the diets of lesser-spotted dogfish, *Scyliorhinus canicula,* gurnards, *Aspatrigula cuculus* and *Eutrigla gurnardus,* and whiting, *Merlangius merlangus.* These species were chosen because they occur both in the North and Irish Seas. However, there is some evidence that dogfish, and other elasmobranchs, are becoming less abundant in the North Sea as a result of fishing pressure. Conversely, gurnards and whiting remain abundant in the North Sea and consequently may be as important as other North Sea scavenging species, such as dabs. The aim of this study was to determine whether these fish alter their normal feeding behaviour by moving into recently trawled areas to feed on either animals killed or dug up by the passage of a beam trawl or on other immigrating scavengers. A site in the Irish Sea was selected because ot is representative of an area which is fished relatively infrequent (McCANDLESS, 1992), characterized by the presence of an epifaunal filter-feeding community (dominated by soft corals and hydroids). This area presents opportunities for long-term research on the ecosystem effects of fishing unavailable in the North Sea through intense fishing pressure.

Under normal conditions, predators and scavengers tend to be highly selective with regard to the size and diversity of prey eaten (eg. WERNER, 1974; HUGHES, 1993). Prey size is closely related to mouth width (eg. KISLALIOGLU & GIBSON, 1976; KAISER *et al.*, 1992), and furthermore, fish avoid prey that have a prey width: mouth gape ratio (pw:gw) of >0.6. Prey at or below this ratio are easily ingested, which tends to maximise the net rate of food intake (eg. KAISER *et al.,* 1992). Feeding behaviour which maximises the net rate of energy intake is termed optimal foraging (CHARNOV, 1976). The criteria defining an optimal prey item depends on a complex interaction between a fish's physiological state and changes in its environment (HUGHES, 1993). Optimal prey can become superceded by smaller, non-profitable prey, if the abundance of the latter is such that the net rate of energy intake attains a level that is higher than would otherwise be achieved (HUGHES & CROY, 1993). Should this occur, it may be manifested an increase in the frequency occurrance of a less preferred species in the diet. This might be interpreted as opportunistic feeding.

GENERAL METHODS

Beam trawling was carried out by the RV Corystes off the east coast of Anglesey, North Wales in August 1992 and April 1993 (Fig. 1). The experimental protocol differed slightly on each occasion as other experiments were incorporated into the design; hence, a description of the differing elements is given below. (Unfortunately it was not possible to fish the same track on both occasions as in April 1993 an oil tanker was anchored over the trawl track worked in August 1992).

In each year, the same plotted track was fished six times as accurately as possible using a 4-m commercial pattern beam trawl fitted with chain matrix (Fig. 2) and a net fitted with an 80 mm diamond mesh codend. The bottom depth varied between 26 to 32 m. Towing speed was approximately 4 knots (ca. 2.0 ms^{-1}).

The ship's position was given by a Sercel NR53 Differential Global Positioning System (DGPS) navigation system, with an average accuracy of ±2.5 m, and relayed to the navigation plotter. The Ship's position was also recorded every 1 second using Microplot software which displayed a plot of the ship's tracks. The trawl was fished along the line of the current to minimise the offset of the trawl track from the ship's plotted track.

The first three tows of each series had two functions; a) to disturb the seabed and create effects similar to those caused by a commercial fishing boat and b) to collect fish which had not been feeding on trawled areas. A further three tows were made along the same plotted track after an interval of 3 h, to collect fish which had migrated into the previously trawled area. The duration of the consecutive tows differed on the two dates. In August 1992 the duration for tows 1-6 was 30, 20, 10, 10, 20 and 30 min respectively, whereas in 1993 all tows were 30 min. All tows were made such that the mid point of each tow had the same coordinates. This protocol was used for other experimental reasons not relevant to this paper. All fishing was carried out between 09.00 h and 18.00 h in daylight (April dawn, 0517, dusk, 1909; August dawn 0526, dusk, 1854 GMT).

Preliminary sampling revealed that dogfish, *Scyliorhinus canicula,* two species of gurnard, *Eutrigula gurnardus* and *Aspatrigula cuculus,* and whiting, *Merlangius merlangus,* were common in the catches. Thus they were chosen as indicator species. 30 specimens each of dogfish and gurnards (August 1992), and 40 whiting (April 1993), were collected from hauls one to three, and from hauls four to six. The time interval between consecutive hauls was as short as possible (ca. 20 min) to reduce the possibility of collecting fish that might have been feeding on the previously fished track.

SIDE-SCAN SONAR OBSERVATIONS

In April 1993, after tows 3 and 6, the trawled area was surveyed with an EG & G 260 dual frequency side-scan sonar system, linked to a side-scan sonar fish, model 262, to check the spread of the trawled area. Records of fish shoals on the sonar trace were enumerated at intervals of 2 min, noting whether they occurred over the fished or unfished areas. During this interval of time an area of ca. 252x200 m of the seabed was surveyed with the side-scan sonar towed at 2.1 ms^{-1}, scanning a track of 100 m to starboard and port. The perpendicular distance of each fish mark from the centre of the trawl tracks was measured to determine the distribution of fish marks in the poximity of the tracks (± 1 mm, ie. ≅ 1 m of seabed).

STOMACH CONTENTS ANALYSIS

To investigate whether the fish were feeding in the trawled areas, each of the fish collected had its entire stomach preserved in 4% buffered formalin for later identification of contents to the lowest possible taxonomic level. Stomach fullness was scored using a scale of 0 (empty) to 10 (full). The contents of each stomach were weighed wet (± 0.01 g) after blotting on absorbant paper.

MORPHOMETRICS

Total length (to the cm below) and maximum mouth gape (± 0.1 cm) (across the articulation of the jaws of dogfish and between the upper and lower jaws of gurnards and whiting) of each fish, were measured using a measuring board and vernier callipers respectively. The widest cross-sectional dimension of each prey item collected from stomach contents was measured using an eyepiece graticule and binocular microscope.

SURVEY OF THE BENTHIC COMMUNITY

A survey of the benthic community around the area of the trawl tracks was carried out to determine range of prey and hence the selectivity of the fish. Five 0.1 m^2 samples of the infauna were taken from an area within ± 500 m of the trawl tracks using a Day grab. Epifaunal abundance was determined using a 4-m commercial beam trawl towed three times for 30 min along a track adjacent to, and parallel (± 500 m) with the trawl tracks. The trawl was rigged as above, but with the codend fitted with a 1 cm mesh liner. Macrobenthos from the trawl catches was counted and identified to the lowest possible taxonomic level on board ship. The Day grab samples were sieved over 1 mm mesh and preserved in 4% formalin, buffered with sodium borate, for later identification. The numerical data from the trawl catches and grab samples were standardised per 1000 m^2. Encrusting animals such as hydroids, sponges and bryozoans, were excluded from the analyses because of the difficulty quantifying them. A comparison of the occurrance of food in the stomach contents with the food available was calculated using Strauss' index (L_i), when $L_i = r_i - p_i$, where r_i is the relative proportion of the item i in the gut and p_i is the relative proportion of the same item in the environment. The index ranges from -1 (strong negative selection) to +1 (strong positive selection). The *R x C* independence *G*-test (SOKAL & ROHLF, 1981) was used to verify the statistical significance of the analysis.

RESULTS

SIDE-SCAN SONAR OBSERVATIONS

In April 1993 a total length of 4,300 m of the seabed was surveyed with the side-scan sonar after tow 3 and 4550 m after tow 6. Immediately after tow 3 (15.24 h to 16.00 h), 11 fish marks were observed over the fished area but only one was observed on the unfished area (Table I) (t-test, t=2.2, df.=19, P<0.04). However, immediately after tow 6 (18.26 h to 19.00 h) the number of marks observed over both the fished and unfished areas had increased by factors of 30 and 11 respectively (Table I). Again there were significantly more fish marks (Fig. 3) over the fished as opposed to the unfished area (t-test, t=4.05, df.=22, P<0.001). Fish marks were most concentrated closer to the trawl tracks, 80 occurred within 50 m of the tracks, 15 occurred from between 50-100 m and 16 from within 100-150 m of the trawl tracks (Fig. 3, x^2=36.1, df.=2, P<0.001).

COMPARISON OF STOMACH CONTENTS WITH AVAILABLE FOOD

The grab and beam trawl samples contained 80 different taxa (34 infauna and 46 epifauna). The 10 most abundant species were infaunal polychaetes and crustaceans which accounted for 72% of the animals collected (numbers/1000 m^2) (Table II). Of these ten dominant animals, only the amphipod, *Ampelisca spinipes,* was eaten in large numbers both before and after beam trawling by gurnards, dogfish and whiting (Fig. 3). The other prey commonly found in the fishes' stomach contents tended to be the less abundant epifauna (Table II).

Nine different prey types were found in the stomachs of gurnards, 8 of which were epifaunal crustaceans and fish (Table II). The proportional occurrence of *Liocarcinus depurator* (swimming crabs), Crangon spp. (shrimps), *Macropodia* spp. (spider crab) and *Callionymus* spp. (dragonet) in gurnard stomachs was greater than in the community (G-test, x^2=276.2, P<0.0001, Table III), which suggests that gurnards feed preferentially on these species. However *A. spinipes* (amphipod) was eaten in similar proportion to its occurrence in the community (Table III). Dogfish ate 12 different prey which were a combination of 8 epi- and 4 infauna, including polychaetes, crustaceans, molluscs, echinoderms and fish (Table II). Dogfish were positively selective for *L. depurator* (L_i=0.04), *Buccinum undatum* (common whelk) (L_i=0.06), *Callionymus* spp. (L_i=0.1), *Eupagurus bernhardus* (common hermit crab) (L_i=0.18) and *A. spinipes* (L_i=0.16) (G-test, x^2=40.1, P<0.001, Table III). The burrowing decapod, *Upogebia deltaura,* occurred frequently in the stomach contents, but it was never collected in our samples, hence determination of selectivity for this species was not possible. It is interesting to note that whereas dogfish ate *E. bernhardus*, the more abundant *E. prideauxi* (hermit crab) was absent from the stomachs examined. Whiting most frequently fed on *Crangon* spp. and *A. spinipes,* for which they were highly selective) (L_i=0.15 and 0.23 respectively) (G-test, x^2=46.1, P<0.001, Table III).

DIETARY CHANGES AFTER BEAM TRAWLING

The total number of prey items eaten by fishes significantly increased after beam trawling (Fig. 3) (gurnards, x^2=19.2, P<0.001; dogfish, x^2=9.07, P<0.005; whiting, x^2=5.7, P<0.025). Consequently, gurnards' stomach contents weight and fullness increased significantly. However, no similar increase was observed in dogfish despite the increase in the number of prey eaten (Table IV). Gurnards significantly increased their intake of *L. depurator, Crangon* spp. and *A. spinipes*. Despite the overall increase in the number of prey eaten by dogfish, no significant difference could be detected for individual prey species. However, *P. serratus* (prawn) and *Crangon* spp. only occurred in dogfish stomachs after the area had been trawled (Fig. 4). After the area had been trawled, whiting significantly increased their intake of *A. spinipes* and their stomachs contained the gonads of the burrowing heart urchin, *Spatangus purpureus*, which were not found in the stomachs of fish collected from the first series of 3 tows.

MORPHOMETRICS

The ratio of total fish length: mouth gape width was not significantly different for either species of gurnard (mean±SE *A. cuculus*, 14.4±0.2, *E. gurnardus*, 14.4±0.3, ANOVA, $F_{1,58}$=0.02, P>0.90), nor was there a significant difference between the relationship of prey width on gape width (ANCOVA, $F_{1,125}$=2.45, P>0.10), hence the data for both species of gurnard were pooled. Within species, the mean lengths (cm) of the dogfish, gurnards and whiting collected both before and after fishing were not significantly different (Table V). The mean size of prey eaten by either gurnards or dogfish did not vary significantly either before or after fishing, however, whiting ate smaller prey after the area had been trawled (Table VI). The calculated prey width: gape width (pw: gw) ratio (estimated from the mean prey width eaten and the mean gape width) for gurnards (0.23), dogfish (0.19) and whiting (0.24) was much lower than 0.6. After fishing, this ratio decreased for both gurnards (0.16) and whiting (0.16), but not dogfish for which it remained similar (0.17).

DISCUSSION

DIET COMPOSITION PRIOR TO FISHING

Dogfish, *Scyliorhinus canicula*, ate a broad range of prey types and sizes, which is similar to other dogfish species, such as *Squalus acanthias*, that maintain a varied diet throughout their life history (HANCHET, 1991). Initially, *S. acanthias* feed mainly on crustaceans and as they increase in size include more fish in their diet (JONES & GEEN, 1977; TANASICHUK *et al.*, 1991). Our estimates of Strauss' index (L_i) suggest that dogfish fed selectively on both large prey, such as *B. undatum*, *L. depurator* and *E. bernhardus*, and small prey such as *A. spinipes* (Table III). The mean width of prey consumed by dogfish was much smaller than their maximum gape width (prey width: gape width=0.19). Despite the ability to consume large prey they continue to include a high percentage of small prey items (mostly *A. spinipes* 31%) in their diet (Table III). In contrast, gurnards ate a less diverse selection of prey, mostly epifaunal crustaceans and fish which is consistent with other studies (DE GEE & KIKKERT, 1993). In particular, they preferentially ate *L. depurator*, *C. cranchii* and *Macropodia* spp., but ate *A. spinipes*, in approximate proportion to its occurrence in the community (Table III). As in other studies of whiting in this size-range (HISLOP *et al.*, 1991), a wide range of prey was consumed, but the majority of the stomach contents were polychaetes and crustaceans. Most of the polychaetes consumed (eg. *Nereis* spp., *Phyllodoce* spp.) are at times free swimming when they become accessible and visible to predators. The crustaceans *P. serratus*, *A. spinipes* and *C. cranchii* occurred in whiting stomach contents more frequently than in the community. The proportion of polychaetes in the diets of both dogfish and whiting was much lower than their occurrence in the community, probably because most of them are infaunal and sedentary, and hence not readily available unless disturbed by natural events such as storms or anthropogenic activities such as trawling.

DIETARY CHANGES AFTER FISHING

Gurnards, dogfish and whiting increased the mean number of prey eaten after fishing. However, stomach fullness and contents weight increased significantly for gurnards, but not for dogfish after intensive beam trawling. Furthermore, no change in the mean prey-size eaten by gurnards or dogfish was detected in specimens collected after the initial fishing. Dogfish maintained a similar diet composition before and after fishing. There was a proportionally greater increase of *A. spinipes* compared with other prey in gurnard diets after fishing. As *A. spinipes* is relatively small compared to most of the prey consumed, this may explain why no increase was detected in either stomach contents weight or fullness. In contrast, whiting ate a greater proportion of small prey after the area had been trawled (Table VI) which is probably associated with their increased intake of *A. spinipes* (Fig. 4). *A. spinipes* inhabits a tube which protrudes above the surface of the sediment (P.G. MOORE, pers. comm.). These tubes are probably damaged as the beam trawl passes over them and the amphipods exposed making them vulnerable to predators. Although ampeliscids undertake nocturnal vertical migrations, these tend to occur after dusk and dawn (MAQUART-MOULIN *et al.*, 1987), which would not explain the observed increase in stomach contents as all fishing occurred outside these hours and in daylight (MACQUART-MOULIN *et al.*, 1987). *A. spinipes* occurs in dense localised aggregations and is clearly an important food source for these fishes and especially if its availability is enhanced by the effects of trawling. We estimate that at our experimental site in the Irish Sea, with an average tow covering 15,120 m^2 of the sea bed and an average density of 140 m^{-2}, the maximum number of *A. spinipes* that could become available as food would be approximately $4.2x10^6$ per hour of fishing with this type of gear. However, our experimental area is rarely beam trawled, hence these estimates may not apply in areas where beam trawling is more common. This amphipod is also found in the North Sea, hence the results reported here are probably equally applicable, and extend to other species such as spiny cockles referred to elsewhere in this report.

It appears that after the passage of the trawl the occurrence of some prey items in the stomach contents of gurnards and whiting increases, eg. *A. spinipes.* Clearly the latter are normally an important component of all the fish diets examined. Beam trawling may increase food availablity such that prey which are normally preferred are displaced. This behaviour is known as frequency-dependent foraging or "switching behaviour" and has been demonstrated in the laboratory using the 15-spined stickleback, *Spinachia spinachia* (HUGHES & CROY, 1993). Sticklebacks normally preferred to consume amphipods rather than smaller, less profitable (in terms of net rate of energy intake) *Artemia.* However, the fish swiched to eating the less preferred *Artemia* when they were encountered in superabundance (HUGHES & CROY, 1993). Similarly, it appears that gurnards and whiting have switched to incorporate a greater proportion of *A. spinipes* in their diet, which would indicate that they are encountered more frequently by fish after an area has been beam trawled.

We observed that, *L. depurator, P. serratus* and *C. cranchii* either increased in the diet of most fish or were only eaten after trawling (Fig. 4). These crustaceans are mobile epibenthic scavengers (WASSENBERG & HILL, 1987; HALL *et al.*, 1990; HEDQVIST-JOHNSON & ANDRE, 1991), which locate carion by following its scent in water bourne currents (SAINTE-MARIE & HARGRAVE, 1987; NICKELL & MOORE, 1992). Presumably invertebrate scavengers aggregate over trawl tracks in response to the odour of animals damaged or killed by beam trawling, where, in turn, they will be vulnerable to predation by fish.

We do not attribute the observed dietary changes to diel variations in feeding activity as all the fishing was carried out during daytime. Moreover, we found no evidence in the published literature to suggest that either dogfish (LYLE, 1979), or gurnards exhibit diurnal feeding patterns. However, ROBB (1981) showed that the mean weight of whiting stomach contents increased steadily after dusk, which approximately coincided with the beginning of our final side-scan record (18.26 h, April). The sudden appearance of fish marks on the side-scan sonar record may also be attributed to diurnal shoaling behaviour. The fish marks (presumed to be shoals of whiting) were viewed simultaneously on the side-scan sonar and on an echo sounder and were positioned within 1 m of the seabed. This observation, coupled with the large proportion of fish marks observed directly over the trawl tracks, and the presence of the gonads of the burrowing purple heart urchin in the stomach contents of whiting, strongly suggests that they were feeding on the previously trawled tracks.

CONCLUSIONS

Our study shows that several species of fish aggregate over beam trawl tracks, either to feed on animals damaged by the beam trawl, or on other scavengers. Beam trawling has been cited as one possible factor that could cause large-scale changes in benthic communities (PEARSON & ROSENBERG, 1987; LINDEBOOM, 1990; BERGMAN & HUP, 1992). While some animals die as a result of the direct effects of trawling (eg. benthos and by-catch) other animals, such as seabirds, are quick to capitalise on these by-products (FURNESS, 1982). This has led to large increases in the populations of certain species whose feeding mode was suited to this food source (FURNESS & HISLOP, 1981). The structure of fish populations is partly dependent on resource partitioning (HALL *et al.*, 1990), hence additional resources, such as those made available by trawling, may favour certain species that exhibit opportunistic feeding behaviour (gurnards and whiting). Therefore beam trawling may indirectly benefit non-comercial species, such as dabs and gurnards, eventually leading to an increase in their populations as happened with birds in the North Sea (FURNESS, 1982).

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TABLE I

The number of shoals of fish occurring either over the fished or the unfished areas per 2 min interval on the side-scan records which were obtained after tow 3 (16.00 h) and tow 6 (19.00 h). All comparisons between the mean numbers of shoals per 2 min were made using the T-test.

	number of shoals/2 min			
	unfished	**fished**	**t-test**	***P***
After tow 3	0.05±0.03	0.58±0.23	2.20	0.04
After tow 6	6.41±1.50	20.4±3.10	4.05	0.001
t-test	4.29	6.34		
P	0.001	0.001		

TABLE II

A list of species and collected with either a Day grab or a 4-m beam trawl. The proportion of each species in the community has been worked out from the estimate of density (n/1000m²). Animals which occurred in the stomachs of gurnards (G), dogfish, (D) and whiting (W) are also indicated.

Day grab samples	density	%		**Samples obtained with the 4-m beam trawl**	density	%	
Ampelisca brevicornis	140000	14.6	G,D,W	*Asterias rubens*	22	<	
Ampelisca macrocephala	28000	2.9		*Astropecten irregularis*	6	<	
Corophium crassicorne	6000	0.6		*Henricia sanguinolenta*	3	<	
Dexamine spinosa	2000	0.2		*Crossaster papposus*	7	<	
Urothoe marina	190000	19.8		*Ophiura ophiura* (adults)	21	<	
Amphitoe rubricola	14000	1.5		*Ophiura fragilis* (adults)	1	<	
Cirolana cranchii	2000	0.2		*Echinus esculensis*	1	<	
Mysidacea	28000	2.9	W	*Psammechinus miliaris*	24	<	
Thia spp.	4000	0.4		*Spatangus purpureus*	3	<	W (gonads)
				Paracucumaria hyndmani	2	<	D
Scoloplos armiger	36000	3.8					
Terebellidae	14000	1.4		*Buccinum undatum*	18	<	D
Ampharete acutifrons	40000	4.1	W	*Neptunia antiqua*	1	<	
Pectinaria koreni	36000	3.8		*Aequipecten opercularis*	1	<	
Lepidontes spp.	44000	4.6		*Modiolus modiolus*	0.5	<	
Magelona spp.	12000	1.3		*Colus gracilis*	0.1	<	
Maldonidae	132000	13.8		*Venerupis rhomboides*	1	<	
Spionidae	36000	3.8		*Archidoris pseudoargus*	0.2	<	
Orbinidae	14000	1.4					
Glyceridae	10000	1		*Liocarcinus depurator*	6	<	G,D
Eteone longa	4000	0.4		*Corystes cassivelaunus*	1	<	
Maloceros spp.	6000	0.6		*Hyas areneus*	7	<	D
Cirratulidae	10000	1		*Macropodia tenuirostris*	11	<	G
Nematonereis unicornis	10000	1		*Eupagurus bernhardus*	2	<	D
Nephtys spp.	6000	0.6	D,W	*Eupagurus prideauxi*	9	<	
Oligochaeta	2000	0.2		*Crangon cranchii*	1	<	G,D,W
Phllodocidae	2000	0.2	W	*Palaemon serratus*	1	<	G,D,W
Nereidae	2000	0.2	W	*Upogebia deltaura*	?		D
				Isopoda	?		G
Nemertini	4000	0.4					
				Callionymus spp.	2.2	<	G,D
Sipunculida	2000	0.2		*Solea solea*	0.5	<	
				Pleuronectes platessa	0.25	<	
Moerella donacina	22000	2.3		*Limanda limanda*	0.6	<	
Nucula nitidosa	8000	0.8		*Plueronectes flesus*	2.5	<	
Parvicardium scabrum	20000	2.1		*Merlangius merlangus*	0.8	<	
Spisula eliptica	18000	1.9		*Scyliorhinus canicula*	0.1	<	
Mysella bidentata	18000	1.9		*Raja naevus*	0.7	<	
Dosinea exoleata	6000	0.6		*Lophius piscatorius*	0.5	<	
Natica alderi	?		G	*Trisopterus minutus*	0.7		
				Cataphractus agonus	3.1	<	
Ophiura fragilis	6000	0.6		*Aspatrigla cuculus*	0.5	<	
Ophiura ophiura	16000	1.7		*Buglossidium*	0.5	<	
Psammechinus miliaris	12000	1.3		*Blennius ocellaris*	0.1	<	
				Microstomus kit	0.2	<	
Aphrodite aculeata	21	<	D	*Sygnathus acus*	0.1	<	
				Ammodytidae	?		G
				Utricina felina	2	<	

TABLE III

Strauss' index of selectivity for the diets of gurnards, dogfish and whiting, comparing the proportion of each species encountered in the stomach contents to it's proportion in the benthic community. Data are presented for stomach collected before and after trawling. The percentage occurrence of each prey species in the community is also given unless no data (nd) were available.

		Gurnards		Dogfish		Whiting	
Species	% in the community	before	after	before	after	before	after
Liocarcinus depurator	0.0006	0.31	0.17	0.04	0.05		
Crangon cranchii	0.0001	0.25	0.24		0.04	0.15	0.01
Palaemon serratus	0.0001		0.05		0.01	0.08	0.01
Ampelisca spinipes	14.6			0.16	0.16	0.23	0.56
Macropodia spp.	0.001	0.16	0.07				
Eupagurus bernhardus	0.0002			0.18	0.18		
Buccinum undatum	0.0018			0.06	0.06		
Natica alderi	nd	0.03	0.01				
Polychaetes	42.9			-0.38	-0.36	-0.36	-0.34
Callionymus spp.	0.0002	0.1	0.05	0.02			
Ammodytes spp.	nd					0.27	0.09
Spatangus purpureus	0.0003						0.9

TABLE IV

The mean ± SE stomach contents wet weigth (g) and fullness (scale of 0-10, empty-full) for dogfish and gurnards before and after intensive beam trawling (n=60). Comparisons are made using the Kruskal-Wallis non-parametric ANOVA (H).

Species	mean ± SE		H	P
Fullness	**before**	**after**		
Dogfish	4.23 ± 2.80	4.63 ± 3.21	0.18	0.67
Gurnards	3.36 ± 3.65	5.04 ± 3.23	6.83	0.009
Contents weight				
Dogfish	7.67 ± 9.15	4.06 ± 4.56	3.05	0.08
Gurnards	0.98 ± 2.57	1.10 ± 1.20	8.47	0.004

TABLE V

The size range of fish collected before and after fishing. Comparisons were made using Oneway ANOVA.

Species		mean ± SE		F	P
	N	before	after		
dogfish	60	55.2±7.1	52.2±6.7	3.03	0.09
gurnards	60	26.7±6.11	24.4±4.9	2.05	0.16
whiting	80	20.8±2.5	19.7±2.7	2.98	0.09

TABLE VI

The change in the mean±SE prey width (mm) in the stomachs of gurnards, dogfish and whiting collected before and after fishing. Comparisons were made using the Kruskal-Wallis non-parametric ANOVA (H). The change in prey width: gape width ratio is also shown for each species.

Species		mean ± SE		H	P
	N	before	after		
gurnards	132	5.78±1.00	4.11±0.23	0.03	0.85
dogfish	153	6.70±1.85	6.14±0.38	1.41	0.23
whiting	130	6.37±1.92	4.43±1.78	8.57	0.004
		prey width: gape width			
gurnards		0.23	0.16		
dogfish		0.19	0.17		
whiting		0.24	0.16		

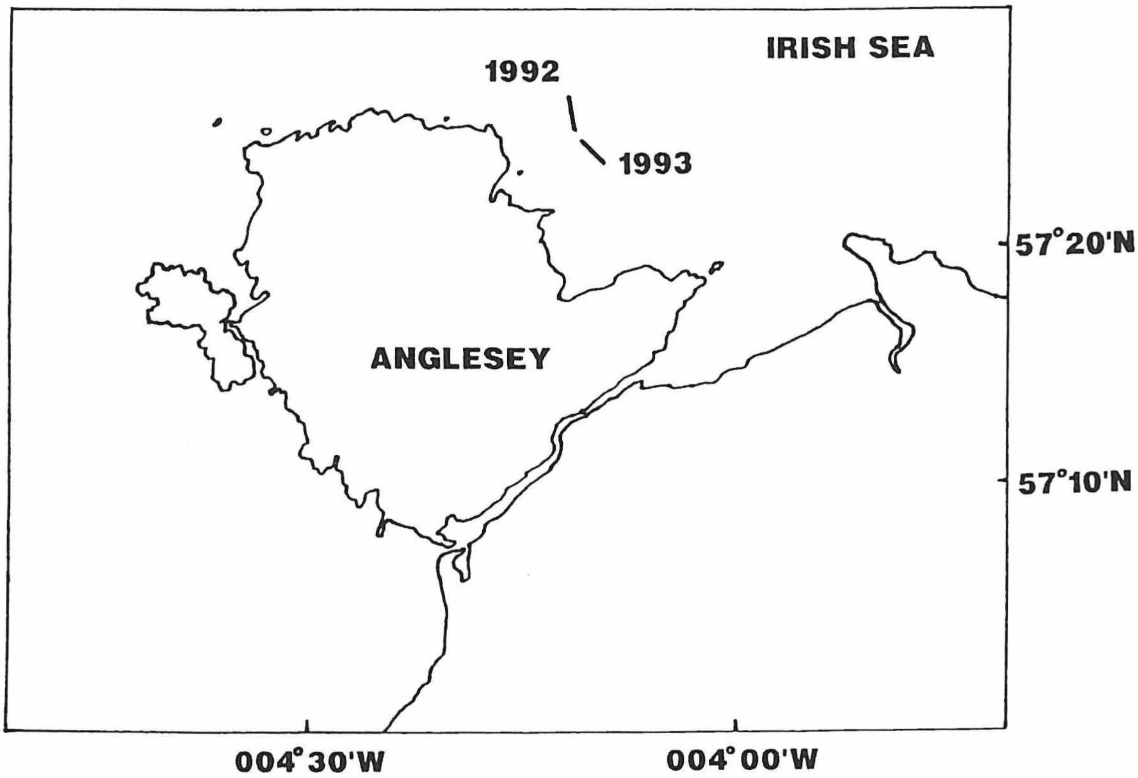

Fig. 1. The location of the study area in the Irish Sea off the north Wales coast and the position of the 4-m beam trawl tows made in August 1992 and April 1993.

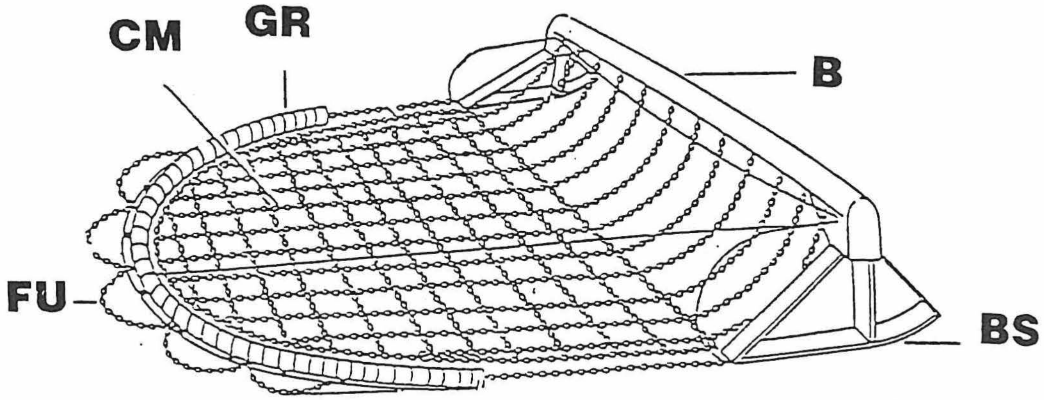

Fig. 2. A diagram of a commercial pattern 4-m beam trawl with the net removed to show the chain matrix (CM), flip-up gear (FU), the ground rope (GR), the beam (B) and beam shoes (BS).

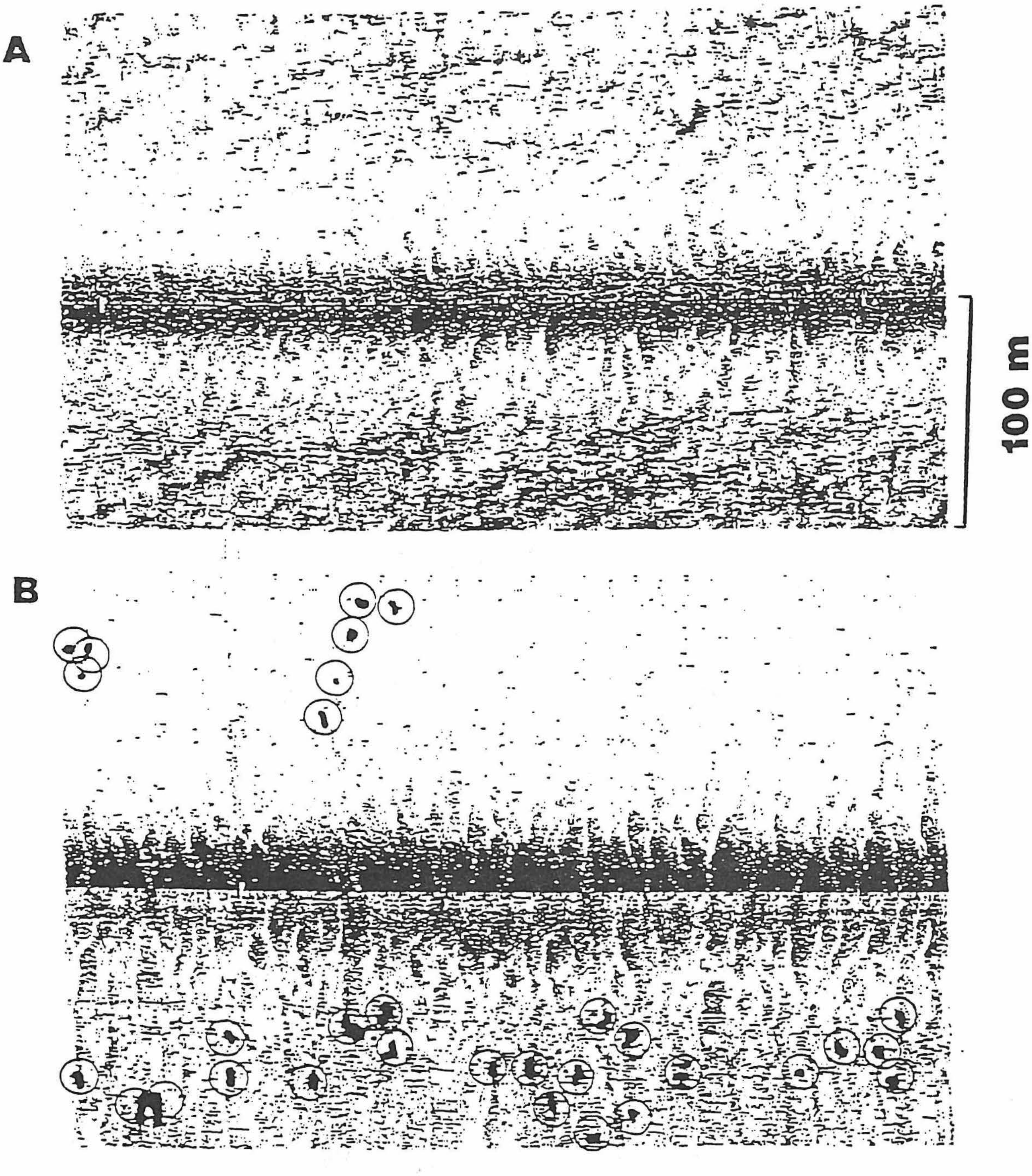

Fig. 3. A portion of the side-scan record (equivalent to 480 m) showing the 4-m beam trawl tracks, visible in the lower half of each side-scan record, (A) at 15.00 h after the first 3 tows and (B) the same area at 18.26 h after 6 tows: the encircled dark areas are fish marks which were observed simultaneously on an echo-sounder.

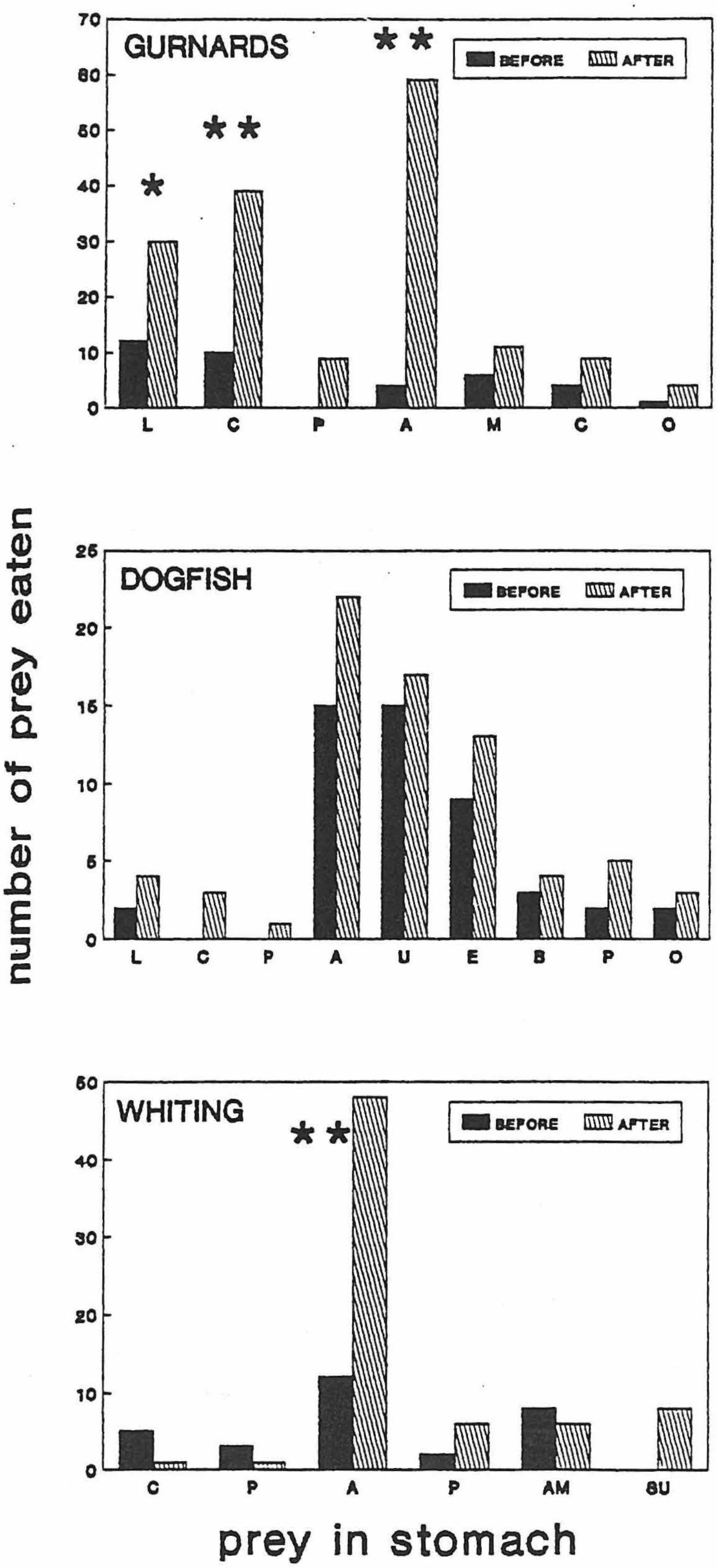

Fig. 4. The mean number of prey per stomach for gurnards, dogfish and whiting which were collected both before, and 3 h after fishing an area with a 4-m beam trawl. Significant differences were determined using the G-test (SOKAL & ROHLF, 1981), $*$=P<0.05, $**$=P<0.01, $***$=P<0.001.

A NEW BENTHOS DREDGE ("TRIPLE-D") FOR QUANTITATIVE SAMPLING INFAUNA SPECIES OF LOW ABUNDANCE

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ABSTRACT

Grabs and corers are commonly used to estimate densities of infauna species quantitatively. However, because of the limited sample size, these equipments are not practicable for sampling species of low abundance. With trawls and dredges much larger sample sizes can be obtained, but the existing types of gear are, at best, semi-quantitative for catching infauna. In the IMPACT-I studies, a prototype dredge has been developed for quantitative sampling larger-sized infauna of low abundance. This "Deep Digging Dredge" (Triple-D) is rigged with an interchangeable blade to collect a strip of the seabed. During the haul, several hundred meters long, the excavated sediment is sieved through a net with a 2 cm stretched mesh-size. The prototype was successfully tested on infauna in fine-grained adhesive sediments in the Wadden Sea, using a 20 cm wide blade with a penetration depth into the sediment of 10 cm. In field studies on sandy bottoms in the North Sea the Triple-D quantitatively caught a number of epifauna and demersal fish species as well. The Triple-D has been extensively used in the IMPACT-I project.

1. INTRODUCTION

In ecosystem studies, densities of infauna species are generally estimated by means of grabs and corers. Well-known samplers are the Van Veen grab and the Reineck box corer (HOLME & MC INTYRE, 1984). In fine sandy sediments, infauna may be sampled quantitatively with a Van Veen grab only in the upper 5 centimetres (BEUKEMA, 1974), whereas samples taken with a Reineck box corer are assumed to be quantitative over the full penetration depth (up to about 30 cm, depending on the type of sediment). Sample size is usually limited to about 0.2 m^2 (Van Veen grabs) and 0.07 m^2 (box corers), occasionally extending to about 0.5 m^2. Because of this limited sample size, grabs and corers are practicable only for estimating abundances of infauna species occurring in relatively high densities.

For an accurate density estimate of infauna species of low abundance, large numbers of grab samples are required. In particular, this applies to species with clustered distributions or to those studies in which small changes in densities have to be detected. In a study on the direct effects of beam trawling on a benthic ecosystem, some large species (e.g. the bivalves *Arctica islandica* and *Acanthocardia echinata*) were never found in even 50 box corer samples, although these species were frequently caught in trawl nets at the same locality, and appeared to be particularly sensitive to beam trawling (BERGMAN *et al.*, 1990; VAN SANTBRINK & BERGMAN, this Report).

Instead of increasing the number of grab samples, trawls and dredges can be used which cover up to several hundreds of square meters in area. However, existing types of this gear are, at best, semi-quantitative for catching infauna (HOLME & MC INTYRE, 1984). Currently, dredges are being developed to estimate densities of cockles in Dutch estuaries (pers. comm. VAN STRALEN, RIVO-The Netherlands), and densities of epibenthos in offshore areas (GORDON, BIO-Canada). However, because penetration depth of the blade of these dredges are less than required for studies as presented in this Report, it was decided to develop a new infauna dredge. It was necessary for the new dredge to excavate a strip of the seabed up to a depth of about 10 cm, i.e. the maximum depth to which the seabed may be disturbed by commercial trawling (LABAN & LINDEBOOM, 1991; BERGMAN & HUP, 1992). This paper provides a technical description of the prototype of the "Deep Digging Dredge" (Triple-D) constructed in early 1993, as well as some preliminary test results.

2. TECHNICAL DESCRIPTION

The Triple-D weighs about 600 kg and is 2 m long, 1.5 m wide and 1.5 m high. The dredge consists of a pair of broad runners connected by a stainless steel cage (mesh size 1 x 1 cm) mounted 5 cm above the seabed (Fig.1). An interchangable blade is fitted in an opening in the underside of the cage. Different blades can be used, varying in penetration depth into the seabed and in width, but with a maximum width of 50 cm. Combinations of blade width and depth built so far are: 30 * 5 cm, 20 * 10 cm and 15 * 15 cm. The blades are designed to excavate a strip of sediment out of the seabed and to transport it into the cage without loosing infauna sideways. The cutting blade is fitted near the rear side of the cage to make transport into the net as short as possible. Longitudinal vertical strips, fixed at both sides of the cutting edge and running to the front side of the cage (dotted line in inset Fig.1), ensure that fauna which is displaced or disturbed due to a "bow wave" of sediment, which is running a few decimetres in front of the blade, cannot escape sideways. The cage prevents any further escape of infauna when transported from the cutting blade to the mouth of the net. Through an opening in the centre of the front panel, with the same width as the cutting blade, epibenthos and fish can be caught as well. A fine-meshed (2 cm stretched mesh size) nylon net with a length of 6 m is tied to the rear side of the cage and is covered by a strong nylon outer net (8 cm stretched mesh size). Above the cage a large depressor plate is fitted to force the cutting blade into the seabed. A spiked measuring wheel (not shown in Fig. 1), mounted on the runner, indicates the length of the haul by means of a magnetic REED-contact, counting the revolutions of the wheel.

Various factors affect the longitudinal stability of the dredge running over the seabed, such as warp length, towing speed, dimensions of the blade, type of sediment and dimensions and position of the depressor. Initial tests revealed that the Triple-D should be towed at a speed of 3 $nM \cdot h^{-1}$ (requiring a towing force of about 1.5 tons), and warp length should be at least about 5 times water depth. To maximize catch efficiency (i.e. proportion of numbers of animals present that is actually caught), the dredge can be trimmed horizontally by changing the point of attachment of the towing warp on the runners. The correct trim can be checked by measuring-wheels fitted at the front and rear of a runner, or simply by assessing the wear on the underside of the runners (excessive wear at the front or at the rear indicates incorrect trim).

3. ASSESSMENT OF CATCH EFFICIENCY

The catch efficiency of the Triple-D was tested by comparing mean densities of an indicator species sampled with the Triple-D and the Reineck box corer. A prerequisite for such a test is that the indicator species should occur in densities sufficiently high to be estimated reliably by box corer, and that the distribution of this indicator species should be more or less homogenuous, both horizontally and vertically in the upper 10 cm of the sediment. The bivalve *Macoma balthica*, living in subtidal fine grained, silty areas of the Dutch Wadden Sea, appeared to be a suitable test species.

Although catch of infauna is the prime function of the Triple-D, epibenthic invertebrates and demersal fish were caught as well. During IMPACT-studies the catch efficiency of the Triple-D for mobile epifauna was compared to catches with a fine meshed beam trawl, a type of gear which is known to give the best possible quantitative estimate (Holme & Mc Intyre, 1984; Kuipers *et al.*, 1992).

3.1. METHODS

3.1.1. INFAUNA

In March 1993, a transect (length about 235 m) near the Wierbalg in the western Dutch Wadden Sea (fine grained, adhesive sediment; water depth 2.5 m) was sampled with a Reineck box corer (sample size 0.07 m^2; n=10). Samples were sieved (over 1 cm Ø), and numbers of *M. balthica* in the upper 0-5 cm of the sediment and in the next 5-10 cm were counted separately. Unfortunately, the catches were pooled before specimens were measured and therefore standard deviations could only be given for total mean densities and not for separate length classes. In this study, about 80% of *M. balthica*, independent of size, were living in the upper 5 cm of the seabed. Immediately after the grab sampling, hauls with the Triple-D (blade depth 10 cm, width 20 cm) were carried out along the same transect (sample area 47 m^2 per haul; n=3). The numbers of *M. balthica* in the catches were counted and a subsample of specimens was measured. The density estimates of the two sampling gears were compared.

3.1.2. MOBILE EPIBENTHOS AND DEMERSAL FISH

In April 1993, a sandy area in the Dutch coastal zone (surface 0.12 km^2; water depth 15 m) was fished with the Triple-D (blade depth 10 cm, width 20 cm) and a 2.8-m beam trawl. The trawl was rigged with 3 tickler chains and a chain tied to the ground rope. An extra rope was wound around the middle of this ground chain over a length of about 80 cm. Mesh size of the body of the net was 2 cm stretched, and of the cod-end 1 cm stretched. Six hauls were made with each gear during daylight. The total area fished with the trawl was 13200 m^2, and with the dredge 412 m^2. Catches were sorted and numbers per species were counted. Densities were estimated only for the most abundant species. Differences in density estimates of the two gears were tested (Mann-Whitney U-test).

3.2. RESULTS

3.2.1. INFAUNA

From the box corer samples, the mean density of *M. balthica* in the upper 10 cm of the sediment was estimated as 78.4 individuals · m^{-2} (s.d. 34.4), whereas from the dredge samples the mean was 61.6 individuals · m^{-2} (s.d. 7.9). By comparing length-frequency distributions of *M. balthica* in box corer samples (including 4 extra grab samples taken near the transect) and in Triple-D hauls (from a subsample of 129 individuals), a relative lack of length classes ≤ 17 mm is noticeable in the Triple-D hauls (Fig. 2). Obviously, this is a consequence of a difference in mesh size selection: 2 cm stretched meshes in the dredge versus 1 cm diameter (round) holes in the sieve used in processing the box corer samples. Indeed, specimens ≤ 17 mm could be pushed through the meshes of the net, while only specimens < 12 mm length (height < 10 mm) pass through the sieve. Therefore, length classes ≤ 17 mm should not be taken into account for this test. Considering only the length classes > 17 mm, the mean density of *M. balthica* collected with the dredge was 39.6 individuals · m^{-2}, which was even higher than the mean of 27.6 individuals · m^{-2} collected with the box corer.

3.2.2. MOBILE EPIBENTHOS AND DEMERSAL FISH

Compared to a 2.8-m beam trawl, the catch efficiency of the Triple-D (Table 1) appeared to be significantly higher for some mobile epibenthic invertebrates, such as crabs (*Corystes cassivelaunus*, adult *Liocarcinus holsatus*) and a brittlestar (*Ophiura texturata*). Density estimates of starfish (*Asterias rubens*) and some other crustaceans (*Crangon crangon*, juvenile *Liocarcinus holsatus*, and *Eupagurus bernhardus*) were not statistically significant.

Of the demersal fish, ≥ I-group sole (*Solea solea*) were caught in significantly higher numbers by the dredge. No differences were found between both gears in catches of 0-group dab (*Limanda limanda*). Only ≥ I-group plaice (*Pleuronectes platessa*) and *Pomatoschistus* spp. were caught in significantly lower numbers in the dredge.

4. DISCUSSION

Although statistical significance could not be tested, the results of the trial in the Wadden Sea show that the mean densities of *M. balthica*, estimated by dredge and by box corer, are at least of the same order of magnitude. This would imply that on fine, adhesive sediments the Triple-D exhibits the required characteristics, namely a constant sampling depth and a sufficient transport of infauna into the net without escape of material sideways. The standard deviation of the total mean densities was much lower for the 3 dredge hauls than for the 10 box corer samples. It can be assumed, that a similar difference in standard deviation would be found for specimens ≥ 17 mm. This would mean that, at least for a pattern of distribution as was found in this study, small differences in mean densities can be detected with more certainty using the Triple-D.

Also on sandy bottoms, the Triple-D did not show signs of unreliability: the dredge caught infauna in expected quantities. However, it has not yet been shown whether the dredge reaches its full working depth on this type of sediment, since a suitable test species is lacking in the Dutch coastal zone.

When sampling epifauna and fish, the trial has shown that only the densities of ≥ I-group plaice and gobies were lower in the Triple-D than in the 2.8-m beam trawl. Apparently, both species are able to avoid the narrow blade, while gobies may also escape through the meshes of the dredge net. Other large flatfish (except sole) and roundfish are probably able to avoid the blade as well. Considering the test results, it must be stressed that catch efficiency of a beam trawl is highly dependent on the number of tickler chains. Rigging a trawl with more and heavier tickler chains may result in increased numbers of benthic animals in the catch (CREUTZBERG *et al.*, 1987).

In conclusion, the Triple-D can be used as a replacement of a grab sampler in studies concerning density estimates of low abundant or clustered infauna species. Furthermore, the Triple-D is a useful tool for estimating densities of certain epibenthic species such as sole, crabs and starfish. The dredge may also be useful to check catch efficiencies of fine meshed beam trawls.

Some improvements of the Triple-D may possibly enlarge the potential applications of this sampling gear. The fitment of (i) a skimming blade (50 cm wide, with a penetration depth of 3 cm) for sampling epifauna, (ii) a longer blade for sampling up to 15 cm deep, and (iii) a finer mesh net for sampling smaller animals will be tested on various types of sediment in the near future.

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Construction plan.-A detailed construction plan of the Triple-D is available from NIOZ.

Notes from the authors. - Recently the catch efficiency of the Triple-D for *Macoma balthica* has again been tested in a similar study in the Dutch Waden Sea. However, in this study the Triple-D was rigged with a fine meshed net (mesh size 1.4 cm stretched), and the set-up of the study allowed for statistical tests. To date, the data have not been fully analyzed, but preliminary results seem to support the conclusions described in this report. The results will be published in the course of 1994. An improved prototype of the Triple-D will be used in IMPACT-II studies.

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TABLE 1

Comparison of catch efficiency of the Triple-D (6 hauls; total fished area 412 m^2) with 2.8-m beam trawl (6 hauls; total fished area 13200 m^2). Differences in mean numbers ($n \cdot 100\ m^{-2}$) were tested with the Mann-Whitney U test (2-tailed).

species	numbers in samples (n*100m-2)				ratio	MWhU-test
	Triple-D		2.8m-beam trawl		Triple-D/	
	mean	st.dev.	mean	st.dev.	2.8m-bt	P
DEMERSAL FISH						
Limanda limanda (0 group)	6.0	3.7	7.9	3.4	0.8	n.s.
Pleuronectes platessa (>0-group)	0.9	0.6	1.2	0.2	0.8	0.016
Pomatoschistus spp.	3.0	3.2	19.5	14.7	0.2	0.016
Solea solea (>0-group)	1.5	1.3	0.05	0.04	31.5	0.036
INVERTEBRATE INFAUNA						
Asterias rubens	6.6	4.7	5.9	2.1	1.1	n.s.
Corystes cassivelaunus	1.7	1.0	0.02	0.1	68.1	0.013
Crangon crangon	61.0	29.6	96.7	32.3	0.6	n.s.
Eupagurus bernhardus	2.8	1.2	3.6	1.9	0.8	n.s.
Liocarcinus holsatus (ad)	9.9	4.9	2.0	1.5	4.9	0.006
Liocarcinus holsatus (juv)	2.5	1.6	2.8	2.5	0.9	n.s.
Ophiura texturata	20.2	4.8	11.9	4.0	1.7	0.025

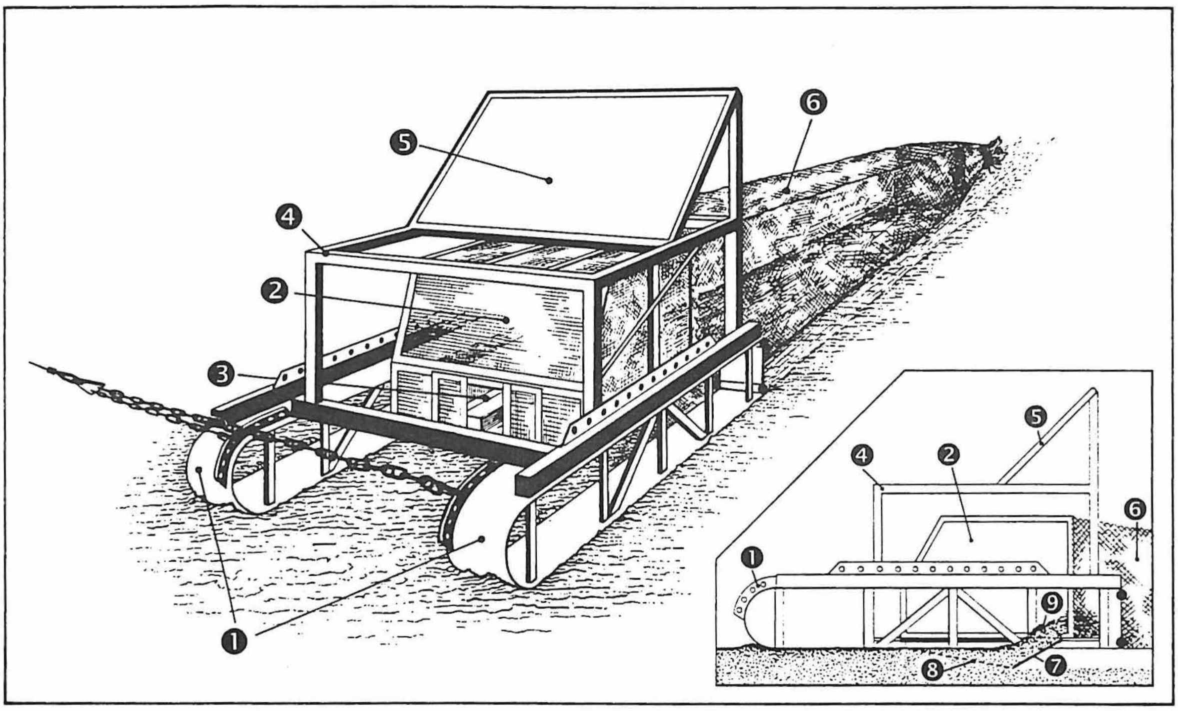

Fig. 1. General view of the prototype of the Triple-D showing the mode of operation (inset).
1. runners; 2. cage (front panel); 3. opening in front panel for catching epifauna; 4. steel bars to protect the cage; 5. depressor; 6. net; 7. cutting blade; 8. (dotted line) front edge of vertical strips, mounted on both sides of the cutting blade; 9. sediment entering the net.

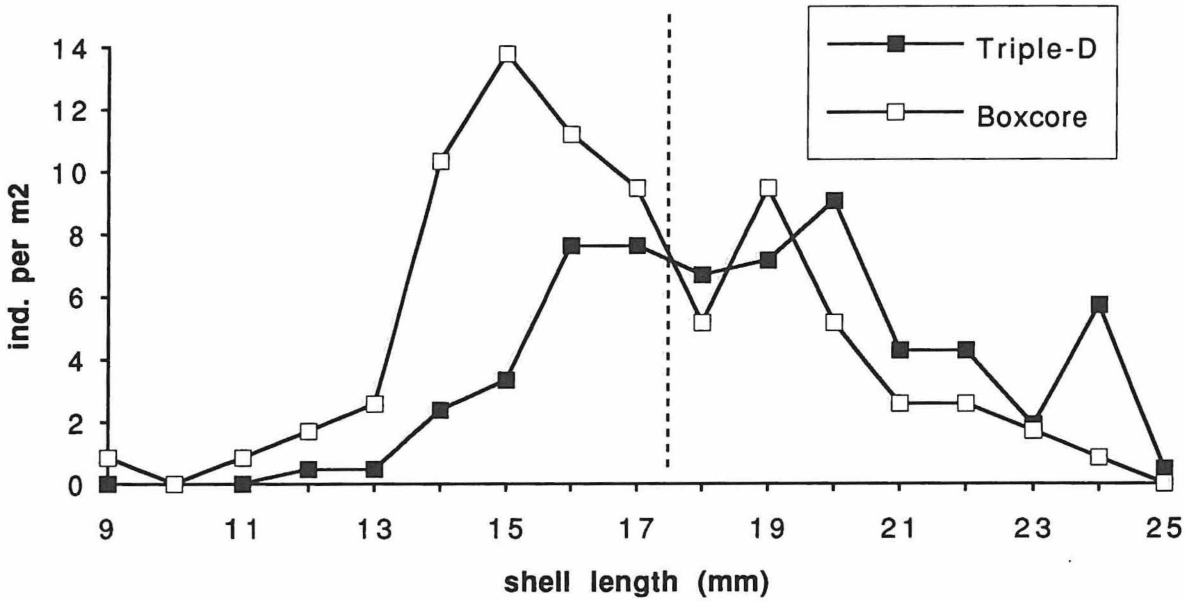

Fig. 2. Length distribution of *Macoma balthica* ($n{\cdot}m^{-2}$) from the box corer samples (n = 91 from 14 grabs covering 1 m^2) and Triple-D (based on a subsample of 129 animals from 3 hauls covering 140 m^2). The dotted line indicates the length class below which it is possible to escape through the meshes of the dredge. Length classes to the left of this line were not taken into account for testing the Triple-D.